LeighFisher

In association with

Synergy Consultants, Inc.

TECHNICAL MEMORANDUM No.9 FINAL

SUSTAINABILITY PLANNING AND MANAGEMENT STRATEGY

Seattle-Tacoma International Airport

Prepared for

Port of Seattle
Seattle, Washington

May 2018

Sustainable Airport Master Plan
Seattle-Tacoma International Airport

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Introduction and Summary

The Port of Seattle has a strategic plan for sustainable growth at Seattle-Tacoma International Airport.

1.1 Background

In accordance with Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5070-6B, *Airport Master Plans*, and FAA Sustainability Guidance,* the Port of Seattle (the Port) has prepared a Sustainable Airport Master Plan (SAMP) for Seattle-Tacoma International Airport

The Port of Seattle owns and operates Seattle-Tacoma International Airport (Sea-Tac), the 9th largest airport in the U.S. in 2016, based on passengers. The staff in the Aviation Division is responsible for the daily maintenance and operation of the Airport which is located approximately 12 miles south of downtown Seattle on about 2,800 acres of Port-owned land within the City of SeaTac. The Port is governed by five Commissioners who are elected at large by the voters of King County, serve four-year terms, lead all inter-governmental functions, and oversee the Executive Director.

Currently Sea-Tac serves commercial passengers, commuters, cargo, and general aviation operations, with a small number of military operations. In 2016, approximately 45.7 million annual passengers (MAP) arrived or departed from Sea-Tac Airport on 407,637 aircraft operations. The Airport also accommodated 366,431 metric tons of cargo in 2016.

The Port had two main objectives for pursuing a *sustainable* airport master plan. The first was to ensure that the Airport's Master Plan and vision for the future would be done as sustainably as possible and align the planning effort with the Commission's goal for the organization to be the greenest, most efficient Port in North America. The Port Commission set this goal as part of its Century Agenda that was approved by the Commission in December 2012.** The second was to advance the sustainability sector in relation to master planning by evaluating emerging trends in sustainability that could affect long-term planning, and piloting or testing new approaches and strategies for integrating sustainability into the Airport's plan.

*http://www.faa.gov/airports/environmental/sustainability/

**Approved Minutes Commission Regular Meeting December 4, 2012. https://meetings.portseattle.org/

This chapter is organized into the following sections:

This guidance and the resulting recommendations are not a replacement for formal environmental review under the National Environmental Policy Act (NEPA) or Washington's State Environmental Protection Act (SEPA).

1.2 Strategic Framework

In developing the overall framework for the sustainability aspect of the SAMP, the Port recognized early on that it would have to consider strategies that are typically outside traditional master planning to meet its ambitious sustainability goals. As master planning efforts must balance conflicting goals and objectives, this is especially relevant for key sustainability categories such as energy and greenhouse gas emissions. For example, if the Port is to meet its goal to double the number of international flights and destinations and, at the same time, reduce greenhouse gases by 50%, it will have to consider a broader range of options in addition to traditional capital development strategies in the SAMP.

This led to a conceptual SAMP framework that combines the traditional planning efforts of **what we build** and **where we build** with sustainability-related concepts of **how we build,** and **how we manage/operate.**

In a traditional master plan, the effort focuses on serving forecast demand with development that achieves the highest operational performance at the lowest dollar and environmental cost. Sustainability Management Plans (SMPs) address how an airport can manage and/or operate its facilities in a sustainable fashion. The SAMP contains alternative development actions and initiatives, opportunities, and actions that address where, what, and how the Port builds combined with how the

Port manages and operates its Airport facilities. Collectively, these initiatives, opportunities, and actions were identified as they will help to achieve the sustainability goals and objectives.

1.3 FAA Support

Given the broader and deeper analyses needed to complete this work, the Port was fortunate to have additional financial support from the FAA. The Port received an FAA Airport Improvement Program (AIP) grant that enabled it to conduct additional research, explore new approaches, and test design strategies that expand on traditional master planning concepts. For example, the FAA funds allowed the Port to extend planning estimates to include potential energy use in a new terminal facility, and even compare the additional cost and environmental benefit from developing the facility with a range of sustainability attributes. These types of exploratory tasks allowed the Port to extend typical planning processes to examine if or how sustainability could be considered, and in some cases compare the additional benefit to what is needed to meet its sustainability goals and objectives.

Several airports have included sustainability concepts in their master plans, but many efforts have focused largely on expanding the environmental elements of sustainability. To align this effort with the full definition of sustainability, the Port committed to applying all three sustainability elements: financial, environmental, as well as social to the SAMP planning process.

Both the financial and environmental element align more readily with traditional master plans, however, integrating the social element into Sea-Tac's planning process presented more challenges and uncertainties. Like many organizations, the Port's social equity programs tend to focus on operational programs such as contracting requirements to encourage small or women-owned business participation, although recently, the Port has expanded its inclusion of social equity factors in its decisions and programs. For the SAMP, the Port integrated social criteria into the planning process where possible, while also recognizing that future operational and capital development strategies would apply emerging and new social equity programs and initiatives.

As with any new and creative endeavor, the SAMP led to a number of challenges and questions particularly in areas where the future is highly uncertain. For example, new technologies and business models continue to emerge for several key areas of sustainability such as energy and transportation. In these situations, the Port again developed specific analyses that are outside the typical master planning process but that were designed to consider those uncertainties and recommend strategies to advance sustainability goals.

As shown throughout this summary document, several aspects of this initiative were highly successful in that they provide insight that planners could use to help Sea-Tac achieve the Port's goals and objectives. The FAA's pilot initiative also demonstrates that planners will need to think broadly about how their facilities connect with community-wide systems such as social programs, and roadway systems and transit beyond traditional planning approaches.

Nevertheless, it is important to note that the FAA is not bound by the recommendations of this effort, nor are they reliant upon the Port's sustainability goals in terms of preparing impact/mitigation statements as part of National Environmental Policy Act (NEPA) processes.

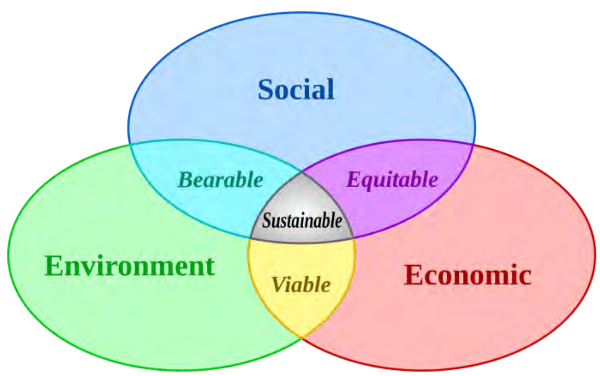
1.4 Defining Sustainability

A key first step to integrating sustainability into the Port's master planning process was to identify how the Port defines sustainability, as well as any Port goals and objectives designed to create a more sustainable Port of Seattle.

1.4.1 Brundtland Definition

"Sustainability" has many definitions, but generally has its origin in the 1987 United Nations Commission on Environment and Development (known as the Brundtland Commission). The Brundtland Commission suggested that development was acceptable and necessary, but that it must be done in a sustainable manner. A plan or development is sustainable if it balances three – often competing – elements: economic/financial, environmental, and social. Actions and development that accomplishes this is known as meeting the "Triple Bottom Line", illustrated on Figure 1-1.

Figure 1-1
The Triple Bottom Line: Economic Environmental, and Social
Seattle-Tacoma International Airport



Source: "Sustainable development," Johann Dréo, Creative Commons, January, 2007.

1.4.2 FAA Sustainability Goals and Objectives

Because the Airport received a grant from the FAA to develop a SAMP, the FAA's approach and definition of sustainability and SAMP requirements influenced the process and integration of sustainability into the master plan. The FAA defines as sustainable actions that:

- Help maintain high, stable levels of economic growth
- Reduce environmental impacts
- Help achieve "social progress," a broad set of actions that ensure organizational goals are achieved in a way that's consistent with the needs and values of the local community*

*http://www.faa.gov/airports/environmental/sustainability/

The FAA also provides guidance for airports preparing sustainable airport master plans, stating that "Sustainability Master Plans (SAMPs) fully integrate sustainability into an airport's long-range planning [and] use(s) baseline assessments of environmental resources and community outreach to identify sustainability objectives that will reduce environmental impacts, realize economic benefits, and improve community relations."*

1.4.3 Port of Seattle Sustainability Goals and Objectives

The following paragraphs describe past strategic planning exercises and sustainability goals that were used to establish updated sustainability goals and objectives for the SAMP.

- **Century Agenda**. The Port has a strong history of developing its own goals and objectives that form the basis of its sustainability programs and initiatives. The Port's drive to move beyond regulatory requirements and advance sustainability flows from the Commission's Century Agenda, which was established in 2011. The Century Agenda includes all three aspects of sustainability and sets ambitious goals for economic, environmental, and social programs at the Port. Table 1-1 lists the Port's Century Agenda Strategic Objectives.

- **Long Range Plan**. The Port of Seattle uses a rolling 5-year Long Range Plan to focus its efforts on job growth and strategic objectives established in the Century Agenda. The Port recently developed additional goals in the Long Range Plan designed to improve customer service, eliminate workforce injuries, increase diversity and inclusion among Port staff, and foster employee development. As these goals are part of the Port's social sustainability efforts, they are included here for reference. Table 1-2 lists the High-Performance Organization objectives in the Long-Range Plan.

- **Aviation Division 2015 Business Plan and 2018 Priorities**. At the beginning of the SAMP process, the Port was preparing its 2015 Aviation Division Business Plan. That business plan included a number of objectives and initiatives that were captured in the SAMP. In revising the SAMP documentation, as the Division's 2018 Priorities were prepared, those initiatives were also captured. Table 1-3 lists the 2018 Priorities whereas the 2015 Business Plan is reflected in Chapter 2.

*FAA, Airport Sustainability Master Plan, Memo from Elliot Black dated May 27, 2010 available at: http://www.faa.gov/airports/environmental/sustainability/media/interim_guidance_sustainable_master_plan_pilot.pdf

Table 1-1
Century Agenda Goals and Objectives
Seattle-Tacoma International Airport

- Position the Puget Sound region as a premier international logistics hub
  - Triple Air Cargo Volume to 750,000 metric tons
- Advance this region as a leading tourism destination and business gateway
  - Make Sea-Tac Airport the west coast "Gateway of Choice" for international travel
  - Double the number of international flights and destinations
  - Meet the Region's Air Transportation Needs at Sea-Tac Airport for the next 25 years
- Use our influence as an institution to promote small business growth and workforce development
  - Increase the portion of funds spend by Port with qualified small business
  - Increase workforce training, job and business opportunities for local communities
- Be the greenest, and most energy efficient port in North
  - Meet all increased energy needs through conservation and renewable sources
  - Meet or exceed agency requirements for stormwater leaving Port-owned or operated facilities
  - Reduce air pollutants and carbon emissions, specifically:

    Scope 1&2 emissions, direct greenhouse gas emissions from Port owned or controlled sources:
    - 15% below 2005 levels by 2020
    - 50% below 2005 levels by 2030
    - Carbon neutral or carbon negative by 2050

    Scope 3 emissions where the Port has influence over, not direct control:
    - 50% below 2007 levels by 2030
    - 80% below 2007 levels by 2050

Source: Port of Seattle: Century Agenda: http://www.portseattle.org/About/Commission/Pages/Century-Agenda.aspx.

- *Strategy for a Sustainable Sea-Tac (called "S3").* In addition to these goals, the Aviation Division developed its first Environmental Strategy Plan in 2009, a five-year plan that sets out goals and initiatives for a variety of environmental categories. In 2014, the Aviation Division developed the second phase of its environmental sustainability plan with a renewed set of goals and objectives, entitled "Strategy for a Sustainable Sea-Tac (S3)."

  Because the Century Agenda environmental goals were crafted as the Port was implementing the Environmental Strategy Plan, S3 adopts the Century Agenda goals for those categories (e.g., air quality, climate, energy). The S3 goals for the remaining environmental categories of water quality, water conservation, wildlife, waste, and buildings/infrastructure are listed in Table 1-4. The S3 goals and objectives were presented to Commission in February 2015.*

*Staff Briefing, Strategy for a Sustainable Sea-Tac (S3) Briefing Memorandum dated January 16, 2015.

To develop specific SAMP objectives, the goals and objectives listed in all four tables were evaluated for corresponding metrics that were then used to evaluate and develop the sustainability portions of the SAMP. The Port derived specific metrics for each of the goals and objectives to measure the impact of various SAMP alternatives and strategies. These metrics are discussed in Section 1.7 of this chapter.

Table 1-2
Long Range Plan Goals and Objectives
High Performance Organization
Seattle-Tacoma International Airport

- Increase customer satisfaction
  - Increase Customer Service
  - Improve customer service between the Port's departments/functions
  - Improve Process efficiencies & effectiveness
- Eliminate Workforce Injuries
  - Reduce occupational injury rate and severity rate
- Become a Model for Workplace Diversity and Inclusion (D&I)
  - Increase management accountability of diversity & inclusion
  - Increase the percentage of employees that agree that the Port of Seattle is committed to diversity and inclusion
  - Increase awareness internally and actively share D&I programs externally
- Foster Employee Development and Leverage Talent
  - Develop a Strong Talent Pipeline
  - Foster awareness of Port-wide talent

Source: Port of Seattle: Long Range Plan: http://www.portseattle.org/About/Pages/default.aspx.

Table 1-3
Aviation Division 2018 Priorities
Seattle-Tacoma International Airport

INTERNAL FACING GOALS

1. Reduce the occupational injury rate (OIR) and days away severity rate by 15% and achieve an Airfield Composite Safety Score of 29 by Q4.
2. Complete all projects from Security Master Plan by Q4.
3. Increase employee engagement in department selected area by 3%.
4. Implement two efficiencies or innovations in each department by Q4.
5. Complete asset management gap assessment by Q3.

EXTERNAL FACING GOALS

6. Achieve the Airport Concessions Disadvantaged Business Enterprise (ACDBE) goal of 22% share of total Airport Dining & Retail program gross sales and a Disadvantaged Business Enterprise (DBE) goal of 8% share of total Airport Improvement Project (AIP) funded construction contracts.
7. Maintain 4 of 6 of the Airport Service Quality (ASQ) Scores. Two remaining goals will be no lower than 90% of year end 2017 by Q4.
8. Develop a sustainable aviation fuel (SAF) strategic plan by Q2 and work towards a partnership with major airlines to advance the use of SAF; Sound insulate at least 20 single family homes by Q4; and assess potential regional storm water solutions by Q4.
9. Surpass budgeted non-aeronautical net operating income of $126.86 Million and achieve Cost per Enplanement (CPE) below budget of $11.35 by Q4.
10. Achieve all 2018 milestones for priority projects (Capital Projects & Planning) and Sustainable Airport Master Plan (SAMP) environmental review by Q4.

Source: http://compass.portseattle.org/aviation/director/Pages/index.aspx.

Table 1-4

Strategy for a Sustainable Sea-Tac Goals and Objectives

Seattle-Tacoma International Airport

- Air Quality and Climate
  - Reduce Airport-owned and controlled greenhouse gas emissions by 15% below 2005 levels by 2020 and 50% by 2035
  - Reduce aircraft-related greenhouse gas emissions by 25% below 2005 levels by 2035
  - Develop a risk analysis examining aspects of airport operations with the potential to be affected by a changing climate (leading)
  - Develop a strategic plan to mitigate the climate change risks
  - Reduce air pollutant emissions by 50% from 2005 levels by 2037
- Buildings and Infrastructure
  - Seek LEED Silver for new construction, additions, and major renovations and minor renovations that modify mechanical, electrical, and plumbing systems and encourage LEED certification for tenant improvements
- Energy
  - Sea-Tac will meet all future growth in energy demand through the most practical and cost-effective conservation measures and renewable energy
- Fish & Wildlife Habitat
  - Sea-Tac will protect, enhance, and steward fish and wildlife habitat while maintaining air transportation safety
- Noise
  - Increase the number of noise compatible units within the noise remedy boundary to 95% through the year 2030
  - Implement noise abatement programs aimed at reducing noise at the aircraft source
- Transportation
  - Increase the percentage of passengers accessing the Airport via environmentally-preferred modes of transportation from 60% in 2014 to 70% in 2020
- Water Quality
  - Contribute to the restoration of Puget Sound and local receiving waters by providing water quality treatment, flow control, and using green stormwater infrastructure (where feasible) for Airport industrial stormwater
- Water Conservation
  - Reduce projected water consumption by 4% in 2020 and 12% in 2030
- Waste Management
  - Divert 85% of construction waste by 2020; 90% by 2025 and reach zero waste by 2035.
  - Divert 50% of terminal solid waste and 15% of airfield solid waste by 2020

Source: Port of Seattle, *Strategy for a Sustainable Sea-Tac*, Commission Mtg, February 10, 2015. http://www.portseattle.org/ABOUT/COMMISSION/MEETINGS/2015/2015_02_10_RM_7c_supp.pdf.

1.5 Applying FAA Guidance

In 2010, FAA developed and issued guidance for airports that opt to include sustainability in their master plans.* The Port followed this guidance throughout the development of the sustainability component of the SAMP. FAA's guidance states that *sustainability contents and scope of the Sustainable Master Plan or Sustainable Management Plan should include and/or address the following at a minimum:*

- Written Sustainability Policy or **Mission Statement** and a description of how it is communicated to airport employees, tenants, and the community.
- Define **sustainability categories** at the airport (e.g., socioeconomics, airport facilities and procedures, and environmental resources (e.g., noise, water, air quality, etc.))
- Conduct **a baseline inventory** or assessment of each defined sustainability category
- For each sustainability category, **establish measurable goals** to minimize the impact or consumption to reduce the airport's overall environmental footprint.
- Identify and describe a range of specific **sustainability initiatives** to help the airport achieve each set goal. An example could be:
  - Goal: To reduce energy consumption by 10% by 2012.
  - Specific sustainable initiatives:
    - Implement a "turn off your light and computer" campaign to raise awareness about unnecessary energy usage.
    - Clean or change furnace filters once a month during the heating season.
    - Use LED "exit" signs and other LED lighting in buildings.
    - Establish airside lighting controls and procedures to turn off or reduce the intensity of airside lighting (runway, taxiway, apron lights, etc.) when not being used.
    - Install solar photovoltaic panels on buildings and/or at ground level."
- Public Participation and Community Outreach.

The Port's approach to meeting FAA requirements for the Mission Statement, the Sustainability Categories, and the Establishment of Measurable Goals and Objectives is described and summarized below. The Port's approach to developing the Baseline Inventory and the Sustainability Initiatives is described in Sections 1.7 and 1.8 of this chapter, respectively.

*The guidance in this section is quoted directly from: Federal Aviation Administration. *Memorandum to Regional Airports Divisions Managers Re: NOTIFICATlON: Airport Sustainable Master Plan Pilot Program*. From: Elliott Black, Acting Director, Office of Airport Planning and Programming. May 24, 2010. https://www.faa.gov/airports/environmental/sustainability/

1.5.1 Port Mission Statement and Vision

As recommended by FAA guidance above, the Port established a Mission Statement and Vision for overall Port facilities in the Century Agenda.* For Sea-Tac Airport, the mission of the Aviation Division is "Connecting our region to the world through flight" and is included in the Port's webpage as well as in a variety of outreach publications and messaging.

1.5.2 Sustainability Categories/Focus Areas

As described above, the FAA's guidance to airports recommends that airports identify categories or areas within which the plan should focus. Since the Port had a well-established sustainability culture before the SAMP was initiated, the focus areas were identified based on the categories used in the Port's goals and objectives.

In addition, the Port added five potential focus areas to the Social/Community Outreach element in an effort to align the social sustainability element with the master planning process. As shown in Table 1-2, the Port's existing social programs focus largely on employee welfare, customer service, and workplace diversity and inclusion. The Port opted to add social/community outreach categories such as land use compatibility and public outreach, as these categories may be applied to the master planning process to consider development options. The general focus areas are combined and listed in Table 1-5 below.

Table 1-5
Port Sustainability Focus Areas
Seattle-Tacoma International Airport

Financial-Operational	Environmental	Social/Community Outreach
Air travel demand	Air quality and climate protection	Employee welfare and workforce development
Gateway of choice	Buildings and infrastructure	Land use compatibility
Customer service	Energy	Community benefits
Project affordability/cost center imbalances	Fish & wildlife	Public outreach
Productivity of existing facilities	Noise	Transparency
Ground vehicle operational efficiency	Transportation	
Aircraft optional efficiency	Water conservation	
Satisfying cargo demand	Water quality	
Renew aging landside infrastructure	Waste management	
Maximize efficient passenger and baggage movement		

Source: Port of Seattle, LeighFisher, Synergy Consultants, March 2018.

*http://www.portseattle.org/about/commission/pages/century-agenda.aspx.

1.5.3 Goals and Objectives

As described earlier in this chapter, the Port has a long list of overall goals and related objectives. This list was narrowed to include those goals and objectives that would pertain specifically to the SAMP development concepts and analyses as described in Chapter 2 of this Technical Memorandum. This includes tasks such as screening among the development concepts identified to create a vision for future air travel at the Airport, as well as various operational needs related to the focus areas.

1.6 Integrating Sustainability into Screening Alternatives

As shown in *Technical Memorandum No. 6 - Alternatives*, the Port's evaluation of the development alternatives includes sustainability as part of the screening criteria used to select among multiple concepts for the future layout of the Airport. The intent of this approach was to minimize the environmental and social impacts of "what and where we build."

In developing the alternatives, the Port considered almost a dozen different concepts for the layout of the Airport. The Port screened these concepts according to key planning priorities such as taxiway operations, passenger convenience, incremental expansion, constructability, flexibility to assign gates, ease of adding international gates, and ability to add gates quickly. To include sustainability among the priorities, the Port added the following five sustainability criteria:

- Reduce taxi/idle/delay
- Minimize impact on wetlands/creeks
- Limit addition of impervious surfaces
- Proximity to noise and light sensitive land uses
- Consistency with zoning.

The addition of sustainability criteria had an influence on the outcome of the Airport layout screening process, although most of the development concepts received almost identical scores for the sustainability criteria. However, in applying the same criteria in screening the cargo layout concepts, the sustainability criteria influenced the overall scoring, and the final alternative for cargo is the more sustainable option.

1.7 Baseline Inventory

During the preparation of the SAMP, data were collected to identify the current performance of the Airport, and recent past if available, relative to the focus areas. Those existing conditions are referred to as the baseline, or in some cases reference year that corresponds to a goal/objective. Chapter 3 of this Technical Memorandum identifies the baseline data and conditions.

This inventory enables the identification of the gaps discussed in Chapter 4 relative to achieving the Port's desired goals and objectives. The sole purpose of this gap analysis was to aid in determining the range of initiatives, opportunities, and actions (sustainability strategies) that the Port might consider implementing. Table 1-6 lists the metrics where data collection was initiated and collected where available.

1.7.1 Developing Financial and Operational Baselines

Baseline conditions were identified from existing Port reports. Some of the financial-operational efficiency metrics do not have a direct baseline, as they are associated with a proposed development or a project. Information between 2010 and 2016 is presented where available. The financial and operational efficiency metrics are listed in Table 1-6.

Table 1-6
Sustainability Metrics
Seattle-Tacoma International Airport

Financial and Operational Efficiency

Airport Activity Metrics
- Is the demand for 2034 served?
- Is the demand in the near-term served?
- Total passengers
- Total Cargo
- Total Aircraft operations
- Total Operations using gates
- Nonstop Domestic Markets
- Nonstop international Cities

Financial Metrics
- Total capital expenditures
- Total revenue
- Total expenses
- Annual cost of maintenance

Facility Space and Condition Metrics
- Terminal (sf)
- Concession (sf)
- Gates
- Facilities meeting LEED
- Number of parking spaces
- Age of infrastructure
- Minimum connect time
- Average walking distance
- Average SSCP wait time
- Peak period SSCP wait time

Survey Metrics
- Customer survey/reactions

Facility Space and Condition Metrics (continued
- Average distance—curb to bag drop
- Average distance—centroid of garage to bag drop
- Last bag cutoff time

Operational Efficiency and Performance Metrics
- Runway crossings
- Incursions
- Delay (min)
- Average taxi time
- Volume/capacity relationship
- Level of service
- Walking distances

Derivative Metrics
- Cost per enplaned passenger
- Debt per enplaned passenger
- Revenue per square foot
- Concession space per passenger
- Turns per gate
- Passengers per gate
- Passengers/square foot
- Age relative to expected life

Project Metrics
- Project cost allocated to airline cost center
- Annual cost of maintenance

Table 1-6 *(continued)*
Sustainability Metrics
Seattle-Tacoma International Airport

Environmental

Air Quality and Climate
- Criteria Air Contaminant and Greenhouse Gas Emissions (metric or short tons, as applicable)
- Dwell time, taxi time, delay (minutes)
- Roadway vehicle miles traveled (VMT)
- Complete climate change risk analysis
- Availability of strategic plan to address climate risks

Buildings and Infrastructure
- # of building with LEED certification
- Square feet of buildings with LEED silver or higher certification

Energy
- Energy consumption (kWh, gallons, therms, MMBTUs)
- Energy per passenger or square foot

Fish and Wildlife
- Acres of open space displaced
- Acres of protected habitat displaced

Noise
- Population within 65 DNL
- Proximity of noise sensitive facilities to new buildings
- Compliance with noise procedures

Transportation
- Percentage of passengers accessing the Airport under the various environmentally preferred modes relative to total O&D passengers
- Environmentally preferred modes: Daily parking, taxi/TNC, door-to-door van, hotel/motel courtesy vehicle, air porters, public transit, and charter/other bus.
- Annual greenhouse gas emissions from passenger and employee transportation

Water Conservation
- Potable water consumption in gallons per yr
- Non-potable water reuse
- Gallons of rainwater captured & reused per yr

Water Quality
- Acres managed by LID
- Percent area runoff managed for flow control
- Percent area runoff treated

Waste Management
- Construction and Municipal Solid Waste generated, diverted, and landfilled (tons)
- Waste diversion rates
- Kilograms of hazardous waste generated, rolling 180 days.

Social and Community Outreach

Employee and Employee Retention
- Number of employees
- Employee turnover/average employee tenure
- Number of employee accidents and injuries
- Number of employee development activities

Community Benefit/Impacts Metrics
- Number of noise or other complaints
- Socioeconomic impact (jobs/payroll/regional economic input)
- Number of jobs, payroll, regional economic benefit
- Number of tenants/ Percentage of tenants headquartered in Puget Sound

Community Outreach
- Number of meetings
- Number of newsletters
- Number of comments received and number of commenters
- Extent of coverage of near-airport and other communities

Project Specific Metrics
- Consistency of propose project with existing zoning
- Proximity to noise and light sensitive land uses
- Roadway LOS/Congestion
- Changes in environmental effects

Source: Port of Seattle Business Plan, SAMP Technical Memorandums 1 and 4, revised in preparing TM9.

1.7.2 Developing Social and Community Outreach Baselines

As described in Section 1.4, the Port's current social sustainability goals are associated with customer satisfaction, employee safety, and workforce diversity and inclusion. The Port's metrics associated with these goals are not readily applied to airport master planning efforts. In addition, the Port is actively developing new social equity programs and initiatives, and as such, little or no data is yet available from which to derive metrics and baselines.

As a result, the Port developed additional social considerations when appropriate in the development planning process and provides qualitative descriptions on how the Port's existing and emerging social equity programs and metrics could influence the development of the Near-Term Projects, described in Section 1.10. For example, when screening airport layout concepts for the Long Term Development Vision, the Port added social considerations such as proximity to noise and light sensitive land uses, and consistency with zoning to the traditional screening criteria. Similarly, the Port expects to add new social metrics to its capital development program, including the Near-Term Projects, as its emerging racial and social equity initiatives are developed.

1.8 Sustainability Initiatives, Opportunities, and Actions

Chapter 4 of this Technical Memorandum identifies numerous candidate strategies that would address the sustainability goals and objectives at Sea-Tac Airport. Collectively, these strategies are referred to as Initiatives, Opportunities, and Actions (IOAs). The strategies are aimed at closing the gaps between baseline conditions and Port goals/targets, and are defined as:

- **Initiatives**. Initiatives are specific new actions that could be taken to enhance performance in one of the triple bottom line focus areas (i.e., make progress towards achieving sustainability goals/objectives).

- **Opportunities**. Opportunities are potential actions that, when applied to the recommendations of the SAMP, could improve triple bottom line performance. At a concept level, it is not a prudent use of resources to develop highly specific actions, but rather identify opportunities that could be incorporated during the engineering and design process for future projects.

- **Actions**. The Port has an ongoing program of actions that it implements to achieve its various goals and objectives. Items in this category would extend the existing program(s) to include recommendations resulting from the SAMP.

The IOAs were identified for each of the triple bottom line categories: financial-operational efficiency, environmental, and social-community outreach.

In some cases, the gaps in each focus area can be easily estimated, such as air quality, greenhouse gases, energy, water, and waste. The collective list of strategies is designed to aid the Port with achieving their sustainability goals and objectives. However, the Port recognizes that even by implementing all the IOAs, the Port may not be able to achieve all of its sustainability goals and objectives in the SAMP.

Thus, the implementation plan discussed later relies on the plan-do-check-act process to adjust programs in the future.

1.8.1 Financial and Operational Efficiency

The primary IOA would be implementation of airport improvements, represented primarily by the Near-Term Projects shown on Figure 1-2. Continuation of Port financial and operational practices will help to ensure that efficiency measures are maintained. Table 1-7, provided at the end of the chapter, list additional high priority IOAs that could be implemented to aid the Port in achieving its financial-operational efficiency goals and objectives for Sea-Tac Airport. These are discussed in Section 4.2 *Evaluating IOA to Achieving Financial and Operational Goals and Objectives*. A full list of IOA is provided in Chapter 5.

1.8.2 Environmental

To achieve the sustainability goals and objectives, the Port will need to implement strategies related to the environment. In many cases it is not possible to quantify the beneficial effects of the IOAs. Chapter 5 of this Technical Memorandum identifies all of the IOAs. Table 1-7 identifies the high priority IOAs for the following environmental focus areas, per FAA sustainability guidance:

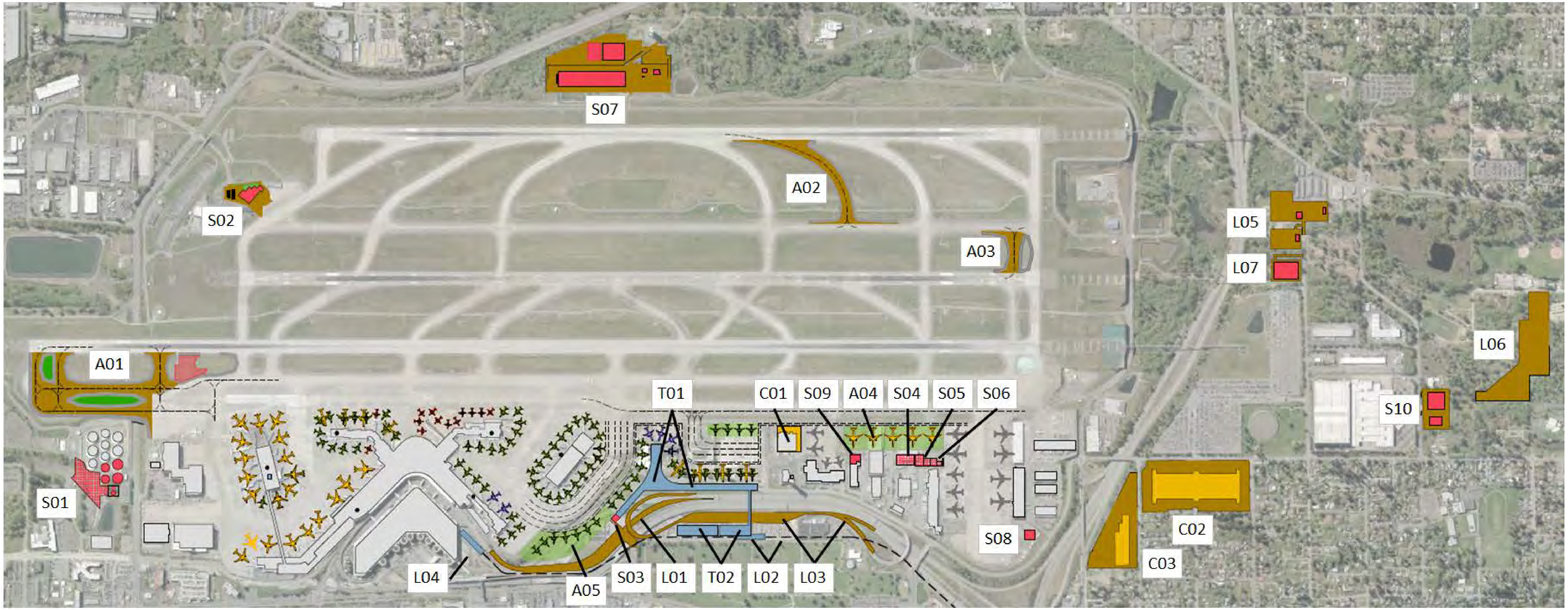
- **Air Quality and Climate Change**. A number of key air quality and climate change IOAs were identified for this category. Priority IOAs include some of the most challenging and long-term actions for the Port including developing a market for sustainable aviation fuel (SAF), reducing emissions from passengers traveling to and from the Airport, and procuring renewable natural gas to heat Port facilities. Most of these IOAs would aid other goals and objectives, such as transportation and energy.

- **Buildings and Infrastructure**. Of the building and infrastructure IOAs identified, all of them would also facilitate reduced environmental footprint in other focus areas as they strive for actions that would result in energy efficiency, water conservation, etc.

- **Energy**. A large number of IOAs were identified for this focus area to address the different fuels (e.g., gasoline, natural gas, diesel, and electricity) used to generate energy at the Port. However, the priority IOAs for this focus area are largely within the Port's control. For example, the Port will continue to implement energy efficiency improvements, install metering, and replace fossil-fuel vehicles with electric. In addition, many of the priority IOAs provide benefits to the climate and air quality focus areas. For example, replacing diesel with renewable diesel or biodiesel has the added benefit of reducing greenhouse gas emissions as well as traditional ("criteria") pollutants such as particulate matter.

- **Fish and Wildlife**. Two IOAs were identified to aid in achieving the fish and wildlife goals and objectives.

Figure 1-2
Near-Term Projects
Seattle-Tacoma International Airport



Airside

A01 Taxiway A/B Extension
A02 Runway 34L Highspeed Exit
A03 Taxiway D Extension
A04 North Harstand
A05 Concourse D Hardstand

Terminal

T01 North Gates
T02 North Terminal & Parking

Cargo

C01 Cargo 4 South Redevelopment
C02 Off-Site Cargo *Ph 1 (L-Shape)*
C03 Off-Site Cargo *Ph 2 (L-Shape)*

Landside

L01 NAE Relocation *(southbound lanes)*
L02 Elevated Busway & Stations
L03 North Terminal Roads/Curbside
L04 Main Terminal North GT Lot
L05 North GT Holding Lot
L06 Employe Parking Surface Lot
L07 Employee Parking Structure

Airport/Airline Support

S01 Fuel Farm Expansion
S02 Primary ARFF
S03 Secondary ARFF
S04 Fuel Rack Relocation
S05 Triculator
S06 Consolidated De-icing Facility
S07 Port Maint. *(Westside Maint. Campus)*
S08 Airline Support *(north)*
S09 Airline Support *(west)*
S10 Centralized Rec. & Dist. Center

Source: Port of Seattle and LeighFisher, 2017.

- **Noise**. The Port has a longstanding Noise Compatibility Plan, which was updated with FAA approval in 2014. In addition to continued implementation of that plan, two specific IOA, in addition to the Part 150 Study recommendations were identified to address noise.

- **Transportation**. As one of the most challenging issues addressed in this analysis, the IOAs for this area include the most difficult to implement. The priority IOAs such as reinstating express bus routes with Sound Transit, obtaining express light rail runs to and from the Airport, or developing a shuttle bus service from urban centers to the airport will require extensive negotiations with external partners and additional funding structures. In addition, more in-depth analyses of both infrastructure and financial requirements will be needed.

- **Waste Management**. Because the Port has already implemented a number of strategies for this focus area, the priority IOAs needed to meet the Port's goals require larger financial investments and possibly collaborative partnerships with other local governments such as King County.

- **Water Quality**. Thirteen IOAs were designed to aid the Port in achieving its water-related goals and objectives to conserve water and improve water quality.

1.8.3 Social and Community Outreach

Table 1-7 lists the high priority Social and Community Outreach IOAs. Chapter 4 of this Technical Memorandum reviews each objective to determine if gaps can be evaluated in future business-as-usual performance for social and community outreach goals. Most of the social and community outreach goals cannot be evaluated for gaps because they are difficult to measure. However, the Port recognizes that some goals, such as 1) Maximize the compatibility of new development with nearby lands, and 2) Identify the benefits of proposed development to the local community, are project specific. As a result, they will be considered as individual development projects are evaluated.

For other non-project specific goals, such as 1) Enhance employee welfare and facilitate diversity, and 2) Be transparent in public communications and increase outreach to the local community, the Port's ongoing programs will continue to operate in coordination with the Near-Term Projects development. For example, the Port will continue to implement its employee development programs such as the Diversity and Development Council and recognizing and supporting women and minorities at the Port through the Women's Initiative and the Champion of Diversity and Inclusion Award. These programs will be supplemented with new social programs as they become available. Similarly, the Port expects to continue to communicate about the SAMP projects through its existing outreach to near-Airport communities with programs such as the Highline Forum and the Sea-Tac Stakeholder Advisory Roundtable (START), community newsletters, social media, and project specific meetings as appropriate.

The Port also has several other new social initiatives that are expected to advance the social element of sustainability in the Near-Term Projects. For example, in the November 28, 2017 Commission meeting, the Commission approved a new motion that directs the Port to implement policy on Priority Hires for project labor agreements. This purpose of this new policy is to provide good family wage jobs to qualified construction workers from economically distressed areas of King County by increasing access to Port of Seattle projects. This policy will likely apply to the Near-Term Projects and may help provide jobs to those historically underrepresented in the construction industry, including women and people of color.*

1.9 Climate Change Research and Sea-Tac Airport Facility Risk

For the SAMP, research was reviewed in 2014 to identify predictions concerning how the climate is expected to change in the future and a summary or synthesis was prepared. In addition, using an Airport Cooperative Research Program (ACRP) tool, the Airport facilities that could be at risk based on these changes were identified. Chapter 6 and Appendix B of this Technical Memorandum summarize the research consulted and identify the facilities that could be at risk.

There have been many studies concerning potential significant changes in the climate that may occur over time. Climate predictions represent general trends that might be expected in the climate. Such predictions are largely based on the underlying assumptions. While regional models can predict a smaller local level (relative to global models), the Puget Sound Region has diverse topography which can materially affect the results. Thus, the information presented in the synthesis is intended to identify regional and state trends and how these trends may affect conditions in the Airport vicinity.

- **National Climate Predictions**. Research indicates that that the world is warming and that the primary cause of this warming is human activity. From the warming, changes in the climate over time are predicted to include: shorter duration of ice on lakes and rivers, reduced glacier extent, earlier melting of snowpack, reduced lake levels due to increased evaporation, lengthening of the growing season, changes in plant hardiness zones, increased humidity, rising ocean temperatures, rising sea level, and changes in some types of extreme weather.

- **Pacific Northwest, State of Washington, Puget Sound Region**. There are general conclusions that are consistent among the reviewed studies (increased temperatures, particularly during the summer; increased winter precipitation, with increased summer droughts, etc.) and the magnitudes vary based on the modeling scenario assumptions (as discussed previously). Global climate change models are not able to simulate regional climate at a precise location. However, with many simulations conducted, these predictions can assist with understanding potential regional changes and these simulations combined with regional climate models enable a more refined characterization at a local level.

Two key climate change effects are expected to be felt at Sea-Tac Airport: increased rainfall intensity and increased temperatures. Heavy rain events are expected to increase from today at 13.4 days of heavy rain to a median of 14 days of heavy rain by the 2030s.

Valdez, V. MEMO: Second Reading of Resolution No. 3736, Priority Hire Policy Directive*; and amending the Policy Directive related to practices for construction labor for projects located on Port property adopted by Resolution No. 3725, November 20, 2017.

Since scientists generally agree that the climate is already changing, and that it will continue to change over time in response to past and present human activity, substantial research and discussion are also occurring about how these changes/effects can be addressed. There are generally two categories of potential responses to human-induced climate change—mitigation (reducing activities that cause climate change and is referred to as climate protection in the Port's programs), and adaptation (adjust the practices, systems, and structures to reduce the negative consequences and take advantage of the opportunities of beneficial changes).

Climate change adaptation planning is a multi-step process aimed at increasing the resilience of infrastructure and operations when confronted with the range of projected climate change impacts. Adaptation planning usually begins with the evaluation of climate change and the risk to various resources associated with the climate change.

1.10 SAMP Near-Term Projects/Development Recommendation

SAMP Technical Memorandum 7 *Facilities Implementation and Financial Feasibility* documents the Port staff recommendation to pursue the Near-Term Projects shown in Figure 1-2.

With completion of the Near-Term Projects, Sea-Tac would have an additional 19 narrow-body equivalent aircraft gates connected to a second terminal via a pedestrian bridge over the North Airport Expressway and cargo warehouse redevelopment and expansion adjacent to the airfield. Airfield projects include taxiway modifications (a 34L high speed taxiway exit, Taxiway D extension, and Taxiway A/B extension) to increase operational efficiency and the creation of new hardstands for passenger and cargo operations. The Near-Term Projects also include landside improvements to provide access to the Second Terminal; connectivity between the Rental Car Facility, Second Terminal and Main Terminal; expanded employee parking; and expanded ground transportation holding lots. Airport/airline support facility projects in the Near-Term Projects primarily replace facilities displaced by passenger and cargo facility development, except for a Centralized Receiving and Distribution Center (a security and operational efficiency project) and expansion of the Fuel Farm. On the west side of the airfield, a campus would be developed to house Airport maintenance.

Key projects shown on Figure 1-2 include:

- A01 – Taxiway A/B Extension –This project would relocate Taxiway B south of Taxiway S and provide a new parallel taxiway, Taxiway A.
- A04 – Taxiway B 500' Separation North –Taxiway B would be moved 100' to the east.
- A05 – Runway 34L High-speed Exit – High-speed exits allow landing aircraft to exit the runway at relatively higher speeds, leading to less time on the runway.
- A07 – Hardstand *(north)* –The hardstand would accommodate 5 aircraft.
- A08 – Hardstand *(central)* –The hardstand would serve 7 aircraft.

- T01 – North Gates – The North Gates project would be a multi-level concourse connected to the Second Terminal via a pedestrian bridge and would serve 19 gates.

- T02 – Second Terminal & Parking –The Second Terminal would include facilities for passenger check-in; passenger and baggage screening; airline offices, baggage conveyance and claim; concessions; and restrooms.

- C01 – Cargo 4 South Redevelopment –The Cargo 4 South site would be redeveloped to maximize warehouse capacity.

- C02 – Off-site Cargo Phase 1 *(L-Shape)* – would include a 330,000-sf building with warehouse and office space, truck terminals, and parking for visitors and employees.

- C03 – Off-site Cargo Phase 2 *(L-Shape)* – would include a 90,000-sf building with warehouse and office space, truck terminals and parking for visitors and employees.

- S01 – Fuel Farm Expansion – Expansion of the fuel farm would include additional settling tank capacity and infrastructure to support the Ports biofuel initiative.

- S07 – West-side Maintenance Campus – Relocation of the Port's Aviation Maintenance Facility from its current location in the North Cargo area is required to clear the site for construction of the A07 Hardstand *(north*) project.

1.11 Sustainability Implementation Plan

One of the key measures of the success of a sustainability program is associated with the follow through on the commitments and the measurement of progress toward reaching goals and objectives. The implementation of sustainability strategies and the Port's prior Environmental Strategy Plan, has been established using the Deming Cycle – also known as the Plan-Do-Check-Act (PDCA) process. Chapter 5 of this Technical Memorandum summarizes the Port's anticipated implementation plan for the sustainability elements of the SAMP using PDCA:

- **Plan (Formulate)**. This SAMP Technical Memorandum represents the first step in documenting the "plan" portion of the process. Defining sustainability and establishing sustainability categories (areas of focus), collecting baseline information, identifying goals and objectives, and recommending IOAs are all part of the planning step. In addition, the IOAs will need to be prioritized based on criteria such as feasibility, cost, and potential sustainability benefits or impacts. In the future, as subsequent steps in the cycle occur, additional consideration of categories/focus areas, baseline condition(s), and goals will likely be necessary.

- **Do (Implement or Take Action)**. Implementing the strategies represents the "do" portion of the process. This involves undertaking the strategies noted in this plan, and taking advantage of the opportunities, as development recommendations of the SAMP are constructed.

Because the sustainability strategies for the SAMP include both operational as well as capital projects, the oversight for the implementation phase would rest with the Airport's senior management, with key capital projects implemented by the Project Management Group (PMG) as directed, and routine management and tracking of the initiatives led by the Airport's sustainability team and other departments as directed.

The Port anticipates that its existing organizational structure will initially be used to implement the recommendations of the SAMP. This includes:

- **Financial/Operational Efficien**cy. Overseeing the financial and operational objectives rests with the Aviation's Division financial group as well as the Operations Department.

- **Environmental.** These activities are implemented by the Port's Aviation Division's Environment and Sustainability Department. In many cases the Aviation Environmental group will work with other departments such as Facilities & Infrastructure, Operations, etc. to assist with the implementation.

- **Social/Community Outreach.** The Port implements its social programs through a number of groups and programs including: Human Resources (staffing), Office of Social Responsibility (job creation and economic development efforts), Noise Abatement and Noise Remedy Office (addressing noise exposure in the community around Sea-Tac), Public Affairs (stakeholder and community outreach), and Aviation Environment and Sustainability.

In addition to the current/ongoing implementation process, the Port anticipates that over time, the implementation of sustainability will continue to evolve. In 2018, the Port initiated a formal review and revision of its project review procedures to include the Sustainability Evaluation Framework. This Framework and the resulting new procedures are expected to aid the Port in implementing sustainable practices for both the Airport development but also within its daily operation. Initial items that will likely be considered:

- Identifying interfaces for the consideration of the performance of sustainability goals and objectives for:
    - Capital improvements
    - Operating and management changes
    - Procurement

- Revising the Port's sustainable construction practice guidelines and creating a centralized list of sustainable design and construction practices

- Formulating training session content for the various lines of business and tenants about sustainability goals and objectives and soliciting suggestions for sustainable strategies

- Establishing timelines and collection process for the reporting of annual performance

The Port's Sustainability Manager serves as a clearing house for information about sustainability and coordinates activities of the various operating arms of the Aviation Division, but responsibility for achieving goals and objectives has and will continue to rest with the various operating arms (e.g., achieving aviation financial goals and objectives will rest with the Aviation financial group within the Finance and Budget Center of Expertise).

- **Check (Report/Confirm)**: the "check" process encompasses the reporting aspect of the implementation. As strategies are implemented, the next step is to track and check the process toward meeting the goals and objectives. Through the Port's *Strategy for a Sustainable Sea-Tac* (S3) Reports, the Port has historically monitored its environmental footprint annually. Through this SAMP, annual reports will continue, and it is expected that progress toward Financial-Operational Efficiency, and Social/Community Outreach goals may be added to this annual report.

- **Act (Adjust/Refine)**: The "act" portion represents what has been learned during the "do" and "check" steps, and effectively adjusts the Port's activities. This involves answering the question of, "What did we learn and how can we do it better next time?" by re-evaluating the issues/categories, goals, and objectives and metrics. During this stage of the cycle, adjustments are often identified. The Port anticipates that it will review its performance annually and adjust accordingly.

1.12 Lessons Learned from the SAMP Process

As part of the FAA issuance of grants for sustainability, the Port was required to submit quarterly reports that highlight progress and challenges. In addition to those reports, the following briefly summarize many of the lessons learned during this study:

- Traditional master plans focus on buildings and facilities in a general way in comparison to the engineering and design process. Sustainable master plans provide opportunities to compare layout concepts and locate buildings in more strategic and sustainable areas of an airport. In this master plan, the Port opted to stay within the airport's current footprint, and thereby reduce or avoid potential resource impacts. As this decision was made at the beginning of the process, the comparison among the airport layout concepts did not show significant differences from a sustainability perspective.

- In this study, some of the major focus areas of sustainability (i.e., energy management, workforce development, diversity and inclusion) cannot be evaluated until after the decision has been made to build and the project is undergoing engineering and design. The primary role for sustainability during the master planning process is to ensure that the Airport's sustainability goals and objectives are considered as development alternatives are considered. This is particularly important relative to environmental and social goals and objectives.

- The challenge in accurately understanding the sustainability gaps made it difficult to identify strategic priorities for the organization. The Port opted not to estimate future levels and quantify the gaps for environmental categories under the sustainability analysis in order to maintain clear boundaries between the voluntary sustainability initiative and the environmental analyses required under NEPA. Airport master plans typically result in recommended improvements, which are included as part of an Airport Layout Plan (ALP). Often FAA will conditionally approve the ALP, with one of the conditions being that the development projects require NEPA approval prior to implementation. As projects on the ALP become ready for implementation and reasonably foreseeable, the NEPA approval process can be undertaken.

  Because NEPA will be conducted for the Near-term Projects, the Port did not estimate future conditions for any of the sustainability categories. For example, a sustainability analysis could forecast future conditions for air pollutants using only a few emission sources. This could result in different air pollutant emissions when compared with a more rigorous NEPA analysis that uses more refined data and procedures. Hence, the sustainability results could appear to conflict with the formal NEPA assessment and could create confusion.

  Similarly, under NEPA, an airport may compare forecasted conditions to defined thresholds of significance whereas sustainability analyses may compare those conditions to voluntary stretch goals. For example, in some circumstances, airports are required to estimate future conditions for air contaminants as ambient air concentrations and compare them to National Ambient Air Quality Standards (NAAQS). Under a sustainability analysis, the future condition for an air contaminant could be developed as simply tons per year, and compared to a voluntary goal such as "50% below 2005 levels" to establish a gap. Sustainability goals are not a requirement from a regulatory perspective. On the other hand, limiting the gap analyses for the environmental sustainability categories to existing conditions may reduce the efficacy of the overall sustainability analysis. In the future, airports should be aware of the potential conflict between the two processes and develop a clear methodology early in the process to address or avoid confusion.

- The Plan-Do-Check-Act process is an established system used in many organizations, and the application of the process to sustainability implementation appears logical. However, the implementation of the process across the numerous stakeholders and actions involved in a comprehensive program that includes all three elements of sustainability has been and will be challenging for large airports.

- The analyses throughout this Technical Memorandum address the three categories of the triple bottom line (financial/operational, environmental, and social) separately, but true sustainability sits at the intersection of the three categories. One of the key benefits of this study was the inclusion of the financial analysis as a primary consideration in future airport planning. However, future sustainability analyses could go further by addressing the following questions: How does the Port balance the financial and operational benefits of Airport growth with the environmental impacts of that growth and the related social concerns? What are the financial and/or operational tradeoffs of individual sustainability measures? And who makes those decisions?

- In the end, the Port posited that it's a necessity to consider sustainability issues and solutions that extend beyond the borders of the project and the organization. The most challenging sustainability problems require the most challenging solutions, and those by nature require more than the Airport itself.

  Climate protection initiatives provide an example of this where the largest sources of emissions are those where airport operators have the least control. To reduce "Port-influenced" or Scope 3 greenhouse gas emissions, airport operators must pursue complex and long-term strategies such as sustainable aviation fuels, improved transit and transportation modes, and extended programs into our underserved communities.

  These require long-term and highly strategic partnerships with key organizations such as airlines, business developers and entrepreneurs, corporations, transit organizations, and other government agencies. For example, legislative and political strategies may be needed to send the necessary market signals that create demand and stimulate product development. Implementation of such partnerships and strategies extends well beyond the timeframes and decision-makers associated with a typical master plan.

- The focus areas of sustainability and corresponding metrics continue to change and advance at a time when the industry is adjusting to the effects of technology and economic conditions. This made it challenging for staff to track new issues and incorporate them while the SAMP was under development. For example, during the SAMP process, the Port undertook a more comprehensive analysis of its social justice/equity programs and approaches. This has resulted in a draft Race and Social Equity Worksheet that is likely to influence how the Port moves forward in its capital development program and hence implementation of development. However, the overall impact will not be realized for several years.

  Similarly, the Port adopted a new Sustainability Evaluation Framework that will have considerable influence in the procedures the Port will use to design the Near-Term Projects and related initiatives. This effort is described in Chapter 5, but full implications of this effort will not be realized for several years into the future.

Table 1-7
High-Priority Initiatives, Opportunities, and Actions – Financial & Operational, Environmental, and Social/Community Outreach
Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline
FINANCIAL & OPERATIONAL				
Enable phased, incremental development			All groups	On-going
Provide revenue-generating space in the terminal facilities in accordance with Port guidelines			EconDev, F&B, F&I	On-going
Annually, set capital budget limits so that total five-year capital spending does not cause forecast CPE to exceed forecast CPE of middle third of 22 peer airports			F&B, Exec Leadership	On-going
Ensure capacity of parking is adequate for revenue increases			AvPlan, OPS	On-going
Expand airfield drivers training			OPS	On-going
Automate ramp insurance validation at airfield access points			OPS, PMG	Short
Install automated gate docking system and gate operating system			OPS, PMG	On-going
ENVIRONMENTAL				
Develop & enforce policy for optimal use of electric preconditioned air (PCA) and ground power unit (GPU) systems	Air Quality, Climate Protection		AvEnv, F&I, EconDev	On-going
Continue to ensure installation and availability of electric preconditioned air (PCA) and ground power unit (GPU) systems at all new and existing gates	Air Quality		AvEnv, PMG	On-going
Install new electric ground support (eGSE) infrastructure as new gates are developed.	Air Quality		PMG, F&I, AvEnv	On-going
Continue to install eGSE infrastructure at Concourses A, B, and the South Satellite (SSAT)	Air Quality, Climate Protection		PMG, F&I	On-going
Educate airline ground staff on use of electric PCA and GPU systems	Air Quality		AvEnv, F&I	On-going

Table 1-7 *(continued)*
High-Priority Initiatives, Opportunities, and Actions – Financial & Operational, Environmental, and Social/Community Outreach
Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline
Work with airlines and other partners to develop and implement a strategic plan for the introduction and use of sustainable aviation fuels (SAF) at the Airport.	Air Quality, Climate Protection		AvEnv	On-going
Work with airlines and other partners to promote replacement of fossil-fueled GSE with eGSE.	Air Quality		AvEnv	On-going
Develop partnerships with transit agencies and strategies to improve the frequency and efficiency of public transit service to the Airport.	Air Quality, Climate Protection	Transportation	AvEnv, PA	Long-term
Continue to develop strategies to provide direct bussing service from economic centers such as downtown Seattle and Bellevue to and from the Airport	Air Quality, Climate Protection	Transportation	AvPlan, AvEnv, Ops	On-going/long-term
Develop an Energy Management Plan that identifies key energy users, any possible energy type conversions (i.e., electric to natural gas, or vice versa), and options available to reduce use	Climate Protection	Energy	F&I, AvEnv, AvPlan	On-going
Identify and upgrade central plant and distribution equipment, including boilers, chillers, and other HVAC system components	Climate Protection	Energy	F&I, PMG	On-going
Replace CNG with renewable natural gas (RNG) in boilers and port-owned fleet vehicles	Climate Protection		AvEnv, F&I, Maint	On-going
Continue to explore opportunities for passengers to check baggage at off-site locations prior to their flight	Climate Protection	Transportation	AVEnv, AvPlan	On-going
Obtain LEED certification North Satellite (NorthSTAR) expansion project	Buildings		AvEnv, PMG	On-going
Conduct a renewable energy feasibility study to determine the design, size, type, location and cost of installing and operating an alternative renewable energy generation system	Energy all		F&I	On-going

Table 1-7 *(continued)*
High-Priority Initiatives, Opportunities, and Actions – Financial & Operational, Environmental, and Social/Community Outreach
Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline
Replace CNG buses and light-duty vehicles with renewable natural gas or electric busses	Energy - CNG	Climate protection	OPS, AvEnv, PMG	On-going
Construct an Automated People Mover (APM) or bus guideway from terminal to consolidated rental car facility to reduce the use of CNG-powered buses	Energy - CNG	Transportation, Climate protection, Fin/Ops	OPS, AvPlan, AvEnv, PMG	Long
Continue to install variable frequency drive (VFD) motors for fans, chillers, and pumps	Energy – Electricity	Climate protection	F&I, PMG, Maint	On-going
Continue to install motor efficiency controllers in escalators and moving walkways	Energy – Electricity		F&I, PMG, Maint	On-going
Continue to upgrade the efficiency of the existing HVAC system	Energy – Electricity	Climate protection	F&I, Maint, PCS	On-going
Purchase and install high efficiency HVAC systems when new terminal buildings are constructed	Energy – Electricity, Natural Gas	Climate protection	FI&, Maint, PCS	Short
Conduct study of species present	Fish & Wildlife		AvEnv	Ongoing
Evaluate quantity of open space and protected habitat displaced as part of every development action	Fish & Wildlife		AvEnv, AvPlan	On-going
Continue to implement the Part 150 Recommendations, including single-family residential sound insulation and other sound insulation programs.	Noise	Social	AvEnv	On-going
Continue to implement the Fly Quiet Program to track compliance with the existing noise abatement procedures	Noise		AvEnv	On-going

Table 1-7 *(continued)*

High-Priority Initiatives, Opportunities, and Actions – Financial & Operational, Environmental, and Social/Community Outreach

Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline
Toll curbside	Transportation	Climate protection, financial	AvPlan, AvEnv, OPS	Short-Intermediate
Develop a transportation management association to assist airport employees with ride-share programs, guaranteed ride home/emergency program, and transit support.	Transportation	Climate protection, social	AvEnv, EconDev, HR	On-going
Continue review project designs and identify opportunities to recycle construction debris	Waste – Construction	Climate protection	AvEnv, PMG	On-going
Work with construction teams to ensure construction waste recycling efforts earn LEED certification credits	Waste – Construction		PMG	On-going
Develop partnership with King County Solid Waste Division to explore secondary sorting (AKA mixed waste processing) facility opportunity for Airport and County waste	Waste – MSW	Climate protection, financial	AvEnv, F&I	Short
Implement high performance Green Cleaning policy and program to support LEED® certification for capital projects	Waste – MSW		AvEnv, F&I	On-going
Continue implementing ACI award-winning green concessions and dining program.	Waste – MSW		F&I, AvEnv	On-going
Monitor and continue to assist airport concessions required to divert their waste, use durables or compostable or recyclable service-ware for "take away" meals provided in terminal areas and provide clearly labeled collection containers for recycling, composting, and garbage.	Waste – MSW	Climate protection, financial	AvEnv, F&I	On-going
Continue encouraging concessionaire donations to local food banks or the Airport USO	Waste – MSW	Climate protection, financial	AvEnv, F&I	On-going

Table 1-7 *(continued)*

High-Priority Initiatives, Opportunities, and Actions – Financial & Operational, Environmental, and Social/Community Outreach

Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline
Add liquid collection stations to all security checkpoints and optimize existing station location and signage	Waste - MSW	Climate protection, financial	AvEnv, F&I	On-going
Continue working with Maintenance, cargo operators and airlines to improve recycling at hangars, in Maintenance work areas, on the ramp, and other remote work locations	Waste - MSW	Climate protection, financial	AvEnv, F&I, Maint, Cargo	On-going
Continue to ensure that secondary containment is used for oil and solvent containers to contain spills	Waste – Haz		AvEnv, F&I, Maint, PCS	On-going
Prepare a Water Use Reduction Plan to identify specific conservation measures	Water Conservation		AvEnv, F&I	On-going
Document and manage construction water usage and other non-standard usage	Water Conservation		PMG, Maint, PCS	On-going
Implement and improve current sub-metering strategies	Water Conservation		F&I, Maint, PMG	On-going
Consider rainwater harvesting and reuse in new facilities where feasible	Water Conservation	Financial	F&I, Maint	On-going
Continue to plant native plants and drought-tolerant landscaping	Water Conservation		AvEnv, F&I	On-going
Install dual-flush toilets that use 0.8-1.6 gpf	Water Conservation		AvEnv, F&I	On-going
Install low impact development where feasible and consistent with Airport operations and FAA design standards	Water Quality		AvEnv, PMG	On-going
Clearly designate aircraft deicer/anti-icer storage and transfer areas	Water Quality		AvEnv, F&I	On-going

Table 1-7 *(continued)*
High-Priority Initiatives, Opportunities, and Actions – Financial & Operational, Environmental, and Social/Community Outreach
Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline
Construct a centralized deicing facility (CDF) and collect and recover deicing fluids	Water Quality		AvPlan, AvEnv, PMG	Short
SOCIAL/COMMUNITY OUTREACH				
Prepare documentation to comply with NEPA/SEPA and coordinate the results with the public			AvPlan, AvEnv	Immediate
Conduct coordination workshops with interested parties concerning the SAMP			AvPlan, AvEnv, PA	On-going
Place all SAMP documents in the public libraries when study is complete			AvPlan	Short
Continue to survey employees regarding their engagement at the Port and concerns			HR	On-going
Implement the Port's social sustainability components in the Long Range Plan			HR	On-going
Leverage the Port's Development and Diversity Council, an internal group of experts who advise, generate ideas, advocate and communicate about employee development and diversity issues, policies, programs and initiatives			HR	On-going
Develop new and supporting existing Employee Resource Groups			HR	On-going
Develop new courses and encouraging employee education on diversity through the J. Loux Learning Library			HR	On-going
Recognize and support women and minorities at the Port through the Women's Initiative and the Champion of Diversity and Inclusion Award			HR	On-going
Continue to identify diversity gaps and needs			HR	On-going
Continue to prepare an environmental management report or a sustainability report			AvEnv	On-going
Create a speakers' bureau that regularly volunteers to present at local meetings and events			PA	On-going

Table 1-7 *(continued)*

High-Priority Initiatives, Opportunities, and Actions – Financial & Operational, Environmental, and Social/Community Outreach

Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline
Prepare annual Long Range Plan Report and highlight sustainability and triple bottom line, make available on the web			Strategic Initiatives Team, AvEnv	On-going
Place all master plan documents in local public libraries			AvPlan	Short

Notes: AvEnv: Environment & Sustainability; AvPlan: Aviation Planning; Cargo: Cargo; EconDev: Economic Development; F&B: Finance & Budget; F&I: Facilities & Infrastructure; HR: Human Resources: Maint: Maintenance; OPS: Operations; PA: Public Affairs; PCS: Port Construction Services; PMG: Program Management Group;

Timeframe: Short: 1-5 years; Intermediate: 6-14 years; Long: 15 years or longer; Ongoing: Ongoing/continuous

Priority: High, Medium, Low, UN: Undecided

Source: Port of Seattle, LeighFisher, Synergy Consultants, April 2018.

Sustainability Vision and Goals/Objectives

The Port of Seattle's Sustainability Vision will establish the priorities to enable the Port's goals and objectives for Sea-Tac Airport to be achieved.

2.1 Introduction

In accordance with FAA Advisory Circular 150/5070-6B, *Airport Master Plans*, and FAA Sustainability Guidance,* the Port of Seattle (the Port) has prepared a Sustainable Airport Master Plan (SAMP) for Seattle-Tacoma International Airport. This chapter of the Technical Memorandum describes the goals and objectives established by the Port of Seattle Commission to guide overall sustainability, how goals and objectives guided development of recommended SAMP development, and how the goals and objectives evolved as the SAMP progressed. The Port's goals and objectives form the foundation of the SAMP.

2.2 Port of Seattle Mission, Vision, and Sustainability Commitment

The Port Commission of the Port of Seattle confirmed its mission and vision statements and sustainability commitment in its 2011 Century Agenda** :

- **Our Mission**. The Port of Seattle is a public agency that creates jobs by advancing trade and commerce, promoting industrial growth, and stimulating economic development.
- **Our Vision**. Over the next 25 years, we will add 100,000 jobs through economic growth led by the Port of Seattle, for a total of 300,000 Port-related jobs in the region, while reducing our environmental footprint.
- **Our Commitment**. The Port of Seattle creates economic opportunity for all, stewards our environment responsibly, partners with surrounding communities, promotes social responsibility, conducts ourselves transparently, and holds ourselves accountable. We will leave succeeding generations a stronger Port.

For Sea-Tac Airport, the mission of the Aviation Division is "Connecting our region to the world through flight".

*http://www.faa.gov/airports/environmental/sustainability/
**http://www.portseattle.org/about/commission/pages/century-agenda.aspx

2.3 Sustainability Goals, Objectives, and Metrics

The terms "goals" and "objectives" are used throughout this Technical Memorandum and the SAMP documentation. In general, goals refer to the purpose to which the Port's activities are directed, serving to define the general intention or outcome towards which the Port is moving in the long-term. Objectives are more narrow in their support of goals, by aiding in establishing targets that can then have an associated metric (or measurement). Often there may be multiple objectives that serve to achieve a broader goal. Objectives are usually shorter-term in nature.

The sources of the Port's goals and objectives are the following.

- **Port Commission**. The Port Commission establishes goals for all divisions and activities at the Port. Many of these goals are defined in the Century Agenda.

- **Port Senior Management**. Port senior management established the Airport's mission, Purpose & Strategic Goals. These goals provide broad direction for the next five, ten, and twenty-five years.

- **Aviation Division**. The Aviation Division established goals and objectives specific to the Airport; these are reflected in the Aviation Division Business Plan and 2018 Priorities, which articulate the Division's approach to achieving the Century Agenda and the Airport's Strategic Goals.

- **Port Sustainability Team and SAMP Team**. These Teams reviewed the goals and objectives established by the Port Commission, Port senior management, and the Aviation Division to determine the best way to apply them as the SAMP was developed. During that review, additional objectives were developed to better satisfy the goals, better differentiate among master plan development alternatives, and facilitate the screening of development alternatives. This review, referred to as "the goal-setting process," generated sustainability goals and objectives.

The evolution of the goals and objectives is described in the subsequent sections.

2.3.1 Sustainability Goals

As the Port neared its centennial of operation in 2011, the Port Commission undertook efforts to establish an agenda—known as the "Century Agenda"—for the next quarter century that would further its mission, vision, and commitment. The Port Commission enhanced the 2011 Century Agenda with its Long Range Plan (which was adopted in 2017). Tables 1-1 and 1-2 in Chapter 1 list the goals and objectives from the Century Agenda and Long Range Plan, respectively.

As a result of the Century Agenda, guiding principles and explicit strategic goals were developed for the Airport. Furthermore, Port staff have included actions in the Aviation Division's business plan and 2018 Priorities to advance progress toward achieving the Century Agenda Vision, Strategies, Objectives, and Long Range Plan. These actions highlight the Port's individual business lines' contributions to the Century Agenda effort.

Because the Port Commission sets directives and strategy for the entire Port of Seattle, including the Airport, the Century Agenda Strategic Objectives are referenced throughout the SAMP as Century Agenda/Long Range Plan Sustainability Goals and Objectives. Collectively, the Century Agenda Goals and Objectives are the foundation for the goals and objectives that guided the SAMP and sustainability at Sea-Tac.

2.3.2 Sustainability Objectives

Within the Aviation Division, Airport leadership prepares its annual priorities. These priorities establish the strategic direction for the division.

2.3.2.1 Aviation Division 2015 Business Plan and 2018 Priorities

SAMP *Technical Memorandum No.* 1 *Background, Process, Goals, and Objectives* identifies in detail the goals associated with the 2015 Business Plan, the plan that existed in 2015 when the heart of the sustainability work for this study was being conducted. Subsequently, the Aviation Division replaced its business plan process with the development of its 2018 Priorities. The environment and sustainability 2018 priorities focus on three aspects of the Airport's goals that are key to realizing long-term Airport growth: increased use of sustainable aviation fuel; regional stormwater planning and solutions; and continued implementation of the Airport's Noise Remedy Program. Table 1.2-3 in the prior chapter includes the Aviation Division's 2018 Priorities.

2.3.2.2 Strategy for a Sustainable Sea-Tac (S3)

The Aviation Division Environment and Sustainability Department established a five-year plan in 2009 entitled the Environmental Strategy Plan (ESP) in the context of the Century Agenda. The ESP was a five-year roadmap for achieving greater environmental sustainability at the Airport. In 2015, the Division developed the next phase of the environmental elements of the sustainability program by creating the *Strategy for a Sustainable Sea-Tac* (also called S3). The Port's environmental goals and objectives were further enhanced by the Commission in 2017.

Since the SAMP study timeline overlapped with preparing the S3, Port staff opted to integrate the two processes, and use the S3 objectives to help direct the screening of alternatives during the SAMP and represent environmental goals and objectives. The S3 objectives are listed in Table 1.2-4 in the prior chapter.

2.3.2.3 Office of Social Responsibility

The Airport's social responsibility programs are part of the Port's Office of Social Responsibility (OSR). The OSR seeks to ensure that the economic (job creation and development) and the environmental (healthy communities) gains made by the Port are done "within a framework of equity, inclusion and equal access."

Social elements of sustainability, as defined by the Global Reporting Initiative, "concerns the impacts the organization has on the social systems within which it operates."* These social systems are the

*Global Reporting Initiative https://www.globalreporting.org communities that live within the local jurisdiction of King County and Washington State; business partners like airlines and contractors; and the Port's employees.

With the update of the Long Range Plan in 2017, the Port Commission strengthened the Port's diversity, inclusion, and social equity program. The 2018 milestones specific to equity include the following, among others:

- Recommend to the Commission a priority hire requirement and aspirational goal on eligible construction projects focusing on apprenticeships, diversity, and preferred entry
- Create quality jobs/equity criteria for the Port's economic development projects, with priority given to those targeting middle wage industries and occupations

In addition, the Port of Seattle is designing a "Model of Equity, Diversity and Inclusion" that will link the Port's values and commitment to equity, diversity, and inclusion to specific behaviors and practices at the organizational, department, and individual levels. The Model will enable the Port to operate more effectively and sustain organizational performance, including:

- Identifying and addressing barriers to opportunity (for example, internally for current employees, attracting future employees, in their Small/W/MBE efforts, in their role in the region as an economic engine, and in efforts to build environmental sustainability)
- Producing innovative and effective solutions
- Achieving higher levels of employee engagement and commitment
- Building more collaborative relationships with the communities they serve

In January 2018, the Port Commission announced an additional initiative, focused on human trafficking. Specifically, the Commission directed the Port staff to make additional efforts to increase the awareness of human trafficking by conducting training and other activities which help Port employees and Airport workers identify signs of possible trafficking, give victims information on how to obtain help, educate travelers about human trafficking, and provide information on how to report suspicious situations or concerns.*

Many of the social responsibility goals and objectives are reflected in the Aviation Division planning activities as well as past business plans and 2018 Priorities. However, other goals identified for the SAMP include:

- Maximize the compatibility of new development with nearby lands.
- Identify benefits of proposed development to the local community.
- Enhance employee welfare and facilitate diversity.

*http://www.portseattle.org/About/Commission/Meetings/2012/RM_20120110_6c_attach.pdf

- Reduce Off-Airport environmental impacts to nearby communities.
- Be transparent in public communications and increase outreach to the local community.

2.3.2.4 Lessons Learned During the SAMP Process

Many of the Port's goals and objectives relate to how the Port staff manage Port-owned facilities and were not part of the consultant scope for preparing the master plan. As a result, the Port identified the following framework for integrating sustainability into the SAMP:

- What we build (a focus of a master plan)
- Where we build (a focus of a master plan)
- How we build
- How we manage our airport (present and future)

During the SAMP, Port staff focused on addressing the goals and objectives that relate to how it manages its facilities, whereas the Consultant Team in concert with Port staff evaluated the "what we build" and "where we build" relative to the goals and objectives. The Consultant Team also developed an evaluation tool to help Airport staff understand the potential resource use associated with "how we build."

Some of the goals and objectives identified in Chapter 1 did not directly lend themselves to screening development alternatives. Therefore, the SAMP process identified additional goals and objectives that were used to help differentiate among development concepts relative to the Century Agenda, Long Range Plan, and the S3. Table 2-1 lists the goals and objectives used in the SAMP process to develop and screen development alternatives and recommendations. These goals and objectives complement the goals and objectives discussed earlier.

In evaluating various development recommendations, the alternatives performed equally relative to some of the goals and objectives. One of the lessons learned when considering alternatives was the need to identify and refine those goals and objectives that clearly enabled the Port to discern differences among development alternatives. For instance, when considering various initial passenger terminal and gate concepts, the alternatives performed equally relative to impacts on natural resources (wetlands, creeks, impervious surface) as well as social considerations (noise, light emissions, and consistency with zoning). However, clear differences existed relative to Airport operational conditions, and reduced taxi/idle/delay (air emissions).* As the planning progressed to more integrated and refined concepts for all functional areas, other goals and objectives were used to screen the options.

*During the 2nd round screening of terminal and gate concepts 12 criteria were identified (7 financial-operational, 3 environmental, and 2 social). However, in round 3 screening, 10 criteria were used (6 financial-operational, 3 environmental, and 1 social); and only 7 of the 10 criteria at this round enabled differentiation of alternatives from one another relative to the goals.

A secondary consideration in the SAMP was the premise that a master plan would identify the facilities that would be necessary to serve forecast demand. The sustainability approach and framework were developed with a focus on the Near-Term Projects that are reasonably expected to be completed within the next five to ten years. The Port recognizes that beyond that timeframe the facilities are conceptual, will undergo additional planning, and may change as a result. In addition, as shown in later chapters, the Port has embraced the Plan-Do-Check-Act cycle which calls for evaluation of progress and adjustments over time. Therefore, it would be expected that the Port would adjust its sustainability program before the Port completes the Near-Term Projects or launches other airport development projects.

2.3.3 Sustainability Focus Areas

When preparing a sustainability plan, the FAA's guidance to airports suggests that the airports identify categories or areas on which the plan should focus. Since the Port of Seattle had a well-established sustainability culture before the SAMP was initiated, the focus areas were identified based on the triple-bottom line and the Port's goals and objectives discussed earlier. As the SAMP proceeded, additional objectives were identified, as noted in Table 2-1 to enable differentiation of the development alternatives relative to achieving various other Port goals and objectives. However, these additional objectives reflected refinements in the overarching goals and remained within the general focus areas, noted in Table 1-5**.** Also noted in that table is that the focus areas include financial-operational, customer service, environmental, and social/community benefits.

The focus areas, in combination with the goals and objectives, served as the basis for considering various sustainability strategies, collectively referred to as initiatives, opportunities, and actions (IOAs) that the Port could implement to move toward achieving its goals and objectives. As part of monitoring progress (the "check" process, in the plan-do-check-act process discussed in Chapter 5 *SAMP Sustainability Implementation Process and Plan*), encourages the identification of metrics to measure progress.

2.3.4 Sustainability Metrics

The Port has a long history of evaluating its progress toward achieving its various goals and objectives as evidenced by the processes and documents mentioned previously. During the SAMP study, consideration was given to the various metrics that the Port uses and would use in the SAMP process to evaluate development recommendations, as well as ongoing plan-do-check-act process. In the context of the two themes "what and where we build" versus "how we manage our operations", the metrics defined in this report are designed to assist the Port with both themes. However, in the context of the SAMP, not all metrics were evaluated as part of considering development recommendations. Table 2-2 lists the broad range of sustainability metrics. As is noted later in this document, data are not currently available for all metrics. However, the metrics are listed to facilitate the current and future sustainability work of the Port of Seattle.

Table 2-1
Sustainability Goals and Objectives
Seattle-Tacoma International Airport

	Goals / Objectives	Potential Metrics
O1:	Enable the Port to achieve its financial goals in the business plan relative to Cost per Enplaned Passenger (CPE) and debt per enplaned passenger (DPE). The following are important to achieving this primary objective: • Enable phased, incremental development • Maximize use of technology to minimize the amount of new development • Provide revenue-generating space in the terminal facilities in accordance with Port guidelines • Ensure that that the cost of meeting facility needs does not exceed the Port's debt goals (i.e., overall affordability, but with total cost of ownership in mind)	• Professional Judgment (cost, spatial allocation) • CPE • DPE • Total project capital costs • Estimated 20-year O & M costs • Total cost of ownership
O2:	Minimize the effect of SAMP recommendations on cost center rate imbalances. This goal was identified as important, as given the Airport lease agreement structure that is based on cost center rates. It would affect the ability to afford future development.	• Percentage of project cost allocated to airline cost centers (for top 4 or 5 projects only)
O3:	Reduce dwell time on the curb front and increase throughput to efficiently accommodate demand in the following ways: • Ensure capacity of public parking is adequate to enable the Port to increase revenue • Provide cruise ship bus interfaces in a way that enhances customer service	• LOS on curb front • Parking spaces • Average walk distance for cruise ship passengers—enplaning and deplaning • Average level changes for cruise ship passengers—enplaning and deplaning
O4:	Minimize aircraft taxi time and reduce airfield congestion associated with ground vehicles in the following ways: • Reduce runway crossings and reduce runway occupancy times • Provide for efficient aircraft de-icing • Develop a Surface Area Management System • Develop aircraft departure sequencing process vs. FAA First Come, First Serve model. • Develop more versatile parking, with RON demand increasing.	• Professional judgment (trade-offs among gate, RON, cargo, and deicing position productivity) • Professional judgment related to the availability of appropriately located runway exits, by airplane design group • Runway crossings • Runway occupancy times • Average aircraft taxi time • Average gate occupancy time during deice conditions
O5:	Satisfy the demand for air cargo in a manner that strives to consolidate cargo areas while minimizing congestion associated with the landside interfaces.	• Utilization ratio (metric tons per square foot of warehouse)

Table 2-1 *(continued)*
Sustainability Goals and Objectives
Seattle-Tacoma International Airport

	Goals / Objectives	Potential Metrics
O6:	Maximize efficient passenger and baggage movement throughout the passenger's trip through Sea-Tac Airport (garage/terminal –to-aircraft, and making connections from aircraft to aircraft): • Maximize passenger throughput and level-of-service (LOS) in the terminal, including security checkpoints. • Maximize the passenger's ease of connection, and minimize wait time at security and check-in. • Maximize customer service: Minimize walking distances. • Minimize development through maximize common use facilities.	• LOS (queuing, curbsides) • Minimum connect time • Average walking distance • Average SSCP wait time • Peak period SSCP wait time • Average distance—curb to bag drop; centroid of garage to bag drop • Last bag cutoff time
O7:	Air Quality and Climate Protection: • Reduce air pollutant emissions by 50% from 2005 levels by 2037 • Scope 1 and 2 emissions, which are direct greenhouse gas emissions from Port-owned or controlled sources, shall be: - 15% below 2005 levels by 2020. - 50 % below 2005 levels by 2030. - Carbon neutral or carbon negative by 2050. • Scope 3 emissions are emissions the Port has influence over, not direct control. The Port-wide goals for Scope 3 emissions shall be: - 50 % below 2007 levels by 2030. - 80 % below 2007 levels by 2050.	• Dwell time • Taxi time • Vehicle miles traveled • Emissions inventory (tons/year) • Scope 1 and 2 emissions per year (MT/year) • Scope 1, 2, and 3 emissions per year (MT/year)
O8:	Buildings and Infrastructure: Seek LEED Silver for new construction, additions, and major renovations and minor renovations that modify mechanical, electrical, and plumbing systems, and encourage LEED certification for tenant improvements.	• Square feet of buildings with LEED silver or higher certification.
O9:	Climate Adaptation: Complete a risk analysis of potential climate change impacts and implications for the Airport and develop a strategic plan for avoiding/mitigating risks.	• Complete risk analysis • Prepare strategic plan
O12:	Waste – Construction: Divert to recycling 85% of construction waste by 2020, 90% by 2025, and reach zero waste by 2035.	• Percent of waste diverted.

Table 2-1 *(continued)*
Sustainability Goals and Objectives
Seattle-Tacoma International Airport

Goals / Objectives	Potential Metrics
O13: Waste - Terminal and Airfield: Divert 60% of terminal solid waste and 15% of airfield solid waste by 2020.	• Percent waste diverted • Tons of Landfilled Waste • Tons of Recycled Waste
O14: Waste - Hazardous: Reduce the volume of hazardous waste generated from Port maintenance and operations to meet requirements for Small Quantity Generator Status by 2020.	• Kilograms of hazardous waste generated, rolling 180 days.
O15: Energy: Meet all future growth in energy demand through the most practical and cost-effective conservation measures and renewable energy.	• Electricity (kWh) consumption per year • Percentage of electricity consumed that comes from renewable sources (kWh's from renewable/total kWh's) • Natural gas (therms) consumption per year • Percentage of natural gas consumed that comes from renewable sources (therms from renewable/total therms) • Gallons of fuel used in fleet vehicles • Total MMBTUs per year
O16: Fish and Wildlife: Protect, enhance, and steward fish and wildlife habitat while maintaining air transportation safety.	• Acres of open space displaced • Acres of protected habitat displaced
O17: Noise: Increase the number of noise compatible units within the noise remedy boundary to 95 percent through the year 2030.	• Percentage of noise compatible units within the noise remedy boundary
O18: Transportation: Reduce the greenhouse gas emissions associated with passenger and employee transportation to and from Seattle-Tacoma International Airport by decreasing the emission intensity of the travel modes and increasing the proportion of trips made using environmentally preferred modes.	• Percentage of passengers accessing the Airport under the various environmentally preferred modes (percentage of passengers using environmentally preferred modes relative to total O&D passengers) • Environmentally preferred modes: Daily parking, taxi, door-to-door van, hotel/motel courtesy vehicle, air porters, public transit, and charter/other bus
O19: Water Conservation: Reduce projected future consumption by 4% over 2008 levels in 2020 and 12% in 2030.	• Potable water consumption in gallons per year • Non-potable water reuse
O20: Water Quality: Contribute to the restoration of Puget Sound and local receiving waters by providing water quality treatment, flow control, and using green storm water infrastructure (where feasible) for Airport industrial storm water.	• Gallons of water treated by infiltration per year • Gallons of rainwater captured and reused per year

Table 2-1 *(continued)*
Sustainability Goals and Objectives
Seattle-Tacoma International Airport

Goals / Objectives	Potential Metrics
O21: Maximize the compatibility of new development with nearby lands.	• Consistency of proposed project with existing zoning • Proximity to noise and light sensitive land uses
O22: Identify benefits of proposed development to the local community.	• Socioeconomic impact (jobs/payroll/regional economic input) • Roadway LOS/Congestion • Changes in environmental effects (O7 thru O20)
O23: Enhance employee welfare and facilitate diversity.	• OSR office to determine – will not differentiate among MP alts
O24: Reduce Off-Airport environmental effects to nearby communities.	• Changes in environmental effects (O7 thru O20)
O25: Be transparent in public communications and increase outreach to the local community.	• Number of interactions with the public (i.e., workshops or open houses) • Number of comments received and number of commenters • Extent of coverage of near-airport and other communities

O#- Objective number; CPE – Cost per enplanement; DPE – Debt per enplanement; O&M - Operations and Maintenance; SAMP=Sustainable Airport Master Plan; LOS – Level of service; SCCP – Security Screening Check Point; LEED – Leadership in Energy and Environmental Design; MT- Metric tons; MMBTU – Million British Thermal Units.

Source: *Technical Memorandum No. 1, Background, Process, Goals and Objective*; Table 3-1.

Table 2-2
Summary of Sustainability Metrics
Seattle-Tacoma International Airport

Focus Area	Metric(s)
Serving demand	• Is the demand for 2034 served? • Total passengers • Tons cargo • Volume/capacity relationship • Space utilization • Level of service (LOS)
Gateway of Choice	• Cost per enplaned passenger • Total passengers • Tons cargo • Nonstop cities/markets served (Number of year-round medium & long-haul service, number of seats, and number of destinations)
Customer service	• Volume/capacity relationship • Level of service (LOS) • Customer survey/reactions • On-time delivery) • Walking distances (ft.)
Project affordability/cost center imbalances	• Cost or debt per enplaned passenger • Total project capital costs • Estimated 20-year O & M costs • Total cost of ownership • Specific airline rates • Percentage of project cost allocated to airline cost center (for top 4 or 5 projects only
Productivity of existing facilities/ operational efficiency	• Turns per gate • Passengers/sf • Delay • Congestion • LOS/volume to capacity ratio • # of Parking spaces • Average walk distance for cruise ship passengers—enplaning and deplaning • Average level changes for cruise ship passengers—enplaning and deplaning
Renew aging infrastructure	• Age of infrastructure • Age relative to expected life • Annual cost of maintenance needs
Maximize efficient passenger and baggage movement	• Minimum connect time • Average walking distance • Average SSCP wait time • Peak period SSCP wait time • Average distance—curb to bag drop; centroid of garage to bag drop • Last bag cutoff time

Table 2-2 *(continued)*
Summary of Sustainability Metrics
Seattle-Tacoma International Airport

Focus Area	Metric(s)
Air Quality and Climate Change	• Tons of criteria pollutant emissions • Dwell time • Taxi time • Vehicle miles traveled • Emissions inventory (tons/year) • Energy consumption • Scope 1,2, and 3 Emissions inventories (Metric tons/year) • Complete risk analysis • Availability of strategic plan
Buildings and Infrastructure	• # of building with LEED certification • Square feet of buildings with LEED silver or higher certification
Energy	• kWh consumed • Gallons of liquid fuels • Therms of natural gas • Energy per passenger • Energy per square foot • Total energy (MMBTU)
Fish & Wildlife	• Acres of open space displaced • Acres of protected habitat displaced • Population of species present
Noise	• Population and housing within 65 DNL and structures that have participated in the Noise Remedy Program • Noise complaints • Proximity of noise sensitive facilities to new buildings • Compliance with noise procedures • Fly quiet metrics
Transportation	• Percentage of passengers accessing the Airport under the various environmentally preferred modes (percentage of passengers using environmentally preferred modes relative to total O&D passengers) • Environmentally preferred modes: Daily parking, taxi, door-to-door van, hotel/motel courtesy vehicle, air porters, public transit, and charter/other bus.
Water Conservation	• Potable water consumption in gallons per year • Non-potable water reuse
Water Quality	• Gallons of water (and %) treated by infiltration per year • Gallons of rainwater captured and reused per year
Waste - Construction	• Tons of annual construction waste • Percent of waste diverted.
Waste – Hazardous	• Kilograms of hazardous waste generated, rolling 180 days.

Table 2-2 *(continued)*
Summary of Sustainability Metrics
Seattle-Tacoma International Airport

Focus Area	Metric(s)
Waste – Terminal and Airfield	• Tons of Landfilled Waste • Tons of Recycled Waste
Employee welfare and workforce development	• Employee turnover • Occupational injury rate and lost work day injury case rate • Annual safety evaluation scores • Placement in jobs; training completion • % of employees agree the that Port act as a single organization with a common vision; % increase toward ideal culture (LRP) • % of processes that are standardized and implemented; % performance plans that link goals to manager or organizational goals through e-performance system (LRP) • % managers who include "lead and manage staff effectively" goal in their PerformanceLink; % of employees who completed diversity and inclusion development opportunity [workshop, classes, council participation, etc.] at least every 3 years (LRP) • # of unique visits to webs pages related to diversity & inclusion; # of free and paid media placements related to diversity & inclusion (LRP) • Employee development activities
Land Use Compatibility	• Consistency of proposed project with existing zoning • Proximity to noise and light sensitive land uses • Noise or other complaints
Community benefits	• Socioeconomic impact (jobs/payroll/regional economic input) • Roadway LOS/Congestion • Changes in environmental effects • Noise or other complaints
Foster local business opportunities	• Number of jobs • Payroll • Number of tenants • $ spent on small businesses; $ spent on WBE/MBE • Percentage of tenants headquartered in Puget Sound
Public outreach	• Number of meetings • Number of newsletters • Number of comments received • Complete coverage of the near-airport communities
Transparency	• Number of meetings • Number of newsletters • Number of comments received

Notes: DNL = Day Night Average Sound Level; LEED = Leadership in Energy and Environmental Design; LOS = Level of Service; LRP= Long Range Plan; MMBTU=Million British Thermal Unit; O&D = origin & destination; O&M = operations and maintenance; SCCP: Security Screening Checkpoint; SF=square feet.

Source: Port of Seattle, Synergy Consultants, March 2018.

Sustainability Baseline Inventory

The sustainability baseline establishes the current situation from which the Port can begin to measure performance against the sustainability goals.

3.1 Introduction

During the preparation of the SAMP, data were collected to identify the current performance of the Airport, and recent past if available, relative to the sustainability metrics identified in the prior chapters. Those conditions are referred to as the baseline. This chapter identifies the baseline data and conditions.

The discussion of baseline conditions follows the categories/focus areas described in Chapter 2. Section 3.1 discusses the first leg of the triple bottom line: financial and operational efficiency conditions, while Section 3.2 discusses environmental conditions, and Section 3.3 discusses social and community outreach conditions.

3.2 Financial and Operational Efficiency Baseline

The baseline financial-operational conditions were identified from existing FAA databases and Port reports which are published annually. Some of the metrics required coordination with Port staff to collect, such as ensuring that the annual financial and operational efficiency data were consistent across the timeframe 2010-2016. Areas where data are not being tracked or are not available are also identified.

As described in Chapter 2, the Port has developed a series of financial and operational efficiency goals and objectives for the Airport. Table 2-3, in Chapter 2, lists the metrics identified to measure progress toward the financial and operational goals and objectives.

Some of the financial-operational metrics do not have a direct baseline, as they are associated with a proposed development or a project. Information between 2010 and 2016 is presented where available. The financial, facility, and operational metrics were grouped as follows to facilitate how this report considers the baseline conditions:

- Airport Activity Metrics
- Operational Efficiency and Performance Metrics
- Financial Metrics
- Facility Space and Condition Metrics
- Survey Metrics

- Derivative Metrics
- Project Metrics

The following subsections discuss the actual conditions and Airport performance relative to these groupings.

3.2.1 Airport Activity Metrics

Technical Memorandum No. 4 Forecasts of Aviation Activity presents a detailed review of the past activity levels at Sea-Tac Airport. Table 3-1 lists the activity statistics for Sea-Tac Airport. Five primary activity metrics characterize an airport: (1) total passengers; (2) enplaned passengers (passengers boarding aircraft); (3) Origin & Destination (O&D) passengers; (4) total annual aircraft operations; and (5) tons of cargo.

Key conditions were: *

- In 2016 there were 21,500,245 enplanements or 45.7 million total passengers;
  - 89.4% of passengers in 2016 originated or ended their travel (called O&D passengers) in the Puget Sound Region:
  - The San Francisco area was the largest domestic O&D market with 10.3% of domestic O&D passengers, followed by Los Angeles with 10.1%, Portland (6%), Spokane (4%), and Denver (3.9%).
  - Tokyo, Japan was the largest international O&D market with 6.1% of international O&D passengers, followed by London in the United Kingdom with 5.0%, Seoul, Korea (4.0%), San Jose Cabo, Mexico (3.7%), and Toronto, Canada (3.2%).
- 332,636 metric tons of cargo served in 2015 increasing to over 366,000 metric tons in 2016.
  - 39.8% of cargo served on passenger aircraft.
  - 60.2% of cargo served by all-cargo aircraft.
- 381,408 annual aircraft operations in 2015 (sum of arrivals and departures) which increased to 407,637 annual operations in 2016.**

As of 2016, Sea-Tac Airport has been one of the fastest growing airports in the United States in terms of total passengers served. Sea-Tac was the 13th busiest airport in the United States and 31st in the world, as measured by total passengers in 2015 and had become the 9th busiest U.S. airport in 2016. Relative to cargo, Sea-Tac was 20th in the United States.***

*Port of Seattle web site, activity statistics.
**FAA TAF. https://taf.faa.gov/
***Airports Council International: http://www.aci-na.org/content/airport-traffic-reports.

Table 3-1
Baseline Airport Activity Metrics (2010-2016)
Seattle-Tacoma International Airport

Year	Annual Enplanements (passengers boarding): Air Carrier	Commuter	Total	Percent International	Percent O&D	Total Passengers (enplaned and deplaned)	Metric Tons of Cargo
2010	12,779,410	2,438,502	15,217,912	9.0%	74.9%	30,436,000	283,226
2011	13,301,074	2,566,474	15,867,548	9.0%	74.1%	31,735,000	279,888
2012	13,509,492	2,571,971	16,081,463	9.7%	74.6%	32,163,000	283,606
2013	13,924,622	2,617,581	16,542,203	10.2%	74.1%	33,084,000	292,585
2014	14,490,210	2,923,787	17,413,997	10.1%	73.7%	34,828,000	333,926
2015	15,984,591	3,576,098	19,560,689	10.3%	69.8%	39,121,000	332,636
2016	17,440,882	4,059,363	21,500,245	10.6%	89.4%	45,737,115	366,431

Year	Annual Aircraft Operations: Air carrier	Air Taxi & Commuter	GA	Military	Total	Aircraft Using Gate/Terminal Parking Position	Total Nonstop Markets: Domestic	International
2010	291,044	18,894	3,273	107	313,318	309,938	75	21
2011	295,931	15,723	3,596	130	315,380	311,654	72	19
2012	293,616	14,704	3,595	152	312,067	308,320	80	20
2013	295,542	13,961	3,515	83	313,101	309,503	84	21
2014	315,600	12,674	4,056	133	332,463	328,274	83	22
2015	368,722	8,401	4,160	125	381,408	377,123	87	23
2016	393,932	10,312	3,287	106	407,637	n.a.	n.a.	n.a.

Source: FAA Terminal Area Forecast downloaded 3-11-2018 for 2008-2016 except for those noted below. n.a. = not available

O&D Passengers, Technical Memo 4, Table 3-4; Cargo (2008-2014) Technical Memo 4, Table 4-2, 2015 Cargo from Port statistic for year ending Dec 2015 (Port web site; International Percentage of Enplanements - Technical Memo 4, Table 3-4; 2015 Operations: Port of Seattle Statistics.

Total Passengers – enplanements *2, rounded to the 1,000 Aircraft using a Gate/Terminal parking position – the sum of Air Carrier and Air Taxi/Commuters.

3.2.2 Financial Report Metrics

The Port is a municipal corporation of the State of Washington, organized in September 1911. In 1942 the local governments in King County selected the Port to operate Sea-Tac Airport. Port policies are established by a five-member Commission elected at-large by the voters of King County. The Port is organized into three operating divisions: Aviation, Maritime, and Real Estate. Financial performance is reported for each division. Divisional business plans and budgets are reviewed and approved by the Commission annually. Once the budgets are in place, they are reviewed annually, and the Port publishes its Consolidated Annual Financial Report. In addition to the Consolidated Report, the Port publishes annually its Financial & Performance Report which contains a review of the performance of each division.

The 2016 Financial & Performance Report noted the following for the Aviation Division:

- Net Operating Income was 3% higher than budget. This was because while operating revenue was lower than budget, the operating expenses were even lower.
- Enplanement growth drove increases in non-airline revenue and enabled the Port's Cost Per Enplanement (CPE at $10.10 in 2016) to be the lowest since 2003. Although there is no mandated reporting of CPE in audited financial statements, many airports include the current fiscal year's CPE in their reports. Cost per enplanement is the industry accepted method for comparing airline costs among airports.
- Improved debt service coverage compared to budget reflected increased cash flow from growth in enplanements.

According to Moody's,* the Port of Seattle had a bond rating of A1 in 2016. A bond rating represents the credit worthiness of a corporation of government bonds. At A1, this signifies "… STRONG capacity to meet its financial commitments but is somewhat more susceptible to the adverse effects of changes in circumstances and economic conditions than … in higher-rated categories."

While airport activity characteristics are tracked on a frequent basis, many of the other financial-operational efficiency metrics are not tracked annually or not available publicly. Table 3-2 shows the baseline financial characteristics for data available through 2016.

3.2.3 Facility Space and Condition Metrics

Facility space and condition metrics enable the Port to identify the facilities that are available, facility needs, and the relative age of facilities in their cycle of renewal. Facility space is a major element of what is evaluated in a master plan, as an inventory is prepared of key airport functional area space and its allocation. SAMP *Technical Memorandum No. 4 Existing Conditions Inventory* documents the baseline condition associated with major Airport facilities.

*https://www.moodys.com/

Table 3-2
Baseline Financial Metrics (2010-2016)
Seattle-Tacoma International Airport

	2016	2015	2014	2013	2012	2011	2010
Operating Revenue (in $1000)							
Aeronautical Revenue	$ 247,811	$ 229,470	$ 228,864	$ 238,735	$ 233,112	$ 207,763	$ 198,843
SLOA III Incentive	$ (3,576)	$ (3,576)	$ (3,576)	$ 14,304	$ --	$ --	$ --
Non-Aeronautical Revenue	$ 221,021	$ 196,844	$ 180,791	$ 160,765	$ 152,960	$ 142,959	$ 135,418
Total Operating Revenue	$ 465,256	$ 422,738	$ 406,079	$ 413,804	$ 386,072	$ 350,722	$ 334,261
Total Operating Expense	$ 261,226	$ 237,655	$ 230,704	$ 225,908	$ 216,556	$ 191,869	$ 181,142
Net Operating Income	$ 204,040	$ 185,083	$ 175,375	$ 187,896	$ 169,516	$ 158,853	$ 153,119
Capital Expenditures	$ 153,887	$ 164,931	$ 155,970	$ 108,841	$ 100,305	$ 166,820	$ 183,578
Landed Weight (in 1000 lbs.)	27,202,000	24,757,000	22,500,491	20,949,155	19,986,628	20,193,785	19,834,101
Performance Metrics							
Cost per enplanement	10.10	10.12	11.48	11.90	13.17	11.76	11.63
O&M Cost per enplanement	11.46	11.26	12.33	Not Reported	Not Reported	Not Reported	Not Reported
Non-Aero Revenue/enplanement	9.70	9.33	9.66	Not Reported	Not Reported	Not Reported	Not Reported
Debt ($million)	$3,176.2	$3,327.7	$3,361.5	$3,111.9	$3,300.6	$3,435.7	Not Reported
Debt Service Coverage	1.53	1.49	1.38	1.40	1.40	1.44	1.39
Days Cash on hand	416	469	405	437	462	Not Reported	Not Reported
Airline Rate Base Cost Drivers							
O&M Cost (in $1000s)	$ 165,427	$ 149,974	$ 145,529	Not Reported	Not Reported	Not Reported	Not Reported
Calculated O&M (in $1000s)	$ 224,170	$ 220,250	$ 214,710	Not Reported	Not Reported	Not Reported	Not Reported

Sources: Port of Seattle 2016 Financial & Performance Report as of December 31, 2016.
Port of Seattle 2015 Financial & Performance Report as of December 31, 2015.
Port of Seattle 2013 Financial & Performance Report as of December 30, 2013.
Port of Seattle 2012 Financial & Performance Report as of December 31, 2012.
Port of Seattle 2011 Financial & Performance Report as of December 31, 2011.
Port of Seattle 2010 Financial & Performance Report as of December 31, 2010.
Port Comprehensive Annual Report 2014, 2013, 2012.
Port Comprehensive Annual Report 2013, 2012, 2011.

Table 3-3 summarizes the baseline facility space characteristics as of 2014 (the baseline year used in the SAMP planning analysis). In a master plan, once an inventory is conducted of current facilities, and the aviation demand forecast has been prepared, an evaluation is conducted of facility requirements. The facility requirements analysis enables airport planners to identify deficits/gaps in available space that would exist as activity levels increase. At the same time, as facilities age, there is the need to renew them (e.g., pavement begins to degrade overtime with use, requiring maintenance and replacement). SAMP *Technical Memorandum No. 5 Facility Requirements and Alternatives* discusses the deficits in space that have resulted in the identification a long-range development vision, that led to the Near-Term Projects.

As part of the SAMP, an evaluation was also conducted relative to the current age of Airport facilities. Appendix A *Task 6.12 Report – Total Cost of Ownership,* Section 3.5.1 *Analysis of Current Terminal Service Life* documents that evaluation. The age of structures reflects the need for maintenance and upkeep, as well as the performance of technology at the time, such as energy conservation measures. Table 3-4 shows that the average age of passenger handling facilities (i.e., terminal and concourse space) was over 24 years old as of 2015.

One of the facility metrics is associated with Leadership in Energy and Environmental Design (LEED) and the amount of facility square footage that is LEED certified. Those conditions are described in Section 3.2 of this chapter associated with the environmental focus area for facilities/buildings and infrastructure.

The Airport's minimum connect time of 90 minutes was noted in the Aviation Division's 2015 Business Plan. At the time of this analysis, information for 2016 was not available concerning average walking distance, average security screening check-point (SSCP) processing and wait times, average distance from curb to bag drop, average distance from centroid of garage to bag drop, and last bag cut off. It is anticipated that in the future, the Port may use such data as a metric of performance for existing and planned facilities.

3.2.4 Operational Efficiency Metrics

Table 3-5 identifies the current operational efficiency metrics. The Port's Aviation 2015 Business Plan and 2018 Priorities identified several operational issues that the Port monitors relative to the efficiency of tenant operations. To identify operational efficiency, the Bureau of Transportation Statistics and the FAA's Aviation System Performance Metric databases were accessed to identify the percentage of departures that are on time, average arrival and departure delay times, and taxi times at Sea-Tac. In addition, the FAA's Accident and Incident Data System* (AIDS) was accessed to identify reported accidents/ incidents. While there were several items reported in the FAA's AIDS database for Sea-Tac, there was only one accident/incident during the same period (2010 through 2016) in the National Transportation Safety Board's database.

*The FAA Accident and Incident Data System (AIDS) database contains incident data records for all categories of civil aviation. Incidents are events that do not meet the aircraft damage or personal injury thresholds contained in the National Transportation Safety Board (NTSB) definition of an accident.

As shown in Table 3-5, the percentage of on-time departures decreased between 2012 and 2016 while at the same time, taxi-time and delay increased. The Port also identifies levels of service and demand-to-capacity ratios associated with various facilities and roadways On-Airport. Chapter 4 of SAMP *Technical Memorandum No.* 5 *Facility Requirements and Alternatives* presents that data in detail for specific facilities.

Table 3-3
Summary of Current Facilities (2014)
Seattle-Tacoma International Airport

Category and Facility	Current Status
Airfield	
Runway length (feet)	
16L-34R	8,500
16C-34C	9,425
16R-34L	11,900
Aircraft gates and parking	
Gates *(a) (b)*	83 *(c)*
Off gate parking positions *(c)*	33 *(e)*
Terminal	
Check-in facilities	
Kiosks with no bag check	40
Agent with bag check	214
Security screening lanes	31
Domestic baggage claim	
Claim devices	16
Claim frontage (feet)	2,619
Landside	
On-Airport parking	
Close in parking garage	12,800
Remote	1,620
Curbside loading/unloading	
Upper drive	1,200
Lower drive	1,290
Curbside roadway lanes	
Upper drive	4
Lower drive	5
Air Cargo	
Warehouse area (square feet)	602,460
Aircraft hardstands	14
Fuel storage	
Volume (million gallons)	17.3
Tank area (acres)	11.9

Table 3-4
Average Size and Adjusted Age of Existing Key Facilities
Seattle-Tacoma International Airport

Facility	Square Foot	Average Building Age (years)
Airport Administration Building	135,000	10.0
Concourse A	371,000	10.0
Concourse B	175,000	30.9
Concourse C	176,000	30.7
Concourse D	165,000	21.1
Main Terminal	1,009,000	27.7
Central Terminal Expansion	399,700	22.3
North Satellite	226,000	23.8
South Satellite	370,000	23.6
Central Plant	30,000	23.8
SUBTOTAL	3,056,000	23.7
Main Terminal Parking Garage	5,142,000	26.6
TOTAL	8,498,000	24.2

Source: CH2M Hill, Table 3-2, Appendix A *Task 6.12 Report – Total Cost of Ownership*. Weighted average age effective 2015.

Table 3-5
Airfield Operational Efficiency (2012-2016)
Seattle-Tacoma International Airport

Year	Percent On-time Airport Departures	Average Taxi-Out and -In (minutes)	Average Airport Departure Delay (minutes)	Average Gate Arrival Delay (minutes)	Number of Accidents/ Incidents at SEA	Incursions (per 1,000 operation)
2012	84.95	20.21	6.68	5.58	24	1.00
2013	83.41	20.98	7.63	6.05	11	2.25
2014	81.85	21.51	8.06	6.59	12	1.47
2015	83.23	23.89	9.81	7.44	4	n.a.
2016	83.45	24.77	8.50	5.93	0	n.a.

Source: On-time statistics https://www.transtats.bts.gov/OT_Delay/OT_DelayCause1.asp?pn=1;
FAA Aviation System Performance Metrics, https://aspm.faa.gov/apm/sys/AnalysisAP.asp
FAA Aviation Safety Information Analysis and Sharing/Accident and Incident Data System (AIDS).
n.a. = not available.

3.2.5 Survey Results

To obtain information about passenger behavior and opinions, including customer service reactions, periodic passenger surveys are conducted. These surveys may be conducted in the terminal or in-flight and may occur quarterly, annually, and as needed. The primary purpose of passenger surveys is to identify reactions to customer service, to identify the transportation modes that are used to access the Airport, to identify wait and delay times on the curbfront or other parts of the Airport. Such surveys can also identify deficits in facility requirements that basic spatial evaluations do not identify.

The Enplaning Passenger Survey (EPS) is a quarterly survey of 600 randomly selected enplaning Sea-Tac passengers that has been conducted since 2014. Where possible, the survey scope and questions are comparable to prior surveys that have been conducted at approximately 5-year intervals in the past (1996, 2000, 2001, 2006, and 2011/2012). The topics covered in the EPS include (among others) frequency of travel; trip duration and purpose; travel group size; number of bags; mode of travel; time spent at the Airport; and use of Airport concessions.

Since 2011, Sea-Tac has participated in the Airports Council International Airport Service Quality (ASQ) program, which provides a benchmark for customer satisfaction at an airport. The ASQ measures overall customer satisfaction and 28 specific service items at more than 260 airports worldwide. The survey identifies gaps in service delivery and helps managers to allocate resources and take actions to increase customer satisfaction.

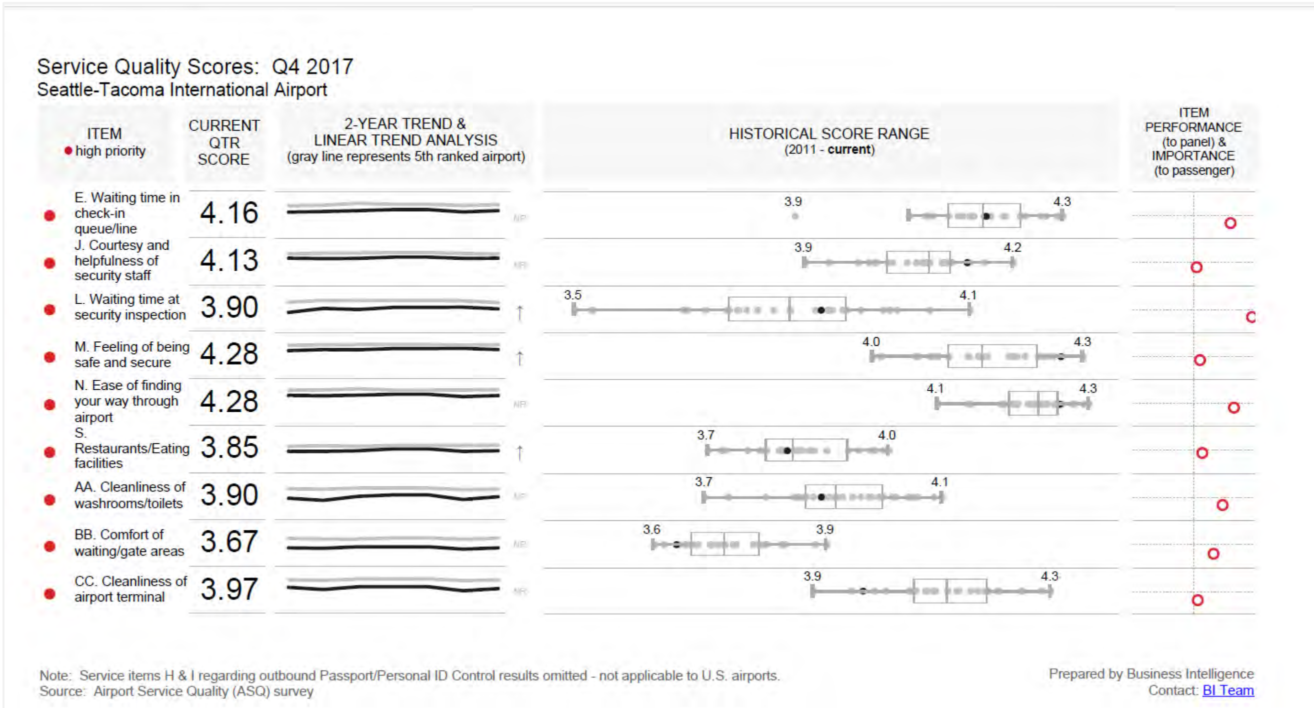
Service quality scores for Sea-Tac's high priority areas, as of Q4 2017, are shown on Figure 3-1 on the following page. The mean score under the Current Qtr Score column is based on a five point scale where 1 = Poor, 2 = Fair, 3 = Good, 4 = Very good, and 5 = Excellent. High priority items score below average levels of service when compared to 25 North American airports in ASQ, and high importance to passengers. These two scores are summarized as the "quandrant score" in the far right column.

In addition, trends for each priority area show that while 2017 scores were not the highest they have been historically, scores have been improving in a few areas.

3.2.6 Derivative Conditions

Derivative conditions reflect the above metrics quantified on a unit basis of another metric. For example, a metric that considers passengers per square feet of concession space would identify the number of passengers from the Airport Activity category and divide that by the square footage being considered (i.e., concession space) that is noted in the Facility Space category. Available derivative data were reported in Tables 3-2 through 3-5.

Figure 3-1
Passenger Survey Results
Seattle-Tacoma International Airport



3.3 Environmental Baseline

The baseline presented in this section summarizes the Port's existing conditions based mainly on 2016 data.

3.3.1 Range of Metrics

Table 2-2 in the prior chapter lists the Port's Airport environmental metrics. These metrics are grouped by various environmental topics. It is important to note that the environmental conditions discussed in this section are described for sustainability planning purposes only, and do not represent the existing conditions analyses used for environmental review under the federal National Environmental Policy Act (NEPA) and Washington State Environmental Protection Act (SEPA). The Port's sustainability goals and objectives and related metrics were developed and adopted voluntarily. .

3.3.2 Baseline Conditions

As discussed in Chapter 2, the Port has identified eight environmental focus areas. The baseline is discussed for each environmental focus area in the following subsections.

3.3.2.1 Air Quality and Climate Change

This section examines air quality and climate change under the Port's voluntary sustainability goals. The information presented here is intended for sustainability analysis and planning only, and is not meant to represent the air quality analyses that will be conducted under the formal environmental regulatory review process for the SAMP. Under regulatory review processes, air contaminants may be assessed and compared to federally established health-based National Ambient Air Quality Standards (NAAQS) for six "criteria" air pollutants: ozone, carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SOx), particulate matter (coarse particles PM_{10} and fine particles $PM_{2.5}$), and lead.

Criteria pollutants are often considered "local air quality," as in general, the emissions remain local to the region or Airport area. The "local" term is designed to differentiate criteria pollutants from greenhouse gases (carbon emissions), which are considered global emissions.

As described in previous chapters, the Port has established voluntary sustainability goals for air quality. For this document, emissions inventories were prepared to estimate the total quantity of emissions that are discharged from various sources at the Airport. Air emissions are measured in tons per year, with greenhouse gases measured in metric tons. Because of the level of effort associated with preparing a "criteria pollutant" emissions inventory and the level of expertise required, such inventories are not prepared annually. Two analysis years are presented for air quality: 2014 and 2016. Because the Port's air quality goal uses a reference year of 2004, this section also identifies the data associated with that condition. The 2014 evaluation used the FAA's Emissions Dispersion Modeling System (EDMS) Version 5.1.4.1, as did the modeling for the reference year. Subsequently, the FAA replaced this EDMS model with a new model that evaluates air quality, greenhouse gas (CO_2), and aircraft noise. The 2016 emissions inventory was prepared using the FAA's Aviation Emission Design Tool (AEDT) Version 2c Service Pack 2.

Air Quality

Criteria pollutant emissions from the following sources were evaluated:

- **Aircraft Engines.** Commercial aircraft typically have two types of engines—those used to power the aircraft on the ground and in flight, and those used to power auxiliary equipment (i.e., auxiliary power units). For purposes of the emissions inventory, the auxiliary power unit engines are separated from the engines powering movement. To model aircraft engine emissions, the number of aircraft operations and fleet mix (aircraft types) were established using the Port's Airport Noise and Operations Monitoring System (ANOMS) for year 2014, whereas the FAA's Air Traffic Activity System (ATADS) radar data were obtained for January 2016 through December 2016. A representative aircraft was determined based on the data obtained and JP Fleets was used to assign engine types for each aircraft.

- **Auxiliary Power Units** (APUs). An APU is an engine on an aircraft that provides energy for functions other than aircraft movement, such as for the avionics/instruments, air conditioning, and heating. For the existing conditions emissions inventory, model defaults were used for APUs.

- **Ground Support Equipment** (GSE). GSE represent the support equipment that is found at an airport that primarily service aircraft, but also the airport. A comprehensive GSE inventory was collected by the Port. For this analysis, GSE was modeled by total population and fuel type.

- **Stationary Sources**. Stationary sources include fixed combustion equipment, such as boilers, pumps, and generators. To estimate emissions, their respective average run hours, were provided by the Port. The generators' horsepower ratings were also provided by the Port to replace default horsepower assignments.

- **Parking Facilities and Roadways**. Parking and roadway sources reflect the ground vehicles that move to and from the Airport and include shuttle buses, taxis, private vehicles, etc. This activity is also referred to as ground access vehicles (GAV). Assumptions for passenger vehicle and roadway traffic were generated for the SAMP through the surface transportation modeling process that evaluated surface traffic congestion, which is documented in *Technical Memorandum No. 5 Facility Requirements and Alternatives*. That analysis provided 2014 assumptions such as average vehicle miles travelled (VMT) for passenger vehicles; VMT for various roadway vehicles, such as shuttle buses, public buses, and taxis; and average speed of each vehicle and roadway type. Parking facilities and roadways were not modelled by the Port in the evaluation of 2016 conditions.

As part of the Environmental Assessment for the Sea-Tac Comprehensive Development Plan (CDP), a criteria pollutant emissions inventory was prepared. That inventory noted the following total emissions for aircraft, APU, GSE, stationary sources, parking, and ground transportation:

- NOx - 1,860 tons in 2004
- VOC - 607 tons in 2004
- CO - 12,009 tons in 2004
- SOx - 143 tons in 2004
- PM_{10} - 28 tons in 2004
- $PM_{2.5}$ - 26 tons in 2004

The CDP emissions are the closest year of an emissions inventory relative to the Port's air quality goal reference year of 2005.

A summary of the 2014 criteria pollutant emissions inventory by emission source type is provided in Table 3-6. Of criteria pollutant emissions, the two pollutants emitted in the greatest quantity were NOx and CO emissions. Combined, they represented 80% of APU emissions, 87% of aircraft emissions, 88% of stationary source emissions, 95% of parking facility-associated emissions, 95% of GSE emissions, and 96% of ground transportation emissions. Overall, NOx and CO emissions represented 91% of the emissions inventory. Emissions associated with aircraft engines and GSE represented 90% of the criteria pollutant emission sources at the Airport.

Table 3-6
Criteria Pollutant Emissions Inventory (2014)
Seattle-Tacoma International Airport

Emission Source	NO_X	VOC	CO	SO_X	PM_{10}	$PM_{2.5}$
	Tons per year					
Aircraft Engines	1,623	242	1,329	158	22	22
APUs	72	5	48	9	8	8
GSE	307	78	2,292	19	20	21
Stationary Sources	17	1	12	0	1	1
Parking	1	2	36	0	0	0
Ground Transportation	32	19	462	2	1	2
Total	2,052	347	4,178	187	53	54

Source: LeighFisher, April 2016 using the FAA's EDMS Version 5.1.4.1.

The Port of Seattle updated its air quality emissions inventory to show calendar year 2016 emissions listed in Table 3-7. In the period between 2014 and 2016, the FAA issued a new emissions model (AEDT) which was used for the 2016 evaluation. AEDT was not used to evaluate parking and ground transportation emissions. Recognizing that the analyses for 2013 and 2016 were prepared using different models, different timeframes, and in the case of ground transportation, different sources, the results are similar. Aircraft continue to be the single largest emitter of NO_X, VOC, and SOx. GSE are the largest emitter of CO and particulate matter (both coarse and fine particles). As would be expected, air emissions of these sources are increasing with increased activity levels.

Table 3-7
Criteria Pollutant Emissions Inventory (2016)
Seattle-Tacoma International Airport

Emission Source	NO_X	VOC	CO	SO_X	PM_{10}	$PM_{2.5}$
	Tons per year					
Aircraft Engines	1,775	261	1,455	162	13	13
APUs	40	3	33	5	5	5
GSE	370	94	2,769	19	25	25
Stationary Sources	18	1	12	0	1	1
Parking	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ground Transportation	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Total	2,267	379	4,841	190	48	47

n.a. = not available.

Source: Landrum & Brown using the FAA's AEDT Version 2c Service Pack 2, Sept 2017.

As shown in the two preceding air quality tables, most air pollutants increased with additional operations while others decreased with advancing engine technology. More specifically, CO, VOCs, NOx and SOx all increased, while PM_{10} and $PM_{2.5}$ both decreased.

Climate Change Protection

The Port's programs for climate adaptation and protection address both the emission of greenhouse gases that are known to alter the climate, as well as actions to adapt to the changing climate. The Port of Seattle was one of the first airports in the county to prepare a comprehensive airport greenhouse gas inventory. This section discusses the boundary of the emissions inventory, the methodology used to calculate greenhouse gases, and then presents the results.

An essential element in preparing a greenhouse gas inventory is the identification of the inventory boundaries. The boundaries establish what sources of emissions that an airport has ownership and control over, and which sources should be included in the inventory. U.S. Environmental Protection Agency (USEPA) and World Resource Institute (WRI) guidance suggest that the following be considered when establishing the boundaries:

- **Organizational structure**. As reflected by control through ownership, legal agreements, joint ventures, etc. In the case of the Port, which has marine and aviation facilities, this inventory boundary was limited to Sea-Tac Airport.

- **Operational boundaries.** Once an entity has determined its organizational boundaries, it then sets its operational boundaries. This involves identifying the emissions associated with its operations and categorizing them as direct, indirect, and optional emissions (Scope 1, 2, and 3 respectively).

  - **Scope 1 (Direct emissions)** are from sources that are owned or controlled by the party. For example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc. The WRI methods refer to direct emissions as Scope 1 emissions.

  - **Scope 2 (Indirect)** from purchased electricity.

  - **Scope 3 (Optional emissions)** are a consequence of the activities of the entity but occur at sources owned or controlled by another party. Scope 3 is an optional reporting category that allows for the identification of all other emissions that are a consequence of the activities of the entity but occur from sources not owned or controlled by the entity.

All discussions of emissions are clear to identify those that are owned and controlled by the Port as Scope 1 and 2, whereas those that are owned and controlled by other parties are referred to as Scope 3; at Sea-Tac Airport, Scope 3 emissions are owned and controlled by Airport tenants and the public accessing the Airport.

While purchased electricity generates emissions off-site, they are considered in a greenhouse gas inventory, whereas they are not considered in the air quality criteria pollutant inventory discussed previously because of the distance from the Airport the emissions are created.

The Port of Seattle was the first airport in North America to participate in the Airport Carbon Accreditation (ACA) Program in 2014 and was accredited at Level 3 Optimisation in 2017. The ACA program is the carbon management certification program designed specifically for airports and the sources of emissions that occur at airports.

Table 3-8 shows the Port's 2014 ACA Greenhouse Gas Inventory for Scope 1 and Scope 2 sources, whereas Table 3-9 shows the 2016 ACA Greenhouse Gas Inventory. Scope 1 and 2 sources reflect the sources owned and controlled by the Port of Seattle and include the Airport's fleet vehicles, stationary equipment (such as generators and natural gas use) and purchased electricity. Scope 3 are emissions that are "Port-influenced." These include emissions from tenants such as the airlines and baggage companies, and motor vehicle emissions from the passengers/general public traveling to and from the Airport.

The dominant source of Scope 1 and 2 emissions is associated with the boiler system burning natural gas (75% of emissions in 2014 and 68% in 2016) followed by purchased electricity at about 14% of Scope 1 and 2 emissions in both years.

Table 3-8
Port of Seattle Scope 1 and 2 Greenhouse Gas Emissions (2014)
Seattle-Tacoma International Airport

Scope/Source			2014 Metric Tons of CO_2	Percent of Total
Scope 1	Stationary Source	Natural Gas Boilers	15,618	75%
	Stationary Source	Diesel in Back-up Generators	160	<1%
	Mobile Source	Gasoline Use in Fleet	1,045	5%
		Diesel Use in Fleet	265	1%
		CNG Use in Fleet	790	4%
Scope 2	Indirect Energy	PSE Electricity Purchased	856	4%
		SCL Electricity Purchased	19	<1%
		BPA Electricity Purchased	2,060	10%
TOTAL			20,814	100%

Source: Port of Seattle, ACA submittal for year 2014. May not add due to rounding.

Table 3-9
Port of Seattle Scope 1 and 2 Greenhouse Gas Emissions (2016)
Seattle-Tacoma International Airport

Scope/Source			2016 Metric Tons of CO_2	Percent of Total
Scope 1	Stationary Source	Natural Gas Boilers	14,484	68%
	Stationary Source	Diesel in Back-up Generators	104	<1%
	Mobile Source	Gasoline Use in Fleet	1,051	5%
		Diesel Use in Fleet	277	1%
		CNG Use in Fleet	2,506	12%
Scope 2	Indirect Energy	PSE Electricity Purchased	1,103	5%
		SCL Electricity Purchased	24	<1%
		BPA Electricity Purchased	1,769	8%
TOTAL			21,318	100%

Source: Port of Seattle, ACA submittal for year 2016. May not add due to rounding.

The trend in greenhouse gas emissions at Sea-Tac shows that emissions are decreasing, despite an increase in activity levels. However, a notable difference occurred in emissions from CNG based fleet vehicles (which showed an increase from 790 metric tons to 2,506 metric tons between 2014 and 2016). A comparison of CNG consumption indicates a slight decrease in consumption (shown in Table 3-6, presented later in this chapter) between 2014 and 2016, but the Port no longer had access to renewable natural gas supply for its fleet vehicles, significantly increasing the emission rate for this fuel, which results in a higher total emission despite roughly the same energy use.

The Port's greenhouse gas goals and objectives refer to a reference year of 2005 or 2007. The closest year for which there is an airport inventory is for year 2007. That inventory noted the following:*

- Scope 1& 2 emissions: 21,500 metric tons in 2007
- Scope 3 emissions: 794,257 metric tons (not including aircraft cruise) in 2007

A final goal relative to climate is associated with developing an infrastructure risk assessment. Chapter 6 *Climate Change and Infrastructure Risk Analysis* documents anticipated climate change conditions and identifies the potential Sea-Tac Airport infrastructure risk due to that change.

3.3.2.2 Buildings and Infrastructure

The Port has a goal (adopted in its Environmental Strategy Plan from 2009) to seek Leadership in Energy and Environmental Design (LEED) certification for new construction, additions and renovations, as well as encouraging tenants to seek LEED certification; in addition, the Port has used a LEED Silver certification target in contract specifications for recent building projects. The United States

*It is important to note that the 2007 inventory was prepared using a different methodology and captured cruise aircraft emissions. The Scope 3 emissions noted above reflect only the aircraft emissions in the landing and takeoff cycle, as reported for 2007 to enable comparison to the more recent inventories.

Green Building Council (USGBC), a non-profit organization founded in 1993 to "transform the way buildings and communities are designed, built and operated" developed the Leadership in Energy and Environmental Design (LEED) Rating System in 2000. Currently LEED certification is using Version 4.0, and the Rating System ranges from the initial Certified rating all the way to the Platinum rating.

LEED has become one of the recognized standards for which sustainable buildings are being documented. Many local, state, and federal government buildings are required to be built to LEED Standard (often to the Silver standard). LEED splits the accumulation of points into sections, based on the focus, from Energy and Atmosphere which focuses on reduction of energy, to Sustainable Sites which focuses on siting which minimizes impact, to Water Efficiency which focuses on the reduction of potable water use in a building. LEED prerequisites define minimum standards that all LEED projects, regardless of certification level, must meet.

Many LEED projects have been initiated at Sea-Tac Airport, some of which are Port-initiated and others through tenant activities. The following are projects initiated at the Airport that have achieved LEED certification:

- **Delta Crown Room, LEED Silver**. located in the South Satellite was the first LEED certified part of the terminal complex at Sea-Tac Airport. The design included low-flow plumbing, energy-conserving appliances, renewable construction materials, and building materials with high-recycled content.

- **Consolidated Rental Car Facility, LEED Silver**. This is a five-story, 2.1 million-square-foot structure completed in 2012 that supports all airport-related rental car operations. Facets of this project include: minimizing areas that require cooling, heating and ventilation; requiring all interior construction to use organic compound paints, sealants, adhesives and carpets; implementing a recycling program throughout the facility; filtering and reusing 85% of water used to wash vehicles; and fully treating both construction and facility storm water to prevent sediment and pollutants from reaching local creeks.

- **Transit Operations Center, LEED Certified**

- **FAA Terminal Approach Control Facility (TRACON), LEED Gold.** Built in 2004, and located west of the airfield, the TRACON consists of a 51,000-sf building that was designed to use natural lighting, glass floors, photo sensor lighting fixtures and recycled materials. Construction methods also complied with a stringent site-specific air quality and recycling plan that resulted in 95% of construction waste being recycled.

- **Air traffic control tower, LEED Certified.** The air traffic control tower is located in the north cargo area and was built by the FAA.*

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*Conversation with Steve Rybolt, 3-23-2018.

For purposes of the Port goals, a focus was placed on Port-owned facilities; while the Port owns the land upon which the TRACON and tower were built, the facilities are owned by the FAA. Table 3-10 summarizes the progress in increasing the number of Port-owned LEED certified buildings. As shown, the Port owned almost 1.9 million sf of LEED-certified buildings as of 2016.

Table 3-10
Size of Port-Owned Buildings with LEED Certification (2010-2016)
Seattle-Tacoma International Airport

Year	Thousand Square Feet of LEED Certified Port-Owned Buildings	Projects Attempting LEED Certification
2010	4.9	3
2011	4.9	3
2012	1,697.8	3
2013	1,855.2	4
2014	1,855.2	5
2015	1,855.2	5
2016	1,855.2	6

Note: The square footage of facilities attempting LEED Certification is not included in the square footage certified above.

Source: Port of Seattle, 2018.

Table 3-4 of this Technical Memorandum provides additional information about building age.

3.3.2.3 Energy

Airport resources use energy in several forms: purchased electricity, natural gas, and liquid fuels. At the Airport, the largest source of purchased electricity is from the Bonneville Power Administration (BPA); power is also supplied to Port facilities from City of Seattle Light and Puget Sound Energy, but on a smaller volume. BPA generates 85% of its power from hydroelectric facilities. In addition to the above purchased electricity, the Port uses natural gas for water and space heating.

Compressed natural gas (CNG), diesel, and unleaded gasoline fuel (collectively, "liquid fuels") are used to power Port-owned vehicles. The Port provides CNG refueling stations and electrical vehicle charging stations to encourage the use of cleaner-burning, energy-efficient vehicles.

Energy is measured based on the type of energy being consumed; electricity is measured in kilowatt hours (kWh or Megawatt hours [MWh] - thousands of kWh), natural gas in therms, unleaded gasoline in gallons, diesel in gallons, and CNG measured in gallon equivalent (GGE). The historical energy consumption is summarized in Table 3-11.

Today, Sea-Tac's single facility that consumes the largest quantity of building power is the Main Terminal (See Tables 4-2 through 4-5 in Appendix *Task 6.12*), which is also the single largest building requiring power and heating/cooling. However, as noted in that appendix, on a per square foot basis, it is also the most efficient use of electrical power. Large spaces that are less efficient (BTU per square footage) are associated with the C1 Building,* North Satellite, and Concourse A.

Table 3-11
Energy Use Summary (2010-2016)
Seattle-Tacoma International Airport

Energy	2016	2015	2014	2013	2012	2011	2010
Purchased Electricity (MWh)	112,251	n.a.	111,985	109,106	113,479	114,259	116,390
Natural Gas (therms)	2,610,907	2,555,579	2,831,029	2,906,670	2,723,127	2,661,720	2,725,559
Gasoline (gallons)	119,250	123,408	118,971	115,430	124,127	121,716	117,362
Diesel (gallons)	27,091	23,734	25,972	24,548	30,499	14,362	17,802
CNG (gallon equivalent)	362,969	368,811	366,484	380,084	330,089	121,658	123,864

Source: Port of Seattle 2016 Environmental Progress Report.

n.a. = not available.

Note that while the Port established a goal of monitoring its purchase of green power, the Port electricity purchases consist of power that is over 90% carbon free, and thus no longer reports separately Green Power.

Relative to natural gas consumption, the largest facility consumers mirror that of electrical use. The largest facility consumption of natural gas is the Main Terminal, but on a square footage energy intensity usage, it is also one of the more efficient. The lesser energy efficient facilities are the North and South Satellites and Concourses B and C, as shown in Table 4-4 in Appendix A, *Task 6.12 Report – Total Cost of Ownership*.

3.3.2.4 Fish and Wildlife

Technical Memorandum No. 8 Environmental Effects Overview summarizes existing biological resources on Airport and in the vicinity. That Technical Memorandum notes that over time, most native plant communities on the Airport and nearby have been displaced by development. Approximately 88 acres of contiguous wetland, stream, and buffer mitigation on Airport property are permanently protected by restrictive covenants.

At this time, the metrics associated with fish and wildlife to enable the Port to meet and exceed its regulatory requirements, are:

- Acres of open space displaced
- Acres of protected habitat displaced

The above metrics are project based and would be assessed as individual projects are considered.

*This building is attached to Concourse C and is one location where baggage is processed.

3.3.2.5 Noise

Noise is an inherent byproduct of aircraft operations and cannot be avoided; thus it is the most common environmental condition encountered at airports. Airport-related noise emanates primarily from aircraft takeoffs and landings. Taxiing aircraft, engine maintenance, and other ground operations also contribute to ambient noise levels.

Federal Aviation Regulation (FAR) Part 150, Airport Noise Compatibility Planning, is the primary federal regulation that guides planning for aviation noise compatibility on and around airports. Part 150 establishes a standard noise assessment methodology/metric, specifies the model to be used, and identifies land uses that are normally compatible or incompatible with various levels of airport noise. The Port of Seattle was one of the first airports to participate in the Part 150 Study process and has completed numerous updates to its original study, the most recent approved by the FAA in 2014.

The FAA has adopted the Day-Night Average Sound Level (DNL) as the single system for determining cumulative noise exposure of individuals to airport noise. DNL is the 24-hour average sound level, in decibels, obtained from the accumulation of all events over a one-year period, with 10 decibels added to sounds occurring between 10 p.m. and 7 a.m. The weighting of nighttime events accounts for the increased annoyance that most residents have associated with noise during the night, when ambient levels are lower, and people are trying to sleep.

Subsequently, the Port has updated the noise contours for 2016, as also shown in the noise exposure table below. The information shown is for general understanding only; the Port's Noise Remedy Program has not been modified, and the Port continues to implement sound insulation programs including outreach, based on the approved Part 150 measures. Table 3-12 summarizes the noise sensitive resources, including residences that have participated in the Port's Noise Remedy Program, within each of the noise contours.

Table 3-12
Existing Noise Exposure (2016)
Seattle-Tacoma International Airport

Scenario/Land Use	65-70 DNL	70-75 DNL	75+ DNL	65 DNL & Greater
People	11,171	218	0	11,389
Residences	4,313	80	0	4,393
Schools	5	0	0	5
Churches/Places of worship	10	0	0	10
Hospitals/Nursing homes	0	0	0	0
Libraries	2	0	0	2

Note: Residences counted, include those that have participated in the Noise Remedy Program.

Source: 2016 data: Landrum & Brown, March 2018 using 2010 US Census block data.

3.3.2.6 Transportation

The Port's sustainability goal for passenger transportation, as noted in Chapter 2, is to:

> *Reduce the greenhouse gas emissions associated with passenger and employee transportation to and from the Airport by decreasing the emission intensity of the travel modes and increasing the proportion of trips made using environmentally preferred modes. The Port defines environmentally-preferred modes as car-pooling, daily parking, taxi/TNC, door-to-door van, rental cars, shuttles, air porters, public transit, and charter buses.*

The Port identified the environmentally-preferred modes by evaluating the carbon intensity of each mode. Curbside drop-off is not environmentally-preferred because the passenger creates two additional vehicle trips (one when the driver returns to their destination after having dropped off the passenger, and another when they return to pick up the passenger). In other words, fewer trips would be generated if the passenger simply drove to the parking garage and parked for the duration of their air travel trip. For that reason, daily parking is noted as "environmentally preferred." However, single-occupancy vehicle trips are less environmentally preferred than multi-occupancy trips (such as shuttles and transit) and taxis/TNCs (transportation networking companies).

Taxis and TNCs such as Uber and Lyft are required to meet strict environmental standards when operating at the Airport. Taxis that pick-up passengers at the Airport must be at least 45 mpg or use alternative fuels, and make efforts to reduce their deadheading (i.e., reduce the number of trips made to or from the Airport without a passenger).

TNCs are also required to meet similar standards, although -- because TNC drivers own their own vehicles -- the Port cannot place strict requirements on the vehicles picking up passengers at the Airport. In response, the Port requires the TNCs to meet an overall environmental standard, referred to as the environmental key performance indicator or E-KPI. The E-KPI allows the TNCs to calculate their overall environmental impact based on the fuel efficiency of the vehicles picking up passengers, as well as the amount of deadheading from each of those vehicles.

The Port conducts annual enplaning passenger surveys to determine the modes through which passengers routinely access the Airport. Surveys include the following modes:

- Private vehicles accessing daily parking facility
- Taxis/TNCs
- Door-to-door shuttle vans
- Hotel courtesy shuttles
- Public transportation (Link Light Rail and Metro Bus) and
- Charter Buses.

Table 3-13 below shows a detailed overview of the ground transportation modes used by passengers traveling to the Airport in 2016. As shown in the table, 56.5% of passengers accessing the Airport used environmentally-preferred modes of transportation, and 44% used other modes (curbside drop-off/pick-up and limo).

The Port also includes employee transportation, referred to as Commute Trip Reduction (CTR), in its sustainability program, although it does not have a specific employee CTR goal.

Table 3-13
Transportation Modes Used by Enplaned Passengers to Access the Airport
Seattle-Tacoma International Airport

Travel mode	2016 Estimated Trips by Mode	Percentage
Curbside drop-off/pickup	16,343,261	42.5%
Limo	408,716	1.1%
Subtotal	16,751,977	43.6%
Environmentally Preferred Modes		
Taxi/TNC	3,269,652	8.5%
Daily Parking	6,130,598	16.0%
Rental Car	5,721,891	14.9%
King County Metro Bus	408,706	1.1%
Door-to-door Van	1,634,826	4.3%
Courtesy Shuttle	2,043,532	5.3%
Sound Transit Light Rail	2,452,239	6.4%
Subtotal	21,661,444	56.5%

Source: Port of Seattle, 2018.

In 2014, 81.2% of Port employees travelled to work by driving alone in their private vehicles; this percentage decreased to 80.8% in 2017. As the 2017 data are the only data available, they are used as a surrogate for year 2016. A summary of commute transportation modes used by Port employees is provided in Table 3-14.

Table 3-14

Transportation Modes Used by Port of Seattle Employees to Access the Airport

Seattle-Tacoma International Airport

Transportation Mode	Percent of Port Employees (percent)
Drive Alone	80.8%
Carpool	5.3%
Vanpool	0.8%
Motorcycle	1.0%
Bus	4.9%
Rail	3.6%
Bicycle	0.4%
Walk	0.3%
Telework	1.4%
Compressed Work Week (CWW)	0.4%
Boarded Ferry with Car/Van/Bus	0.6%
Used Ferry as Walk On	0.3%
Other	0.1%

Source: Port of Seattle, email from Scott DeWees, 1-29-2018.

3.3.2.7 Water Conservation

The Port of Seattle has recognized that increases in Airport activities have made demands on the public water supply which is primarily provided by Seattle Public Utilities (SPU). Moreover, the Port recognizes the importance of area-wide coordination and development of water conservation programs. The Port has developed a conservation program that provides a positive effort toward conservation of the region's water supply.

Past activities have included technical assistance to Port customers, implementation of the use of low-flow fixtures, supply and service meters to identify unauthorized consumption, and for identification of distribution system leakage, Water Smart Technology program, and landscape management. The following list demonstrates how conservation has been promoted and achieved through various hardware and plumbing design standards established in the Port's Design Guidelines for new construction:

- Flush toilets meeting a maximum flow requirement of 1.6 gpf (Dual flush 1.1 gpf/1.6 gpf) must be installed in women's restrooms.
- Urinals must have a maximum allowable flow of 0.5 gpf.
- Sinks must have a maximum flow of 0.5 gpm with a 10 second cycle.

- Flow control devices such as shut off valves and nozzles are required on all water outlets.

- Constant running equipment such as water fountains is notallowed.

- Flow control devices such as self-closing faucets, push buttons, or infrared sensors are required on sinks and showers where codes permit.

- Meters must be provided for main supply lines larger than 3/4-inch, for monitoring water consumption, and troubleshooting. One meter is required for each building or large building zone.

The following additional conservation program regulations have been implemented for existing buildings:

- Flow control devices are required for constant running equipment such as water fountains.

- Adjustable water flush valves are required on water closets and urinals.

- Low flow shower heads are required.

- Flow restriction devices are required for sinks and showerheads.

- Replacement of broken or inefficient irrigation heads is required.

The Port works closely with SPU to reduce overall water use where feasible and participates in a commercial incentive conservation program called "Water Smart Technology Program." Current incentives offered via this program to commercial customers include replacing older high-flow flush valve models, using water savings equipment or landscape, using efficient coin - operated machines, replacing inefficient food steamers, more efficient cooling and refrigeration systems, medical equipment and improving process water usage.

The Port has also established Landscape Design Guidelines (currently in revision) for promoting efficient irrigation. Areas covered by grasses that require watering beyond what is naturally provided in the Puget Sound area have been reduced. The 2006 Landscape Design Standards (LDS) call for a minimum of 50% of all landscape materials to be native or drought-tolerant species. Other irrigation requirements include the use state-of-the-art water conserving features, such as moisture or precipitation sensors, rain shut-off device(s), pressure regulator valve(s) and master control and flow sensing valve(s).

Although overall water use at the Airport has increased, conservation measures have resulted in a decrease in the water consumption rate when measured on a per passenger basis (see Table 3-15). Between 2010 and 2016, the consumption rate has decreased from 6.9 to 5.3 gallons per passenger. With the increase in the number of passengers from 31.6 million in 2010 to 45.7 million in 2016, the annual volume of water consumed would have been over 70 million gallons greater in 2016 if the consumption remained at the 2010 rate of 6.9 gallons per passenger.

As part of the SAMP, a review was conducted of source of water consumption in 2013. That analysis, documented in Appendix A *Task 6.12 Report – Total Cost of Ownership* indicates the following major consumption sources as listed in Table 3-16. Appendix A *Task 6.12 Report – Total Cost of Ownership,* reports that the most notable amount of water is consumed in the Main Terminal (see Appendix A, Chart 4-10). That evaluation found that 56% of water use was for Port-owned and -operated functions (30%) and tenant (outside the aircraft operations area) functions (26%). Tenant use inside the aircraft operations area included 11% for use inside the terminal and 3% outside the terminal. Restroom water consumption represented 16% of water consumed, whereas the cooling towers (which operate when the chillers operate to provide the necessary heat rejection for the chillers) consumed 10%, and other uses made up the remaining 4%.

Table 3-15
Potable Water Use (2010-2016)
Seattle-Tacoma International Airport

Year	Potable Water Use (gallons)	Potable Water use/passenger (gal/pax)
2010	217,428,779	6.9
2011	223,496,221	6.8
2012	201,657,593	6.1
2013	210,272,166	6.0
2014	229,009,371	6.1
2015	270,688,582	6.4
2016	243,682,410	5.3

Note: Water use per passenger was calculated by dividing water use by number of passengers.

Source: Port of Seattle Facilities and Infrastructure water usage reports based done SPU water supply meter readings.

Table 3-16
Sea-Tac Water Use Sources (2013)
Seattle-Tacoma International Airport

Water Use Source	Consumption Percent
Port Operations	30%
Tenant (outside AOA)	26%
Restrooms	16%
Tenant (in terminal)	11%
Cooling Tower	10%
Tenant (outside terminal)	3%
Other	4%

Source: CH2M Hill, Appendix A *Task 6.12 Report – Total Cost of Ownership*. Chart 4-36.

3.3.2.8 Water Quality

Nearby Sea-Tac Airport are a series of wetlands and streams including Miller Creek, Walker Creek, and Des Moines Creek. Each of these creeks drains directly to Puget Sound. Therefore, Airport activities, particularly those associated with stormwater runoff, have the potential to affect water quality. The Port has developed a robust stormwater management program that meets and, in many cases, exceeds stringent regulatory requirements.

Stormwater runoff is managed within two separate systems, the stormwater drainage system (SDS) and the industrial wastewater system (IWS). Table 3-17 provides a summary of stormwater managed within each of these systems.

Table 3-17
Volumes of Treated Stormwater and Glycol (2011-2016)
Seattle-Tacoma International Airport

	Stormwater		Industrial Waste System (IWS)			
					BOD *(b)* Receiving Secondary Treatment	
Year	Area Treated for Flow and Water Quality *(a)* (acres)	Area Served Aviation Compatible LID (acres)	Runoff Treated by IWTP (MG/Year)	Runoff Receiving Secondary Treatment (MG)	Pounds	(Percent)
2011	1,207	272	369	191	952,568	98.4
2012	1,207	272	284	185	2,130,224	99.5
2013	1,207	272	300	146	556,635	96.4
2014	1,207	272	317	100	670,204	96.6
2015	1,207	272	285	66	289,638	89.9
2016	1,207	272	385	60	220,501	76.2

(a) Airport's stormwater runoff is treated for flow control and water quality.
(b) Aircraft deicing and anti-icing fluids are the primary source of BOD in the airports industrial wastewater.

LID= Low Impact Development, BOD = Biological oxygen demand, MG= Million gallons, IWTP = Industrial Wastewater Treatment Plant

Sources: 1. Low Impact Development Guideline Figure 2-2, Revised June 2017.
2. Annual Industrial Wastewater Summary Reports.

3.3.2.9 Waste Management

The Port published the *Seattle-Tacoma International Airport Solid Waste Management Plan 2014*, in June 2015. That document is consistent with the FAA's 2014 Guidance on Airport Recycling, Reuse, and Waste Reduction Plans. The Port's Solid Waste Management Plan documents existing conditions, identifies and evaluates opportunities to further reduce Port waste, and recommends specific strategies to help the Port achieve its waste reduction and recycling objectives. In 2016, the Port completed its Solid Waste Generation Forecast and Capacity Analysis.

The Port generates municipal solid waste (MSW), hazardous waste, and construction and demolition-debris (C&D or CDL) waste. MSW, hazardous waste, and C&D are generated from passenger activity in terminals and airfield activity, volumes of hazardous materials used, and construction activity, respectively.

Solid Waste

The Port uses a centralized waste collection system divided between terminal and support, and airfield areas. MSW collected in publicly- and non-publicly accessible terminal and support areas are transported to central collection sites by contracted janitorial crews, tenants, and Airport Maintenance staff. The MSW is transported using tilt trucks, service carts, or similarly dedicated equipment and/or vehicles. Deplaned MSW collected from aircraft and airfield support facilities is transported to collection sites by airline staff, ground support staff, and other tenants.

In 2015, activity at Sea-Tac generated 6,692 tons of MSW; waste generation increased to 7,328 tons in 2016. From the terminal about 2,340 tons, or 32% of MSW generated was diverted from the landfill in 2016. Diversion is defined as redirecting a material for reuse, recycle, or composting instead of disposing it as waste. About 260 tons, or 9%, of the 2,855 tons of waste materials generated from the airfield in 2016 was diverted. Additional MSW generation and recycling data from 2010 to 2016 are provided in Table 3-18. It is important to note that the Port implemented additional requirements for concessionaire recycling in 2017 which is not yet reflected in the baseline data.

Table 3-18
Terminal and Airfield Municipal Solid Waste (MSW) Generation and Diversion (2010-2016)
Seattle-Tacoma International Airport

Year	Terminal MSW Generation (tons)	Terminal MSW Diversion Rate (percent)	Airfield MSW Generation (tons)	Airfield MSW Diversion Rate (percent)
2010	5,494	24%	NA	NA
2011	5,704	27%	NA	NA
2012	5,665	30%	NA	NA
2013	5,762	30%	2,136	10%
2014	6,144	31%	2,225	10%
2015	6,692	33%	2,551	9%
2016	7,328	32%	2,855	9%

Source 2015 Environmental Progress Report, 2016 and Port staff communication with LeighFisher and Synergy Consultants, March 2018.

Hazardous Waste

The Port's Hazardous Waste Program ensures proper management of hazardous waste material generated by Port Operations and Maintenance. All wastes are managed under the federal Resource Conservation and Recovery Act (RCRA), Toxic Substances Control Act (TSCA), and Washington State Dangerous Waste Regulations. Waste under the Port's Hazardous Waste Program includes:

- Hazardous/dangerous waste including paints, solvents, part cleaners, degreasers, and aerosols.
- Universal waste including batteries, lights and other mercury containing materials, and CRT monitors.
- Vehicle and equipment maintenance wastes including off-specification fuels, used oil/filters, and spent antifreeze.

- Electronic scrap, including computers, and non-CFC containing appliances, and other electronics.
- Equipment containing refrigerant, appliances.
- PCB and Non-PCB waste.
- Off-specification and abandoned chemical products.
- Contaminated soil.
- Petroleum-contaminated sludge from industrial wastewater treatment plant (IWTP).
- Runway rubber and paint chips from Airfield maintenance.
- Prescription medicine not claimed from the Lost and Found office.

Hazardous wastes are accumulated at over 20 designated accumulation areas at Port maintenance facilities around the Airport. A summary of the hazardous waste generation at the Airport is provided in Table 3-19.

Table 3-19
Hazardous Waste Generation (2010-2016)
Seattle-Tacoma International Airport

Year	Hazardous Waste Generation (pounds)	Hazardous Waste Generation (tons)
2010	2,429	1.21
2011	2,535	1.27
2012	1,558	0.78
2013	2,607	1.30
2014	2,670	1.34
2015	2,411	1.21
2016	1,057	0.53

Note: Pounds converted to tons by dividing by 2,000.

Source: Port of Seattle, 2016 Environmental Progress Report, 2017.

As indicated by comparing waste generation in 2010 to 2016 in Table 3-19, the Port has reduced its hazardous waste generation, despite increases in operations and passenger activity. However, there has been some fluctuation in total hazardous waste over the 7-year period. The reduction, while activity has increased, may be attributed to the Port's participation in the Washington State bio-accumulative toxics reduction initiative program, which focused on removing mercury containing switches from Port vehicles, and the State Electronics Challenge, which encourages procurement of environmentally-friendly office equipment and safe disposal of electronics. In addition, the maintenance department has replaced some hazardous chemical products with safer alternatives.

Construction Waste

To minimize construction waste, the Port developed a Construction Waste Management specification to help implement Best Management Practices that reduce construction, demolition, and land clearing debris generated by the Port and its contractors.

As shown in Table 3-20, the Port diverted approximately 94 to 100% of airfield and landside construction waste in 2014 and 2015, respectively. This includes all construction waste generated from Port construction projects and Port Construction Services small works projects from airfield, and landside projects. The Port diverted approximately 91% and 37% of terminal construction waste in 2014 and 2015. The lower rate in 2015 was due to there being more mixed construction demolition and land clearing debris in comparison to other projects in other years; diversion increased to 100% in 2016. The Airport generated more highly recyclable metal (57 tons) and concrete (18 tons) in 2014 and landfilled more mixed Construction Demolition and Land clearing (CDL) debris in 2015 (79 tons) vs. 2014 (16 tons).* A summary of the 2014 through 2016 construction waste recycling performance is noted in Table 3-20.

Table 3-20 shows that the Port generated notable amounts of airfield construction waste in 2015 and 2016. This is due to the major rehabilitation of the center runway at Sea-Tac. Despite initiating a large construction project, the Port maintained a high diversion rate of 96% to 99% for airfield construction waste in 2015 and 2016. This was due to extensive reuse and recycling of materials from the existing runway used in the new runway. The existing concrete from the runway was recycled and crushed on site into gravel that was used as the sub-base for the new runway, taxiways, shoulders, and blast pads. Similarly, existing asphalt from the shoulders and blast pads was taken to asphalt plants for recycling into new asphalt.

Table 3-20
Construction Debris Waste Generation and Diversion
Seattle-Tacoma International Airport

Year	Terminal Construction Waste Generation (tons)	Terminal Construction Waste Diversion Rate (percent)	Airfield Construction Waste Generation (tons)	Airfield Construction Waste Diversion Rate (percent)	Landside Construction Waste Generation (tons)	Landside Construction Waste Diversion Rate (percent)
2014	186	91.3%	1,579	94%	10,690	99%
2015	126	36.7%	469,188	96%	4,224	100%
2016	166	100%	286,289	99%	7,819	99%

Source: Port of Seattle, 2015 Environmental Progress Report, 2016 and 2015 Construction Waste Management Annual Summary Report by the Port of Seattle.

*Email from Jeremy Webb (Port of Seattle), March 26, 2018 to Mary Vigilante (Synergy Consultants).

3.4 Social and Community Outreach Baseline

The following sections discuss the metrics that are used to evaluate performance on social and community outreach goals and objectives. Following a discussion of the metrics is the identification of existing conditions relative to those metrics. It is important to note that the social metrics capture the positive effects of the Airport in the region, but also the negative effects, as well as workforce-related issues of importance to the Port.

Table 3-21 lists the current known conditions relative to the social and community outreach metrics. Existing metrics are presented, where available.

Table 3-21
Baseline Social and Community Outreach Metrics
Seattle-Tacoma International Airport

Metric	2016	2014	2013	2011
Number of Aviation Department Employees	832	856	836	764
Airport workers earning college credits through onsite classes	77	83	n.a.	n.a.
Airport related jobs *(a)*	n.a.	n.a.	171,796	n.a.
Airport related payroll (Million) *(a)*	n.a.	n.a.	$6.10	n.a.
Airport related expenditures (Billion) *(a)*	n.a.	n.a.	$16.30	n.a.
People within 65 DNL+	11,400	n.a.	4,880	n.a.
People within 70 DNL+	220	n.a.	-	n.a.
People within 75 DNL+	0	n.a.	-	n.a.
Dwellings within 65 DNL+ *(b)*	4,393	n.a.	1,890	n.a.
Dwellings within 70 DNL+ *(b)*	80	n.a.	-	n.a.
Dwellings within 75 DNL+	0	n.a.	-	n.a.
Number of Noise Complaints Received	2,959	2,172	2,507	1,788
Transit routes serving SEA	2 + Light Rail	2 + Light Rail	2 + Light Rail	2
Development Based Metrics				
Roadway LOS				
Proximity to noise or light sensitive uses	Associated with future development projects			
Consistency with Zoning				

Note: for most of the social programs, data is not collected annually, due to the cost of such studies.

(a) The Airport's Economic Impact Study was updated in 2018, using 2017 data. Data through 2016 were used in this report, so the 2017 data were not reported here.

(b) Note that the dwellings include those that have participated in the Noise Remedy Program.

n.a.= not available.

Source: Port of Seattle Records, 2018.

3.4.1 Existing Social and Community Outreach Baseline

3.4.1.1 Employees and Employee Retention

As of 2016, the Port of Seattle's Aviation Division had 832 employees ranging from executives to airport maintenance workers and including police and fire functions. The Port invests heavily in the education and training of its employees and that of tenant employees based at the Airport. In early 2014, the Port Commission introduced the Quality Jobs Initiative, recognizing that the Airport must have a stable, well-trained workforce. In the initial phase of the initiative, the Port established a minimum hiring, training, wage and compensation requirement for aeronautical workers. In the second phase of the initiative, the Port established policies for concession employees that were designed to support opportunities that foster economic prosperity, entrepreneurialism, increase job availability, and security.

In contrast to the number of Port employees, there were about 14,500 people working subject to security badges at Sea-Tac in 2014. In 2014, total-airport employment turnover for the Airport was significant but varied by employer from approximately 25% to above 80% per year. Almost all the turnover occurred in entry-level positions.*

3.4.1.2 Quality Jobs

Through the Port's office of Social Responsibility, the Port supports programs that provide quality job training, job placement, pre-apprenticeships, and other education and career development services. The Port Jobs program serves both employers and job seekers. The Airport Jobs Office serves as a centralized hub for employment at Sea-Tac Airport, enabling job seekers to connect with Airport tenants and related employers who need qualified candidates. The Port also supports the Airport University, that helps workers advance and provides job skills and college credit classes on-site. As of the end of 2014, over 83 airport workers had earned college credits through courses offered on-site in partnership with Highline Community College. In 2016, 77 airport workers had earned college credits.

3.4.1.3 Employee Safety

The Port has implemented a wide range of programs designed to reduce accidents and injuries of employees and the traveling public at Sea-Tac Airport. An example is the Safe-Catch Award, as implemented through the Airfield Safety Management System, which has been implemented as a safety promotion platform to encourage the reporting of safety hazards and issues and to recognize individuals or business that have caught a safety or hazard trend, gap or misstep, and presented this information in a meaningful, proactive, and positive manner. In addition, the Port has formed the Sea-Tac Safety Action Committee.

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*Commission Agenda Staff Briefing Memo dated June 26, 2014 "Minimum Requirements for Aeronautical Workers with Safety and Security Responsibilities at Seattle-Tacoma International Airport."

3.4.1.4 Diversity and Inclusion/Equity Metrics

With the update of the Long Range Plan in 2017, the Port Commission strengthened the Port's diversity, inclusion, and social equity program. The metrics attached to these initiatives are reflected in Chapter 1 of this document. At this time, baseline data was not available for these metrics.

3.4.1.5 Community Benefit/Impacts Metrics

Sea-Tac Airport is the source of many benefits to the Puget Sound Region, but it also exerts negative impacts on the adjacent communities. This section briefly summarizes the benefits and impacts.

Regional Economic Benefits

In 2013, Sea-Tac Airport resulted in generation of nearly 171,800 jobs for residents of the Puget Sound Region with a payroll of over $6 billion.* The activity at the Airport was responsible for over $16.3 billion in regional economic contribution. As noted in the Port's study "From airport workers who live in neighboring communities to cherry farmers in Central Washington, and from shops in tourist destinations like Pike Place Market to corporate giants like Microsoft and Boeing, Sea-Tac touches nearly every aspect of the economy …. Tourism is a big business in Washington, ranking as the state's fourth largest industry in terms of Gross Domestic Product. Sea-Tac Airport is a gateway for tourist activity across the entire state, including several rural counties where tourism is especially important to local economies."**

In addition, the economic impact study noted that a total of 119,685 manufacturing, agricultural and other jobs were related to air cargo shipments from Sea-Tac to overseas and domestic destinations in 2013. "With daily, non-stop service to dozens of domestic and international destinations, the Airport is the Northwest's primary air cargo gateway. Transport by air freighters and in the holds of passenger planes is especially important for high-value and perishable cargo, or when speed is critical. Certain industries, including some considered to be leading sectors of modern economies, need access to air cargo facilities to maximize competitiveness. In the Northwest, air cargo at Sea-Tac supports industries such as:

- Aerospace
- High-value agriculture including cherries and blueberries
- Fresh seafood
- Life sciences such as pharmaceuticals and medical devices
- High-tech manufacturing***

*The Port updated its economic impact study in January 2018, using 2017 data. However, because this report relies on data through 2016, for consistency across the metrics, the 2013 data were used.
**Port of Seattle brochure titled "The Economic Impact of Seattle-Tacoma International Airport."
***Port of Seattle brochure titled "The Economic Impact of Seattle-Tacoma International Airport."

About 9 million out-of-town visitors arrived via Sea-Tac for business or pleasure in 2013. When these travelers spent their money in our region, it generated substantial economic impacts, including $365 million in state and local taxes."

Environmental Conditions

While the Airport exerts positive impacts on the Region, it also generates environmental effects on the communities nearby. SAMP *Technical Memorandum No. 8 Environmental Effects Overview* summarizes current environmental conditions across environmental media including air quality, water quality, wetlands, floodplains, and others. Many of these conditions are characterized by citizens as affecting the quality of life of airport neighbors. In response, the Port of Seattle has implemented extensive mitigation programs. The largest is the Port's Noise Remedy Program. Since Program inception, the Port has:

- Acquired 1,400 homes in the most severely affected area and relocated the residents, including 388 units associated with constructing Runway 16R/34L.
- Sound insulated about 9,400 single family homes, 6 condo complexes with 236 units, and 7 Highline School District schools, 14 buildings at Highline Community College, 3 private schools, 2 churches and 1 convalescent center.
- Acquired and relocated residents in 5 mobile home parks (359 units).*

In 2016, about 11,400 people in 4,393 dwelling units live in the 65 DNL** and greater noise contour, as listed in Table 3-12. The 65 DNL is a sound level that FAA considers significant aircraft noise and for which noise sensitive uses are not compatible unless sound insulated; note that the 4,393 dwelling units include residences that have participated in the Noise Remedy Program which includes sound insulation. The Port continues its outreach efforts to these residences, consistent with FAA-approved Part 150 measures. The Port has also worked with the FAA to develop noise abatement procedures that are designed to reduce aircraft noise impacts. In addition, the Port was one of the first airports in the country to prepare a Part 150 Noise Compatibility Plan in the 1980s and has continued to update its study, such as the one approved by the FAA in 2014.***

The Port of Seattle has acquired land for noise purposes and has developed plans to redevelop those lands to support regional economic development needs. Specifically, the Port and the Cities of Burien, Sea-Tac, and Des Moines have been planning for joint economic development projects on lands north and south of the Airport. These projects would return the acquired land to the tax rolls of the local communities. The Port is also taking part in community business development committees, and sponsoring Chamber of Commerce events. Port staff serve on School District and College boards and

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*https://www.portseattle.org/Environmental/Noise/Sound-Insulation/Pages/default.aspx

**Day-Night Average Level (DNL) – a 24-hour average sound level metric required for use in evaluating aircraft noise at airports that includes a weighting for nighttime (10 pm-7 am) noise.

***Port of Seattle, Final Seattle-Tacoma International Airport *Part 150 Noise Compatibility Study Update*, October 2013.

contribute as volunteers to community events, and the Port has provided funding for community projects.*

The second most often cited impact of the Airport is associated with air pollutant emissions. As noted in the Port's 2015 and 2016 *Environmental Progress Report*,** a number of actions have been implemented by the Port to reduce emissions and other environmental impacts as described earlier in this report.

There are two bus routes that serve Sea-Tac Airport in addition to the Sound Transit Link Light Rail. Sound Transit Route 574 serves cities south (Lakewood, Tacoma, Kent/Des Moines, SeaTac). Sound Transit route 560 connects White Center to Sea-Tac Airport.

The Port of Seattle Social Responsibility Office has developed a racial and social justice checklist/tool kit for the Port that will aid in considering future equity/inclusion metrics.

3.4.1.6 Community Outreach

The Port of Seattle has made a significant commitment to public outreach both in terms of involving the public in its evaluation and decision process but also to provide continual briefings on its activities. Similarly, the Aviation Division implements a wide range of public outreach activities to the region and communities in the immediate vicinity of Sea-Tac Airport.

The Port conducts meetings with the local communities and publishes information documents for widespread distribution. Meetings and outreach activities include:

- Participation in South King County community activities
- Meetings with the Cities of SeaTac, Burien, Des Moines, Normandy Park, Federal Way, and others
- Meetings and other outreach associated with specific studies, such as this Sustainable Airport Master Plan; Three sets of public meetings have been held concerning the progress of the SAMP
- Activities related to the Port's S3 Program
  - Conducted the annual Environmental Challenge with Raisbeck Aviation High School students for the last eight years on a variety of airport issues ranging from energy to solid waste to transportation to and from the Airport.
  - Completed Sustainable InSights campaign redesign and installed new messaging at 14 terminal locations to educate travelers and employees about Airport sustainability initiatives.

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*Port of Seattle, Seattle-Tacoma International Airport, Managing a Green Airport, August 2007.
**Port of Seattle, 2015 Environmental Progress Report, Strategy for A Sustainable Sea-Tac https://www.portseattle.org/Environmental/Documents/2015_env_progress_rept.pdf April 2016.

– Integrated sustainability into North Satellite (NorthSTAR) design by including plans for a living wall, permanent sustainability messaging, and environmentally inspired art features.

– Awarded Environmental Excellence Award for outstanding environmental accomplishments annually for the last eight years.

– Updated Port website with airport environmental content to highlight recent progress reports and initiatives.

- Publications distributed by the Port to keep the interested public informed of airport activities are:

  – Flyer *Air Mail*, distributed quarterly; and

  – Connections, an email newsletter about current activities at the Airport and port-wide.

The Port also maintains a Noise Abatement Office to hear and respond to complaints regarding aircraft noise and to monitor compliance with noise abatement procedures. Residents can submit comments and complaints through the web https://www.portseattle.org/Environmental/Noise/Pages/Noise-Comment-Form.aspx or by calling the noise hotline at 206-787-5393 or toll-free 1-800-826-1147. Noise complaints ranged from 839 in 2012 to 2,959 in 2016.* In addition, the noise office has a fly quiet program that honors airline efforts in noise reduction and abatement programs.**

3.4.1.7 Project Specific Social and Community Outreach Metrics

As part of the SAMP, a series of community-based metrics were identified for purposes of evaluating the SAMP development alternatives. Since they would be future development based, there is no available existing condition.

*Port of Seattle, Noise Abatement Office. June 1, 2016.

**https://www.portseattle.org/Environmental/Noise/Noise-Abatement/Pages/Fly-Quiet.aspx

Sustainability Initiatives, Opportunities, and Actions

The SAMP resulted in the identification of a wide range of strategies to aid the Port in achieving its sustainability goals and objectives. The sustainability strategies are summarized as Initiatives, Opportunities, and Actions (IOAs).

4.1 Overview of the SAMP Initiatives, Opportunities, and Actions

This chapter summarizes the Port's goals and objectives identified in Chapter 2 *Sustainability Vision and Goals/Objectives* and, based upon Chapter 3 *Sustainability Baseline and Future Conditions*, identifies known gaps relative to the goals/objectives. Then strategies, referred to as Initiatives, Opportunities, and Actions (abbreviated as IOAs) are identified that are aimed to close the gaps. IOAs are defined as:

- **Initiatives**. Initiatives are specific new actions that could be taken to enhance performance in one of the triple bottom line focus areas (i.e., make progress toward achieving sustainability goals/objectives);

- **Opportunities**. Opportunities are potential actions that, when applied to the recommendations of the SAMP, could improve triple bottom line performance. At a plan level, it is not a prudent use of resources to develop highly specific actions, but rather identify opportunities that could be incorporated during the engineering and design process for future projects; and

- **Actions**. The Port has an ongoing program of actions that it implements to achieve its goals and objectives. Items in this category would extend the existing program(s) to include recommendations resulting from the SAMP.

This chapter documents the IOAs as they relate to the triple bottom line categories and goals/objectives identified in Chapters 1 and 2. First, this chapter discusses how the consideration of the various goals and objectives helped frame the SAMP Long Range Development Vision and resulting Near-Term Projects. Then, for each of the triple bottom line categories, the gaps relative to the goals/objectives are identified based on the inventory conducted in Chapter 3, followed by specific IOAs that could be considered by the Port. In the following Chapter 5, *Implementation Process and Plan*, these IOAs are prioritized based on (1) the likelihood they will assist the Port in meeting Commission Century Agenda goals, (2) ease of implementation, and (3) ability to assist the Port in meeting remaining sustainability goals and objectives. The IOAs also form the basis of the Port's recommendations to implement the findings from this initiative.

4.1.1 IOA Sources

In preparing the IOAs for the SAMP, a review was conducted of the Port's business plan, the Port's *Strategy for a Sustainable Sea-Tac* (S3) Program, 2015 Environmental Management Report, the Sustainable Aviation Guidance Alliance (SAGA) database,* and other industry resources. The purpose of that review was to identify possible IOAs that would aid the Port in achieving its goals and objectives. Because the Port's approach to sustainability includes the financial (and operational) element as well as social and environmental, the SAMP Near-Term Projects themselves are considered IOAs under this framework. As shown throughout the SAMP documentation, these projects are designed to enable the Port to meet its goals and objectives. This chapter discusses the IOAs that were found to potentially be of benefit.

Each IOA was designed to fill gaps and improve performance as measured by metrics associated with a sustainability goal and/or objective. In identifying IOA, consideration was given to: (1) unique metrics; (2) who (which Airport group/department) would be responsible for its implementation; (3) when it could be implemented (timeframe); (4) duration of implementation (if applicable); (5) how it could be implemented; (6) cost and potential funding sources; (7) review cycles; (8) possible obstacles to implementation; and (9) potential benefits.

Where possible, characteristics of the IOAs were quantified to the extent appropriate. Recognizing the sustainability implementation plan described in Chapter 5 *SAMP Implementation Process and Plan*, it is expected that further refinement of IOAs would occur as appropriate.

While the SAMP development recommendations are for the Near-Term Projects, the other sustainability elements of the study considered longer-term sustainability actions so that Port staff could have a framework for items that might take longer to implement.

4.1.2 Identifying the Gap to be Filled

Chapter 2 discusses the sustainability goals and objectives and the metrics designed to measure performance relative to the goals and objectives. Chapter 3 identifies the baseline (current) conditions.

The gaps needed to frame the need for IOAs were determined by simply subtracting current conditions from the Port goals/targets. Because the goals and targets are for future years, the gaps can be considered to represent the lower end of the expected gap between performance and the goals. As such, the gaps identified and presented in this chapter are estimates intended to be used to identify the breadth and general magnitude of IOAs that may be needed as well as to prioritize sustainability categories and corresponding strategies. The gaps are identified for each focus area where information was available.

As discussed earlier, future environmental conditions are not known at this time and will be the subject of more rigorous review processes, including NEPA and SEPA.

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*Sustainable Aviation Guidance Alliance information can be found at: http://www.airportsustainability.org/.

As the gap results presented in this chapter show, gaps exist for almost all of the Port's sustainability goals and objectives. This indicates that additional strategies (IOA) will be required in virtually all focus areas.

4.1.3 Identifying the Near-Term Projects to Meet Airport Facility Needs

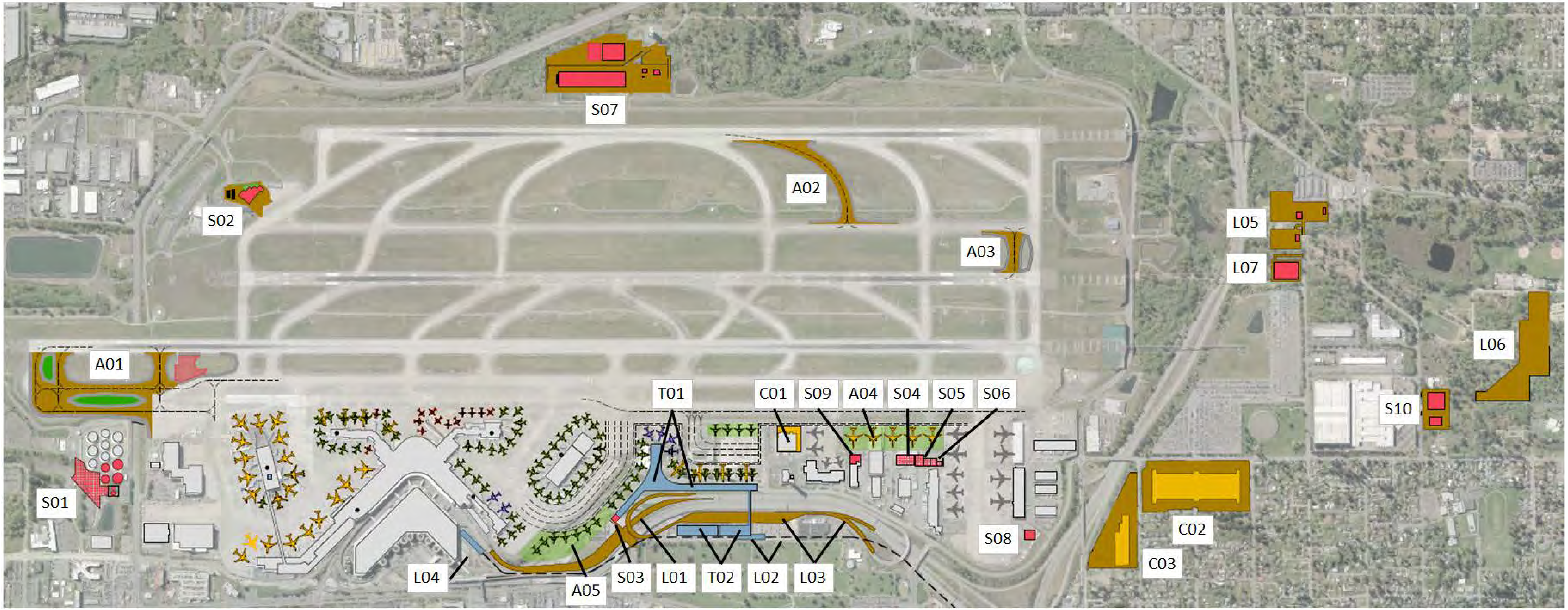
To meet the Airport's facility needs through 2027, the Port identified the Near-Term Projects, shown in Figure 4-1, which are intended to accommodate an estimated 56 million annual passengers and approximately 477,660 annual aircraft operations. The year 2027 corresponds to when substantial gate, hardstand, and terminal space is estimated to become operational with specific improvements included in the Near-Term Projects. Later sections of this chapter identify IOAs that the Port could voluntarily implement to complement the Near-Term Projects, and in many cases, could implement independently to fill the gap relative to the sustainability goals and objectives.

With completion of the Near-Term Projects, Sea-Tac would have an additional 19 narrow-body equivalent aircraft gates connected to a second terminal via a pedestrian bridge over the North Airport Expressway, and cargo warehouse redevelopment and expansion adjacent to the airfield. Airfield projects include taxiway modifications (a 34L high speed taxiway exit, Taxiway D extension, and Taxiway A/B extension) to increase operational efficiency and the creation of new hardstands for passenger and cargo operations. The Near-Term Projects also include landside improvements to provide access to the Second Terminal; connectivity between the Rental Car Facility, Second Terminal and Main Terminal; expanded employee parking; and expanded ground transportation holding lots. Airport/airline support facility projects in the Near-Term Projects primarily replace facilities displaced by passenger and cargo facility development, except for a Centralized Receiving and Distribution Center (a security and operational efficiency project) and expansion of the Fuel Farm. On the west side of the airfield, a campus would be developed to house airport maintenance.

Projects shown in Figure 4-1 include:

- A01 – Taxiway A/B Extension –This project would relocate Taxiway B south of Taxiway S and provide a new parallel taxiway, Taxiway A.
- A02 – Runway 16R-34L Blast Pads –The existing blast pads on RWY 16R-34L would be expanded to standard 220'x400' size.
- A03 – Taxiway L Relocation *(a current planned project expected to be completed in 2018)* –Taxiway L would shift approximately 400' to the south.
- A04 – Taxiway B 500' Separation North –Taxiway B would be moved 100' to the east.
- A05 – Runway 34L High-speed Exit – High-speed exits allow landing aircraft to exit the runway at relatively higher speeds, leading to less time on the runway.
- A06 – Taxiway D Extension –This project would extend Taxiway D from Runway 16C-34C west to Taxiway T.
- A07 – Hardstand *(north)* –The hardstand would accommodate 5 aircraft.

Figure 4-1
Near-Term Projects
Seattle-Tacoma International Airport



Airside

A01 Taxiway A/B Extension
A02 Runway 34L Highspeed Exit
A03 Taxiway D Extension
A04 North Harstand
A05 Concourse D Hardstand

Terminal

T01 North Gates
T02 North Terminal & Parking

Cargo

C01 Cargo 4 South Redevelopment
C02 Off-Site Cargo *Ph 1 (L-Shape)*
C03 Off-Site Cargo *Ph 2 (L-Shape)*

Landside

L01 NAE Relocation *(southbound lanes)*
L02 Elevated Busway & Stations
L03 North Terminal Roads/Curbside
L04 Main Terminal North GT Lot
L05 North GT Holding Lot
L06 Employe Parking Surface Lot
L07 Employee Parking Structure

Airport/Airline Support

S01 Fuel Farm Expansion
S02 Primary ARFF
S03 Secondary ARFF
S04 Fuel Rack Relocation
S05 Triculator
S06 Consolidated De-icing Facility
S07 Port Maint. *(Westside Maint. Campus)*
S08 Airline Support *(north)*
S09 Airline Support *(west)*
S10 Centralized Rec. & Dist. Center

Source: Port of Seattle and LeighFisher, 2017.

- A08 – Hardstand *(central)* –The hardstand would serve 7 aircraft.

- A09 – Taxiway Fillets [*NOT SHOWN]* –Fillets which currently do not meet standards would be improved when the fillet/area needs a reconstruction or impacted by a project.

- A10 – Taxiway Q Hot Spot/Runway Incursion Mitigation (HS/RIM) *(a current planned project expected to be completed in 2018) [NOT SHOWN]* – Adjustments would be made to the Taxiway Q centerline paint markings and in-pavement taxiway centerline lights.

- T01 – North Gates – The North Gates project would be a multi-level concourse connected to the Second Terminal via a pedestrian bridge and would serve 19 gates.

- T02 – Second Terminal & Parking –The Second Terminal would include facilities for passenger check-in; passenger and baggage screening; airline offices, baggage conveyance and claim; concessions; and restrooms.

- C01 – Cargo 4 South Redevelopment –The Cargo 4 South site would be redeveloped to maximize warehouse capacity.

- C02 – Off-site Cargo Phase 1 *(L-Shape)* – would include a 330,000-sf building with warehouse and office space, truck terminals, and parking for visitors and employees.

- C03 – Off-site Cargo Phase 2 *(L-Shape)* – would include a 90,000-sf building with warehouse and office space, truck terminals and parking for visitors and employees.

- L01 – North Airport Expressway (NAE) Relocation *(southbound lanes)* –The reconstructed southbound lanes would include the same number of lanes as exist today and would result in the elimination of the cell phone waiting lot as well as Air Cargo Road and associated on/off ramps south of Gate E125 and air traffic control tower.

- L02 – Elevated Busway & Stations –This project would provide a connection for passengers accessing the Main Terminal, Second Terminal, and Rental Car Facility (RCF). The Main Terminal busway station would be at level 4 at the north end of the existing Main Parking garage and over the Main Terminal North Ground Transportation (GT) lot.

- L03 – Second Terminal Roads & Curbside – Landside improvements are required to provide ingress/egress to the Second Terminal and to connect the existing roadway system, providing access to/from the existing Main Terminal.

- L04 – Main Terminal North Ground Transportation (GT) Lot – Expansion of the existing lot to accommodate increased demand of charter and cruise passenger buses.

- L05 – North Ground Transportation (GT) Lot – A new GT lot is needed to replace the S 160th St. GT lot displaced by the Elevated Busway.

- L06 – Employee Parking Surface Lot –A new 1,500 stall employee parking surface lot would be constructed on Port owned property north of SR 518.

- L07 – Employee Parking Structure –A new parking structure of up to 2,000 stalls would be constructed on Port property adjacent to and west of the North Employee Parking Lot.

- S01 - Fuel Farm Expansion – Expansion of the fuel farm would include additional settling tank capacity and infrastructure to support the Port's sustainable aviation fuel (SAF) initiative.

- S02 – Primary Aircraft Rescue and Firefighting (ARFF) station – Relocation of the Primary ARFF station from its current location in the Cargo 6 area is required to clear the site for construction of T01 North Gates.

- S03 – Secondary ARFF –With the relocation of the Primary ARFF station, a Secondary ARFF is needed to provide ambulatory response to the Terminals and Concourses; fuel spill and fire response to the concourse ramp areas, and back-up emergency response to the airfield.

- S04 – Fuel Rack Relocation – Relocation of the fuel rack from its current location in the Cargo 6 area is required to clear the site for construction of T01 North Gates.

- S05 – Triculator –To facilitate the A08 Hardstand *(central)* project, the triculator (a waste grinder) would be relocated to the North Cargo area east of the new A07 Hardstand *(north)*.

- S06 – Consolidated De-icing Fluid Storage Tanks – In an effort to consolidate storage of aircraft deicing fluid and to clear a site for the construction of T01 North Gates, deicing fluid tanks are proposed on both the north and south ends of the airfield.

- S07 – West-side Maintenance Campus – Relocation of the Port's Aviation Maintenance Facility from its current location in the North Cargo area to clear the site for construction of the A07 Hardstand *(north*) project.

- S08 – Airline Support *(north)* & S09 – Airline Support *(west)* – To accommodate displaced Ground Service Equipment (GSE) maintenance and aircraft maintenance functions from the United Airlines maintenance building and Swissport cargo facility, and aircraft maintenance functions from the United Airlines maintenance building, two airline support buildings/expansions are planned.

- S10 – Centralized Receiving & Distribution Center (CRDC) – A new CRDC is needed to improve security and more efficiently screen and move supplies to concessionaires in the current and future passenger terminals.

These projects are described in greater detail in SAMP *Technical Memorandum 7 Facilities Implementation and Financial Feasibility.*

During the screening of SAMP alternatives, the Port tested an approach to integrating sustainability into determining the location of new facilities, or the "what/where we build" part of the SAMP process. In this approach, the Port adjusted the screening process for selecting airport layout concepts by adding sustainability issues such as reducing impacts to wetlands, and proximity to noise and light sensitive land uses to its list of screening criteria. As documented in *Technical Memorandum No. 5 Facility Requirements and Alternatives,* concepts for satisfying the needs of major functional areas of the Airport were screened against criteria related to the triple bottom line. Table 4-1 illustrates how the triple bottom line was considered in screening 10 different terminal concepts.

Table 4-1
Example Terminal Alternative Screening Using Sustainability Criteria
Seattle-Tacoma International Airport

ROUND TWO SCREENING RESULTS
Seattle-Tacoma International Airport

Criteria	Concept									
	1A	2A	4A	5A	6A	1B	4B	6B	9B	10B
Taxiway operations	-1	-1	-1	1	-1	-1	1	0	-1	1
Passenger convenience	0	1	-1	-1	0	-1	0	-1	0	1
Incremental expansion	-1	-1	-1	0	-1	-1	-1	-1	-1	0
Constructability	-1	-1	0	1	0	1	1	1	0	1
Flexibility to assign gates	0	1	0	-1	0	1	0	0	0	-1
Ease of adding international gates	1	1	-1	-1	1	-1	1	-1	1	1
Ability to add gates quickly	1	-1	1	1	1	1	-1	-1	1	1
Reduced taxi/idle/delay	-1	-1	-1	1	-1	-1	1	-1	-1	0
Impact on wetlands/creeks	0	0	0	0	0	0	-1	-1	0	0
Limits addition of impervious surfaces	0	0	0	0	0	0	-1	-1	0	0
Proximity to noise and light sensitive land uses	0	0	0	0	0	0	-1	-1	0	0
Consistency With Zoning	0	0	0	0	0	0	-1	-1	0	0
Score summary	-2	-2	-4	1	-1	-2	-2	-8	-1	4

-1 poor/undesrable
1 good
0 neutral

Source: *Technical Memorandum No. 5 Requirements and Alternatives*, LeighFisher and Synergy Consultants.

The first seven rows of the matrix indicate how the terminal concepts were screened against criteria related to financial and operational goals and objectives (shown in blue). The next three rows of the matrix indicate how the terminal concepts were screened against criteria associated with environmental goals and objectives, and the final two rows of the matrix indicate how the terminal concepts were screened against criteria related to social and community outreach goals and objectives. At each stage of the screening, criteria for all goals were considered. Only those that would enable a scoring that differentiated among alternatives were used; if criteria would score the same across all alternatives, they were not considered as their inclusion would not alter the screening process.

The Port also tested an approach to including a number of sustainability attributes in selecting among two main airport layout alternatives: a two-terminal option versus a one-terminal option. The two-terminal option was selected for inclusion in the SAMP Long Term Development Vision over the one-terminal option largely because of sustainability goals and objectives. In addition, the terminal development reflected in the Near-Term Projects reflects gates and terminal space that would be needed in the near-term within the context of the Long-Term Development Vision.

SAMP Task 6.12 described the evaluation of the one-terminal concept versus the two-terminal concept relative to sustainable construction (documented in Appendix A *Task 6.12 Report - Total Cost of Ownership*). The two-terminal concept was selected because:

- Total construction cost would be less although the draft Task 6.12 analysis, documented in Appendix A, suggests that the total cost of ownership, as evaluated at a concept level, could be greater with two terminals versus a single terminal.
- Risk (e.g., risk related to construction cost and the ability to efficiently accommodate future activity) would be less.
- Flexibility (e.g., flexibility related to airline assignments and load balancing) would be greater.
- Phasing and constructability would be greatly simplified.
- Passenger level of service, both during and after construction, would be greater.

The Near-Term Projects shown in Figure 4-1 illustrates the cargo facilities identified to try to meet the SAMP forecasts of air cargo activity through 2027, discussed in Chapter 2 *Sustainability Vision and Goals/Objectives*. The Port Commission's Century Agenda establishes a goal for air cargo activity that exceeds the SAMP 20-year forecast. Therefore, the facility requirements associated with the Century Agenda goal are greater than the requirements associated with the SAMP forecasts and would require sacrifices in meeting other demands (such as passenger processing) if the development goal of not acquiring land were maintained. As in satisfying policies and goals, future tradeoffs would be required to achieve the Century Agenda cargo goal. For purposes of the SAMP, focus was on satisfying forecast natural demand and increasing facilities' efficiency.

The risks to achieving the Port's financial and operational efficiency goals and objectives involve:

- Time needed to plan, engineer, and construct facilities and infrastructure and the potential inability to bring on new or renovated facilities as quickly as needed to satisfy demand

- Time needed to gain support from key airport tenants
- Limited supply of developable Airport land
- Cost of facilities
- Fluctuations in aviation demand or unexpected changes in activity
- Changes in fundamental industry operations, programs, and policies (e.g., changes related to security or regulations)
- National economic conditions
- Adverse effects of climate change as discussed in Chapter 6 of this Technical Memorandum

In general, the development recommendations of the SAMP are designed to improve operational efficiency, accommodate regional air travel demand, and in the near-term timeframe achieve the overall goals and objectives of the Century Agenda, Long Range Plan, and Port Aviation Division Priorities. Before these recommendations can be implemented, they must first be reviewed and approved under both the Washington State Environmental Policy Act as well as National Environmental Policy Act and undergo engineering and design.

In the sections that follow, opportunities that new facilities would afford relative to the Port's goals and objectives are discussed. The sections are organized according to the triple bottom line categories.

4.2 Evaluating IOAs to Address Financial and Operational Goals and Objectives

This section identifies IOAs that contribute toward addressing financial and operational goals and objectives, which were described in Chapter 1 and 2 of this Technical Memorandum.

4.2.1 Gaps to be Filled to Address Financial-Operational Efficiency Goals and Objectives

Most of the goals associated with the financial-operational efficiency focus categories are expected to be addressed by the SAMP development recommendations, as discussed later or through implementation of specific strategies (IOAs) reflected in the Port's 2015 Aviation Business Plan and 2018 Priorities. In the case of financial and operational goals and objectives, the specific metrics for this part of the triple bottom line were grouped into seven (7) categories. To evaluate the gaps, these categories are used, as noted in Chapter 2, as:

1. **Airport Activity**. The forecast of aviation demand identifies the anticipated growth in activity at Sea-Tac. The Near-Term Projects would serve existing demand and near-term passenger growth by providing: airfield modifications, additional gates, other terminal facilities, and landside improvements such as modified/expanded access and circulation. However, Technical Memorandum No. 7 notes that existing airfield/airspace constraints are estimated to result in severe congestion and aircraft delays as activity approaches 15-year forecast demand (forecast to occur in 2029). Given these constraints, improvements depicted in the SAMP Long-Term

Development Vision that are not included in the Near-Term Projects will be subject to further study.

2. **Operational Efficiency and Performance Metrics**. The SAMP identified several facility deficiencies (discussed in other Technical Memoranda) that affect the operational efficiency and performance of the Airport. The need for gates helps drive the metrics related to on-time departures, taxi-out and taxi-in, aircraft departure delays, and aircraft arrival delays. By fulfilling the Near-Term Projects, the operational efficiencies through 2027 would largely be achieved, though average delays would increase relative to existing conditions. In addition, the proposed Near-Term Projects would minimize automobile dwell time at the curbs, efficiently accommodate roadway demand, and enable the Port to increase parking revenue by ensuring an adequate supply of public parking. Efficiency/performance metrics related to safe airfield operation (such as accidents/incidents and incursions) are related to a variety of factors beyond the scope of this evaluation; however, the SAMP Near-Term airfield projects would increase operational efficiency and help address these issues relative to the business-as-usual.

3. **Financial Metrics**. The Port estimated the potential financial impacts associated with the Near-term Projects.* The analysis considered estimated ongoing and future capital expenditures, future cost per enplanement (CPE), and estimated debt, among other factors. These estimates were compared to what were considered reasonable future financial metrics such as maintaining CPE within a "competitive" range.

   The analysis indicates that, with vigilant cost management and other measures, the Port could complete the Near-Term Projects and still meet the future financial metrics. Therefore, there are no major gaps with respect to the financial metrics determined at this time.

   However, continued escalation in construction costs, potential fluctuations in future demand, and the potential added costs of implementing sustainability initiatives could all affect the Airport's ability to achieve the future targets. Port staff continue to monitor these issues, and the "financial framing" of sustainability implementation is a key consideration for the implementation plan presented in Chapter 5 of this Technical Memorandum.

4. **Facility Space and Condition Metrics**. The SAMP identifies several facility deficiencies (discussed in other Technical Memoranda). By fulfilling the Near-Term Projects, the facility space needs within the near-term would largely be achieved. Recent projects and projects under construction will help to address facility age issues by providing updated electrical and mechanical systems.

5. **Survey Metrics**. At this time, it is not possible to identify survey metric gaps. However, it is anticipated that additional surveys would be completed in the future to facilitate engineering and design of the terminal facilities, and Port staff coordination would be needed to ensure the connection between sustainability data needs and survey instruments/data collection.

*Memo To: Stephen P. Metruck, Executive Director From: Lance Lyttle, Aviation Managing Director, Borgan Anderson, Director, Aviation Finance & Budget. Re: *Airport financial forecast, including impacts of Sustainable Airport Master Plan projects.* Commission Briefing, May 8, 2018.

6. **Derivative Metrics**. As additional data collection occurs, it is anticipated that derivative metric data will be generated.

7. **Project Metrics**. As refinements occur to the Near-Term Projects in the engineering and design process, it is expected that project metrics may be identified. Thus, at this time, it is not possible to identify project specific metric gaps.

4.2.2 Specific Financial-Operational Efficiency IOAs

This section discusses the IOAs focused on the financial and operational efficiency goals and objectives. In this category, most of the IOAs are strategies noted in the Port's 2015 Business Plan or 2018 Priorities.

Goal/Objective: Enable the Port to achieve its business plan financial goals relative to cost per enplaned passenger (CPE) and debt per enplaned passenger (DPE)

To enable the Port to achieve its financial goals in the business plan relative to CPE and DPE, the Near-Term Projects incorporate the following key opportunities:

- Enable phased, incremental development.
- Employ maximum use of technology and enhanced processes to minimize the amount of new development.
- Provide revenue-generating space in the terminal facilities in accordance with Port guidelines.

In addition, the Port will need to monitor peer airport CPE annually to ensure that Sea-Tac Airport's CPE is competitive with the CPEs peer airports. The Port routinely follows these additional IOAs:

- Consistently measure budget proposals and capital budget plans against CPE and DPE.
- Annually, set capital budget limits so that total five-year capital spending does not cause forecast CPE to exceed established CPE targets.

Goal/Objective: Minimize the effect of SAMP recommendations on cost center rate imbalances

This goal was identified as important: given that the Sea-Tac Airport lease agreement structure is based on cost center rates, an imbalance would affect the Port's ability to afford certain types of future development. Strategies designed to satisfy this goal will require further financial analysis related to the final SAMP Long-Term Vision development. Strategies to address this part of the Triple Bottom Line are reflected in SAMP *Technical Memorandum 7 Facilities Implementation and Financial Feasibility*.

Goal/Objective: Reduce dwell time on the curb front and increase throughput to efficiently accommodate roadway demand

Measures to improve operation of the terminal curb fronts are listed elsewhere in this chapter such as the Transportation category in Section 4.3.2. In addition, the Port will need to provide efficient cruise ship bus interfaces to ensure that the curbfront does not become further congested.

Section 4.3 discusses several additional transportation IOAs that are designed to increase the use of environmentally preferred modes of transportation. In general, these modes of transportation would also reduce congestion on area roadways, thus improving efficiency.

Goal/Objective: Minimize aircraft taxi time and reduce airfield congestion associated with ground vehicles

The Near-Term Projects would afford opportunities to implement facilities planned to reduce runway crossings, reduce runway occupancy times, enhance the efficiency of ground vehicle movements, provide for efficient aircraft de-icing, and provide efficient off-gate aircraft parking to accommodate remain overnight aircraft and aircraft awaiting gates.

In addition, the Port has identified the following actions related to airfield efficiency as part of its 2015 Business Plan:

- Develop a Surface Area Management System.
- Develop aircraft departure sequencing process vs. FAA First Come, First Serve model.
- Expand airfield drivers training.
- Automate ramp insurance validation at airfield access points.
- Install automated gate docking system and gate operating system.

Goal/Objective: Satisfy the demand for air cargo in a manner that strives to consolidate cargo areas while minimizing congestion associated with the landside interfaces

The cargo development reflected in the Near-Term Projects assumes that two cargo sites are necessary in the long term because the southern boundary of the north cargo area cannot extend much beyond its existing location due to passenger terminal expansion.

Key cargo-related IOAs include:

- A revised business model designed to reduce the number of relatively small and inefficient cargo facilities and enhance productivity
- The allocation of sufficient space to permit efficient landside operations for accessing the facility and enabling parking for cargo trucks

In addition, the Port's 2015 Business Plan identified several actions, such as:

- Develop new airside cargo building capacity sufficient to accommodate market growth and the relocation needs of existing facilities, consistent with the SAMP.
- Consistent with the Port's goals and objectives regarding increasing non-aeronautical revenue to reduce CPE, develop leasable off-airport warehouse and logistics support facilities.

Goal/Objective: Maximize efficient passenger and baggage movement throughout the passenger's trip through Sea-Tac Airport

The passenger terminal element of the Near-Term Projects was carefully planned to incorporate IOAs to maximize (1) efficient passenger and baggage movements through the Airport, and (2) passenger level-of-service at all functions. The key feature of the Near-Term Projects related to efficiency and service is the second passenger terminal, which affords the opportunity to off load demand to an appropriately-sized, state-of-the-art, facility and then revitalize the existing terminal so that it can deliver similar efficiency and service to an appropriate level of passenger activity. The passenger terminal concept included in the Near-Term Projects and Long-Term Development Vision is fully described in SAMP *Technical Memorandum 7 Facilities Implementation and Financial Feasibility.*

4.3 Evaluating IOAs to Address Environmental Goals and Objectives

This section identifies IOAs relative to environmental goals and objectives.

4.3.1 Gaps to be Filled to Address Environmental Goals and Objectives

This section documents the estimated gaps for each of the environmental sustainability focus areas. The following subsections briefly discuss the gaps between the Port's established goals/objectives and the baseline conditions for each environmental focus area. Anticipated future conditions have not been estimated for this analysis; information on future environmental conditions is expected to be provided through the SAMP environmental review process, and can be used to refine and better understand estimated gaps.

4.3.1.1 Air Quality and Climate Protection

Goal/Objective: **Reduce air pollutant emissions by 50 percent from 2005 levels by 2037.**

Gap: Table 4-2 compares the results presented in Chapter 3 to identify the reduction needed (based on 2016 numbers) to achieve the goal/objective of a 50% reduction in criteria pollutants relative to 2005 levels. Note that an emissions inventory for 2005 is not available. Therefore, the gap was calculated relative to the Comprehensive Development Plan (CDP) EA baseline condition (year 2004).

The "Emissions at Approx Goal/Target" represent 50% of the 2004 emissions, which approximates the goal. Then, the "Gap" represents the difference between 2016 emissions and the goal, listed as total ton reduction of each pollutant. As the table below shows, reductions are needed (based on 2016 conditions) to meet the Port goals for almost all of the criteria pollutants.

Table 4-2
Gap in Achieving Criteria Pollutant Emissions Target
Seattle-Tacoma International Airport

Emission Source	Tons per year					
	NO_X	VOC	CO	SO_X	PM_{10}	$PM_{2.5}$
2004 Total (CDP EA Baseline)	1,860	610	12,010	140	30	30
2016 Total	2,267	379	4,481	190	48	47
Emissions at Approx Goal/Target (50% from 2004)	930	300	6,010	70	20	20
GAP	1,337	79	(1,529)	120	28	27

Source: Synergy Consultants, March 2018 using data from Table 3-2, rounded to the nearest 10 tons.

The major sources of air pollution for all six criteria pollutants in the table above are aircraft engines and ground support equipment (GSE).

***Goal/Objective*: Reduce Airport-owned and controlled greenhouse gas emissions by 15% below 2005 levels by 2020, 50% by 2030, and to carbon neutral or negative levels by 2050.**

Gap: A greenhouse gas inventory has not been prepared for 2005. However, the Port's 2006 inventory could be used as a surrogate. Table 4-3 shows the Scope 1 and 2 emissions by year. The Target 15% and Target 50% identify the reduction in 2006 emissions that would achieve the goal. The "gap" shows the reductions needed (based on 2016 emissions) to achieve the targets. As shown, substantial reductions are needed to meet both targets. Scope 1 and 2 greenhouse gas emissions are heavily influenced by the source and extent of building energy use.

Table 4-3
Gap in Achieving Scope 1 and 2
Seattle-Tacoma International Airport

	MT CO2e/yr
2006 (Reference year)	21,500
2016 (Existing)	21,320
2020 Target (15% re: 2006 MT)	18,280
2030 Target (50% re: 2006 MT)	10,750
GAP: 2020 Target	3,040
GAP: 2030 Target	10,750

***Goal/Objective*: Scope 3 emissions are emissions the Port has influence over, not direct control. The Port-wide goals for Scope 3 emissions are: 50% below 2007 levels by 2030, and 80% below 2007 levels by 2050.**

Gap: Table 4-4 identifies the 2006 emissions from an earlier Port greenhouse gas inventory for only Scope 3 sources (nearly 794,260 metric tons); 2007 emissions are not available. The Port's 2016 ACA Scope 3 emissions were about 682,440 metric tons. Aircraft operations are the dominant Scope 3 source at 60% of the emissions. As the table notes, comparison of 2016 Scope 3 emissions with the future targets shows that existing emissions exceed the targets substantially.

Table 4-4
Gap in Achieving Scope 3
Greenhouse Gas Emission Targets
Seattle-Tacoma International Airport

	MT CO2e/yr
2006 (Reference year)	794,260
2016 (Existing)	682,440
2030 Target (50% of 2006 MT)	397,130
2050 Target (80% of 2006 MT)	158,850
GAP: 2030 Target	285,310
GAP: 2050 Target	523,590

***Goal/Objective*: Complete a risk analysis of potential climate change impacts and implications for Sea-Tac Airport and develop a strategic plan for avoiding/mitigating risks.**

Gap: With the completion of the Chapter 6 *Climate Change and Infrastructure Risk Analysis* in this Technical Memorandum, this goal would be met. Although this goal would be met, IOAs are identified for this goal in the subsequent section.

4.3.1.2 Buildings and Infrastructure

***Goal/Objective*: Seek LEED Silver for new construction, additions, and major renovations and minor renovations that modify mechanical, electrical, and plumbing systems, and encourage LEED certification for tenant improvements.**

Gap: At the time of this analysis, the Port owned approximately 1,855,000 square feet of space that is LEED certified under the Building Design + Construction (BD+C) system. The Port is pursuing LEED certification (with a goal of Silver) for the International Arrivals Facility (450,000 square feet), NorthSTAR (181,000 square feet), and Concourse D Hardstand Holdroom (32,500 square feet) projects, all under construction. If these three projects achieve LEED certification, total Port-owned LEED-certified space would increase by 35% achieving this building and infrastructure goal.

On an ongoing basis, the Port is pursuing LEED "Master Site" credits that can be applied to all eligible projects, making it easier to achieve LEED certification for future construction. In addition to LEED BD+C, the U.S. Green Building Council maintains a certification program for building operations and maintenance, LEED O+M. The Port does not have any specific goals related to O+M certification, and at this time, there are no LEED O+M-certified buildings at the Airport.

4.3.1.3 Energy

***Goal/Objective*: Meet all increased energy needs through conservation and/or renewables.**

Gap: Table 4-5 summarizes energy use in 2014 (the reference year) and 2016, and identifies reductions needed to meet the goal. In most categories, energy use in 2016 was lower than in 2014, indicating that at the present, reductions are not needed. However, continued efforts to reduce energy use are needed for the following reasons:

- Given the relationship of energy use to weather, data for one year cannot be considered representative.
- Energy use directly related to operational activity (unleaded gasoline and diesel) is expected to increase over time.
- Although this analysis does not include future energy use associated with the Near-Term Projects, in the absence of specific project design details, it is reasonable to assume that energy use will increase.
- The 2016 numbers do not include energy use for the projects under construction.

Table 4-5
Gap in Achieving Energy Consumption Target
Seattle-Tacoma International Airport

Year	Electricity (MWh/year)	Natural Gas (therms)	Unleaded Gasoline (gallons)	Diesel (gallons)	CNG (gal equiv)
2014 (reference year)	112,030	2.8 million	121,800	25,970	366,480
2016 Actual	112,250	2.6 million	119,300	27,090	362,970
GAP	220	0	0	1,120	0

All numbers rounded to the nearest 100 units of energy

Source: Synergy Consultants, March 2018.

4.3.1.4 Fish and Wildlife

***Goal/Objective*: Protect, enhance, and steward fish and wildlife habitat while maintaining air transportation safety.**

Gap: The metrics associated with fish and wildlife are associated with specific project effects. Therefore, once the specific effects of future projects are identified, the ability to achieve the fish and wildlife goals/objectives will be reviewed.

4.3.1.5 Noise

***Goal/Objective*: Increase the number of noise compatible units within the noise remedy boundary to 95 percent through the year 2030.**

Gap: Based on the estimated noise exposure in the 2014 Part 150 Study, and the number of units in the Noise Remedy Program boundary that still need sound insulation, noise-compatible units represent approximately 27 percent of the total units within the noise remedy boundary. Therefore, continued efforts are needed to meet the Port goal, and are described in Section 4.3.2 below.

4.3.1.6 Transportation

***Goal/Objective*: Reduce the greenhouse gas emissions associated with passenger and employee transportation to and from Seattle-Tacoma International Airport by decreasing the emission intensity* of the travel modes and increasing the proportion of trips made using environmentally preferred modes.**

Gap: In 2014, approximately 60% of passengers traveling to Sea-Tac were using environmentally-preferred modes. This includes taking a taxi/TNC, transit, door-to-door shuttle, rental car, or driving directly to the Airport and parking in the parking garage for the duration of their trip. The most recent passenger survey for mode share, conducted in 2016, shows that number declining to approximately 56% reporting using an environmentally-preferred mode to access the Airport. Therefore, increasing ridership on environmentally preferable modes would require the implementation of additional strategies.

4.3.1.7 Waste Management

***Goal/Objective*: Divert to recycling 85% of construction waste by 2020, 90% by 2025, and reach zero waste by 2035.**

Gap: A construction waste gap was not calculated, as the ability to recycle construction waste is based on the specifics of a project being constructed. Table 3-15 in Chapter 3 notes that the Port achieved the 2020 and 2025 goals in 2014 and 2016 (91% to 100% of construction waste diverted) but fell short of the goal in 2015 based on the terminal construction diversion. Zero waste, associated with the 2035

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*Emission Intensity is a measurement the emissions of a travel mode divided by the number of passengers it conveys. It represents the emission-efficiency of a travel mode.

goal would require a slight improvement over actual 2014 levels in the terminal, airfield, and landside; if 2016 diversion levels can be maintained, the Port will essentially meet the goal.

***Goal/Objective*: Reduce the volume of hazardous waste generated from Port maintenance and operations to meet requirements for Small Quantity Generator Status by 2020.**

Gap: Table 3-14 in Chapter 3 shows that hazardous waste generation ranged between 0.53 tons and 1.34 tons over the 2014-2016 period. The threshold for a small quantity generator is 1,000 kilograms or less a month, or 12,000 kilograms per year; 12,000 kilograms is 1.1 ton per month or 13.2 tons per year. Thus, the Port is already meeting the Small Quantity Generator goal. However, in keeping with objectives of continued environmental improvement, IOAs were identified to address hazardous waste.

***Goal/Objective*: Divert 60% of terminal solid waste and 15% of airfield solid waste by 2020.**

Gap: Table 4-6 identifies the existing MSW. For the terminal and airfield, substantial increases in recycling are needed to meet the Port targets. Extensive recycling efforts for the terminal and airfield have not achieved continued increases in the recycling rate, and creative solutions will need to be found to make progress toward the goal.

Table 4-6
Gap in Achieving Waste Targets
Seattle-Tacoma International Airport

Year	Annual Terminal MSW Generation (Tons/Year)	Terminal Recycling Rate	Terminal Waste Recycled (Tons/Yr)	Annual Airfield MSW Generation (Tons/Year)	Airfield Recycling Rate	Airfield Waste Recycled (Tons/Yr)
2016 (Existing)	7,328	32%	2,345	2,855	9%	257
2020 Target		60%	4,400		15%	430
GAP			2,055			173

Source: Synergy Consultants, March 2018

4.3.1.8 Water Conservation

***Goal/Objective*: Reduce projected future consumption by 4% over 2008 levels in 2020 and 12% in 2030.**

Gap: In 2008, Airport activity consumed about 227.5 million gallons of water; therefore, the 2020 target is 218.4 million gallons and the 2030 target is 200.2 million gallons. Table 4-7 summarizes existing water consumption and identifies reductions needed (relative to 2016 levels) to meet Port targets. As shown, substantial reductions are needed.

Table 4-7
Gap in Achieving Potable Water Use Target
Seattle-Tacoma International Airport

Year	Annual Potable Water Consumption (MG/Year)
2008 (reference year)	227.5
2014 (Existing)	229.0
2016 (Existing)	243.7
2020 Target (4% reduction from 2008)	218.4
2030 Target (12% reduction from 2008)	200.2
GAP: 2020 Target	25.3
GAP: 2030 Target	43.5

MG = Million gallons

Source: Synergy Consultants, Inc., March 2018

4.3.1.9 Water Quality

***Goal/Objective*: Contribute to the restoration of Puget Sound and local receiving waters by providing water quality treatment, flow control, and using green storm water infrastructure (where feasible) for Airport industrial storm water.**

Gap: The Airport currently meets the Port goal. As projects and IOAs, are implemented, however there are opportunities noted below to contribute to the restoration of receiving waters.

4.3.2 Specific Environmental IOAs

This section discusses the IOAs focused on the environmental goals and objectives. Many of these measures are already being implemented by the Port. Other IOAs noted here are suggested means for helping to meet Port sustainability goals. These goals, as well as any Port decisions to adopt or implement IOAs are voluntary.

***Goal*: Reduce air pollutant emissions by 50% from 2005 levels by 2037.**

As noted in Chapter 3, the greatest contributors to most of the air pollutant categories are aircraft engines and ground support equipment. The following candidate air quality IOAs were identified by emission source:

Aircraft engine sources

- Further evaluate adding End-Around Taxi-ways (EATs) to reduce taxi-idle delays. As part of the next phase of planning after the SAMP, it is expected that the Port will identify airfield improvements that would help to reduce ground-movement delays, such as EATs.

- Develop & enforce policy for optimal use of electric preconditioned air (PCA) and ground power unit (GPU) systems.
- Continue to ensure installation and availability of electric preconditioned air (PCA) and ground power unit (GPU) systems at all new and existing gates.
- Educate airline ground staff on use of electric PCA and GPU systems.
- Work with airlines and other partners to develop and implement a strategic plan for the introduction and use of sustainable aviation fuels (SAF) at the Airport.

Ground Support Equipment sources

- Install new electric ground support (eGSE) infrastructure as new gates are developed.
- Continue to install eGSE infrastructure at Concourses A, B, and the South Satellite.
- Work with airlines and other partners to promote replacement of fossil-fueled GSE with eGSE.

Ground Transportation sources

- Improve public transportation information displays and signage at baggage claim, ticketing, and parking garage for Link Light Rail.
- Provide convenient access for using public transit including bus routes and link light rail originating at Sea-Tac.
- Install additional electric vehicle (EV) charging stations in the Sea-Tac Airport garage and encourage passengers to use electric vehicles and EV charging stations when traveling to/from the Airport.
- Research and promote car-sharing programs for passengers traveling to and from the Airport, particularly those using zero emission or low-emission vehicles. These programs reduce dead-heading and encourage the use of clean vehicles.
- Develop partnerships with transit agencies and develop strategies to improve the frequency and efficiency of public transit services to the Airport.
- Continue to develop strategies to provide direct bussing service from economic centers such as downtown Seattle and Bellevue to and from the Airport.

The extent to which these measures would reduce air pollutant emissions is not known at this time. The benefits of any individual IOA would be a function of the breadth of its implementation. Of the potential IOAs noted, the measures that could have the greatest benefit are the end around taxiways and maximum conversion of GSE to electric. The end-around taxiways would reduce emissions from aircraft, a dominant source of emissions of most pollutants. Maximum conversion of GSE would address another dominant source, but in turn, would increase electrical consumption. Many of the above IOAs would also result in reduced greenhouse gas emissions or increase the public use of environmental friendly modes of transportation.

***Goal*: Reduce Scope 1 and 2 greenhouse gas emissions by 15% below 2005 levels by 2020, and 50% by 2030.**

The following IOAs could assist the Port with reducing greenhouse gas emissions from sources owned and controlled by the Port:

- Develop an Energy Management Plan that identifies key energy users, any possible energy type conversions (e.g., electric to natural gas, or vice versa), and options available to reduce use.
- Identify and upgrade central plant and distribution equipment, including boilers, chillers, and other HVAC system components.
- Replace CNG with renewable natural gas in boilers and port-owned fleet vehicles.
- Convert unleaded gasoline vehicles to electric vehicles throughout the remaining port-owned fleet vehicles. Require use of biodiesel or renewable diesel in all remaining diesel vehicles in the fleet.

***Goal*: Reduce Scope 3 greenhouse gas emissions by 50% below 2007 levels by 2030 and 80% below 2007 levels by 2050.**

By definition, the Port has limited authority to control emissions from Scope 3 emission sources such as aircraft and ground support equipment. Ground transportation is also a major source of Scope 3 emissions and related IOAs are also identified in the Transportation section below. Several of the following IOAs would assist with reducing greenhouse gas emissions from aircraft operations, which represent 60% of the Scope 3 emissions. Estimates of potential emissions reductions are noted where available:

Aircraft engine sources

- Work with airlines and other partners to develop and implement a strategic plan for the introduction and use of sustainable aviation fuels (SAF) at the Airport
- Add end-around taxiways (EATs) to reduce taxi-idle delays.

Aircraft engine sources

- Continue to install electric ground support (eGSE) infrastructure at Concourses A, B, and the South Satellite and at all new gates.
- Develop & enforce policy for optimal use of electric preconditioned air (PCA) and ground power unit (GPU) systems.

Ground Transportation sources

- Research and promote car sharing programs for passengers traveling to and from the Airport, particularly those using zero emission or low emission vehicles. These programs reduce deadheading and encourage use of clean vehicles.
- Use high-fuel-economy taxis and high-environmental-performing TNCs.
- Install additional electric vehicle (EV) charging stations in the airport garage and encourage passengers to use electric vehicles and EV charging stations when traveling to and from the Airport.
- Toll Airport drives.
- Work with regional partners to develop a bus shuttle service from economic centers in such as downtown Seattle and Bellevue to provide service for passengers traveling to/from the Airport.
- Provide a convenient access for using public transit including bus routes and link light rail originating from Sea-Tac.
- Develop a Commute Trip Reduction action plan to enhance employee commute program.
- Improve public transportation information displays and schedules at baggage claim, ticketing and parking garage for Link Light Rail.
- Develop partnerships with transit agencies and develop strategies to improve the frequency and efficiency of public transit service to the Airport.
- Work with existing private shuttle companies to improve service to and from the Airport for passengers.
- Continue to explore opportunities for passengers to check baggage at off-site locations prior to their flight.

The extent to which these measures would reduce greenhouse gas emissions is not known at this time. The benefits of any individual IOA would be a function of the breadth of its implementation. Of the potential IOAs noted, the measures that could have the greatest benefit are the end-around taxiways and the implementation of SAF. Many of the above IOAs would also result in reduced criteria pollutants or increase the public use of environmental friendly modes of transportation.

Goal (Climate Adaptation): The Port's goal was to complete a risk analysis of potential climate change impacts and implications for Sea-Tac and develop a strategic plan for avoiding/mitigating risks.

- As part of the SAMP, this goal would be achieved. Chapter 6 *Climate Change and Infrastructure Risk Analysis* presents an initial screening analysis of the facilities and infrastructure that could be at risk with anticipated climate change effects. As is noted in that chapter, the science of evaluating climate change is evolving. Thus, the Port should continue to monitor changes in climate prediction and periodically reassess the effects of climate change on facility and infrastructure risk.

- Airports play an important part in regional recovery after extreme weather events. The Port could convene periodic working sessions with other regional agencies to identify regional plans for extreme event recover and how the parties can work together.

Goal (_Buildings and Infrastructure_; _B&I)_: The Port has an established policy of LEED certification for new construction and renovations, has used an objective of seeking LEED Silver for new construction, additions, and major renovations and minor renovations that modify mechanical, electrical, and plumbing systems, and encourages LEED certification for tenant improvements.

Through the certification of new and renovated facilities under LEED, the Port could see benefits across many of its operational, financial, environmental and social goals and objectives. Specific B&I IOAs are:

- Obtain LEED certification for North Satellite (NorthSTAR) renovation and expansion project.

- Obtain LEED certification for International Arrival Facilities (IAF) project.

- Obtain LEED certification for Concourse D Hardstand Holdroom project.

- Obtain USGBC Master Site designation, apply credits, and continue to work with USGBC to obtain additional Master Site credits.

- Assign team members to obtain a USGBC LEED professional accreditation to support future LEED certification projects.

- Collect & apply "lessons learned" from previous LEED certification projects.

All of the above measures would aid the Port in achieving its goals and objectives in the B&I category.

Goal (energy): Meet all future growth in energy through conservation and renewables.

As is noted in Chapter 3, the Port uses electricity, natural gas, unleaded gasoline, diesel, and CNG. Therefore, candidate IOAs were identified by fuel type. The following candidate IOAs could aid the Port in reducing its airport energy use or identify renewable sources to supplement existing sources. While many are somewhat similar and would have beneficial impacts on air quality and climate, each IOA is identified for purposes of enabling future consideration of the differences among the options. Those identified, by emission source, include:

All Fuels

- Prepare a Green Fleet Plan to replace Port vehicles with higher efficiency or electric vehicles.
- Focus on management and reduction of plug and process loads.
- Implement and improve current sub-metering strategies and focus energy efficiency improvements on areas with high energy use.
- Consider energy storage technologies
- Issue a request for proposal for the purchase of renewable natural gas (RNG).
- Conduct a renewable energy feasibility study to determine the design, size, type, location and cost of installing and operating an alternative renewable energy generation system.

Unleaded Gasoline

- Perform a study to determine the main consumer of unleaded gasoline at SEA and target initiatives that replace these vehicles with electrified and alternatively-fueled equipment.
- Use alternatively-fueled and/or hybrid construction equipment vehicles.
- Replace unleaded gasoline-powered grounds-keeping and construction equipment with electric equipment where practically feasible.
- Purchase, operate, and maintain alternatively-fueled, electric, and hybrid vehicles.

Diesel

- Replace diesel use with renewable diesel or biodiesel.
- Replace diesel-powered grounds-keeping and construction equipment with electric equipment where practically feasible.
- Use alternatively-fueled and/or hybrid construction equipment vehicles.
- Purchase, operate, and maintain alternatively-fueled, electric, and hybrid vehicles.

CNG

- Replace CNG for buses and light-duty vehicles with renewable natural gas or electric buses.

- Construct an Automated People Mover (APM) from terminal to consolidated rental car facility to reduce the use of CNG-powered buses.

Electricity

- Install evacuated tube solar collectors on rooftops of Concourses B and C to provide steam/hot water for the buildings' HVAC system.
- Install high efficiency water heaters in the HVAC system of Concourses B and C.
- Decouple only the heating plant and replace with high efficiency decentralized heating plants.
- Improve insulation of building envelope on Concourses B and C, and New Second Terminal building.
- Install revolving doors at main passenger entrances to create an airlock and reduce heat transfer.
- Install high reflectance roofing materials on rooftops of all terminals.
- Continue to install variable frequency drive (VFD) motors for fans, chillers, and pumps.
- Continue to install motor efficiency controllers in escalators and moving walkways.
- Install daylight timers lighting fixtures in the terminal building.
- Continue to upgrade the efficiency of the existing HVAC system.
- Purchase and install high efficiency HVAC systems when new terminal buildings are constructed.

Natural Gas

- Install evacuated tube solar collectors on rooftops of Concourses B and C to provide steam/hot water for the buildings' HVAC system.
- Install high efficiency water heaters in the HVAC system of Concourses B and C.
- Decouple only the heating plant and replace with high efficiency decentralized heating plants.
- Replace the existing Natural Gas-fired Steam Boilers with On-Site Generation using renewable fuels.
- Install revolving doors at main passenger entrances to create an airlock and reduce heat transfer.

- Purchase and install high efficiency HVAC systems when new terminal buildings are constructed.

- Continue to pursue partnerships with producers of natural gas from renewable sources.

SAMP Task 6.12 consisted of a significant review of the Airport's energy systems. Appendix A *Task 6.12 Report – Total Cost of Ownership* contains a detailed review of building energy. The final chapter of that appendix identifies recommendations relative to energy with a focus on terminal energy options.

There is an extensive list of IOAs relative to energy use that could be implemented, and new strategies are likely to continue to arise as technology evolves. The extent to which these measures would reduce energy is not known at this time. The benefits of any individual IOA would be a function of the breadth of its implementation relative to the energy consumer. As electricity and natural gas are the two largest energy types consumed (on a unit basis), the Port has and will likely continue to focus on reducing electricity and natural gas use. However, in the Puget Sound Region, access to Bonneville Power electricity (hydro power) is low cost and low carbon. Therefore, a greater focus should be placed upon natural gas use reduction or conversion to renewables.

Goal (Fish and Wildlife): Protect, enhance, and steward fish and wildlife habitat while maintaining air transportation safety.

The following IOAs were identified that could be implemented to achieve the Port's goals and objectives:

- Conduct study of species present.

- Evaluate quantity of open space and protected habitat displaced as part of every development action and identify and implement measures as needed.

These measures would achieve the fish and wildlife goals/objectives.

Goal (*Noise*): Increase the number of noise compatible units within the noise remedy boundary to 95 percent through the year 2030.

In 2014 the FAA approved the Port's comprehensive Part 150 Noise Compatibility Plan that identifies airport operational and land use compatibility actions. This Technical Memorandum study did not re-evaluate those recommendations, but rather reinforces the implementation of the recommendations. Key candidate noise IOAs are:

- Continue to implement the Part 150 Recommendations, including single-family residential sound insulation and other sound insulation programs.

- Complete a Ground Run-up Enclosure when feasible to do so, if warranted by the level of ground run-up activity.

- Continue to implement the Fly Quiet Program to track compliance with the existing noise abatement procedures.

The purpose of the Part 150 Study Noise Compatibility planning process is to identify a balanced and cost-effective program for reducing aircraft noise exposure. Thus, implementation of the Part 150 recommendations will aid the Port in moving towards its noise reduction goals. Included in the Part 150 recommendations are specific actions to reduce noise and offer programs to residents severely affected. It is possible that additional actions will be needed over time as aircraft operations increase.

Goal (*Transportation*): Reduce the greenhouse gas emissions associated with passenger and employee transportation to and from Seattle-Tacoma International Airport by decreasing the emission intensity of the travel modes and increasing the proportion of trips made using environmentally preferred modes.

The following transportation candidate IOAs were identified:

- Provide a convenient access for using public bus routes originating from Sea-Tac
- Develop a Commute Trip Reduction action plan to enhance employee commute program
- Provide direct and easy access for passengers to public transportation and hotel shuttles.
- Improve public transportation information displays and schedules at baggage claim, ticketing and parking garage for Link Light Rail.
- Develop partnerships with transit agencies and develop strategies to improve the frequency and efficiency of public transit service to the Airport.
- Work with shuttle companies to improve service to and from the Airport for passengers.
- Increase the number of EV charging stations in the parking garage, and promote the use of EVs
- Work with car-sharing companies to provide access to environmentally-friendly vehicles for passengers traveling to and from the Airport (see same strategy for GHG reductions above).
- Continue to explore opportunities for passengers to check baggage at off-site locations prior to their flight.
- Institute tolling for access to the curbside.
- Develop a transportation management association to assist Airport employees with ride-share programs, guaranteed ride home/emergency program, and transit support.

- Provide incentives for rideshare and loyalty programs.
- Allow passengers and employees free transit rides with airline ticket.
- Ride-free area for Link Light Rail to provide offsite curbside pick-up and drop off

All of the above IOA could help to increase the number of passengers using environmental friendly modes of transportation. A secondary benefit of increasing the use of environmentally preferred modes of transportation is a reduction in air quality and greenhouse gas emissions, but also potential reduction in congestion affecting nearby communities.

Goal (*Waste Management*; *Construction)*: Divert to recycling 85% of construction waste by 2020, 90% by 2025, and reach zero waste by 2035.

The following IOAs were identified:

- Continue to review project designs and identify opportunities to recycle construction debris.
- Work with construction teams to ensure construction waste recycling efforts earn LEED certification credits.
- Continue to review contractor submittals for compliance with construction debris specifications and track performance.
- Donate project waste that cannot be reused or salvaged to a cooperating agency
- Improve sustainability language and requirements into airport contracts.
- Update Rules for Airport Construction, 2014 Edition.
- Recycle scrap metal from construction projects.

As is noted in the prior section, the Port achieved the 2020 and 2025 goal in 2014 (91% to 100% of C&D was diverted) but fell short of the goal in 2015 based on the terminal construction activities. By 2016, the goal was again achieved. The above IOA would help ensure that the goal is met and provide further movement toward the 2035 zero waste goal.

Goal (*Waste Management*; *Terminal and Airfield)*: Divert 60% of terminal solid waste and 15% of airfield solid waste by 2020.

The Port has an existing program to address municipal solid waste (MSW) that has reduced waste to landfill. The following candidate IOAs were identified:

All MSW waste

- Develop partnership with King County Solid Waste Division to explore secondary sorting (AKA missed waste processes) facility opportunities for Airport and County waste.
- Implement high performance Green Cleaning policy and program to support LEED® certification for capital improvement projects.

Terminal waste

- Continue implementing ACI award-winning green concessions and dining program.
- Evaluate options for Zero Waste certification for Sea-Tac Airport Office Building
- Monitor and continue to assist airport concessions required to divert their waste, use durables or compostable or recyclable service-ware for "take away" meals provided in terminal areas and provide clearly labeled collection containers for recycling, composting, and garbage.
- Develop a long-term strategy to increase source separation rates by conducting a study on the feasibility of a developing a regional waste processing facility and in collaboration with regional partners, including but not limited to King County and local jurisdictions.
- Pilot new approaches to helping passengers quickly identify and separate recyclable and/or compostable materials to increase diversion rates at disposal locations in the Terminal.
- Continue encouraging concessionaire donations to local food banks or Sea-Tac USO.
- Add liquid collection stations to all security checkpoints and optimize existing station locations and signage.

Airfield waste

- Continue working with Maintenance, cargo operators and airlines to improve recycling at hangars, in Maintenance work areas, on the ramp, and other remote work locations.

The extent to which these measures would reduce waste is not known at this time. The benefits of any individual IOA would be a function of the breadth of its implementation. The greatest shortfall relative to the gap is in the airfield MSW.

Goal (Hazardous *Waste Management)*: Reduce the volume of hazardous waste generated from Port maintenance and operations to meet requirements for Small Quantity Generator Status by 2020.

The following IOA were identified to continue to minimize the use of hazardous waste at Sea-Tac:

- Continue to ensure that secondary containment is used for oil and solvent containers to contain spills.
- Evaluate the practice of using pig cleaning pipes instead of using solvents.
- Continue to purchase and place collection bins for used batteries, electronics and light bulbs.

As is noted in the prior section, the it is anticipated that the Port's hazardous waste management goal will continue to be met in the future. However, because hazardous material use is expected to increase, IOA were identified.

Goal (*Water Conservation*): Reduce projected future consumption by 4% over 2008 levels in 2020 and 12% in 2030.

The following candidate IOAs were identified to aid the Port in conserving potable water and reduce its overall water consumption:

- Prepare a Water Use Reduction Plan to identify specific conservation measures.
- Document and manage construction water usage and other non-standard usage.
- Implement and improve current sub-metering strategies.
- Consider rainwater harvesting and reuse in new facilities, where feasible.
- Develop and implement a Green Concessions Policy with water conservation requirements.
- Continue to plant native plants and drought-tolerant landscaping.
- Install dual-flush toilets that use 0.8-1.6 gpf (gallons per flush).
- Purchase waterless, regenerative vacuum sweepers (with dust control specifications) to clean roads, taxiways and runways.

A net reduction in water consumption would also reduce operating costs and improve the financial bottom line. All of the above IOA would aid in reducing water consumption. At this time, it is not possible to identify the specific contribution that each IOA could make to reducing water use.

Goal (*Water Quality*): Contribute to the restoration of Puget Sound and local receiving waters by providing water quality treatment, flow control, and using green storm water infrastructure (where feasible) for Airport industrial storm water.

The following candidate IOAs were identified to address water quality improvements:

- Install extended compost amended filter strips in runway and taxiway infields.
- Install low impact development where feasible and consistent with airport operations and FAA design standards.
- Clearly designate aircraft deicer/anti-icer storage and transfer areas.
- Assess green roof on new facilities and construct where any resulting wildlife threats are managed.
- Construct a centralized deicing facility (CDF) and collect and recover deicing fluid.

The Port has an extensive and generally state-of-the art program for addressing its water quality goals. The above IOA would contribute to the Port's water quality goals and objectives.

4.4 Evaluating IOAs to Address Social and Community Outreach Goals and Objectives

Chapter 2 *Sustainability Vision and Goals/Objectives* documents the Port's process of establishing social goals and objectives.

4.4.1 Gaps to be Filled to Address Social and Community Outreach Goals and Objectives

The following summarize the Port's social and community outreach goals/objectives and gaps to addressing goals.

***Goal/Objective*: Maximize the compatibility of new development with nearby lands.**

Gap: This goal is project specific and will need to be considered as individual projects are evaluated.

***Goal/Objective*: Identify benefits of proposed development to the local community.**

Gap: This gap cannot be quantified at this time, as it is project specific.

***Goal/Objective*: Enhance employee welfare and facilitate diversity.**

Gap: As discussed in Chapter 3, the Port is continuing the expand and develop its employee welfare and diversity programs, and recently identified metrics in the 2017 Long Range Plan. The Port is now establishing systems to track these metrics, and will evaluate gaps as appropriate data becomes available.

***Goal/Objective*: Reduce Off-Airport environmental effects to nearby communities.**

Gap: These issues will be explored as part of the environmental review process for the Near-Term Projects.

***Goal/Objective*: Be transparent in public communications and increase outreach to the local community.**

Gap: As described in Chapter 3, the Port has comprehensive outreach programs and initiatives ranging from school programs to routine meetings with local communities and governments to website and other social media outreach. Because the Port is also continuing to develop new outreach programs (e.g. the Sea-Tac Advisory Round Table or StART), metrics are not yet available to identify potential gaps.

4.4.2 Specific Social and Community Outreach IOAs

This section discusses the IOAs focused on social and community goals and objectives.

Goal/Objective: Maximize the compatibility of new development with nearby lands

By its definition, this goal is associated with proposed projects at Sea-Tac Airport. It served as screening criteria for the review of development alternatives associated with the SAMP. As a goal/objective, it will also be useful to the Port as other projects are identified in the future. IOAs identified to address this goal are:

- Identify the effects of development projects, such as the Near-Term Projects, on land use.
- Identify measures to achieve compatibility.

Before implementation of the Near-Term Projects or other projects at Sea-Tac Airport, compliance with requisite National Environmental Policy Act (NEPA) and State Environmental Policy Act (SEPA) requirements would need to be met. Those evaluations would include consideration of land use compatibility.

Goal/Objective: Identify benefits of proposed future development to the local community

Proposed development has the potential to create impacts to the local community that can be positive as well as negative. Creating an awareness of the beneficial effects of the Near-Term Projects and other Airport projects was the focus of this goal and associated IOAs.

Candidate IOAs identified include:

- Prepare documentation to comply with NEPA/SEPA and coordinate the results with the public.
- Conduct coordination workshops with interested parties concerning the Near-Term Projects and long-range development vision.
- Place all SAMP documents in the public libraries when the study is completed.

These IOAs are focused on the SAMP but can be applicable to any development at the Airport. Relative to showing the benefits of proposed development, information concerning socio-economic benefits (jobs, payroll, regional expenditures) as well as environmental effects benefits would be identified during the NEPA process for development projects.

Goal/Objective: Enhance employee welfare, and facilitate diversity

An important element of sustainability of an airport is ensuring that the needs of Airport staff are adequately addressed. The Port has an active Human Resource Department that strongly supports our Development and Diversity program for Port employees and works with airport tenants to ensure an available workforce for its tenants. The candidate IOAs identified for this goal, focused on Port employees, include:

- Continue to survey employees regarding their engagement at the Port and concerns.
- Continue to develop and implement a wide range of social justice initiatives focused on development and diversity programs, partnerships, and initiatives including:
  - Developing and implementing a Port model of equity, diversity, and inclusion,
  - Developing employees at all levels of the organization to support growth, improve engagement, and job satisfaction,
  - Developing and implementing a labor relations strategy to increase the number of represented employees with development plans and participate in development activities,
  - Leveraging the Port's Development and Diversity Council, an internal group of experts who advise, generate ideas, advocate and communicate about employee development and diversity issues, policies, programs and initiatives,
  - Developing new and supporting existing Employee Resource Groups,
  - Developing new courses and encouraging employee education on diversity through the J. Loux Learning Library,
  - Recognizing and supporting women and minorities at the Port through the Women's Initiative and the Champion of Diversity and Inclusion Award.
- Continue to identify diversity gaps and needs.

Goal/Objective: Reduce Off-Airport environmental effects to nearby communities

A social benefit of the Port's environmental program is designed to reduce off-airport adverse environmental effects. Section 4.3 of this Technical Memorandum discusses the environmental IOAs. The candidate IOA associated with this goal/objective is: Continue to prepare an environmental management report or a sustainability report. It also supports the following goal/objective.

Goal/Objective: Be transparent in public communications and increase outreach to the local community

The Port of Seattle is a special purpose public agency. As has developed with all forms of government, citizens are often frustrated with the lack of openness and transparency that sometimes accompanies public agency operations. Chapter 3.3 discusses the Port's existing programs designed to enhance transparency at the Port. The following candidate IOAs are designed to aid with these existing programs:

- Create a speakers' bureau that regularly volunteers to present at local meetings and events.
- Prepare annual sustainability reports for the triple bottom line and make them available on the web.
- Place all master plan documents in local public libraries when the study is completed.

4.5 Sustainability Tradeoffs

As is evidenced in the material in the preceding section, much will have to be accomplished to achieve the Port's goals and objectives. Sustainability aims to follow the "win-win" philosophy, as illustrated previously in Figure 1-1 by the "sweet spot" at the intersection of the economic (financial-operational efficiency), environmental, and social focus areas in the "Triple Bottom Line" figure. Yet organizations implementing sustainability programs through initiatives, opportunities, and actions must often make difficult decisions. Studies indicate that multi-faceted and complex organizations must make tradeoffs in one or more focus areas, as rarely can a true balance be achieved. Tradeoffs could refer to a compromise between at least two sustainability goals/objectives that conflict with one another.

Accordingly, it is expected that the Port will likely need to make tradeoffs given the gap analysis discussed in this chapter. In some cases, various focus areas will have higher priority than others. In others, achieving the goals/objectives in the timeline suggested while satisfying other airport needs will not be possible. Much of how sustainability implementation is factored into the day-to-day business of the Port will determine how those tradeoffs are made and how it affects other parts of the SAMP and the sustainability IOAs.

Some of the tradeoffs the Port faces will likely face:

- Determining how to efficiently serve all facets of airport demand
  - Making highest and best use of land for serving passengers, with cargo consuming the remaining prime space. Then enabling support to "fit" into the residual areas
  - Collaborating with regional partners to ensure that the Airport and surrounding communities have necessary infrastructure and transportation systems to support growing demand for Airport services

- Maximizing the regional economic contributions through growth in cargo to the levels suggested by the Century Agenda – which would require either land-use tradeoffs or the acquisition of land

- Deciding how to finance the facility improvements that are needed (including infrastructure renewal) while minimizing the environmental effects and increasing Sea-Tac Airport's social benefits

- Achieving the environmental and social/community outreach targets suggested while at the same time fostering growth in air travel demand

Making tradeoffs does not mean a decision is either inferior or not sustainable. Rather, it is likely that the tradeoffs would be temporal in nature (meaning that in the short-term a strategy or group of strategies are not possible, but rather would occur later in time to give priority to a conflicting category/focus). The next chapter, *Sustainability Implementation Process and Plan*, is designed to have the Port monitor progress toward the goals, and to create an organizational structure that monitors the tradeoffs. The Plan-Do-Check-Act process is designed to recognize the need for tradeoffs, so that the adjusting process can work to address changes that may be needed in the goals/objectives, and IOAs.

SAMP Sustainability Implementation Process and Plan

The Port of Seattle will integrate its SAMP Implementation Process into the ongoing Airport Sustainability Program with participation from the entire organization.

5.1 Implementation Approach

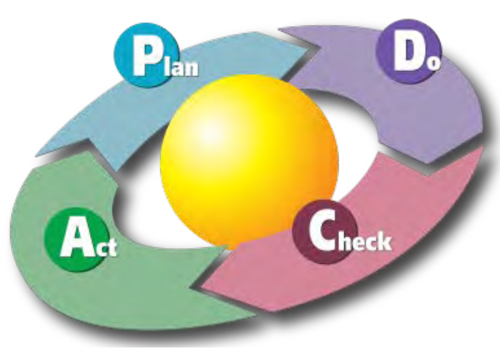
One of the key measures of the success of a sustainability program is ensuring that the organization follows through on its commitments and measures progress toward reaching goals and objectives. The Port has an informal policy of striving for continual progress and improvement in its activities. Many airports have found that the Plan-Do-Check-Act (PDCA) cycle serves to ensure that implementation. This section discusses the Plan-Do-Check-Act cycle and how the proposed implementation approach fits within the existing Port structure.

5.1.1 Overview of the Plan-Do-Check-Act Cycle

This section further defines the implementation of the Sustainable Airport Master Plan; it defines how the Port will implement the sustainability initiatives, opportunities, and actions (IOAs), collectively considered sustainability strategies defined in the prior chapter. Since this is the first Sustainability Implementation Plan formalized by the Port of Seattle, it is expected to serve as the foundation for future Port plans and strategies.

The implementation of sustainability strategies and the Port's prior Environmental Strategy Plan, has been established using the Deming Cycle – also known as the Plan-Do-Check-Act process and illustrated on Figure 5-1. The following describe the Plan-Do-Check-Act cycle that is designed to lead to continuous improvement over time in the areas being measured.

Figure 5-1
The Deming Cycle
Seattle-Tacoma International Airport



Source: The Deming cycle, https://en.wikipedia.org/wiki/PDCA.

5.1.1.1 Plan (Formulate)

The Sustainability Implementation Plan and the corresponding SAMP tasks that form the foundation of the findings presented here represent the first step in the "plan" portion of the process. The sustainability tasks of the SAMP including 1) clearly defining sustainability categories, 2) identifying goals/ objectives, 3) collecting baseline information, and 4) suggesting IOAs, are all part of the planning.

As described in the following sections, the Port is continuing to develop its sustainability programs and will incorporate those changes accordingly. In the future, as subsequent steps in the cycle occur, Port staff will work with stakeholders across the Airport to evaluate the practicality of the IOAs, estimate the environmental benefits associated with the selected IOAs, and develop action plans and project designs for the highest priority actions. Additional consideration of categories/issues, baseline condition(s), and goals will likely be necessary. The Port will use the findings and recommendations of this SAMP analysis to inform its environmental sustainability strategy moving forward and set its sustainability priorities.

5.1.1.2 Do (Implement or Take Action)

Implementation of the strategies represents the "do" portion of the process. This involves undertaking the strategies noted in this plan, and taking advantage of the opportunities, as development recommendations of the SAMP are constructed. The IOAs are designed to move toward achieving the goals and objectives. By "doing," the Port enhances its culture of sustainability.

5.1.1.3 Check (Report/Confirm)

After implementing strategies/IOAs, the "check" process encompasses the reporting aspect of the implementation. As strategies are implemented, the next step is to track and check the process toward meeting the goals and objectives. Through the Sea-Tac Airport's Environmental Progress Reports and related reports such as the Long Range Plan and Port's Annual Report, the Port has historically monitored annual progress on its financial, social, and environmental activities. These annual reports will continue, and it is expected that progress towards all three sustainability elements -- financial-operational, social, and environmental goals -- will be shared and highlighted.

5.1.1.4 Act (Adjust/Refine)

The "act" portion represents what has been learned during the "do" and "check" steps. This involves answering the question of, "What did we learn and how can we do it better next time?" by re-evaluating the issues/categories, goals, and objectives and metrics. During this stage of the cycle, adjustments are often identified. The Port anticipates that it will review its performance annually (or at appropriate milestones) and adjust accordingly.

In addition, the Port will continue to adjust its sustainability programs and initiatives in response to changes in priorities and demands from a range of stakeholders including airline partners, near-by communities, businesses and other communities across King County and our region. The Port also expects to adjust its programs based on economic and/or market changes that influence priorities and overall budgets.

The following sections provide further elaboration on the "plan-do-check-act" process that the Port is committed to implement.

5.1.2 The Port's Current Implementation Approach

The Port has an active ongoing program of implementing sustainability measures Port-wide. The leadership associated with the Port's sustainability program is demonstrated through the Port Commission's Century Agenda, Long Range Plan, and Sea-Tac's Environmental Strategy Plan as discussed in Chapter 2. These programs have been further refined for day-to-day activities for the Airport in the Aviation Division's Strategy Plan, Business Plan and 2018 Priorities, also discussed in prior chapters. The Aviation Division programs have been managed through the activities of the following groups:

- **Financial/Operational Efficiency**. Overseeing the financial and operational objectives rests with the Aviation Division's financial group as well as the Operations Department. Reporting on financial and operational performance occurs on a regular basis, including annually within the Port's Financial Report and the Port's Performance Report.*

- **Environmental**. These activities are implemented by the Port of Seattle Aviation Division's Environment & Sustainability Department. Activities and programs have been under the umbrella of the 2009 Environmental Strategy Plan and the 2015 Strategy for a Sustainable Sea-Tac. The Port prepares an annual Environmental Progress Report for Sea-Tac Airport that identifies progress toward achieving Port environmental goals and objectives.

- **Social and Community Outreach**. The Port implements its social programs through several groups and programs including: Human Resources (staffing), Office of Social Responsibility (job creation and economic development efforts), Public Affairs (stakeholder and community outreach) and Noise Abatement and Noise Remedy Office (addressing noise exposure in the community around Sea-Tac).

<u>Port's Implementation Plan</u>

Plan – This Tech Memo represents the Port's initial step in developing the sustainability approach to the SAMP.

Do – Upon Commission approval and adoption, and after NEPA/SEPA compliance, the Port would implement the Near-Term Projects while at the same time implementing appropriate sustainability strategies/IOAs.

Check – The Port will review metric performance at least annually. The Sustainability Manager will coordinate the collection of data.

Act – The Port will adjust the Plan,

These groups are involved in developing the framework of the Port's aviation plans, implementing the plans and the recommended strategies, reporting on progress, and then periodically adjusting the Port's efforts, although they do not routinely integrate the information in the same fashion as the SAMP sustainability implementation plan.

*http://www.portseattle.org/About/Financial-Info/Pages/default.aspx.

5.1.2.1 Capital Projects

In the implementation of capital projects, the Port has a formal review process for how it proceeds with development. Today, ideas for capital projects arise in several forms. Projects may arise out of a formal planning process that is overseen by the Aviation Division Planning Group. Individual lines of business may also identify capital projects. Together, all capital improvement ideas ultimately come before the Aviation Division's Investment Committee before moving on to approval (as needed) from the Airline Affairs Committee and the Port Commission. Before the Investment Committee approves a project, the Aviation Division's Budget Committee must confirm that sufficient funding is available for the project.

5.1.2.2 Operational/Management and Procurement Strategies

Implementation of various operational and management strategies within the Aviation Division typically occurs through a wide range of approaches. Strategies are derived either at the management level in response to direction from the Port Commission or in response to industry needs and requirements and then passed to the various operating group/line of business where they are incorporated into the annual business plans.

In addition, strategies may arise based on a line of business/operating group identifying the needs and bringing it to the attention of Airport management. When expenditures of funds or staffing needs associated with a strategy arise, then approval must come from the Aviation Division's senior management through the budget process to ensure that adequate funding is available. Ultimate approval for significant items (as well as annual approval of the Port budget) must go before the Port Commission to move forward.

5.1.3 Integrating the Port's Sustainability Management Plan with the SAMP Implementation

The IOAs identified and discussed throughout the document will be implemented through capital projects as well as strategic planning or operational initiatives. In addition, the Port Commission recently directed staff to revise its current project review processes to integrate even greater levels of sustainability into both its capital projects and initiatives. As a result, the Near-Term Projects and IOAs may include additional sustainability attributes or considerations. This new Commission directive and its potential impacts on SAMP-related IOAs are discussed in more detail below.

5.1.3.1 Port Sustainability Evaluation Framework

The Commission directive to develop and implement this new approach is described in the *Revised Energy and Sustainability Motion* and the corresponding Attachment A: *Port Sustainable Evaluation Framework* (the Framework). The Commission adopted both the Motion and Framework on December 19, 2017. The Framework builds on the Port's existing sustainability categories to include new criteria such as energy resilience and creates new sustainability categories such as reducing light pollution, advancing social justice, leveraging partnerships, and advancing innovation.

The Commission directed staff to apply the Framework to project review procedures for both capital projects such as building new facilities, and operational initiatives such as purchasing renewable fuels or evaluating new on-road transportation strategies. As such, the new procedures will be applied to the

SAMP Near-Term Projects during design review, which will occur after multiple milestones have been reached such as completing regulatory environmental review, obtaining Commission approval, and other milestones as appropriate. These procedures are not expected to influence the Near-term Projects.

To integrate the concepts of the new Framework into the Port's existing project review processes, the Port is convening an internal stakeholder group comprised of key departments across the Port including Environment and Sustainability, Operations (OPS), Facilities and Infrastructure (F&I), Engineering (ENG), Project Management Group (PMG), and Human Resources (HR) to advise and oversee the process.

The stakeholder group will research and draw on a number of rating systems and performance metrics including but not limited to Leadership in Energy and Environmental Design (LEED), Living Building Challenge (LBC), and ENVISION. Because airport facilities operate quite differently from office or retail buildings, the Port expects that the final set of tools and performance metrics may reflect a combination of several ratings systems or approaches.

In addition to existing sustainability rating systems, stakeholders will evaluate the Port's Racial Equity Worksheet and make recommendations to advance social justice within the new procedures as appropriate.

The stakeholder group is expected to finalize their recommendations for a revised set of project review procedures by early 2019. Once those procedures have been reviewed and approved by senior management and the Commission, the Port expects to fully integrate those procedures into design review for Port projects, including the SAMP Near-Term Projects as well as operational initiatives listed in Tables 5-1 through 5-3 (at the end of this chapter). The revised procedures will not substantially alter the proposed projects, including the Near-Term Projects, but rather will make sustainability attributes and their potential costs and benefits more transparent in the pre-design phase. This will enable decision-makers to evaluate and weigh the pros and cons of those attributes as appropriate.

5.1.3.2 Reporting on Progress

As noted in the prior section, the Port reports its progress and performance for each of the triple bottom line categories separately in different reports. Because of the success of that implementation and management style, it is expected that will continue.

The Port's Center of Expertise for Environment and Sustainability will serve as a clearing house for information about sustainability and coordinate activities of the sustainability review process across all operating arms. Responsibility for achieving sustainability goals and objectives will rest with the relevant operating arm (e.g., achieving Aviation financial goals and objectives will rest with the financial group of the Aviation Division).

The following portion of this chapter identifies the specific methods that the Port staff anticipates using to implement the SAMP sustainability IOAs and follows the previously defined Plan-Do-Check-Act cycle within the context of the current organizational structure.

5.2 PLAN – Develop/Refine the Implementation of Sustainability Initiatives at Sea-Tac Airport

The Plan portion of the Plan-Do-Check-Act cycle shows the Port's approach to implementing the sustainability initiatives and actions described throughout the previous sections of this report as the Port begins to develop and build the various parts of the SAMP. In addition, the Port recognizes that since the Near-Term Projects and are defined only broadly, the Port must conduct additional sustainability analyses as the projects move to engineering and design as part of its sustainability implementation plan. As such, Section 5.2 describes two sustainability planning phases: *Phase 1*, which summarizes the initial planning approach to including sustainability throughout the process and in the original vision, and *Phase 2*, which describes in more detail how the Port will analyze sustainability for the Near-Term Projects as well as implement the IOAs described above.

5.2.1 Phase 1: Initial Sustainability Planning Approach

As described in Chapter 1, the Port's framework for integrating sustainability into its activities focused on three main stages of the plan:

- What/where we build (through the planning process, such as the SAMP)
- How we build
- How we operate

5.2.1.1 What/Where we Build

Building size, volume, number, and location are major influencers of sustainability. The Port's decision up front to plan within major site boundaries (to the extent feasible) means that the SAMP, and in particular, the Near-Term Projects, would mostly be limited to already-developed areas and would have limited impacts on natural resources. The Port's attempt to integrate sustainability into the first stage of planning is demonstrated in the additional environmental sustainability criteria applied to the scoring and selection of the overall development concepts.

As shown in Technical Memo No. 5 *Facility Requirements and Alternatives,* the sustainability criteria, after refinement, provided some impact or influence on the selection of development alternatives for various functional areas (see Section 4.1.3 of this Technical Memorandum). This influence was largely due to the refinement in the goals and objectives as listed in Table 2-1 which narrowed the broader goals and objectives established by the Port Commission.

In addition, the use of operational and financial metrics to develop SAMP implementation and phasing, resulting in the Near-Term Projects, integrates sustainability. Lastly, the Port found that traditional planning principles such as locating facilities and infrastructure in ways that maximize efficient movement of aircraft and passengers aligns well with the financial and operational elements of sustainability.

5.2.1.2 How We Build

The analysis in Chapters 3 and 4 of this Technical Memorandum is on existing conditions. As discussed in Chapter 2, the Airport's green building goal is to seek Leadership in Energy and Environmental Design (LEED) certification at the silver level for new construction, additions and renovations, as well as encouraging tenants to seek LEED certification. As such, all new buildings are expected to achieve LEED Silver, although there may be instances where this is not possible due to design limitations or conflicts with other sustainability goals. This practice, augmented by implementation of the Framework noted earlier, should help to integrate sustainability into the Near-Term Projects. However, the extent of that integration will not be known until the future buildings have been designed. For that reason, the analysis of gaps in Chapter 4 is conservative in that it likely overestimates the sustainability needs.

During SAMP planning, the Port analyzed the potential cost and resource use of building the new Second Terminal using a range of sustainable building assumptions. As shown in Appendix A of this Technical Memorandum, sustainability could provide some reductions in greenhouse gas emissions through more efficient energy use when compared to building out the main terminal.

5.2.1.3 How We Operate

The Port also recognized early in the process that it was unlikely to meet its sustainability goals only through green building attributes or limiting project location; the gap analysis in Chapter 4 of this Technical Memorandum reinforces that conclusion. As a result, the Port added an operational component to the SAMP to incorporate key sustainability initiatives into its Long Term Development Vision. As shown in the list of IOAs in Chapter 4 of this document, many sustainability IOAs will require operational strategies such as procuring renewable fuels or requiring energy efficient equipment and appliances.

The process of formulating the sustainability component of the SAMP consisted of five steps:

1. **Identify goals and objectives**. See Technical Memorandum No. 1, which is summarized in Chapter 2 of this document which notes how the goals and objectives evolved during the study. An outgrowth of the goals and objectives was the identification of metrics that would enable measurement of progress toward achieving the goals and objectives.

   Goals are established at the highest level of the Port of Seattle, through the Port Commission, and in this case, the Century Agenda. Objectives then flow from the Commission to the various operating arms of the Port. In the case of the Aviation Division, objectives have been established through the Business Plan, 2018 Priorities, and other plans to guide the Division to achieving the broader goals.

2. **Cross check goals and objectives with areas of importance to the Airport**. Under the FAA's grant process, these are referred to as focus areas. Focus areas have metrics that the Airport wishes to track. Chapters 1 and 2 of this Technical Memorandum note the Port's consideration of focus areas.

3. **Establish a baseline** that identifies the conditions relative to the various metrics for each focus area. Chapter 3 of this Technical Memorandum identifies the baseline (and in some cases a reference year) applicable to the focus areas. Ownership of the information needed to support the preparation of a baseline, resides with the various operating arms. Looking forward, the Port must ensure that its data systems continue to track key metrics to support its sustainability goals and objectives.

4. **Identify the gap** relative to the Airport's goals and objectives. Chapter 4 of this Technical Memorandum notes the gap relative to the goals and objectives.

5. **Identify Initiatives/Opportunities/Actions** (IOAs) that could be implemented to aid the airport in achieving the goals and objectives. Chapter 4 of this Technical Memorandum notes the various IOAs that have been identified.

5.2.2 Phase 2: Analyzing Near-term Projects and Implementing IOAs

The second phase will focus on analyzing the Near-Term Projects for sustainability opportunities. The approaches and procedures for both new capital projects and IOAs are combined here because both will follow new Port procedures designed to integrate sustainability into all Port projects, both capital and otherwise. In addition, the IOAs described in this document include both capital projects, such as installing new electric infrastructure to power fleet vehicles, and other non-capital projects such as procuring renewable natural gas for use in airport boilers.

As noted in Section 5.1.3, these new approaches and procedures are currently being developed as directed in the December 19, 2017 Motion. The Motion directs staff to implement the Sustainable Evaluation Framework for Port projects, including capital projects and other decisions. As described above, these procedures will advance sustainability concepts in both capital and operational initiatives and provide more transparency to senior management and the Commission throughout the project refinement and detailed design process.

The Port expects that these new procedures will directly affect how the Port builds new capital facilities under the SAMP. For example, the Framework directs the Port to consider the use of distributed energy systems, where much of the energy used by a facility is generated either at or near the facility. When the new procedures are finalized, the Port expects to be able to identify and evaluate opportunities in new facilities to install these types of systems. Depending on the outcome of the analyses and the characteristics of the facilities, distributed energy, when combined with extensive energy efficiency strategies for new buildings, could result in the Port being able to achieve net zero energy for the first time in near-term SAMP facilities.

These procedures will also help illustrate how a given strategy may affect several different categories in either a positive or a negative way. For example, an IOA such as upgrading lighting to be more energy efficient could result in an initial cost, but with significant cost savings over the life of the IOA (resulting in helping meet both financial and energy-related goals). Alternatively, adding new outdoor lighting would need to be considered against the Framework directive to reduce light pollution. In these instances, the Framework enables the Port to consider lower levels or motion sensitive lighting for its facilities. Therefore, to prioritize the implementation of individual IOA, the effect that the IOA would have across all goals and objectives should be reviewed prior to implementing one IOA over another.

While IOAs rest with the group overseeing the performance relative to the goal/objective, there is often an overlap in effects. The Port expects that the combination of the new procedures, stakeholder buy-in from across the Port, and the Environment and Sustainability Center of Expertise to advocate as necessary to identify, prioritize, and implement IOAs and ensure that sustainability is fully integrated into capital projects.

In addition to the capital facilities, the Port includes a number of operational strategies in its SAMP concept to meet its sustainability goals into the future. This approach is particularly important if the Port is to balance all three elements of the sustainability concept. For example, the Port's goal to reduce greenhouse gas emissions is challenged not only by existing emission levels and sources such as aircraft operations and ground transportation, but also by the projected growth in these sources. As shown throughout the SAMP, the Port expects to implement a number of capital improvements to maintain efficient operations and financial sustainability, but those improvements are not expected to reduce emissions enough to meet the Port's Century Agenda goals for greenhouse gas emissions.

In light of this, the Port is developing a long-term strategy aimed at bringing sustainable aviation fuels (SAF) to the Airport that includes both capital and operational components. Although the total amount of SAF that could be provided to our airlines at the Airport remains uncertain, the Port is implementing a strategy that would advance SAF development and potentially bring the fuel to this facility. The Port began this effort by developing an SAF feasibility study to understand the capital improvements, such as mixing tanks and pipelines, needed to transport, store, and distribute SAF at the Airport. The on-Airport improvements are included in the SAMP Near-term Projects. The Port also completed a financial feasibility study to identify mechanisms to cover the incremental cost between SAF and fossil jet fuel.

The second phase of the strategy is to work collaboratively with several partners to create a market signal that would incent fuel developers to produce SAF for the Puget Sound region, and specifically for the Port's airline partners. If successful, this strategy would enable the Port to reduce its Scope 3 emissions and support the Port's purpose and mission to advance economic development in the region. In order to "send the market signal," the Port is currently working with stakeholders to understand potential financial barriers and exploring strategies such corporate "green fly funds" or offset programs that could be leveraged to reduce the incrementally high cost of SAF.

Similarly, the Port's Scope 3 greenhouse gas emissions are also increased by the passengers traveling in single-occupancy vehicles to and from the Airport, yet necessary to operate the Airport. The Port is pursuing capital improvements such as installing more electric vehicle charging stations in the Parking Garage that would help to reduce overall emissions.

However, to achieve significant reductions, the Port must evaluate operational strategies such as tolling the Airport drives, promoting transit services, and developing a transportation management association to reduce greenhouse gas emissions. In addition, the Port is exploring multiple variations of express bus service to the Airport including:

- Service from park and ride lots or transit centers. This could also include remote check-in service of passenger baggage, and

- Service among economic centers such as Seattle, Bellevue, and other cities. This service could be operated by the Port, a private entity, or by a transit agency such as Metro King County or Sound Transit.

This approach to include operational strategies is necessary if the Port is to meet its social equity goals as well as its financial and environmental goals. The Port's social equity and diversity programs (described in Chapter 4) include several operational approaches that focus on community outreach and engagement in addition to job training programs and other employee development strategies.

These strategies are integral to the Port meeting its social sustainability goals and are expected to influence the Airport's capital development projects through a new initiative, noted in Section 5.1.3 of this chapter that will include the Racial Equity Worksheet as part of the implementation of the Sustainability Evaluation Framework. For example, the Racial Equity Worksheet includes specific directives for staff to understand if project proposals have impacts in specific geographic areas (neighborhoods, areas, or regions) and for the Port to consider the racial demographics of those living in the area(s). These directives will be included in the Port's new project review procedures, as described in section one of this chapter, and enable the Port explore opportunities to advance social justice throughout its project development processes.

The Port has several other new social initiatives that are expected to advance the social element of sustainability in the Near-term projects. For example, in the November 28th 2017 Commission meeting, the Commission approved a Motion that directs the Port to implement policy on Priority Hires for project labor agreements. This purpose of this new policy is to provide good family wage jobs to qualified construction workers from Economically Distressed Areas of King County by increasing access to Port of Seattle Projects. This policy will likely apply to the Near-Term Projects and may help provide jobs to those historically underrepresented in the construction industry, including women and people of color.*

Similarly, the Port also implements the Veterans Fellowship Program which supports veterans returning to civilian life by providing short-term (six-month) employment that will assist veterans in a variety of areas such as identifying transferable skills, career assistance, and exposure to corporate business practices. The Port actively recruits for the Veterans Fellowship Program at local colleges and military bases.

*Valdez, V. MEMO: Second Reading of Resolution No. 3736, Priority Hire Policy Directive; and amending the Policy Directive related to practices for construction labor for projects located on Port property adopted by Resolution No. 3725, November 20, 2017.

More recently, the Port piloted a new environmental justice tool aimed at providing support to underserved communities located in the Duwamish neighborhood in south Seattle. The Port recognizes that community residents in this area may face disproportionate risks when compared with other Seattle neighborhoods in response to the cumulative impacts from additional public health, economic, and environmental effects associated with their neighborhood. The Port worked with Duwamish Valley community members to provide the Port with a list of opportunities that would help address concerns and impacts from Port operations, and the Port recently funded additional work to help implement the effort.* The Port expects that the results of this initiative, including the tools to work collaboratively with the community, will be applied to the community dialogue with the near-airport communities throughout the development of the Near-term projects.

Finally, the Port would likely refine the SAMP Near-term Projects as they undergo engineering and design. The biggest area of where changes over time in the plan would be expected, is in *how we operate*, reflecting the lessons learned from the "Do" part of the Plan-Do-Check-Act cycle, recognizing that the Port would be responsive to its tenant needs and the evolution of the aviation industry. In addition, a lesson learned in the SAMP process is how important changes in the operation will be to achieve the sustainability goals and objectives, since development alone will not achieve them.

The Port's Aviation Environment and Sustainability Department, through the Sustainability Manager, would be responsible for ensuring that the sustainability components of the SAMP are evaluated and implemented as appropriate. Development of the goals would rest with the various operating arms of the Airport and the Commission, as noted previously. Development of the IOAs would occur both through the Planning Group and the various operating lines of business. However, the master registry of IOAs would be kept by the Aviation Sustainability Manager. Reporting on progress, as noted above would continue under its current approach through the various operating lines of business but would be coordinated through the Port's Sustainability Manager. It is expected that all reports would be completed by the 2nd quarter of each year.

5.3 DO – Implementing the Strategies and Taking Advantage of the Opportunities Designed to Achieve the Goals/Objectives

Once an organization has identified the strategies that it would take, it is then incumbent on the staff to implement those strategies, representing the "Do" portion of the Plan-Do-Check-Act cycle. The commitment of organizational staff and defining clear roles and responsibilities are required to ensure success.

As shown in Tables 5-1 through 5-3 (at the end of this chapter), the roles and responsibilities (which department/ groups at the Airport would take the lead and any supporting groups/departments) are identified for each recommended IOA. These roles will be clarified either prior to or during the implementation of the IOAs. In addition, the specific steps, resources needed (i.e., staffing, financial, equipment), responsible parties, deliverables, and priorities will also be clarified during the planning process.

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*Leavitt, E, Senior Director, Billingsley, C. and del Fierro, S. MEMO: *Contract Amendment for Duwamish Valley EPA Environmental Justice Project*. Port of Seattle Commission Meeting. April 10, 2018.

Tables 5-1 through 5-3 identify the general timeline for when the implementation for each recommended IOA would be expected. For example, some strategies may require tenant or stakeholder approval; others may require engineering and environmental review. SAMP *Technical Memorandum No. 7 Facilities Implementation and Financial Feasibility* identifies the intended schedule and sequence for the Near-Term Projects, to be refined and confirmed in the Capital Improvement Plan (CIP). That Technical Memorandum addresses the *What and Where We Will Build* discussed previously.

The *How we build* process would rest with the Port's project sponsors and the Capital Project Program Management Group (PMG) who oversees the construction process. The IOAs identified in the prior chapter note that the Port would implement the "How We Build" IOAs as various projects are undertaken. In addition to the new project procedures expected to be developed through the 2018 Framework initiative, the Port may opt to revise its tenant construction manual as well as Port architectural standards to include additional sustainability requirements. Several airports have implemented a formal Sustainable Project Construction Design Manual to capture its "how we build" processes, and the Port may opt to develop a similar manual after having completed the Framework initiative. Such a manual was beyond the scope of the SAMP, but it is likely that the Port would expand its current four construction documents to capture sustainability strategies.*

These existing Port documents contain various elements about the design and construction practices required by the Port. It is anticipated that at some time in the future, the Port would review these practices and modify them based on lessons learned. In addition, the Port may opt to prepare an integrated document that captures its sustainable design and construction practices.

As projects transition from the "Plan" to the "Do" side, capital projects go through refinements and into engineering and design. During this process, the Aviation Division Sustainability Manager would continue to ensure that the new procedures are followed, as well as collect and retain project information (sustainability strategies that move forward and those that are subtracted) as part of the Port's tracking of its sustainability strategies.

IOAs that are management and operation based (that do not involve capital improvements) would transition to the various operating lines of business as part of the business planning process. Some IOAs may also be implemented in response to specific conditions and needs. However, implementation would be the responsibility of that various operating line.

5.4 CHECK – Confirming that Continual Progress is being Achieved

The Port has chosen to report its progress toward achieving goals and objectives on an annual basis. The reporting process is expected to continue to follow past reporting as:

- **Financial/Operational Efficiency**. Financial and operational performance occurs annually within the Port's Financial Report and the Port's Performance Report as reported by the Aviation Division's financial group and the operations department.

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*The Port has a current 2015 Tenant Design and Construction Process Manual; 2015 Construction Safety Manual; 2014 Rules for Airport Construction; and 2014 Tenant Improvement Construction General Requirements.

- **Environmental**. The Port would prepare annual reports for the *Strategy for a Sustainable Sea-Tac* (S3) Program which reports on progress toward achieving the environmental goals and objectives. Information relative to the S3 metrics is tracked by various staff members in the Port's Aviation Environment and Sustainability department. The Aviation Division Sustainability Manager then prepares the annual report;

- **Social and Community Outreach**. The Port's Office of Social Responsibility (OSR) prepares a social responsibility report each year. Included in the OSR reports are progress relative to: Supporting small business, workforce development; and community outreach (including noise/sound insulation).

An essential element of the Check step is the communication about progress. Port staff anticipates conducting briefings before the Port Commission regularly during the year, subject to Port Commission scheduling. As noted above, each group within the Aviation Division produces annual environmental reports that measure progress using established metrics.

One of the tasks for the Sustainability Manager is to remind the operating lines of business about the reporting process and to collect data from the various groups. At some point in the future, the centralized collection of data and reporting could occur under the direction of the Sustainability Oversight Committee. However, the evaluation of progress relative to the goals and objectives would remain within the various operating lines.

5.5 ACT – Assess Performance and Adjust Where Needed

Once the Port has reviewed its actual performance, consideration should be given to the need to adjust the Port's sustainability activities. As performance is evaluated, over time, the Port may wish to adjust its goals/objectives, categories/focus areas, broaden or narrow the metrics being reviewed, or alter the implementation plan. Thus, this step involves identifying those aspects of the process that could be improved. It is anticipated that the Port would ask the following questions before determining how best to improve the process:

- What prevented the Port from making progress toward achieving its goals and objectives?

- What issues accelerated/facilitated progress? Will these continue?

- Are there areas where the Port could have done better? If so, why?

- Are there new objectives? Are there existing objectives that are no longer as important?

- What new information came to light that has not previously been considered?

- Have the Port's priorities changed and if so, why?

- Have economic, market forces, or regional issues changed?
- Are there new focus areas/metrics that should be considered?
- Did one or more of the Port's strategies not achieve what was expected? Why?
- Are there new IOAs that would better suit the Port's needs?
- Are refinements needed in the Plan? In the list of IOAs?
- What has been the reaction from stakeholders?

Acting or adjusting would typically involve updates to the Plan, the list of IOAs, the metrics, or the implementation process. In some cases, the need to improve performance would be quantitative (Were the specific numerical goals/objectives achieved?) and in other cases qualitative, based on personal judgment. In all cases, the conclusions should be documented, to be transparent.

The Port anticipates undertaking an airport master plan every 5-10 years, depending on industry changes, and adjusting various sub areas as needed. Adjusting the Port's sustainability programs is expected annually in response to a review of the Port's performance. However, a wholesale revision and update to this implementation Plan is expected to occur after 5 years (prior to 2023).

Table 5-1

Sustainability Initiatives, Opportunities, and Actions (IOAS) – Financial/Operational

Registry/Roles and Timelines

Seattle-Tacoma International Airport

Candidate IOA	Other Sustainability Benefit	Responsible Groups	Timeline	Priority
Enable phased, incremental development		All groups	On-going	High
Employ maximum use of technology and enhanced processes to minimize the amount of new development		All groups	On-going	UN
Provide revenue-generating space in the terminal facilities in accordance with Port guidelines		EconDev, F&B, F&I	On-going	High
Consistently measure budget proposals and capital budget plans against CPE and DPE.		F&B, PMG	On-going	UN
Annually, set capital budget limits so that total five-year capital spending does not cause forecast CPE to exceed forecast CPE of middle third of 22 peer airports		F&B, Exec Leadership	On-going	High
Ensure capacity of parking is adequate for revenue increases		AvPlan, OPS	On-going	High
Provide efficient cruise ship bus interfaces	Transportation	AvPlan, OPS	Intermediate	UN
Develop a Surface Area Management System		OPS	Short	UN
Develop aircraft departure sequencing process vs. FAA First Come, First Serve model.		AvPlan, OPS	Short	UN
Expand airfield drivers training		OPS	On-going	Medium
Automate ramp insurance validation at airfield access points		OPS, PMG	Short	Medium
Install automated gate docking system and gate operating system		OPS, PMG	On-going	High
A revised business model designed to reduce the number of relatively small and inefficient cargo facilities and enhance productivity		AvPlan, OPS	Short-intermediate	UN
The allocation of sufficient space to permit efficient landside operations for accessing the facility and enabling parking for cargo trucks	Transportation	AvPlan, OPS	Short-intermediate	UN
Develop new airside cargo building capacity sufficient to accommodate market growth (as feasible, balancing cargo and passenger needs) and the relocation needs of existing facilities, consistent with the SAMP	Transportation	AvPlan, OPS	Short-intermediate	UN
Consistent with the Port's goals and objectives regarding increasing non-aeronautical revenue to reduce CPE, develop leasable off-airport warehouse and logistics support facilities		F&B, EconDev, PMG	Short-intermediate	UN
Maximize efficient passenger and baggage movement throughout the passenger's trip	Transportation	AvPlan, OPS	Short	UN

Notes: AvEnv: Environment & Sustainability; AvPlan: Aviation Planning; Cargo: Cargo; EconDev: Economic Development; F&B: Finance & Budget; F&I: Facilities & Infrastructure; HR: Human Resources: Maint: Maintenance; OPS: Operations; PA: Public Affairs; PCS: Port Construction Services; PMG: Program Management Group;

Timeframe: Short: 1-5 years; Intermediate: 6-14 years; Long: 15 years or longer; Ongoing: Ongoing/continuous

Priority: High, Medium, Low, UN: Undecided

Source: Port of Seattle, LeighFisher, Synergy Consultants, April 2018.

Table 5-2
Sustainability Initiatives, Opportunities, and Actions (IOAS) – Environmental
Registry/Roles and Timelines
Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline	Priority
Implementation of Airport Development Improvements, such as the Near-Term Projects	All		AvPlan, PMG, PCS	Long-Term	
Develop & enforce policy for optimal use of electric preconditioned air (PCA) and ground power unit (GPU) systems	Air Quality, Climate Protection		AvEnv, F&I, EconDev	On-going	High
Continue to ensure installation and availability of electric preconditioned air (PCA) and ground power unit (GPU) systems at all new and existing gates	Air Quality		AvEnv, PMG	On-going	High
Install new electric ground support (eGSE) infrastructure as new gates are developed.	Air Quality		PMG, F&I, AvEnv	On-going	High
Continue to install eGSE infrastructure at Concourses A, B, and the South Satellite (SSAT)	Air Quality, Climate Protection		PMG, F&I	On-going	High
Educate airline ground staff on use of electric PCA and GPU systems	Air Quality		AvEnv, F&I	On-going	High
Work with airlines and other partners to develop and implement a strategic plan for the introduction and use of sustainable aviation fuels (SAF) at the Airport.	Air Quality, Climate Protection		AvEnv	On-going	High
Work with airlines and other partners to promote replacement of fossil-fueled GSE with eGSE.	Air Quality		AvEnv	On-going	High
Improve public transportation information displays and signage at baggage claim, ticketing, and parking garage for Link Light Rail	Air Quality, Climate Protection	Transportation	F&I, AvEnv	On-going	Medium
Provide a convenient access for using public transit including bus routes and link light rail originating from Sea-Tac	Air Quality, Climate Protection	Transportation	AvEnv, AvPlan, F&I	On-going	Medium
Install additional electric vehicle (EV) charging stations in the Sea-Tac Airport garage and encourage passengers to use electric vehicles and EV charging stations when traveling to/from the Airport	Air Quality, Climate Protection		AvEnv, EconDev, F&I	Short	Medium

Table 5-2 *(continued)*
Sustainability Initiatives, Opportunities, and Actions (IOAS) – Environmental
Registry/Roles and Timelines
Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline	Priority
Research and promote car-sharing programs for passengers traveling to and from the Airport, particularly those using zero emission or low-emission vehicles.	Air Quality & Climate Protection	Transportation	AvEnv, EconDev	On-going	Medium
Develop partnerships with transit agencies and strategies to improve the frequency and efficiency of public transit service to the Airport.	Air Quality, Climate Protection	Transportation	AvEnv, PA	Long-term	High
Continue to develop strategies to provide direct bussing service from economic centers such as downtown Seattle and Bellevue to and from the Airport	Air Quality, Climate Protection	Transportation	AvPlan, AvEnv, Ops	On-going/long-term	High
Develop an Energy Management Plan that identifies key energy users, any possible energy type conversions (i.e., electric to natural gas, or vice versa), and options available to reduce use	Climate Protection	Energy	F&I, AvEnv, AvPlan	On-going	High
Identify and upgrade central plant and distribution equipment, including boilers, chillers, and other HVAC system components	Climate Protection	Energy	F&I, PMG	On-going	High
Replace CNG with renewable natural gas (RNG) in boilers and port-owned fleet vehicles	Climate Protection		AvEnv, F&I, Maint	On-going	High
Require use of renewable diesel in all remaining diesel vehicles in the fleet	Climate Protection		F&I, PMG	On-going	Medium
Use of high-mileage taxis and high-environmental-performing TNCs	Climate Protection		AVEnv, OPS	On-going	Medium
Toll Airport drives	Climate Protection	Transportation, Financial	AVEnv, AvPlan, OPS, F&B	Intermediate	High
Develop a Commute Trip Reduction action plan to enhance employee commute program	Climate Protection	Transportation, social	AVEnv, EconDev, HR	On-going	Medium
Work with existing private shuttle companies to improve service to and from the Airport for passengers	Climate Protection	Transportation	AVEnv, AvPlan, OPS	On-going	Medium-Low
Continue to explore opportunities for passengers to check baggage at off-site locations prior to their flight	Climate Protection	Transportation	AVEnv, AvPlan	On-going	High

Table 5-2 *(continued)*
Sustainability Initiatives, Opportunities, and Actions (IOAS) – Environmental
Registry/Roles and Timelines
Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline	Priority
Monitor changes in climate predictions	Climate Adaptation		AvEnv	Ongoing	Medium
Participate in regional activities for plans to address extreme weather events	Climate Adaptation		AvEnv	Ongoing	Medium
Obtain LEED certification North Satellite (NorthSTAR) expansion project	Buildings		AvEnv, PMG	On-going	High
Obtain LEED certification for new International Arrival Facilities (IAF) expansion project	Buildings		AvEnv, PMG	On-going	Medium
Obtain LEED certification for new Concourse D Hardstand Holdroom project	Buildings		AvEnv, PMG	On-going	Medium
Obtain USGBC Master Site designation, apply credits, and continue to work with USGBC to obtain additional Master Site credits	Buildings		AvEnv, PMG	On-going	Medium
Assign team members to obtain a USGBC LEED professional accreditation to support future LEED certification projects	Buildings		AvEnv, PMG	On-going	Medium
Collect & apply "lessons learned" from previous LEED certification projects	Buildings		AvEnv, PMG	Short	Medium
Prepare a Green Fleet Plan	Energy all	Transportation, Climate Protection	AvEnv, Maint	On-going	Medium
Focus on management and reduction of energy required for plug and process loads	Energy all	Climate protection	F&I, AvEnV, PMG	On-going	Medium
Implement and improve current sub-metering strategies and focus energy efficiency improvements on areas with high energy use	Energy all		AvEnv, PMG, F&I	Short	Medium
Research emerging energy storage technologies	Energy all		AvEnv, AvPlan	Short	Medium
Conduct a renewable energy feasibility study to determine the design, size, type, location and cost of installing and operating an alternative renewable energy generation system	Energy all		F&I	On-going	High
Require contractors to use alternatively-fueled and/or hybrid construction equipment vehicles	Energy - liquid fuels	Climate protection	AvEnv, PMG, Maint, PCS	Short	Medium

Table 5-2 *(continued)*
Sustainability Initiatives, Opportunities, and Actions (IOAS) – Environmental
Registry/Roles and Timelines
Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline	Priority
Replace unleaded gasoline-powered grounds-keeping and construction equipment with electric equipment where practically feasible	Energy - liquid fuels	Climate protection	F&I, Maint, PCS	On-going	Medium
Replace CNG buses and light-duty vehicles with renewable natural gas or electric busses	Energy - CNG	Climate protection	OPS, AvEnv, PMG	On-going	High
Construct an Automated People Mover (APM) or bus guideway from terminal to consolidated rental car facility to reduce the use of CNG-powered buses	Energy - CNG	Transportation, Climate protection, Fin/Ops	OPS, AvPlan, AvEnv, PMG	Long	High
Install evacuated tube solar collectors on rooftops of the Concourse B and C to provide steam/hot water for the buildings' HVAC system	Energy – Electricity, Natural Gas	Climate protection	F&I, AvEnv, PMG	Short	Medium
Install high efficiency water heaters in the HVAC system of Concourse B and C	Energy – Electricity, Natural Gas	Climate protection	Maint	Short	Medium
Decouple the heating plant and replace with high efficiency decentralized heating plants	Energy – Electricity, Natural Gas	Climate protection	Maint, F&I	Intermediate	Low
Improve insulation of building envelope on Concourse C, B, and New North Terminal building	Energy – Electricity	Climate protection	Maint, F&I, PMG	Intermediate to Long	Medium
Install revolving door on main passenger entrances to create an airlock and reduce heat transfer	Energy – Electricity, Natural Gas	Climate protection	Maint, F&I	Short	Medium
Install high reflectance roofing materials on rooftops of all terminals	Energy – Electricity		PCS	Short	Medium
Continue to install variable frequency drive (VFD) motors for fans, chillers, and pumps	Energy – Electricity	Climate protection	F&I, PMG, Maint	On-going	High
Continue to install motor efficiency controllers in escalators and moving walkways	Energy – Electricity		F&I, PMG, Maint	On-going	High

Table 5-2 *(continued)*

Sustainability Initiatives, Opportunities, and Actions (IOAS) – Environmental

Registry/Roles and Timelines

Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline	Priority
Install daylight timers lighting fixtures in the terminal building	Energy – Electricity		F&I, Maint, PCS	On-going	Medium
Continue to upgrade the efficiency of the existing HVAC system	Energy – Electricity	Climate protection	F&I, Maint, PCS	On-going	High
Purchase and install high efficiency HVAC systems when new terminal buildings are constructed	Energy – Electricity, Natural Gas	Climate protection	FI&, Maint, PCS	Short	High
Conduct study of species present	Fish & Wildlife		AvEnv	Ongoing	High
Evaluate quantity of open space and protected habitat displaced as part of every development action	Fish & Wildlife		AvEnv, AvPlan	On-going	High
Continue to implement the Part 150 Recommendations, including single-family residential sound insulation and other sound insulation programs.	Noise	Social	AvEnv	On-going	High
Complete a Ground Run-up Enclosure when feasible to do so, if warranted by the level of ground run-up activity	Noise		AvEnv, AvPlan	Long Term	Medium
Continue to implement the Fly Quiet Program to track compliance with the existing noise abatement procedures	Noise		AvEnv	On-going	High
Provide direct and easy access for passengers to access public transportation and hotel shuttles	Transportation	Climate protection	AvPlan, OPS	On-going	Medium
Toll curbside	Transportation	Climate protection, financial	AvPlan, AvEnv, OPS	Short-Intermediate	High
Develop a transportation management association to assist airport employees with ride-share programs, guaranteed ride home/emergency program, and transit support.	Transportation	Climate protection, social	AvEnv, EconDev, HR	On-going	High
Develop incentives for rideshare and loyalty programs	Transportation	Climate protection, social	AvEnv, F&B, EconDev	Short-Intermediate	Medium

Table 5-2 *(continued)*
Sustainability Initiatives, Opportunities, and Actions (IOAS) – Environmental
Registry/Roles and Timelines
Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline	Priority
Allow passengers and employee free transit rides with airline ticket.	Transportation	Climate protection	AvEnv, EconDev, PA	Short-Intermediate	Medium
Ride-free area for Link Light Rail to provide offsite curbside pick-up and drop off	Transportation	Climate protection	AvPlan, EconDev, PA	Short-Intermediate	Low
Continue review project designs and identify opportunities to recycle construction debris	Waste – Construction	Climate protection	AvEnv, PMG	On-going	High
Work with construction teams to ensure construction waste recycling efforts earn LEED certification credits	Waste – Construction		PMG	On-going	High
Continue to review contractor submittals for compliance with construction debris specifications and track performance	Waste – Construction		AvEnv, PMG	Short	UN
Donate project waste that cannot be reused or salvaged to a cooperating agency	Waste – Construction	Climate protection	AvEnv, PMG	On-going	Medium
Improve sustainability language and requirements into airport contracts	Waste – Construction		AvEnv, PMG	On-going	Medium
Update *Rules for Airport Construction, 2014 Edition*	Waste – Construction		AvEnv, PMG	Short	Medium
Recycle scrap metal from construction projects	Waste – Construction		AvEnv, PMG, PCS	On-going	Medium
Develop partnership with King County Solid Waste Division to explore secondary sorting (AKA mixed waste processing) facility opportunity for Airport and County waste	Waste – MSW	Climate protection, financial	AvEnv, F&I	Short	High
Implement high performance Green Cleaning policy and program to support LEED® certification for capital projects	Waste – MSW		AvEnv, F&I	On-going	High
Continue implementing ACI award-winning green concessions and dining program.	Waste – MSW		F&I, AvEnv	On-going	High
Evaluate options for Zero Waste certification for the Airport Office Building	Waste – MSW	Climate protection, financial	AvEnv, F&I	Short & Intermediate	Medium

Table 5-2 *(continued)*
Sustainability Initiatives, Opportunities, and Actions (IOAS) – Environmental
Registry/Roles and Timelines
Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline	Priority
Monitor and continue to assist airport concessions required to divert their waste, use durables or compostable or recyclable service-ware for "take away" meals provided in terminal areas and provide clearly labeled collection containers for recycling, composting, and garbage.	Waste – MSW	Climate protection, financial	AvEnv, F&I	On-going	High
Pilot new approaches to helping passengers quickly identify and separate recyclable and/or compostable materials to increase diversion rates at disposal locations in the Terminal	Waste – MSW	Climate protection, financial	AvEnv	On-going	Medium
Continue encouraging concessionaire donations to local food banks or the Airport USO	Waste – MSW	Climate protection, financial	AvEnv, F&I	On-going	High
Add liquid collection stations to all security checkpoints and optimize existing station location and signage	Waste - MSW	Climate protection, financial	AvEnv, F&I	On-going	High
Continue working with Maintenance, cargo operators and airlines to improve recycling at hangars, in Maintenance work areas, on the ramp, and other remote work locations	Waste - MSW	Climate protection, financial	AvEnv, F&I, Maint, Cargo	On-going	High
Continue to ensure that secondary containment is used for oil and solvent containers to contain spills	Waste – Haz		AvEnv, F&I, Maint, PCS	On-going	High
Evaluate the practice of using pig cleaning pipes instead of using solvents	Waste – Haz		AvEnv, Maint	Intermediate	Medium
Continue to purchase and place collection bins for used batteries, electronics and light bulbs	Waste – Haz		F&I, Maint	On-going	Medium
Prepare a Water Use Reduction Plan to identify specific conservation measures	Water Conservation		AvEnv, F&I	On-going	High
Document and manage construction water usage and other non-standard usage	Water Conservation		PMG, Maint, PCS	On-going	High
Implement and improve current sub-metering strategies	Water Conservation		F&I, Maint, PMG	On-going	High
Consider rainwater harvesting and reuse in new facilities where feasible	Water Conservation	Financial	F&I, Maint	On-going	High

Table 5-2 *(continued)*

Sustainability Initiatives, Opportunities, and Actions (IOAS) – Environmental

Registry/Roles and Timelines

Seattle-Tacoma International Airport

Candidate IOA	Focus Area/Goal-Objective	Other Sustainability Benefit	Responsible Groups	Timeline	Priority
Develop and implement a Green Concessions Policy with water conservation requirements	Water Conservation		AvEnv, EconDev	Short	Medium
Continue to plant native plants and drought-tolerant landscaping	Water Conservation		AvEnv, F&I	On-going	High
Install dual-flush toilets that use 0.8-1.6 gpf	Water Conservation		AvEnv, F&I	On-going	High
Install extended compost amended filter strips in all runway and taxiway infields	Water Quality		AvEnv, PMG	Immediate	Medium
Install low impact development where feasible and consistent with Airport operations and FAA design standards	Water Quality		AvEnv, PMG	On-going	High
Clearly designate aircraft deicer/anti-icer storage and transfer areas	Water Quality		AvEnv, F&I	On-going	High
Assess green roof on new facilities and construct where any resulting wildlife hazard threat is effectively managed	Water Quality		AvPlan, AvEnv	On-going	Low
Construct a centralized deicing facility (CDF) and collect and recover deicing fluids	Water Quality		AvPlan, AvEnv, PMG	Short	High

Notes: AvEnv: Environment & Sustainability; AvPlan: Aviation Planning; Cargo: Cargo; EconDev: Economic Development; F&B: Finance & Budget; F&I: Facilities & Infrastructure; HR: Human Resources: Maint: Maintenance; OPS: Operations; PA: Public Affairs; PCS: Port Construction Services; PMG: Program Management Group;

Timeframe: Short: 1-5 years; Intermediate: 6-14 years; Long: 15 years or longer; Ongoing: Ongoing/continuous

Priority: High, Medium, Low, UN: Undecided

Source: Port of Seattle, LeighFisher, Synergy Consultants, April 2018.

Table 5-3

Sustainability Initiatives, Opportunities, and Actions (IOAS) – Social / Community Outreach

Registry/Roles and Timelines

Seattle-Tacoma International Airport

Candidate IOA	Other Sustainability Benefit	Responsible Groups	Timeline	Priority
Prepare documentation to comply with NEPA/SEPA and coordinate the results with the public		AvPlan, AvEnv	Immediate	High
Conduct coordination workshops with interested parties concerning the SAMP		AvPlan, AvEnv, PA	On-going	High
Place all SAMP documents in the public libraries when study is complete		AvPlan	Short	High
Continue to survey employees regarding their engagement at the Port and concerns		HR	On-going	High
Implement the Port's social sustainability components in the Long Range Plan		HR	On-going	High
Leverage the Port's Development and Diversity Council, an internal group of experts who advise, generate ideas, advocate and communicate about employee development and diversity issues, policies, programs and initiatives		HR	On-going	High
Develop new and supporting existing Employee Resource Groups		HR	On-going	High
Develop new courses and encouraging employee education on diversity through the J. Loux Learning Library		HR	On-going	High
Recognize and support women and minorities at the Port through the Women's Initiative and the Champion of Diversity and Inclusion Award		HR	On-going	High
Continue to identify diversity gaps and needs		HR	On-going	High
Continue to prepare an environmental management report or a sustainability report		AvEnv	On-going	High
Create a speakers' bureau that regularly volunteers to present at local meetings and events		PA	On-going	High
Prepare annual Long Range Plan Report and highlight sustainability and triple bottom line, make available on the web		Strategic Initiatives Team, AvEnv	On-going	High
Place all master plan documents in local public libraries		AvPlan	Short	High

Notes: AvEnv: Environment & Sustainability; AvPlan: Aviation Planning; Cargo: Cargo; EconDev: Economic Development; F&B: Finance & Budget; F&I: Facilities & Infrastructure; HR: Human Resources: Maint: Maintenance; OPS: Operations; PA: Public Affairs; PCS: Port Construction Services; PMG: Program Management Group;

Timeframe: Short: 1-5 years; Intermediate: 6-14 years; Long: 15 years or longer; Ongoing: Ongoing/continuous

Priority: High, Medium, Low, UN: Undecided

Source: Port of Seattle, LeighFisher, Synergy Consultants, April 2018.

Climate Change and Infrastructure Risk Analysis

Climate change through mid-century is expected to continue produce periodic volatile weather conditions. The predicted long-term risk to Airport infrastructure is from increased extreme rainfall events, cooling needs, and facility effects associated with increased rainfall and temperatures.

6.1 Overview of Climate Change Effects

For this Sustainable Airport Master Plan, research was reviewed in early 2014 to identify current predictions concerning how the climate is expected to change in the future and a summary or synthesis was prepared. Because of the age of that research, and that climate change research has continued since that review, the material is provided in Appendix B *Climate Change Research Synthesis*. The following sections provide a very brief summary of that research, indicating predictions of further climate changes at a national level, and regional/state/local level. While the majority of the scientific community agree with the evidence that human activities, particularly those that generate greenhouse gases, are causing the greatest recent changes in the climate, this section notes that conclusion, but does not summarize that portion of the research.

Climate predictions represent general trends that might be expected in the future climate. Such predictions are largely based on the underlying assumptions. While the regional models discussed in the next sections can predict a smaller local level (relative to global models), the Puget Sound Region has diverse topography which can materially affect the results. Thus, the information presented in the synthesis included in the Appendix is intended to identify regional and state trends and how these trends may affect conditions in the Airport vicinity. Various infrastructure and facilities could be at risk to the effects of climate change. This chapter focuses on the infrastructure and facilities that could be at risk.

There have been many studies concerning potential significant changes in the climate that may occur over time. Because the conclusions depend upon the assumptions, this section was prepared to synthesize the prediction methodologies and specifically identify the leading models that are referenced in many of the studies considered in this synthesis. Key factors that have been identified as affecting future climate predictions are:

- The rate at which levels of greenhouse gas concentrations change (e.g., continue to increase or decrease, and if they decrease, at what levels)

- How strongly features of the climate - sometimes called climate vectors (e.g., temperature, precipitation, and sea level) - respond to the expected changes in greenhouse gases

- Natural influences on climate (e.g., volcanic activity, sun intensity) and natural processes within the climate system (e.g., changes in ocean circulation patterns)

With IPCC Fifth Assessment Report issued in 2013, scenarios called Representative Concentration Pathways (RCPs) were evaluated to provide a "flexible, interactive, and iterative approach" to climate change scenarios. The four RCPs that were selected by IPCC represent a range of greenhouse gas concentrations and climate forcing. These scenarios are identified by their approximate radiative forcing (RF, W/m^2) reflecting the effect that greenhouse gases have on climate. The RCPs indicate levels that could be reached during or near the end of the 21st century and are referred to as RCP2.6,* RCP4.5, RCP6.0, RCP8.5.** Table 6-1 summarizes the conclusions of the RCP scenarios.

Table 6-1
Summary of Global RCP Conclusions
Seattle-Tacoma International Airport

Scenario	Atmospheric carbon dioxide concentrations in 2100 (used as input to most model assumptions	Temperature Increase 2081-2100 relative to 1850-1900 baseline (°C)		Global Mean Sea Level Rise for 2081-2100 relative to a 1986-2005 (meters)	
		Average	Likely Range	Average	Likely Range
RCP2.6	421ppm	1.6°C	0.9-2.3°C	0.40m	0.26-0.55m
RCP4.5	538ppm	2.4°C	1.7-3.2°C	0.47m	0.32-0.63m
RCP6.0	670ppm	2.8°C	2.0-3.7°C	0.48m	0.33-0.63m
RCP8.5	936ppm	4.3°C	3-2-5.4°C	0.63m	0.45-0.82m

Source: Represented concentration Pathways Fact Sheet, Australian Government Department of Environment.

The RCPs are climate scenarios that represent:

- **RCP2.6**. The emission pathway is representative of scenarios that lead to very low greenhouse gas concentration levels. To reach these radiative forcing levels, 2050 global greenhouse gas levels would need to be reduced by 50% relative to 1990 levels and be near or below zero net emissions post 2050.

- **RCP 4.5**. This scenario is generally a stabilization scenario in which global greenhouse gas concentrations and total radiative forcing is stabilized by 2100 and some believe is generally consistent with ambitious emission reductions. In this

*Some research refers to RCP2.6 as RCP3DP - where 'PD' stands for Peak and Decline.

**Burkett, V.R., et al, 2014: Point of departure. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and* Sectoral *Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 169-194. Available at http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap1_FINAL.pdf scenario, greenhouse gas emissions increase slightly before they begin to decline after 2040.

- **RCP 6**. This scenario, considered another intermediate level, is another stabilization scenario in which greenhouse gas emissions and radiative forcing are stabilized by 2100. In this scenario, greenhouse gases peak in 2060 at 75% above today the decline to 25% by 2100.

- **RCP 8.5**. This RCP is characterized by increasing greenhouse gas emissions over time and is generally considered a business- as-usual scenario.

These evaluations, as well as other independent lines of investigation, demonstrate that the world is warming and that the primary cause of this warming is human activity. From the warming, changes in the climate over time are predicted to include: shorter duration of ice on lakes and rivers, reduced glacier extent, earlier melting of snowpack, reduced lake levels due to increased evaporation, lengthening of the growing season, changes in plant hardiness zones, increased humidity, rising ocean temperatures, rising sea level, and changes in some types of extreme weather.

In general, the following changes are expected in the future in the Pacific Northwest:

- **Temperature**. Warming is projected to continue throughout the 21st century. For the 2050s (2040-2069 relative to 1970-1999), annual average air temperature is projected to rise +4.2°F to +5.5°F, on average. Much higher warming is possible after mid-century. The frequency and duration of extreme heat events (days over 92 °F) is projected to increase.

- **Precipitation**. Average annual change in precipitation likely to be small (+1% to +2%) but wetter winters and drier summers are likely. More precipitation is expected to fall as rain rather than snow at mid and low elevations.

- **Heavy Rainfall**. Future occurrences of heavy rainfall are projected to be more frequent and more intense. Models project the heaviest 24-hour rain events will intensify by +22%, on average, by the 2080s. These are expected to occur 8 days per year by 2080 compared to 2 days per year historically.

- **Natural Variability**. Seasonal, year-to-year, and decade-to-decade variations such as El Nino Southern Oscillation (ENSO), and the Pacific Decadal Oscillation (PDO) will remain important features of local climate, at times amplifying or counteracting the long-term trends caused by rising greenhouse gas emissions.

6.2 Climate Evaluation Using the ACRP Tool

In 2015, the Airport Cooperative Research Program completed Report 147 *Climate Change Adaptation Planning- Risk Assessment for Airports*. This project produced both a tool to assist airports with identifying climate effects but also a guidebook to help airport practitioners understand the specific impacts climate change may have on their airport, to develop adaptation actions, and to incorporate those actions into the Airport's planning processes. Using these resources, the effects that can be anticipated in 2030 and 2060 are based upon the climate research noted in Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. The results of use of the ACRP Report 147 tool (Airport Climate Risk Operational Screening -ACROS) produced the information shown in Table 6-2.

Table 6-2
Summary of Projected Climate Change Conditions (Days/Year)
Seattle-Tacoma International Airport

	2013	2030			2060		
Climate Vector	Baseline	25th PCTL	Median	75th PCTL	25th PCTL	Median	75th PCTL
Hot Days (≥90°F)	2.3	3.1	6.4	12	4.3	12.4	26.5
Very Hot Days (≥100°F)	0	0	1.6	4.8	0.1	4.2	12.9
Freezing Days (≤32 °F)	10.1	1.7	5.5	8.7	0	1.9	6.6
Frost Days (≤32 °F)	80.2	64.8	68.8	71.9	41.7	51.7	59.4
Hot Nights (≥68 °F)	0	0.1	0.8	1.4	1.6	5.2	12.8
Humid Days (≥65 °F)	0	0	0.1	0.2	0.8	1.1	1.3
Snow Days (>2 in)	8.3	3.4	4.8	5.5	0	0.6	1.2
Storm Days (>0.15 in)	42.4	42.7	43.5	44.5	43.1	45.3	47.8
Heavy Rain (1 Day)	13.4	13.7	14	14.5	14.2	15	16.1
Dry Days	27.2	28.5	29.6	30.6	30.4	33.2	35.6
Sea Level Rise (BFE)	0	0	0	0	0	0	0
Cooling Days (≥65 °F)	69.1	75.3	80.6	80.8	84.6	98	98.3
Heating Days (≤65 °F)	244.8	230.2	231.3	234.6	208.2	211.1	219.2

(PCTL = percentile, BFE = base flood elevation)

Source: LeighFisher, using ACROS.

Note: See Appendix C ACROS Results concerning the climate vectors above.

The ACROS tool enables the user to identify the potential changes in climate in various periods based on specific climate vectors in years 2030 and 2060. The climate vectors that the ACROS tool enables the evaluation are shown in Table 6-3. High confidence indicates less uncertainty than medium or low confidence; low-confidence vectors have the most uncertainty. Note that even "low" confidence implies that the vector may still be of value, and contrasts sharply with no confidence, as is seen for vectors like wind and fog. In the latter case, it was either (i) unfeasible to construct the vector based on data constraints, or (ii) the vector was constructed for the historical period but was impossible to project into the future because of biases in the models.

Table 6-3
Climate Change Metrics/Vectors
Seattle-Tacoma International Airport

Climate Vector	Description	Confidence
Hot Days	High temperature $\geq 90^{o}$F	High
Very Hot Days	High temperature $\geq 100^{o}$F	High
Freezing Days	High temperature $\leq 32^{o}$F	High
Frost Days	Low temperature $\leq 32^{o}$F	High
Heating Days	Mean temperature $\geq 65^{o}$F	High
Cooling Days	Mean Temperature $\geq 65^{o}$F	High
Cooling Degree Days	Departure of mean temperature $\geq 65^{o}$F	High
Heating Degree Days	Departure of mean temperature $\leq 65^{o}$F	High
Hot Nights	Low temperature $\geq 68^{o}$F	High
Humid Days	Mean dew point temperature $\geq 65^{o}$F	High
Snow Days	Snow accumulation $\geq$2 in.	Medium
Storm Days	Thunderstorm rainfall $\geq$0.15 in.	Low
Heavy Rain (1 day)	Daily rainfall $\geq$0.8 in.	Low
Heavy Rain (5 day)	Total 5-day rainfall	Medium
Dry Days	Consecutive days of rainfall <0.03 in.	Medium
Sea Level Rise	Daily runway flooding (National Flight Data Center elevation)	High
Sea Level Rise – Base Flood Elevation (BFE)	Relatively infrequent but substantial flooding	High
Wind	Prevailing wind direct and speed	None
Fog	Visibility $\leq$0.25 miles	None

*Vector were investigated, but not included in the ACROS tool due to lack of confidence in existing models.

Source: ACRP Report 147.

6.2.1 Effects Predicted for Sea-Tac

Two key climate change effects are expected to be felt at Sea-Tac Airport: increase rainfall intensity and increased temperatures. As noted in Table 6-2, heavy rain events are expected to increase from today at 13.4 days of heavy rain to a median of 14 days of heavy rain. The size and frequency of regional flooding events are projected to increase with warmer temperatures. Warmer temperatures increase flood risk by causing more precipitation to fall as rain rather than as snow.

The Puget Sound region is expected to experience overall sea level rise throughout the 21st century, increasing the likelihood of coastal flooding and erosion. Locally, some areas may experience sea level rise or decline, and changes in sea level are expected to occur in a variable, non-linear fashion. While the region is expected to be affected by sea level rise, Sea-Tac Airport is located about a mile east of the coast and at an elevation of 433 feet above sea level and is not expected to experience any direct effects of sea level rise.

Low-lying areas and most of the Puget Sound shorelines are expected to experience increase in sea levels throughout 2100. Regionally, absolute sea level is projected to rise by an average of 24 inches by 2100. An increase of sea level of this magnitude will increase the frequency of coastal flooding events. An increase of sea level of only 6 inches increases the probability of the 100-year flood event from a 1% annual probability to 5.5%. An increase of more than 24 inches in sea level shifts the 100-year flood to a 1-year flood, or a 100% probability of occurring every year.

Based on the data noted in Table 6-2, in addition to extreme rainfall events, the primary effects at Sea-Tac are expected to be increased cooling demand. The number of Hot Days (days where the temperature is above 90°F) is expected to increase from 2.3 days in 2013 to a median number of days of 6.4 days by 2030 and 12.4 days by 2060. Very Hot Days (days were the temperature is above 100°F) is expected to increase from 0 days in 2013 to a median number in 2030 of 1.6 days and to 4.2 days in 2060. As a result, the number of Cooling Days is expected to increase 16% by 2030 (an increase from 69.1 days to 80.6 days by 2030). By 2060 relative to 2013, Cooling Days are expected to increase nearly 42% from 69.1 days to 98 days.

One of the tasks undertaken in SAMP Task 6.12 was to consider the effects of climate change on energy use. That evaluation found that in the last 44 years, the annual cooling degree days have increased on average in that time span. These ongoing climate and climate change impacts can affect the building HVAC.

Some amount of heating has been required for the Sea-Tac Airport Main Terminal for most of the year. Cooler evening hours when the internal heat gain is low and there is no solar heat gain, perimeter spaces may require heating, even in the warmer months (April to June, and September to October). Heating degree days are the number of degrees that a day's average temperature is below 65°F. Since 1970, the temperature fluctuations year-to-year have had an impact on the building's heating components and therefore the energy consumption and cost to operate the equipment (more steam production required). Heating degree days per month from 1970 to 2014 show that a slight reduction over time has been occurring whereas the trend in Cooling Degree Days (the number of degrees that a day's average temperature is above 65°F) have been increasing.

6.2.2 Climate Change and Adaptation Activities

The prior section presented a summary of the extensive research that has been conducted about potential changes in climate. Since scientists generally agree that the climate is already changing, and that it will continue to change over time in response to past and present human activity, substantial research and discussion is also occurring about how these changes/effects can be addressed. There are generally two categories of potential responses to human-induced climate change:

- Mitigation (reducing activities that cause climate change) and
- Adaptation (adjust the practices, systems, and structures to reduce the negative consequences and take advantage of the opportunities of beneficial changes).

Climate change adaptation planning is a multi-step process aimed at increasing the resilience of infrastructure and operations when confronted with the range of projected climate change impacts. The steps suggested by a number of parties experienced with preparing a climate change adaptation plan is to:

1. Identify existing climate conditions
2. Prepare a projection of anticipated climate changes over time
3. Identify critical assets/facilities and operations
4. Inventory vulnerability of assets and operations
5. Prioritize risk
6. Identify strategies to reduce or eliminate risk

In adaptation planning, it is important to update and re-evaluate the critical assets and the vulnerability. How risk is viewed (risk perception) and accepted (risk tolerance) plays a significant role in the risk evaluation. Risk perception and tolerance can vary widely between individuals, over time, and/or with different thresholds. Risk will also change over time. New information on climate change and climate impacts will become available, allowing for better quantification of risks. Non-climatic factors like changes in air travel demand or growth will also place additional demands on an airport facilities, services, and systems, compounding the risk associated with climate change impacts. Finally, preparedness planning itself may reduce risk associated with specific climate change impacts.

The Appendix B *Climate Research Synthesis* summarizes activities at a national, state, and local level to plan for and adapt to the anticipated changes in climate. As is noted, there is a wide range of actions that are being taken to prepare for climate change.

6.2.3 ACRP Tool Results for Sea-Tac Airport Sustainable Airport Master Plan

The Sustainable Airport Master Plan included both the preparation of a greenhouse gas inventory, but also a synthesis of anticipated climate change conditions and how those conditions might affect airport facilities. This section documents the later portion of the evaluation, as the greenhouse gas considerations are discussed in Chapter 3 *Sustainability Baseline and Forecast Business-as-Usual Conditions*. The term climate is defined by very long-term processes over many years to decades, whereas the term weather deals with day-to-day weather variations that are experienced.

The risk analysis conducted for the SAMP relied upon the Airport Cooperative Research Program (ACRP) Report 147 *Climate Change Adaptation Planning- Risk Assessment for Airports*. Accompanying the ACRP report is an electronic assessment tool called Airport Climate Risk Operational Screening (ACROS) that was developed to help airports ask the question, "Within the entire airport, what's most at risk to projected climate changes?" As the report states, the ACROS tool uses a formula to compute an estimated level of risk for assets and operations at an airport.

In conducting the risk analysis, the risk was characterized as High, Medium, and Low. This characterization was based on the consideration of criticality and vulnerability.

Criticality is defined as "the importance of the asset or operation to overall functioning of the airport, and high criticality can reflect a single asset or operation that is a significant component of the airport system, as well as an asset that has a high degree of connectivity between other assets and operations within the airport system". In contrast, vulnerability is "the sensitivity of an asset or operation to a climate stressor." Vulnerability is dependent on the ability of the existing infrastructure and operations to accommodate a specific climate change vector (e.g., higher temperatures) as well as the degree of change expected.

In preparing the Risk Assessment for the SAMP, the Port is meeting its initial Climate Protection Goal (see Chapter 2.2).

The ACRP tool evaluates the potential impact of the change in climate on the airport assets. The term "impact" refers to climate stressors, such as floods, higher temperatures, and heavy rainfall events:

1—Asset/operation is unlikely to be affected by this impact.
2—Asset/operation is likely to be impaired by this impact.
3—Asset/operation is likely to be significantly impaired or disabled by impact.

The initial ranking of risk includes the traditional dimensions (likelihood × consequence = vulnerability), as well as a few additional dimensions:

- **Timing**. A ranking of the climate risk is provided for both the years 2030 and 2060;
- **Criticality and connectivity**. The importance of each asset for overall airport functioning is assessed.
- **Magnitude of change to climate vector**. A larger change to a more hazardous state is considered of greater importance than smaller changes. This assumption is a simplification, but it is useful to help initially distinguish higher and lower risk assets and operations.

The climate change risk estimate used by the ACROS tool is simple multiplication:

Risk = (Criticality)× (Vulnerability)× (Climate Vector _)

Where:

Criticality: an integer from 1–3 (user input identified earlier). This variable estimates degree of importance to the airport.

Vulnerability: an integer from 1–3 (user input, identified earlier) which estimates the consequence of an individual stressor × likelihood of negative impact to an individual asset (the traditional dimensions of risk).

Climate Vector D: the change, in number of days, for each vector (contained in the tool) which estimates magnitude of shift toward more hazardous conditions.

This formula is used by the ACROS tool to rank risks is a first step in developing insight into the airport's highest priority risks. The tool uses this formula to group assets and operations into three categories using natural breaks (a statistics-based data clustering method): red, yellow, and blue for higher to lower overall risk. Although the tool and process are not structured to translate risk exposure directly into cost, this qualitative approach provides an initial, reasoned judgment as to the exposures toward which airports could direct their attention and resources.

Appendix C *ACROS Results* shows the results of the evaluation**.** The risks in these top two categories are:

- High
  - Failure of the building envelopes
  - Reduced aircraft throughput capacity
- Medium
  - Change in tourism and seasonal enplanements
  - Degradation of roofing material and external seals (similar to the building envelop that has a high risk)
  - Increased HVAC demand
  - Potential drawing in smoke (from regional fires) throughout outdoor air handling system
  - Reaching utility capacity due to increased demand
  - Decreased utility reliability
  - Failure of underground utilities due to expansive soils
  - Loss of pavement integrity
  - Reduced road visibility
  - Decreased food resources
  - Outbreak of contagious diseases

6.3 Port of Seattle Airport Infrastructure and Facility Risk Analysis

In 2015, Seattle-Tacoma International Airport conducted research on local climate impacts and vulnerability assessment approaches. This included meetings with UW Climate Impacts Research Group, SoundTransit, and Washington State Department of Transportation (WSDOT). The two latter organizations have conducted federally-funded climate change vulnerability assessments and provided several reports and lessons learned.

This research was applied to the results of the ACRP Tool titled the Airport Climate Risk Operational Screening Tool (ACROS). As with any vulnerability assessment, the greatest organizational effort is to determine if these climate vectors currently cause operational or infrastructure impacts to an airport, and to what degree they might cause impacts in the future (i.e. where the airport is vulnerable to climate change)

6.3.1 Assessment of Significant Impacts

The challenge with assessing climate vulnerability at a location like Sea-Tac Airport is that impacts to facilities and operations from weather have never been severe (e.g. airport closures or crippling damage). The greatest impact to the Airport's facilities or assets occurred due to the Nisqually earthquake in 2001 (non-weather). The greatest impact to the Airport's operations was also the Nisqually earthquake, along with snow/ice, and incidents at other airport locations affecting air traffic.

To date, impacts associated with climate change such as summer periods of temperatures above 90°F, wind storms, and heavy precipitation events are within the normal variability of various weather patterns (i.e., El Nino Southern Oscillation, Pacific Decadal Oscillation, etc.) and have not significantly impacted operations. While not directly monitored, anecdotally these events have resulted in increased energy use for indoor temperature regulation, downstream bed scour, and channelization on overflowing creeks, and increased pumping system maintenance.

The climate change vectors identified by the ACROS tool as having High or Moderate impacts were further evaluated in relation to the current capacity of the impacted systems or infrastructure through internal stakeholder meetings, or, where the impact was predicted to be minor, an assessment of what might occur. These impacts were then assigned a "vulnerability" category (green, orange, red) that denotes whether the current operations and asset maintenance/replacement plan will be sufficient to address the potential impacts. The results are presented in Table 6-4.

As shown in Table 5-4, almost all identified vulnerabilities can be managed within current operations and asset replacement cycles, except for the stormwater infrastructure.

6.3.2 Stormwater and IWS Infrastructure

To address concerns about the future capacity of the Airport's stormwater infrastructure, Port staff convened a group of internal stakeholders. The stakeholders explored several different approaches to assess vulnerability including exploration of asset issues or failures to date, predicted future climate impacts, and a criticality analysis methodology used by Federal Department of Transportation-funded evaluations.

Table 6-4
Sea-Tac Vulnerabilities from Climate Change
Seattle-Tacoma International Airport

Climate Change Vector	Potential Impact	Vulnerability at Sea-Tac Airport
Increased rainfall intensity in winter	Flooding/pooling on runways	Increased demand on stormwater conveyance systems
Higher summer temperatures	Hotter terminal spaces	Increased cooling demand (approx. 16% by 2030)
	Reduced pavement integrity	Faster degradation of paved surfaces
	Runway scheduling	Heavy aircraft will require use of 34R-16L on very hot days
	Stress on roofing and building materials	Increased maintenance/replacement of roofing or building materials
Decreased summer precipitation	Increased regional wildfires and smoke	Smoke could affect flight paths and local air quality
	Decreased summer water supply	Increased water conservation measures
Increased storms (high winds and rain)	Runway scheduling	Aircraft spacing may be increased during storm events
	Power outages due to wind	Capacity of generator systems

Legend:
- Red: Vulnerability should be addressed in near-term before scheduled replacement/renewal (none applicable)
- Orange: Vulnerability should be addressed in medium-term as assets are replaced/renewed
- Green: Vulnerability is already addressed in current operations and asset replacement cycle, but should be monitored for changes

Source: Port of Seattle, March 2018.

The group determined that it was easier to evaluate vulnerability to systems or areas of the Airport (e.g. runway drainage basins) rather than by groups of individual asset types (e.g. ponds, lift stations, manholes) listed in the asset management system.

The greatest challenge of evaluating the vulnerability of Sea-Tac Airport's stormwater infrastructure is that it's contained underground and there is no simple way to evaluate how close to capacity it is during storm events. There have been no incidents of runway ponding or flooding in the past, and until that specific impact is reached, there will be no easy way to determine how close to capacity (i.e. how vulnerable) it operates during heavy rainfall events.

The runway and apron conveyance systems for Sea-Tac's pre-2015 infrastructure is designed to a 25-year storm event, based on 24-hour duration. The runway conveyance systems for the center runway, rebuilt in 2015, were assessed based on the ability to manage surface flooding without impacting runways and taxiways and pipe replacement cost. Pipe size was increased to a greater design criterion (i.e., either 50- or 100-year 24- hour event, depending on how easily the capacities of different components could be accommodated) in those segments posing possible flood risk to runways and taxiways, and where incremental pipe costs were considered nominal. While this approach proved successful to address a perceived vulnerability, it was not done in a systematic way (i.e. not incorporated into standard project evaluation criteria), which could be missed in a future asset replacement project.

6.3.3 Recommendations

The results of this assessment suggest that, except for stormwater infrastructure, most of Sea-Tac's climate change-related vulnerabilities can be addressed via the existing operation and asset management plans, and no further preparation is required. However, it is important to monitor for changes.

One suggestion discussed with Sea-Tac's maintenance department is to develop a methodology within the Computerized Maintenance Management System (Maximo) for tracking when an asset or facility is repaired or replaced due to a weather-related impact, along with the existing system that monitors the frequency of replacements.

Monitoring of the Airport's energy use relative to ambient air temperatures is already on-going.

The only system of assets that was deemed 'moderately' vulnerable at Sea-Tac Airport is the stormwater and IWS infrastructure. Based on the results of the internal stakeholder meetings, it is recommended that the Airport conduct a thorough re-examination of the Airport's Design Criteria, and re-evaluate the conveyance modeling, particularly as it relates to stormwater conveyance systems to ensure that as assets are replaced, they can accommodate increased rainfall intensity and higher summer temperature events.

Appendix A
Task 6.12 Report – Total Cost of Ownership

Background

Task 6.12 is the analysis of the airport utilities and buildings from a sustainability viewpoint. Energy and utility savings are analyzed with Total Cost metrics to predict impact of future airport expansion and renovation at a Master Planning Level.

1 INTRODUCTION

One of the key functions of a master plan is to develop the goals, guidelines, and objectives necessary to meet the current and future needs of the airport in terms of ongoing sustainable operation, passenger growth, economic growth, and other demands. Alternative solutions are defined as part of the process to provide a flexible plan to meet these goals, guidelines, and objectives. These alternatives provide different paths and solutions that meet the needs of the airport. Each alternative is considered both for its merit as well as potential pitfalls during the master planning analysis.

This task looks specifically at how these different alternatives considered in the overall master plan affect the built environment and infrastructure of the airport. To increase passenger traffic and economic growth, buildings must be modified, expanded, or added to the current configuration, which in turn impacts the provided utility systems such as HVAC, plumbing, and electrical distribution. Each of the alternatives impact these in different ways. In addition, each of these alternatives impact costing over the life cycle of the airport.

2 TRADITIONAL MASTER PLANNING VS. SUSTAINABLE MASTER PLANNING VS. SUSTAINABLE MASTER PLANNING/TOTAL COST OF OWNERSHIP (TCO)

2.1 Why are we doing it?

Planning for future passenger growth requires careful development of the buildings, operations, and infrastructure of the Airport. Without a strong plan, growth would be erratic, be prematurely outdated, not meet the needs of the Airport, and could potentially cause future conditions that would hinder operation of the airport.

With the increase in passenger traffic and operations at the airport, the airport facilities and utility infrastructure must also increase to meet these requirements. Developing a plan for the growth of the facilities and infrastructure that anticipates this growth of passenger traffic is the most important function of a strong master plan.

Building and utility growth have traditionally been focused solely on developing the needs of what happens inside the space instead of also focusing on how the space impacts what is happening outside of the space. A focus of sustainability – building infrastructure that minimize the impact to the environment – has become a major part of modern construction. Federal, state, and local building codes and ordinances continue to require new construction to be more efficient and environmentally friendly. Energy codes focus on energy efficiency of the facility, while environmental agencies focus on how the facility reduces and manages air, water, and waste pollution.

Developing the plan for the buildings and infrastructure allows the Airport to integrate their goals with the plan for growth, not only in the operation of the Airport, improving costs, and improving the passenger experience, but also in minimizing the Airport's impact on the environment. Understanding these influences will also help determine the overall financial cost of the growth. The objective of the Master Plan is to maximize the spaces available to accommodate the anticipated passenger traffic, while minimizing the environmental impacts and carbon footprint of the Airport as a whole.

Understanding the impact of decisions made today is important for this planning process. Using the information we know today about how the Airport operates with the goals of the future growth allows us to predict future outcomes. Decisions made within the Master Plan can significantly impact future growth or operations. Understanding the existing limitations of both buildings and the utility infrastructure allow us to plan for the future by maximizing use prior to renovation, renewal, or expansion. Smart development not only reduces financial costs of the growth, but can be sustainable. Decisions of the environmental impact of inefficient systems or wasteful operations are weighed against the impact of construction waste and the social and passenger impacts of construction.

To do this, it is important to determine what the important goals of the Airport are and to rank decisions based on these goals. These goals should be aligned with the airport's strategy and identify the appropriate key performance indicators (KPI) that the airport will establish for the levels of service. Growth of buildings and infrastructure at the expense of the environment does not make sense. Ranking what is important – passenger accommodations, passenger experience, social impacts, financial costs, and environmental impacts – will help frame decisions about how the Airport should grow. Development of a methodology to help frame these decisions is crucial in determining when to build, how to build, and what will be impacted when you build.

In order to prove that the decisions made today meet their intended purposes, it is also important to develop metrics and measurements to validate and verify that the intended goals are being met. As the Master Plan is being executed, these methods will continue to frame the means to verify that growth meets the expectations of airport operations without sacrificing the environment or social components or be done in a way that does not consider the entire life of the decision.

For these reasons, this task investigates current environmental conditions at the Airport regarding the Terminal and other buildings and the utility infrastructure. Understanding the current condition provides a method to predict future impacts and possibilities.

2.2 Traditional Master Planning

Traditional master planning is a multi-year process to develop a long range vision to guide investment of the built environment, facilities, campus, and infrastructure to support the airport's strategy through defined goals. Master planning provides a high-level plan set out to define objectives and strategies to manage this development and investment over time. The master planning process documents how the Airport can develop and redevelop in the future by exploring opportunities for expansion and renovation that is well thought out and meets the needs of the Airport. It does not dictate exactly how the expansion will occur, but rather develops the framework of what should occur.

Master planning is important because it allows the Airport Stakeholders and community to understand what the overall goals are and how these impact the overall campus and surrounding community. It identifies areas that should be developed and those areas that should be redeveloped or renovated to meet these goals.

Master plans contain non-physical considerations such as funding sources, economic considerations, scheduling when these changes should occur, and what needs to be completed before these changes can occur. The Master Plan serves as the blueprint for how the final buildout should look based on the anticipated growth, development, and needs for the Airport. It is a visual representation of where the Airport is now, where it should be or needs to be in the future, and what is required to get there. Since the Master Plan can also be time sensitive, it is equally important to define when it should happen.

For buildings and utility infrastructure, this means determining what buildings or systems need to be added, modified, or removed to meet the overall growth and operations goals. It looks at operational flows to determine the best "path" for efficient operation of the Airport. It identifies passenger and cargo growth expectations, the predicted schedule for this growth, and the needs to meet the growth. Undeveloped or previously developed land necessary for these new structures need to be developed and prepared in anticipation of this expansion. New buildings and facilities can create problems with traffic, parking, and transportation around the airport. Utility services that support the airport such as water, wastewater, and energy will need to be able to accommodate the additional capacity by the time that the new facilities open. The expansion of the airport can bring additional noise and other impacts to the surrounding community. Master planning considers all of these factors and attempts to identify these impacts and what should be done to mitigate any issues.

2.3 Sustainable Master Planning

Where traditional master planning looks at expected growth and improved flow of facilities and infrastructure, sustainable master planning combines these goals with the established goals and objectives to minimize the environmental impact and improve overall efficiency at the Airport.

A sustainable master plan focuses on what is meant to be a sustainable airport and how the Airport meets their objectives and goals associated with sustainability. It defines the values for which to evaluate decisions made during the master planning process. The different options are reviewed within the Master Plan to evaluate them based on their impact to the environment and the consequences thereof.

The sustainable master plan combines existing policies, strategies, goals, and objectives into a single streamlined plan that integrates with the projected development of the Airport. Where traditional master plans focus primarily on a single entity (i.e., the Airport), sustainable master plans have a community focus. Reducing impacts to the community by setting goals and commitments that align to the Airport's sustainability values is an important function of the sustainable master plan. Metrics and strategies developed within the sustainable master plan can be tracked and reported demonstrating the progress made during the execution of the plan.

2.4 Sustainable Master Planning with a TCO Focus

Costs associated with traditional master plans are typically focused on capital improvements and rarely focus on life cycle costs of operation and maintenance and the cost to renew the asset in order to maintain the function of the Airport. Capital funding set aside to plan, design, and build new assets rarely extend to these ongoing costs.

It is important to understand the total cost of ownership (TCO) of an asset. The Total Cost of Ownership represents all costs associated with the life cycle of an asset, from initial planning to design to construction to operation and maintenance to replacement to demolition. It considers all costs associated with the asset so that decisions regarding development and growth provide the "whole truth" about the impacts of building the asset.

Decisions based solely on "first cost" may not present the overall economic impact of the decision. For example:

> Option 1: Standard efficiency asset, standard construction. Lower first cost.
>
> Option 2: High efficiency asset, improved construction. Higher first cost.
>
> Option 1 will cost less upfront, but additional energy costs, additional operation/maintenance costs, and shorter design life will end up making Option 1 cost more over the life cycle of the asset.

TCO and sustainability can have similar goals and objectives. Both are concerned with assessing the long-term impacts of decisions within the master plan, focusing on ways to extend life of an asset with the smallest impact. Both require analysis of a diverse range of inputs and rely on similar data for that analysis. Both sustainability and TCO consider the impacts of operations in its analysis. Both consider optimal situations for disposal versus recycling of the asset (but the factors considered are often times different).

Sustainability decisions are not always compatible with TCO, however. Whereas TCO combines all of the relevant costs of an asset into a combined cost and uses that cost in making an investment decision, many of the factors considered in sustainability cannot be quantified in terms of cost.

There are several approaches that can be used to make decisions when both sustainability and TCO are consideration for decisions. One option is to use a mixed set of criteria to judge an option. Both TCO and sustainability decisions are made independently and then factored into an overall score of the decision. Another approach is narrow down options based on a set TCO criteria. The filtered results are then compared based on sustainability. The final approach is to make decisions about options based on their overall sustainability. Once the options are narrowed down based on acceptable environmental impact, they are reviewed using TCO to find the best overall option.

2.5 Using the Information Gathered From the SAMP in "How We Build"

This task plays an important part in the overall Sustainable Airport Master Planning (SAMP) process. Decisions made about sustainability and costs not only affect the buildings and utility infrastructure of the Airport, but it also impacts other facets of the Master Plan.

3 WHAT IS INCLUDED IN REPORT?

This report summarizes the analysis and findings of the two-year study regarding master planning the combined TCO-focus and sustainable focus of future growth of buildings and utilities at Seattle-Tacoma International Airport (Sea-Tac).

This section provides background of the master planning process, the impacts of building and utility growth on the overall sustainability goals for the master plan, and how Total Cost of Ownership can be used to evaluate these impacts to aid in the decision-making process and compare several different scenarios. It defines the basic background of the various buildings and utilities at the Airport.

Section two describes the *Objectives* of this process. It defines what we want to discover through this process and how this discovery will connect to other Tasks within the Sustainable Master Plan.

Section three provides the approach that was used to define, analyze, and develop the existing conditions of the airport facilities, utilities, and costs and what procedures were used to predict and forecast future conditions.

Section four documents the findings on energy, water, and utility consumption and associated costs for the buildings analyzed within this task. This information is then converted to various metric "key performance indicators" that are used to understand how energy and water are used for various operations at a master planning level. Capital costs, operating costs, renewal costs, and demolition costs are estimated based on existing conditions in order to develop the total cost of ownership of the airport's asset.

Section five forecasts the future utility consumption, cost, and environmental impacts based on various sustainable construction strategies ranging between standard efficiency (energy code minimum compliance) to a net neutral energy building. A methodology is developed to test and predict overall costs and socioenvironmental impacts of each of these targeted levels of sustainable construction. The information is analyzed and used to forecast the overall impacts, which are documented in this section.

Section six provides the case study of comparing the major growth model comparison for Sea-Tac. Analysis of the various options are tested based on overall TCO, utility consumption, infrastructure, and environmental impact.

Section seven provides other building and utility-related considerations to maximize efficiency and productivity, minimize costs, minimize environmental impact, and minimize the dependency on public utilities.

The final section provides a conclusion of the findings and defines how the information derived from this task will integrate to other sections of the SAMP.

4 PORT GOALS AND AIRPORT OBJECTIVES

4.1 Port of Seattle Strategic Goals[1]

One of Seattle-Tacoma International Airport's Purpose and Strategic Goals is "lead the US airport industry in environmental innovation and minimize the airport's environmental impacts".

The Port of Seattle has recently published their new "mission statement" for Port owned and operated developments and assets. The Century Agenda describes specific strategies and objectives that assist the Port to grow as an international leader.

Further understanding of these goals and objectives and how they relate to the SAMP is discussed in Technical Memorandum 7.

This task focuses on the buildings and energy and water utilities at the airport. One of the major goals for the Port of Seattle is to "be the greenest and most energy efficient port in North America". A big part of this energy efficiency and environmentally friendly goal comes from responsible development of these buildings and utilities.

Sea-Tac is a renowned sustainable airport in one of the greenest cities in the world. Reducing environmental impacts is key to this goal. Port goals to "meet all increased energy needs through conservation and renewable sources" and "reduce air pollutants and carbon emissions" both demonstrate this commitment to sustainability. Understanding how these goals can be implemented is a big part of the SAMP objective, especially as discussed within this task.

4.1 Aviation Sustainability Objectives[2]

Technical Memorandum 7 further analyzes specific objectives defined by the Seattle-Tacoma International Airport Aviation Planning group. One of the primary strategic goals listed in the Aviation Business Plan in 2014 was to "operate a world-class international airport by managing our assets to minimize the long-term total cost of ownership." This goal is directly related to this task, and provides guidance to the importance of why understanding asset costs throughout their entire lifecycle needs to not only be understood, but also understand how decisions made can influence these costs.

In addition, the Port of Seattle Commission adopted 25-year environmental goals on October 4th, 2011, referred to as the *Port's Century Goals.*. The goals directly impact the amount of energy used and resulting environmental impacts from their use. Within these goals, specific metrics involving buildings and utilities included the following:

- Reduce air pollutant emissions by 50% from 2005 levels.
- Reduce greenhouse gases from all port operations by 50% from 2005 levels.
- Zero additional energy use from 2012; future growth in energy usage is met through conservation and renewable sources.

An energy focus group further defined energy related goals as follows: Reduce electricity consumption by at least 5% by 2020 from a 2012 baseline, and additionally as determined by increased energy demand. Increase the percentage of electricity consumed that comes from renewable or zero carbon sources by 3% by 2034 from a 2012 baseline. Reduce natural gas consumption by at least 5% by 2020 from a 2012 baseline, and additionally as determined by increased energy demand. Increase the percentage of natural gas consumed that comes from renewable or zero carbon sources by 50% by 2034 from a 2012 baseline.

Finally, a water conservation focus group defined the water related goals as follows: Implement water saving, grey-water use, and rainwater collection measures that will reduce projected future consumption of potable water in 2020 and 2025 by 6% and 12%, respectively from a 2013 baseline.

4.2 Asset Management Objectives[3]

The Port of Seattle has a sustainable asset management policy (EX-15, *Sustainable Asset Management* Policy, dated 6/27/2007) that is used to guide decisions made during planning, design, construction, and operation/maintenance for a building managed by the Port. Policy EX-15 was adopted on 2/6/13 by the Port Commission. The policy intent is to determine and minimize the total cost of ownership of an asset, reduce long-term capital and operating costs, guide decision making on disposal of assets, forecast future renewal and replacement, and whenever possible, and to the extent practicable, reduce adverse environmental impacts and conserve natural resources. The policy uses a combined environmental and economic approach to guide decision-makers through these processes.

The policy has four primary purposes:

- Provide an added tool for the Port Commission in the decision making process.
- Reduce long-term capital and operating costs

- Support environmentally-sustainable development
- Conserve Resources.

A team of Sea-Tac employees was chartered in 2013 to discuss how to better apply Policy EX-15 to current and future assets that are managed by the Port. The proposed short term and long term goals for the process were:

Short Term Goals:

- On-boarding of new assets (first priority):
  - Documenting the existing "AS IS" process that currently exist
  - Identify gaps with information flow and process handoff with the current processes
  - Develop desired outcome processes, making connections to fill in the gaps
  - Implement these desired outcome processes, communicating roles and responsibilities, and providing training and tools
  - Begin to measure compliance to the process by 2014
- Existing assets that have already been recorded in PeopleSoft, Maximo and/or F&I Asset Management System (second priority):
  - Coordinate F&I and Maintenance hierarchies for existing assets in Maximo

Long Term Goals:

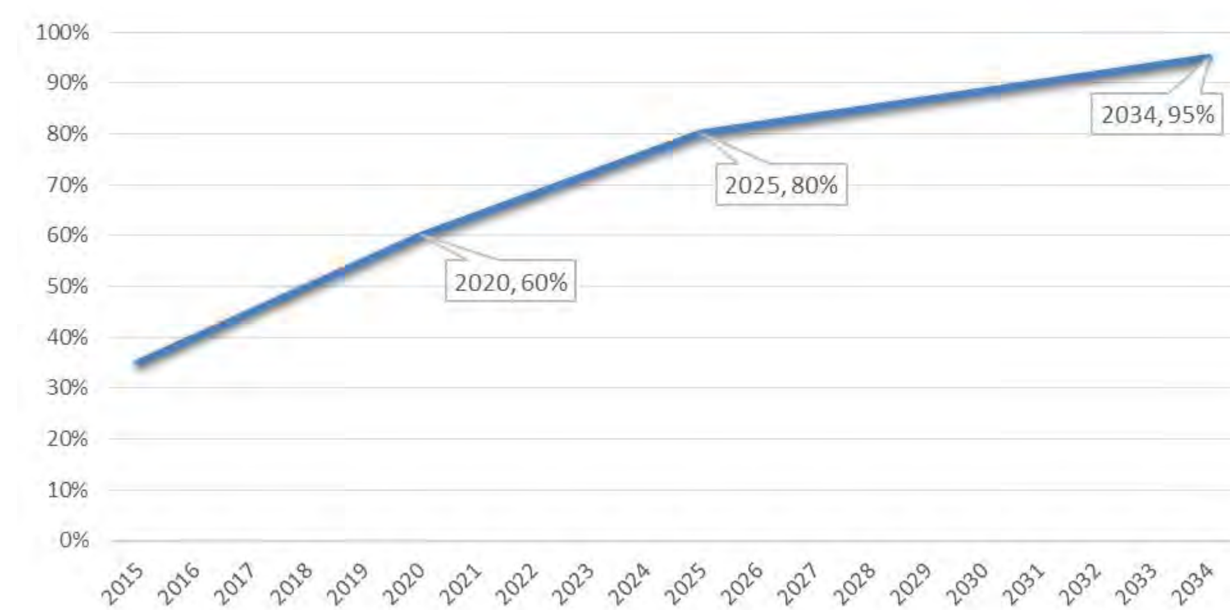
- Create an effective system with appropriate software, processes, and people to manage physical Aviation assets to minimize CPE and environmental impacts.
- Align Port asset systems (PeopleSoft, Maximo, other)
- Forecast long-term renewal and replacement requirements using a 20-year horizon
- Use asset information to refine maintenance programs and/or renewal/ replacement plans, and minimize asset energy use
- Based on forecast, level project capital expenditures over time

The outcome developed two primary recommendations:

- By 2020, 60% of capital expenditures decisions will reflect Total Cost of Ownership (TCO) By 2025, that number increases to 80%, and by 2034, the number increases to 95%.
- The percentage of capital expenditures that undergo a Total Cost of Ownership analysis before purchase, per year should be reported annually.

For this process, the Port of Seattle will need to establish the base dates, units of costs and time to be measured, and discount or inflation rates. Indexation shall be determined for location and tender price adjustment on all base build elements. The extent of risks and uncertainty and other sensitivity analysis that is to be applied, should also be established as part of this process.

Chart 1-1
Capital Expenditure Decisions Reflecting Sustainable TCO



This chart reflects how many projects, by percentage that will use TCO analysis as part of the process of decision.

3 UNDERSTANDING TOTAL COST OF OWNERSHIP

The US aviation markets experienced unprecedented growth from 1970 to 1990. Airports were overwhelmed with the growth requirements to meet passenger demands. New large airports were built and other iconic airports were expanded to meet these needs.

The 1990's resulted in a downturn of the aviation industry. Factors such as skyrocketing fuel costs drove high ticket prices reducing the passenger traffic seen a decade before. New challenges redefined the aviation industry in the new millennium, including responding to security impacts driven from the New York City terrorist attacks and the economic recessions that occurred in early 2000s through 2010. According to *Fiscal Times*, airports in the US posted a $63B loss between 2000 and 2010. This affected capital building programs and maintenance budgets. This drove assets beyond their recommended useful life and deferred much of the key maintenance.

These issues of increased operational costs due to security, energy costs, and aging infrastructure drove airports to put more focus on economics. Many airports today are managing assets that were built during the high growth era and are now quickly approaching or past the end of their useful life. The number and extent of aging assets in airports managed over multiple departments and standards makes it difficult to understand the total financial impact of all of these assets.

Priority must be given to maintaining operation of the airport and maintaining passenger experience so development of more robust criteria for which funding is spent needed to be developed.

Traditional planning for construction involves initial costs required to plan, design, and build the facility or system. This only covers a small part of the big picture. In order to understand the full financial and economic impact to the new facility, it is important to understand its *Total Cost of Ownership* (TCO). TCO is a quantifiable, not theoretical, means to understand the total cost impact of an asset.

Total Cost of Ownership is well developed in other sectors of industry such as manufacturing, public utilities, hospitals, universities, and data/telecommunications, but been a recent trend in the aviation industry. ACRP and other groups are introducing new studies to better understand TCO for airports.

Total Cost of Ownership is the "cradle to grave" process of evaluating the economic performance of a building and its assets over the life of the building and beyond. TCO balances initial capital expenses to build an asset with the long-term operational and disposal expenses. These expenses may include energy and water costs, janitorial, operation costs, maintenance costs, renewal costs, demolition costs, and disposal costs. For Sea-Tac, this also includes impacts to environment and the community. TCO allows the Port to explore multiple options that meet performance and program needs to determine each option's impacts in these areas. In addition, trade-offs between low initial capital expense and on-going long-term expenses can be reviewed to determine the overall cost of each. Finally, TCO analysis allows the Port to review operational aspects to both existing and planned renovation/expansion projects to determine how these different modes of operation (such as amount of maintenance) impact the total cost, at a master planning level.

3.1 Major Elements of TCO

Understanding total cost of ownership means understanding all costs associated to the asset over its useful life cycle. Assets are defined as something of value that an entity owns, benefits from, or has use of, in generating income or providing a current or future benefit. In the case of this report, assets include the buildings, furnishings, equipment, systems, infrastructure, roadways, utilities, and other entities that can be built, bought, or acquired.

Refer to Attachment E for more specific information about specific explanation and theory on TCO, including types of costs, understanding life of an asset, economics, discounting, reliability, and maintenance.

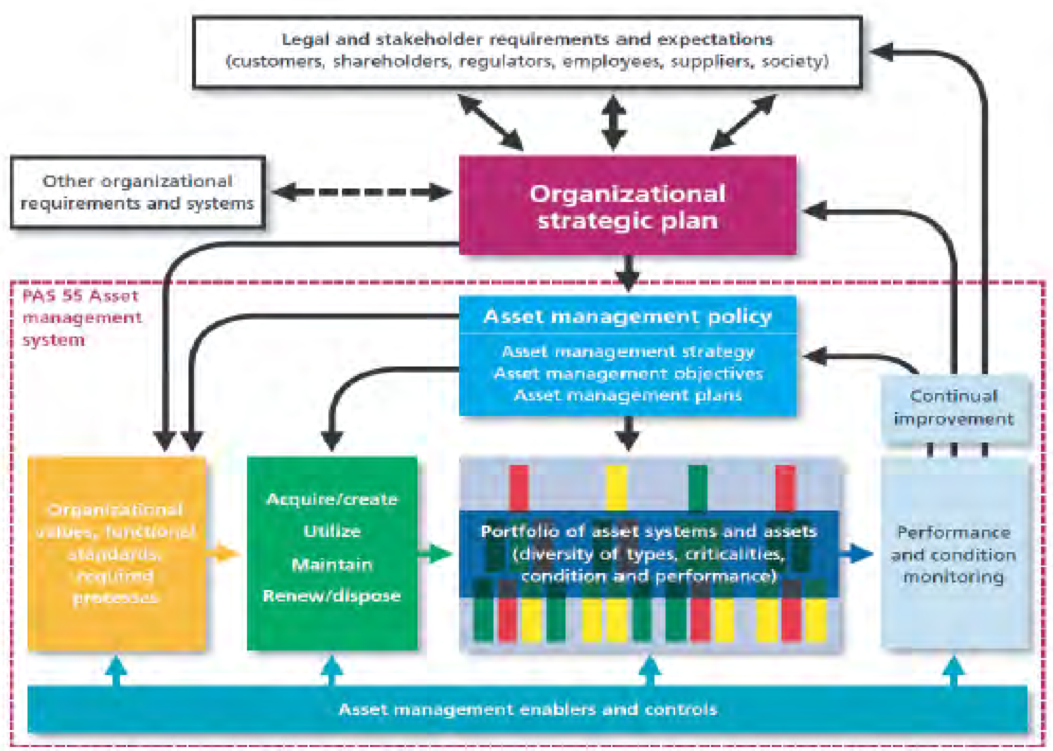
3.2 Benefits of Implementing TCO Program

One of the primary tenets of developing a TCO-based strategy for forecasting and planning future expenditures is having a robust asset management program. ISO 55000 is an ISO standard that describes the process of Asset Management. The Institute of Asset Management, along with the British Standards Institution, developed the Publicly Available Specification Standard in 2004 and revised in 2008. In 2014, ISO adopted the Standard as ISO 55000. [4]

The Airport Cooperative Research Program (ACRP) is the aviation section of the Transportation Research Board. They have developed many papers on airport sustainability. The ACRP 69 *Asset and Infrastructure Management for Airports—Primer and Guidebook* is based on the British Standards Institution's (BSI) Publicly Available Specification Standard 55 (which defines the optimized management of physical assets). It describes the following benefits of implementing an asset management program:

- Improve system's performance and enhance customer's experience
- Improve environmental health and safety
- Optimize return on investment and growth
- Long-term planning, confidence, and performance sustainability
- Demonstrate the best value for money within a constrained/uncertain funding/budget environment
- Demonstrate in a form of controlled and systematic process the legal, regulatory, and statutory compliances
- Demonstrate active consideration of the asset's sustainable development over its lifecycle
- Reduce risk and improve corporate governance through having a clear and systematic decision making processes
- Improve internal and external values through having a better reputation, services delivered, and staff satisfaction
- Implement more effective and efficient procurement processes

Figure 1-1
PAS 55 Asset Management Strategy



Source: PAS 55

3.3 Why Use TCO?

Total Cost of Ownership is a powerful asset financial analysis that includes direct and indirect costs over the asset's life cycle to establish a better understanding and planning for ongoing activities at the airport. With funding being fixed and both capital and operational expenses being scrutinized, it is important to understand how each decision about an asset affects the Airport's bottom line. Where large capital expenditures are typically financed through bonds, costs for ongoing operation and maintenance expenses come from the Airport's fixed budget.

Total cost of ownership provides the analysis needed to consider the full impact of the asset, looking not only at first costs, but at whole-life costs. The initial cost may only represent 10-25% of the total costs for the asset for its design life. Energy costs, operational costs, and renewal costs are the other major cost streams that represent the rest. Consideration of only initial costs could result in much higher O&M costs (from 30% to 60% of the life cycle costs). Where some assets may have lower CAPEX cost, the resulting increase of OPEX or decreased life would drive more frequent expensive renewal costs. A study by Society of Automotive Engineers (SAE) found that if you spend 5% more at the front end of the asset's life cycle, you could save approximately 15% throughout the asset's lifecycle.

TCO allows decision makers to understand when it makes sense to spend more on maintenance to extend the service life of an asset and when it does not make sense due to factors such as reliability, passenger traffic, space repurposing, or inherent inefficiencies in the asset. TCO extends beyond the initial planning phase of an asset. A robust asset management program will continue the goals and objectives set forth by the initial TCO plan and refine decisions during execution by allowing for "course corrections" as needed.

3.3.1 Asset Management

Many airports today are managing assets that were built during the high growth era, and are now quickly approaching the end of their useful life. Because of this, many U.S. airports are either retrofitting their facilities while incurring very high capital replacement costs, or they are currently suffering under the highest possible level of ongoing operation and maintenance costs.

Successful asset management programs continue the TCO analysis that started in the planning stages of the asset. Using risk, reliability, and maintenance philosophy, one of the primary goals of asset management is to extend service life of the all of the assets for as long as possible for the least cost possible.

Asset management enables decision makers to understand when to repair or replace assets on a continual bases so that so that the downtime is minimized (mean time between failure) and less disturbance to the airport operations. Through a reliable asset management program, the downtime is scheduled to accommodate the operations and activities throughout the airport, so that failure of an asset is not an unplanned event. Unplanned failures tend to be more costly to repair and are disruptive to Airport operations. This focused understanding of the asset allows for more thoughtful financial decisions by influencing those decisions to be based on needs and challenges of the asset. These needs can include considerations for reliability, vulnerability of the asset, security requirements, regulatory changes, inefficiencies of the asset, or planned alterations of the Airport that make the asset obsolete. Asset management enables the efficient and cost effective operation of the asset by ensuring the long-term sustainability of the system.

Using an asset management system that prioritizes funding decisions based on the criticality of an asset is important. Funding for repair and renewal should be focused on the most critical or vulnerable assets first. These are assets that are imperative to Airport operation or those that likelihood of failure without intervention is high. Once the risks and consequences of failure are established, assets with the highest risks of failure or the most significant consequences of failure are prioritized above others.

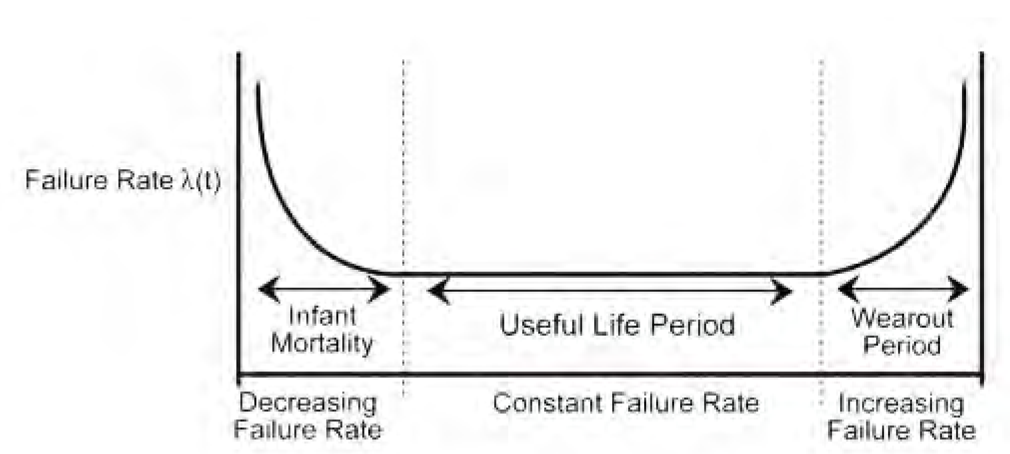
The remaining assets are then ranked based on their risk, which factors both the consequence of failure and probability of failure into the rating. This risk value allows decisions of funding and execution of maintenance be prioritized based on overall risk of the asset.

3.3.2 Maintenance

Maintenance costs reflect one of the major components within the asset's total cost of ownership. Improperly maintained assets experience premature failure and high renewal costs to replace the asset. Planning for maintenance – both during the TCO planning as well as the ongoing asset management – can not only control and minimize overall costs, but also reduce the potential for disruptive failure of the asset.

The need for maintenance depends on the asset's potential for failure. Maintenance is intended to prevent failure by maintaining efficient operation during the asset's service life. There are many failure modes, and each one depends on the type of asset and its functionality. One of the famous failure modes is the bathtub curve. The "bathtub curve" shows that failure of asset based on three periods along the lifespan of an asset: the startup period, the design life, and the "wearout" period. Improper design, improper maintenance, lacking commissioning, and other factors can cause an asset to fail during or shortly following construction. This is referred to as "infant mortality". As the asset is tested and commissioned, the potential for failure significantly decreases. Conversely, there is a point beyond the service life of the asset that the potential for failure increases no matter how much it is maintained. This is referred to as the "wearout period". The service life tends to remain consistently flat throughout the service life, depending on the operation and maintenance of the asset.

Figure 1-2
Failure Rate vs. Time



When an asset is new, its chance or early failure ("infant mortality") drops exponentially. For the asset's useful life, the failure rate is relatively low and constant, depending on conditions and maintenance. At the end of its useful life (the "wearout period"), failure rates increase exponentially.

3.3.3 How Other Factors Play a Part in TCO

Environmental Considerations

Sustainability is often difficult to analyze or measure in terms of "total cost of ownership". Traditional environmental impacts to total costs involve cost of energy and water or systems required to minimize amount of greenhouse gases emitted by the building assets. Some other impacts do not have widespread agreement in how to quantify their impacts in term of financial terms. Therefore, other metrics need to be developed to quantify their impacts.

As part of the sustainability program at Sea-Tac, environmental objectives play a major role. The airport operations have an impact on the local, regional, and global environment. The impact is on water quality, air pollution, noise, climate change, and solid waste. The environmental objectives complement the Port of Seattle's *Century Agenda* for being one of the "greenest" airports in the world. Some goals to consider regarding building and infrastructure assets include:

- Implement the strategic environmental and energy efficiency programs to the asset management process.
- Design, procure, and install low carbon, energy, water, and cost efficient assets
- Understand the impacts of sustainability. Index individual assets should not be based only on their cost, but also their impacts on the environment.
- Achieve and maintain an acceptable maintenance and renewal sustainability index (Ratio of estimated budget to projected expenditure for maintenance and renewal of assets over a defined time period of 5,10, or 20 years, based on Port of Seattle's bonds and debt cycle. The index should be part of informing decision makers of the local environmental consequences and effects potentially caused by different project options.
- Are existing assets able to be recycled? Does recycled asset reduce overall environmental impacts?
- Environmental impacts and costs should consider the manufacturing process and transport of materials.

3.3.4 Ongoing Asset Management

Many airports today are managing assets that were built during the high growth era, and are now quickly approaching the end of their useful life. Because of this, many U.S. airports are either retrofitting their facilities while incurring very high capital replacement costs, or they are currently suffering under the highest possible level of ongoing operating costs.

3.4 Relationship Between Maintenance Spend and Design Life

After prioritizing and determining the design life of the asset, the Airport should determine the amount of maintenance spending required to renew the asset as they reach the wearout period.

Replacement costs can be assessed by reviewing the amount budgeted to replace an asset versus the costs associated with extending its useful life.

Sea-Tac in 1961

Chapter 5 of this report discusses the relationship between spending of maintenance costs for an asset compared to the intended design life.

4 AIRPORT BUILDINGS

In 2015, Seattle-Tacoma International Airport had over forty-two million passengers, making it the 14th busiest airport in the United States. This is an almost 13% increase in passengers from 2014.

The Port of Seattle originally built Sea-Tac in 1944, in response to the militarization of the existing civilian airport, Boeing Field. The new $4.3M airport opened on October 31, 1944.

4.1 Terminal

The "Terminal" in this report consists of all portions of the building – including concourses and satellites – that make up passenger enplanements and aircraft operations. Over three-million square feet, the current terminal is made up of four main concourses, two satellites, main Terminal (ticketing, baggage, etc.), central terminal food court, and an administration building. These different sections are a result of several expansions and renovations that have occurred since the original terminal opened in 1949.

The first concourse, named the "north concourse" (later Concourse D), was first opened in 1959 and offered a two-story building housing four gate positions for the airport. The second concourse, named the "south concourse" (later Concourse A), open in 1961, adding approximately 688' of length to the terminal building.

In December of 1964, the 800-foot long Concourse B was opened, adding six more gates, bringing the total to nineteen gates.

In July 1966, Concourse C opened, housing international arrivals, customs, immigration, and other governmental offices. It was extended to include another ten gates, expanding to thirty-five total gates, four years later.

A major expansion plan began in 1967 through 1973 to increase the overall size and capacity of the airport. Both the North Satellite and South Satellite were built in 1973. The underground "people mover" (STS) was installed to transfer passengers from the Main Terminal to the satellites. Also in 1973, a new $28M terminal was built over and around the original 1949 structure. The new terminal quadrupled the public space for the airport.

In the mid-1980's, the Main Terminal is again renovated with an additional 150' added to the north end. Concourse D is expanded in 1987, adding a rotunda that provided four additional gates. In 1993, Concourses B, C, and D were renovated, adding 150,000 square feet and renovating 170,000 square feet of the existing concourses. Major systems (HVAC) were renovated in concourses B and C in 1984 and Concourse D in 1993.

Sea-Tac in 1981

In 2004, a major renovation and expansion to Concourse A was completed. The newly renovated Concourse A opened on June 16, 2004, adding 14 gates and new STEP and administration building. The new Central Terminal Expansion (CTE) replaced the previous central terminal on the following year, June 2005. The CTE houses the main food court and retail concessions for all four main concourses.

Today, the airport operates up to 75 contact gates:

- Concourse A: 14 gates (A1 through A14)
- Concourse B: 12 gates (B3 through B12, B14 through B15)
- Concourse C: 10 gates (C2 A-M, C3, C9, C11, C14 through C18, C20); 15 parking slips
- Concourse D: 11 gates (D1 through D11)
- North Satellite: 14 gates (N1 through N3, N6 through N16); 5 parking slips
- South Satellite: 14 gates (S1 through S12, S15 through S16); 1 parking slip

New expansions are being planned for the airport. NorthSTAR will renovate and expand the existing North Satellite. The International Arrivals Facility (IAF) will be an expansion to Concourse A and will include a passenger corridor (tunnel or bridge) to move passengers from South Satellite to new IAF facility.

4.1.1 Terminal Assets

Renewal of various construction components (assets) within the Terminal has occurred for each of the older concourses and terminal. The following table indicates the dates of the most recent replacement or major refurbishments of major building components.

Table 1-1
Building Construction Components

	Year Renewed	Replaced Roof R-Value	Curtain Wall Replaced?	Window/ Glazing U-Value/SC/SGHC	Skylight R-Value/ Shading Coeff.
Administration Building	2004	20	√	0.31/0.55/- to 1.09/0.66/-	29/0.2
Terminal Concourse A	2004	25	√	0.31/0.55/- to 1.09/0.66/-	29/0.2
Terminal Concourse B	1992	20	√		29/0.2
Terminal Concourse C	1992	20	√		29/0.2
Terminal Concourse D	2014	25	√	1.10/0.66/0.57 to 0.29/0.27/0.23	29/0.2
Main Terminal (Ticketing)	2010, 2011, 2013	25	√	1.10/0.66/0.57 to 0.29/0.27/0.23	29/0.2
Central Terminal Expansion	2004	25	√	0.31/0.55/- to 1.09/0.66/-	29/0.2

4.2 Parking

The 13,000-car parking garage is one of the largest garages (under one roof) in the United States. The eight-story parking garage houses the majority of passenger vehicular traffic, with surface parking lots operated by Doug Fox handling overflow and long-term parking.

The first part of the parking garage was built in the 1967 to 1973 expansion. Other expansions occurred later which eventually brought the parking garage to its current size of just over 5.1 million square feet.

The primary system in the parking garage is lighting. Lighting for the garage has been replaced with an ongoing program to improve overall energy efficiency. In addition, electric car charging stations have been added to the garage. Conveyance systems (elevators and escalators) move people up and down the garage.

The central plant for the terminal is located in the garage.

4.3 Central Plant

The central mechanical plant (CMP), or central plant, houses all of the refrigeration and steam equipment used to cool and heat the terminal and satellites, and to heat domestic hot water for use in the restrooms.

Refer to Section 5.2 below for information about equipment located in the central plant.

4.4 Cargo

The Port of Seattle owns and operates approximately 540,000 square feet of cargo facilities to the north of the terminal. The aging cargo facilities house various airport and tenant operations, including Cargo Building 4, which is the airport maintenance facility.

The cargo facilities are served by unique building electrical systems and have dedicated HVAC systems not associated with the central plant.

5 UTILITIES

Seattle-Tacoma International Airport spends over $5.7M a year on utility costs to operate the Airport. This does not include the added costs associated with operating the central plant, the preconditioned air plant, and the other site-generated utilities at the Airport.

There are three major categories of utilities at Seattle-Tacoma International Airport that are reviewed and analyzed within this report: building-related energy systems, site-generated energy systems, and public utilities. As new buildings and infrastructure are added for increased passenger growth, the amount spent on these utilities will continue to grow. Rising costs of energy and other utilities exasperates this issue. One way to better plan and control for these costs is to reduce overall demand requirements of the Airport through more efficient use of the utilities. At the same time, considerations for converting some of the utility consumption to site-generated and renewable sources will not only provide relief in utility costs, but will also in turn reduce the environmental impacts of the Airport.

5.1 Building-Related Energy Systems

Seattle-Tacoma uses two major energy utilities and two minor energy utilities for operations of buildings and flight-line equipment. Electricity is sourced by three different utility companies to supply power to the Airport Terminal, Parking Garage, Central Plants, Hangars, Cargo, and ancillary buildings.

Power to Seattle-Tacoma International Airport originates from multiple Puget Sound Energy (PSE) utility feeds to two separate switchyards with ring bus configurations (an electrical distribution configuration that allows portions of the system to be isolated for maintenance purposes minimizing impacts to other sections of the distribution). Each ring bus is fed from two independent 115kV overhead feeders. Feeders tapped off of the ring buses feed four 15/20/25 MVA step-down transformers which reduce the voltage level to 12.47kV for site distribution to the terminals and central plant. A third PSE overhead feeder distributes 12.47 kV power to ancillary buildings and tunnels around the airfield.

Three distribution centers distribute power to twenty-two major power centers located throughout the airport. The primary Bonneville Power Administration (BPA) service powers the 12.47kV distribution providing redundant feeders to various main-tie-main switchgear in the terminals and then to unit substations or "power centers" stepping down the voltage to the final utilization voltage of either 4160V or 480V

Natural gas is used for the boilers at Sea-Tac, as well as distributed to the Preconditioned Air plant for heating and use in various cargo and satellite buildings, such as the ARFF, fleet maintenance building, bus maintenance building, rental car facility, distribution center, and pump house. In addition, tenants procure natural gas directly from the public utilities, each with their own stand-alone meters.

In addition, renewable natural gas (biogas) is used for buses at the Airport. Diesel fuel is used both for the standby generators, as well as fleet vehicles.

5.2 Site-Generated Energy Systems

Energy utilities generated on site include chilled water, steam, and glycol and ice for the Preconditioned Air plant.

The main terminal chiller plant is comprised of eight chillers totaling 14,450 tons of cooling capacity. The eight water-cooled centrifugal chillers are connected to five cooling towers (totaling 17,500 tons) for heat rejection. Three plate-and-frame heat exchangers, totaling 2,700 tons, are connected to the system and provide "free cooling" when the condenser water temperature is below 49°F.

The chilled water distribution is based on a primary-secondary-tertiary setup. Secondary pumps distribute water to three main loops in the terminal: north (approximately 20%), west/middle (approximately 70%), and east (approximately 10%).

Tertiary pumps distribute to 200 mechanical rooms and 87 major air handling units in the terminal serving the approximately 3.1 million square foot of conditioned space.

Steam is produced by the Central Mechanical Plant by four boilers that produce 130,000 pounds per hour at 84% to 87% overall efficiency. Steam is then distributed and converted to heating and domestic water in the utility tunnels and mechanical rooms throughout the Airport terminal.

The Preconditioned Air (PCA) system was recently completed in 2013. The $43M project used grants from the Voluntary Airport Low Emissions (VALE) grant to partially fund the project. The system uses a dedicated glycol chiller plant and steam from the Central Mechanical Plant to provide tempered PCA for use by the aircraft when they are at the apron in order to reduce fuel consumed, noise, and carbon emissions from the aircraft when parked. The PCA system supplies air to 73 gates. The system can be expanded to one hundred gates.

The PCA system has three modes: cooling, heating, and ventilation. When the outdoor temperature is 50°F or lower, the PCA system is in heating mode. When the temperature is between 50°F and 60°F, the PCA system is in ventilation (no tempering) mode. When the outdoor temperature exceeds 60°F, the PCA system is in cooling mode.

5.3 Public Utilities

Outside of energy utilities, Sea-Tac also procures water, storm, and sanitary services from the local utility. This report focuses on the water resources for the Terminal, understanding current consumption rates, expected future demand, and opportunities to reduce the need for public utility-sourced potable water.

5.4 Connections to other Tasks

Utilities at Seattle-Tacoma International Airport not only represent a major cost to operation of the airport, they also represent the majority of carbon emissions related to buildings at the airport. Although carbon emissions from ground and air vehicle combustion is the most significant, site emissions from the burning of natural gas in the production of steam, use for heating, and the use for cooking still represent a significant amount. In addition, source emissions related to the production, refining, and transportation of both electricity and natural gas increase the overall carbon footprint. This report discusses some of the general impacts of these utilities at the Airport. Technical Memorandum 7 provides a more thorough discussion of the environmental impacts related to the use of the utilities.

Objectives

The purpose of Task 6.12 is to develop a combined evaluation process to better understand the impacts of differing options involving buildings and utilities at the Airport during the Master Planning program.

1 STUDY GOALS AND OBJECTIVES

The overall purpose of this Task is to understand the relationship between master planning decisions made regarding buildings, facilities, and utility infrastructure and their influence on environmental and economic goals of the Port of Seattle and Seattle-Tacoma International Airport. As these facilities and systems grow, develop, and redevelop to meet the needs of the Airport, they will affect overall operational costs and impact the environment and community. It is important to understand these relationships between sustainability and total cost of ownership in order to make the best decisions at the lowest overall cost and impact.

Understanding and defining what total cost of ownership (TCO) means is key. Identifying each "cost stream" will allow for decisions to be made that reflect not only cost of implementation, but also ongoing cost throughout the service life of the asset. Meaningfully identifying these costs and what affects them will allow for decisions not only during planning, design, and construction, but also through operation, maintenance, renewal, and end-of-life.

Documenting existing conditions provides the means to predict the future performance and cost of the Airport. Understanding the current condition will allow Sea-Tac to build a strategy for defining how new buildings and infrastructure will be built or developed within the Master Plan.

This report focuses on three major categories: buildings, utilities, and cost. It integrates with other tasks within the Master Plan to understand potential solutions for future growth and how the effect

of these items can and will affect other aspects of the airport. Buildings focus on the Main Terminal, including the North Satellite and South Satellite, the main parking garage, and the cargo facilities. Utilities focuses on energy utilities – both public sourced and site generated – as well as water. Cost analyzes each cost stream in order to provide a predictable model of future cost based on master planning decisions.

This report will analyze high-level options being considered in the Master Plan that involve building and utility related development. Using sustainability metrics and TCO data, each option is reviewed to report overall forecast based on the selected scenario. From there major alternatives will be further refined to analyze how differing levels of sustainable construction can influence overall costs.

Finally, this report establishes metrics of existing and forecasted performance that can be used to establish goals, but can be used to verify and refine goals as the plans develop further.

1.1 How Do Differing levels of Sustainable Construction Affect Overall TCO?

There are many goals when building new assets, buildings, and infrastructure. From methods of construction to how the contract will be executed, decisions are made prior to each project during the planning, design, and pre-construction phases which not only affect the building during construction, but can also affect the way that the building will perform throughout its design life.

One of the major decisions that will be determined is "How sustainable will the new facility be?" Different building types, uses, performance requirements, ownership arrangements, public perceptions, life expectancies, and desires for branding will affect this decision and set the goals for the building. Whether it's low cost, minimal code compliant buildings or LEED Platinum or Net Zero Energy Buildings, the planning and execution of construction can be dramatically different based on the decision. Additionally, not only the construction cost (CAPEX) of the project can be different, but the Total Cost of Ownership can be considerably different, as well. It is important to understand and define the different ways to plan, design, and build new and renovated assets.

For example, depending on how energy efficient, "environmentally friendly", or sustainable a building is, costs for design and construction will vary. Architectural and engineering design costs increase for sustainable buildings where activities such as LEED is required due to the additional administrative, charrette, workshops, complexity, and documentation that would be required. LEED and other certified projects have additional fees associated with those programs and can require specialty consultants such as commissioning agents that may not be required for non-LEED projects. Complex sustainability strategies such as geoexchange, renewable energy systems, or specialty ultra-efficient building envelope systems will require contractors that specialize in this type of construction. These contractors may require higher fees than traditional contractors. The equipment purchased for construction can also be much more expensive than its standard efficiency counterpart. In turn, there are potentially grants and incentives available from federal, state, and local entities to offset these costs.

In addition to design and construction costs (CAPEX), ongoing operational and maintenance costs will vary based on how sustainable the building is. Some systems, such as cogeneration, renewable energy systems, or specialty control systems may require higher skilled operators and maintenance staff. Local service contractors may not have the expertise in all facets of certain high efficiency or green technology, requiring contractors to travel to Seattle to service equipment. However, sustainable buildings will typically have much lower energy costs and can have reduced maintenance costs. Many times, sustainable buildings are built more robustly, with both reduced potential for maintenance and longer design life. In addition, renewable energy systems may have the opportunity to provide revenue through the "sale" of energy back to the utility if not used by the building by offsetting total energy consumed with the amount of energy produced.

It is important to understand these relationships between sustainability and TCO. This report discusses some of these relationships and helps to establish a decision framework where both sustainability goals and TCO are considered. It will determine some of the cost/benefit analysis of the different sustainable construction options. It will define the traditional cost model for various asset types and then define the impact – both to the environment and TCO – for these construction options.

1.2 When does it Make Sense to Build New vs. Renovate Existing?

Traditional models on whether to build new facilities or renovate/reuse existing facilities, assets, and infrastructure are being challenged as new regulatory, financial, and institutional requirements are driving for more sustainable and more economically-focused decisions.

It is important to understand the cost and budget considerations, funding restrictions, and other factors that impact decisions on whether assets should be renewed, replaced, or repaired. With a robust asset management program with a TCO strategy, better analysis tools can be developed to understand the cost and benefit of each of these options. There are many factors that a TCO program should consider in order to rank these. Some of these include:

- Availability of asset, including the land which is required;
- Understanding of intended design life of the asset, and how this design life will influence other issues such as maintenance costs;
- Whether building in a new location, renovating existing space, or demolishing existing space and building new in same place;
- Schedule requirements for the asset;
- Intent of the space/asset;
- Reliability, criticality, and vulnerability of the asset;
- Whether existing flow of operation will be improved by new construction.
- Existing deferred maintenance.

These decisions will impact other facets of the TCO and operation of the Airport. For example, if an asset must be renovated in place, or demolished and built new in same location, the existing occupants/passengers will be displaced from the existing locations and temporarily housed in another location, which may not have adequate infrastructure to accommodate the temporary occupant load. Having to spend CAPEX on these "enabling" functions should be considered in overall TCO discussions.

This report analyzes some of these decisions and provides a framework to consider multiple options when comparing different scenarios. Using TCO methodology, renovation versus new construction can be reviewed and recommendations made based on best overall benefit to the Airport. Other items, such as flow improvements are discussed in other Tasks of the Master Plan.

2 TASK SCOPE OVERVIEW

The primary objective of this report is to provide a master plan-level quantitative analysis of sustainability and cost management goals identified by the Port, to test if they are achievable and, if so, identify a strategy to meet the goals with recommended capital improvements. This subtask developed a comprehensive approach to sustainable facilities, including a 20-year strategy for repurposing existing facilities and developing new facilities.

Specific endeavors addressed best cost strategies for capital decisions, understanding how operations and maintenance affect service life, measures to conserve energy and water resources, and to identify climate change mitigation opportunities with campus building development efforts. Total cost of ownership amortization and metrics were developed to identify optimal facility renovation and expansion opportunities, considering:

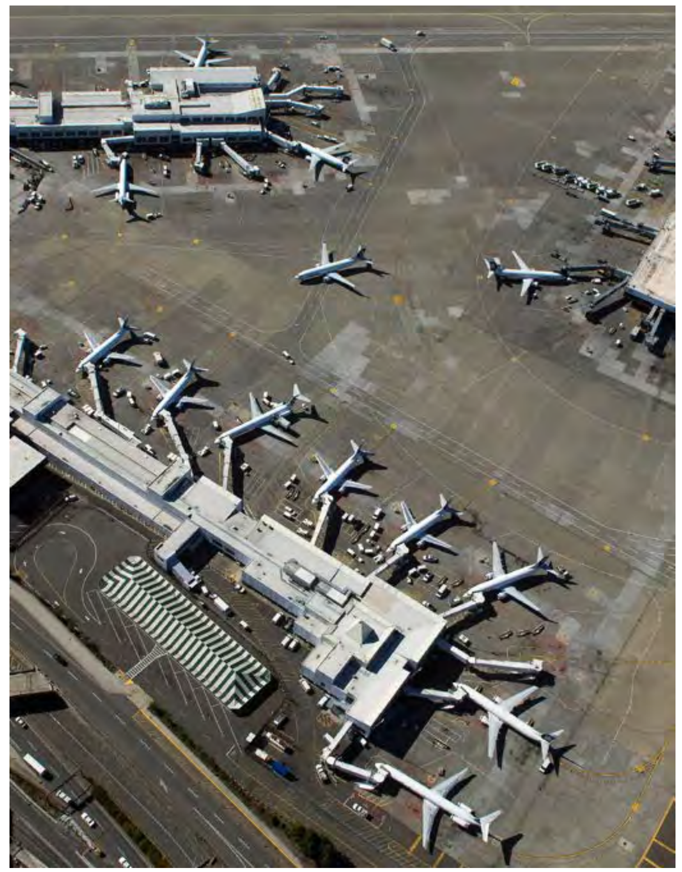
- Alignment of capital program to strategic objectives.
- Business case timing for repair/replacement of specific facility assets.
- Short and long term CAPEX and OPEX budgets allocation
- Better allocation of resources throughout the assets' Whole lifecycle interventions, considering cost, risk, and condition.
- Risk management plan to reduce risk/uncertainty and have a mitigation plan in place

The consolidated approach for this task divided the work effort into three parts: "concepts" (buildings), "economics" (assets), and "engineering systems" (utilities).

Potential site level existing consumption patterns, projected energy usage, renewable energy opportunities, power generation, and alternative distribution opportunities for Port campus level utility infrastructure were explored. Using this information and defined construction/demolition/renovation/maintenance rates, capital expenditures (CAPEX) and operational expenditures (OPEX) will be calculated to determine overall cost of Ownership over a nominal twenty-five year span.

The report determined which of the utility-related goals identified within the Sustainability Workshops were realistic and achievable. The report also defined the method for which campus-wide building asset and utility decisions can be reviewed in order to determine their overall cost and impact to the Airport.

2.1 Building Scope



This subtask concentrated upon building level energy conservation, climate mitigation, and water optimization opportunities contained within the building footprint boundaries of each existing and projected building. Using high level conceptual analysis tools, building optimization and conservation opportunities were explored at both an individual level and an aggregated perspective. Existing Port facilities, building renovations, and projected building expansions were examined.

In order to ascertain usable existing building energy usage and to make reasonable consumption assumptions, the main terminal was categorized into distinctive portions as allocated in the following.

- Concourse A
- Concourse B
- Concourse C
- Concourse D
- Administrative Building
- North Satellite
- South Satellite
- Main Terminal including STEP and Central Expansion
    - Terminal Baggage Level/Bridge Level
    - Terminal Satellite Transit Level
- Central Plant
- Main Parking Garage
- Air Cargo/Warehouse

In addition, the analysis considers two current planned expansions that are in the process of being designed and then built. Forecasting of terminal-wise costs, energy/utility consumption, and environmental impacts considers these two additions in the future condition. They are:

- IAF Expansion
- Northstar Expansion

Finally, two optional alternatives for growth of the terminal and concourses are being considered for expansion (refer to other Tasks in SAMP for additional information). Costs associated with the construction, operation, maintenance, and demolition, as well as energy/utility cost and consumption and its environmental impacts are considered in the study's 20-year plan forecast.

2.2 Energy Systems and Utilities Scope

Campus level Port energy consumption, water usage, and strategies for utility infrastructure occurring outside of each individual building footprint was analyzed to determine appropriate metrics, scope, and recommendations. This overall site level approach considered existing consumption patterns, projected energy usage, renewable energy opportunities, power generation, and alternative distribution opportunities for Port campus level utility infrastructure.

2.3 Asset Management/TCO Scope

A high level condition assessment, inventory, and management of buildings, systems, and campus utility infrastructure assets were explored in order to determine appropriate options and allocations. Specific endeavors included "best practices" analysis, and whole life costing calculations. Short, medium, and long term cost of ownership strategies were identified and utilized throughout the discovery analysis. Strategic, tactical, and operational facility issues were considered at a level of detail appropriate for a master plan.

3 BENCHMARKING

Measuring airport performance is key to understanding that procedures set in place are meeting the goals set forth by the Airport. One way to measure this performance is to benchmark it and use these benchmarks to monitor current levels, track improvements and setbacks, and compare performance of the Airport with others.

Benchmarking not only provides a "report card" of performance on such things as passenger traffic, enplanements, operations, social issues, economic trends, efficiency, and environmental metrics, but it also provides "apples to apples" comparisons with other similar and not similar buildings.

Benchmarks are used to develop and test goals and objectives. Understanding current performance and benchmarking that performance allows for the creation of improvement goals. For example, a "ten-percent reduction of energy consumed as compared to 2012 value" is both a definable and measurable goal. Current energy consumption can be compared to the historic 2012 value.

Benchmarks can be used to understand impacts on utility infrastructure. Understanding current capacity of the infrastructure – such as the electrical service – and knowing the capacity limits can set boundaries to growth or trigger capital programs for improvement and upgrade to the service.

Benchmarks can be used to develop operational and maintenance budgeting for the Airport. Understanding and relating asset metrics to operations and maintenance requirements – as is done with asset management programs – can actively predict future requirements for operations staff growth or reductions based on current and near-term needs.

Finally, benchmarks and other key indicators can be used to provide report tools to document performance such as sustainability. Understanding these current performance indicators and their upward or downward trend can be reported in sustainability reports or other media outlets.

Benchmarks and performance indicators are used in this report to document existing efficiency, consumption, and costs, as well as used to forecast potential future consumption and costs based on various optional master planning scenarios.

3.1 Types of Benchmarks

There are many different types of benchmarks used in industry. Benchmarks are used to compare current conditions to historical ones and can be used to forecast potential outcomes for the Airport based on current trend. Likewise, benchmarks can be used to compare performance against other facilities.

Energy and aviation-focused professional groups focus on the development of benchmarking airports and analyze these benchmarks to get an understanding to what they indicate about the facility. When comparing benchmarks between facilities, it is important to note that many factors and variables may affect how the performance is benchmarked. Instantaneous benchmarking (taking a single or small sample of information) can lead to inaccurate or incomplete results since it does not represent the complete picture of what the Airport sees in terms of operation, passenger activity, and weather.

Comparing different facilities can provide many challenges to normalize the data. Extensive variables between the two facilities can prevent true "apples to apples comparison. For example, climate can considerably affect the energy use of an airport. Airports in warmer climates will use more energy in warmer months, whereas those in cooler climates will use more energy in cooler months. Seattle, for instance, has a moderate climate compared to Phoenix or Minneapolis, but outdoor temperatures are below the minimum space temperature for 94% of the year. Other variables, such as passenger density, equipment density, size of terminal, and whether an Airport is a hub or not can considerably impact performance benchmarks.

There are three major groups considered when comparing an Airport's performance: industry peers, regional facilities, and similar types of facilities.

Industry peers include other similar sized airports. Information made available by groups such as the Airport Cooperative Research Program (ACRP) allow airports to not only develop comparisons between airports, but can also demonstrate "what is possible" by understanding what other airports have achieved. It can be used to set goals and objectives when analyzing your own energy performance. Airports need to not only compare themselves with other United States based airports. Global airports can also provide good information for comparison.

Regional books are non-airport facilities in same region that have similar energy profile to an airport. Benchmarks for a region are typically developed by public utilities and local chapters of US Green Building Council (USGBC), American Institute of Architects (AIA), and the American Society of Heating Refrigeration and Air conditioning Engineers (ASHRAE). With all buildings within a region having similar climate, the building can be directly compared to understand energy density (amount of HVAC, electrical, lighting, and process in a building) versus overall efficiency of the building.

Finally, benchmarking against similar buildings can provide other important information that might not otherwise be available. Where benchmarking performance at airports is relatively limited and in its infancy, other similar facilities – such as hospitals, convention centers, and university campuses – have a long history of monitoring energy, measuring energy efficiency, and benchmarking sustainability. These can provide data to understand impacts of a high-occupancy multiple building campus to overall energy consumption. Other buildings with similar benefits would be transit and port facilities or other complex, heavy-commercial buildings.

3.2 Metrics and Key Performance Indicators (KPI)

In order to understand total cost of ownership for building and component assets, metrics of measurement must be established. Technical Memorandum 7 discusses established key performance metrics used by the master planning reporting in three categories: financial-operational focus area, environmental focus area, and social/community outreach. These follow the "triple bottom line" approach to understanding the overall performance of the Airport.

This Task will address a few of these established metrics for understanding current trends and for developing a forecast for the future. Pertinent scales of measurement are utilized in the discovery analysis, calibration of data, and projections. The metrics provide various perspectives of data and provide valuable insights.

For financial-operational focus areas, the following metrics will be addressed:

- Total project capital costs ($/SF)
- Total revenue and total expenses ($/SF)
- Estimated 20-year O & M costs ($/SF)
- Total cost of ownership ($/SF)
- Age of infrastructure
- Age relative to expected life

For environmental focus area, the following metrics will be addressed:

- Total energy consumption (kWh, gallons, therms)
- Energy per passenger or area
- Total potable water consumption in gallons per year
- Potable water consumption per passenger or area
- Non-potable water reuse
- Gallons of water treated by infiltration per year
- Gallons of rainwater captured and reused per year

Refer to Technical Memorandum 7 for additional information on these and other metrics used.

3.3 ACRP 09-10

In 2015, the Airport Cooperative Research Program (ACRP) through the Transportation Research Board (TRB) commissioned ACRP 09-10 to help document energy use and benchmark airports. Texas A&M University's Engineering Experiment Station and the Energy Systems Laboratory documented energy use at ten participating airports and used the information to create the Airport Terminal Building Energy Use Intensity (ATB-EUI) benchmarking tool. The tool inputs data about the airport Terminal, including terminal area distribution (how much each major area comprised of the entire Terminal), the energy density of the entire airport, and the energy density of the major areas. It then compares it based on climate zone, size of airport, and whether airport is considered a hub. The inputted data is then used by ACRP and compared to provide a more comprehensive energy benchmark for airports. The airports in the study are not specifically listed, rather referred to by size and climate region.

Chart 2-1
ATB-EUI: Terminal Area Distribution for Various Airport Sizes

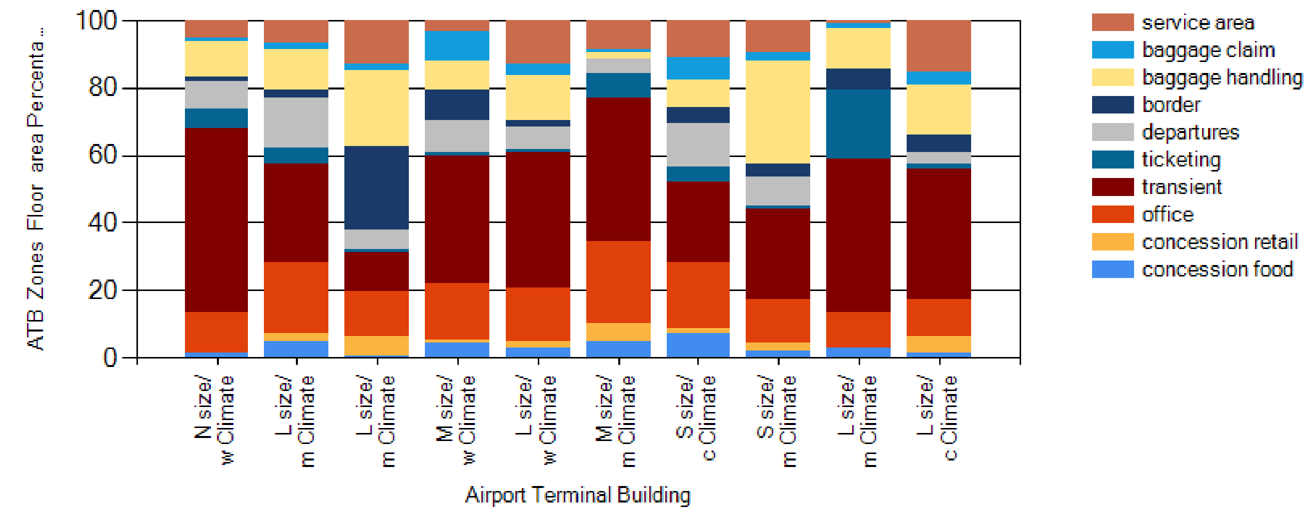


Chart 2-2
ATB-EUI: Terminal Building Energy Density – Calculated

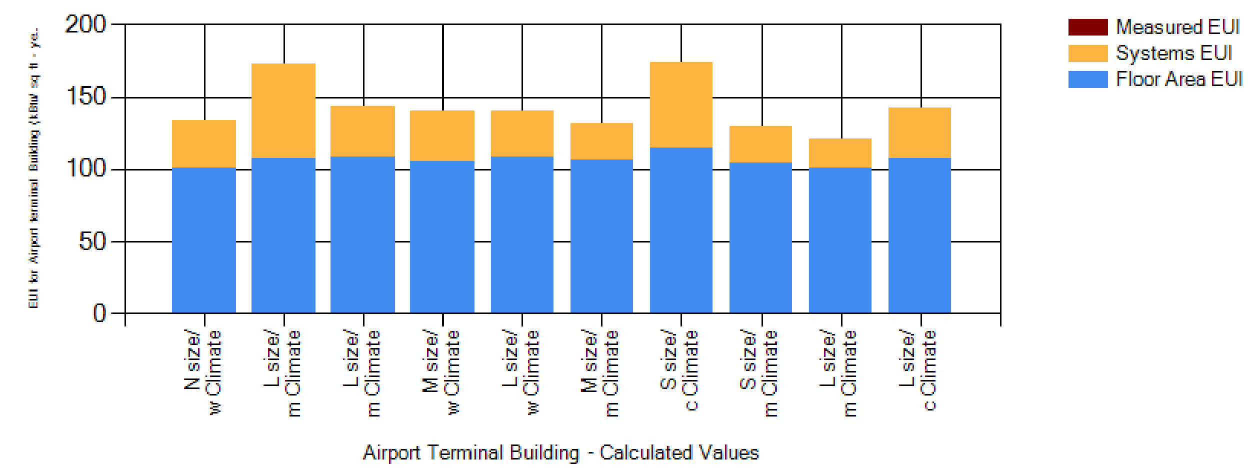


Chart 2-3
ATB-EUI: Terminal Building Energy Density - Measured

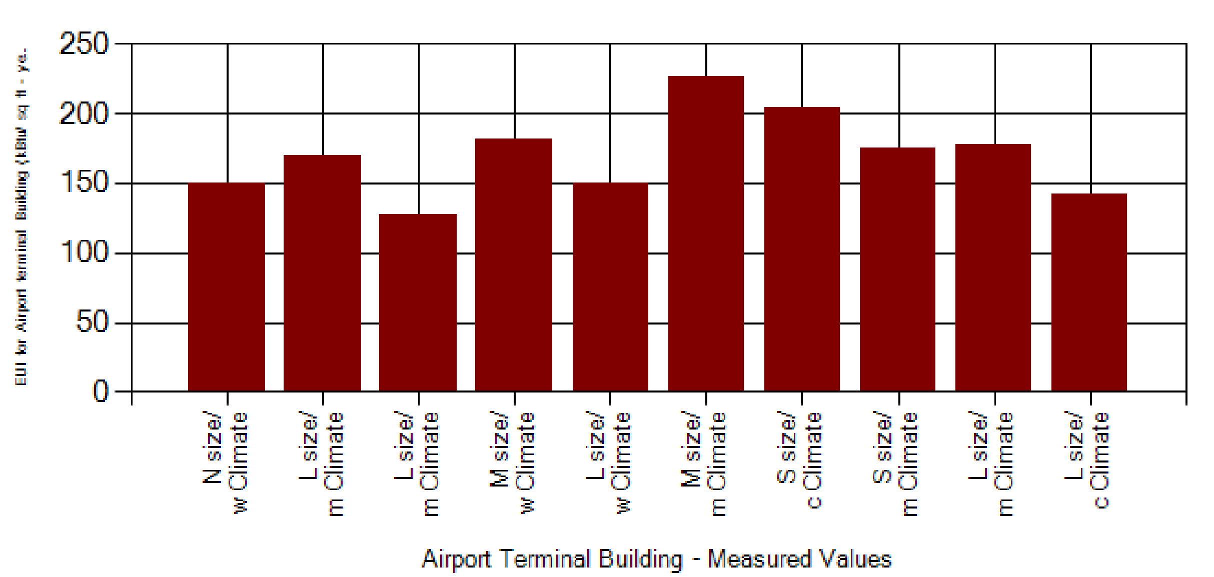
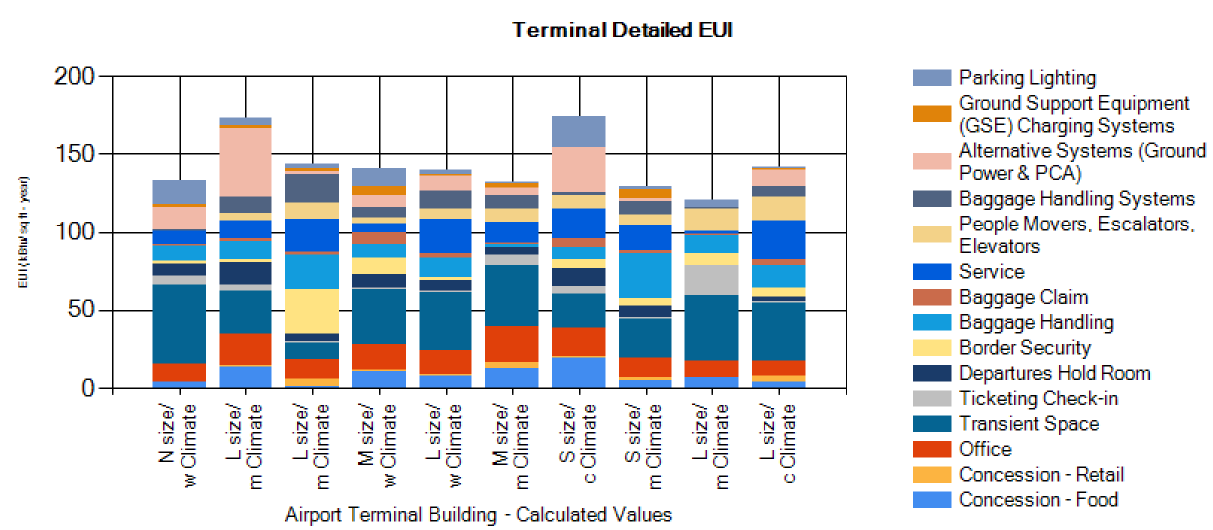


Chart 2-4
ATB-EUI: Terminal Detailed EUI - Calculated



EUI is discussed in more detail in Section 3 *Approach*.

3.2 Other Benchmarking Studies

Outside of ACRP, there are other benchmarking studies that are considered for performance and efficiency comparisons for this analysis.

Two of the largest cross-industry benchmarking studies for energy use and efficiency are the Environmental Protection Agency's (EPA) *EnergyStar* program and the US Energy Information Administration's (EIA) *Commercial Building Energy Consumption Survey* (CBECS). EnergyStar is a predominantly volunteer program where commercial, governmental, institutional, and industrial buildings analyze their energy use and report to the survey. Normalized based on climate and size, facilities in the top 25% of efficiency are recognized with the EnergyStar label. Even though airports and transportation terminals are not a current property type recognized by EnergyStar, the organization tracks energy-related information for these building types. *Airports Going Green* has promoted the idea for EnergyStar for Airports.

The CBECS study, last compiled in 2012, is a national survey that collects information on the consumption and expenditures of buildings. The study is sorted based on size, building type, and geographic region. Even though airports are not considered a major category, information from the report can be used to predict energy use.

In addition, US Department of Energy has several other programs that compare and analyze a building's energy use and efficiency. Lawrence Berkeley National Laboratory (LBNL) *Action-Oriented Benchmarking Studies* is a study of energy used by commercial buildings in California. It uses the 2006 Commercial End Use Survey (CEUS) database that was developed by the California Energy Commission. This survey goes into granular detail about different factors of energy use, such as HVAC systems, lighting systems, and hot water generation systems. In addition, LBNL developed the *EnergyIQ* benchmarking tool for non-residential buildings.

The National Institute of Building Sciences produces the *High Performance Building Data Collection* Initiative. In response to scaled down and delayed CBECS results, NIBS established the HPBDC to identify the path forward for collecting and reporting data on high performance buildings, including both energy use and other attributes. Information from this initiative are published in the Whole Building Design Guide (WBDG).

Private agencies provide benchmarking studies, as well. The two most popular are ASHRAE and US Green Building Council. The American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) publishes many books on different high performance buildings. These studies discuss benchmarks discovered in the analysis for these books. Sea-Tac was recently recognized by ASHRAE for the Pre-Conditioned Air system. The US Green Building Council's (USGBC) LEED program includes documentation of results for buildings applying for and certified as a LEED recognized building. The new LEED V4 includes specific requirements that metrics must be provided to LEED to use for analysis and comparison of various building types and certification levels.

Finally, the aviation industry has produced several benchmarking tools beyond ACRP. During the 2011 *Airports Going Green* conference in Chicago, discussions were made about the need for benchmarking airport energy and water sustainability. Several studies resulted from these discussions. Airports Council International – North America (ACI-NA) provides many financial and performance benchmarking surveys, in addition to their *Going Greener* initiatives. The Air Transport Research Society (ATRS) provides the *Global Airport Benchmarking Report*, discussing airport productivity and efficiency, cost, and results for 205 international airports.

4 ANALYSIS OF ALTERNATIVES AND OPTIONS

Other than benchmarking existing conditions and trends to determine current performance, this Task reviews major decisions regarding buildings and infrastructure within the Master Plan. These "alternatives" represent methods of growth for the Airport to meet its needs by 2034. Each alternative is analyzed to determine the effect to cost, efficiency, environmental impact, and operation of the Airport.

The analysis looks at criteria and assumptions developed through the SAMP process, including the creation of models, investigation, workshops, discussions, and review of current and previous data to determine an understanding of each alternative. This information is used to develop future trending predictions. Current market trends and technology are taken into consideration for the analysis, as are forecasted impacts for future regulatory, financial, and social requirements.

The models are used to develop criteria for evaluating overall total cost of ownership for the Airport, as well as building energy and water efficiency, and other facets of the Master Plan discussed in other Technical Memorandums.

The major alternatives reviewed within this Task involve the potential methods of growth by the Airport to meet its forecasted needs by 2034. The first comparison is determining the impacts that different building scenarios have to overall energy usage, water usage, and cost to the Airport. This alternative looks at two primary scenarios: renovating and expanding the existing Terminal and building a separate stand-alone Terminal to supplement the existing. A third case is also considered briefly – the "no build" scenario. This scenario anticipates that the existing Terminal accommodates the passenger growth without expansion. This scenario looks only at the impacts to energy and water usage to the existing Terminal, and does not consider spatial requirements, regulatory requirements, and system growth requirements (such as increased parking or additional HVAC to accommodate additional passengers).

The other major comparison within this report is determining the cost/benefit of different methods of sustainable construction, from minimum code compliance to net zero energy use buildings. These options are reviewed to understand how each affect the overall cost and utility consumption of the Airport. In addition, considerations for the implementation of renewable energy, onsite energy generation, and storage of rainwater are also discussed.

Finally, the report discusses the tools developed to model and predict cost of buildings and the consumption/cost of utilities. Energy and water models are developed to test different sustainability options. Cost models are developed to understand the impacts of cost for each of the alternatives analyzed and how these can be used to predict future costs.

In order to develop the models to provide a reliable forecast, the models are created to analyze the current conditions. Outputs from the models are validated and calibrated using available measured data. The models are then expanded to include the various expansion and renovation options to understand overall impacts and cost. Select parameters are modified in the model to test different optional scenarios. This information is accumulated and compared to understand each alternative.

These tools can be used for ongoing planning of facilities and infrastructure during the execution of the master plan. Further tool refinement can consider more granular details to further narrow down the options considered.

Approach

Task 6.12 involves the two-year analysis of how cost and energy/utility affect Airport building and infrastructure growth. The approach developed to determine these effects is important in forecasting for future costs and energy/utility consumption for each potential alternative.

1 APPROACH OVERVIEW

A major function of the master planning process is to develop strategies to meet goals and objectives within the plan. As these goals and strategies are being developed, certain alternatives and optional courses of action will be proposed that can meet these goals. It is important to research and analyzed these options within the structure of the master planning process to understand how each contribute to the master plan and how each will effect airport operations.

Buildings and infrastructure represent a large portion of Seattle's plan to accommodate future passenger growth. It is important to understand the limitations of current buildings and systems and understand how renovating or expanding them or building new buildings will affect things like environmental footprint, infrastructure, cost of operation, flight capabilities, community impacts, etc. Task 6.12 looks at two of these: costs and infrastructure. Understanding how new buildings will impact the current infrastructure and what the additional buildings will require in the way of future energy and water demand is important in determining the merits and drawbacks of different master planning choices.

In order to develop these metrics, however, an approach is needed to be developed in order to understand existing conditions, benchmark performance, and forecast future needs based on the different alternatives. The approach taken was a six-step process:

1. Document existing processes. Gather data to understand existing infrastructure and to be used to build a simulation model. Benchmark existing performance.
2. Develop a simulation model based on these existing conditions. Validate model outputs using actual consumption information.
3. Use site investigation, workshops, interviews, benchmarking, and other research and experience to fill gaps where necessary.
4. From the alternatives and options for the master plan, define model inputs using criteria and loading from existing conditions where needed and modern sustainable building materials and systems.
5. Simulate energy and water consumption. Determine cost impacts.
6. With results of major alternatives, change options based on various sustainability strageies and scenarios (such as level of sustainable construction).

1.1 Approach Used to Analyze and Understand Objectives

The approach analysis uses three different sets of tools to simulate cost, energy consumption, and water consumption: "shoebox" models, custom developed spreadsheet tools and third party software, and custom TCO costing model. These are described in greater detail within this Section.

The *shoebox* model can be used to validate assumptions by comparing results of existing terminal simulation with actual utility consumption trends. Once a set of data inputs and assumptions are determined to be within tolerance, the data is used to build expanded models including the various alternatives. This information is used not only to determine impacts for renovations for the existing terminal, but also shows how each alternative can affect energy demand. The information helps to "break down" building components where submeters are not currently installed to better understand how each of these components impact the overall energy use.

Software tools "fill the gap" by providing specific and specialized analysis where appropriate. Specific third party tools are cited when used.

Finally, a custom TCO costing model was developed to perform master planning level costing analysis for the different options. Adjustment of different options result in different costing outputs.

2 ESTABLISHING TARGET LEVELS OF SUSTAINABLE CONSTRUCTION

For planning of new construction, each new facility will be required to meet one of several sustainability classifications, based on factors such as environmental impact, budget, duration (whether the facility is temporary or permanent), and operational needs. These classifications include no build, standard construction, sustainable construction, and zero impact construction. Each classification has impacts to TCO, both with initial capital expenditures, as well as ongoing operations and utility costs. It is important in the analysis of the proposed building to understand these costs and the environmental impacts related to each option.

Regulatory standards govern Port construction. These standards have increased performative requirements over time with each published standard. The following Chart 3-1 provides an overview of the energy optimization required with regulations from 1980 through 2010.

Chart 3-1A
Improvements to ASHRAE 90.1: 1975-2015

(from ASHRAE, 2010)

Energy component energy usage has also increased performative requirements over time with each published standard. Chart 3-0 provides an overview of major system components contribution to energy.

Chart 3-1B
Decrease Energy Use of Each Component Over Time

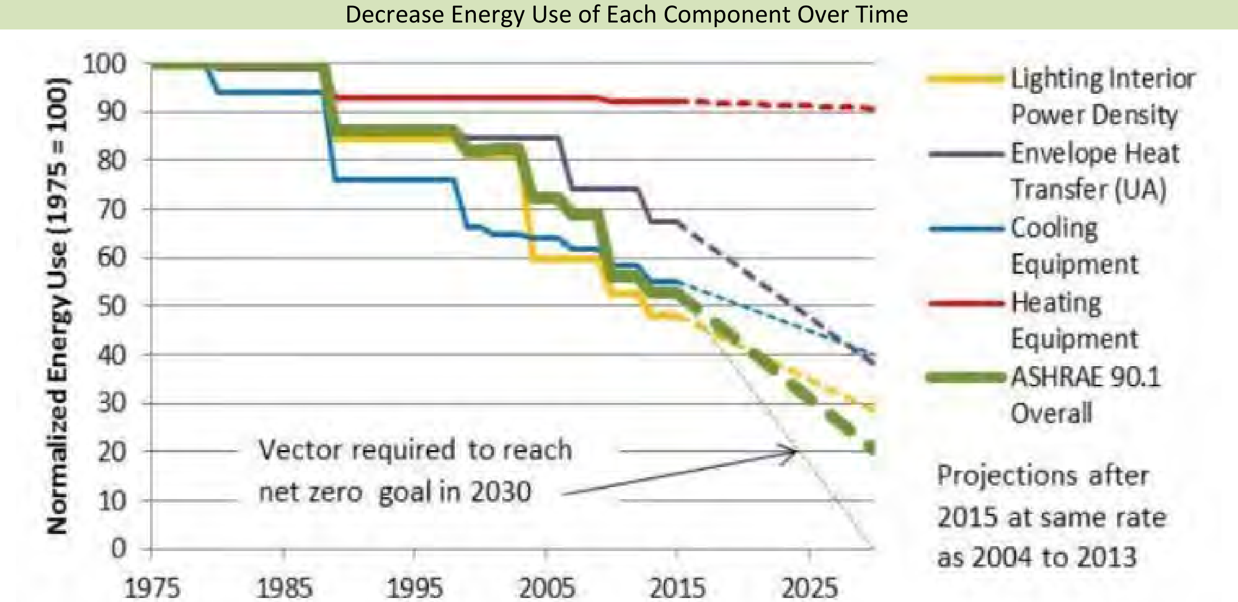


Figure 3-6 breaks down the EUI targets for years 1975 to 2031 into their individual components. Note that lighting power and envelope efficiency are the most impacted, whereas the heating efficiency decreases slightly over time. (from ASHRAE)

2.1 No Expansion Approach

One foundational option available to the Port is to simply not build any additional facilities to accommodate future growth. This existing performance approach does provide an informative perspective of operations but does not take into account future efficiencies, enplanement growth, technological advances, and programmatic influences. The initial benefit to this approach is that capital expenditures (CAPEX) are initially minimized leaving only operational expenses (OPEX) required by the Port. However, if this approach is pursued, building upgrades will eventually be required and each of these will then be required to bring the affected scope of work compliant to the building code adopted at the time of renovations. When this is encountered, additional renovation costs (RENEX) to the projects will be required. A "no build" solution would result in a significant building decay and loss of Airport operation, and therefore is not a considered option.

2.1.1 Existing Energy Performance

A "no build" energy performance alternative assumes that the existing building energy efficiency will not change from its current performance level while cost of energy continues to escalate over time. As a result of maintaining these static energy efficiency levels, the overall operational cost will continue to increase and the efficiency ratio will decrease. This option should be relegated only to minor renovations where the building envelope and energy systems (HVAC, lighting, and water heating) are not being modified.

In some cases, the efficiency of the current construction meets or nearly meets the current Washington State Energy Codes as some renovated buildings have been upgraded with improved thermal envelopes. However, as a whole, the overall building efficiency is less than current code levels and some of the older stock will require additional expenditures in order to bring into compliance. Additionally, the efficiency of the existing building envelope and associated building systems will become further from Energy Code compliance the longer the span between when it was built and the date of the current code.

2.1.2 Existing Water Performance

A "no build" water performance alternative assumes that the existing water efficiency will not change from current levels while the cost of water continues to escalate over time.

The Port has instituted a series of standard water fixture efficiencies that are currently being implemented throughout the main terminal building. These efficiency measures calibrate the terminal to a modest water conservation level that exceeds the current Washington State Plumbing Code levels.

The following list describes the current adopted Port water efficiency standards.

- *Toilet* *1.28 GPF*
- *Urinal* *0.50 GPF*
- *Public Lavatory* *0.50 GPM*
- *Kitchen Faucet* *2.20 GPM*
- *Shower* *2.00 GPM*

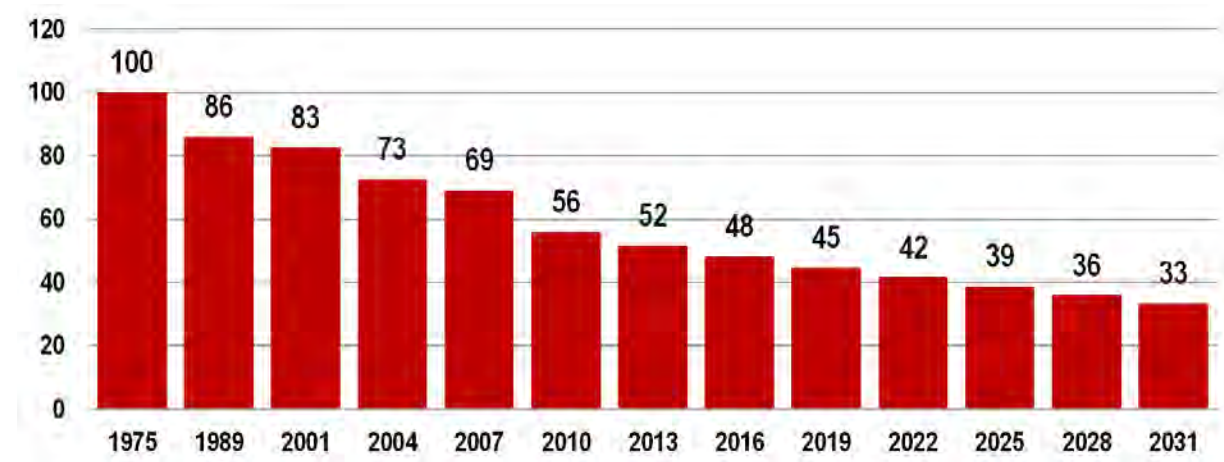
2.2 Minimum Code Compliance Approach (Standard Construction)

This business as usual scenario assumes that any new construction or major renovation will comply with the Washington State Building and Energy Codes in effect at the time of permitting. The building code performance efficiencies will increase over time requiring additional energy and water conservation measures to be employed into buildings. As a result, this approach will increase both building efficiencies and operational savings over time. It is considered the baseline for comparison.

This code minimum approach follows the regulations in place at the time of construction. This is the historic pattern utilized by the Port in construction projects. As building codes incorporate more stringent requirements over time, projects that follow this path will by default increase energy performance. It should be noted that buildings there is a limit to maximizing the energy efficiencies from envelope, system, and lighting. Renewable energy will be required in order to meet the 2031 energy reduction building code trajectory targets.

Chart 3-2, utilizing a 100 scale use intensity index, illustrates the energy reduction trends through 2031. Trends from 1975 through 2016 are based upon publically available information and trends from 2016 through 2031 are based upon the published 2031 goals. The projected values are spread equally between the commencement and ending points. This table outlines a regulatory approach to construction meeting the applicable published energy code.

Chart 3-2
EUI Targets for ASHRAE 90.1 and Energy Codes



This chart shows EUI targets (based on 100% of 1975 value) for 1975 to 2031. 2016-2031 are predicted based on current trends and expected regulations.

2.2.1 Baseline Regulatory Energy Performance

The current Washington State Energy Code is similar to ASHRAE 90.1-2010 Energy Standard for Buildings Except Low-Rise Residential Buildings. As the majority of the current facilities were constructed prior to the current iteration of the Washington State Energy Code, they as a whole measure below this baseline energy efficiency standard. As additional buildings or major renovations are implemented the cumulative effect will raise building performance.

2.2. 2 Baseline Regulatory Water Performance

The current Port water efficiency standards exceed the minimum water conservation standards required by the Washington State Building Codes. Although published data is unavailable, it is anticipated that required water conservation levels will increase over time. As a result, water efficiencies through building expansion or major renovation will also increase with a code minimum "business as usual" approach.

2.3 Sustainability Measured Approach (LEED)

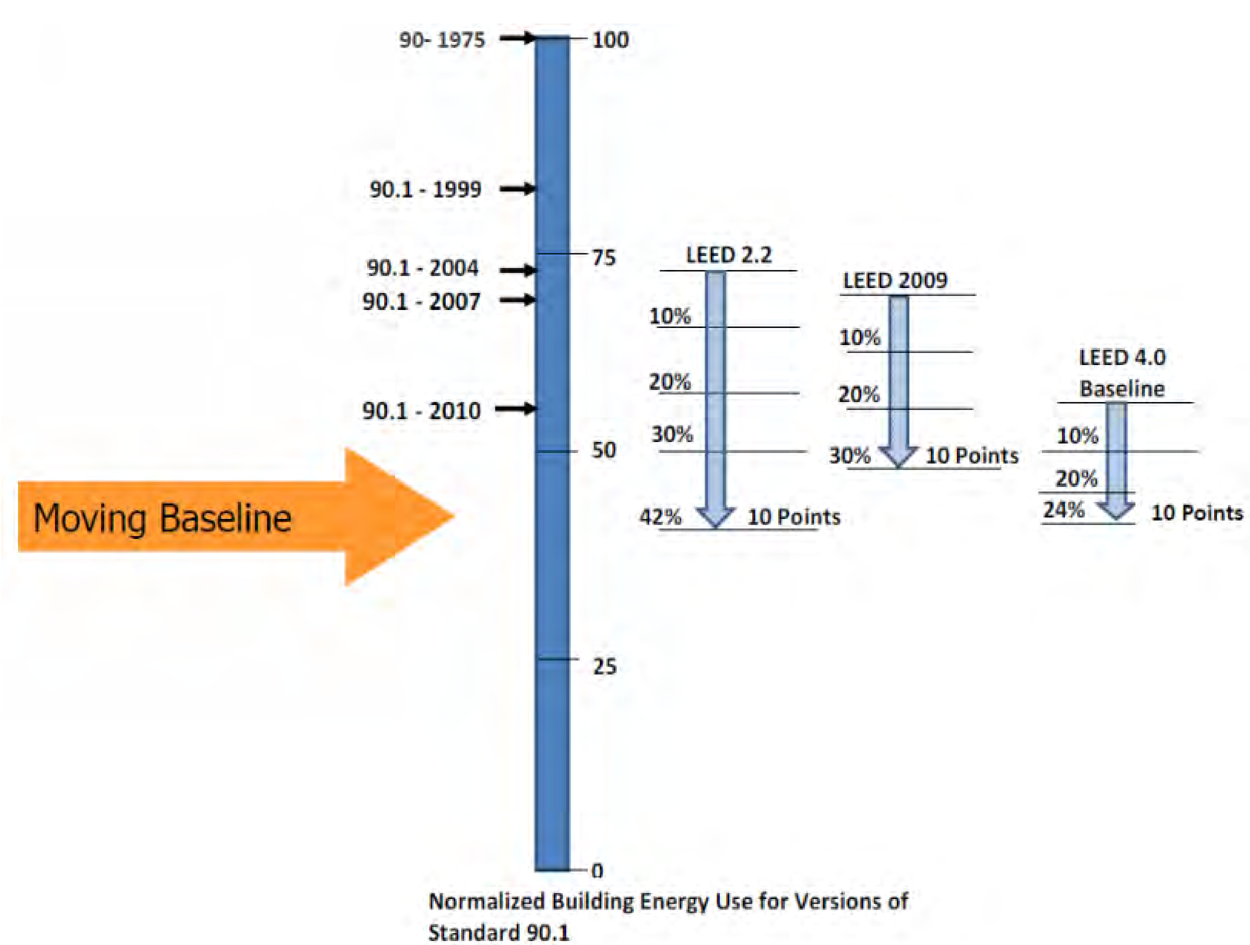
A sustainability approach assumes that any expansion or major renovation construction activity will be designed and construction to third party defined sustainability measurements such as the United States Green Building Council LEED Rating System. Projects meeting the rating system criteria require energy and water performance that exceeds the code minimum regulatory approach.

The Port's Century Agenda plan strives to provide LEED certification compliance for buildings. The following sections codify additional implementation measures required for projects, and are divided into LEED minimum pre-requisite and LEED Silver compliance paths.

2.3.1 LEED Sustainability Energy Performance

Figure 3-1 provides a normalized comparison of LEED over time with ASHRAE 90.1 energy standards.

Figure 3-1
Comparison of LEED over Time

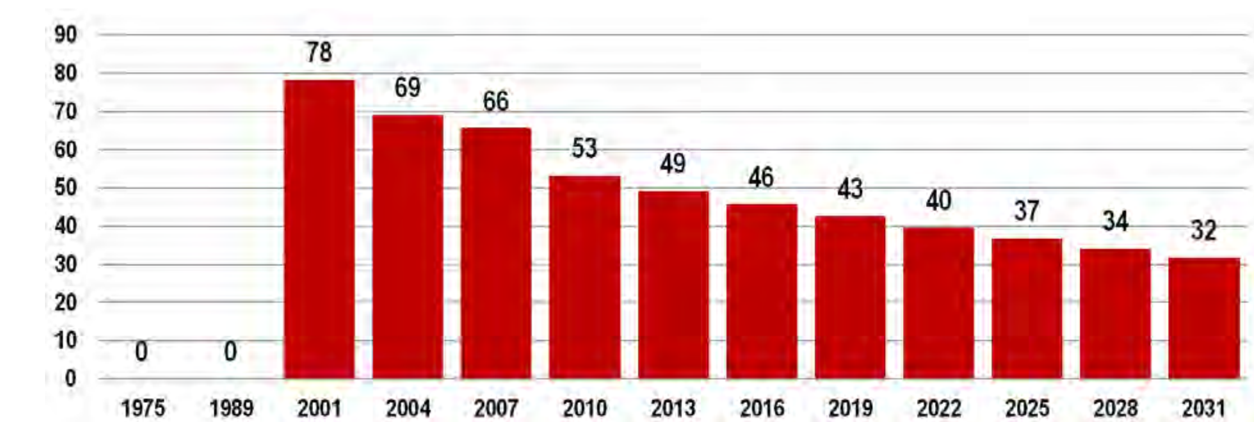


Based on normalized EUI of 100% of 1975 efficiency, Figure 3-1 shows the relative efficiency scale that is the basis of the last three versions of LEED.

The LEED Minimum approach projects a modest 5% building performance improvement over the building code standards in place at the time of construction.

Chart 3-3 looks at meeting a minimum LEED pre-requisite conditions for energy reduction compliance. A nominal 5% improvement as outlined in the LEED NC v4 standard establishes the baseline multiplier for the roadmap. The table illustrates the anticipated LEED Minimum premium over building code energy efficiencies through 2031.

Chart 3-3
EUI Targets for LEED Projects

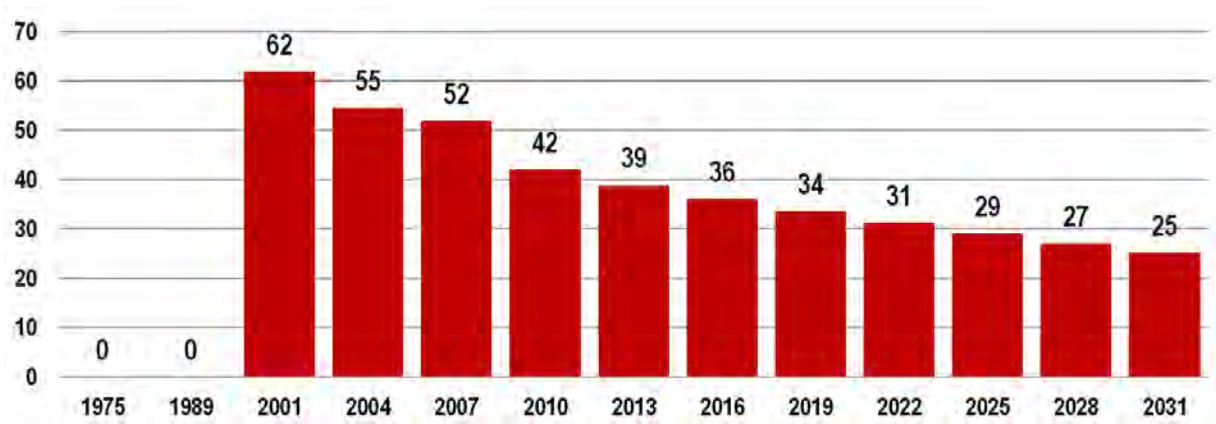


This chart shows EUI targets (based on same EUI used in energy code compliance case) for 2001 to 2031. 2016-2031 are predicted based on current trends and expected regulations.

The LEED Silver approach projects a 25% building performance premium over the building code standards in place at the time of construction.

Chart 3-4 looks at a LEED Silver overlay to the historic and projected energy efficiency information. A nominal 25% energy efficiency reduction from the published referenced standards was applied to calculate the conservation percentages. This table outlines the Port LEED certification goal thresholds for building construction. The table illustrates the anticipated LEED Silver premium over building code energy efficiencies through 2031.

Chart 3-4
EUI Targets for LEED Silver Projects



Similar to Figure 3-3, the EUI targets for LEED Projects obtaining Silver Certification.

2.3.2 LEED Water Conservation

Minimum LEED 2009 interior water efficiency baseline governs primary plumbing fixture performance of toilets, urinals, lavatory and kitchen faucets, and showerheads. A minimum performance efficiency of 20% must be met as a precondition to attainment. The performance is measure against a baseline level of efficiency. Points are achieved with efficiencies above this threshold bracketed at 30%, 35%, or 40% attainment measures. A maximum of 4 points is available. The following list describes the minimum baseline requirements for LEED 2009.

- Toilet – 1.6 GPF
- Urinal – 1.0 GPF
- Public Lavatory (restroom) faucet – 0.5 GPM at 60 psi
- Private lavatory faucet – 2.2 GPM at 60 psi
- Kitchen faucet (except used exclusively for filling) – 2.2 GPM at 60 psi
- Showerhead - 2.5 gpm at 80 psi per shower stall

LEED v4 increases the available point structure for indoor water use reduction attainment with points achieved for efficiencies above the baseline bracketed at 25%, 30%, 35%, 40%, 45%, and 50% measures. A maximum of 6 LEED points is achievable with LEED NC v4. The minimum baselines are also more stringent in LEED v4. All LEED projects registered after October 1, 2016 are required to pursue v4.

Proposed Port standards currently meet the minimum prescriptive baseline for LEED 2009 toilets, urinals, and faucets, earning approximately two LEED points. Additional measures are encouraged as the standards may not be sufficient for future building code and LEED attainment performative requirements. Improved plumbing fixture technologies are now commercially available that increase water conservation levels above current practices that warrant consideration and validation. The following minimum measures are encouraged.

- Toilet 1.10 GPF
- Urinal 0.125 GPF
- Public Lavatory 0.35 GPM
- Shower 1.50 GPM

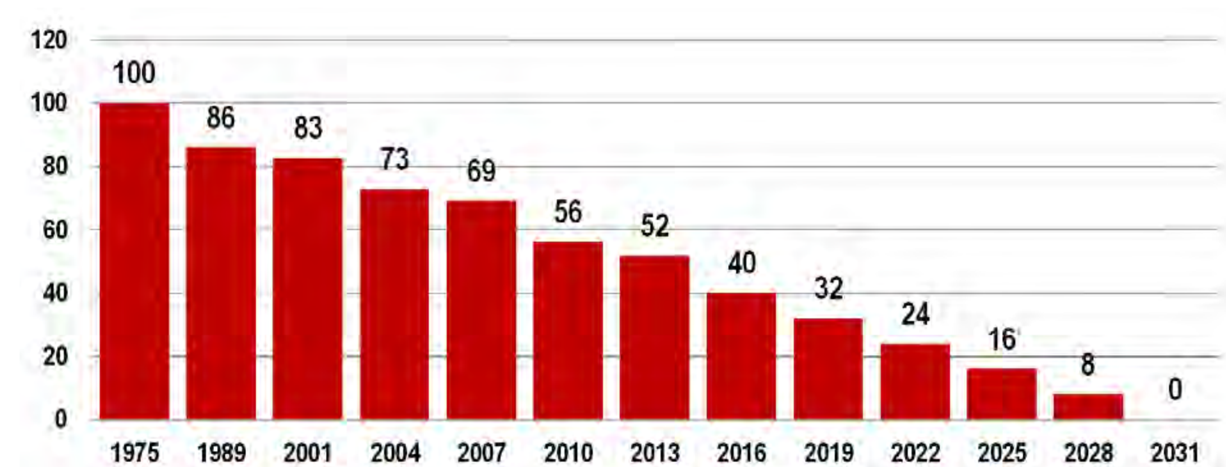
2.4 Net Zero Approach

A Net Zero approach requires an aggressive accelerated building performance premium over the building code regulations in place at the time of construction and over LEED standards. This approach includes net zero energy and water usage.

2.4.1 Net Zero Energy Performance

Chart 3-5, based upon the ASHRAE 189.1 standard goals as published in the ASHRAE 2020 Vision Plan, outlines the regulatory roadmap to net zero energy usage and illustrates an aspirational approach to building construction. The table illustrates the anticipated path toward net zero energy attainment over building code energy efficiencies through 2031.

Chart 3-5
Pursuit of NZEB: EUI Targets to Obtain Net Zero by 2031



SOURCE: ASHRAE 2020 PLAN, PNNL STUDY, PROJECTIONS 2016-2031 NORMALIZED EQUALLY FROM PUBLISHED 2016 DATA

Using same scale as previous Figures, Figure 3-5 demonstrates EUI targets for Net Zero Energy Buildings (NZEB). Note that the energy used is based on the difference of energy obtained from public utilities and the energy generated on-site through renewable means.

2.4.2 Net Zero Water Performance

A net zero water consumption approach requires aggressive potable water conservation goals. Pursuing this requires a combination of maximum fixture efficiency, gray water, reclaimed water, and water harvesting measures. Net Zero Water usage is determined by the simple formula below.

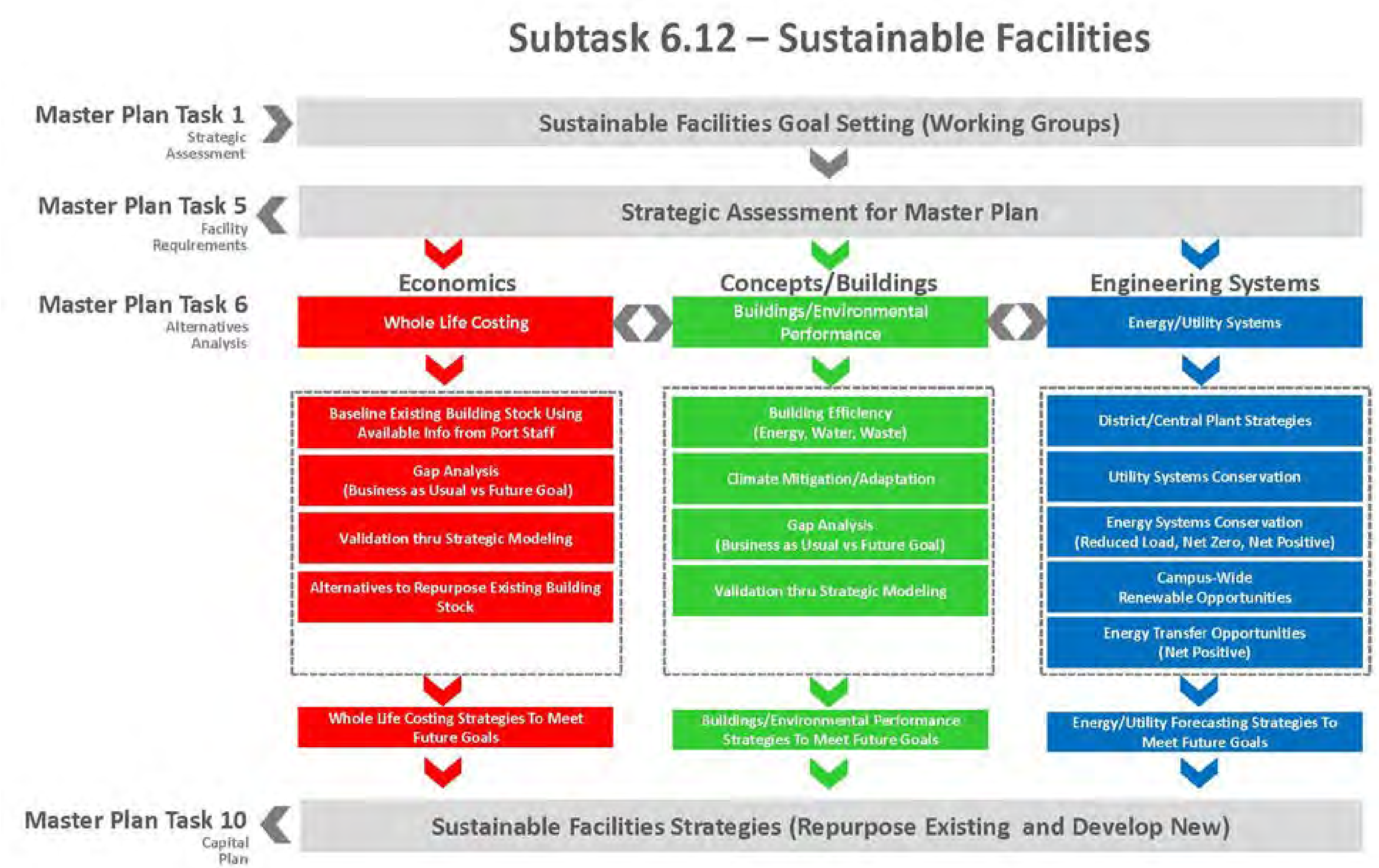
Water consumption = Water Conservation

In addition to maximizing indoor fixture efficiency, gray water solutions that collect flow fixture water can be re-used in the flushing fixtures. Condensate collection would be another potential collection source. Both of these options are directly proportional to usage and are not dependent upon weather conditions. If additional water collection measures are needed, rainwater capture options can be explored. These are weather dependent. A purple pipe infrastructure option may also be explored to achieve net water usage.

3 PROCESSES AND PROCEDURES

The SAMP looks at all facets of the Airport in forecasting and developing sustainable facilities that meet the needs for Seattle-Tacoma International Airport over the next twenty years. Task 6 within the Master Plan looks specifically at alternative solutions for these needs and develops the analysis and testing required to fully define, understand, forecast, and decide on these alternatives. This report specifically focuses on those alternatives associated with economics, buildings and concepts, and engineering systems.

Figure 3-2
Development of the Sustainable Facilities Strategy for Master Plan



Economics focus on establishing cost data for use in comparison of the different scenarios in order to develop and analyze the total cost of ownership. The report baselines existing building stock using available asset data from the Port in order to develop cost structures for the different asset types. Where information was not available, gap analysis was performed to determine other resources used to gather and define the missing data. Strategic cost models were developed to validate the information and to test each of the alternatives considered. The cost models also considered reuse and redevelopment options of existing building stock.

The buildings and concepts focus on major facilities at the Airport and their performance and development needs to meet the Master Plan goals. This task focuses on the energy intensity aspects of these facilities. Discussions of spatial requirements and flow of operation are covered in other Sections of the Master Plan. Environmental and climate interactions with the buildings is discussed in Technical Memorandum 7.

Engineering systems focus on energy utilities – public and site generated – and water systems specific to the facilities discussed above. Understanding the impacts and limitations of these utilities allow for development of a plan to grow while mitigating excessive cost, consumption, or environmental impact.

As growth is a dynamic process, so is development of the strategy to plan for the growth. Understanding the goals of this study is important in developing the process to define, analyze, test, and predict different outcomes based on the potential scenarios.

The development of the task involves implementation of reasonable processes and procedures necessary to govern the analysis. The procedures were developed in concert with the Port and concentrated primarily on building, utilities, and assets. Information was gleaned through a combination of data collection, benchmarking, goal setting, information evaluation, on-site visitations and interviews with Port representatives.

To understand the impacts of different building and infrastructure alternatives, it is important to first define what should be tested and how it should be tested to get the results and forecasts needed for the master plan. The Master Plan takes a "10,000-foot elevation" approach in development of this analysis. It focuses on the development and redevelopment of the Airport assets to meet goals and objectives, improve passenger and cargo growth capacity, and improve flow of operation. Since planning decisions are based across entire Airport over a long time span, granular detail of each asset is not needed to understand the impacts of each decision. The Master Plan only serves as a "road map" for development. It does not focus on the execution of the development, itself. The planned outcome within the Master Plan is fully tested through its execution and the plan is ratified as key assumptions, goals, objectives, or situations change.

Processes are established to analyze the alternatives derived through the master planning process. These processes are used to test how each one of these alternatives meets the needs, goal, or objective or how they benefit the overall Airport.

To develop the processes, the master planning team used a combination of workshops and team discussions to understand the focus on this task and how the information is important to the overall master plan. Through these workshops, the testing procedures were refined to focus on specific and critical aspects of those planning decisions.

The strategy is a three-stage approach: document existing conditions, develop models to test alternatives, and forecast the resulting findings for each alternative. The strategy further establishes methods for which the information would be benchmarked and integrated to other Tasks within the overall Master Plan.

The *documentation* phase is used to establish the baseline performance of the existing facilities and utilities at the Airport. Fully understanding the impacts of different alternatives first requires a general understanding of the current condition in order to comprehend the scale of the differences.

The *model development* phase is used to visually simulate existing building performance. Once this building performance has been calibrated with existing data and validated within an acceptable planning-level tolerance, the models are used to test the various alternatives. The model is expanded to match the potential growth of the Airport and the data output from these models is used to understand the impact to the Airport. Parameters within the models are then further modified to demonstrate optional construction methods and other testable function.

The *forecasting* phase reports the findings from the model analysis and other research and recommends the path forward to the overall Master Plan, based on the findings.

3.1 Methodology

Data collection is an important function within the master planning process. Data is important in order to build analysis models, understand current situations, and to establish goals and objectives for which a baseline is required.

Information was obtained from many sources for this Task. Each of these different sources were used to build the analysis model and understand the energy and water profile for the major buildings at the Airport.

Existing information was gathered and reviewed for applicability. This included review of existing models, reports, papers, drawings, and documents. Proposed documents for new expansions (International Arrivals Facility) and major renovations (Northstar) were reviewed to understand potential changes to existing data. Existing utility consumption and costs were reviewed as were building automation system (BAS) trends.

Workshops were held with various groups to discuss mechanical and electrical infrastructure, spatial considerations for new building growth, and master plan alternatives. Interviews were held with key stakeholders. Site observations were made throughout the process to understand existing conditions and to verify data gathered.

In the development of the information, industry-standards were reviewed from aviation industry sources, such as Airport Cooperation Research Program (ACRP). Benchmarks from energy standards (such as ASHRAE and USGBC) and energy codes (Washington State Energy Code) were used to establish baselines. Costing benchmarks from International Facility Management Association (IFMA) were used to develop cost tables for different assets.

The information gathered was validated through a three step process. The first step was to compare information among different sources to verify consistency of information. The next step was to review the information across benchmarks from other similar facilities to make sure information appeared to be within the expected range for a facility of this type, climate, and size. If information seemed suspect, it was flagged – not necessarily rejected – and additional information or confirmation was sought to verify data, The final step was to review information with the combined Port and engineering Team to scrutinize information and determine which information would be used.

Once data was proven to be acceptable to use, it was input into analysis models. Model outputs were validated with existing consumption information and used to forecast future conditions when certain parameters were changed.

3.2 Information Sources

Reliable information is needed to develop a useful baseline for which to establish and test the master plan. Although granular detail is not needed during a planning process, it is important that the information used is accurate. Errors, anomalies, and incorrect assumptions can significantly affect the reliability of the results and impact the overall starting point of the master plan. If goals are set based on these baselines, then the ability to achieve these goals can be affected by inaccurate results.

When information was not available, gap analyses were developed to identify the missing information and determine the best source to obtain the information. In some cases, information published from industry sources, technical societies (such as ASHRAE or USGBC), and aviation-focused industry sources (such as ACRP) were used to predict the missing information. Other cases, alternate methods were used to determine this information. For example, the Airport's BAS provided trends were used to predict energy usage for central plant equipment that was not submetered. Experts from both industry and from the Airport Stakeholder teams provided empirical estimates for other data.

The information not directly sourced from the Airport (predicted information) was discussed among the Master Plan team to identify potential uncertainty of the information and the risk and consequences of that uncertainty. One example was electrical metering. Submeters are not currently installed throughout the Terminal. Information derived from the substation power centers as well as review of the electrical system among the Stakeholders produced an electrical profile with acceptable confidence for use in the analysis. Another example of uncertainty was development of cost values for all asset types. Exact cost values were not available through the Asset Management program for all asset types. The Team worked with the Airport estimator to establish CAPEX costing and used information from IFMA, the CBRE Whitestone Manual, and other Airports to estimate OPEX costs for the missing assets. The total cost of ownership for a known facility was then modeled and verified based on actual cost data.

These validation checks allowed assumptions to be tested based on known information. If the checks were within an acceptable tolerance, the risk of using the data was assumed to be low. Likewise, if the check was outside the acceptable tolerance, the risk was identified as too high and additional information was sought to improve the data inputs.

Refer to Appendix C for raw data provided by Port of Seattle that was gathered and analyzed during the development of the Master Plan. The information provided is listed by its source.

3.2.1 Data Collection

Fundamental to the discovery analysis is the collection and understanding of existing available information. This report condenses foundational data essential to determining appropriate building energy and water analysis. Collection of existing building spatial, consumption, and operational metrics was gathered to determine appropriate master plan impact levels.

For buildings analyzed within this study, basic Port provided building and utility information was gathered in order to develop a baseline conditions, "shoebox" modeling, asset categorization, and future forecasting. The following elements were pursued during the development of this study.

Energy

- Review of existing and projected building construction and operation energy conservation plans.
- Review of existing building inventory spatial summary and allocation tabulations.
- Review of associated building energy consumption, efficiency, utilization, and allocation data.
- Review of pertinent building level energy management systems and operational controls.
- Review the relationship of tenant area energy usage and overall building conservation.
- Review of electricity and gas meter locations and identify what they serve
- Review of existing Port identified comparative benchmarks and pertinent measurement standards.
- Calculate existing Energy Use Intensity (EUI) for facilities and utility type.

Water

- Determine existing building water consumption related to current building construction and operation activities.
- Calculate projected building water consumption related future construction, anticipated occupancy usage patterns, and operation activities.

Utilities

- Information on existing public utility service entrances and location of utility support equipment (meters, etc.).
- Review of existing utility usage for the site (maximum demand load for power and natural gas, historic water usage, etc.).
- Master utility plans and / or reports related to project site within last 10 years .
- Survey of existing hydronic utilities and their generation equipment, such as chillers and boilers.
- Understand historic trending of the operation of the equipment including performance challenges.
- Understanding the control strategies and how the generation equipment communicates demand with the end users.
- Understand the electrical power service, including any switch yards, medium voltage distribution, major electrical substations and transformers, standby and emergency power generation systems, and existing onsite power generation systems (renewable sourced).
- Review of existing sub-metering utility locations.

3.2.2 Benchmarking

The following Comparative Benchmarking and Attainability Metrics were established for the report.

- Using readily attainable or Port provided sources, benchmark comparative facilities to determine appropriate key performance indicators, measures, and opportunities.
- Compare energy reduction targets and recommendations to other sustainable measurement metrics.
- Determine Site Utilization Intensity goals and energy reduction strategies to other industry leading standards.
- Compare recommended energy conservation strategies with existing airport sustainable design guidelines.

3.2.3 Interviews

F&I Interviews

Facilities and Infrastructure manages the complete operation of the Airport's mechanical, electrical, and other system infrastructure. Numerous interviews were conducted with the Port F&I staff to obtain existing energy usage information and to provide relevant commentary from previous studies and projected procurement plans. These interviews were conducted through a series of conference calls, data inquiries, and multiple onsite meetings.

Aviation Environmental Planning Interviews

Additional interviews were held with Sea-Tac aviation environmental planning department representatives to provide additional perspective and useful information pertinent to this study, including the environmental impacts of the energy systems, additional commentary on how energy is consumed, and understanding of the current water use strategies for the airport.

3.2.4 Onsite Investigations

Site investigations occurred throughout the data collection process. Existing drawings were reviewed to understand overall flow of various utility and energy systems. Each building within this portion of the Master Plan was observed during operation to understand loading and to establish process load density estimates.

3.3 Developing Building Processes

Understanding the existing building stock is important in the process to develop plans for the development and redevelopment of the Airport to meet the growth and performance goals.

The LFA Team worked closely with Port staff to develop conceptual forecasting models included in the SEA-TAC Sustainable Airport Master Plan. These customized models explored what-if scenarios related to building energy conservation and water optimization opportunities, as well as understanding environmental impacts. Each was analyzed at individual building and collective campus levels to measure the anticipated impact of each element.

A key component was the assessment of energy efficiencies that can be built into alternatives for both new and renovated airport facilities. A second pivotal component identified water conservation opportunities with the facilities. Climate and environmental opportunities were identified and information integrated into Technical Memorandum 7.

Working with airport representatives, approaches to building energy and water saving optimization goals were explored to establish a high-level attainment strategies. Information determined and discovered during the building analysis provided direct input to the work delineated in the Utility and Whole Life Costing sections.

The master planning team reviewed existing facility energy usage and the developed high-level evaluation models that enabled multiple building optimization forecasting scenarios. In particular, the following building types and building level components were explored:

- Terminal
    - Main Terminal
    - Terminal Administration Building
    - Terminal Concourse A
    - Terminal Concourse B
    - Terminal Concourse C
    - Terminal Concourse D
    - Terminal Central Terminal Expansion
    - North Satellite
    - South Satellite
    - Central Plant (located in Parking Garage)
- Parking
    - Parking Garage
- Cargo
    - Cargo 1-4, owned and operated by POS

3.3.1 Validation of Energy Profile

Custom models were developed to validate concept level energy and water efficiency measures using spreadsheets and commercially available simulation software. The purpose of this quantitative approach was two-fold: one, determine if the goals established by policy and strategy in the sustainability working groups in Subtask 1.2 (Setting Sustainability Goals) are achievable; and, two, if achievable, identify the specific capital and operational measures needed to achieve the goals for Task 10 (Long-Range Development Plan and Strategy).

A combination of commercially available building energy performance simulation tools (such as IES Virtual Environment) and custom-built spreadsheet analysis tools were used for this analysis and to establish appropriate goals and targets in a dashboard format. These were provided at the following levels of detail.

- Airport-wide campus scale.
- Individual Building scale (including block load estimates for MEP systems)

The primary purpose of the energy performance simulation software was the development of a "shoebox" model. A "shoebox" model is a thermal version of an architectural massing model. Unlike conventional energy simulations, a "shoebox" model is used for master planning efforts to understand high level decisions and their impacts on the building. Each wall, light fixture, and equipment is not represented in the model, rather a shell to understand weather impacts and power densities for lighting, ventilation, and process loads to understand internal effects. Granular details included in conventional energy models are not needed when understanding the high-level impacts required for a master plan.

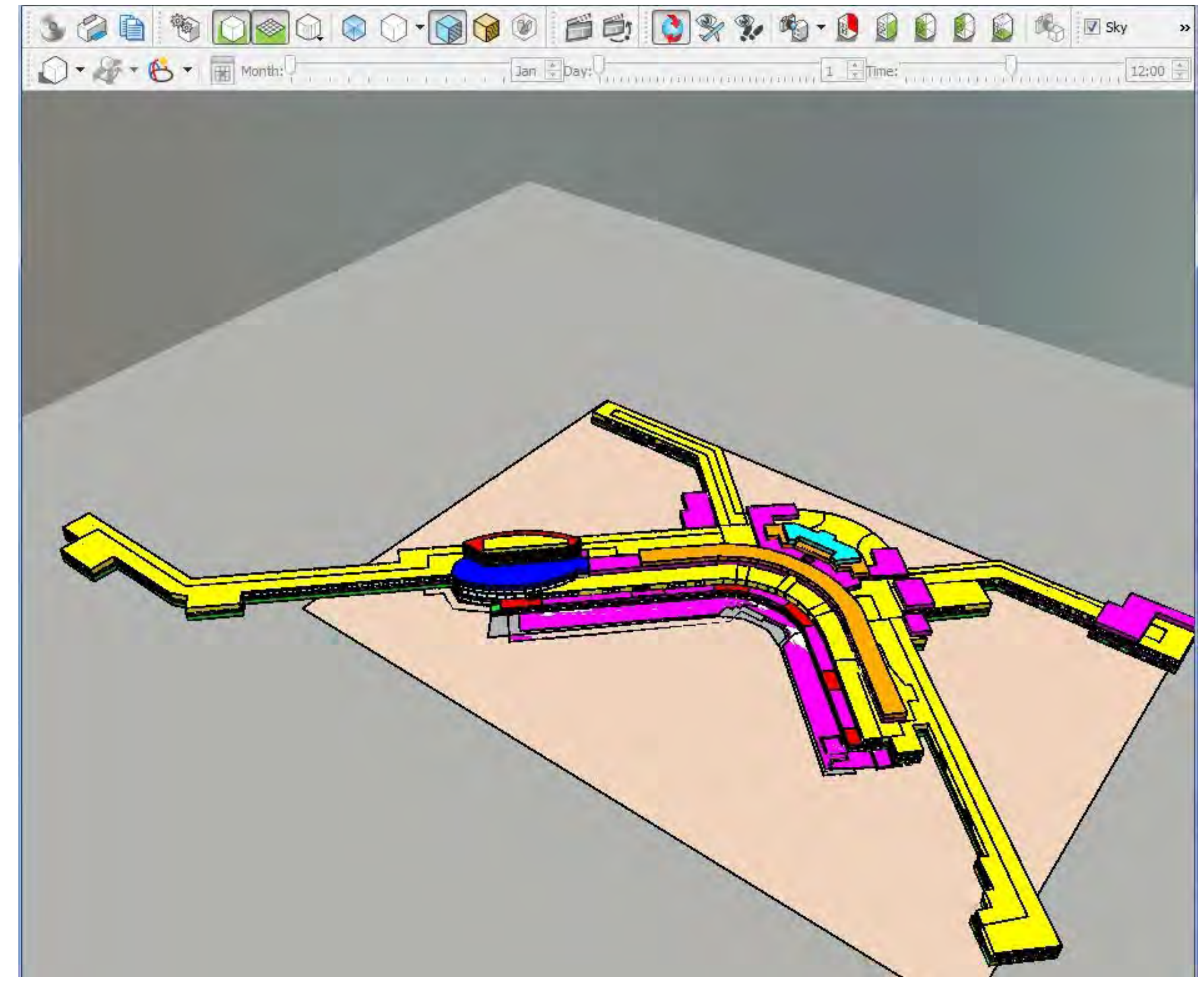
The "shoebox" model was built for several purposes. The first was to understand how the buildings' envelope, lighting, HVAC systems, and process equipment loads used energy in the building. Information was known about the building lighting, ventilation, and envelope, and therefore the process load could be calibrated using historical electrical load, natural gas (steam), and chilled water data provided by the Port. The building simulation was modeled at a conceptual high-level block load analysis. Determining how each of these major systems affect the overall energy use was critical in understanding the impact each has to the overall energy profile. Energy profiles are documented in the next Section.

The second purpose was to use this information to test master planning level decisions on the airport buildings and proposed alternatives. The different models were modeled independently in the same shoebox model fashion and compared. After the baseline energy consumption is determined for each alternative, certain parameters (such as quantity or type of insulation, lighting density, HVAC efficiency, etc.) were adjusted to understand how each of these impact the baseline energy use.

The simulation software was used as a dynamic time-based analysis to refine the spreadsheet analysis and to provide validation at a conceptual high-level, appropriate for a master planning effort. Generic energy efficiency measures selected from the listing below were considered on a selective basis to establish potential viability attributable to other airport-wide campus buildings included in the master planning efforts.

- Building form and orientation.
- Lighting and daylighting.
- HVAC Systems (Heating, Cooling, and Ventilation)
- Renewable potential
- Utility reduction potential
- Operational schedules (HVAC and lighting)
- Thermal (building envelope).
- Water (occupant based from design day flight schedules).

Figure 3-3
Energy Model of Existing Airport Main Terminal



Energy Model of the Main Terminal split into zones based on occupancy type, building construction, systems, and direction of building. Energy Model created using IES Virtual Environment.

After the shoebox model of the existing terminal was calibrated, models for the one terminal and two terminal alternatives (refer to other Task 6) were created using the same process loading densities and new expected passenger density. Resulting energy consumption baselines for each alternative was determined and used to compare each scenario as part of an overall TCO analysis.

The baseline represents the "standard", minimum code compliance method of construction for the new facilities. Parameters within the shoebox model were changed to account for differences due to more sustainable construction. These included energy efficient systems, use of renewable energy, and improved envelope performance.

3.3.2 Development of Baseline

In order to determine impacts of future expansion or renovation, compare alternatives, or to predict future consumption and cost, a present-day “baseline” was established. This baseline was generated from the shoebox modeling efforts and used to establish potential modifications and their effect in comparison with current operation. In addition, the baseline was used to establish “Business as Usual” curves for comparing and predicting overall utility and energy consumption and asset cost.

Traditional sustainable energy comparisons use Energy Use Intensity (EUI) to compare energy use between facilities and for use in development of improvement goals. EUI, as well as Water Use Intensity (WUI), were used to document energy use per building reviewed by the Master Plan.

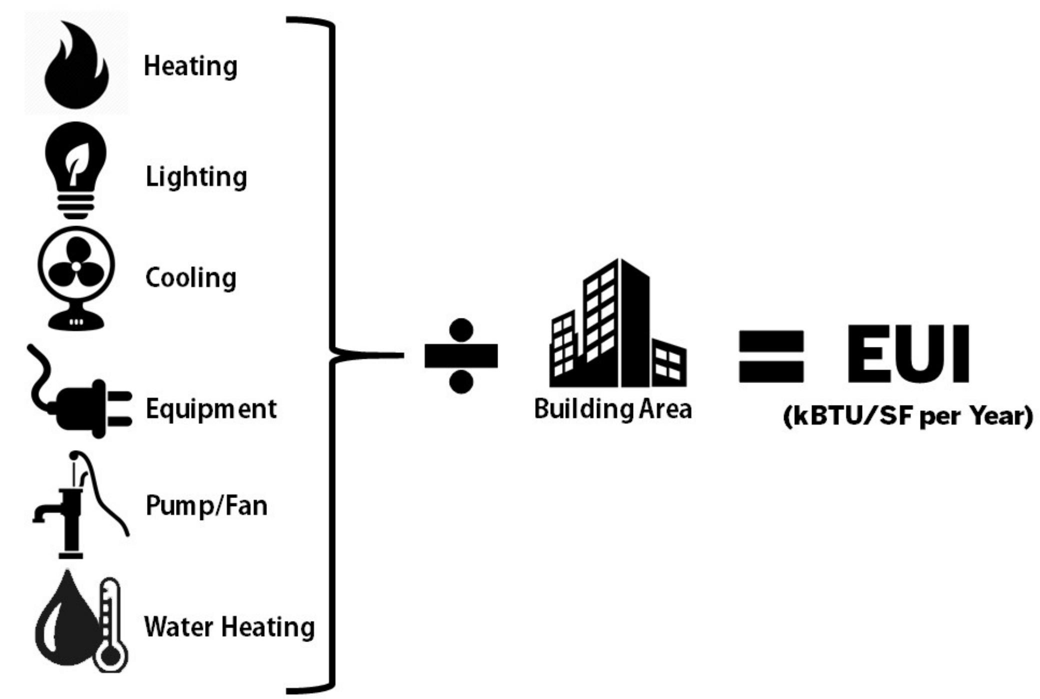
Energy Use Intensity

Energy Use Intensity, or EUI, is used to describe a building’s total energy use. It is expressed as annual energy consumption per building area. It's calculated by dividing the total energy consumed by the building in one year (measured in kBTU or GJ) by the total gross floor area of the building in square feet. Total energy use includes all electrical and fuel/natural gas *demand* of the building. Adjusted EUI will sometimes exclude energy obtained from a renewable source.

It is used by many to understand energy consumption density within a building. The Environmental Protection Agency’s EnergyStar program uses EUI in its Portfolio Manager, which is used to document a building’s energy use and basis for certification of the EnergyStar certification. EUI targets are discussed in many of the energy codes, such as ASHRAE, and sustainability programs, such as USGBC’s LEED, the American Institute of Architects 2030 Challenge or the Living Building Challenge.

EUI is total energy used within a building. Figure 3-4 graphically shows how it is calculated.

Figure 3-4
Breakdown of Energy Use Intensity



EUI has many benefits and drawbacks. Some of these include:

Benefits:

- Industry standard approach
- Simple to calculate and understand.
- Allows building of different sizes to be compared.
- Demonstrates improvement as EUI numbers decrease.
- Allows planning level understanding of energy consumption.

Drawbacks:

- Does not consider climate. Buildings in different climates cannot easily be compared.
- Does not easily allow buildings of different types to be compared. For example, a very energy efficient laboratory would have a higher EUI than a very poor efficiency warehouse.
- Does not consider impacts of process loads. EUI targets for energy codes typically focus only on HVAC, water heating, and lighting related energy use. Heavy equipment power loads skew the numbers higher and building efficiency has a less impact to reducing the EUI.

- EUI does not consider hours used a day. An office building or school that is in operation 8-9 hours a day compared against a building that operates 24 hours a day would not have compatible EUIs. Buildings operated for fewer hours use less energy.
- EUI penalizes heavily used buildings and rewards low occupancy buildings. Empty buildings have very low EUI, regardless of their efficiency.
- Typical EUI numbers do not differentiate where the energy is being used and what energy type (electricity, natural gas, etc.) is being used.
- Penalizes smaller footprint (energy denser) operations.

So why use EUI? Since all of the buildings have similar operation, similar climate, and similar occupancy, normalizing each building's EUI can allow one to understand relative efficiency of each building and to predict future building energy consumption.

In order to calculate EUI for each of the buildings, annual electrical consumption for each building was analyzed based on load center meters (refer to next section for more detail) and information calculated using the energy models. The energy considered was split into three parts: electrical power, refrigeration (chilled water) power, and natural gas consumption.

Water Use Intensity

Water use intensity is a non-traditional metric used as part of this study. It uses the same philosophy as EUI to report and baseline water usage per building. Water use intensity is defined as quantity of water consumed (from all sources, potable and nonpotable), measured in kGal per year divided by the total square footage of the building.

WUI has similar benefits to EUI, but many of the drawbacks associated with EUI would not apply. For example, water use can be compared against buildings of varied climates, sizes, and uses. Higher WUI numbers would truly represent buildings that consume more water per square foot.

Figure 3-5
Development of Component Energy Use

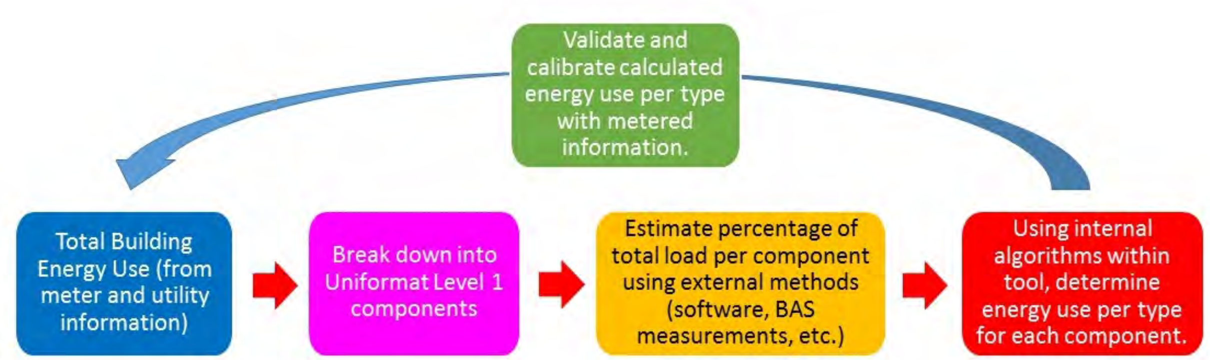


Chart explains how overall energy use, based on consumption information, is broken down into individual components, without existing meters.

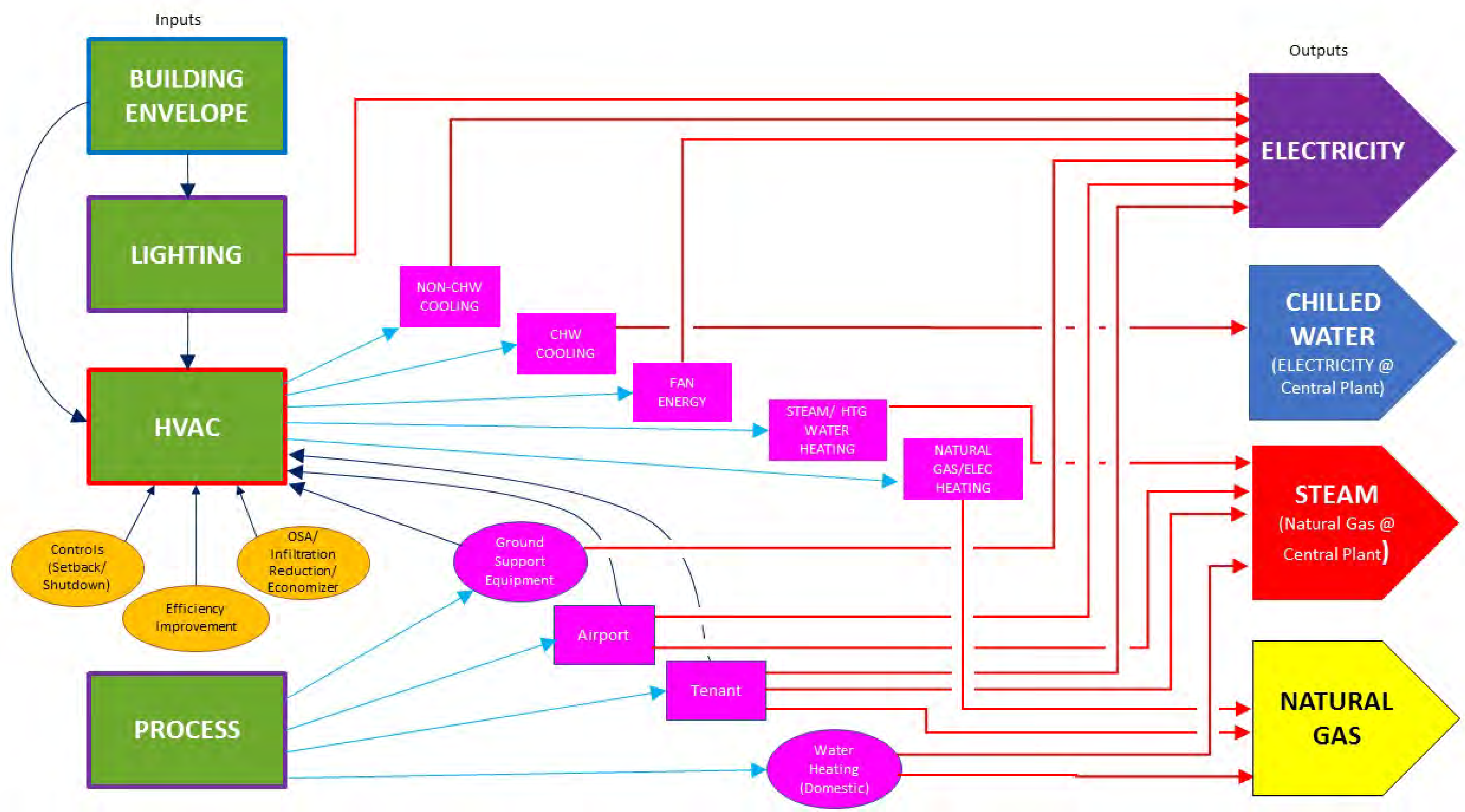
3.3.3 Interpolation of Component and Process Loads

Once total energy consumption was determined by building, it was divided into its components (envelope, lighting, HVAC, process, and water) in order to effectively use the information for reasonable comparison and prediction. Once the components were defined and information estimated, an existing total energy/utility consumption curve was created. Actual utility consumption data (utility bills, trend information) was compared to these curves to both validate and calibrate the energy simulation results.

The energy use components were used to analyze different options within the building. The amount of energy or utility was determined for each component at an annual "Master Planning" level.

Many of the existing facilities had meters that were used to obtain energy consumption information. However, a large majority of areas did not have the amount of granularity required for quantifiable component and process load definition. A combination of shoebox modeling, review of existing utility information, identifying appropriate assumption levels, and existing meter information was used in the study. Each item was identified and discussed with the Port to provide appropriate allocation of items. The following narrative briefly describes some particular loading items that required validation and calibration.

Figure 3-6
Understanding How Components Impact Each Energy Utility



This flowchart shows each of the energy utilities and how the different components of the building – whether part of the envelope or a system – use those utilities. The information from this flow chart was used to establish energy consumption per energy type and per building component type.

Lighting

Energy consumption patterns associated with interior lighting were estimated based on lighting power density requirements in place at the time of construction or renovation, allocation of square footage, and historic operational scheduling. Adjustments were made for daylighting (based on annual solar TMY data). Exterior lighting analysis and classification was independent of interior lighting and calibrated through historical data and existing exterior metering.

Envelope

Building envelope information (insulation, walls, roof, glazing) was provided by the Port of Seattle for the Main Terminal. For buildings where envelope could be otherwise estimated, the envelope was estimated based on site observation and prediction based on age of construction. Information was input into "shoebox model" on a block load basis. Exterior building was modeled using Seattle climate data and normalized building area, roof area, wall area, percent glazing, infiltration, and thermal insulation. Operational schedule were derived based upon mutual discussion between the master planning team and Port of Seattle. Exterior walls and associated glazing was modeled in the direction that it faces to simulate solar impacts to the building.

HVAC

Energy for HVAC was split into the following categories:

- Chilled water cooling (predominant use at Terminal and Satellites). For purposes of this analysis, all terminal space HVAC equipment is considered chilled water cooling)
- Non-Chilled Water cooling (such as DX equipment. For purposes of this analysis, all cargo facilities use DX cooling when cooling is provided)
- Steam/heating water (predominant use at Terminal and Satellites. For purposes of this analysis, all terminal spaces are heated by steam generated systems).
- Natural gas/electrical heating
- Fan energy

The combination of external software tools, information provided by Port of Seattle, meter information, Airport-wide building automation system trend data, mutually-agreed-upon method for determining energy consumption, and team discussion was used to define each component as a percent of total consumption over the course of the year.

Process Loads

Estimated total power usage of process loading such as motors, conveyance equipment, computer/data equipment, tenant airline equipment, TSA equipment, concession equipment, and other non-lighting and non-HVAC equipment for total energy output were derived from a combination of existing utility information, metering, and conversations with Port representatives.

Energy for process loads was considered in two ways: electricity required to operate the equipment and the impact of the process load on the building chilled water (electricity) and steam (natural gas) systems.

Since process loads were the most difficult to predict, in some cases, the known envelope, HVAC, and lighting components were subtracted from the overall energy use to calculate the process load. This process load is then converted to a process load density (measured in watts per square feet) for each building function (terminal/ticketing, concourse/hold rooms, concession, administration, baggage claim, back-of-house, baggage handling, etc.) for use as an input for the tested alternatives.

3.3.4 Concessions and Tenant Spaces

Tenant spaces are typically submetered and therefore information related to their energy performance is more readily available.

For analysis purposes, the concessions were split into three categories: retail/non-cooking, food/non-cooking, and food/cooking. Retail spaces have the lowest use of electricity and natural gas as verified by the submeter data. Food concessions that do not have kitchens (such as Starbucks), have a mid-level range of energy used. Restaurants, both "fast food" and "sit down" types, have similarly high electricity and natural gas use.

It was assumed that the new concessions in the alternative concourse and terminal spaces would have a similar percentage of square footage of concessions as existing Terminal/concourses and that the energy density would be a blended mixed rate combining one-third of the area as retail, one-third as non-cooking food, and one-third as restaurants.

3.3.5 Calibration of Model to Existing Data

Much of the raw data provided through various sources required evaluation and analysis to determine the validity and reliability of the information. A pivotal step in this study was the calibration of the shoebox model to existing data. During this effort, annual energy loads were calibrated with actual metered information and utility consumption patterns provided by Port of Seattle. Existing HVAC, envelope, lighting, and process loads were calculated and percentages were derived for baseline conditions. Future projections were derived from a calibrated existing shoebox model.

3.4 Establishing Utility/Energy/Water Processes

Information regarding existing energy and utility systems was received from Facilities and Infrastructure, Aviation Planning, and Environmental groups at Sea-Tac. This information was used to baseline existing conditions and to estimate future cost impacts due to proposed expansions and alternatives.

Where buildings focus on energy density per building type, the utility processes focus on the overall impact from and to the utility. Utility service, utility size, system distribution, metering schemes, bottlenecks, constraints, environmental considerations, and other facets were reviewed to understand these impacts. Energy was reviewed from a system standpoint, not a single building standpoint. The energy was analyzed on a monthly basis for multiple years in order to understand weather impacts to both energy and water consumption.

Information about system operation was developed based on review with Airport *building automation system*, discussion with F&I management and department leads.

Metering strategies and information on existing meters was provided by both F&I and Aviation Planning groups for both Port-owned and operated facilities, as well as tenant submeters. Review of energy providers understanding how each energy system is sourced, distribution, rate structures, and limitations were also reviewed with both.

Water analysis and information about current water efficiency strategies was provided based on interviews and information provided by Aviation Planning.

Information on emissions was reviewed with the Environmental group and is documented in Technical Memorandum 7.

3.5 Establishing Cost Processes

Building Assets were identified and categorized into industry standard ASTM Uniformat II Level 2 classifications. Uniformat is a format created for the building industry to classify each of the major building elements into categories. Level 1 describes the primary categories: substructure, shell, interiors, services, equipment and furnishings, special construction/demolition, and site. This report focuses only building substructure, shell, furnishings/equipment, and services. Level 2 describes secondary categories. Each of the primary categories are split into major components that make up Level 1. For instance, Level D Services is split into conveying (D10), plumbing (D20), HVAC (D30), fire protection (D40), and electrical (D50). A full listing of asset types used for this analysis is shown in Table 3-1. These represent the level of granularity of information used for the master plan analysis for both cost and energy/water consumption. For example, energy was considered for a building in its totality, not as individual components of an HVAC system.

Utilizing this cataloging methodology provided normalization opportunities to operational, maintenance, renovation costs and allowed for projections of anticipated building life expectancy.

Table 3-1
Uniformat Level I and II Asset Categories

A	SUBSTRUCTURE	
	A10	FOUNDATIONS
	A20	BASEMENT
B	SHELL	
	B10	SUPERSTRUCTURE
	B20	ENVELOPE
	B30	ROOF
C	INTERIORS	
	C10	CONSTRUCTION
	C20	STAIRS
	C30	FINISHES
D	SERVICES	
	D10	CONVEYING
	D20	PLUMBING
	D30	HVAC
	D40	FIRE PROTECTION
	D50	ELECTRICAL
E	FIXTURES, FURNISHINGS, AND EQUIPMENT (FF&E)	
	E10	EQUIPMENT
	E20	FURNISHINGS

3.5.1 Analysis of current Terminal Service Life

In order to calculate existing "average" building age for this analysis, all Uniformat II Level 2 assets were determined or estimated for each building. A "weighted" average age was calculated based on the total square footage of the asset within the building (see Table 3-2). For example, if the building's major assets have been completely unchanged for the majority of the systems since it was constructed, then the average age is considered to be the age since the building was first occupied. If major assets within the building have been renewed or replaced, then the average age represents the age of each of the assets weighted based on the replacement cost of those assets. Finally, if a building has several expansions that differ in age when they were constructed (such as the Main Terminal or the parking garage), then the weighted age is based on the area (square footage) weighted average of each of the individual weighted age assets within the building. Since the age is caculated for each of the Level 2 assets, the weight is further blended based on the specific components average age. For example, if a building's substructure and superstructure were built 25 years ago, but the glazing and roof was updated five years ago, then the average age is blended based on the age of each component (by area). As another example, the HVAC system in a building may be fifteen years old, but 30% of it was replaced five years ago. The "age" of the HVAC would be 70% of fifteen years and 30% of five years or an average of twelve years.

The information used for asset age was provided by the Port of Seattle for this estimate.

Table 3-2
Existing Terminal and Garage Size and Adjusted Age

	Sqft	Average Building Age
Terminal Administration Building	135,000	10.0
Terminal Concourse A	371,000	10.0
Terminal Concourse B	175,000	30.9
Terminal Concourse C	176,000	30.7
Terminal Concourse D	165,000	21.1
Main Terminal	1,009,000	27.7
Terminal Central Terminal Expansion*	399,700	22.3
North Satellite	226,000	23.8
South Satellite	370,000	23.6
Central Plant	30,000	23.8
SUBTOTAL	3,056,000	23.7
Garage	5,142,000	26.6
TOTAL	8,498,000	24.2

Expected useful life of assets was established based on industry standard expectations. Agencies and organizations (such as IFMA and ASHRAE) publish information about the life expectancy of various building components and equipment. Expected life per asset type used for analysis are listed in Appendix E.

Each assets' blended age was then compared to the expected useful life to understand the "residual life" of the asset. The residual life is the amount of time, in years, that an asset is expected to operate before the wearout period. Residual life is important to determine for existing assets because it signals when renewal costs should be expected. If the current "age" of the asset exceeds the useful life, it can also indicate the possible presence of deferred maintenance or high maintenance and operations costs.

3.5.1 Development of Cost Matrix and Analysis Tools

A total cost of ownership (TCO) analysis tool was developed for this Task. The spreadsheet based calculator is used to test the total costs (including CAPEX, OPEX, renewal, and demolition costs) of different options tested during the Master Plan. Energy costs are derived from the energy models and input into the Total Cost of Ownership analysis calculator.

The calculator is based on a set of initial cost densities (cost per square foot) compiled in order to calculate the total cost of ownership of the various alternatives and options for the Master Plan. Costs densities were determined for each of the different Level 2 asset types for each of the building types and consolidated into a single cost matrix.

The cost matrix is split among different existing building types: terminal/ticketing, concourse, satellites, administration, back-of-house, baggage, satellite transit stations, corridor/tunnel, central plant, cargo, and parking garage. Each building and area type represents a similar area within the new Master Plan alternatives. Each of these building area types were further separated into Level 2 asset designations. Basic asset information was provided by the Port of Seattle to populate the cost matrix.

The existing area of each asset was tabulated and entered into the matrix. For example, the administration building is approximately 135,000. The roof of the administration building is 22,400 square feet, or 17% of total area. Another example includes HVAC. If the building is 200,000 square feet, but only 50,000 square feet is heated and cooled, then the HVAC is 25% of the total area of the building.

The next section of the asset cost matrix was developed to track existing conditions of existing assets that were used in understanding renewal and maintenance spending strategies. Current condition and intervention history was noted using a factor-based system between one and five, where "one" would represent "poor" current condition or "poor" reliability and a five would represent "excellent" current condition or "excellent" reliability. Where condition or intervention was not known, general "neutral" conditions were assumed.

Critical ("Importance") factors were also assigned to each asset. This three level factor noted whether the asset was not critical, somewhat critical, or highly critical. These differed, based on the building type. For instance, HVAC was noted as "somewhat critical" in back-of-house spaces, but "highly critical" in terminal and concourse passenger spaces.

Assumptions about the age, expected service life, and residual life of each of the current assets per building or area were entered into the matrix.

The next section provided costs for each of the asset types. These costs included those for CAPEX (planning, design, and construction), OPEX (repairs, maintenance, and operations), renewal, and demolition/disposal. CAPEX costs were provided on a cost per square footage basis for the different asset types from the Airport's estimation firm. These high-level costs were further estimated using a factored approach. The raw cost per square footage per asset type and per building type was assigned based on experience for construction projects at Seattle-Tacoma International Airport. Where data gaps arose, benchmarked information from equivalent systems and sources was utilized. Assumptions were captured to retain visibility on the levels of uncertainty and to test sensitivities. The first factor included an airport "inefficiency" factor. This cost represents general condition cost implications to contractors to accommodate the various safety, security, and space constrained requirements and limitations at the Airport. Renewal costs associated with replacement of existing assets in an active operational Airport require a higher level of this factor. The other factor applied to the costs was a "program cost" factor. This represented the costs to Sea-Tac to plan, design, bid, and manage construction at the airport. The total CAPEX cost (per asset) was then provided as the raw cost with the additional inefficiency and program cost factored into the cost. These CAPEX costs were evaluated and validated based on recent construction projects at the Airport to verify that they were within an acceptable tolerance for use in the master planning analysis.

OPEX costs (excluding energy, water, wastewater, and storm water costs) were estimated based on information from three primary sources. First, the Port of Seattle had documented operational costs for some of the asset types within the matrix. These were used "as is". Where there were gaps in information, costs were estimated based on information from industry sources, such as IFMA and the Whitestone Manual (*The Whitestone Facility Maintenance and Repair Cost Reference 2014-2015*. 19th ed. N.p.: CBRE| Whitestone, 2014. PDF), and operation and maintenance cost information from other airports. This data was then compiled per building and converted to an overall annual operation and maintenance cost, which was reviewed by Port of Seattle to verify that it was within an acceptable tolerance.

Since operations and maintenance costs are lower after startup and commissioning and highest near the end of the asset's useful life, a low and high percentage factor was established to reflect these differences. The model anticipates that the OPEX cost are lowest (the low percentage factor multiplied by the OPEX cost) when the asset has first been built or "renewed" and highest (the high percentage factor multiplied by the OPEX cost) at the end of the service life. The adjusted OPEX cost is then represented as an increasing value bookended between these two factored percentages for the life of the asset. At the end of its service life, the cost model assumes that the asset would be renewed and then the OPEX cost would revert back to the lower value.

Renewal costs themselves are determined based on the capital cost. As stated previously, renewal costs are higher than capital costs for two reasons. The first reason is that construction within an active operational airport requires "microphasing", after-hour construction, temporary equipment, and a using more "surgical" approach to remodeling. Microphasing is the requirement to construct an asset in very small phases in order to reduce downtime or the requirement to provide accommodations through temporary spaces that will house displaced occupants and passengers. The second reason that renewal costs are higher than initial CAPEX is that the replacement of a single asset is typically much more expensive than the replacement of many or all of the assets. For example, the initial cost to build the HVAC system within a new building is less expensive than to replace the same HVAC system by itself later. For these reasons, renewal costs are expressed as a factor multiplier to the CAPEX costs. For example, for a single asset type, it might be estimated that renewal of an asset is 25% higher than the initial CAPEX cost, so the renewal cost would be calculated by multiplying CAPEX by 125%.

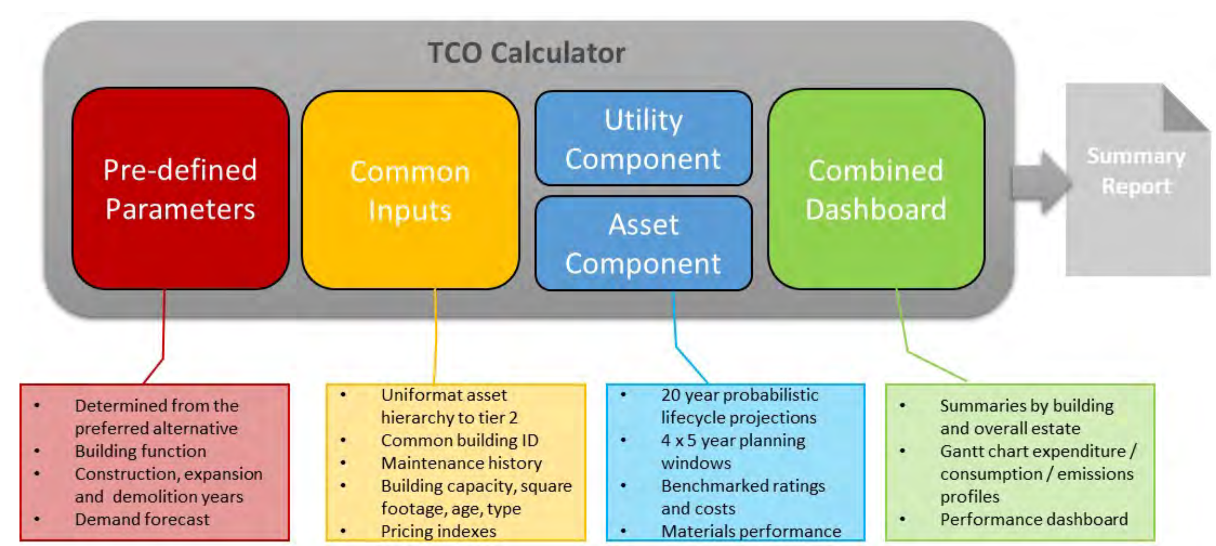
Finally, the estimator assigned values of the demolition and disposal of the assets based on the CAPEX cost. For example, demolition costs for an asset are estimated at 15% of the CAPEX value. Therefore the demolition costs for the asset is CAPEX multiplied by this factor.

The time value of money was considered within the cost calculator, as well. Inflation rates for each CAPEX and OPEX based costs were estimated based on the *Organization for Economic Co-operation and Development* (OECD) predictor for USA (from 2020 to 2060) for all years within this study. Energy utility rate increases were based on US *Energy Information Administration* forecast for electricity and natural gas pricing for the Pacific Region in Commercial/Transportation market. These factors further impacted costs such as OPEX and renewal as time went on.

This calculator was prepared in order to extrapolate intervention costs over the whole life of the asset portfolio. This was set out on a building by building basis and to a granularity of Uniformat level 2. The same common inventory, source data and definitions were deployed as for other Tasks involving these alternatives.

Whole life intervention cycles were developed in order to align with the Port of Seattle's strategic objectives, taking due awareness of costs, condition, performance, safety and risk. Constraints, including funding, access, legislation and indexation were considered at a conceptual master plan level, only and are not directly reflected in the output.

Figure 3-7
TCO Calculation Tool Process



Application of TCO Calculator

Information in the TCO calculator was developed to demonstrate how components (envelope, HVAC system, lighting, process equipment, etc.) influence a building's individual energy cost/consumption and determine the relationship of individual building or component assets to the overall campus. Both utility consumption and cost of ownership were tracked within the calculator to compare different scenarios and alternatives.

Component energy and utility was tracked at a building-level on a percentage basis for annual energy/utility consumption. Consumption was based on actual meter data or estimated within the "shoebox model" when the information was not already known. The calculator allowed the adjustment of allocation percentages to impact the components overall energy or water use.

The asset tracking analysis was developed and organized in the following structure. Refer to information provided in Appendix E.

- Building Asset Data
    - Overall Area
    - Footprint Area
    - Port Premium Multiplier
    - Overall 30-year $/SF
    - Uniformat Level 2 component
    - Component Percent Cost

- Building Asset Data
    - Current Condition
    - Age
    - Expected Service Life
    - Residual Life
    - Renewal Period
    - Reliability

- Asset Management
    - Construction Cost
    - Airport Premium Cost
    - Total Cost
    - Operational Cost
    - 50-year Operational Cost
    - Replacement Value
    - Demolition Cost
    - Disposal Cost
    - 50-year demolition cost

3.6 Evaluation and Analysis Criteria

The preferred alternative scenario, set out by the Master Planning process, determined the high level parameters such as building function, demand, construction, modification and demolition dates. The long term priorities, performance targets and demand forecasts were provided by the Port of Seattle to guide the overriding strategy. The Asset Management principles to be applied were aligned to these pre-defined constraints and to the Utility calculations. The Asset calculator informed facility renovation and expansion decisions, considering the timing, type and whole-life cost of for repair/replacement options.

3.7.1 Evaluation of Alternatives

With the campus baselines established, the calculator and models provided a means to compare alternatives and their impacts to utility consumption, operation/capital cost, and climate over the span of thirty years. Preselected alternatives were defined so that the parameters can be input into the calculator to determine overall actual impact.

Variable methods of Sustainable Construction

Multiple approaches for construction philosophy can be tested through various runs of the spreadsheet calculator and using the energy models. Using up to three levels of potential sustainable construction, costs associated with construction (CAPEX), operating expenses (OPEX), and energy costs can be determined external to the calculator input into the spreadsheet. Examples of sustainable construction approaches include an energy code minimum approach, a moderate sustainable approach (such as LEED Silver), and an aggressive sustainable approach (such as LEED Platinum or Net Zero). In addition, the cost and energy/water impacts of increasing passenger traffic within the existing building stock is analyzed to determine the "no build" case. Although this is not considered an alternative within the Master Plan nor does it consider spatial limitations of passengers or whether existing systems can accommodate the increased passenger growth, this provides a "business as usual" baseline demonstrating how increased passenger traffic affects energy and cost.

Impacts of Renewable Energy and Rainwater Harvesting

Opportunities for use of renewable energy such as photovoltaic energy production, geothermal (geo-coupled) HVAC systems, solar thermal, biogas, and others, are reviewed at the both the building and site implementation levels. Impacts of these systems, as well as the costs associated with them are noted for overall building and campus-wide energy consumption savings and associated cost implications.

Impacts of Central Plant Modifications and Improvements

The energy model and other custom tools created for this study analyze the existing central plant efficiencies to determine energy consumption per ton-hour of chilled water or MBH of steam at various loading levels based on information provided by the Port of Seattle. In addition, new central plant equipment can be modeled to understand the overall impacts to energy consumption as well as costs associated with these changes. These models also are able to demonstrate high-level effects of being decoupled from the central plant, as well.

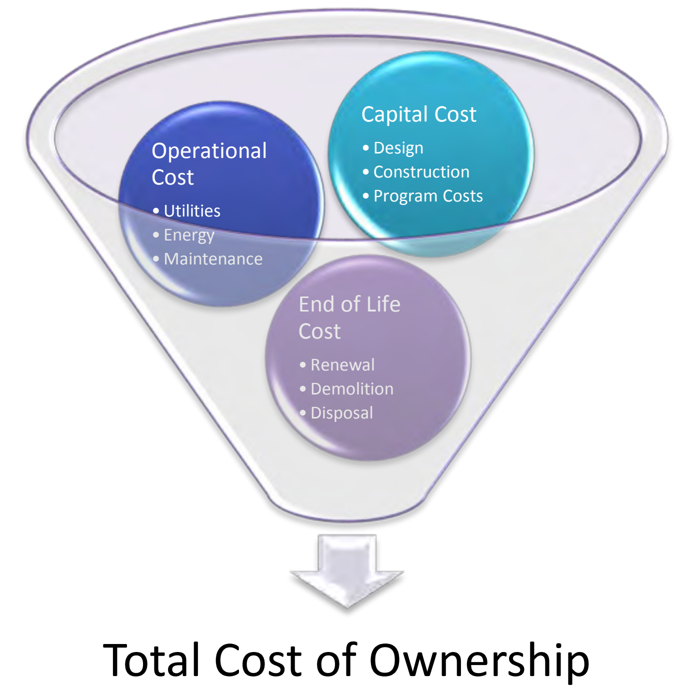
Impact of Energy System Transfer

Where there are opportunities to transfer energy from one type to another (such as from electric heating to natural gas heating), the model can analyze this energy transfer and show its impacts to overall consumption and cost.

3.7 Integration of Models

Since multiple models and analysis tools were used to develop different aspects of the research for this task, it is important that a method for which the integration of all of the outputs are brought together to provide one cohesive look at how the different alternatives within the Master Plan that involve the development and redevelopment of building stock and utility infrastructure affect the total energy and water profile for the Airport, as well as understand how each impacts the Airport's total cost of ownership of the assets involved.

It is important to combine the outcomes of the energy and water simulations for the different tested alternatives with the TCO cost matrix to understand overall benefit that one alternative has over the other or how either alternative improves the status quo of the current Airport operation.



Outputs from the energy and water models are provided in both consumption and costs. Costs for these utilities impact overall OPEX, and therefore the total cost of ownership. Existing facilities that are renovated or renewed with assets that are more efficient and sustainable their predecessors will represent renewal costs (due to the planning and construction of the asset), and variations in operational cost that is directly and indirectly related to the quality and efficiency of the replacement. All maintenance and repair costs should reduce with an asset that has been renewed. In addition, a higher quality asset may have lower OPEX costs than the predecessor. In addition, the energy costs associated with the new higher efficiency equipment would be less than the one that was removed. For new facilities, costs are all additive. New construction includes not only CAPEX costs, but additional Airport OPEX costs associated with the new asset. The OPEX costs varies, however, based on quality and efficiency of the asset.

These different alternatives and optional construction or maintenance spend methods have varying impacts to the TCO. Understanding both components (utility consumption and costs) is important to understand this relationship. Inefficient systems may not need much preventative maintenance since the renewal costs of a substantially more efficient system will be considered against continued maintenance spending added to the increased energy cost, as well as the consideration for increased revenue, increased operational benefit, better passenger experience, better social benefit, or better environmental benefit.

Finally, the integration of these models is important to understand other factors reviewed within other tasks of the Master Plan. For example, the energy and water consumed (as simulated in the models) will have a direct environmental impact to the Airport. This information will be integrated with the analysis and recommendations of these other Tasks.

4 DECISION MAKING FRAMEWORK

Technical Memorandum 7 provides a framework that recommendations from the analysis of these scenarios will be presented. This framework develops the method to discuss the Initiatives, Opportunities, and Actions (IOAs) that are recommended from these findings. These recommendations cover the entire environmental and sustainability aspect of the Master Plan. Specific building and infrastructure recommendations and goals established within that process includes:

Energy Conservation Goals:

- Determine campus wide building energy consumption reduction targets.
- Determine energy optimization goals for existing and projected construction.
- Establish effective evaluation criteria to determine overall energy efficiency goals.

The following Water Conservation Goals were established for the report.

- Identify opportunities and attainment levels for increased potable water conservation in existing facilities.
- Identify opportunities and projected attainment levels with potable water conservation strategies in projected future building construction.

Overview of Existing Conditions

As an innovative approach to the traditional Master Planning process, the Port of Seattle looks at impacts of total cost and sustainability in planning for Seattle-Tacoma International Airport. This Section provides an overview of existing conditions at the Airport in regards to cost and sustainability of the buildings and utility infrastructure reviewed within this study.

1 INTRODUCTION

This chapter documents the findings about existing buildings, utilities, and cost researched and analyzed for the Master Plan. It is separated into three sections: Building and Facilities Overview, Energy and Water Utility Overview, and Cost Overview.

The *Building and Facilities Overview* focuses on specific metrics and benchmarks about the buildings themselves. This includes an analysis of the Terminal area densities. Area densities of the existing Terminal are necessary to set the framework for which energy, water, and costs are analyzed. New alternatives for terminal expansion would have differing area densities, depending on whether a new Terminal was built or if the existing Terminal was expanded. Developing these relationships and the impacts of consumption and costs to these relationships is important to building expansion models. In addition, this section provides a cursory review of how climate of Seattle impacts the building energy use. Finally, this section documents both overall energy and water use intensity for the different buildings within this study. Comparison EUI benchmarks are provided for other Airports.

The *Energy and Water Utility Overview* takes a "deeper dive" in understanding the true source, distribution, usage, and consumption of electricity, natural gas, steam, chilled water, preconditioned air utilities, and water. It looks at utilities both in terms of consumption and cost, and briefly discusses environmental impacts of each. The split between Airport and tenant energy use is discussed. Finally, this section documents water usage across different areas of the Terminal and across different usages, both potable and non-potable.

The *Cost Overview* section focuses on using the cost matrix developed for this project to identify costs for each, based on the assets present in each of the building areas. It provides a good understanding of how each building type impacts the overall total cost of ownership for Airport-owned and operated facilities at Sea-Tac.

2 BUILDING AND FACILITIES OVERVIEW

Although there are many types of facilities at Seattle-Tacoma International Airport, such as distribution warehouse, maintenance buildings, FAA buildings, air traffic control tower, rental car facility (RAC), fire station (ARFF), terminal radar approach control (TRACON), fuel facilities, and hangars, this Section focuses on the three major types of buildings at the Airport: the terminal (Main Terminal, all concourses, and satellites), the parking garage, and Airport-owned and operated cargo facilities.

These facilities represent the majority of energy consumption and costs associated with the Airport. This Section reviews the relative size of each, as well as their energy and water efficiency from a building-wide perspective.

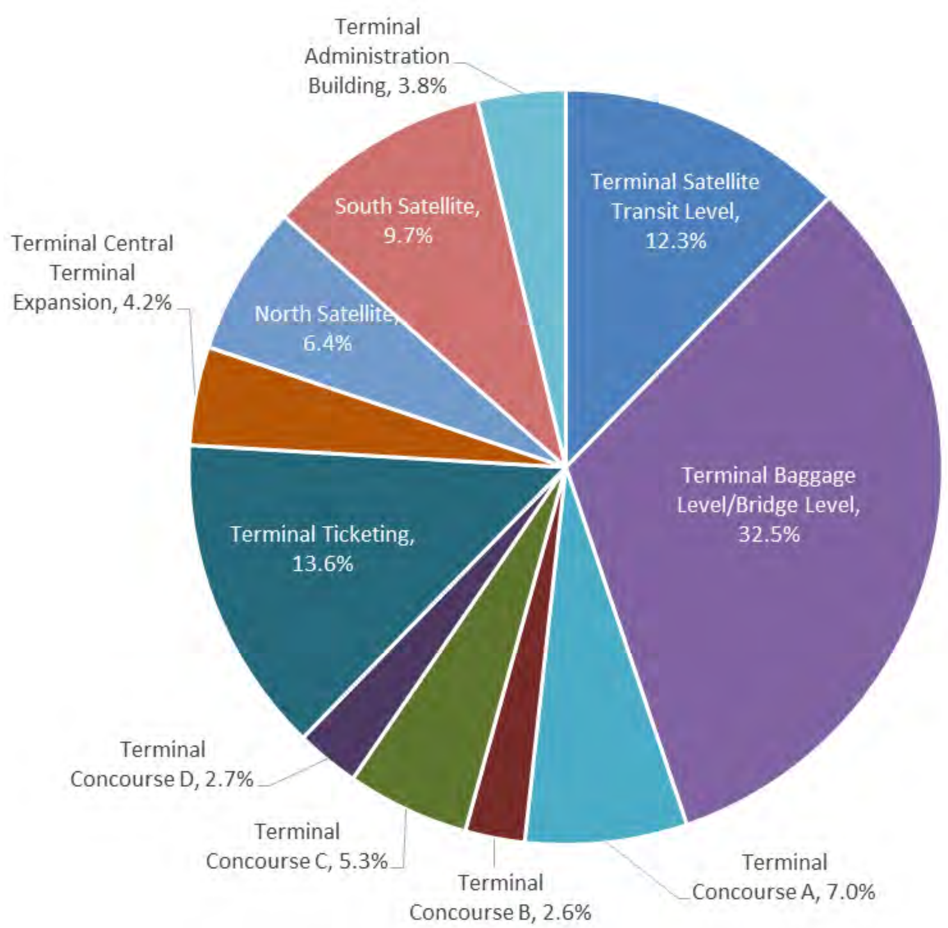
First, it is important to understand the general size of the terminal, garage, and cargo facilities. Table 4-1 shows the breakdown, by area of the Terminal. In addition, it shows the sizes of the garage, cargo, and terminal, with percentage (by area) of each. Chart 4-1 graphically shows the terminal breakdown per area, such as baggage handling, concourses, satellites, administration building, ticketing, etc.

Table 4-1
Current Terminal and Garage Breakdown, by Area

	Footprint (sqft)	Total Area (sqft)	Percentage
Terminal Satellite Transit Level	405,350	405,350	12.33%
Terminal Baggage Level/Bridge Level	812,350	1,067,700	32.47%
Terminal Concourse A	210,900	228,600	6.95%
Terminal Concourse B	84,000	84,000	2.55%
Terminal Concourse C	145,940	172,900	5.26%
Terminal Concourse D	85,400	89,550	2.72%
Terminal Ticketing	255,900	448,850	13.65%
Terminal Central Terminal Expansion	77,600	138,800	4.22%
North Satellite	91,500	211,000	6.42%
South Satellite	93,200	317,600	9.66%
SUBTOTAL		3,288,350	
Terminal		3,288,350	36.7%
Garage		5,142,000	57.3%
Cargo*		540,740	6.0%
TOTAL		8,971,090	

* - for Cargo facilities included in this Study

Chart 4-1
Current Terminal Breakdown, by Area



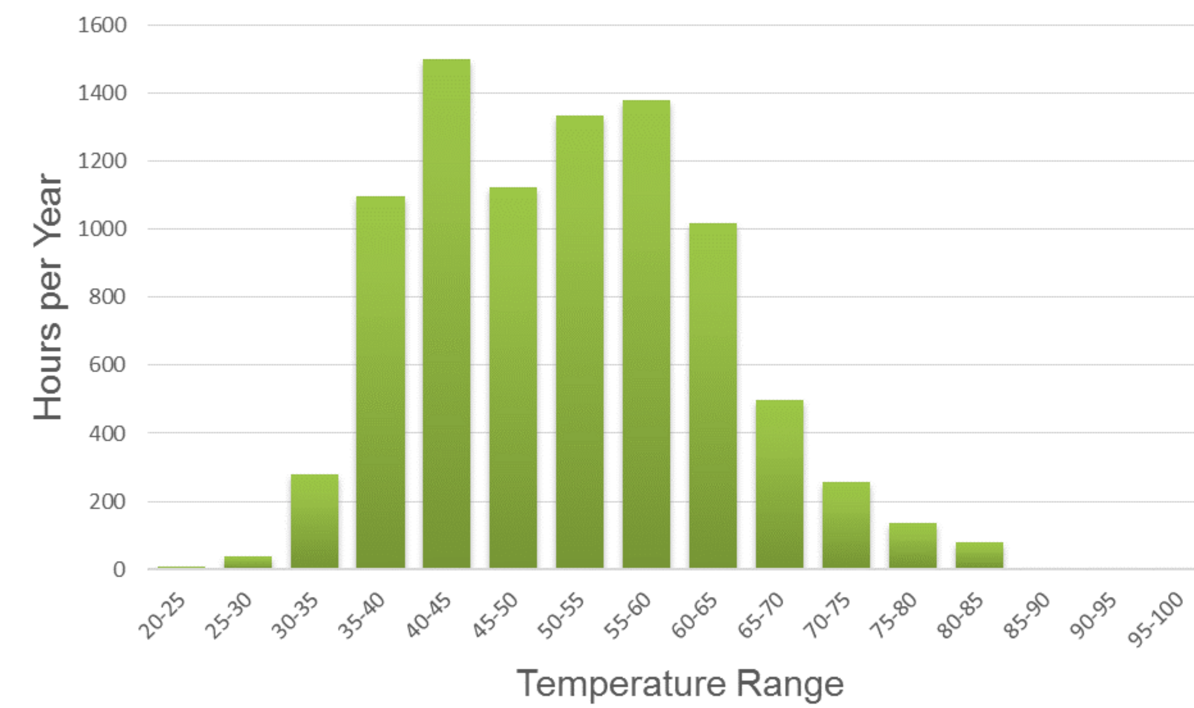
This table and chart breaks down the entire terminal into unique areas, based on percentage. Each of these are tested for energy/water usage and cost estimating.

This information is important in understanding both the comparison in sizes of these facilities for analysis of both costs and energy/water consumption and how the existing terminal and parking compare to future proposed expansions and new construction.

2.1 How Seattle Climate affects Systems

Seattle, Washington is a very moderate climate with mild summers and winters, and high amounts of precipitation. Over the course of a year, there are only 324 hours below 35°F and 12 hours above 85°F of an average year based on the National Renewable Energy Laboratory (NREL) *Typical Meteorological Year* (TMY3) data. The chart below graphs the amount of hours per each "bin" of 5-degree band of temperature.

Chart 4-2
Weather Bin Data for Seattle, Washington



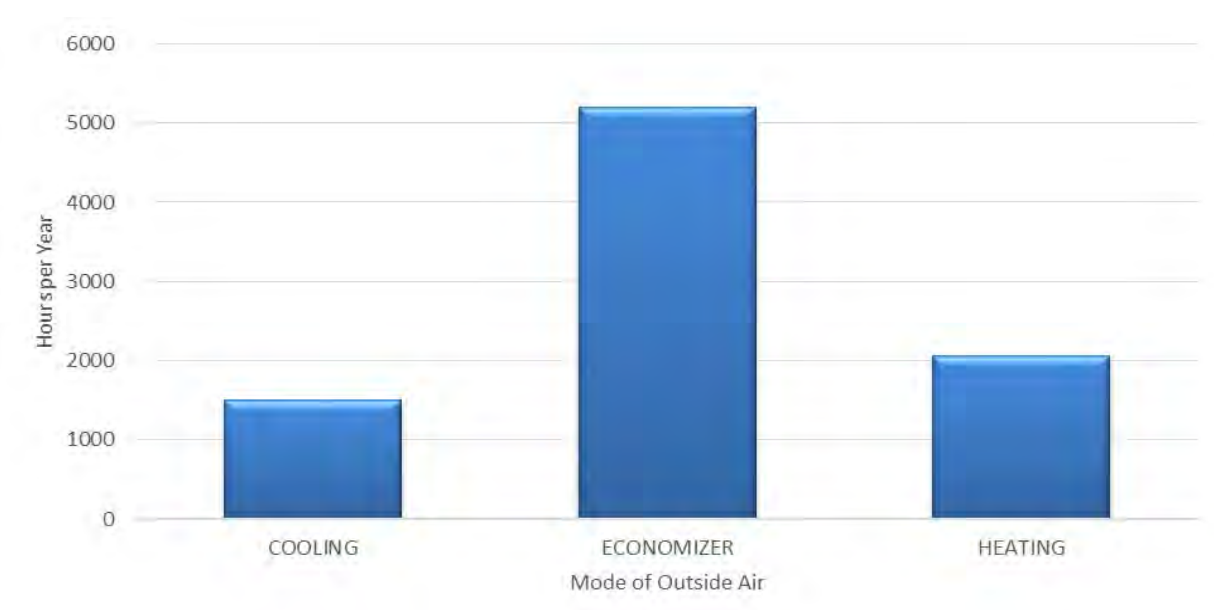
Total annual hours per temperature range (based on 8760 annual hours). The average temperatures in Seattle range between 35F and 80F on an annual basis, with majority of the hours per year between 40F and 60F. This mild climate reduces the impacts of outdoor temperature on the Terminal.

This moderate weather significantly reduces the refrigeration requirement for the facility. With over 8200 hours a year below the 70°F (standard minimum "space" temperature), the need for heating far outweighs the need for cooling.

For this reason, the chiller plant does not impact overall consumption of energy significantly. This means that significant improvements to chiller efficiency have only a minor effect to the overall energy consumption. Refer to Section 2.2 for more information.

In addition, cooler weather allows for a greater use of airside and waterside economizers as compared to more extreme climate regions. Internal HVAC loads are comprised of heat generated by people, equipment, and lighting. Additional heat is generated by the solar heat gain through the roof, walls, and glazing. In warmer months, this heat must be offset with the HVAC system. Traditional HVAC systems use refrigeration (via chilled water) to remove this heat. For mild and cooler climates like Seattle, the cooler weather can provide some or all of the cooling required to offset this internal and solar heat gain.

Chart 4-3
Effects of Outside Air Temperature on Space HVAC System and Economizer Use



Since internal heat gain is present all year, it is important to take advantage of the cooler weather to condition the terminal. The use of airside economizers to reduce requirements for refrigeration cooling can occur for over 5000 hours per year. The other hours are either too warm or too cold to effectively use to condition the terminal.

It is also important to understand degree days to understand how the HVAC and building energy correspond to the climate and weather conditions. Cooling Degree Days are the number of degrees that a day's average temperature is above 65°F. For example, if the average daily temperature for a given day is 73°F, then the cooling degree day, base 65°F (CDD65) for that day is 8°F. Daily average temperature values below 65°F are considered 0°F degree days.

Chart 4-2A displays the annual cooling degree days (base 65°F) since 1970. This demonstrates the temperature fluctuations year-to-year that have an impact on the building's HVAC components and therefore the energy consumption and cost to operate the equipment (more run hours). Chart 4-2B breaks down the cooling degree days per month from 2010 to 2014 to display the warmest months (those that require the most usage from the refrigeration equipment). The Chart indicates that there are no daily average temperatures above 65°F from October to April. Since the Terminal space temperature setpoint is between 70°F and 75°F, this means that the cooler weather during these months can be used to reduce the need for refrigeration for cooling the Terminal.

Chart 4-4A
Annual Cooling Degree Days (CDD65) for Seattle, Washington (1970-2014)

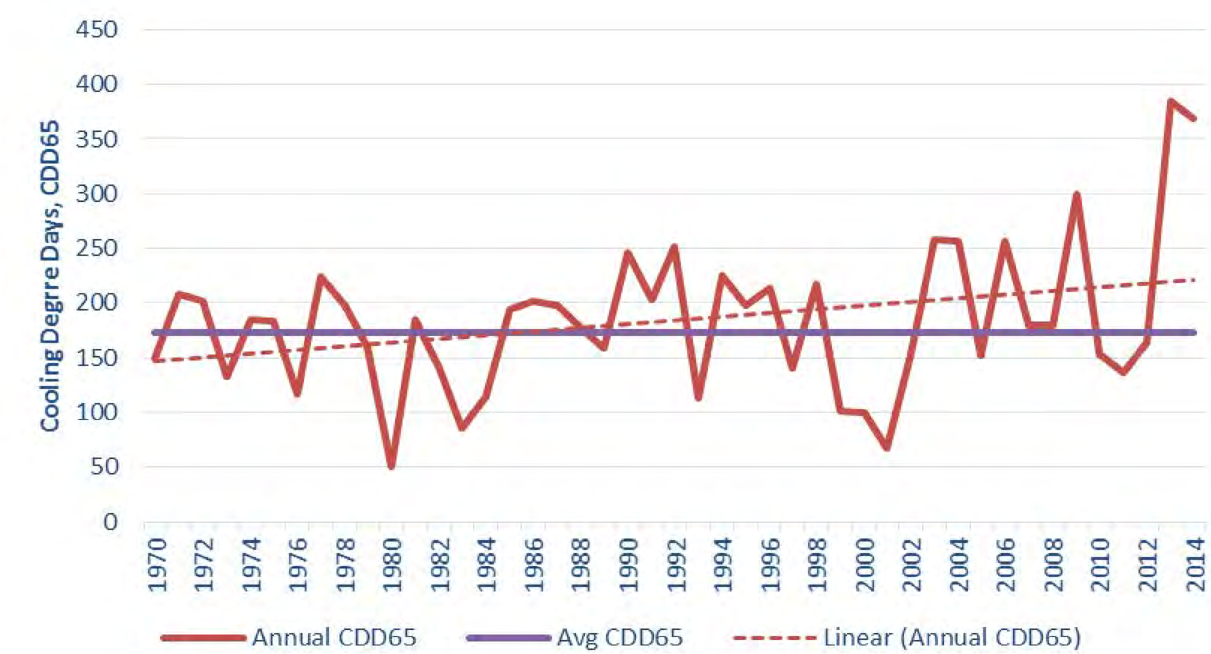
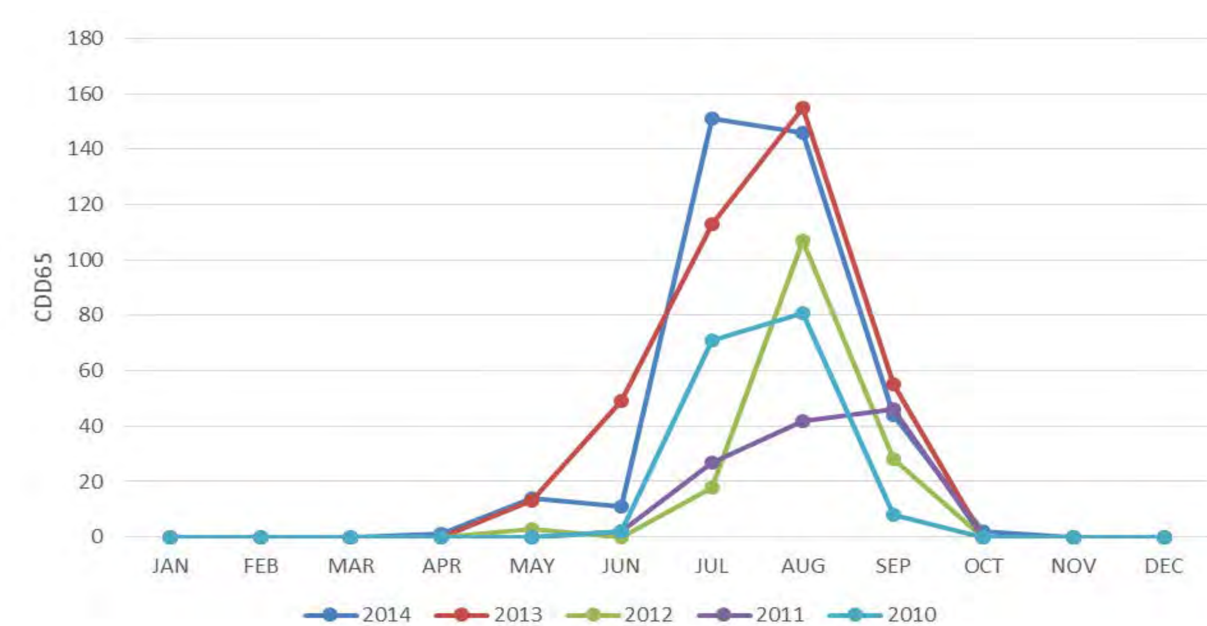


Chart 4-4B
Monthly Cooling Degree Days (CDD65) for Seattle, Washington (2010-2014)



In the last 44 years, the annual cooling degree days have increased on average in that time span. Technical Memorandum 7 discussed many of these ongoing climate and climate change impacts that can affect the building HVAC.

In contrast, some amount of heating may be required for the Terminal for most of the year. Cooler evening hours when the internal heat gain is low and there is no solar heat gain, perimeter spaces may require heating, even in the warmer months (April to June, and September to October). Heating degree days are the number of degrees that a day's average temperature is below 65°F. For example, if the average daily temperature for a given day is 45°F, then the heating degree day, base 65°F (HDD65) for that day is 20°F. Daily average temperature values above 65°F are considered 0°F degree days.

Chart 4-3A displays the annual heating degree days (base 65°F) since 1970. This, too, demonstrates the temperature fluctuations year-to-year that have an impact on the building's heating components and therefore the energy consumption and cost to operate the equipment (more steam production required). Chart 4-3B breaks down the heating degree days per month from 2010 to 2014 to display the coolest months (those that require the most usage from steam and other heating sources). The graph indicates that every month other than July and August have average daily temperatures below 65°F, meaning that heating in some form may be required, depending on offsetting internal loads.

Chart 4-5A
Annual Heating Degree Days (CDD65) for Seattle, Washington (1970-2014)

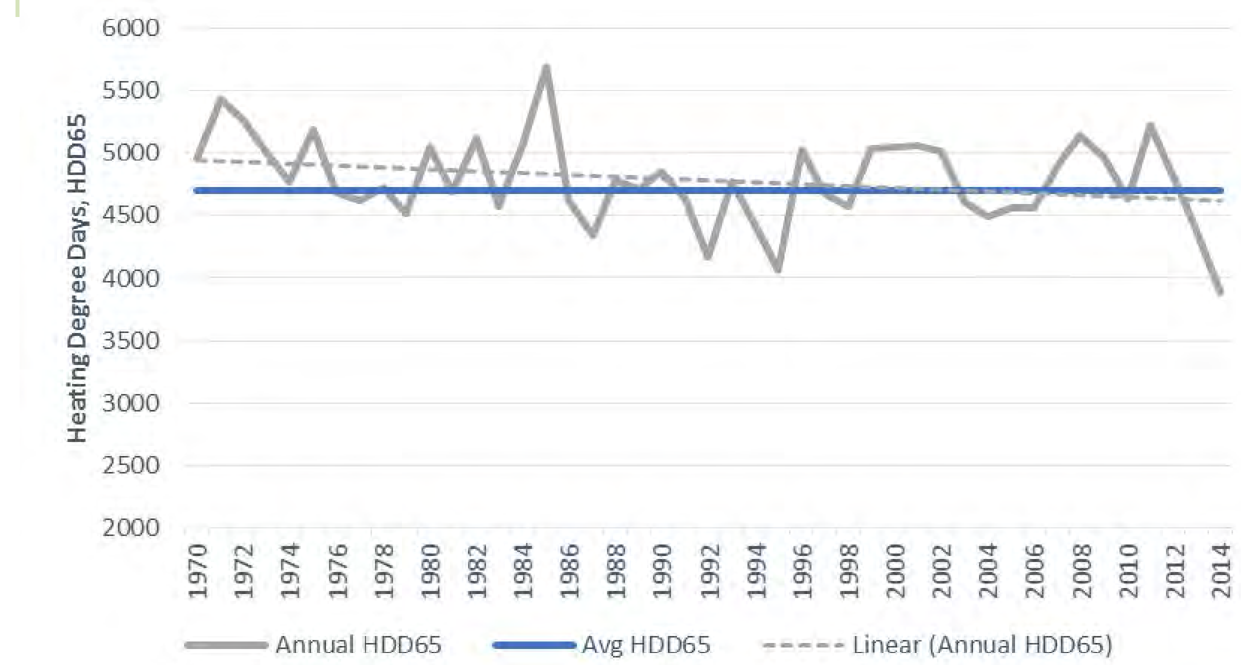
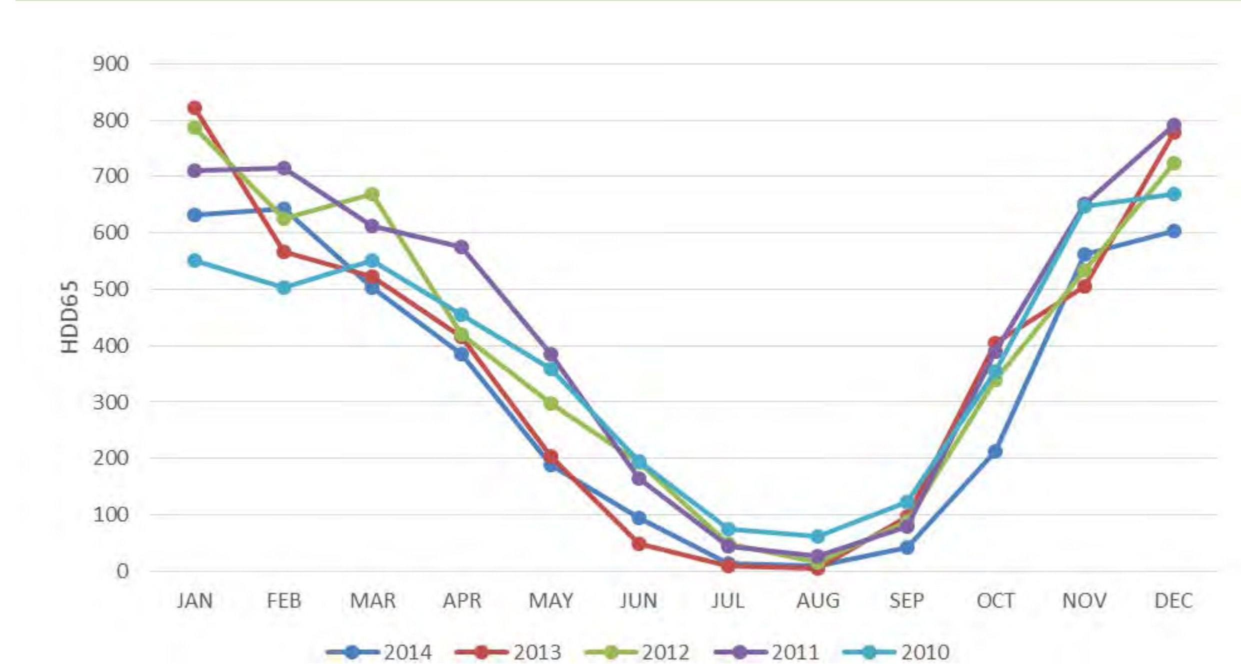


Chart 4-5B
Monthly Heating Degree Days (CDD65) for Seattle, Washington (2010-2014)



The annual heating degree days (base 65°F) shows a much larger impact for heating than cooling (CDD65 of 173 vs. HDD65 of 4697, annually). For this reason, heating for the Terminal has a greater impact than cooling, and therefore the efficiencies of steam production and the heating systems will have a more significant impact on energy consumption and costs than refrigeration, depending on costs of electricity and natural gas.

Rainfall intensities are discussed within the climate discussion of Technical Memorandum 7. Understanding precipitation quantities and trends for Seattle is important in defining potential water harvesting strategies for the facilities. Due to the amount of rainfall in Seattle (averages 37.5" of rain and snow a year), rainwater harvesting should be strongly considered to minimize needs for water from public utility for non-potable uses such as toilet and urinal flushing, cooling tower makeup, cleaning, and irrigation.

2.2 Intensity Factors

As discussed in the Approach section, Energy Use Intensity (EUI) is used to compare the energy usage for different facilities on a consumption per square foot basis. For the purposes of this analysis, EUI is used for four purposes: understand overall EUI for the Terminal, understand how much energy is sourced between electricity and natural gas, understand the energy density differences between various buildings and building areas, and to understand how Sea-Tac compares to other similar Airports. For water, WUI is used to understand how much water is used per area, and per different uses within the Airport.

2.2.1 Energy Use Intensity

Energy Use Intensity (EUI) is the total amount of energy consumed, in kBTU, divided by the area of a building, in square feet. It includes all energy sources, including electricity (public utility and site generated), natural gas, and other fuels such as diesel. For this analysis, electricity and natural gas is included. The EUI is shown in four different ways: electricity-only, electricity-only with central plant, natural gas-only, and total EUI. Electricity-only represents electricity consumed directly within the building via lights, equipment, HVAC and ventilation fans, etc. Since the central plant converts one energy type (electricity) to another (chilled water), the chilled water produced by the central plant can be directly used to estimate electricity usage per ton of refrigeration. The central plant consumes only an insignificant amount of chilled water, and therefore the vast majority is distributed to the Terminal and satellites. The power required to operate the chillers, cooling towers, and associated pumping systems annually was split based on overall building consumption of chilled water energy per year. Kilowatt-hours per ton-hours supplied was calculated and then each buildings usage of chilled water in ton-hours was converted to KWh.

Since natural gas for the primary service is solely dedicated to the boilers (other natural gas use is for tenant concessions, which is separately metered), natural gas usage is assumed to be converted to steam which is then distributed to the terminal and PCA plant. Like the chillers, the energy required to produce, distribute, and convert steam was split among each building based on their annual consumption.

Electrical power consumption for the building was based directly on the amount of electricity consumed based on the load center meter readings. This power represents HVAC ventilation, lighting, conveyance equipment, STS equipment, airport and tenant loads, and other process loads for each building. Since the garage is unconditioned, the EUI for the garage only represents power measured through the electric meters. The cargo buildings natural gas and electrical power were metered and used to calculate total cargo EUI.

The first table (Table 4-2) shows the electrical EUI for each building based only on the power being used directly by that building. The second table (Table 4-3) shows the EUI for each building including both primary electrical power and energy required to provide chilled water to serve the buildings' HVAC systems. In this scenario, the garage only includes primary power of the building (not including the central plant) since the central plant utilities do not serve the garage.

The second table (Table 4-2) shows the electrical EUI for each building including both primary electrical power and energy required to provide chilled water and steam/hot water to serve the buildings' HVAC systems. In this scenario, the garage only includes primary power of the building (not including the central plant) since the central plant utilities do not serve the garage.

Table 4-2
Energy Use Intensity – Electricity Only, Primary Use

Location	Area (sf)	Electricity Usage (kBTU)	Electrical EUI (kBTU/SF)
Main Terminal, CTE	1,208,659	85,808,388	71.0
Concourse A, STEP	706,489	77,790,188	110.1
Concourse B	175,190	16,500,432	94.2
Concourse C	175,780	16,009,104	91.1
Concourse D	164,540	14,163,212	86.1
C1 Building	53,428	12,921,244	241.8
North Satellite	225,637	25,412,576	112.6
South Satellite	369,738	31,328,984	84.7
STS and Tunnel Vent		11,423,376	
SUBTOTAL	3,079,461	291,357,504	**94.6**
Parking Garage	5,142,400	37,549,060	7.3
Cargo	540,740	20,239,984	37.4
TOTAL	8,772,600	349,146,550	**39.8**

Table 4-3
Energy Use Intensity – Electrical Only, including Central Plant

Location	Area (sf)	Electricity Usage (kBTU)	Electrical EUI (kBTU/SF)
Main Terminal, CTE	1,208,659	103,233,550	85.4
Concourse A, STEP	706,489	86,278,000	122.1
Concourse B	175,190	19,657,600	112.2
Concourse C	175,780	19,176,900	109.1
Concourse D	164,540	16,733,100	101.7
C1 Building	53,428	13,627,300	255.1
North Satellite	225,637	29,478,800	130.6
South Satellite	369,738	37,992,100	102.8
SUBTOTAL	3,079,461	326,177,350	**105.9**
Parking Garage	5,142,400	37,549,060	7.3
Cargo	540,740	20,239,984	37.4
TOTAL	8,772,600	383,966,394	**45.1**

The next table (Table 4-4) shows the natural gas EUI for each building including both primary usage and energy required to provide steam/hot water to serve the buildings' HVAC systems. In this scenario, the garage does not use natural gas. Cargo natural gas usage is for water heating and indirect/direct heaters for the buildings.

Table 4-4
Energy Use Intensity – Natural Gas only, including Central Plant

Location	Area (sf)	Natural Gas Usage (kBTU)	Natural Gas EUI (kBTU/SF)
Main Terminal, CTE	1,208,659	106,460,900	88.1
Concourse A, STEP	706,489	51,857,400	73.4
Concourse B	175,190	19,288,800	110.1
Concourse C	175,780	19,353,800	110.1
Concourse D	164,540	15,700,700	95.4
C1 Building	53,428	17,941,200	80.7
North Satellite	225,637	24,843,200	110.1
South Satellite	369,738	40,709,000	110.1
SUBTOTAL	3,079,461	296,155,000	**91.7**
Parking Garage	5,142,400	0	0
Cargo	540,740	9,885,000	18.3
TOTAL	8,772,600	306,040,000	**33.4**

Table 4-5 shows the total EUI for each building including both primary usage and energy required for central plant utilities for both electricity and natural gas combined. Also included in the amount of energy consumed per building area (both electricity and natural gas) stated as a percentage of total energy usage for the buildings analyzed in this study.

Table 4-5
Energy Use Intensity – Total Energy Usage

Location	Area (sf)	Energy Usage (kBTU)	Percentage of Total Energy	Total EUI (kBTU/SF)
Main Terminal, CTE	1,208,659	209,694,500	34.5%	173.5
Concourse A, STEP	706,489	138,135,400	22.7%	195.5
Concourse B	175,190	38,496,384	6.3%	222.3
Concourse C	175,780	38,530,700	6.3%	219.2
Concourse D	164,540	32,433,800	5.3%	197.1
C1 Building	53,428	17,941,200	3.0%	335.8
North Satellite	225,637	54,322,000	8.9%	240.7
South Satellite	369,738	78,701,100	12.9%	212.9
SUBTOTAL	3,079,461	608,255,084		**197.7**
Terminal	3,079,461	608,255,084	81.1%	105.9
Parking Garage	5,142,400	37,549,060	10.5%	7.3
Cargo	540,740	30,125,000	8.4%	55.7
TOTAL	8,772,600	675,929,144		**78.5**

The following chart graphically demonstrates the EUI for each building, the terminal spaces as a whole, and the combination of terminal, garage, and cargo spaces. The blue represents primary electricity, the orange represents power due to the refrigeration system (chilled water), and the gray represents the natural gas usage.

Chart 4-6
Comparison of EUI by Building/Area

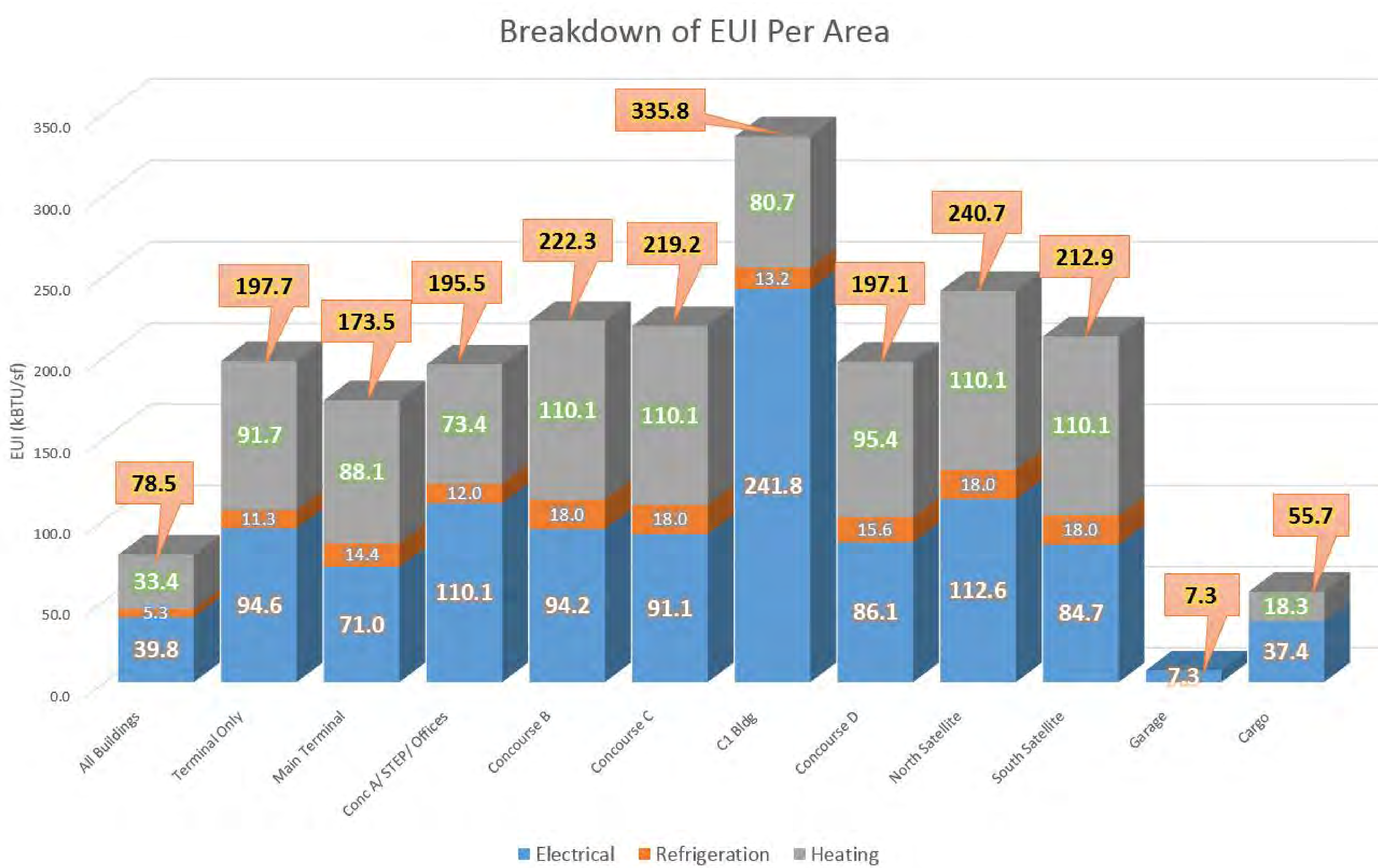


Chart 4-5 shows each building, area, or major renovation and its EUI based on annual consumption of electricity and natural gas for 2014. The EUI is broken down into electrical, refrigeration, and heating components. Chilled water and steam energy is applied to the building/area that is being served.

From this information, the C1 building uses the most energy per square foot as compared to the other areas. However, the C1 building only consumes about 3% of the total energy used for this comparison. This means that significant improvements to the efficiency of this building would only have a minimal impact to the overall consumption of energy. In comparison, the Main Terminal has a EUI almost half of the C1 Building, but represents 34.5% of the total energy used in the Terminal.

In order to "rank" the building areas based on both efficiencies and how much energy of the total that they consume, a normalization factor was established. The normalization factor is based both on the EUIs of the building areas, as well as the percentage of total each building area represents. First, the EUIs for each area were normalized based on the highest EUI. Second, the percentage of energy as part of the total energy consumed for the terminal was normalized for each of the building areas. These two factors were multiplied together, establishing a normalized "efficiency x influence" factor. Since this factor normalizes both as a function of energy density (assumed efficiency) and how much energy it uses, the new factor ranks the most impactful areas based on their size and efficiency. Numerically higher factors represent where most of the focus should be given for potential energy efficiency and sustainability since they represent the largest and potentially least efficient spaces. Chart 4-6 shows these factors for each space within the Terminal.

Chart 4-7
Energy Intensity and Influence Normalization - Terminal

Extending this to the campus, Chart 4-7 shows how each of the building types – terminal, garage, and cargo – rank based on potential energy savings.

Chart 4-8
Energy Intensity and Influence Normalization - Airport

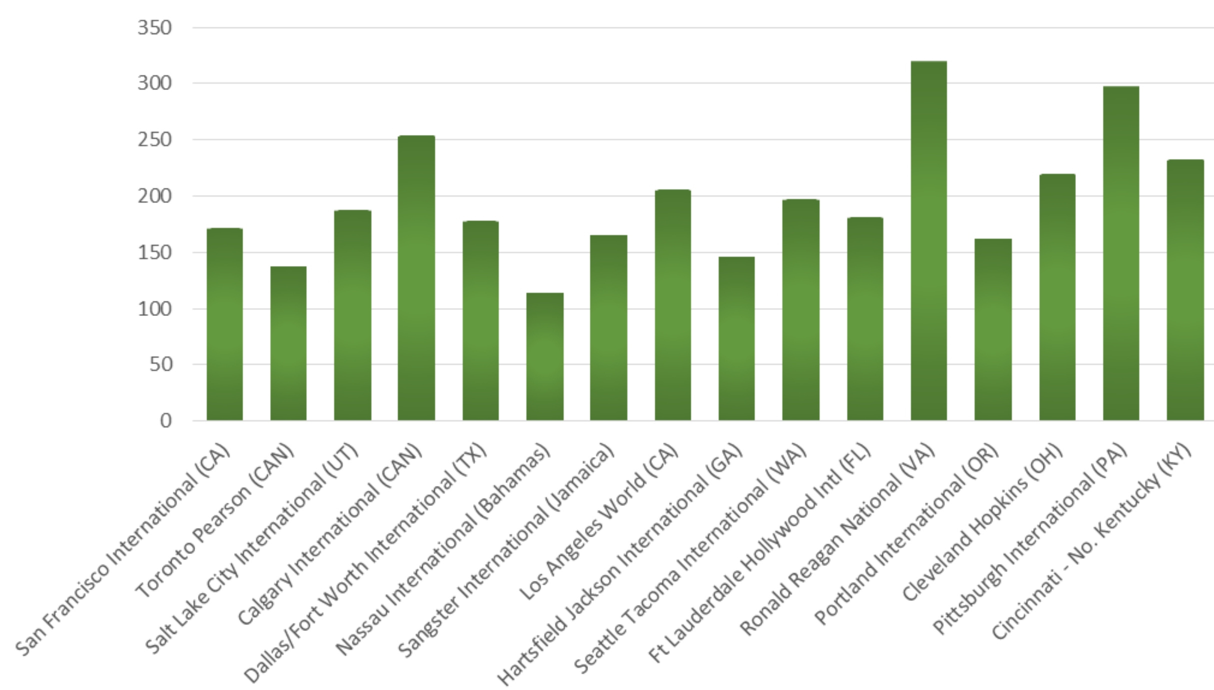
Chart 4-6 indicates that, even though the C1 building has the highest EUI, it has the lowest influence due to its small size. Likewise, even though the Main Terminal has one of the lowest EUIs, it is one of the largest areas (one of most energy consumed) and therefore has the highest ranking. In addition, it shows that since Concourses B, C, and D have similar EUIs and energy consumed, that they each have similar ranking toward the bottom of the chart. The South Satellite, with more energy consumed has a bigger impact than the North Satellite, which has a larger EUI.

Chart 4-7 strongly indicates that the Terminal should be the primary focus for energy and sustainability, since it represents a significantly higher number than both the garage and cargo buildings.

Finally, in comparison with other airports, Seattle is centralized of those reviewed. The *Clean Air Partnership*, in conjunction with Stantec, Inc., an Edmonton, Alberta Canada professional services company, developed a study documenting the various EUIs for airport terminal buildings. The EUIs stated vary considerably due to factors such as building geometry, passenger density, climate, passenger traffic, and other factors. It should also be noted that it is not known whether these EUIs include the energy from the central plant, preconditioned air, and flight line equipment (passenger boarding bridges, generators, etc.) within the calculation as has been done with the EUI above.

Chart 4-8 shows each Airport and the stated EUI, for comparison.

Chart 4-9
Airport EUI Benchmarks

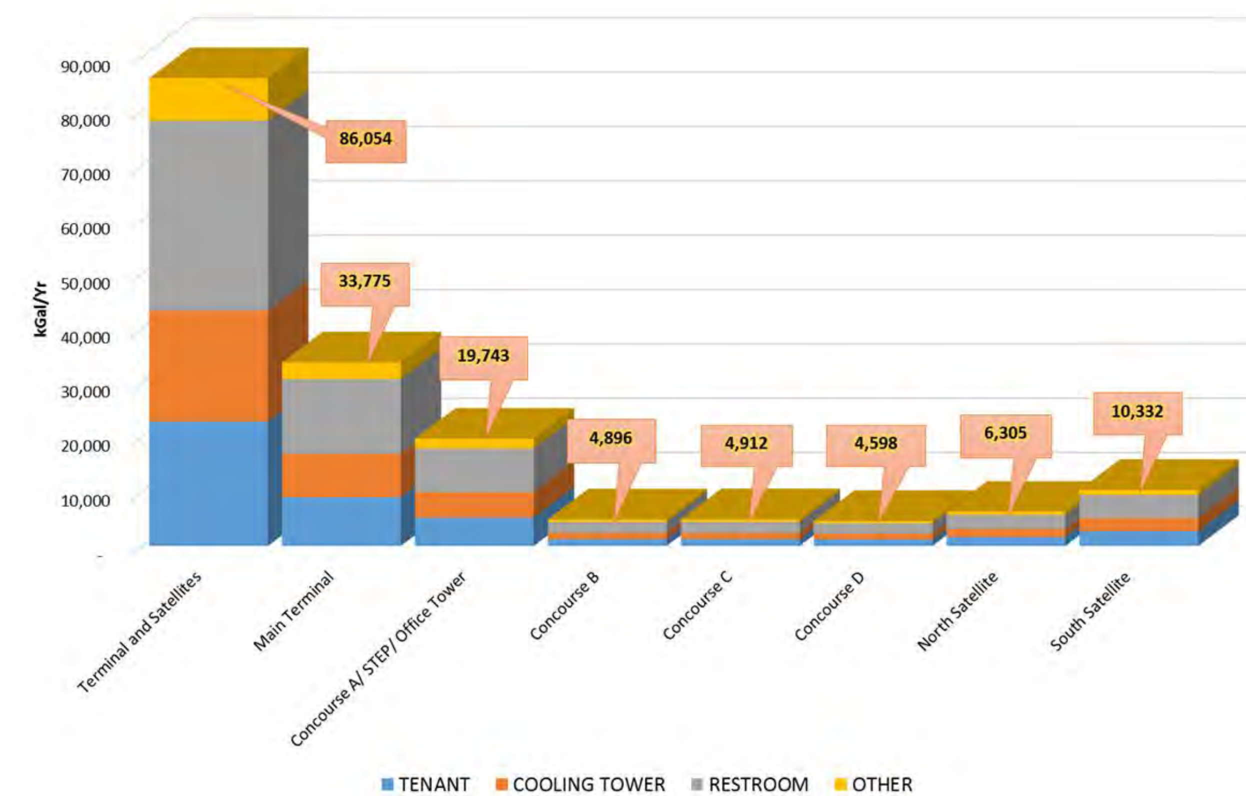


For more detailed information about specific energy use, especially how chilled water, steam, and PCA affect the consumption of electricity and natural gas, refer to Section 3 of this Chapter.

2.2.2 Water Use Intensity

Like Energy Use Intensity, the calculated "Water Use Intensity" is used to demonstrate the amount of water used per building annually in "kilo" gallons per square foot. The amount of water considered includes primary water usage in each of the building's restrooms, as well as water used by tenants, and other purposes. Water used for makeup for boilers and cooling towers is distributed in the same manner as the chilled water and steam above. Water for cooling tower makeup is added to each building. The following chart demonstrates each buildings' water consumption for comparison:

Chart 4-10
Comparison of Water Usage by Building/Area



Restroom usage is based on enplanements and assumed consistent for all public restrooms in the Terminal. Cooling Tower water is split based on Refrigeration value in EUI analysis. Other represents process water used.

For more detailed analysis of water usage, refer to the Section 3.4 of this Chapter.

3 ENERGY AND WATER UTILITY OVERVIEW

This next section reviews the findings of the energy and water utilities on the Sea-Tac Airport campus. It focuses on understanding how electricity, natural gas, and water are consumed at the airport. It documents the central plant utilities – chilled water, steam/hot water, and preconditioned air plant – to understand how these influence the overall energy consumption profile. This section investigates consumption trends among the different energy types. It documents existing split between electricity and natural gas and how each impact the overall costs and environmental impact to the Airport. This information is important to understand the current state of energy and water consumption at the airport, in order to predict future consumption trends. Trending energy and water usage based on certain parameters – construction, efficiency, occupancy, etc. – will allow to predict future usage based on maintaining and/or changing these parameters for future facilities. Constructing efficient buildings (highly insulated, low-e glazing, considerations for minimizing total energy impacts) with efficient lighting, water heating, and HVAC will reduce the overall consumption of energy. It is important to understand how much this component represents of the overall energy consumption in order to realize the impact of these measures.

3.1 METERING

Seattle-Tacoma International Airport currently only meters major utilities at the highest levels for electricity, natural gas, water, sewer, and solid waste.

Many tenants are submetered for electricity. Some tenants are also independently metered for natural gas and water use.

3.1.1 Existing Metering Implementation

Seattle-Tacoma International airport currently lacks adequate metering for many of its utilities associated with the terminal. This is the case with electricity, with only meters located at the main substations. Both the 50MW North Substation and the 50MW South Substation have two meters that monitor power for the majority of the Main Terminal, parking, central plant, airfield power, and ancillary buildings. Several substation load centers are monitored monthly throughout the terminal in order to obtain electrical consumption and are the basis of information used within this report to verify actual electricity consumption.

Natural gas for the terminal is metered at the gas main entrance located near the cooling towers. The natural gas only serves the four boilers located in the central plant that provide steam for heating the terminal and producing domestic hot water.

Water is metered at the service main entrance. General trends of water consumption are listed below, but irregular spikes of water consumption have been recorded during periods of construction.

The DDC control system monitors chilled water consumption in several locations – primarily in more recently renovated portions of the terminal, such as Concourse A and CTE. Older legacy portions, such as Concourses B and C are not yet fully integrated into the DDC system to track total energy (BTU) consumed per space.

Steam metering is minimal at the airport. The infrastructure to monitor steam consumption is not currently in place.

For concessions, HVAC costs are built into the lease. The concession is generally responsible for providing their own hot water. Many tenants are submetered for electricity, natural, gas, and/or water. There are currently 140 electrical submeters serving tenant spaces, both concessions in the terminal and cargo/support facilities located outside of the terminal.

Thirteen of the cooking concessions in the Main Terminal and South Satellite are independently metered via the DDC system. The tenant consumption is insignificant in comparison to the campus boiler loads.

There are sixty-seven DDC meters and seventy manual meters that submeter water usage throughout the airport.

The Port is actively developing strategies to add additional metering where feasible and as funding is available. Most new metering is through the Airport DDC building automation system.

3.2 Electricity

Power to Seattle-Tacoma International Airport originates from multiple PSE utility feeds to two separate switchyards with ring bus configurations. Each ring bus is fed from two independent 115kV overhead feeders. Feeders tapped off of the ring buses feed four 15/20/25 MVA step-down transformers which reduce the voltage level to 12.47kV for site distribution to the terminals and central plant. A third PSE overhead feeder distributes 12.47 kV power to ancillary buildings and tunnels around the airfield.

Three distribution centers distribute power to twenty-two major power centers located throughout the airport. The primary BPA service powers the 12.47kV distribution providing redundant feeders to various main-tie-main switchgear in the terminals and then to unit substations or "power centers" stepping down the voltage to the final utilization voltage of either 4160V or 480V

Large electrical consumers include the baggage handling systems, lighting, STS (APM) system, the central plant, the PCA ice plant, and the ground support equipment (including *Posicharge* system). The terminal lighting was mostly renovated or installed approximately ten years ago and is overall efficient.

An emergency power distribution system distributes stand-by power to critical and life safety loads throughout the terminals, parking areas and central plant. The emergency power is derived by diesel driven generators at 4160V and feed into each end of a triple ended switchgear. Two generators feed each end of the switchgear with the normal power connected to the middle or "third end" of the emergency switchgear.

3.2.1 Utility Providers

The primary source of electrical power at Seattle-Tacoma International Airport is purchased wholesale power from Bonneville Power Administration and serves the two main substations serving the north and south of the airport. Tenant power for concessions comes from this source. Other sources from Puget Sound Energy, serves the bus maintenance facility and distribution center. New buildings outside of the Main Terminal use this power source, depending on its location on the site. Seattle City Light provides power to rental car facility and runway/airfield lighting north of the runways. It is likely that expansions and "greenfield" buildings would not expand this service.

The Port of Seattle purchases electricity from BPA at a current rate of $0.038 per kilowatt-hour, including transmission costs for up to 17.3 megawatt-hours of electricity per month. This is the negotiated wholesale rate for this primary service. Current (2014) electrical billing history shows that the maximum monthly consumption was 13.6 MWh during August. This represents 78.6% of allotted capacity at this rate structure. Should expansions to the airport cause additional power requirements to exceed this allowance, a second "tier" of energy would need to be negotiated with the service provider (BPA). This would be purchased at market rate for wholesale, retail, or renewable customers and would range from the current rate (or lower) of $0.038/kWh to a high rate of $0.181/kWh (renewable energy for a retail customer). It is likely that the current rate be extended to the new maximum limit to handle the additional load.

The Port forecasts energy consumption requirements for the next twenty years for BPA every year. The next market purchase forecast will be between 2017 and 2020.

3.2.2 Existing and Current Proposed Renewable Energy Implementation

Currently, the Seattle-Tacoma International Airport does not utilize large-scale renewable energy at the airport. Renewable energy is mainly limited to signs and outdoor lighting that utilize photovoltaic cells and batteries.

The North Satellite terminal is implementing a design to incorporate infrastructure for future photovoltaic panels. An evaluation was presented to the Port of Seattle by the North Satellite Project design team in May of 2014 on the feasibility of implementing photovoltaic system for the renovation project. It was recommended in the report that the proposed PV system would meet the necessary ROI requirements for the project. It was further recommended that the analysis be reevaluated should funding incentives or grants be made available or if current PV technology improved or reduced cost. The report does not include indirect benefits relative to "green" marketing.

3.2.3 Emission Equivalent from Electrical Power (site)

Refer to Technical Memorandum 7 for a more "in depth" analysis of environmental impacts for all Airport site related activities, including energy consumption. This section briefly summarizes electrical emission equivalent for Sea-Tac.

Below is a table of emission factors for three electrical providers at the airport. The information for the emissions was provided by the Climate Registry or by the utility (in the case of BPA).

Table 4-6
Annual Site Energy Emissions for Public Utilities

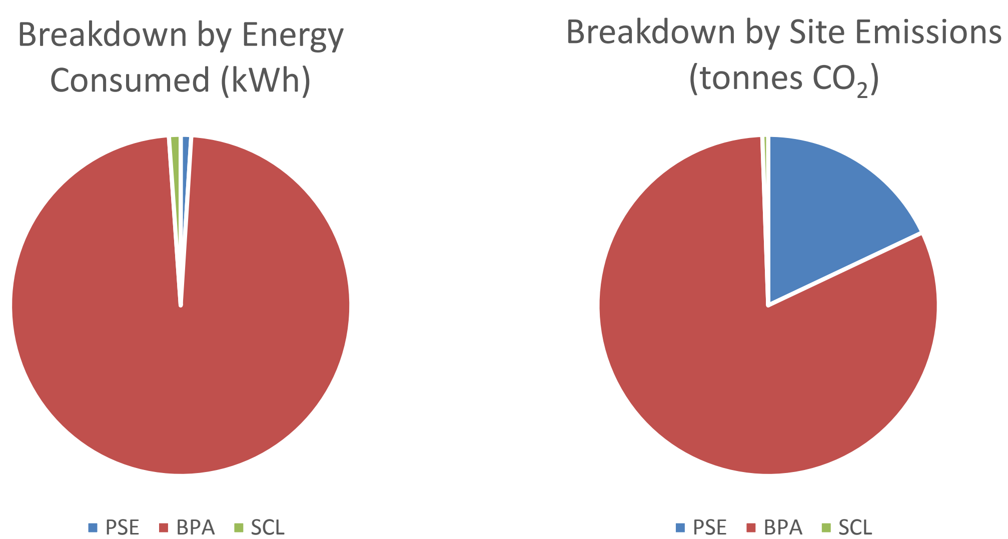
Year	Source	Converted Emission Factor	Converted Units	Estimated Annual Consumption (kWh)	Total CO2 (tonnes)
2011	PSE Electricity	0.00039338	tonnes CO2/kWh	1,474,000	580
2012	PSE Electricity	0.00040306	tonnes CO2/kWh	1,474,000	594
2013	PSE Electricity	0.00044304	tonnes CO2/kWh	1,474,000	653
2014	PSE Electricity	0.00044721	tonnes CO2/kWh	1,474,000	659
2011	BPA Electricity	0.00002171	tonnes CO2/kWh	145,000,000	3148
2012	BPA Electricity	0.00001674	tonnes CO2/kWh	145,000,000	2427
2013	BPA Electricity	0.00001984	tonnes CO2/kWh	145,000,000	2877
2014	BPA Electricity	0.00001946	tonnes CO2/kWh	145,000,000	2822
2012	SCL Retail Electricity	0.00001161	tonnes CO2/kWh	1,640,000	19

Emission factors change annually for electricity due to mix of fuels that is produced. .

The emissions listed are defined as "site" energy (in lieu of "source" energy). It is assumed that it is delivered as secondary energy and accounts for the fuel used to convert the energy. It does not account for lifecycle emissions. For this reason, renewable energy is considered an emission factor of 0.

As the Table demonstrates, electricity procured from PSE has over twenty times the effective emissions of carbon dioxide than that of the electricity procured from Seattle City Light and BPA. BPA power is comprised of approximately 98% carbon-free energy through hydro-power and other renewable sources.

Chart 4-11
Electricity Consumed per Utility Provider vs. Site Emissions

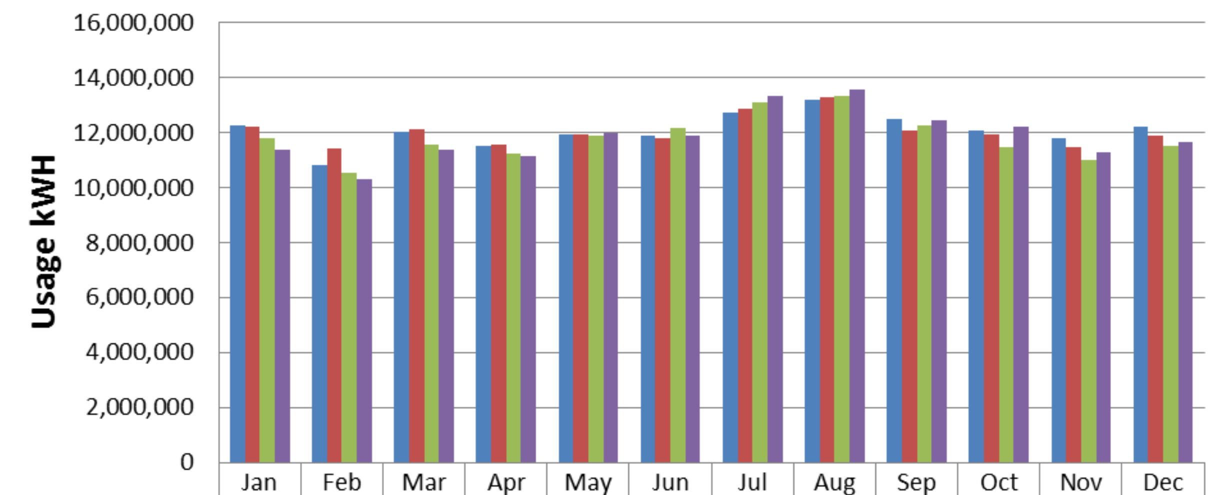


The chart on the left represents how much energy is procured from each of the utility providers (as a percentage of the whole). The chart on the right represents the total emissions from electricity based on amount consumed. Even though the amount of electricity procured by PSE is a small percentage of the total, the effective site emissions represent nearly 20% of total effective carbon dioxide due to electrical power.

3.2.4 Existing Costs and Consumption

The Port of Seattle maintains records for their monthly consumption of electricity and uses it to document efficiency and consumption trends. The annual consumption for the main terminal meters, not including sub-metered tenants, was as follows for the past four years:

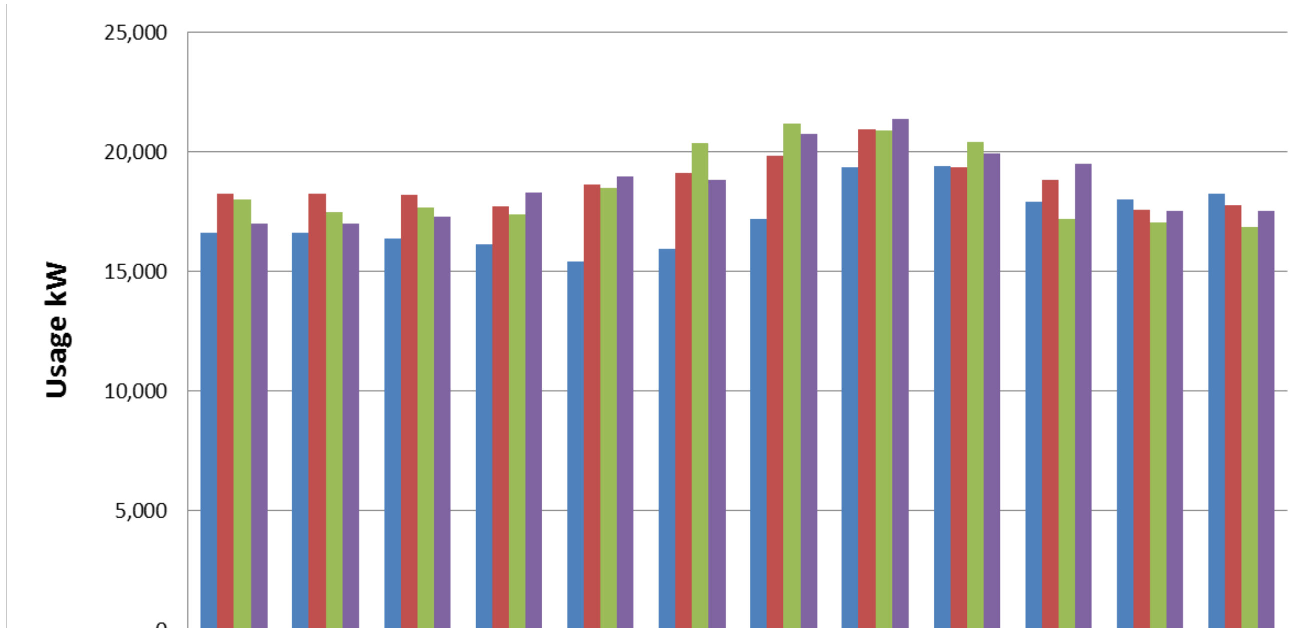
Chart 4-12
Actual Electrical Power Usage (2011-2014)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011 Actual	12,234	10,820	12,029	11,502	11,938	11,906	12,740	13,179	12,500	12,081	11,795	12,228
2012 Actual	12,222	11,410	12,100	11,558	11,952	11,801	12,880	13,262	12,082	11,948	11,460	11,896
2013 Actual	11,807	10,510	11,578	11,250	11,900	12,154	13,082	13,311	12,271	11,445	11,019	11,527
2014 Actual	11,371	10,302	11,361	11,133	11,979	11,887	13,328	13,561	12,449	12,206	11,280	11,666

In addition, the electrical demand for the terminal, not including the sub-metered tenants, was the following between 2011 and 2014:

Chart 4-13
Actual Electrical Power Demand (2011-2014)



2011 Actual	16,634	16,626	16,357	16,146	15,409	15,924	17,180	19,346	19,384	17,934	18,026	18,262
2012 Actual	18,246	18,251	18,207	17,721	18,651	19,101	19,847	20,929	19,363	18,818	17,569	17,770
2013 Actual	17,990	17,497	17,659	17,405	18,494	20,383	21,173	20,869	20,396	17,174	17,062	16,865
2014 Actual	17,007	16,980	17,274	18,286	18,969	18,849	20,733	21,376	19,925	19,493	17,550	17,511

3.2.5 Historical Trends

In summary, the annual consumption of energy demonstrates that the terminal averages nearly 144,000 megawatt-hours of electricity and that the overall consumption is trending downward.

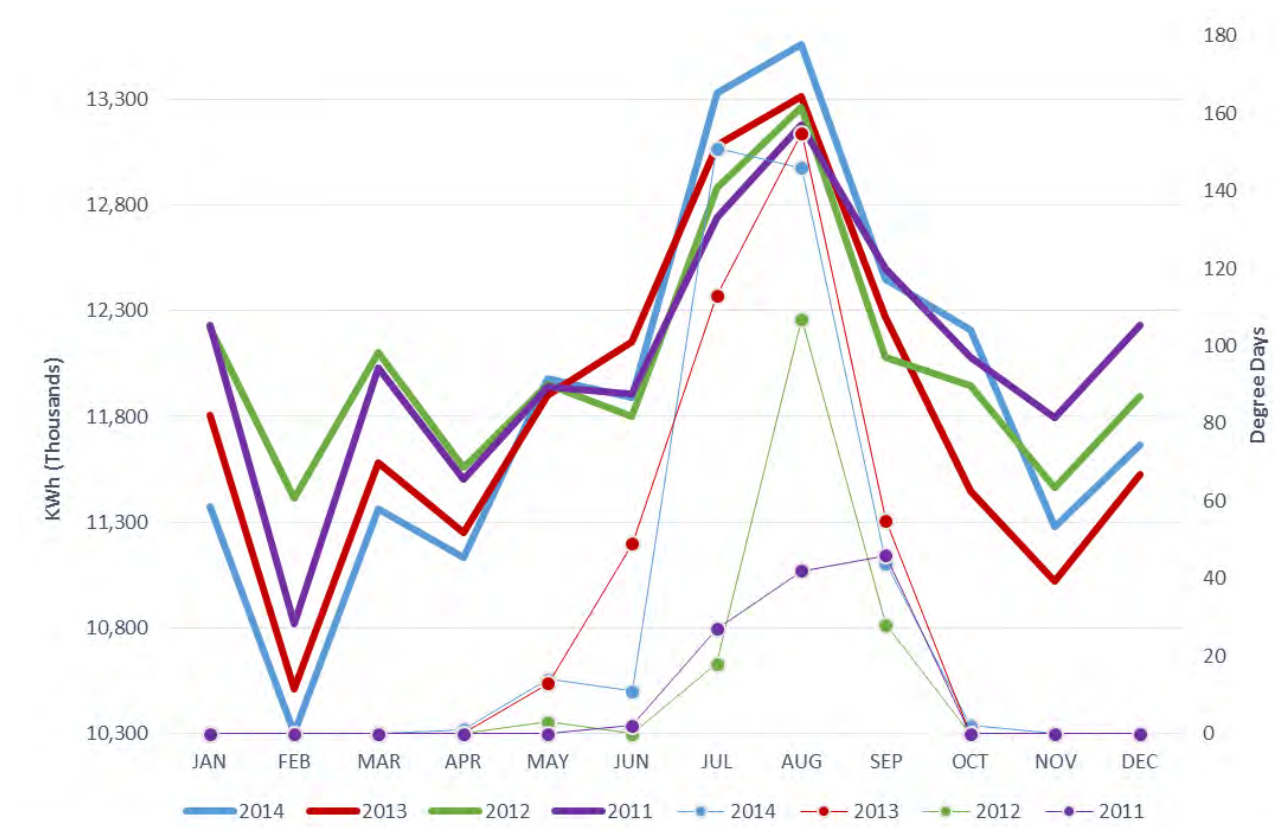
Table 4-7
Electrical Consumption per Year (Main Terminal)

Year	MW-hr
2010	145,135
2011	144,959
2012	144,576
2013	141,859
2014	142,528
Average	143,811
Trend	-831 MW-hr/year

Annual electrical consumption has decreased in the last five years, from an annual consumption of 145.1 MW-hours in 2010 to a low of 141.9 MW-hours in 2013. This can be attributed to a combination of internal retrocommissioning completed by the Facilities and Infrastructure group, more concise monitoring and verification procedures applied, and the implementation of three stages of energy efficiency audits. Other factors include replacement of garage lighting with LED fixtures, and replacement of ticketing FIDs with more efficient LCD video screens.

Chart 4-13 charts the trends for monthly electrical consumption with the associated cooling degree days between years 2011 and 2014.

Chart 4-14
Electrical Consumption vs. Degree Days Trend



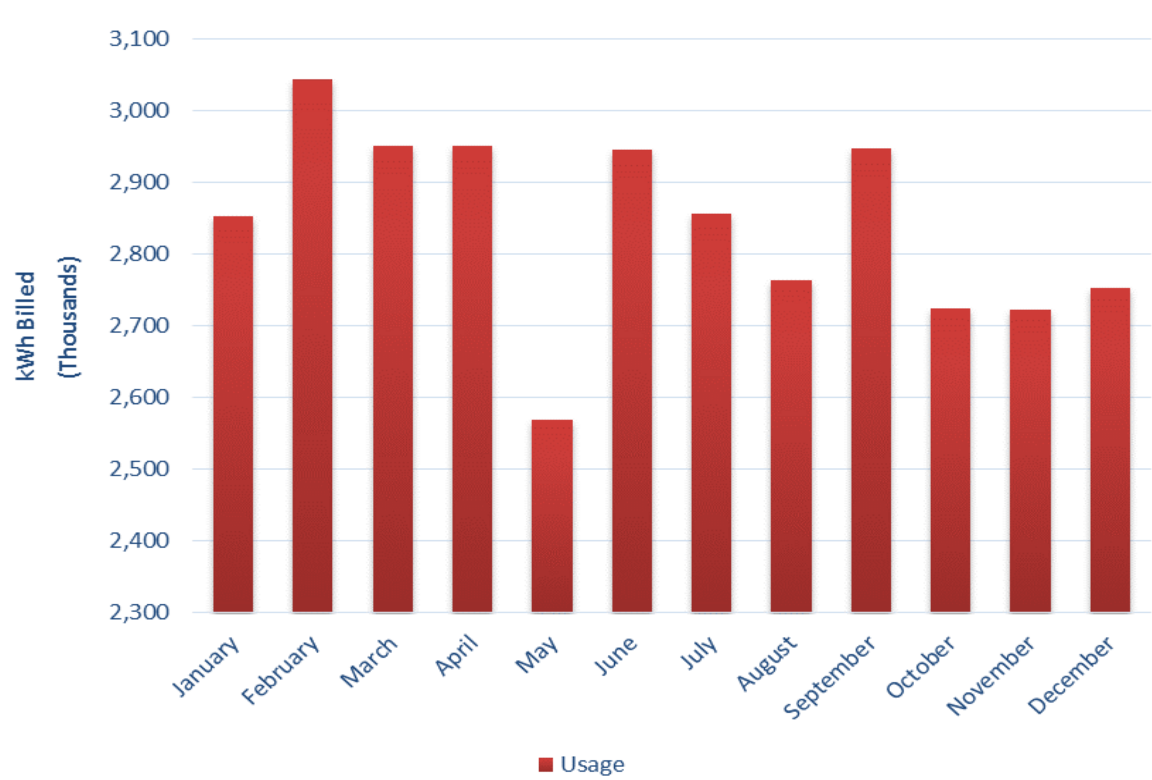
The trends indicate the influence that cooling (chilled water production and HVAC usage) has on the overall consumption. June through August in 2013 and 2014 had considerably more degree days than in the two years prior. In turn, the electrical consumption of those months exceeded the previous two years.

The trend also indicates that that the monthly consumption dropped steeply in November through April for 2013 and 2014 in comparison to 2011 and 2012. This drop in consumption is likely contributed to the retrocommissioning activities. Likewise, it may explain why the significant increase in summer month cooling degree days only resulted in a slight increase in monthly consumption.

3.2.6 Tenant Electricity Consumption: Cost and Revenue

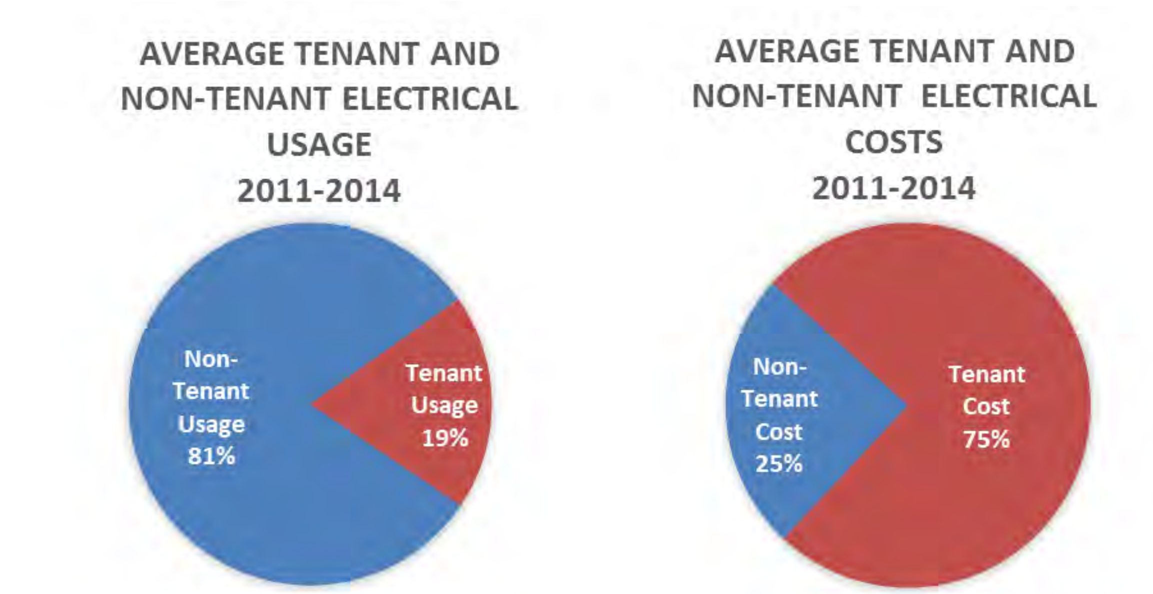
In 2014, tenants' submeters averaged between 2.7MWh to 3.0MWh per month of usage. This includes concessions within the terminal, airline hangars, fueling facilities, and cargo facilities. Electricity is purchased from both BPA and PSE by the Port of Seattle, and charged tenant rate which includes actual demand and usage costs, maintenance, corporate allocation, depreciation, etc.

Chart 4-15
Tenant Submetered Electricity Usage – Terminal (2014)



Billed usage for tenants in 2014 is as follows:

Chart 4-16
Average Tenant vs. Non-Tenant Electricity Usage (2011-2014)



Between 2011 and 2014, tenant energy represented approximately 19% of energy consumed in the terminal. Tenants, however, paid 75% of the energy costs associated with the Terminal. This is important information in understanding potential impacts for the Total Cost of Ownership. Since utility costs are one of the major components of OPEX, funding sources via tenant utility rates helps to offset these costs and therefore reduces the airport-funded TCO.

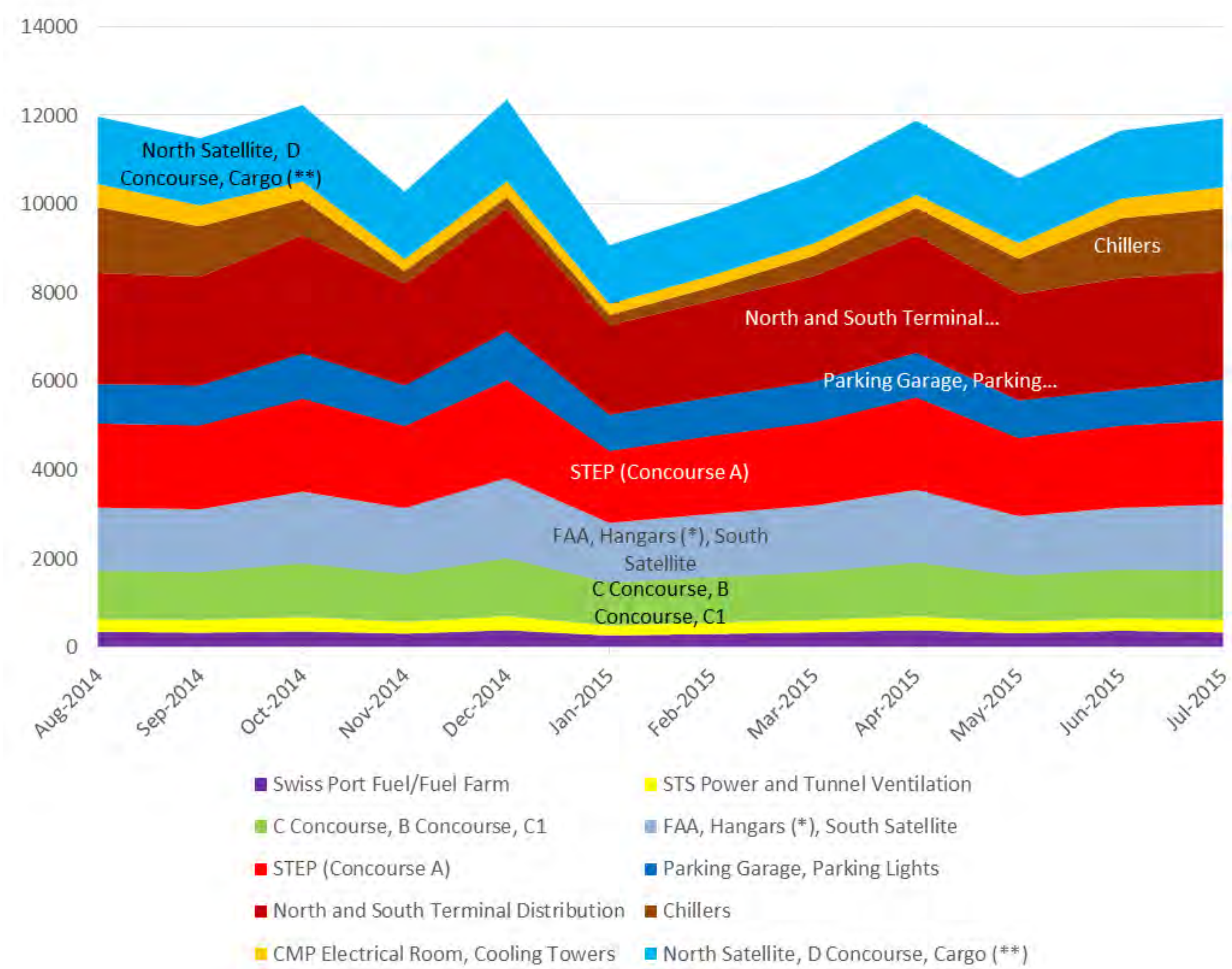
3.2.6 Electrical Consumption per Building Area

Reviewing the logs of the 5kV distribution centers that serve the individual buildings or areas within the terminal, it can be determined how much power each building or area consumes.

Electricity is used for production and distribution of chilled water, distribution of hot water, HVAC systems, lighting, process and equipment loads, cooking loads, computer loads, PC Air production, charging of electrical vehicles, and other uses.

Electrical distribution power centers are logged monthly. The data provided give a comprehensive indication how electricity is distributed throughout the airport for the main service. Analyzing monthly meter readings for main 12.5kV feeders provide a detailed understanding of how much electricity each Concourse, Terminal, or building associated with the main service uses. Additionally, since most all buildings are served by redundant feeders, the logs indicate how much power is being distributed by which substation. Finally, the meter logs indicate the monthly electrical demand which indicates if the building or area uses the power consistently, or cycles on and off (such as the chillers, which have a high demand, but low overall usage). For 2014, the following chart demonstrates how the electrical usage was distributed on a monthly basis.

Chart 4-17
Electrical Consumption by Building and Building Area

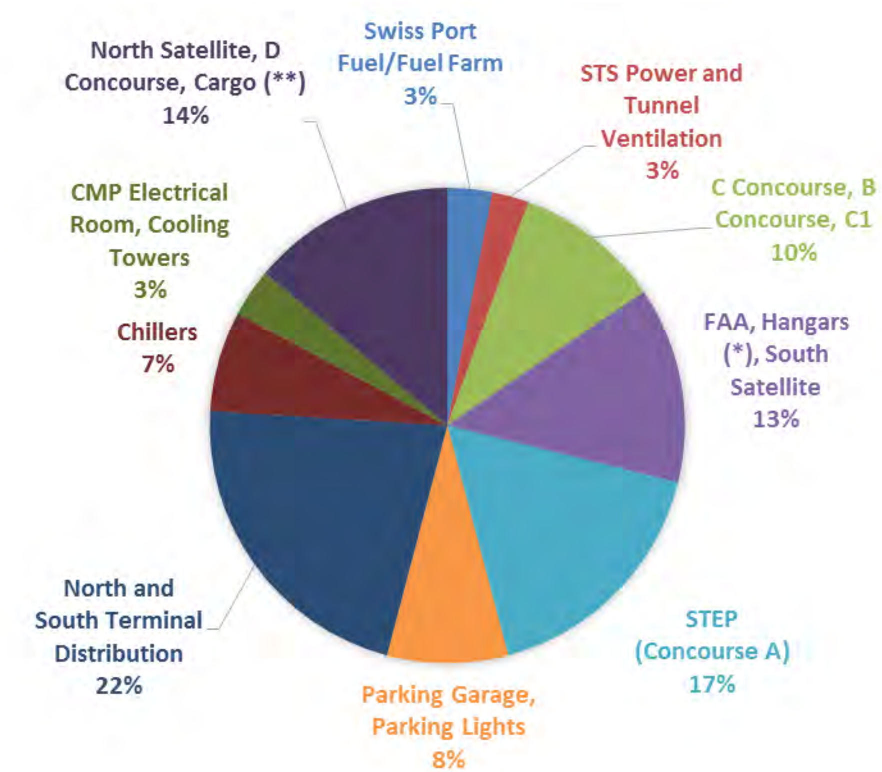


The graph indicates electricity that is used directly within the building area. It is separated by the electrical distribution, since the power meters associated with the substations were used to derive the information. It is assumed that the power used within each of the represented buildings is wholly within the substation and that no cross-feeding is occurring. It is also assumed that the substations associated with the building areas do not include additional non-building related electrical loads. Unlike the EUI analysis above that the included both the energy for the chiller with the air handling unit ventilation fans for a combined energy for each area, this analysis splits the electrical load into how it actually occurs. The refrigeration equipment (chillers and associated equipment) are represented within the central plant. Terminal-related cooling only includes fans within the HVAC equipment.

As the chart indicates, the Main Terminal (noted as "North and South Terminal Distribution") uses the most power, followed by the Concourse A and STEP expansion, the feeders that serve Concourse D/North Satellite/ Cargo, and the feeders serving the FAA equipment/hangars/South Satellite. The chillers, central mechanical plant, and STS use the least power per month.

By percentage, the following chart displays this breakdown of electrical consumption per area, on an annual basis, based on Chart 4-15:

Chart 4-18
Annual Electrical Consumption by Building and Building Area, by Percentage



This information is important because it predicts how much electricity future buildings will require. Understanding the construction, operation, and efficiency of the building and comparing it to a similar building with more efficient HVAC, lighting, and building components can assist in prediction of future electricity usage.

3.3 Natural Gas and Other Fuels

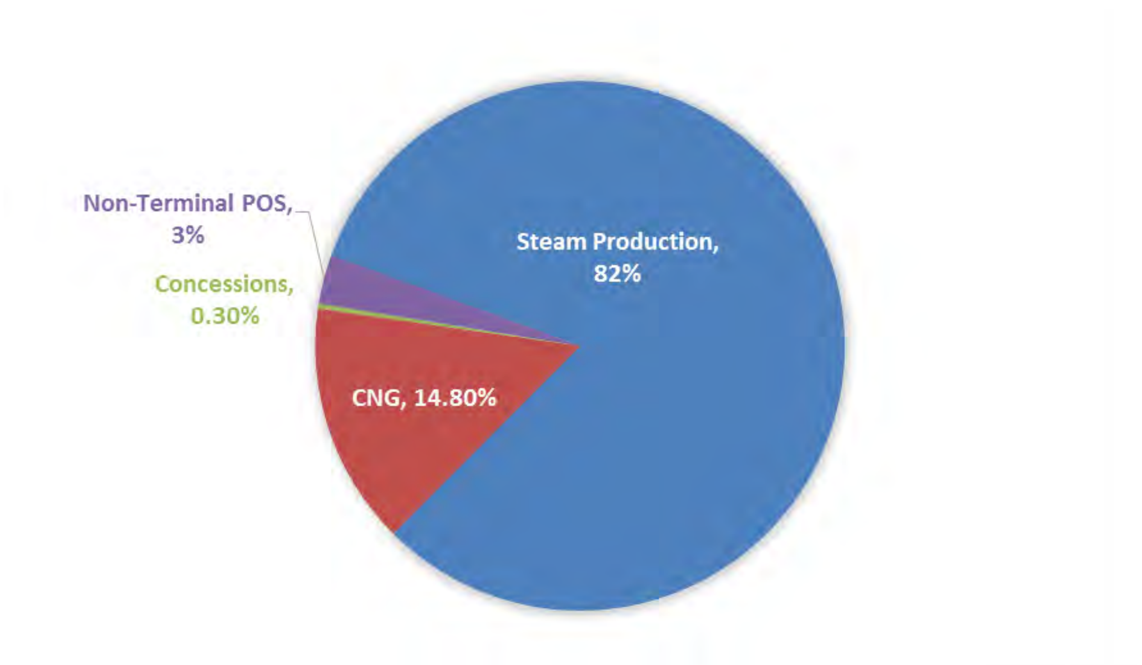
Historically, Puget Sound Energy has been the primary supplier of natural gas. In August 2013, the natural gas service was replaced with wholesale market broker called Cost Management Services (CMS). They provide the service to the steam boilers that provides terminal space heating, domestic water production, and PCA heat.

The existing natural gas utility service is used for four primary purposes: space heating, water heating, cooking, and vehicle fueling. Space heating is the largest consumer, with a significant amount of natural gas sent to the central plant for use to fire the four steam boilers. The major service entrance and meter enters the central plant near the cooling towers. The remaining natural gas service entrances serving Port controlled and operated buildings remain PSE. It is separately metered and enters the CTE, Concourse B, and South Satellite for tenant use

Other fuel at the airport includes diesel fuel used for standby generators and fleet vehicles and gasoline used in other land vehicles at the airport.

Diesel fuel and gasoline is procured from SeaPort Petroleum. Biogas (renewable natural gas) is purchased through Clean Energy Fuels for fueling of some of the bus fleet.

Chart 4-19
Total Natural Gas Consumption, by Percentage



3.3.1 Site Use of Renewable Natural Gas (Biogas)

Renewable natural gas is currently used only for CNG fueling of airport fleet vehicles and buses. The current contract limits the use of biogas to this purpose, due to the RIN credits provided for its use.

3.3.2 Emissions from Natural Gas and other Fuels

Refer to Technical Memorandum 7 for a more "in depth" analysis of environmental impacts for all Airport site related activities, including energy consumption. This section briefly summarizes electrical emission equivalent for Sea-Tac.

Below is a table of emission factors for the five primary fuel types used at Sea-Tac. The information for the emissions was provided by the Climate Registry.

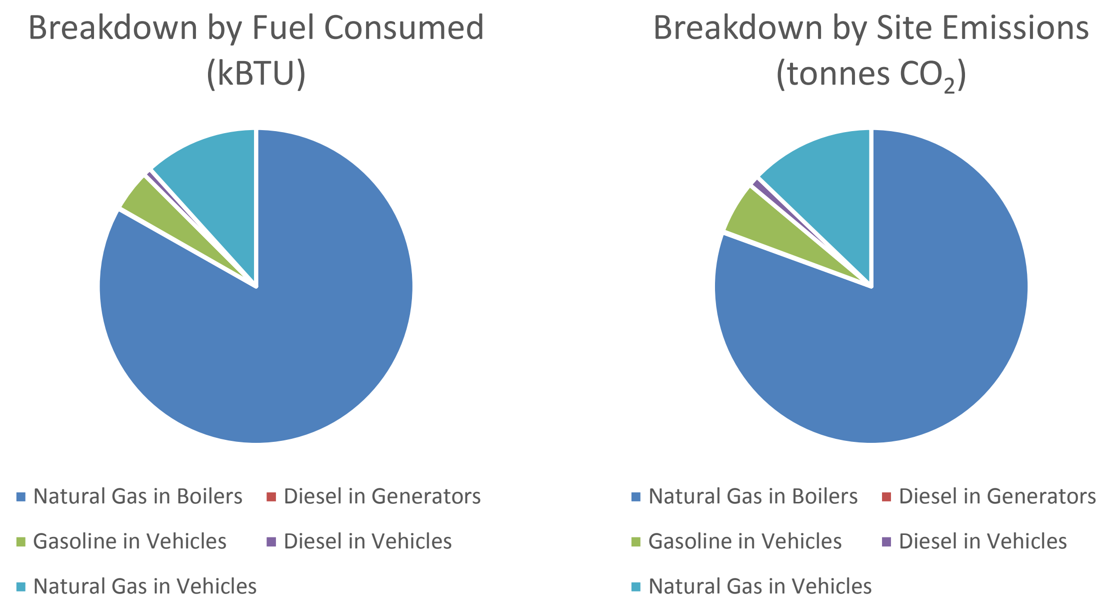
Table 4-8
Annual Site Fuel Emissions for All Uses

Source	Converted Emission Factor	Converted Units	Estimated Annual Consumption	Total CO2 (tonnes)
Natural Gas in Boilers	0.005302	tonnes CO2/therm	2,835,100 therms	15032
Diesel in Generators	0.01021	tonnes CO2/gallon	2000 gallons	20
Gasoline in Vehicles	0.00878	tonnes CO2/gallon	115,200 gallons	1011
Diesel in Vehicles	0.01021	tonnes CO2/gallon	20,000 gallons	204
Natural Gas in Vehicles	0.00684018	tonnes CO2/GGE	350,000 GGE	2394

The emissions listed are defined as "site" energy (in lieu of "source" energy). It is assumed that it is delivered as primary energy and accounts for the fuel combusted on site in the boilers, vehicles, generators, or heaters.

As the Table demonstrates, each of the fuel sources are consistent between amount consumed and carbon emitted.

Chart 4-20
Annual Fuel Consumption by Usage vs. Emissions from Fuel



The graphs show that the relative emissions for each of the fuel types and usage is comparable to its emissions.

3.3.3 Existing Costs and Consumption

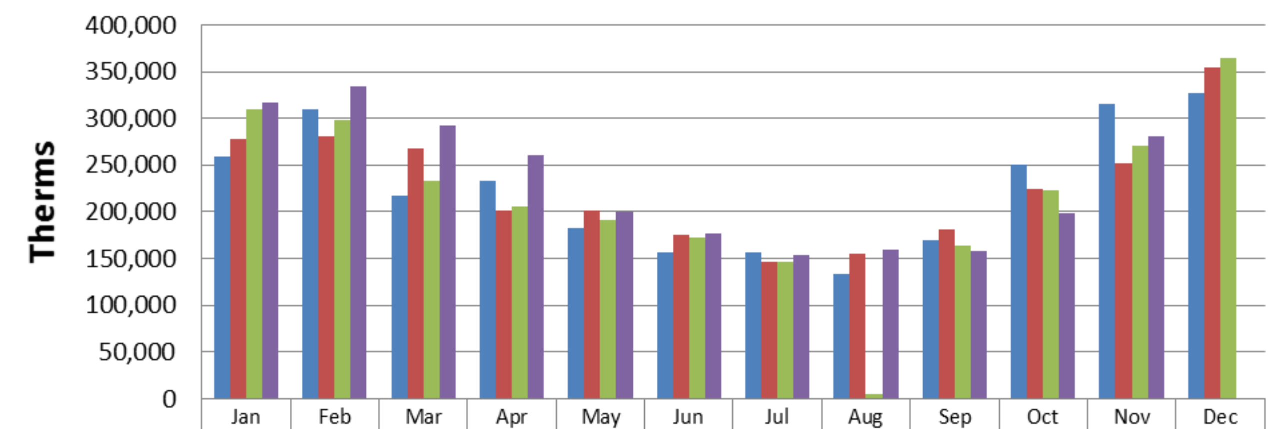
Ten years ago when Concourse A was built, there was a significant increase in natural gas. After this increase, the consumption of natural gas annually was consistent for most years. Starting in 2013, the consumption data becomes irregular, likely due to the implementation and commissioning of the preconditioned air (PCA) system. As this system went online and was tuned properly, the overall efficiency of the system benefited and reduced steam (natural gas) consumption.

In addition, billing for natural gas changed. Previously, natural gas was billed monthly, midpoint to midpoint. In August 2013, the cycle changed, which skews the data for that year further.

Unlike electricity, there is a clear understanding what the natural gas is used for. Steam production is the largest consumer of natural gas on the site. Steam is used for heating the building, heating domestic water, and for heating preconditioned air.

Baseline natural gas use can be determined by comparison of the annual usage. Summer months used little steam for space heating and therefore the production would be for these other uses.

Chart 4-21
Actual Natural Gas Usage (2011-2014)

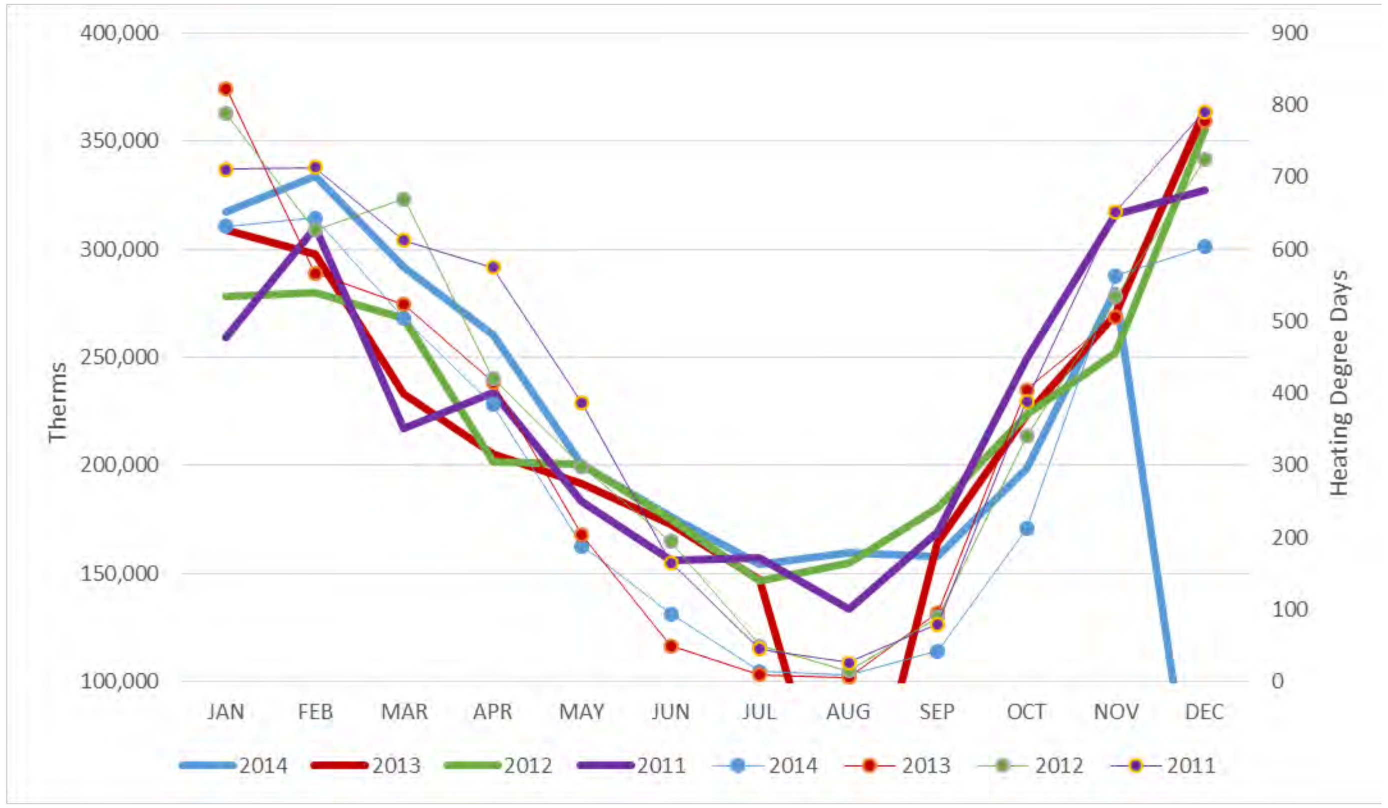


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011 Actual	259,450	309,986	216,820	233,670	183,142	155,985	156,956	133,384	169,122	249,926	316,142	327,334
2012 Actual	278,168	280,057	268,020	201,421	200,700	175,146	146,549	155,012	180,598	223,798	252,173	355,124
2013 Actual	309,007	297,682	233,131	204,978	191,328	172,747	146,897	4,614	164,493	223,645	270,027	364,720
2014 Actual	317,135	333,758	291,850	260,603	200,254	176,109	154,000	159,672	157,756	198,484	280,923	0

Annual natural gas consumption is higher in 2014 as compared to previous three years. Year 2013 had the lowest annual consumption at 2,585,000 therms, compared to nearly 2,720,000 therms in 2011 and 2012. August 2013 has an anomalously low consumption. This can be explained due to the change in utility contract having different service dates.

Chart 4-19 charts the trends for monthly natural gas consumption with the associated heating degree days between years 2011 and 2014.

Chart 4-22
Natural Gas Consumption vs. Heating Degree Days Trend



This indicates that the outdoor temperature greatly affects the natural gas consumption of the Terminal.

3.3.4 Other Fuels

In addition to natural gas, there are other fuels consumed at the airport. Table 4-9 indicates average yearly consumption for all fuels, including natural gas, used at the Airport.

Table 4-9
Fuel Consumption per Fuel Type

Type	Fuel/Energy	Location Or Facility	Approximate Use per Year
Stationary Combustion	Natural Gas	Central Plant Boiler	2,700,000 therms
		Pump House	1,500 therms
		Fleet Maintenance Facility (AC2)	65,000 therms
		Fire Department	30,000 therms
		Miscellaneous Sources	< 100 therms
		Bus Maintenance Facility	30,000 therms
		Distribution Center	8,500 therms
		Pre-Conditioned Air (warming component)	54,000 therms
	Diesel	Standby generators for Airfield lighting; pump house; central plant	2,000 gallons
Mobile Combustion	Gasoline	Port of Seattle Aviation Fleet Vehicles	115,000 gallons
		Business Travel using Personal Vehicles	200 gallons
	Diesel	Port of Seattle Aviation Fleet Vehicles	20,000 gallons
	Natural Gas	Natural Gas in Fleet Vehicles & Buses (Biogas)	125,000 GGE

3.3.5 Natural Gas Consumption by Usage

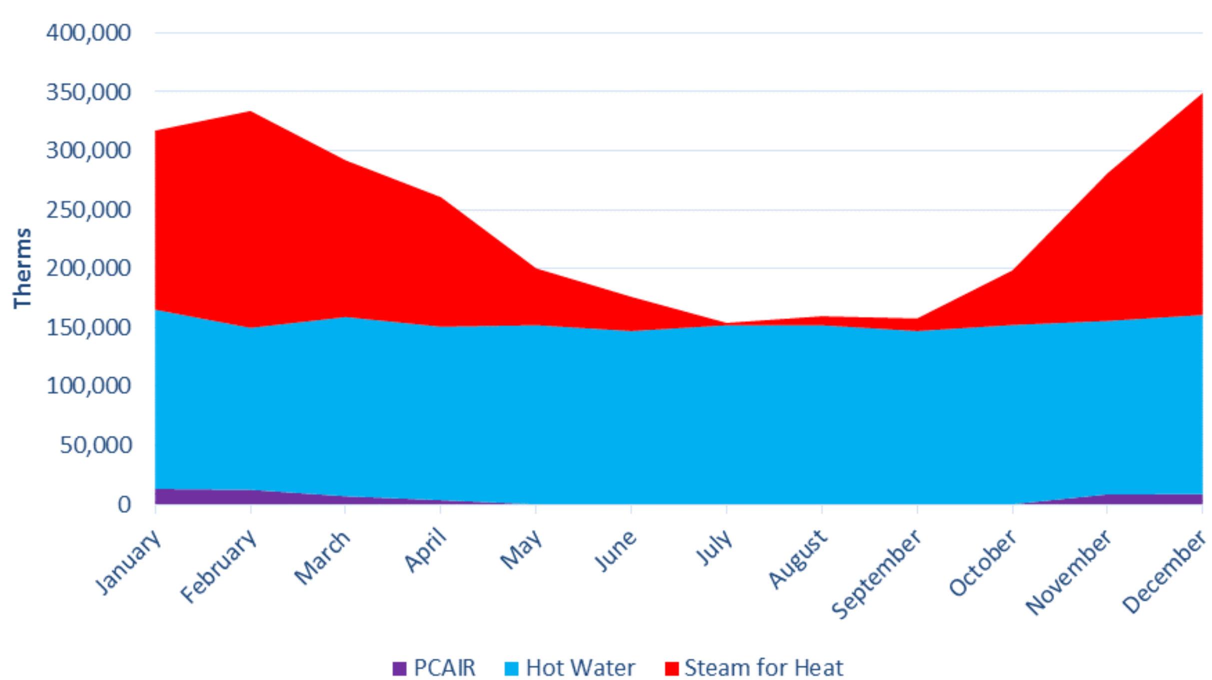
Natural gas is purchased for four main purposes at Seattle-Tacoma International Airport: steam production, CNG for vehicle fueling, concession (cooking), and for heating of cargo and other non-terminal Port-owned buildings. The amount of gas purchased is as follows:

Table 4-10
Natural Gas Consumption per Usage

Purpose	Therm Equivalent
Steam Production	2,722,889
CNG	492,311
Concessions	8,492
Non Terminal POS	98,850
Natural Gas in Rental Car Facility Buses	225,000 GGE

This indicates that the overwhelming use for natural gas at the airport is for production of steam in the Central Mechanical Plant (over 82%). This steam is used to heat water for HVAC systems, heat water for plumbing systems, and heat water for the PC Air system. Based on use of the energy model and consumption logs, the chart below demonstrates how the steam (natural gas) is consumed by these functions on a monthly basis:

Chart 4-23
Monthly Natural Gas Consumption per Usage



The PCAir and steam for heat are influenced by the outside temperature (see above). The hot water production is influenced by total passenger traffic. More passengers require more hot water for use in lavatories. Traditionally, passenger traffic increases for Seattle in the summer months.

The natural gas itself does not distribute to other parts of the building, with the exception of tenant natural gas piping which is connected to a dedicated service and meter separate from the main service, The main gas meter indicates how much steam is produced. The existing steam boilers are 87% to 89% efficient, meaning that the steam produced has 87% to 89% of the total energy (BTUs) than the natural gas it takes to produce it.

Because steam meters are scarce throughout the terminal, it is difficult to predict the amount of natural gas consumed per area of the Main Terminal or Satellite terminals.

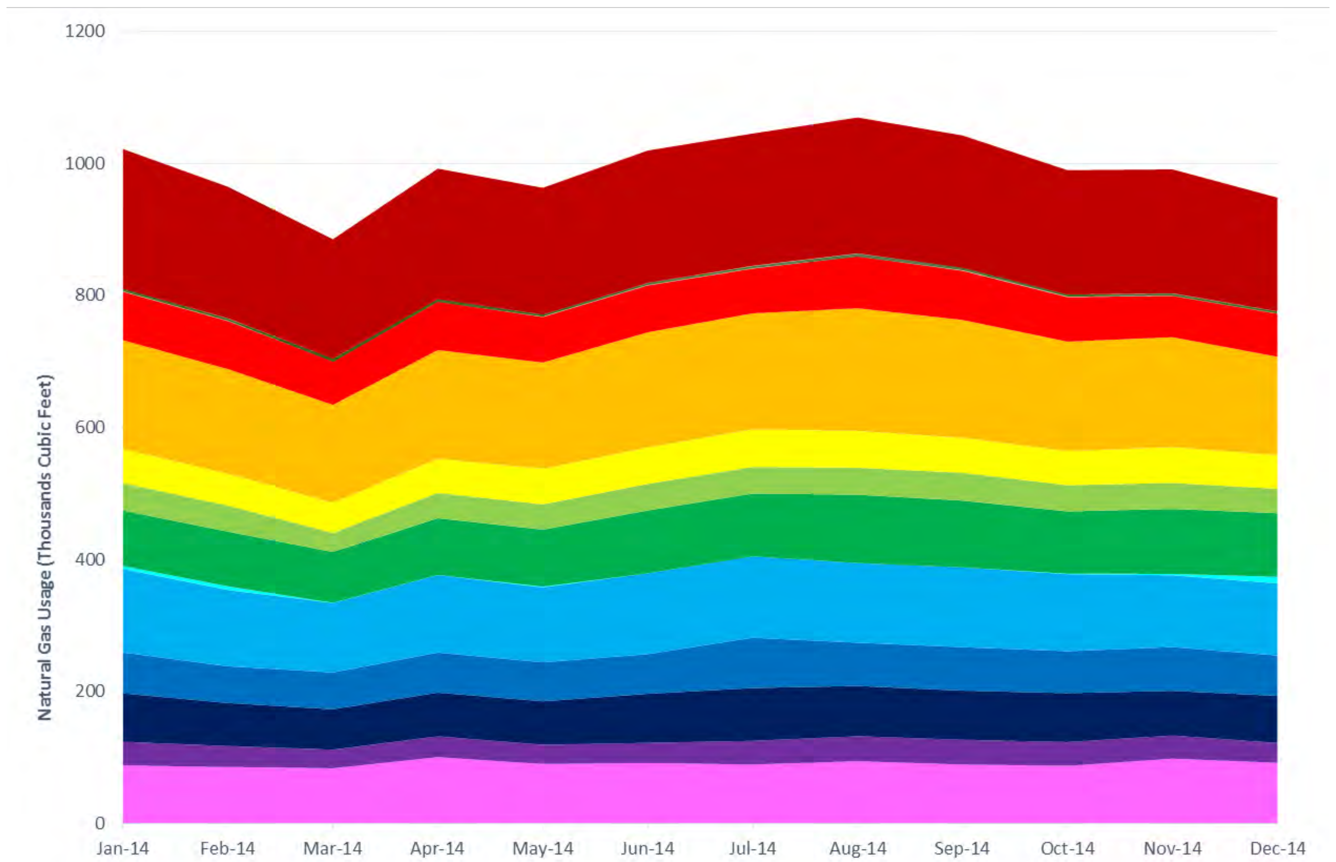
Estimates, based on the energy model indicate that the Main Terminal, including the CTE uses approximately 38% of annual steam production. Concourses A (including STEP), B, C, and D use approximately 18%, 7%, 7%, and 6%, respectively. The North and South Satellites use approximately 9% and 14% of annual steam produced, respectively.

For Port-owned buildings outside of the Main Terminal, the pump house uses approximately 1,500 therms, the Fleet Maintenance Facility uses approximately 65,000 therms, the fire station uses approximately 30,000 therms, the bus maintenance facility uses approximately 30,000 therms, the distribution center uses approximately 8,500 therms, and other buildings use approximately 54,000 therms annually. The Pre-Conditioned Air system uses approximately 54,000 therms annually.

3.3.6 Tenant Natural Gas Consumption and Cost

Cooking concessions have individual service lines and meters for natural gas. Currently, there are thirteen concessions that are submetered for natural gas. Their consumption is as shown on Chart 4-24.

Chart 4-24
Monthly Natural Gas Consumption per Tenant (All Tenants with Natural Gas Meters)



Each stack represents the amount of natural gas consumed by a tenant for that month

Some cargo and maintenance facilities use natural gas for direct space heating and hot water production.

3.4 Site Generated and Central Plant Utilities

The Central Mechanical Plant produces chilled water and steam for use by the Main Terminal for space HVAC and domestic hot water production. In addition, steam is used for heating of PCA. Warehouses, cargo facilities, and other remote buildings utilize stand-alone HVAC systems and are not connected to Central Plant.

Chilled water and steam are two of the site-generated energy systems used by the Airport. Electrical power for chillers, cooling towers, and pumps is converted to the production of chilled water, which is pumped throughout the terminal and satellites to individual air handling units and use to reject heat from the terminal. Since the chilled water is consumed within the terminal and not the central plant itself, this analysis assumes the energy required to produce the chilled water is assigned to the specific area for which it is used.

Likewise steam production represents the entire non-tenant natural gas usage for the terminal. Steam production via boilers is distributed to the Terminal and satellites to use directly for heating or to be converted to hot water for heating or for heating of potable water. Similar to chilled water, the natural gas associated with the steam production is assigned to the areas for which the steam is used.

Preconditioned air is used by aircraft when parked at the gate (in order to reduce runtime of aircraft engines). The preconditioned air plant uses glycol cooled by ice chillers and heated by steam from the central mechanical plant. The energy required for these utilities is converted from electricity and natural gas.

This section discusses findings regarding the chilled water plant, steam plant, and preconditioned air plant.

3.4.1 Energy Efficiency Audits

Facilities and Infrastructure group has performed three existing energy efficiency audits on the existing Central Plant and HVAC systems. These audits have been used to fine tune operation of equipment and maximize efficiency of operation for the chiller plant, plate-and-frame heat exchanger, boiler, etc. The efforts have included added measurement and verification capabilities within the DDC system to continuously monitor energy usage and trends. Part of this effort includes retrocommissing of existing systems, to confirm that they are operating as intended and to identify system issues which may be leading to energy waste.

Stage 1, 2 and 3 audits have been completed and implemented. Proposed Stage 4 audits are in progress. These audits have already resulted in savings of both electricity and natural gas, as noted in this Section.

3.4.2 Chilled Water

The main terminal chiller plant, located in the parking garage, is comprised of eight chillers totaling 14,450 tons of cooling capacity.

The eight water-cooled centrifugal chillers are connected to five cooling towers (totaling 17,500 tons) for heat rejection. Three plate-and-frame heat exchangers, totaling 2,700 tons, are connected to system and provide “free cooling” when the condenser water temperature is below 49°F.

The chillers are moderately efficient with good reliability. Paired with the plate-and-frame heat exchanger and Seattle’s mild weather, the overall efficiency of the chiller plant is comparable to other more efficient systems such as ground-coupled geothermal.

The chilled water distribution is based on a primary-secondary-tertiary setup. Secondary pumps distribute water to three main loops in the terminal: north (approximately 20%), west/middle (approximately 70%), and east (approximately 10%).

Tertiary pumps distribute to 200 mechanical rooms and 87 major air handling units in the terminal serving the approximately 3.1 million square foot of conditioned space.

Chilled water is metered in several locations in the Main Terminal. Some areas, such as the data center, Concourse B, and Concourse C are not currently metered. The best instrumentation is located in the South Terminal Expansion and Central Terminal Expansion.

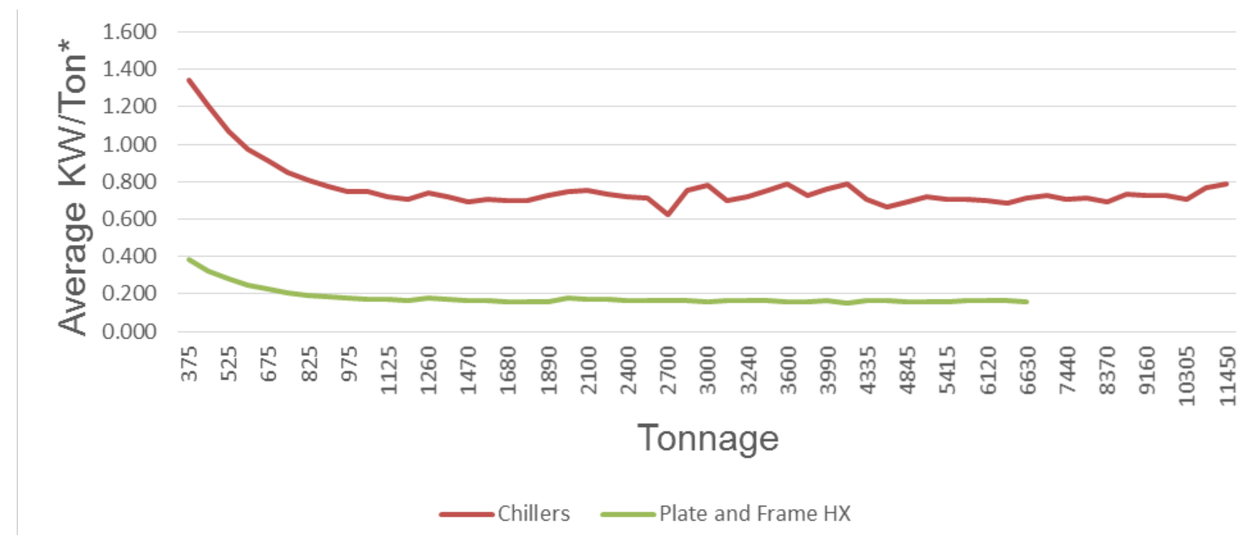
The chillers' sizes and efficiencies are as follows:

Table 4-11
Chiller Size and Efficiency

Chiller	Year Installed	Tonnage	Full Load Efficiency (kw/ton)	Part Load Efficiency
1	2010	2150	0.62	0.551
2		1500	0.602	0.551
3		2100	0.614	0.551
4		2100	0.614	0.551
5		1500	0.602	0.551
6		1500	0.602	0.551
7		2100	0.614	0.551
8		1500	0.602	0.551

With pumping and cooling tower energy considered, this results in the following theoretical efficiency curves, based on tonnage:

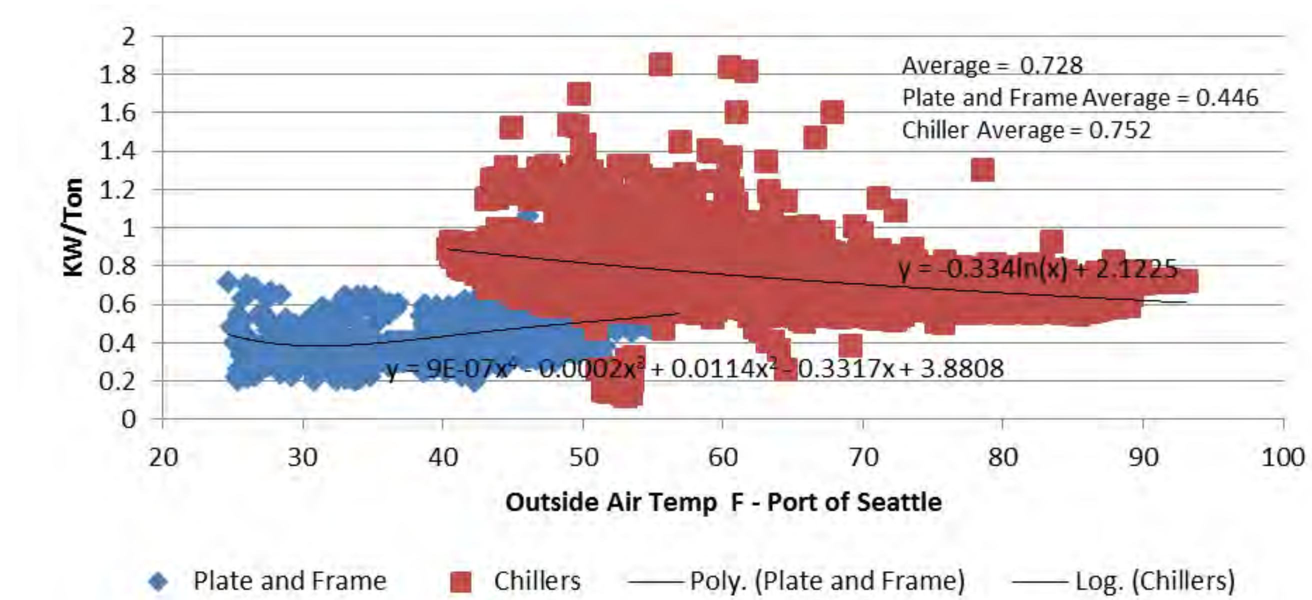
Chart 4-25
Existing Central Plant Loading Efficiency Curve



The "plate and frame HX" curve is used when the outside temperature is below or equal to 49°F. The "chillers" curve is used when the outside temperature is above 49°F.

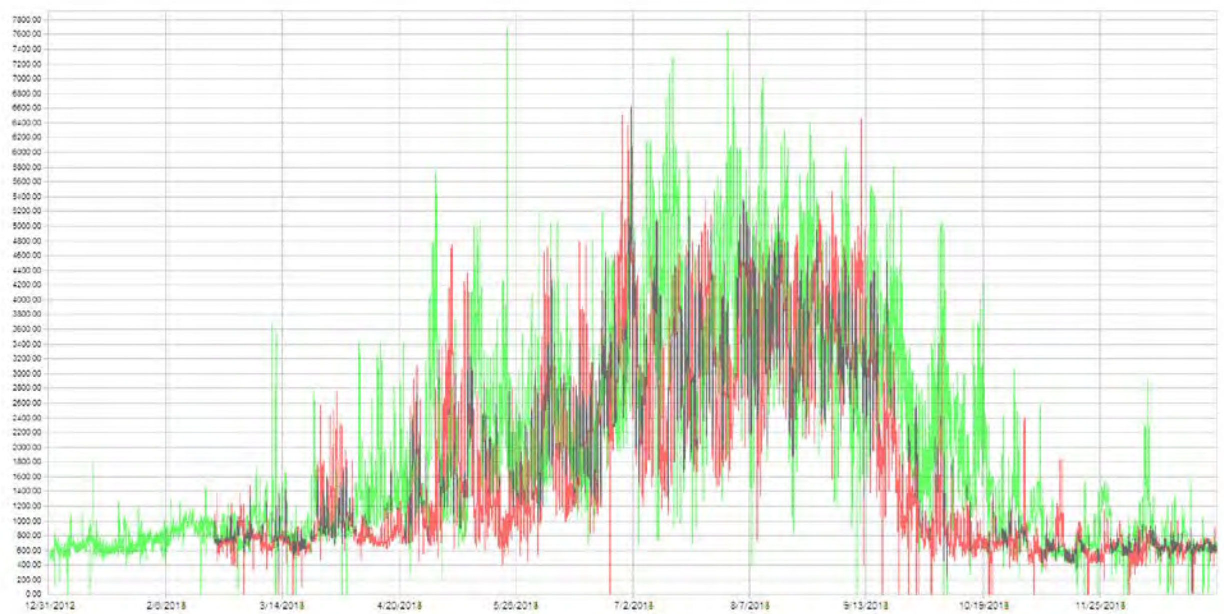
Actual power consumption (considering chillers, pumps, and cooling towers) was tracked in 2014 for the chiller plant and resulted in the following relationship, based on outside air temperature:

Chart 4-26
Total Power Delivered for Chilled Water (Feb to Nov 2014)



Red "dots" indicate when plant operated with chillers. Blue "dots" indicate when the plate-and-frame heat exchanger is in operation. The peak output measured at the central plant in 2014 was approximately 7600 tons in August.

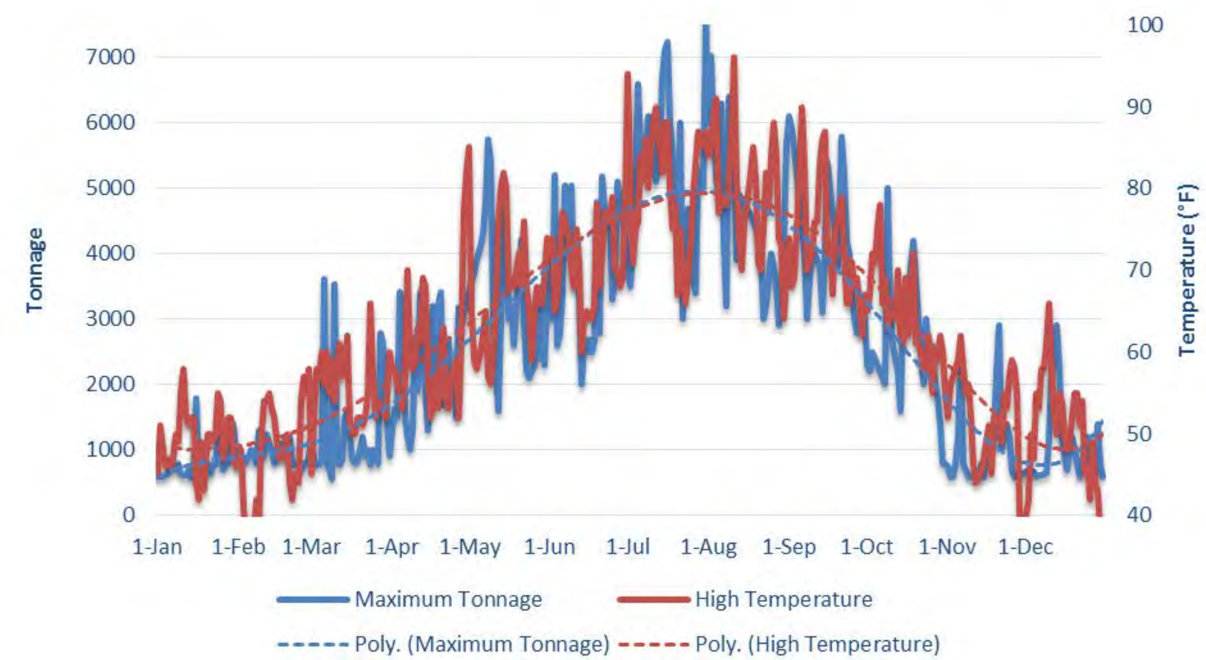
As further analysis, the chilled water tonnage was trended for two consecutive years (2013 and 2014) on a daily basis to track chiller usage. The following graph displays the tonnage throughout those two year periods. The red line represents 2013. The green line represents 2014.



As shown in the picture, annual chiller usage between years is similar.

To understand the impact of weather, and demonstrate how outside temperature affects chiller tonnage requirements, the following graph for 2014 overlays the chiller daily tonnage with the daily maximum temperature.

Chart 4-27
2014 Daily Maximum Chiller Tonnage vs. Daily High Temperatures



As can be seen with the polynomial trend lines, the chiller tonnage very closely matched the outside air temperature.

This information is used within the model to simulate energy for cooling the terminal. Outside air temperature is the primary impact to the amount of tonnage within the building. The remaining "baseline" tonnage represents the lighting, people, and equipment internal load within the terminal.

3.4.3 Steam

Steam is produced by the Central Mechanical Plant by four boilers that produce 130,000 pounds per hour at 84% to 87% overall efficiency.

Overall, steam metering is minimal at Sea-Tac airport, so trend data is difficult to obtain. Since the primary natural gas service entry serves only the boilers, there is a direct relationship between steam produced to amount of gas consumed. Based on 2010 to 2014 data (information above in section about natural gas), the boilers consistently consume natural gas at a steady rate, based on outside weather conditions.

For purposes of this analysis, it is assumed that the steam energy profile is a direct relationship with the natural gas profile and therefore the natural gas profile is used to predict steam usage requirements. Since a portion of the steam is used for the preconditioned air plant, the quantity of steam is discussed in that section below. The remaining steam is used within the Terminal and satellites.

3.4.4 Pre-Conditioned Air Plant

The Preconditioned Air system was recently completed in 2013. The $43M project used grants from the Voluntary Airport Low Emissions Grant to partially fund the project. The system uses a dedicated glycol chiller plant and steam from the Central Mechanical Plant to provide tempered PCA for use by the aircraft when they are at the apron in order to reduce fuel consumed, noise, and carbon emissions from the aircraft when parked. The PCA system supplies air to 73 gates. The system can be expanded to one hundred gates.

Use of PCA system allows the reduction of aircraft fuel consumption and carbon emitted. It is estimated that the Sea-Tac PCA system saves approximately five million gallons of fuel ($15M cost to airlines), 40,000 metric tonnes of CO_2 and seventy-three tons of nitrogen oxides (NO_X) annually.

The PCA system has three modes: cooling, heating, and ventilation. When the outdoor temperature is 50°F or lower, the PCA system is in heating mode. When the temperature is between 50°F and 60°F, the PCA system is in ventilation (no tempering) mode. When the outdoor temperature exceeds 60°F, the PCA system is in cooling mode.

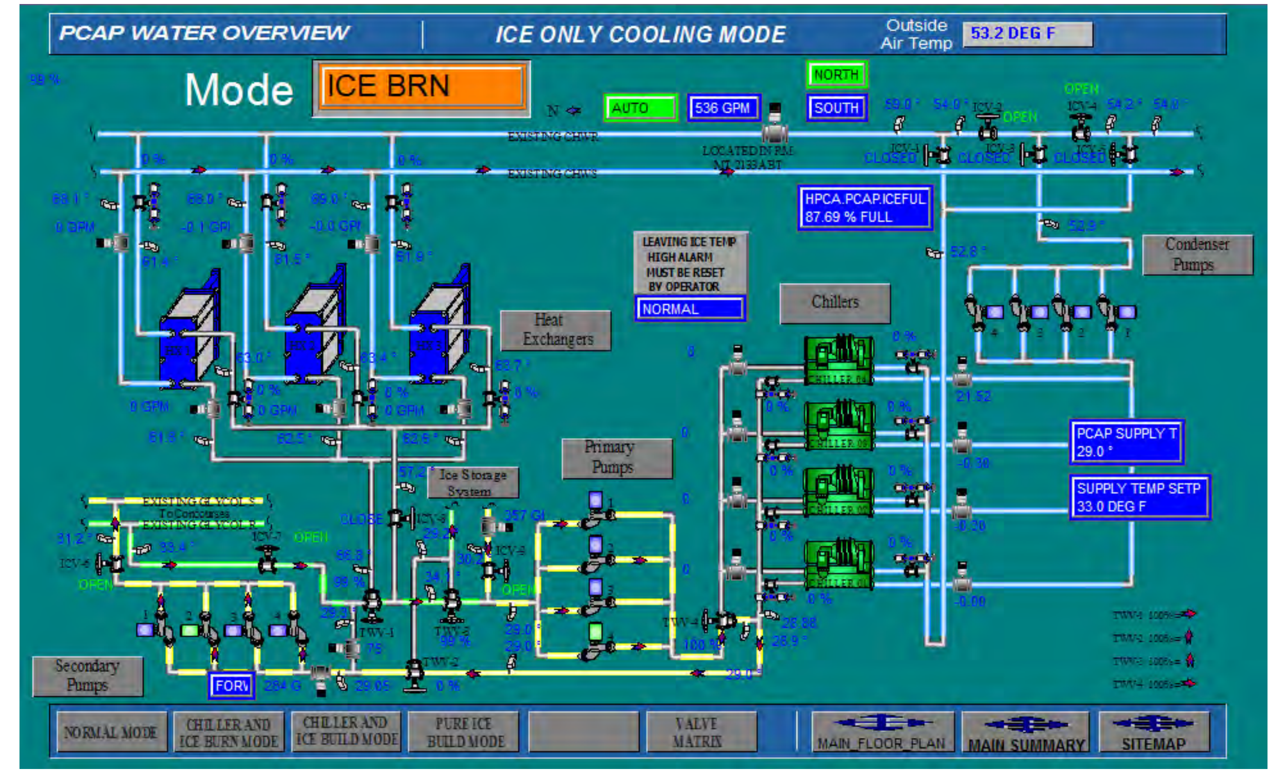
The PCA system is monitored and controlled with the Airport DDC system.

Heating Mode

The PCA plant heating mode has five independent systems that include pumps and steam-to-hot-water heat exchangers to produce hot water for heating. The heat exchangers have a maximum steam consumption of 1,700 to 3,600 pounds of steam per hour each.

Cooling Mode

The PCA plant uses four 300-ton glycol chillers to produce 7,875 ton-hours of ice. The 25% glycol solution (approximately 20°F freezing temperature) is distributed by four primary 2000 gpm pumps and four secondary 1300 GPM pumps to three 900-ton heat exchangers that produce ice for sixteen ice tanks. Main terminal chilled water return is used for condenser water for the chillers.



Airport DDC system screen showing the PCA ice system with glycol chillers, heat exchangers, and pumps.

Gate Air Units

There are sixty-four PCA gate units in operation: fifteen 70-ton units and forty-nine 33-ton units that range in blower horsepower between 30hp and 50hp.

Ground Support Equipment and *Posicharge* equipment

The existing eGSE vehicle charging power system for the north half of the airport utilizes considerable electrical power. The quarterly consumption of electricity for the Posicharge system is approximately 260,000 kWh, or over 1M kWh annually. With Alaskan Airlines using the system, the consumption increases to 275,000 kWh annually.

Based on consumption of equipment power, it is estimated that the charging equipment has an effective efficiency of 50%. The initial losses were in the 70-80% range, but adjustment of the equipment has improved it to 50%. Parasitic losses from the charging equipment are known to be high and smarter charging systems are being investigated.

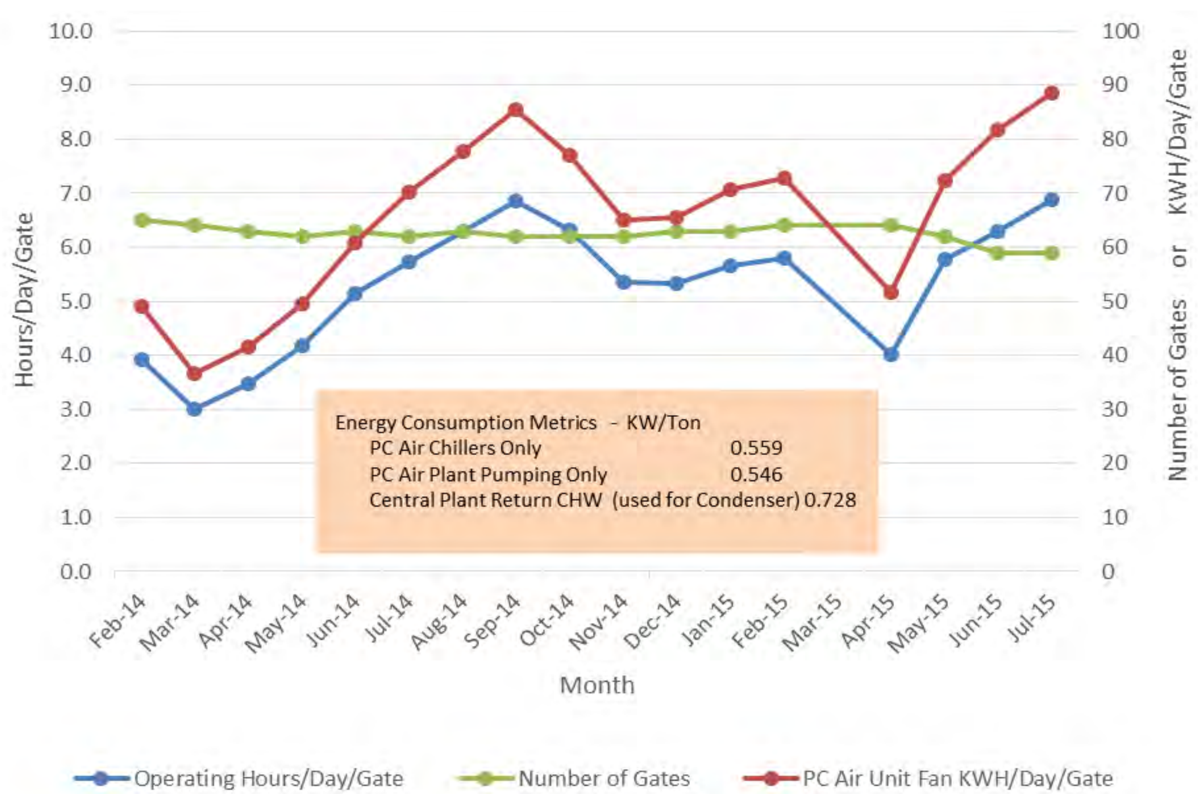
Precondition Air Plant energy consumption

Three main utilities used to produce PCA are electrical power for the blowers, electrical power (equivalent) for the glycol and main chillers and associated pumping, and natural gas expended in production of steam for heating hot water for heating the PCA.

Since instrumentation does not currently exist to accurately measure steam consumption for the PCA plant, an estimate was used to determine the impact of the PCA to the overall system. Steam consumption was compared prior to operation of the PCA plant and compare to consumption after the plant was in operation. The consumption was adjusted using heating degree days to normalize weather conditions for the various years. Based on this analysis, in 2013, the PCA system used approximately 83,900 therms of natural gas via steam from the Central Mechanical Plant. In 2014, this number reduced to 54,000 therms.

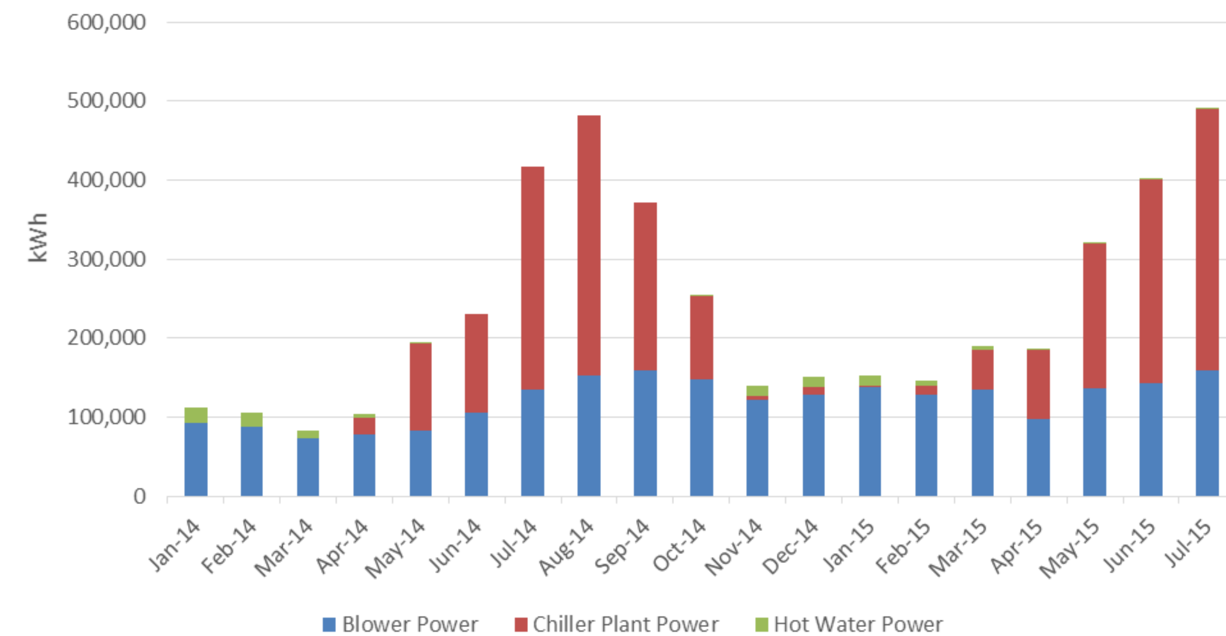
Chilled water consumption and electrical power utilized in the operation of the PCA plant can be more accurately estimated and monitored. Based on the operation of the PCA plant in 2014 through July of 2015, the Preconditioned Air system efficiency is determined to be the following:

Chart 4-28
Preconditioned Air Operating Data 2014-2015



Electrical power for the PCA plant is split into three parts: power for gate blower units, power for glycol and main chillers, and power for hot water pumps. From January 2014 to July 2015, the electrical power usage has been as follows:

Chart 4-29
Electrical Usage by PCA Plant



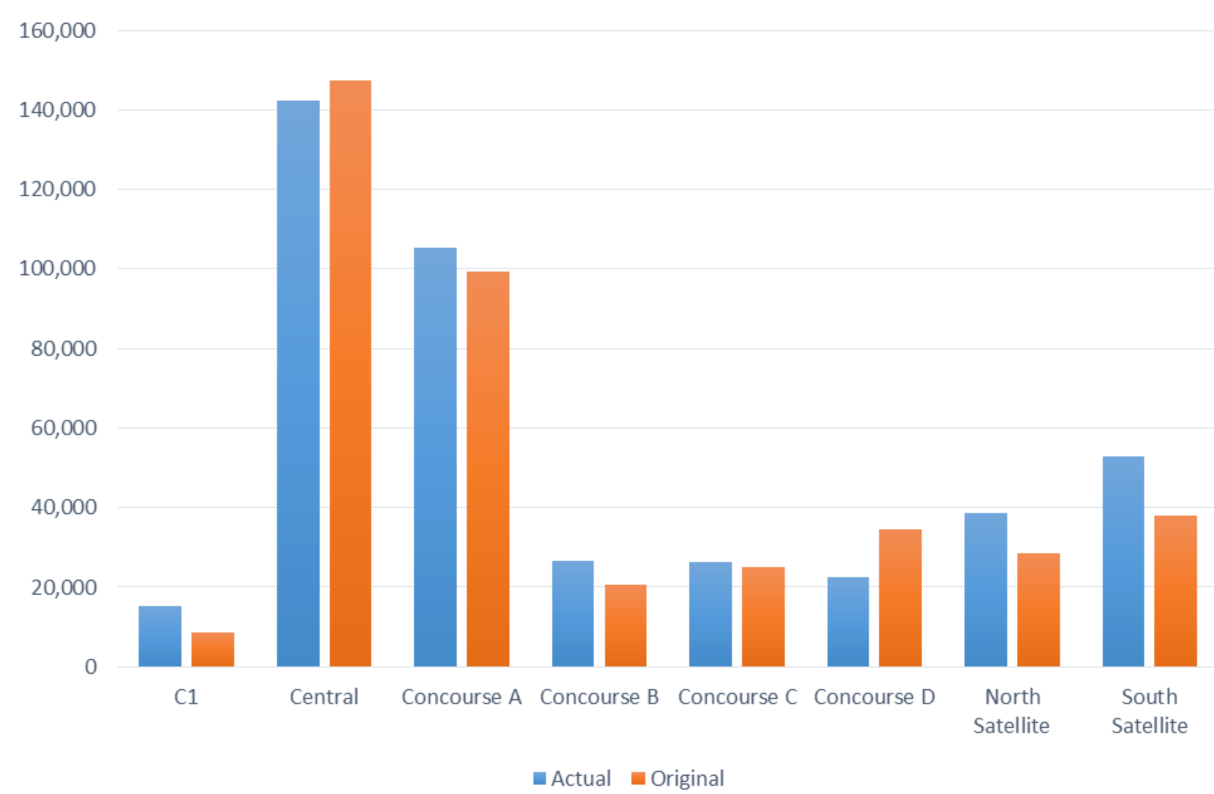
The power for the blower corresponds with the number of gates operating as shown in the previous graph. Chilled water power is based on weather conditions.

3.5 Energy Consumption per Function

It is important to understand how much of what type of energy is being used in the existing terminal to forecast how these levels will change as new buildings are built, or existing buildings are renovated. Understanding existing trends play an important part in developing strategies for energy conservation, energy planning, and infrastructure improvement.

The energy model developed was used to estimate energy consumption for various buildings, functions, and options. In order to validate the energy model, the outputs were calibrated to the actual 2014 energy use, based on billed consumption. Weather information was calibrated based on 2014 values, as well. As a result, the calibrated energy model outputs were well within tolerance of the actual values.

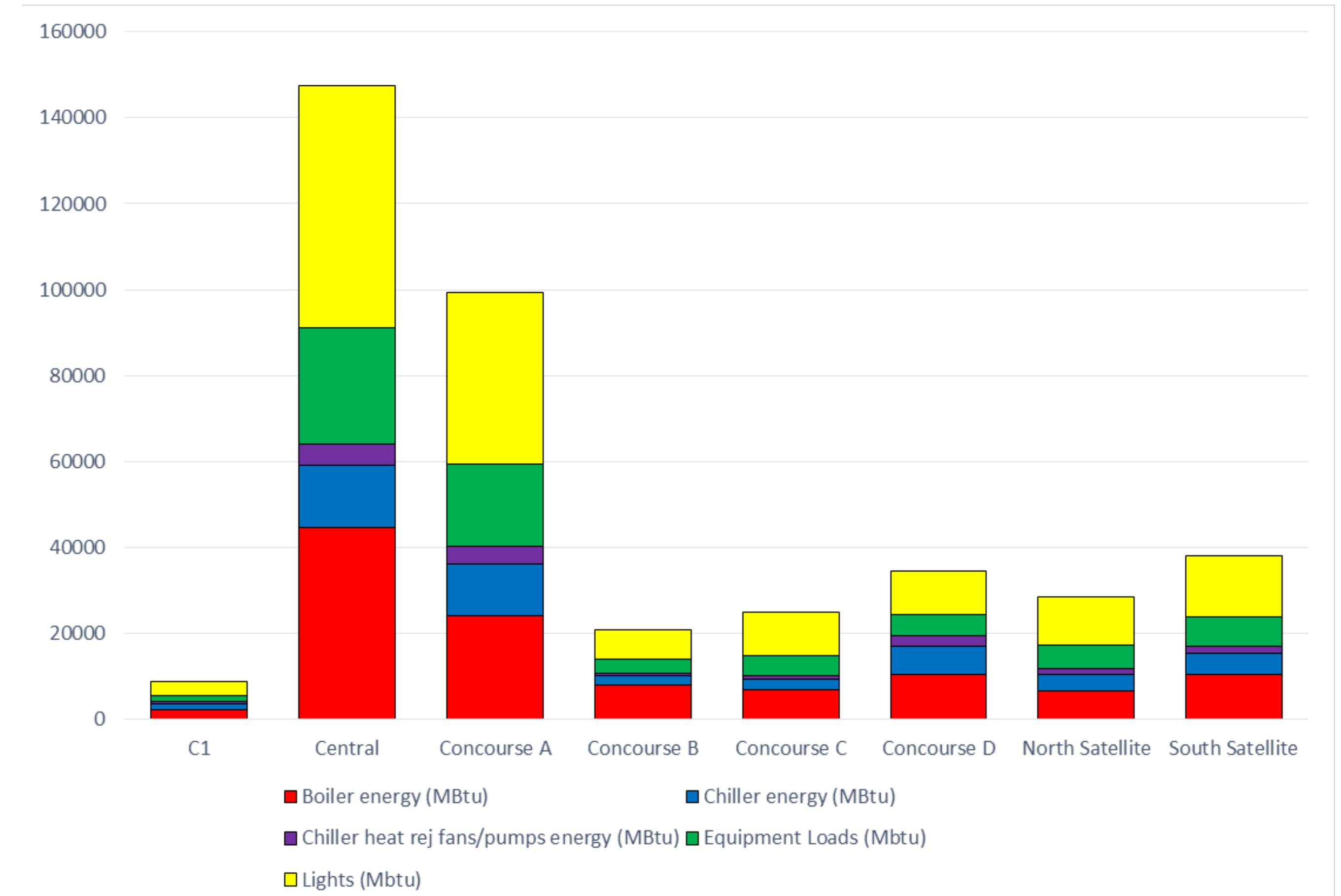
Chart 4-30
Total Energy Consumption (MBtu): Energy Model vs. Actual 2014 Consumption



Output energy for Concourse A, Concourse B, Concourse C, Central Terminal, and CTE was close to the actual consumption. The deviations for Concourse D and the North and South Satellites were more significant, but remain within master planning tolerance.

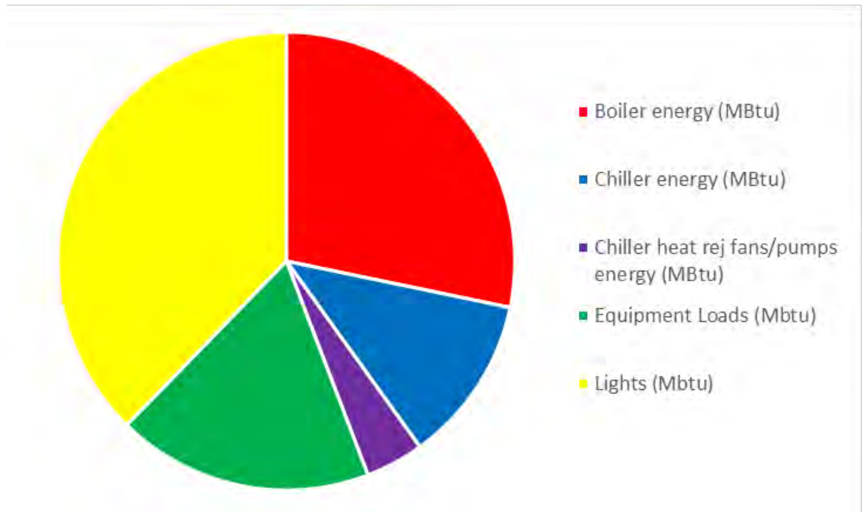
The model reports energy consumption in a variety of ways. One way, is the energy consumed by various functions. These functions are the major categories of energy usage for the terminal, converted to MBTU, for comparison. These function include: boiler energy, chiller energy, fan and pump energy, equipment energy, and energy for lighting. The following graph shows the amount of energy consumed within the major building areas of the Terminal for these categories:

Chart 4-31
Energy Consumption per Function, by Building



In total for all buildings within terminal, the following graph displays the breakdown of energy consumed per function:

Chart 4-32
Total Energy Consumed per Function (Terminal)



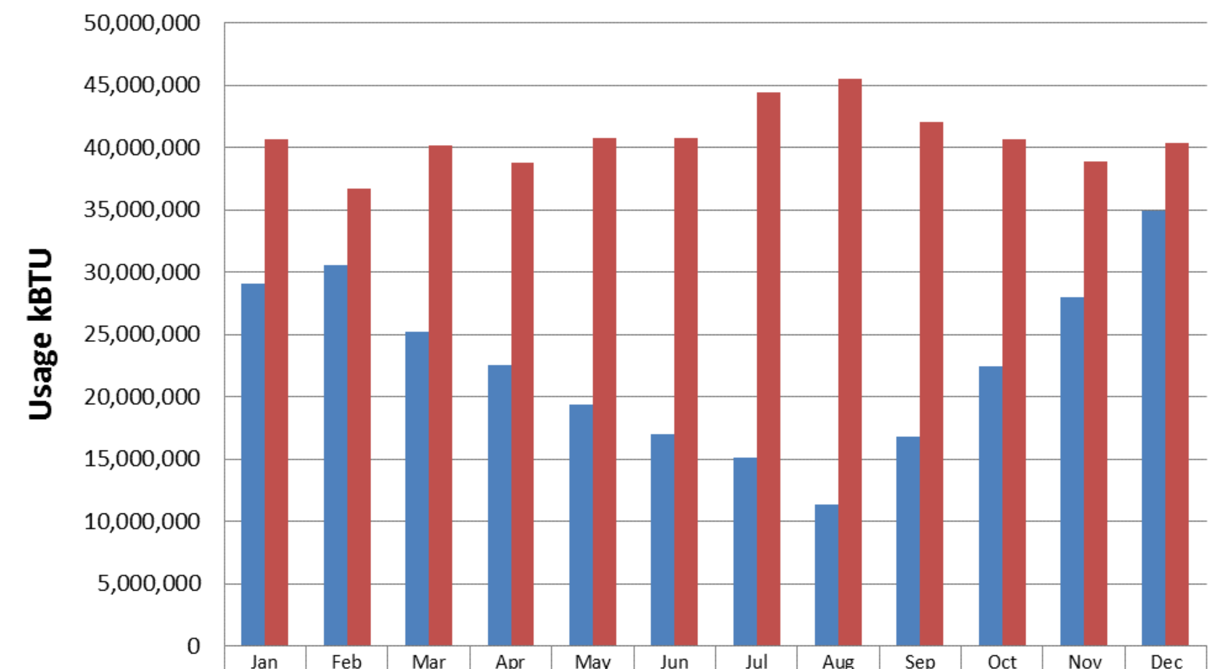
3.5.1 Comparison of Energy Used: Cost and Consumption

In summary, the Main Terminal, North Satellite, South Satellite, Parking Garage, and Central Mechanical Plant share a common electrical service. Natural gas for heating of air and water for these enter the Central Mechanical Plant and distributes steam throughout the terminal. Likewise, some power is used to produce chilled water to distribute to mechanical rooms throughout the Main Terminal, North Satellite, and South Satellite.

The consumption of electricity is fairly consistent throughout the year. This is widely due to the consistency of the operation and the mild summer weather minimizing chiller requirements. The consumption of natural gas, however, is significantly impacted by time of year. Since the main natural gas service is used entirely for steam production, when less steam is required, less natural gas is required. Some steam is required year-round for production of domestic hot water used in lavatories.

Converting monthly usage for both electricity and natural gas, the following chart demonstrates how both utilities are consumed over the course of the year:

Chart 4-33
Total Energy Consumed by Energy Type (Average 2011-2014 Annual Consumption)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gas Demand Kbtu	29,094,0	30,537,0	25,245,5	22,516,8	19,385,6	16,999,6	15,110,0	11,317,1	16,799,2	22,396,3	27,981,6	34,905,9
Elec Usage Kbtu	40,634,8	36,717,7	40,151,9	38,765,4	40,750,8	40,732,4	44,385,9	45,479,0	42,057,8	40,674,1	38,861,0	40,364,5

This results is in annual electrical usage of 489,576,000 kBTU and annual natural gas usage of 272,289,000 kBTU, resulting in a 64%/36% split, respectively.

Based on energy bills for years, 2011 to 2014, the average cost for electricity was $0.032 per kWh and the average cost for natural gas was $0.427 per therm. This results in an electrical cost of $4.6M and a natural gas cost of $1.2M, or 80% and 20%, respectively.

Chart 4-34
Comparison of Terminal Consumption and Cost: Electrical vs. Natural Gas (2011-2014 Average)

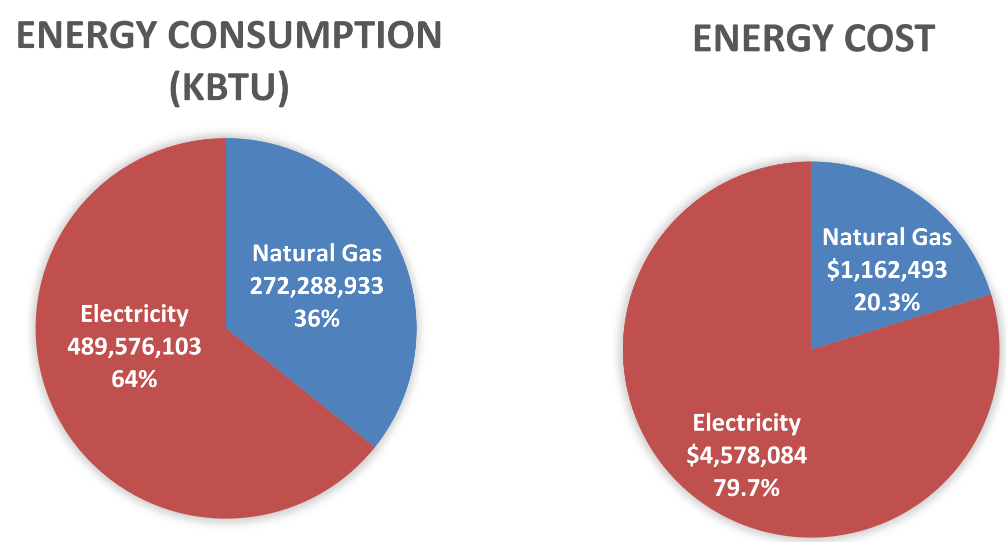
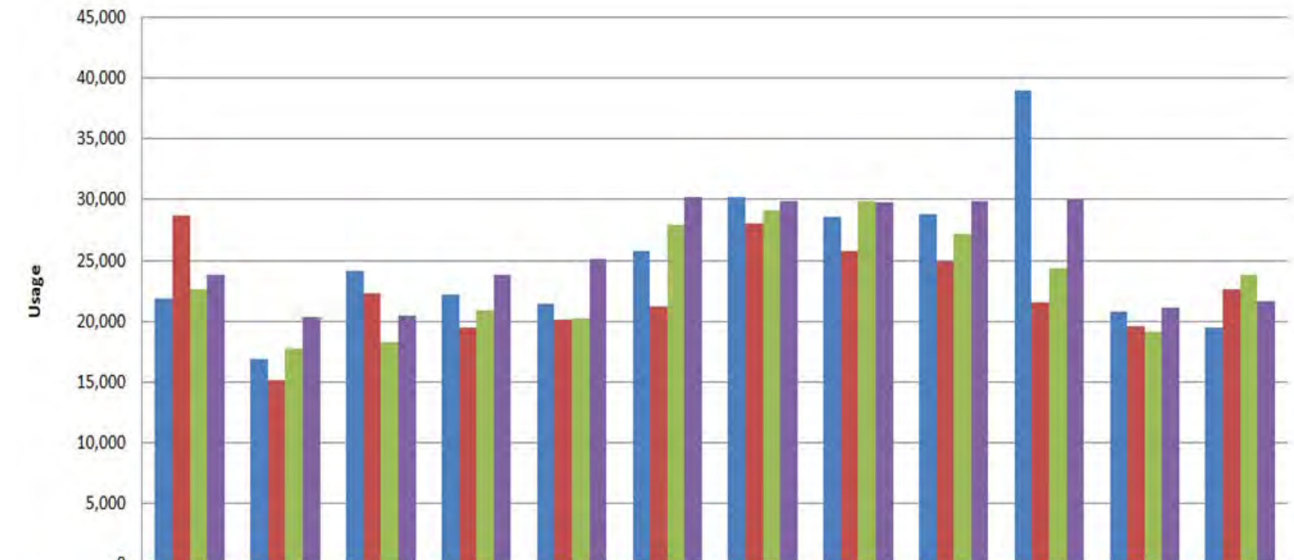


Chart 4-35
Port-owned Properties' Water Usage (2011-2014)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011 Actual	21,819	16,862	24,087	22,229	21,391	25,767	30,205	28,531	28,797	38,927	20,730	19,426
2012 Actual	28,691	15,108	22,347	19,528	20,138	21,172	28,082	25,743	24,911	21,557	19,630	22,670
2013 Actual	22,574	17,700	18,334	20,906	20,289	27,892	29,071	29,913	27,118	24,338	19,110	23,848
2014 Actual	23,864	20,333	20,428	23,793	25,095	30,253	29,845	29,784	29,887	29,931	21,132	21,635

On a cost per kBTU basis, electricity had an average cost of $0.0094 per kBTU and natural gas had an average cost of $0.0043 per kBTU. This indicates that electricity is currently 2.2 times more expensive per BTU than natural gas at this pricing structure. Natural gas would need to rise to $0.94 per therm to be the same as electricity. Natural gas is a variable rate, based on market, and has had a maximum cost of $1.054 per therm in the past ten years, but that has trended downward since 2006 (the high point).

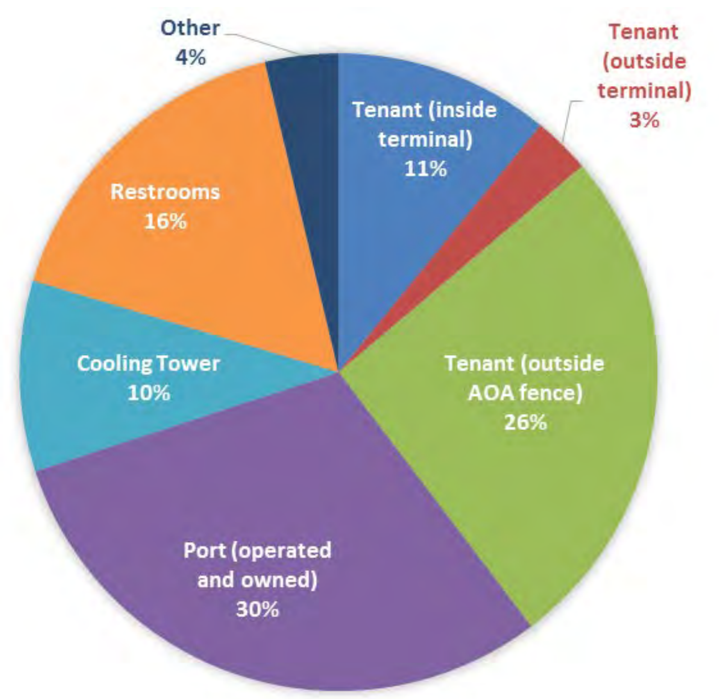
Considerations for heating types or use of gas-sourced energy production (such as cogeneration) should account for this diversity of energy pricing.

3.6 Water

Currently, Sea-Tac water consumption is handled through direct domestic water lines servicing the port. Onsite reclaimed water or district purple pipe system infrastructure current does not service the terminal. As a result, costing models for water consumption are governed by domestic potable water servicing charges. The current rate is approximately $6 per cubic foot. It is anticipated that this rate will increase significantly in the future.

The following tables illustrate historic potable water usage for the years 2011- 2014. A detailed water usage analysis of the 2013 year is also provided for reference.

Chart 4-36
Water Usage by Type (2013)



The graph indicates that that Port owned and operated (non-restroom) is the biggest annual consumer of potable water. Tenant usage outside of "AOA fence" is the next biggest user of water. Restroom water usage accounts for only 16% of the water used and cooling tower/boiler makeup water usage is approximately 10% of the total. Tenant usage for concessions represents approximately 11% of the annual consumption.

On a monthly basis, two primary functions of water - cooling towers and restrooms – vary throughout the year.

The Seattle-Tacoma International Airport proposed water fixture efficiency standard is as follows:

Men's

- Water Closet – 1.28 GPF
- Urinal – 0.125 GPF
- Lavatory – 0.51 GPM

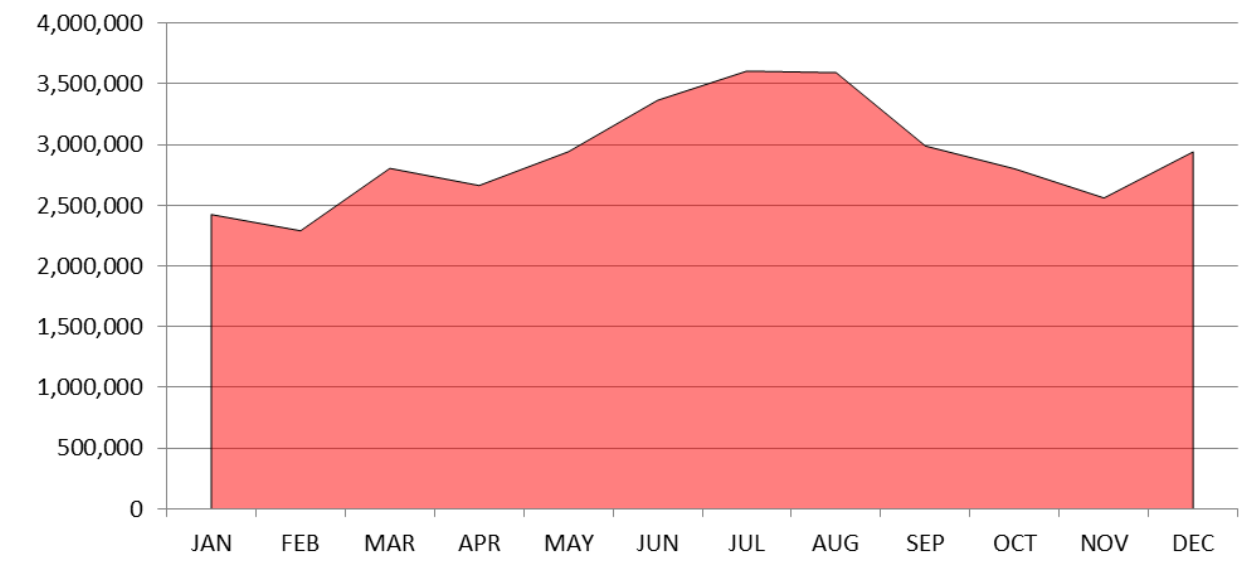
Women's

- Water Closet – 1.6GPF/1.1 GPF
- Lavatory – 0.51 GPM

These rates equal or exceed the minimum water efficiency rates for LEED V4 Prerequisite by 33% and meet the requirements of WE Credit 2.

For consumption, the amount of water used in 2013 on a monthly basis is as shown in Chart 4-34:

Chart 4-37
Monthly Water Usage for Terminal Restrooms (2013)

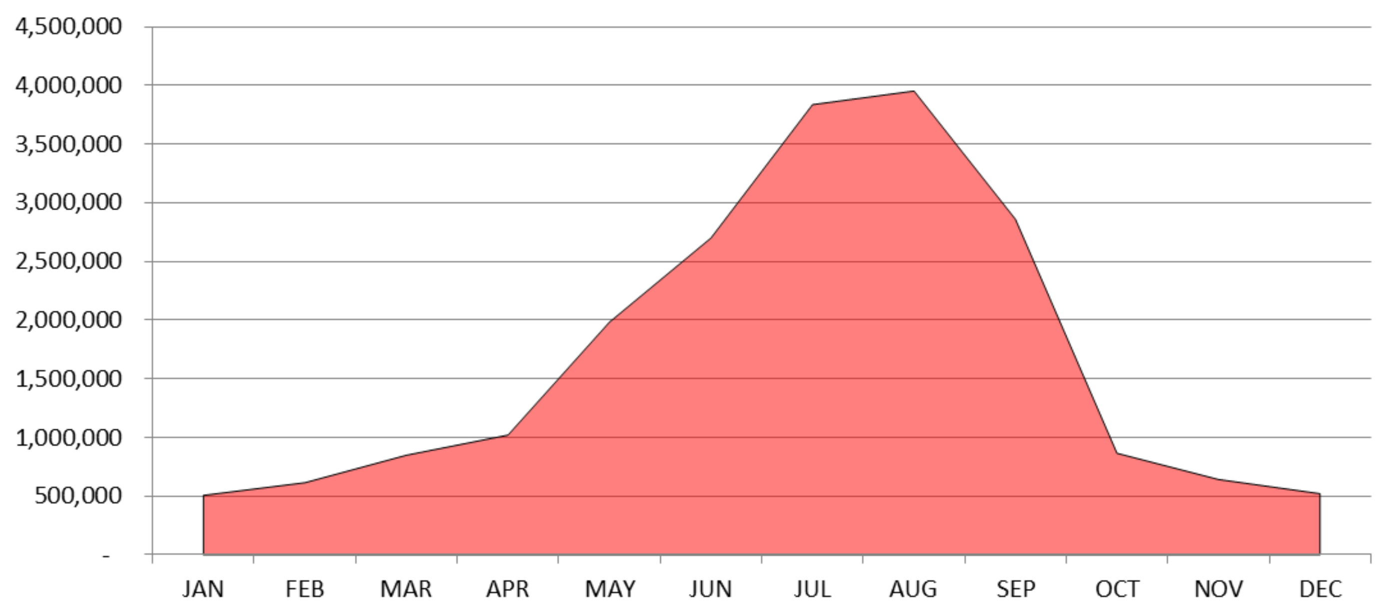


The peak over the summer months (June, July, and August) coincides with higher passenger traffic in summer months. Restroom water usage closely matches passenger traffic within the terminal and can be used to predict water usage in future terminal expansions and construction.

Another large usage of water is from cooling towers. The cooling towers operate when the chillers operate in order to provide the necessary heat rejection for the chillers.

Chart 4-35 indicated monthly water usage for the cooling towers. Cooling tower water makeup is due to four factors: evaporation, drift, spillage, and blowdown. Evaporation of water occurs when water is dropped over "fill" material in order to remove heat of the water. "Drift" is water that spills from towers due to wind blowing against the tower. Spillage is water from leaks and other orther mechanical means. Finally, blowdown is water that is purposefully replaced from a cooling tower to reduce overall contamination and mineral concentration that builds up over time. Of these four factors, blowdown is the largest contributor of water makeup, followed by evaporation. Controlled monitoring of contaminants and concentrations of minerals in the water can allow better control of water quality and less frequent occurrences of blowdown (reducing water makeup requirements).

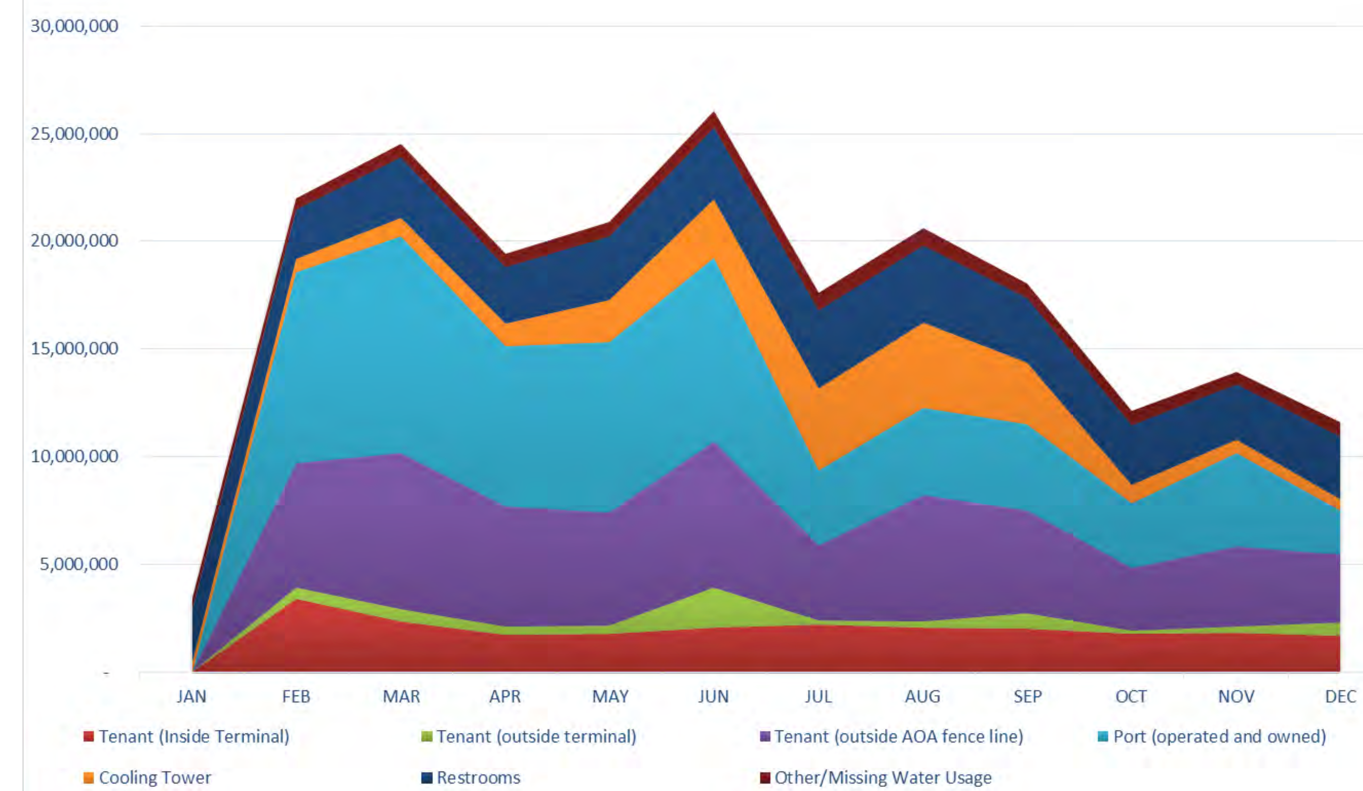
Chart 4-38
Monthly Cooling Tower Water Usage (2013)



As shown in the graph, the cooling tower water usage was greatest between May through October which matches the chiller operation. August was the month with the greatest water requirement.

Chart 4-39 shows water usage on a monthly basis for all water types.

Chart 4-39
Monthly Water Usage by Type (2013)



On an annual basis, Seattle-Tacoma International Airport uses approximately 208,000,000 gallons (278,000 CCF) annually. Chart 4-40 shows the annual usage, in comparison with enplaned passengers. It indicates that since 2007, the enplaned passenger traffic has increased but the usage has dropped. The resulting gallon of water used per enplaned passenger is shown in Chart 4-41.

Chart 4-40
Annual Water Usage (2000-2015)

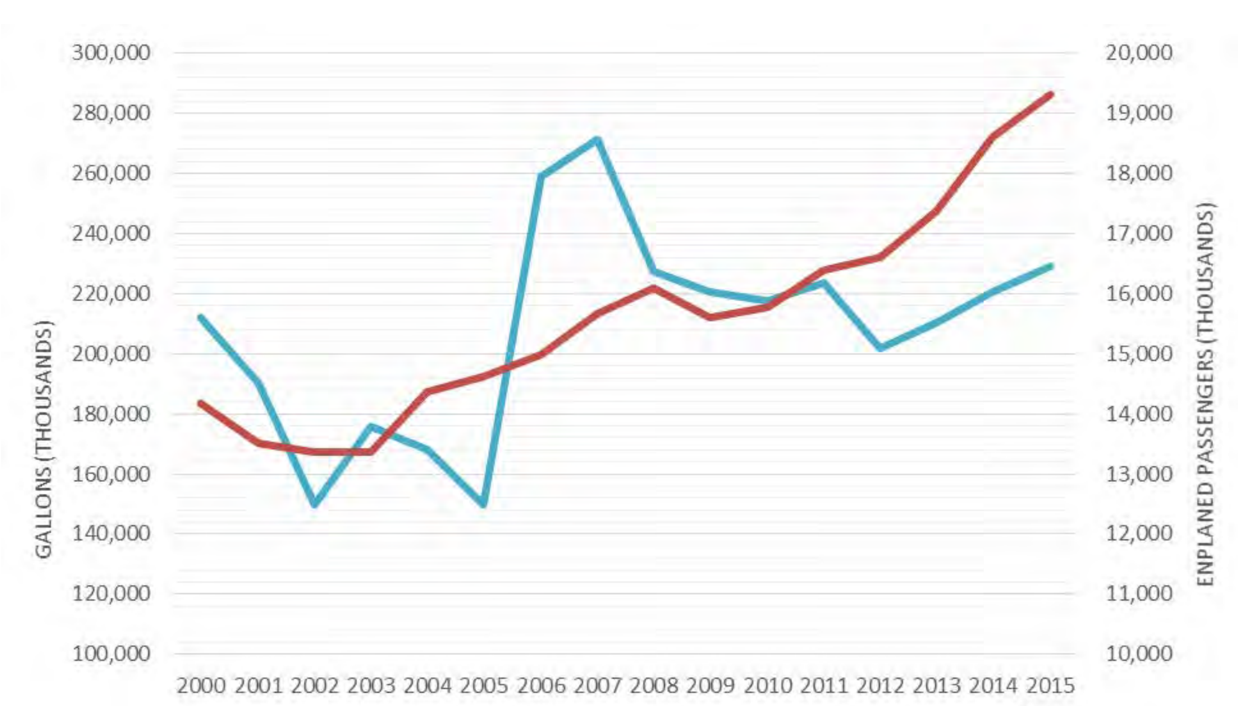
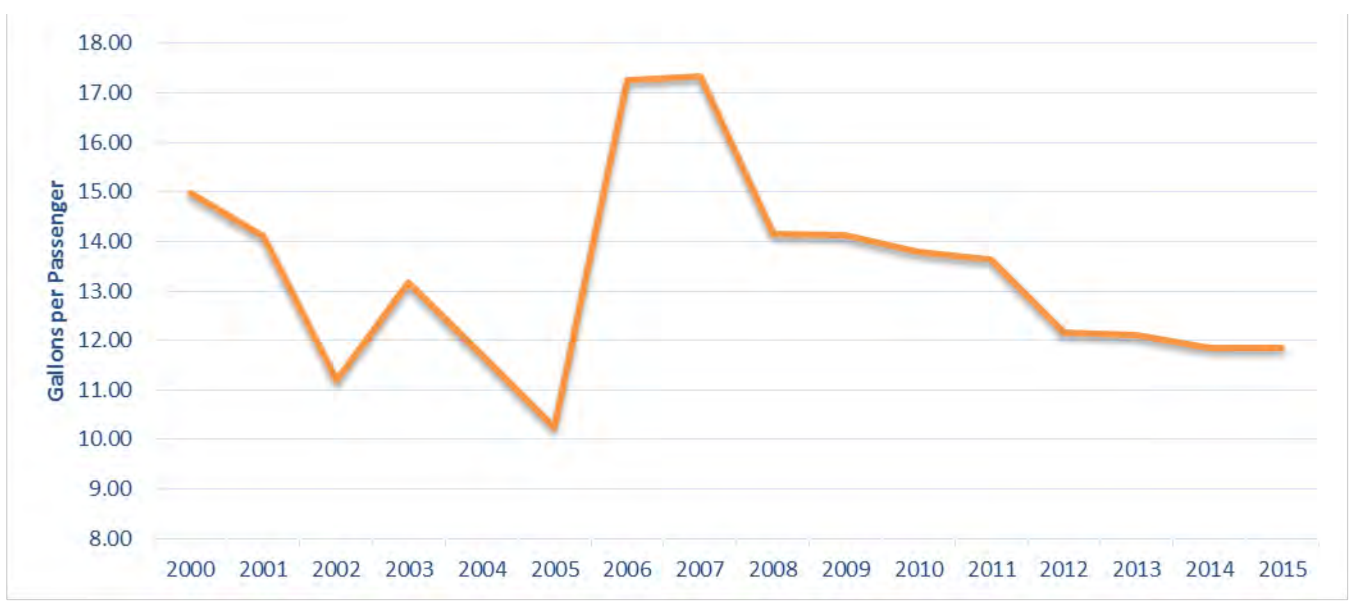


Chart 4-41
Gallons of Water Used per Enplaned Passenger (2000-2015)



3.6.1 Onsite Resources

Reclaimed water, derived from greywater, rainwater, or municipal purple pipe systems are presently not utilized at the Port. It is encouraged to explore these technologies for increased water conservation and diminished operational asset costs.

3.7 Distribution Constraints

Distribution constraints have been discussed briefly for all major energy systems. Constraints come in the form of impedances, barriers, or obstacles of the infrastructure itself, or imposed restrictions either by the authority having jurisdiction, public utility, or the Port of Seattle themselves.

A few examples are limitations of electrical infrastructure in certain areas of the Airport which would impede growth in those areas without significant investment in infrastructure upgrades. Other limitations might include the size of service entering the airport entry point is not adequate for the projected growth. Another are current energy tier structured contracts that may require re-negotiation of a portion or all of the utility based on new projected demand. Finally, the use of a certain fuel, such as biogas (*renewable natural gas*), is currently limited to vehicular use based on contractual terms. Extended use may require new agreements that affect both supply, cost, and environmental impact of the service.

Understanding these constraints needs to be research in the next phases to understand the logistics and costs associated with these barriers. Total cost decisions should reflect any additional costs and impacts (such as operational downtime) that come from upgrading the infrastructure distribution.

4 COST OVERVIEW

In order to forecast future costs of construction, operation, and demolition, it is important to understand current costs associated with the terminal, garage, and cargo facilities. The overall costs for the existing facilities are split into their varied Uniformat Level II assets (refer to Table 3-1) to understand how each of the asset types affect costs. The asset costs were broken down into capital expenses (CAPEX), operating and maintenance expenses (OPEX), renewal costs, and demolition costs. Utility costs were used from the above Section 3.

The terminal was split into unique areas to differentiate the nuances between the different area types. These include ticketing, concourse, satellite terminal, baggage, baggage handling, administration, and STS. From these various building types, area types, asset types, and cost types, a Level II cost matrix was created in order to validate the cost densities by checking the resulting TCO with actual costs.

4.1 Cost Matrix and Cost Comparisons

Refer to Attachment D for full cost matrix. The following sets of graphs depict how each building type (terminal, garage, and cargo) compares in overall Airport TCO. In addition, the graphs depict how much of the TCO is split between CAPEX, OPEX, utility cost, renewal costs, and demolition costs.

This analysis does not consider current age or residual life of the asset. The cost information is based on the asset post construction and assumes all assets are the same age. Renewal costs are therefore assumed to be based on the predicted number of renewal cycles for the different asset types within a building area. For example, furnishings and finishes will renew often. HVAC and other systems will renew approximately mid-lifespan of the building. Concrete superstructure will not require renewal for the life of the building (assuming no catastrophic events).

Chart 4-42
Predicted 50-year TCO per Building Type

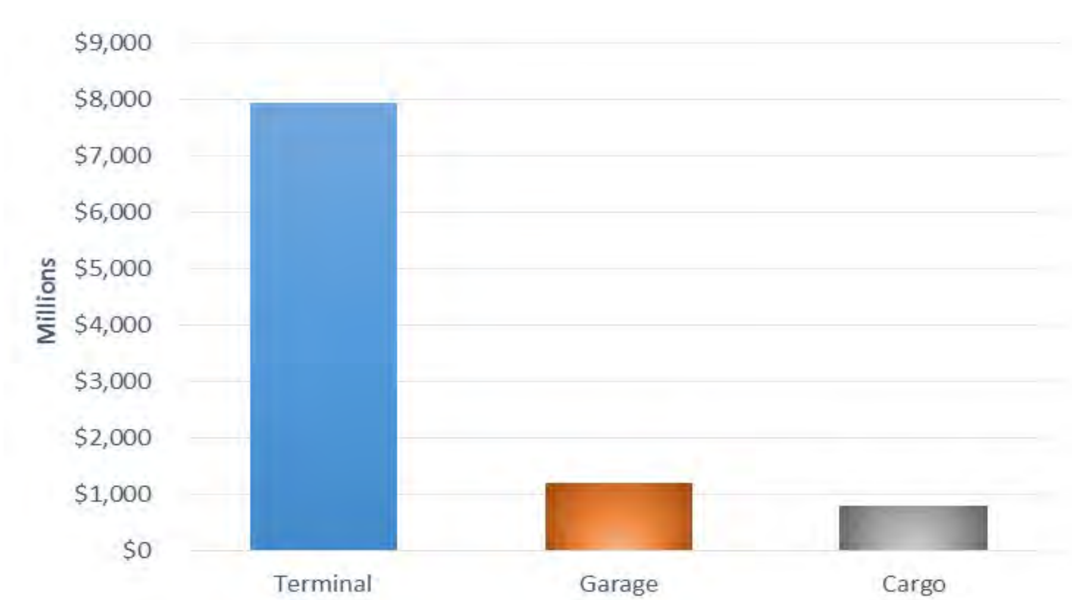
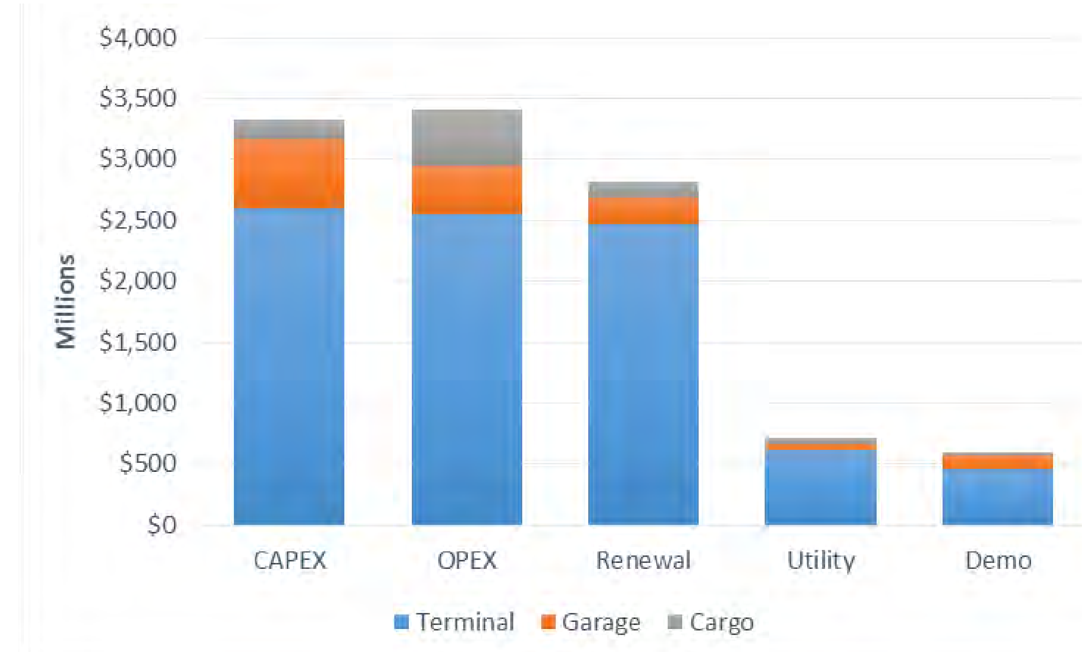


Chart 4-43
Predicted 50-year TCO by Cost Type



Capital costs (CAPEX) include estimated construction cost per square foot for each of the Uniformat Level II assets within each of the building types. In fact, CAPEX and OPEX costs for the terminal vary between each of the type of operation of the terminal: main terminal (ticketing), concourse, baggage, STS, administration offices, and central plant. Operational costs are assumed as an average cost for its life span. A minimum and maximum OPEX (based on percent of average OPEX cost) is used to demonstrate that OPEX costs are lowest when the asset is new and greatest at the end of its service life. For purposes of this analysis, the assumption is that this increase of OPEX cost occurs linearly over the course of its service life.

Renewal costs are analyzed at an asset level. In this comparison, an asset's estimated service life is based on the industry expected service life.

Utility costs include estimated costs for electrical, natural gas, and water. Existing rate structures are used to estimate these costs. Actual costs will vary, as energy and water rates will increase over the span of the study period.

Demolition and disposal costs are estimated as a percentage of the construction cost (without program cost added).

All costs shown do not consider inflation or discounting. Both inflation and discounting will be considered for alternatives in Chapter 6.

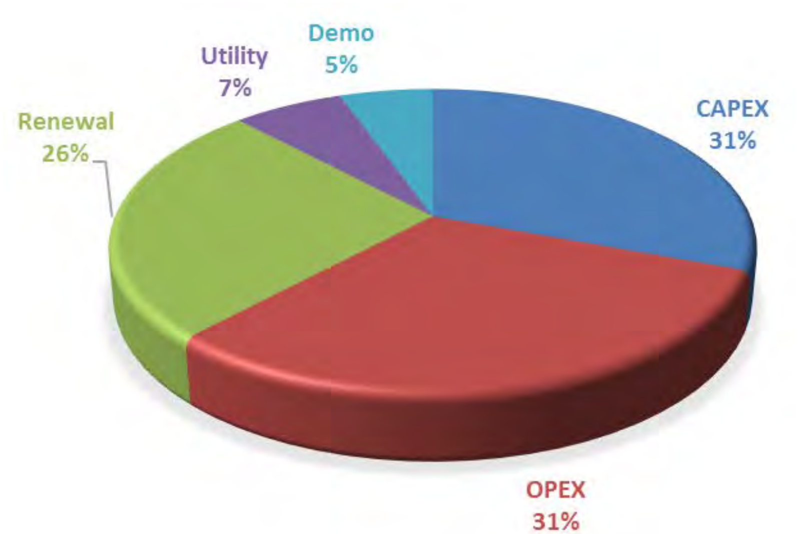
The Terminal costs include all sections of the Main Terminal, satellite terminals, and the central plant. The garage costs includes the five sections of the existing parking garage, excluding the central plant. The cargo is the sum total of all Port-owned cargo buildings, totaling 540,000 square feet. The TCO costs represents the sum total for each building type. Each cost type (CAPEX, OPEX, utilities, RENEX, and demolition) are also compared per building type.

The terminal represents approximately 3.3M square feet of space for this analysis, with a TCO of $7.9B, or $2390/sf. The parking garage represents approximately 5.1M square feet with a TCO of $1.2B, or $233/sf. The cargo areas represent 541K square feet with a TCO of $797M, or $1474/sf.

How much of each cost adds up to become the total cost? The following charts demonstrate how each cost (CAPEX, OPEX, Renewal, utilities, and demolition) impacts the total cost. Although the percentages are different for the different building types, in general, capital cost, operation cost, and renewal cost represent the greatest percentage of the whole.

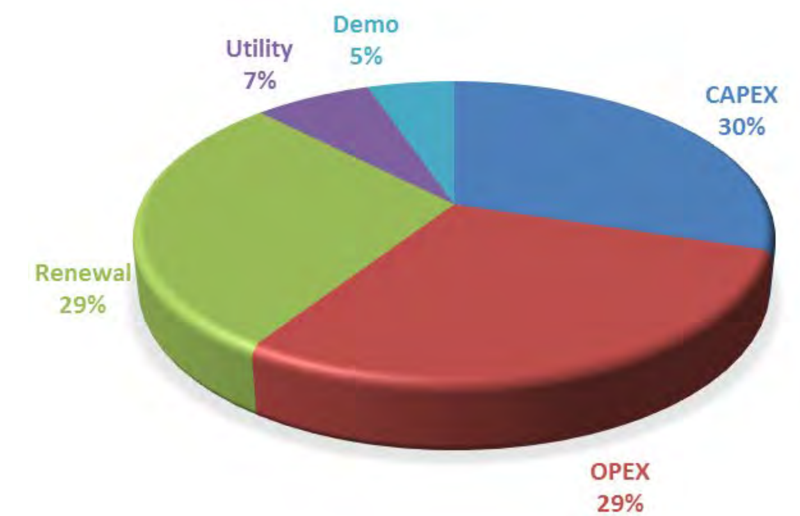
The following represents this breakdown for all building types:

Chart 4-44
Cost Type by Percentage – Terminal, Garage, and Cargo



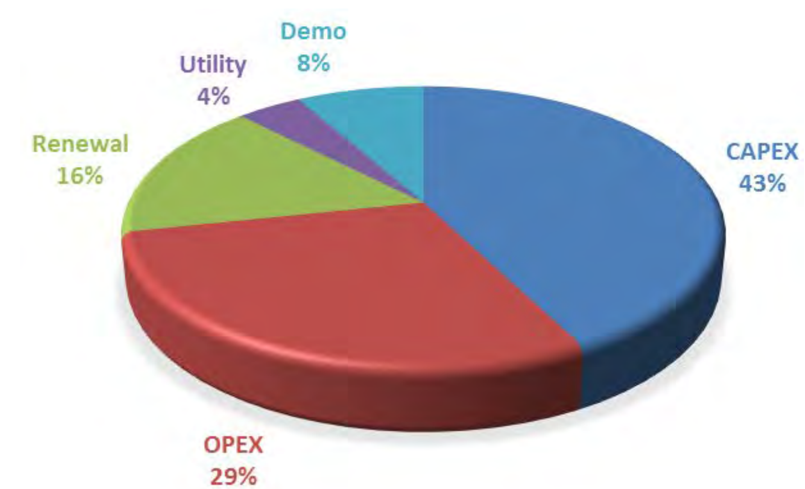
The terminal breakdown is very similar to the overall graph:

Chart 4-45
Cost Type by Percentage – Terminal Only



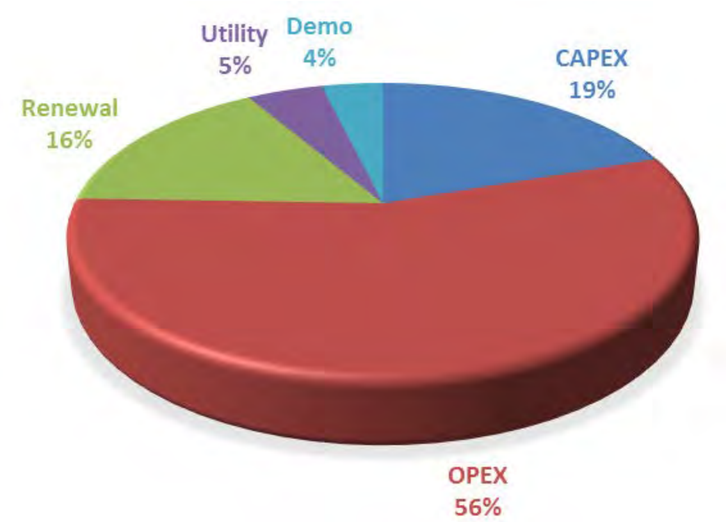
The garage, however, has less operations cost (due to simplicity of systems), and therefore the initial CAPEX is dominant:

Chart 4-46
Cost Type by Percentage – Garage Only



Finally, the cargo facilities have lower first cost, but the ongoing OPEX costs to maintain their facilities are higher:

Chart 4-47
Cost Type by Percentage – Cargo Only



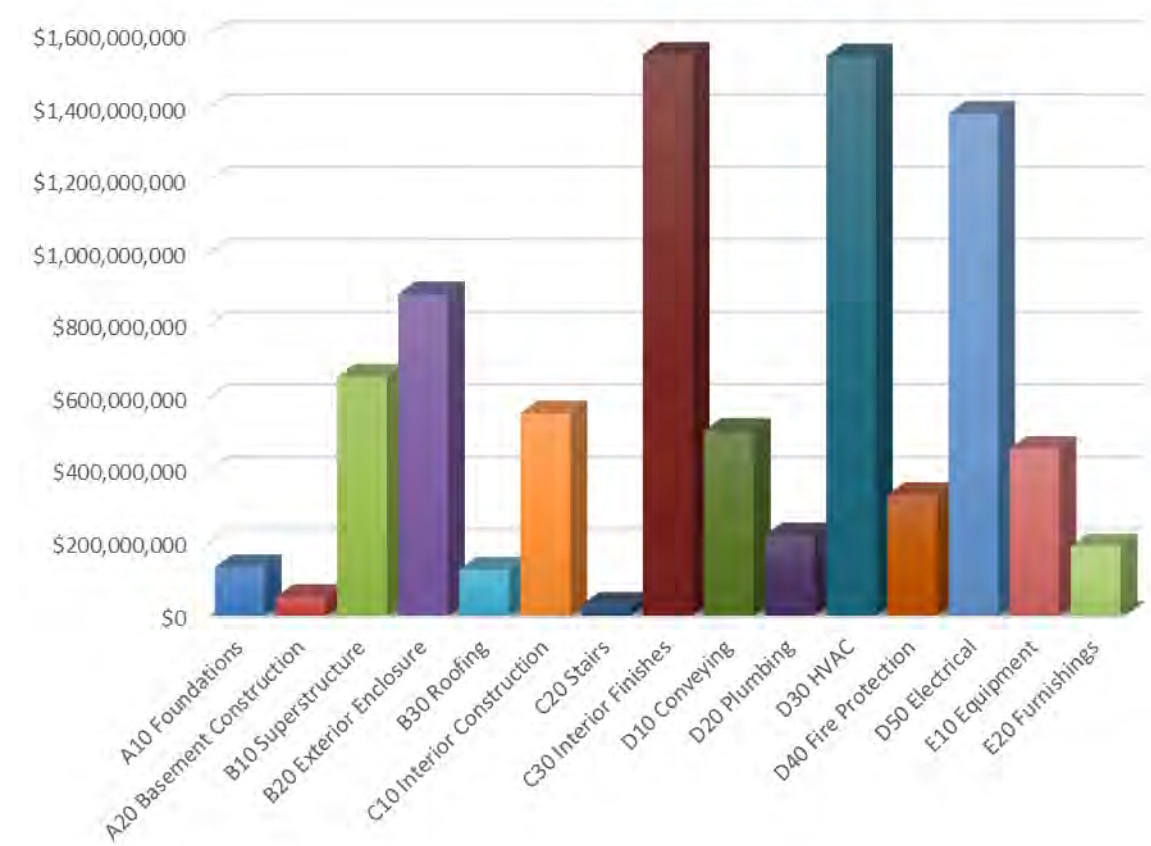
4.2 *Cost Comparison per Asset Type*

Finally, how does each of the assets affect the overall cost of the building? Some assets are more expensive initially (superstructure, for example), but have little-to-no renewal or operational costs. Other assets have a lower initial capital cost (interior finishes or HVAC, for example), but require ongoing renewal costs and operational costs.

Utility costs, program costs, and demolition costs were not considered in these graphics, as those costs are represented by the entire building, and not necessarily associated with a single asset.

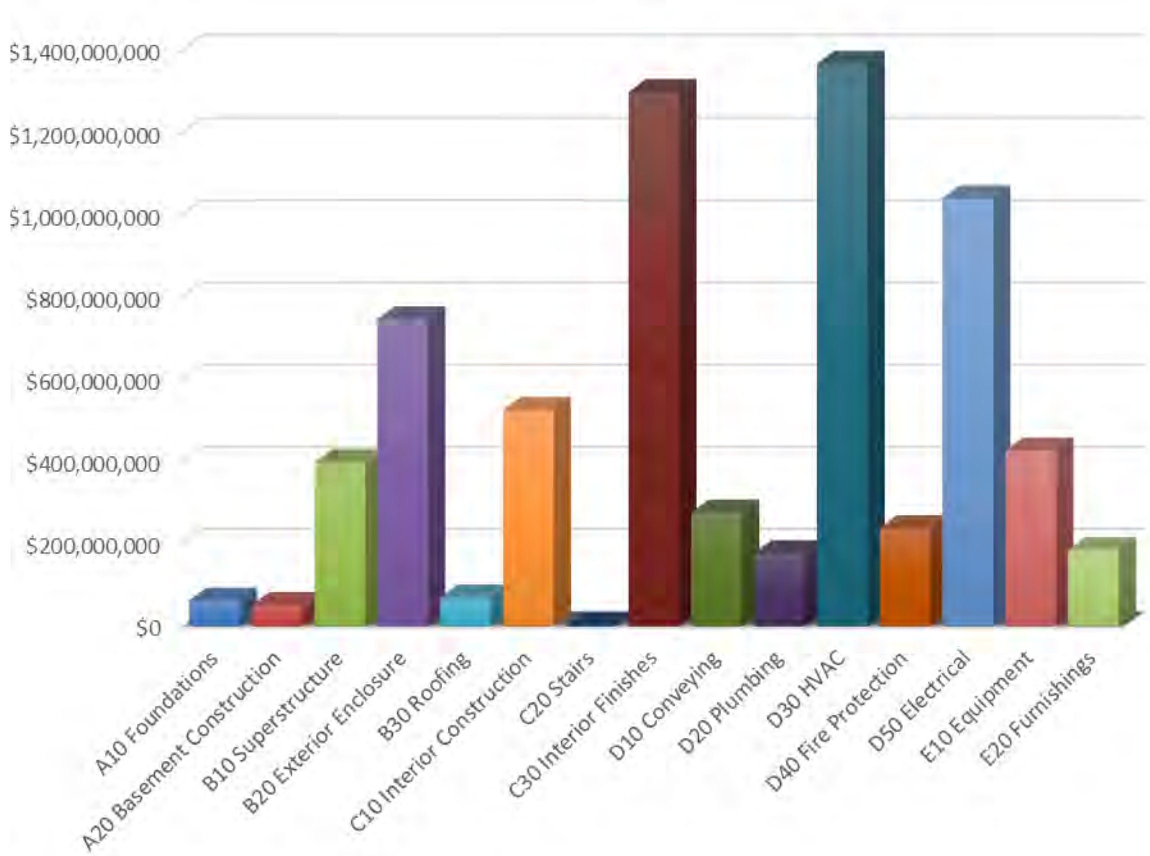
For all building types, the following chart represents how each asset affects the total price:

Chart 4-48
Cost per Asset Type – Terminal, Garage, and Cargo



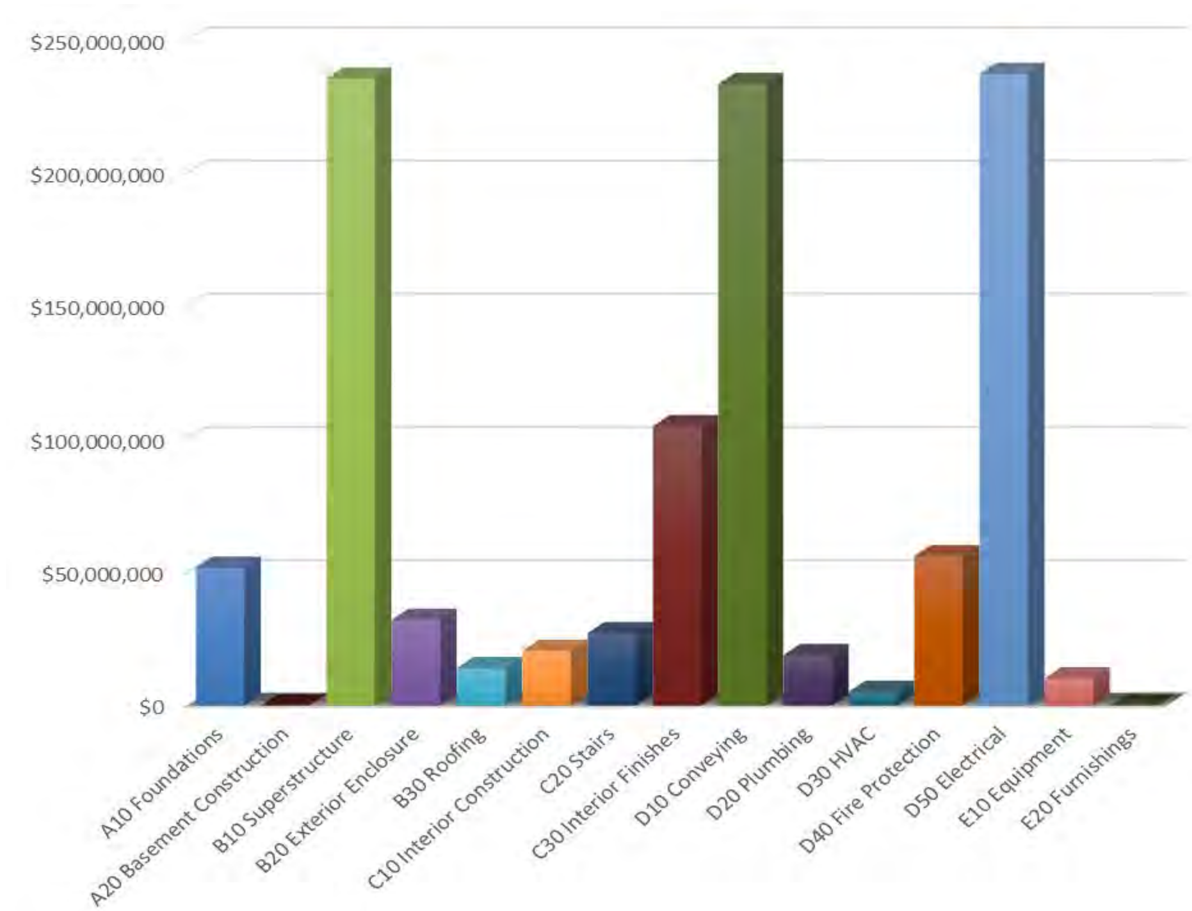
For the terminal, each asset is represented in the following chart:

Chart 4-49
Cost per Asset Type – Terminal Only



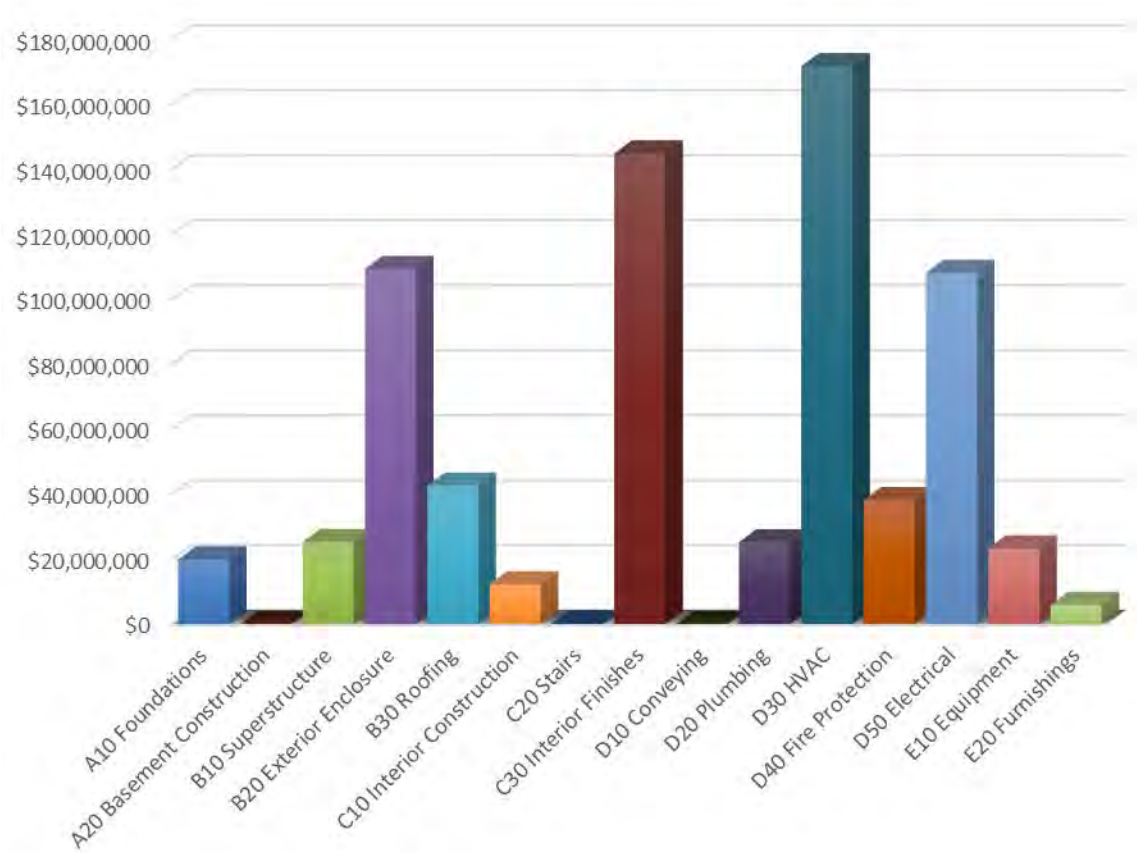
For the garage, each asset's cost impact is represented in the following chart:

Chart 4-50
Cost per Asset Type – Garage Only



Finally, for the cargo buildings, each asset's cost impact is represented in the following chart:

Chart 4-51
Cost per Asset Type – Cargo Only



ANALYSIS OF MASTER PLANNING OPTIONS

Master planning is about setting goals and objectives and then developing optional courses of action to meet those goals. This Section reviews asset management and sustainable building construction options that are considered in this analysis.

1 INTRODUCTION

This task is about understanding the impacts between different alternatives for buildings and infrastructure to determine both the environmental impacts, as well as the Total Cost of Ownership. Buildings and infrastructure represent one of the most significant portions of the overall operations costs for the Airport. Decisions made in order to meet future goals need to consider these costs, especially ongoing costs for operation, maintenance, and utilities. In order to make educated decisions, it is important to look at different scenarios and how the scenarios impact these costs. One of the primary decisions for planning, design, and constructing a building is understanding what level of efficiency should be designed for. A "standard" construction building may have less upfront CAPEX, but cost much more long term due to higher utility costs, OPEX costs, and shorter design life. Comparably, a high efficient building may have a higher first cost, but the reduction in energy and water costs, extended design life, and reduced operations and maintenance costs may result in a lower long term TCO.

2 TARGET LEVELS OF SUSTAINABLE CONSTRUCTION

Defining different target levels of sustainable construction provides the mechanism for which to test these options for new construction and major remodels. Understanding what each level entails helps to define not only the expected levels of efficiency, but the costs required to obtain them. From these definition, simulations can be developed to test each to understand cost and consumption impications.

2.1 Code Minimum

All new construction projects or renovations must comply with the Washington State Energy Code, at a minimum. New building materials for exterior walls, roofs, and glazing must meet certain insulation standards. Building HVAC equipment and water heating equipment have minimal efficiency standards that must be met. The lighting power density (amount of power required for lighting divided by the area) has a set amount that it cannot exceed.

In general, the Washington State Energy Code is similar to the 2010 edition of the ASHRAE 90.1 Standard *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Requirements for building insulation and window construction exceed requirements of ASHRAE 90.1. Water efficiency is based on the Environmental Protection Agency's minimum requirements set forth in EPAct 1992 and EPAct 2005.

In terms for comparison between various levels of sustainability, this level is referred to as "standard construction". It represents the minimum that all new buildings and major renovations must comply with. However, the minimum standard is an upgrade to existing airport materials and system efficiencies. New construction or major renovation (renewal) would result in less energy in comparison with the legacy terminal. Additionally, the new construction would "reset" O&M costs, significantly reducing those, as well.

2.2 LEED Project ("Sustainable Construction")

The United States Green Building Council (USGBC), a non-profit organization founded in 1993 focused on reduced environmental impact, developed the Leadership in Energy and Environmental Design (LEED) Rating System in 2000. Currently on Version 4, the Rating System becomes the template for which to prove how environmentally-minded an occupied building is, from the initial *Certified* rating all the way to the premium *Platinum* rating.

LEED has become the recognized standard for which sustainable buildings are being documented. Local, state, and federal government buildings are typically required to be built to LEED Standard (usually Silver).

LEED splits into sections, based on the focus, from *Energy and Atmosphere* which focuses on reduction of energy, to *Sustainable Sites* which focuses on siting which minimizes impact, to *Water Efficiency* which focuses on the reduction of potable use in a building. Prerequisites define minimum standards that all LEED projects, regardless of certification level, must comply with.

The USGBC works closely with ASHRAE in the development of their rating systems. The Energy prerequisites and subsequent opportunities to obtain credits toward certification are based on ASHRAE 90.1 (currently the 2010 version). ASHRAE has developed the Standard 189.1 to provide additional guidelines and governances for buildings to demonstrate their energy efficiency.

Prerequisite energy efficiency is currently an improvement of 5% better than the ASHRAE 90.1 Standard (3% for a major renovation). Since the Washington State Energy Code is also based on ASHRAE 90.1, with a more stringent envelope insulation and glazing construction material requirement, the energy efficiency levels between the State energy code and LEED Prerequisite are currently very similar. It is assumed that this trend will continue as both codes develop and likely use ASHRAE Standard 90.1 as their basis.

In order to obtain LEED Silver, fifty "points" must be awarded for a project. Of the 110 possible points available for the *BD+C: New Construction and Major Renovation* Rating System, there are a possibility of eighteen points from energy efficiency alone. These points represent between 6% and 50% improvement of ASHRAE 90.1 for new construction and 4& to 48% for major renovation.

Since nearly half of the available points are required to obtain LEED Silver, a significant portion of these should come from energy efficiency. Between 14% and 24% reduction from the ASHRAE standard represents five to ten points.

Since LEED analysis to demonstrate a savings from the ASHRAE benchmark is based on all energy from a building, heavy process loaded buildings (buildings with power and fuel used for equipment other than HVAC, lighting, or water heating, such as office equipment, baggage conveyors, automated people movers, security and scanning equipment, etc.) tend to be much more difficult to demonstrate a reduction of energy than more traditional buildings with less dense process loads. These process loads are used in the analysis for both the baseline comparison case, as well as the proposed efficiency case. If lighting, HVAC, and water heating only represent 50% of the total energy for a building, a 5% reduction of total energy would require a 10% reduction from this equipment. A 24% overall reduction would require a 48% reduction from this equipment. For these reasons, LEED can be more difficult to obtain for high density process equipment buildings.

For water efficiency, LEED Version 4 now looks at all water usage for a building, not just restrooms (as in past Rating Systems). This includes cooking, laundry, and cooling tower uses. Water prerequisites are typical industry water efficiency values. Additionally, plumbing fixtures now require to be certified by the Environmental Protection Agency's WaterSense certification. LEED credit points are awarded for a reduction beyond this standard, from 25% to 50% reduction representing from one to six points.

Although this report discusses the energy and water aspects of LEED, the LEED process has additional benefits beyond just these systems. The LEED program also has social and environmental benefits, in addition to the energy and water reduction benefits stated above.

Finally, it should be determined whether adopting this level of sustainability means that the building will be LEED *certifiable*, meaning that it meets the LEED prerequisite and other requirements of LEED, or whether the project will actually be registered and certified through USGBC. Undergoing the LEED process requires some additional costs and commitment over the cost of efficiency. Program costs, including LEED registration fees, subconsultant fee increases, and full time commissioning agents, represent an increase in CAPEX costs (although minimal in comparison with overall CAPEX costs). In addition, there are commitment requirements – from the designer, contractor, and Port standpoint – that must be followed for a LEED project.

2.3 Net Zero Building

Rising energy prices, reduced dependency on fossil fuel-based energy, and reducing factors that can influence climate change are all reasons that net zero buildings are being built. Conventionally, "net zero" buildings refer to generating the same amount of energy as is consumed, but programs such as Architectural 2030 Challenge and Living Building Challenge also promote net zero water buildings, as well. These are buildings that use most or all of its non-drinking water from harvested sources.

Generally, a net zero energy building (NZEB) is a building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is roughly equal to the amount of renewable energy created on the site. The specifics of what is considered NZEB has many variations and definition, depending on regulatory requirements, political targets, specific climate conditions, indoor conditions, or other factors. The National Renewable Energy Laboratory (NREL) defines a NZEB based on several different criteria. These include:

- *Zero net site energy use* - In this type of NZEB, the amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building. In the United States, "zero net energy building" generally refers to this type of building.

- *Zero net source energy use* - This NZEB generates the same amount of energy as is used, including the energy used to transport the energy to the building. This type accounts for losses during electricity transmission. These ZNEs must generate more electricity than zero net site energy buildings.

- *Net zero energy emissions* - Outside the United States and Canada, a ZEB is generally defined as one with zero net energy emissions, also known as a zero carbon building or zero emissions building. Under this definition the carbon emissions generated from on-site or off-site fossil fuel use are balanced by the amount of on-site renewable energy production. Other definitions include not only the carbon emissions generated by the building in use, but also those generated in the construction of the building and the embodied energy of the structure. Others debate whether the carbon emissions of commuting to and from the building should also be included in the calculation.

- *Net zero cost* - In this type of building, the cost of purchasing energy is balanced by income from sales of electricity to the grid of electricity generated on-site. Such a status depends on how a utility credits net electricity generation and the utility rate structure the building uses.

- *Net off-site zero energy use* - A building may be considered a ZEB if 100% of the energy it purchases comes from renewable energy sources, even if the energy is generated off the site.

- *Off-the-grid* - Off-the-grid buildings are stand-alone ZEBs that are not connected to an off-site energy utility facility. They require distributed renewable energy generation and energy storage capability (for when the sun is not shining, wind is not blowing, etc.).

A NZEB increases overall energy efficiency and decreases consumption as low as possible, and then uses site generation from a renewable source to generate power. Typically, these renewable energy sources would be solar photovoltaic or wind. Other site-generation systems, such as cogeneration, would reduce overall power requirements, but would not be considered applicable renewable site generation.

The Department of Energy has launched several initiatives to help lower the incremental costs of commercial NZEB by 2025, in order to meet the intent of the *Energy Independence and Security Act of 2007*. Launched in August 2008, the DoE developed several public-private partnerships to achieve marketable NZEB by 2025. These collaborations focus on research and development to lower costs associates with technologies required for NZEB, such as renewable energy and emerging efficiency technologies. The National Laboratory Collaborative on Building Technologies (NLCBT) is charged with much of this research. Comprised of the Argonne National Laboratory, Lawrence Berkeley National Laboratory

(LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory, and Pacific Northwest National Laboratory (PNNL), this collaboration develops recommendations for implementing NZEBs. Commercial Building Energy Alliances (CBEAs) and Commercial Building National Accounts (NAs) with the DoE selected twenty-three partner companies and organizations that conduct cost-shared research and development to construct buildings that achieve 50% savings above ASHRAE 90.1-2004 and 30% savings for retrofits. The intent is to test emerging technologies and speed marketability of different energy savings trends.

Today, the New Buildings Institute (NBI) publishes information about zero net energy (ZNE) verified buildings and ZNE "emerging" buildings that are pursuing NZEB status. They maintain a database of known NZEB. There are currently six ZNE Verified and ZNE Emerging buildings over 100,000 square feet in size. The largest two buildings are the Vacaville Transit Center in Vacaville, CA (261, 358 square feet) and NREL's own Research Support Facilities (RSF) in Golden, CO (218,001 square feet). There are four NZEB in Washington state, ranging between 1400 square feet and 52,000 square feet. The largest is the Bullitt Foundation Cascadia Center for Sustainable Design and Construction in Seattle. There are currently no transportation terminals that are ZNE Verified or ZNE Emerging. Since parking garages are considered non-occupied spaces, they are not included in the study.

Since NZEB buildings are somewhat new trend, the NREL published a white paper recommending specific strategies for those pursuing a NZEB (*Cost Control Strategies for ZEB: High-Performance Design and Construction on a Budget*). Several of these strategies have direct applicability to current and future considerations for building a NZEB at the airport. These include:

- The process of developing strategy for a NZEB is required to be a "holistic, comprehensive" approach to control costs.
- Identify items critical to NZEB goals and value engineer those items that are not crucial to these goals.
- Develop a delivery method where the energy targets are as important as other performance requirements for the building. Consider stating the energy goals requirement within the RFP;
- Leverage energy modeling early and often;
- Increased use of passive energy efficiency strategies that better use the capabilities of the building envelope.
- Increase use of innovative HVAC strategies that decouple ventilation from space conditioning and reduce fan energy.
- Increase the use of building monitoring and feedback controls to understand performance. This is critical (occupant interaction with what is occurring at the building) for NZEB. Avoid unnecessary controls and moving components that can drive up costs and require constant calibration.
- Hiring knowledgeable designers and contractors, Inexperienced designers will oversize equipment and therefore increase energy usage. Inexperienced contractors overbid on technology where they have limited experience, driving up CAPEX. Both experienced designers and contractors can also make better decisions on use of materials and design elements that both reduce construction costs, and increase building efficiency.
- Consider simple passive strategies such as building orientation, massing, and layout to minimize thermal loads. Consider window placement for daylight redirection, Consider natural ventilation (especially in mild environment of Seattle). Use solar shading to reduce thermal impacts.
- Consider alternative financing options for high cost systems, such as ESCO, leasing, etc.
- Integrate experienced subcontractors early in design process to incorporate value engineering decision making.
- Maximize use of offsite fabrication (especially where "lay down" areas at an airport are premium space).
- Leverage cost savings from HVAC reduction to invest in other improved efficiency options.
- Consider emerging and unconventional strategies;
- Standardize building construction components (windows, wall sections, etc.) to reduce cost through economies of scale.
- Take advantage of demand-side rebates and supply-side grants and incentive programs (where possible) provided by local utilities to help reduce costs.

So what buildings make sense for Sea-Tac? Buildings with large roof areas and low energy use intensities are the most optimum to implement NZEB. Terminals and concourses have considerable "process" energy from flight equipment, conveyance equipment, and baggage handling equipment that make it difficult to reduce overall energy profile. Savings from the HVAC and lighting would need to offset these process loads.

Cargo warehouses, hangars, and parking garages are the best candidates for NZEB. These facilities tend to both have lower overall energy and have large enough roofs to mount solar photovoltaic panels. The next Section compares solar PV available resource with energy density for the Seattle area. In addition, these facilities tend to have low to no requirement for water. The large roofs can be used to harvest what water they do require.

As technology and research continue, the costs of NZEB will continue to decrease. NZEB have two main factors in their costs: the cost of the energy (or water) efficiency and the cost of the site generation. Currently, the energy and water efficiency cost impacts for a NZEB are similar to those of a LEED Gold or LEED Platinum building. The cost of the renewable energy site generation can be cost prohibitive without grants or incentives (at current performance and panel costs).

2.4 "Business as Usual" (No Expansion Case)

Although not an option considered in the master plan, a fourth consideration analyzed was the "what if" scenario that there was no expansion or renovation to accommodate the passenger traffic increase. In this scenario, existing systems are modeled with the increased number of passengers, door openings, and ventilation. It does not consider overcrowding, passenger frustration, egress or other occupancy code limitations. It does not consider whether existing air handling equipment and distribution can accommodate the increased load requirements. The HVAC systems in this simulation remain the existing efficiency, but allow the energy model to set the required size.

In this case (shown in the next Section), energy cost and consumption will be based on existing equipment efficiencies and the capacities required to properly cool, heat, and ventilate the increased passenger traffic.

This scenario would result in higher OPEX costs (both energy and O&M) and renewal costs than other scenarios. The increase in passengers would result in an equipment being used more often and potentially beyond its operating limitations, increasing the potential for failure and decreasing service life of the asset.

3 COSTS OF SUSTAINABLE CONSTRUCTION

Sustainable construction has historically been thought of as being significantly more expensive than standard construction. In the early days of LEED (LEED 2.1 and LEED 2.2), typical quotes for conventional buildings such as schools or office buildings were LEED Certified buildings had 2% to 5% additional cost on construction and LEED Silver buildings had a premium upward of 5% to 10%. As sustainable construction and LEED become more wide-spread, these costs have decreased and in many building types, LEED buildings can have similar budgets than standard construction buildings.

The General Services Administration (GSA) was one of the first to study the true costs to LEED. Back in 2002, when LEED was in its infancy, they concluded that LEED adds 2.5% to 7% of construction costs (2-2.5% for LEED Silver and 7% for Gold). Later in 2003, the Sustainable Building Task Force (SBTF), which represents forty California state agencies, concluded from an ongoing study that LEED Certified buildings add little to no additional costs, a LEED Silver requires approximately 2% increase, and a LEED Platinum requires 6% increase.

A similar study done by Seattle showed that the average incremental costs to meet LEED Silver for all of their municipal projects was 1.7%.

The BuildingGreen Group developed specific costs in their 2015 paper *The Cost of LEED V4.* These costs are credit by credit and represent various building types and regions. In the case study, the increases for LEED V4 ranged between 0.05% and 0.5% for LEED administration, documentation of credits and prerequisites, energy model, and commissioning.

The costs associated for LEED construction, however, is only part of the issue. At complex, high-energy load facilities, such as an airport terminal, process loads (electrical power for equipment, including train, baggage handling equipment, security and scanning equipment, convenience power for passenger use) must be included in overall calculations to meet energy savings criteria within LEED. A ten-percent reduction to ASHRAE 90.1-2010 for all power usage is a LEED prerequisite. A substantial amount of available credits are associated with improving on that target. Although the same process loads are included in both the baseline calculation and proposed calculation within LEED, higher density process equipment lowers the impact of efficient HVAC and lighting. For example, if the process equipment represents 50% of the total load and the HVAC and lighting represent the other 50%, then a 20% reduction of energy for HVAC and lighting must be obtained *to meet the prerequisite* for LEED V4. For these reasons, HVAC and lighting costs can rise significantly to meet the credit needs for LEED.

3.1 Inflation and Discounting

In order to understand and compare multiple alternatives, it is important to analyze costs in terms of the "time value of money". Money spent in the future does not have the same value as today. Inflation, escalation, and other factors drive up costs.

Typical TCO life cycle costing analysis considers all costs in terms of present day dollars. The analysis then escalates the costs of all future years of occurrence based on the inflation rate. Finally, the analysis discounts these costs back to the original base date in order to determine the net present value (NPV).

TCO can be calculated using either a "constant cost" approach or a "current cost" approach. The constant cost analyses excludes general inflation in its analysis. In contrast, the current cost analysis includes general inflation, discount rates, and energy rate escalation. This approach is recommended for all federally funded projects and is the method used with the alternative analysis to compare various costs.

Since discount rates and inflation rates can significantly impact TCO decisions, it is important to remain consistent across all master planning analysis with these factors.

Inflation rates are based on two sources: the Office of Management and Budget and the *Organization for Economic Co-operation and Development* (OECD) predictor for USA from 2020 to 2060. Based on these sources, 2.04% inflation rate is used for this study.

The discount rate is based on the economic metrics set at the early stages of the master planning effort. For this analysis, discount rates are assumed to be 6.5%.

3.2 Utility Forecasting and Impact to Overall TCO

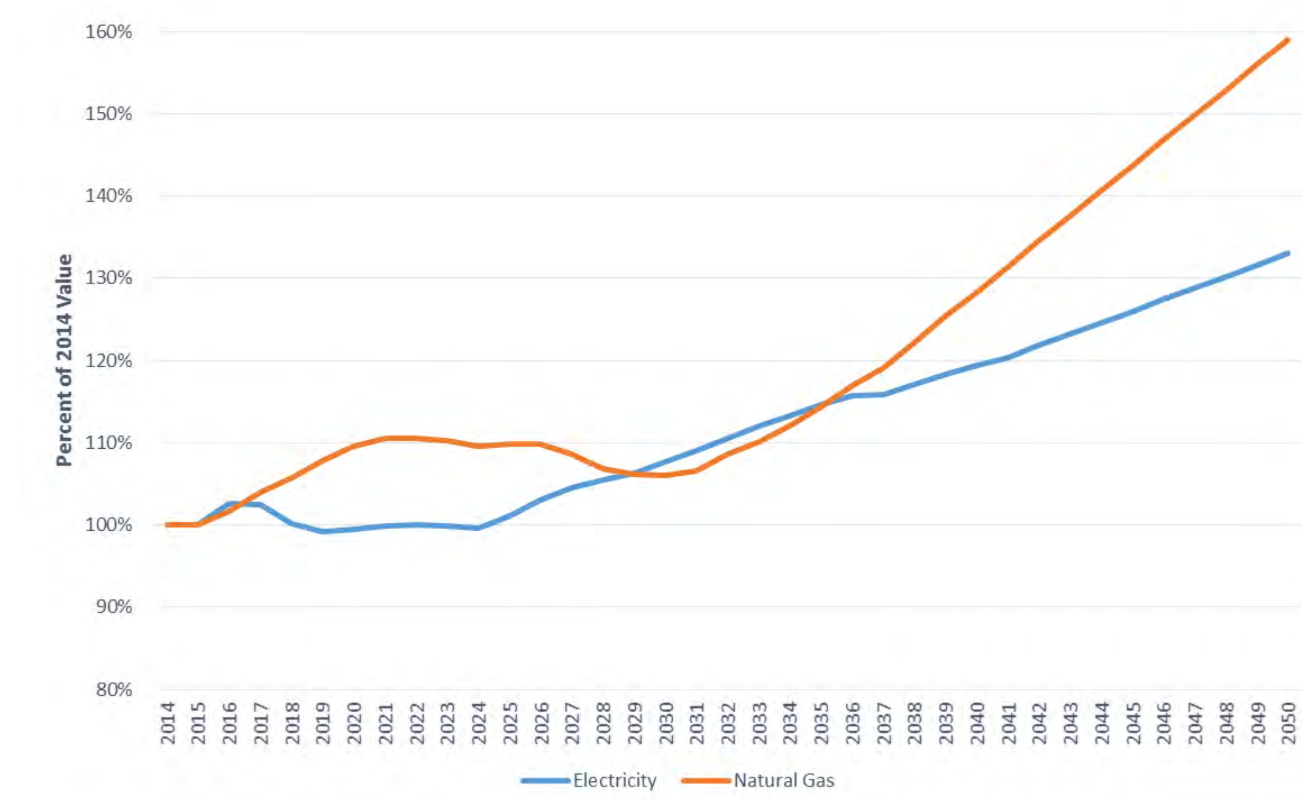
Tier 1 electricity costs, natural gas costs, and water costs at the airport are the basis of the utility cost portion of the OPEX. Based on Chart 4-41, the utility costs represent 7% of all costs for the terminal, garage, and cargo.

For energy utilities, 80% of the energy costs come from electricity usage and 20% costs come from natural gas usage, based on analysis. Even though the electricity is primarily generated by hydropower, the costs of natural gas can still have an impact to the electricity costs. Between 2005 and 2010, natural gas costs rose exponentially, causing significant nation-wide increases to electricity costs, as well. It is important to understand the volatility of the utility rates and how it impacts the overall TCO.

The US Energy Information Administration tracks energy consumption, costs, and rates for all regions, for many sectors, for many business types, and for different energy types. Using their electricity and natural gas pricing forecast for the Pacific Region in Commercial/Transportation market, predictions can be made to the cost of electricity, natural gas, and other fuels. Based on these forecasts, natural gas and electricity remain somewhat consistent for ten years and increases exponentially after that. Since many of the buildings that are being considered as part of the master plan are built after this time, energy costs should be a significant factor in considerations for sustainability. Assuming no other changes, an increase of 40% of energy costs can raise the overall TCO by 3-4%.

The following chart is the basis of costing analysis done for various options. It represents the yearly forecasted energy costs for both electricity and natural gas based on the 2014 cost rates. Although actual market rates can differ, it provides the basis for which future costs can be predicted.

Chart 5-1
EIA Forecast for Electricity and Natural Gas Pricing – Pacific Region – Commercial/Transportation Sectors



3.4 Operation and Maintenance Cost Impacts

In addition to the energy and water cost savings for sustainable buildings, the costs to operate and maintain the building is also affected by the type of building and level of sustainability.

In general, LEED buildings tend to have less ground maintenance requirements, less janitorial requirements, and better waste and recycling accommodations. The use of regional low-maintenance plant life in landscaped areas minimizes the need for ongoing irrigation, pesticide, and herbicides required with more traditional approaches. Use of materials that are easily cleaned and durable reduces janitorial time and extends life of the furnishings.

“Green” buildings have better monitoring and control, allowing the building operators to better diagnose equipment performance and discover potential faulty equipment prior to failure. Once equipment has failed, the system, especially if critical like the HVAC system, will face costly repair costs due to after-hours labor. Discovering potentially failing equipment prior to the ultimate failure will allow the airport to schedule repairs when they are convenient and less costly.

"Green" buildings tend to have emerging technology systems in order to reduce overall energy impacts. These systems can be non-traditional and will require better trained operators and specialty maintenance staff. Some equipment may require specialty technicians, and not traditional mechanical contractors or repair technicians. These technicians may not be local to the Puget Sound area and therefore require additional costs and schedule impacts for travel.

There have been several studies in regards to the impact of green buildings on ongoing operations and maintenance costs. The General Services Administration (GSA) released a white paper in August 2011 called *Green Building Performance: a Post Occupancy Evaluation of 22 GSA Buildings*. In this study, the GSA focused on comparing OPEX for a variety of buildings, both considered "green" and those that were not considered "green". In the study, two buildings from the Puget Sound area were compared with the other buildings. One was a 660,000 square foot Seattle courthouse, built in 2004. The five-hundred occupant building received an EnergyStar score of 85.

The other regional building in the study was a 205,000 square foot office building located in Auburn. The building was originally a warehouse space built in 1944 and renovated to office space in 2006. The LEED Silver facility has 675 fulltime occupants and has an EnergyStar score of 96.

In this study, GSA found that "green" buildings used 25% less energy, 19% lower aggregate OPEX, 36% less CO_2 emissions, and 27% higher occupant satisfaction than their traditional counterparts. The data for maintenance costs were based on IFMA *Facilities Less the 5 Years Old* and BOMA *All Sector Total Buildings Rentable Area* data. Energy costs were based on EnergyStar data. Water use comparisons were based on IFMA *50th Percentile, 2009* data.

In the study, the Auburn facility had the lowest EUI of all twenty-two buildings reviewed. The Seattle facility was well below the national average EUI, according to EnergyStar. Both buildings had EnergyStar scores above 85, making them EnergyStar certifiable buildings.

In the study, the top third performing buildings of the twenty-two had reduced the aggregate maintenance costs by 47% as compared to the national average. Even the middle third buildings that were considered "green" reduced the maintenance costs by 15%.

Costs associated with a campus, such as Sea-Tac, are blended among all buildings. Operations, janitorial, grounds maintenance, maintenance staff, and other employees or outside contractors must be used for ongoing operation of the airport.

3.5 Demolition and Reuse

Sustainable buildings can have considerable impacts to demolition and disposal costs, both as increases and decreases over traditional demolition costs. Existing buildings demolished using sustainable methodology also have different cost considerations than the traditional method.

Sustainable demolition focuses on reduction of waste that will be sent to landfills. The building components will be reused in new construction by the airport, recycled as salvage or sold for reuse by others, or used as a component of another material (such as aggregate). Metals, woods, concrete, and building components such as structure, doors, windows, fixtures, pavers, lighting, etc. are all candidates for reuse.

A 2009 case study completed by Canadian firm Pacific Labour stated that sustainable demolition has a premium of almost 21% over standard demolition, but the additional costs are made up through salvage value of recycled materials or from reduction of capital costs associated with reused materials.

The higher demolition costs are due to the "surgical" nature of removal that must occur. Traditional demolition used a "wrecking ball" approach where all material was disposed of together and sent to landfill. Sustainable demolition is more labor intensive. Individual components are decommissioned and separated. Items that can be reused for future construction must be stored until their use is required. The schedule required for the activity is also longer than traditional demolition and must be taken in consideration for overall construction scheduling.

Especially in the Pacific Northwest, the market to buy and sell salvaged materials is very mature. All types of recycled goods can be sold and therefore the waste to landfill be diverted. Studies in Massachusetts show that reductions of 50% waste diverted are no to low costs and with the value of salvaged materials, 99% reductions can actually be cheaper than traditional disposal (considering value of recycled material).

New green buildings – such as LEED buildings – focus on materials that contain recycled materials or are built from materials that can be recycled in the future. King County has a robust construction and demolition recycling program. They have published guides for diversion of construction and demolition waste that have become the basis of other communities' similar programs. Their *Recycling Economics Worksheet* calculates the cost differences between recycling demolition waste and not recycling the waste. In the commercial hauler example, the cost not to recycle was twenty-three times more expensive ($45K vs. $2K) than to recycle the waste (non-labor costs).

3.6 Environmental/Social Benefits

There are considerable environmental and social benefits for implementation of sustainable construction. From improved passenger comfort, public appreciation, employee well-being, improved community reputation, to reduced impact on the environment, reducing the carbon footprint of the built environment is a big part of overall airport sustainability.

Technical Memorandum 7 discusses specific environmental and social benefits. Refer to this document for additional details and specific information.

4 BUSINESS CASE TIMING FOR REPAIR VS. RENEWAL OF ASSETS

Maintenance costs are a considerable portion of overall OPEX costs. Maintenance provides ongoing operation and performance of an asset. It is generally performed in anticipation of (preventative) or in reaction to (reactive) a failure. Maintenance is performed on a system because all assets and systems deteriorate and fail over time. Maintenance is done to maintain or restore system performance to a specified level or to ensure that the necessary reliability of the system is being met. Reactive maintenance is typically more expensive than preventative maintenance due to potential for downtime, lack of reliability, or impact to operation. Failure to perform maintenance will have effects ranging from minimal to catastrophic. In general, however, whenever assets are not maintained, their dependability will decline.

Preventative maintenance can improve the reliability of a given asset, but requires ongoing OPEX in the form of personnel labor, outside labor, parts, and system downtime. If an asset or system is poorly designed, installed, or not operated correctly, maintenance cannot improve its performance beyond those limitations. Maintenance simply restores an asset to a previous state or prolongs the current condition of the asset. In addition, all assets have a "wear out" period and an expected service life. Although some assets suffer from premature failure due either to environmental conditions, manufacturing defects, improper operation, or other factors, most assets have predictable asset life, based on a given amount of ongoing maintenance. Some assets, such as central plant equipment and HVAC units, are traditionally repaired. Finishes and equipment, which may be difficult to repair, are renewed when they reach failure. Finally, other non-mechanical factors can affect the service life of the asset. For example, technology advances may make the existing asset obsolete. Regulatory requirements may restrict ongoing use of an asset. Programs can change that also require modifications to the building that prevent further use of the asset.

Economic benefits of renewal vs. repair sometimes need to be considered. If the cost of operation and maintenance of an asset is higher than the cost not to operate and maintain the asset, then renewal may be the best option, regardless of the residual life of the asset. There are six factors to contemplate when considering whether to renew an asset before its service life: criticality, vulnerability, efficiency, availability, environmental impact, and cost.

When considering the reliability of an asset, consideration is given to the uncertainty, risk, and consequence of failure. Failure Mode and Effects Analysis (FMEA) can be used to identify these risks and define consequence of the risks for each of the assets. Assets deemed critical to Airport operation should be given highest priority. Those assets with the highest vulnerability to failure or the greatest consequence of failure should have a robust maintenance plan (refer to *Background* Section 3.3).

Availability of parts for an asset is another consideration for maintenance vs. renewal. Assets that have difficult to get parts or require service personnel not located within the region should be considered for renewal. The impact of a lengthened downtime can adverse effects to the operation of not only the Airport, but the tenant airlines and concessionaires.

The last three that are considered are efficiency, environmental impact, and cost. Efficiency has a direct correlation to cost, whereas environmental impact has an indirect one. Assets with low efficiency that require excessive energy or water drive up utility costs. The potential savings in utility costs and reduction in operation and maintenance costs are weighed against the costs of renewal. To optimize overall performance and TCO, these life cycle costs are considered throughout the design life of each asset that uses energy or water.

Assets that have environmental impacts, such as pollution, noise, or others, do not necessarily correlate directly to overall costs, but can require expensive remediation or political considerations if they continue to operate.

In general, however, the largest consideration for establishing the business case timing for renewal vs. ongoing maintenance spending is cost. It is important to understand to understand the service life of an asset and recognize when the asset is in the "wear out" zone. The intent of preventative maintenance is to attempt to service the asset prior to it's entering of the wear out zone. Preventative maintenance would extend the operation and reduce possibility of failure. The problem is determining when the wear out zone is occurring. Providing preventative maintenance prior to the wear out zone tends to be unneeded and does not provide much benefit to the cost spent. Providing maintenance after the asset has worn out and failure is imminent is too late and maintenance spent is costs that could be used for renewal.

Figure 5-1
Preventative Maintenance Strategy

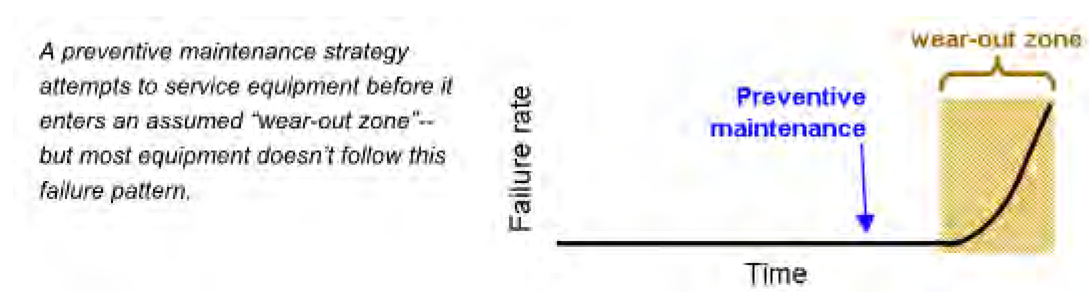
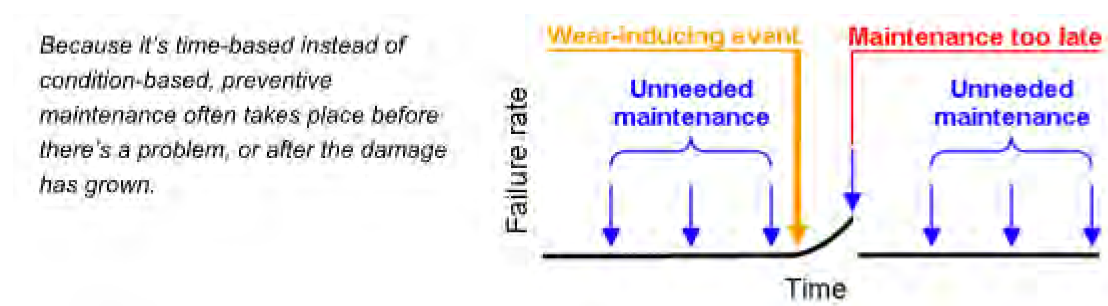


Figure 5-2
Actual Preventative Maintenance



For these reasons, adopting a predictive maintenance or reliability centered maintenance program for the more critical assets is important. It will assist the maintenance staff is understanding and predicting when the wear out zone would occur.

5 ESTABLISH CRITERIA TO DETERMINE LEVEL OF SUSTAINABLE CONSTRUCTION

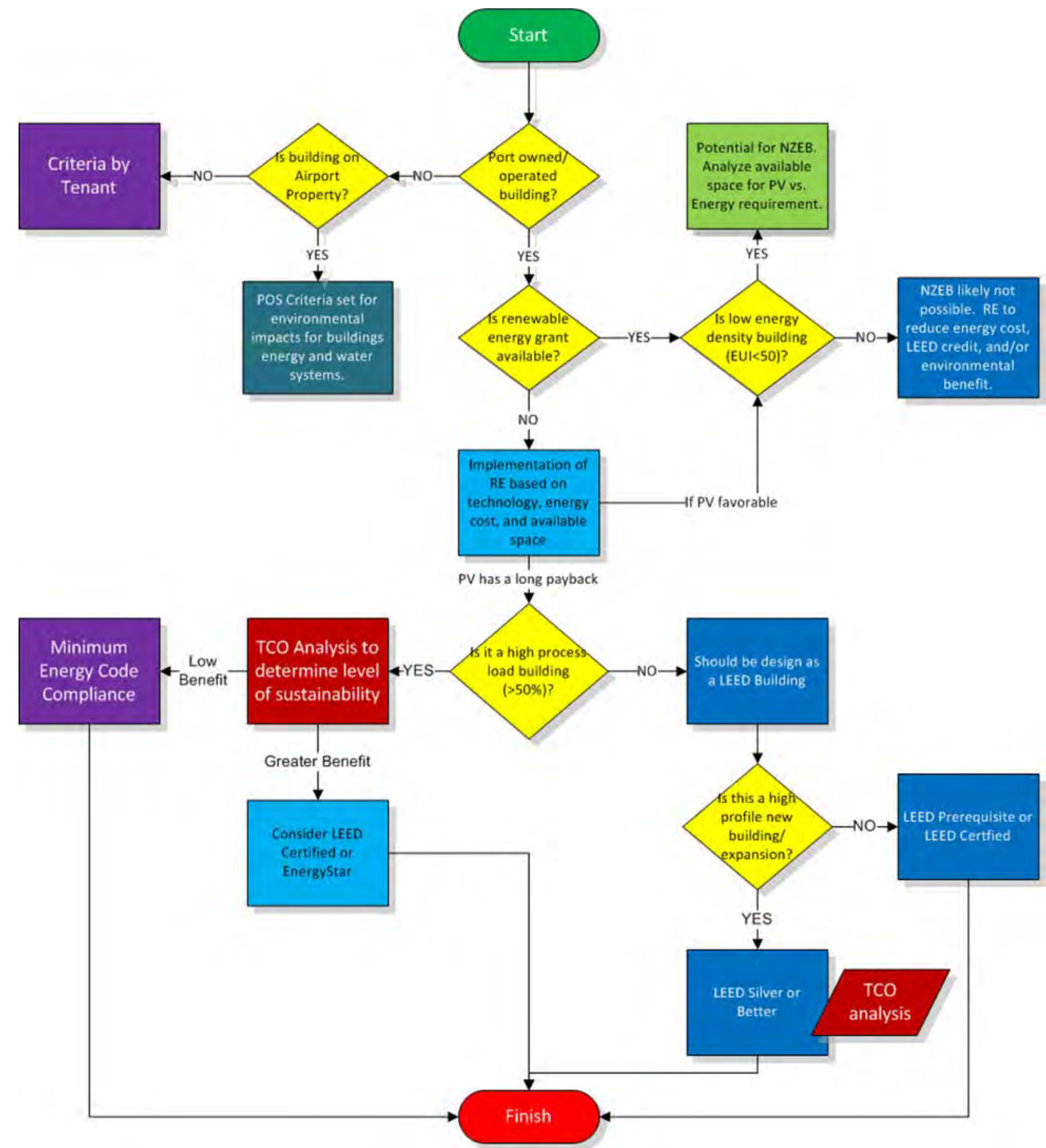
When comparing the various levels of sustainability, the next Section goes into detail about how each component (boilers, chillers, equipment, lighting) is impacted when different efficiencies of equipment and qualities of construction materials (insulating values, for example). The levels compared are minimum energy code compliance, LEED prerequisite/LEED Silver, and net zero buildings.

The LEED prerequisite and minimum energy code requirements are very similar. In some ways, the Washington State Energy Code exceeds ASHRAE 90.1, which is the code the WSEC is based on. Since LEED also uses ASHRAE 90.1 for its analytic, the two programs have similar requirements. LEED requires the 10% improvement over ASHRAE 90.1-2010, whereas the portions of the envelope requirements that exceed ASHRAE 90.1 in the Washington State Energy Code represents a value near that improvement. In addition, the current water efficiency guideline used by the Port of Seattle exceeds the prerequisite requirements for water efficiency within LEED.

For these reasons, many of the spaces within the future Terminal expansion would have similar results for WSEC and LEED Prerequisite. The one building type that may struggle to meet LEED requirements would be high process load buildings. Since all loads (including process loads) must be included in the LEED EAp2 calculations, improving the HVAC, lighting, or water heating enough to provide an overall reduction of 10% may be difficult.

The following flowchart displays the recommendations decisions based on type of building:

Figure 5-3
Building Sustainability Level Flowchart



Based on the analysis, the flowchart provides the recommended level of sustainability for different building types. Buildings not owned or operated by the Port of Seattle would be designed per the tenant's guidelines, assuming that energy and water is separately metered for the facility. Those buildings on the Airport property would require compliance with the Airport general guidance for environmental considerations.

For Port owned and/or operated buildings, the decision whether to plan, design, and build a net zero building comes down to two major issues: the amount spent on renewable energy and the amount of energy used within a facility. Current photovoltaic panel efficiency, amount of solar resource available limit the amount of power to be generated. Only low energy density buildings with larger roof areas have the potential to produce enough energy to compensate for power used annually. Currently, since PV panels have a long payback period, the decision is not favorable from a TCO standpoint unless a grant is available. As the costs of PV panels decrease, the efficiency of the panels increase, and the cost of energy increases, the payback period will decrease, and become a more favorable option. If implementation of renewable energy is favorable – either through grants or improved financial terms – but the building has a higher energy density, a net zero building would likely not be possible (since the amount of PV panels required would exceed the size of the building). Implementing renewable energy systems can be used to pursue LEED certification, especially higher levels such as Gold and Platinum certification.

If implementation of renewable energy is not feasible, the building process energy density will determine what level of LEED certification should be pursued. If the building has a "high process load" (a lot of equipment not related to lighting, HVAC, or service water heating), LEED certification will be difficult. LEED comparisons compare the energy of the proposed building system to a baseline energy amount. Process loads are carried by both models. If a building has a 50% process load, then the energy reduction required to meet the LEED 10% reduction prerequisite would be 20% savings of the energy for lighting, HVAC, or service water heating. If the building has a 75% process load, this increases to a 40% energy reduction, just to meet the prerequisite. For this reason, high process buildings should be determined through TCO analysis to determine how sustainable they should be designed and built. Buildings that benefit from a more sustainable approach (such as LEED or EnergyStar) through significant energy reduction, reduced operation costs, and increased service life, should consider LEED or EnergyStar. Those that don't, should be designed and built to meet the minimum energy code requirements.

If the building process load is less than 50%, then the building should meet LEED prerequisite at a minimum. The existing Terminal is approximately 20-25% process loads, and 30-35% lighting loads, 20-25% heating loads, and the remaining cooling and ventilation loads. If the building is "high profile" (e.g., public accessible space), TCO analysis shall be done to determine if the building should be designed and built to LEED Silver or better.

FORECASTING MASTER PLANNING ALTERNATIVES BASED ON TOTAL COST

This Section compares the total cost and energy usage of two major master planning alternatives: whether to renovate and expand existing terminal, or to build a second terminal.

1 INTRODUCTION

This Section analyzes different alternatives to growth within the overall Master Plan to determine the potential outcome through comparison of capital costs, operating costs, renewal costs, and energy (electricity and natural gas) for the two alternatives presented.

In addition to developing the TCO for a standard efficiency terminal (meeting the minimum requirements of the Washington State Energy Code), this section discusses the impacts to TCO for building sustainable and net zero facilities.

2 ALTERNATIVES

2.1 *One Terminal Alternative*

This alternative assumes that the existing Main Terminal will be enlarged and new concourses will be added to both the north and south of the terminal.

Table 6-1
One Terminal Configuration*

Building	SqFt	Year Online
ARFF Station	23,000	2018
APM Station	32,000	2033
Pier 1 Concourse	78,000	2022
Pier 1 Ramp	47,000	2022
Pier 2 Concourse	100,000	2033
Pier 2 Ramp	60,000	2033
Pier 3 Concourse	104,000	2034
Pier 3 Ramp	62,000	2034
Pedestrian Tunnel	21,000	2032
Connector Concourse	141,000	2032
Connector Ramp	85,000	2032
Ticketing Expansion	150,000	2026
Baggage Level Expansion	110,000	2026
Central Plant	30,000	2022
Garage Reduction	-149,000	2026
TOTAL ADDED AREA	1,043,000	

* Based on One Terminal Phasing Diagrams developed in SAMP.

2.2 *Two Terminal Alternative*

This alternative assumes that a new Terminal will be built to the north of the existing with new concourses associated with the terminal. A new parking garage will be added to accommodate the new Terminal.

Table 6-2
Two Terminal Configuration**

Building	SqFt	Year Online
ARFF Station x2	23,000	2018, 2033
Pier 1 Concourse	78,000	2022
Pier 1 Ramp	47,000	2022
Pier 2 Concourse	100,000	2033
Pier 2 Ramp	60,000	2033
Pier 3 Concourse	104,000	2034
Pier 3 Ramp	62,000	2034
Connector Concourse	141,000	2031
Connector Ramp	85,000	2031
Ticketing Expansion	31,000	2022
Baggage Level Expansion	31,000	2022
New Garage	1,602,000	2031
New Terminal Baggage	165,000	2031
New Terminal Ticketing	130,000	2031
Utility/Support/Sec. Level	130,000	2031
NSAT Pedestrian Tunnel	21,000	2022
Tug and Baggage Tunnel	42,000	2031
Central Plant	30,000	2022
Pedestrian Bridge	19,000	2031
SUBTOTAL ADDED BUILDING	1,217,000	
SUBTOTAL ADDED GARAGE	1,602,000	
ST ADDED BRIDGE/TUNNEL	82,000	
TOTAL ADDED AREA	2,901,000	

** Based on Two Terminal Phasing - Three Pier Diagrams developed in SAMP

Figure 6-1
One Terminal Alternative Final Layout

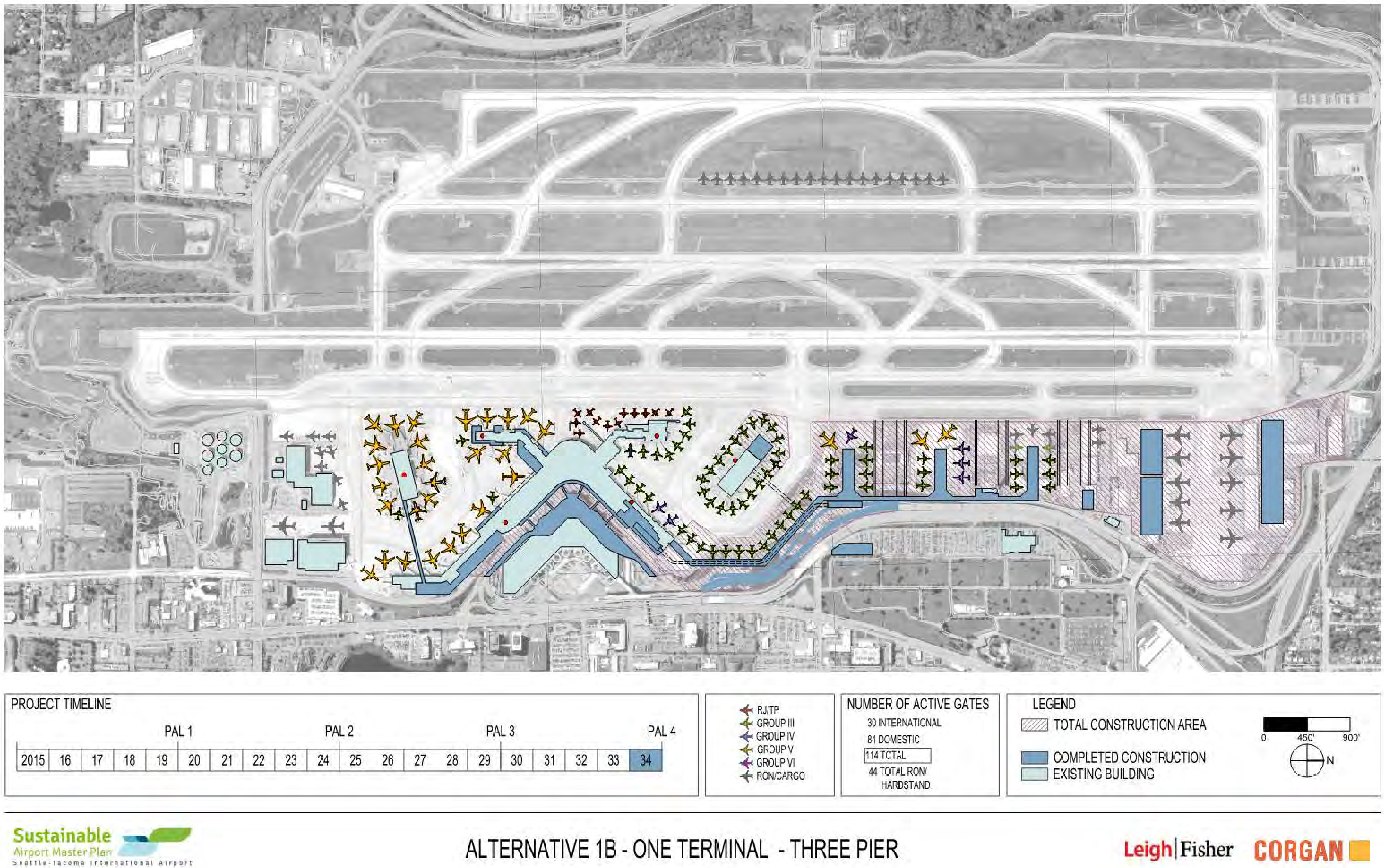
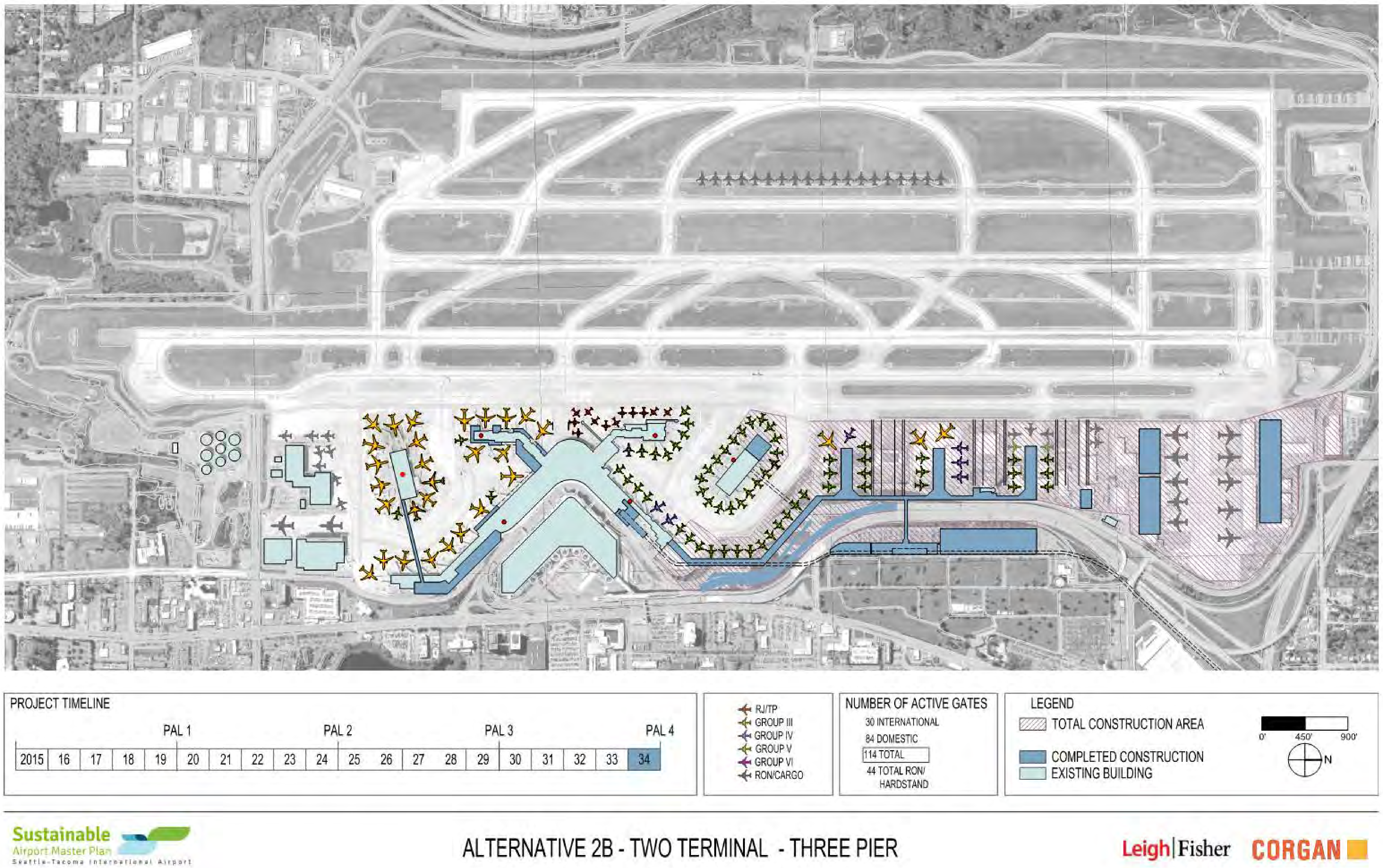


Figure 6-2
Two Terminal Alternative Final Layout



2.3 Assumptions

The following assumptions were made in development of these costs:

- Costs associated with analysis are based on approved asset cost input tracking matrix, approved by Port of Seattle on September 25, 2015.
- Only costs associated with buildings are considered. Site and airside improvements and modifications are not included.
- Due to distance from existing central plant, and prohibitive costs associated with replacing utility corridor mains to the north loop to feed north expansions, both one and two terminals are assumed to require new central plants.
- Energy Use Intensity (EUIs) for electricity and natural gas are based on existing terminals. Future building EUIs are based on predicted code requirements for the facility.
- Assets are considered at Uniformat Level 2. Estimated life before renewal is based on industry standard for standard maintenance. Variations of maintenance spend will affect asset life, but this analysis only is comparing same spend rate for both alternates to compare costs associated with those alternates. Impacts of maintenance spend will be reviewed on the chosen alternative in separate report.
- Energy and OPEX costs associated with unchanged portions of the existing buildings is not reflected in this analysis. This study only considers costs associated specifically with each alternative.

2.4 Methodology

For the operating and renewal costs associated with each alternative, the average OPEX cost is applied from year of occupancy to estimated life end for each of the Uniformat Level 2 assets. The OPEX costs range between the minimum percentage when new to the maximum percentage at end of its service life. This study considers that each asset within an overall building renews at different rate. For example, interior finishes have a much shorter service life than building superstructure. Therefore, renewal costs are applied to interior finishes more frequently than that of the superstructure.

Once the asset has been renewed, the OPEX annual costs associated with the asset reset to its minimum rate.

The timeframe of the overall SAMP analysis is between the years 2015 and 2034. In order to quantify the impact of renewal costs to the overall TCO, the analysis of this report extends to 2050. This is because many of the planned assets are not built until the end of this time period (2034). Many of these assets listed would not reach the end of it service life in that time span (pre-2034), so their renewal costs are not reflected in the total cost for that time period. Renewal costs are a major component of TCO and without these costs reflected, may skew the result in the shorter time span. Therefore, the analysis extends the OPEX and renewal costs until 2050 so that the trends between the two scenarios can be identified, allowing most assets to develop through their service life and require renewal at least once.

Energy costs associated with each alternative are split between electrical and natural gas. This analysis predicts energy usage for the new buildings associated with a new central plant and renovated/expanded buildings with the existing central plant.

Annual and accumulative charts that follow demonstrate costs, both annually and accumulatively for the analysis period.

2.5 Baseline Case Outcome: CAPEX

Dave Nash with C&N Consultants, as part of the master planning team, provided initial estimates for CAPEX for the two alternatives. Table 6-3 provides the CAPEX cost for the different components of the two alternatives. The costs are in 2015 dollars and no escalation has been added to account for when the construction may occur. The cost estimates also include the following:

- Total construction cost and design/estimating contingency of 20%.
- Washington State sales tax @ 9.5%
- Contingency during construction @ 10%
- Project soft costs @ 30%
- Port of Seattle reserve @2%
- CAPEX assumed 5% inflation from 2015 to 2016 and 3.5% per year thereafter

Table 6-3
Capital Costs per Alternative

One Terminal (Option 1B)	CAPEX	Distribution	Future Dollars	Discounted NPV
Remove interior ramps in Level 1	$726,000	0.1%	$1,076,000	$538,000
Remove Pedestrian Bridges from Level 4 and relocate to Level 5	$19,315,000	2.1%	$28,607,000	$14,310,000
New Garage Level 5 entrance and exist lanes and roadway	$21,027,000	2.3%	$31,143,000	$15,578,000
Remove western edge section of Parking Garage Levels 6 to 8	$32,570,000	3.6%	$48,241,000	$24,131,000
Expand Departure Level façade by 25'-0" including removing interior ramps	$54,272,000	6.0%	$80,384,000	$40,209,000
Remodel interior of exist. Terminal Level 1	$60,303,000	6.7%	$89,317,000	$44,677,000
Remodel interior of exist. Terminal Level 2	$66,477,000	7.4%	$98,461,000	$49,251,000
New/Expanded Utility Plant	$85,559,000	9.5%		
System transfer OB/IB baggage between Main Terminal and North Gates	$75,578,000	8.4%	$111,940,000	$55,994,000
Relocate/replace/install elevator cores, escalators, vent stacks as required to move upper drive functions and rental car unto level 5 of garage	$128,067,000	14.2%	$189,683,000	$94,882,000
Expand Ticket and Baggage Claim Levels at Concourse North	$178,907,000	19.8%	$264,985,000	$132,549,000
New North of Terminal Garage for 3,750 Cars	$179,280,000	19.9%	$265,537,000	$132,825,000
- **TOTAL OPTION ONE PROJECT COSTS**	**$902,081,000**	**100.0%**	**$1,234,390,000**	**$617,457,000**

Two Terminal (Option 2B)	CAPEX	Distribution	Future Dollars	Discounted NPV
Baggage System & Tunnel Between North Terminal & Airside Corridor	$7,936,000	1.1%	$13,961,000	$5,086,000
Pedestrian Bridge Between North Terminal and Airside Concourse	$51,842,000	7.4%	$91,196,000	$33,224,000
New Utility Plant For North Terminal	$85,559,000	12.3%		
New North Terminal Garage for 5,000 Cars	$213,068,000	30.6%	$374,812,000	$136,551,000
New North Terminal	$281,160,000	40.4%	$494,594,000	$180,189,000
Ticket & Baggage Expansion at North End of Existing Terminal Building	$56,337,000	8.1%	$72,715,000	$46,793,000
TOTAL OPTION TWO CONSTRUCTION COSTS	**$695,902,000**	**100.0%**	**$1,047,278,000**	**$401,843,000**

2.6 Baseline Case Outcome: OPEX, Renewal, and Total Costs

For other costs (OPEX, utility, and renewal costs), Table 6-4 provides a summary for both alternatives. Utility costs include escalation (based on the US Energy Information Administration for the Pacific Region in Commercial/Transportation market). Operating costs and utility costs are predicted based on the expected date of finished construction for each of the proposed assets. For example, if the Pier 1 concourse is not built in the *One Terminal* alternative until 2022, the OPEX costs and utility costs associated with the Pier 1 concourse occur on and after that date. Prior to that date, no OPEX or utility cost is estimated for this asset. Likewise, renewal costs are based on the date the asset is planned to be constructed. Using the expected lifespan of the asset, renewal costs are implemented when the asset renewal period is expected. Short life assets, like finishes, will renew often in the simulation, whereas long-term assets (like the building superstructure) may not renew at all within the study period.

Since many of the new buildings are built toward the end of the study period for the SAMP (2034), the analysis for these costs was simulated in two ways. The first method included all costs within the study period between 2015 and 2034. In this method, very little renewal will occur during this timespan. The second method was to extend the study period out to 2050. Most renewable assets go through at least one life cycle with this extended study period. Costs listed are shown for both cases.

Table 6-4
Operations Costs, Renewal Costs, and Energy Costs Per Alternative

Alternative	2015-2034 OPEX and Renewal Cost (Present Value)	2015-2050 OPEX and Renewal Cost (Present Value)	2015-2034 OPEX and Renewal Cost (w/Inflation*)	2015-2050 OPEX and Renewal Cost (w/Inflation*)
One Terminal Option	$80,316,000	$464,547,000	$109,083,000	$798,362,000
Two Terminal Option	$83,934,000	$532,282,000	$114,880,000	$920,846,000
Percent Difference	*4.31%*	*12.73%*	*5.05%*	*13.30%*

Alternative	2015-2034 Energy Cost (Present Value)	2015-2050 Energy Cost (Present Value)	2015-2034 Energy Cost (w/Escalation**)	2015-2050 Energy Cost (w/Escalation**)
One Terminal Option	$6,908,000	$25,364,000	$7,468,000	$30,680,000
Two Terminal Option	$7,463,000	$30,594,000	$8,112,000	$37,106,000
Percent Difference	*7.44%*	*17.09%*	*7.94%*	*17.32%*

Alternative	2015-2034 Total Energy, OPEX, and Renewal Cost (Present Value)	2015-2050 Total Energy, OPEX, and Renewal Cost (Present Value)	2015-2034 Total Energy, OPEX, and Renewal Cost (w/inflation and escalation)	2015-2050 Total Energy, OPEX, and Renewal Cost (w/inflation and escalation)
One Terminal Option	$87,224,000	$489,911,000	$116,551,000	$829,042,000
Two Terminal Option	$91,397,000	$562,876,000	$122,992,000	$957,952,000
Percent Difference	*4.57%*	*12.96%*	*5.24%*	*13.46%*

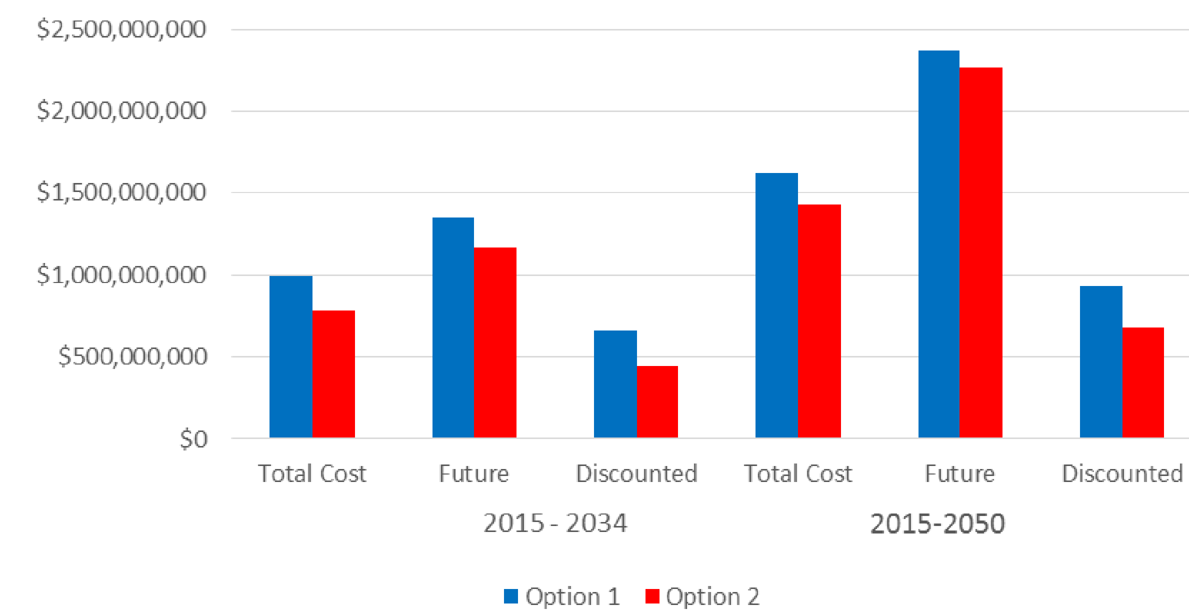
* Based on *Organization for Economic Co-operation and Development* (OECD) predictor for USA from 2020 to 2060.

** Based on *US Energy Information Administration* forecast for electricity and natural gas pricing for the Pacific Region in Commercial/Transportation market.

Overall, the difference in OPEX, renewal, and energy costs is minor accounting for the difference of area involved with the two alternatives (1,043,000 sq. ft. for One Terminal and 2,901,000 sq. f.t for Two Terminal). This difference in area represents a 2.8:1 ratio difference between Two Terminals and One Terminal, whereas the OPEX, renewal, and energy costs represent a 1.130 to 1.135:1 ratio between Two Terminals and One Terminal (using 2015 to 2050 span). For total costs, the *One Terminal* alternative is 1.26:1 of the *Two Terminal* alternative using the 2015 to 2034 span and 1.13:1 using the 2015 to 2050 span. In net present value (NPV) terms, this results in a 1.48:1 ratio between One Terminal and Two Terminals (for 2015 to 2034) and 1.36:1 (for 2015 to 2050).

Refer to Chart 6-1 for total costs in present day, future, and net present value terms.

Chart 6-1
Total Costs per Alternative (including future and NPV costs)



The left three groups represent the TCO between 2015 and 2034. The right three groups represent TCO between 2015 and 2050. Neither group includes demolition costs or considers residual value at end of life, because it is assumed that the terminal(s) will remain in operation in 2050. The first of the group's columns in the TCO in present value. The middle of group's columns is the TCO in future dollars, assuming inflation and utility rate escalation. The last of the group's columns is the discounted net present value. These costs do not reflect CAPEX, OPEX, renewal, or energy costs for the existing Terminals, garage, cargo, or planned NorthSTAR and IAF facilities.

Since water usage is directly associated with number of passengers vs. efficiencies of fixtures, the amount of potable water used is directly related to passenger traffic.

Charts 6-2 through Chart 6-4 show the annual and accumulative costs during the study periods. Chart 6-5 through Chart 6-7 show the predicted energy cost, with and without utility rate escalation. Increases in costs within all of these charts are based when each alternative's assets are being built. The cost associated with the asset built within a given year is based on the cost matrix established within this project. Chart 6-8 shows water usage within the 2015 to 2034 study period.

Chart 6-2
Annual OPEX and Renewal Costs for One vs. Two Terminals

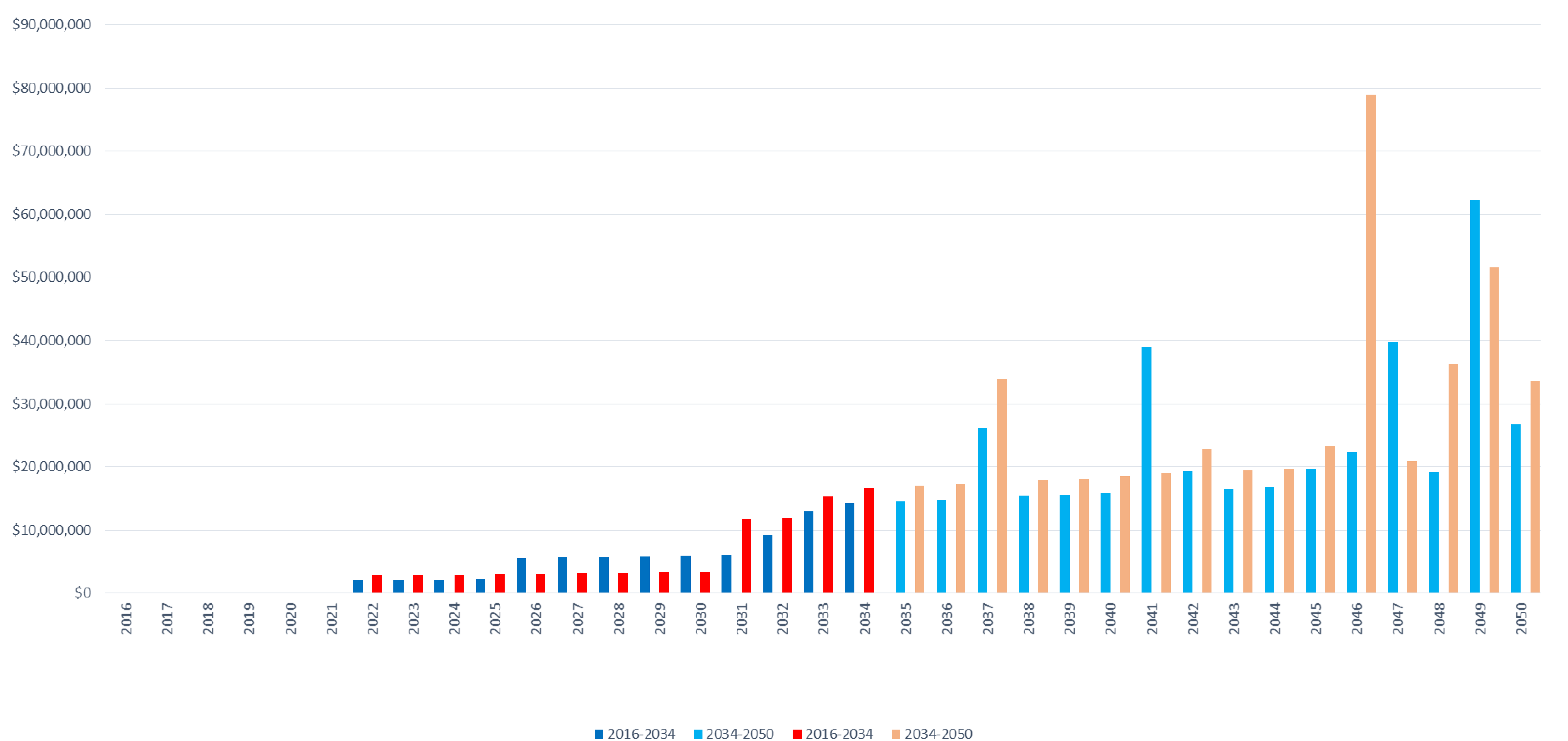


Chart 6-3
Accumulative OPEX and Renewal Costs for One vs. Two Terminals

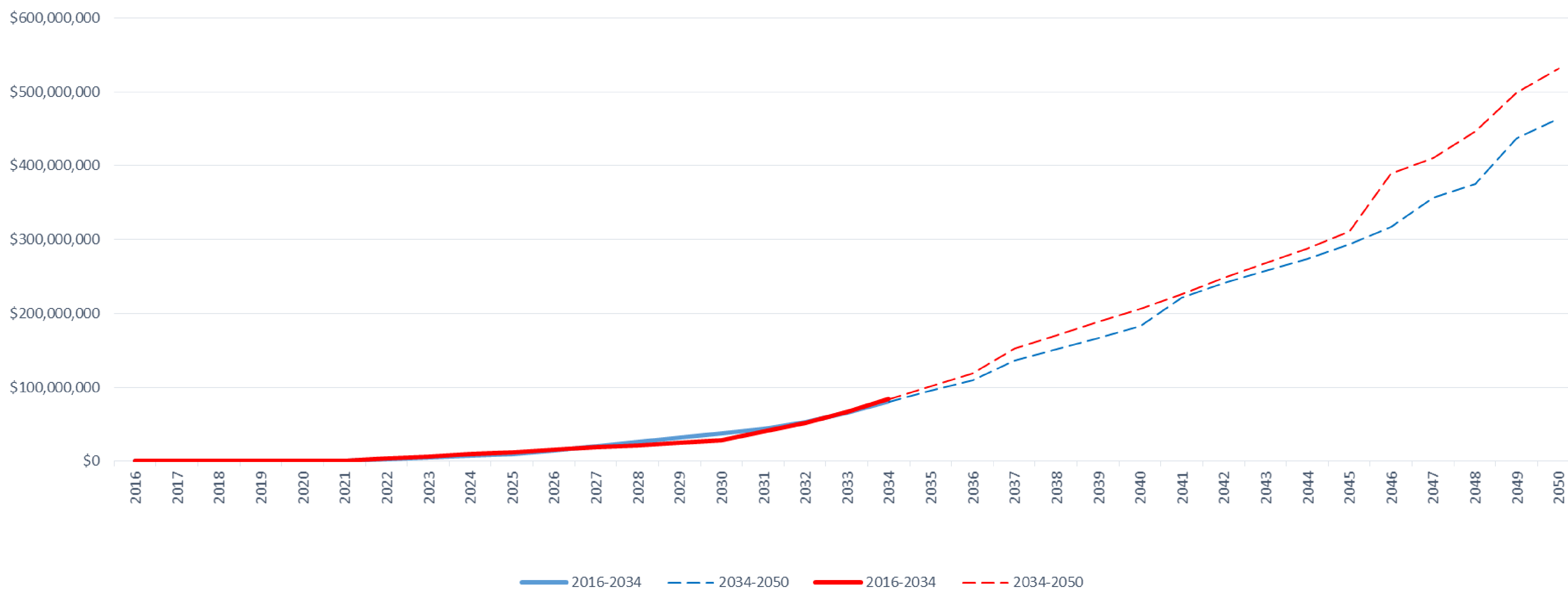


Chart 6-4
Accumulative Inflation-Adjusted OPEX and Renewal Costs for One vs. Two Terminals

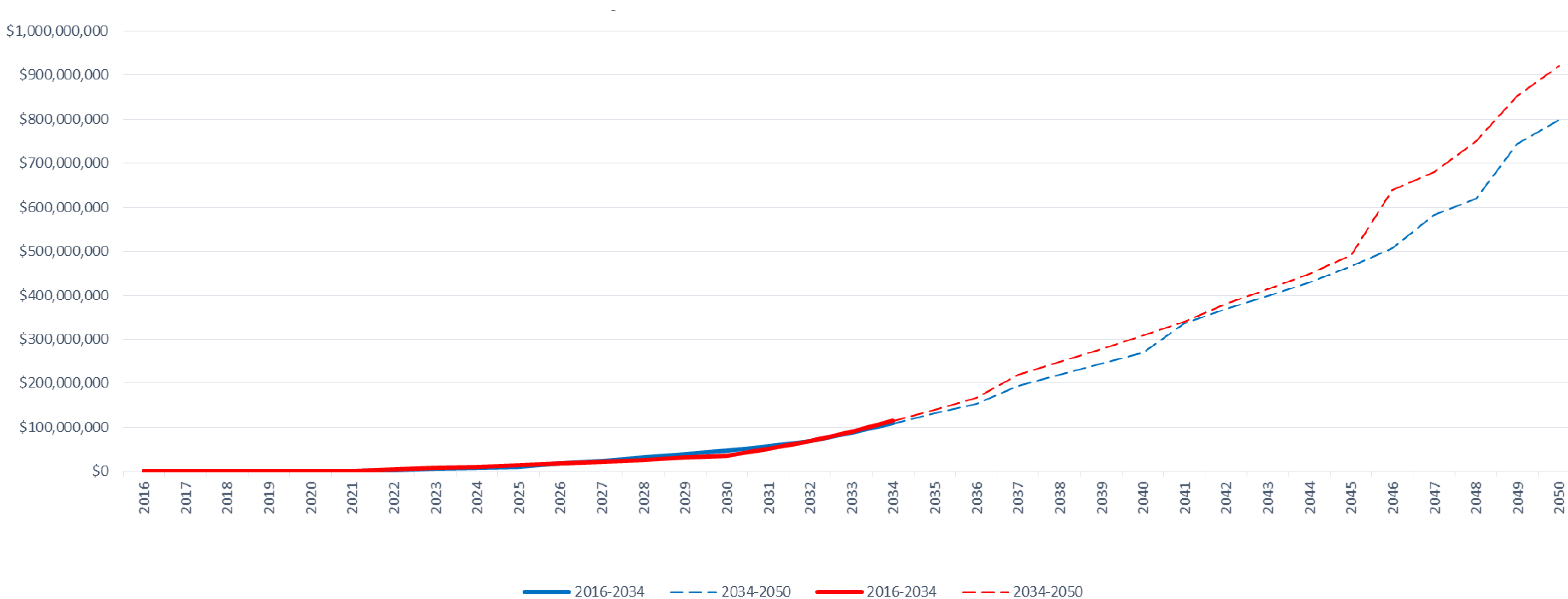


Chart 6-5
Annual Electrical Costs for One vs. Two Terminals (Adjusted based on EIA forecasted cost escalation of electricity)

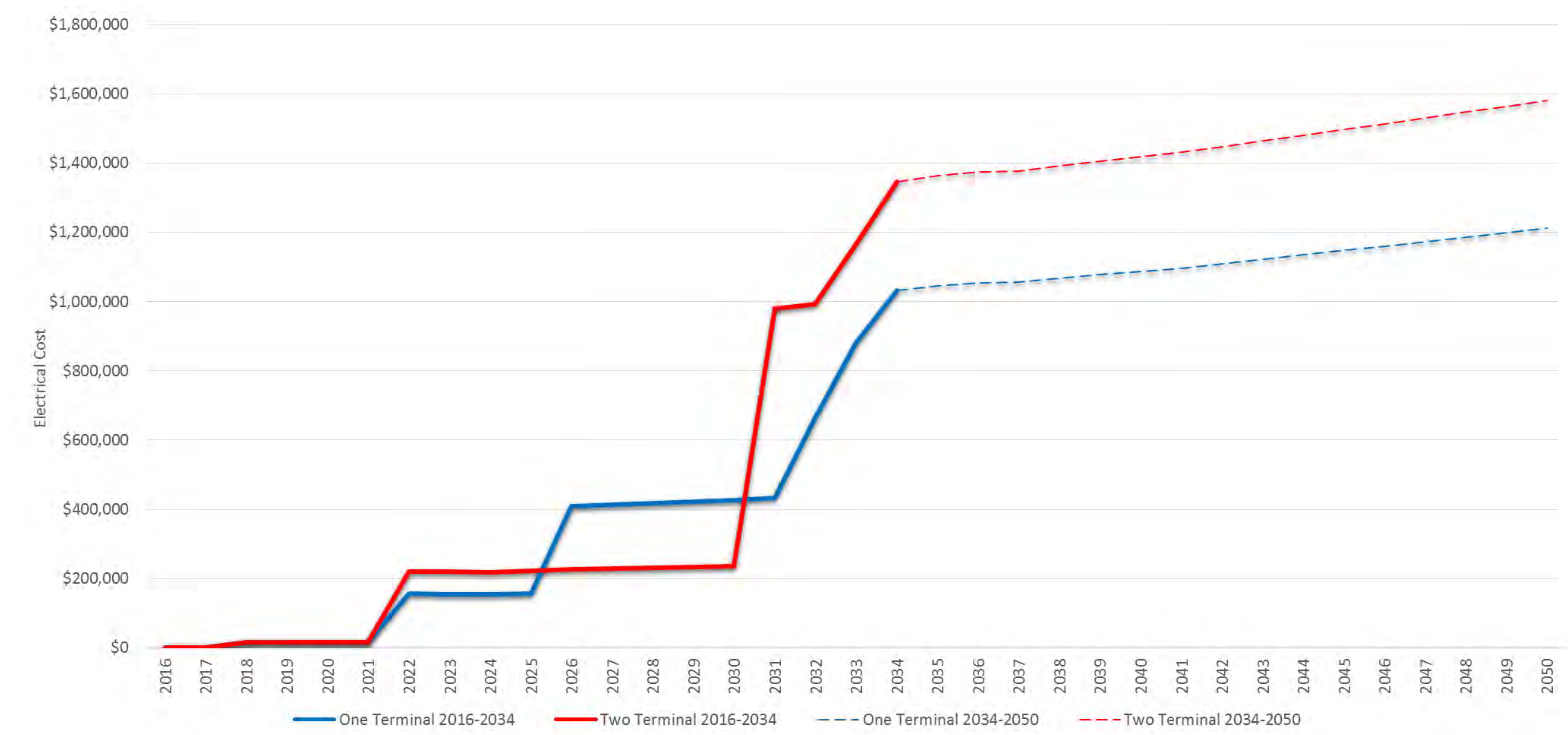


Chart 6-6
Annual Natural Gas Costs for One vs. Two Terminals (Adjusted based on EIA forecasted cost escalation of Natural Gas)

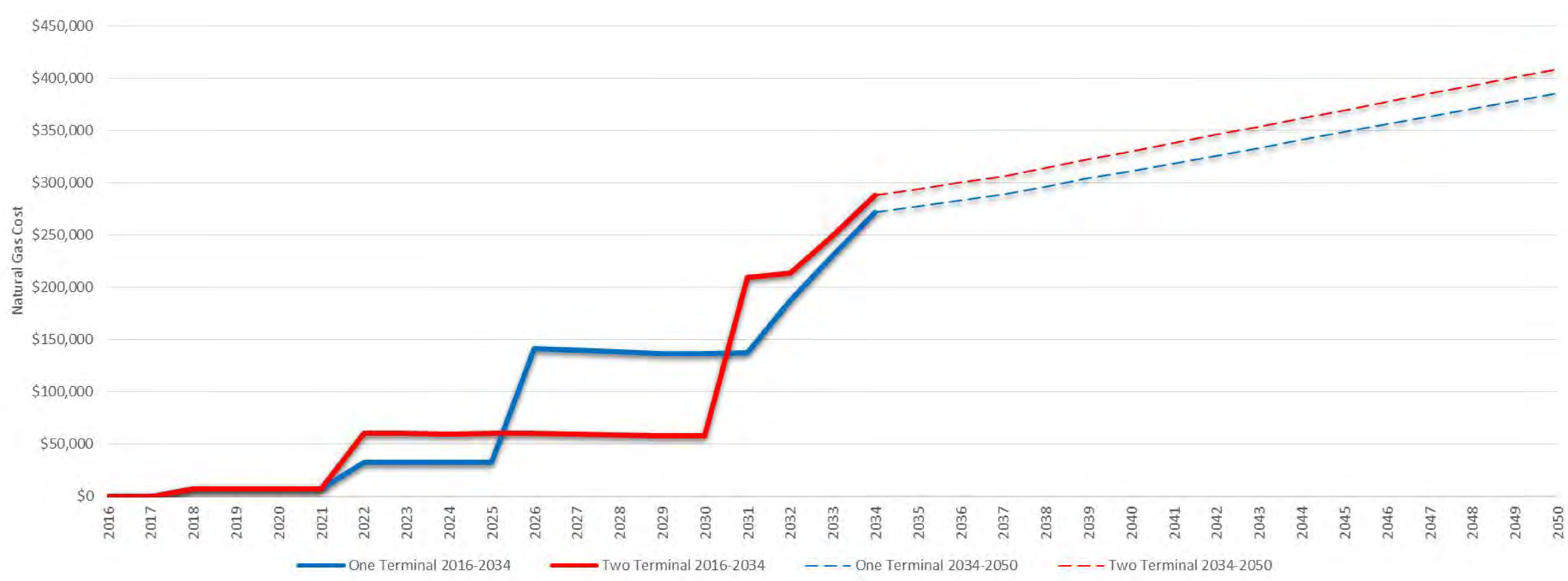


Chart 6-7
Accumulative Energy Costs for One vs. Two Terminals (Adjusted based on EIA forecasted cost escalation of Energy)

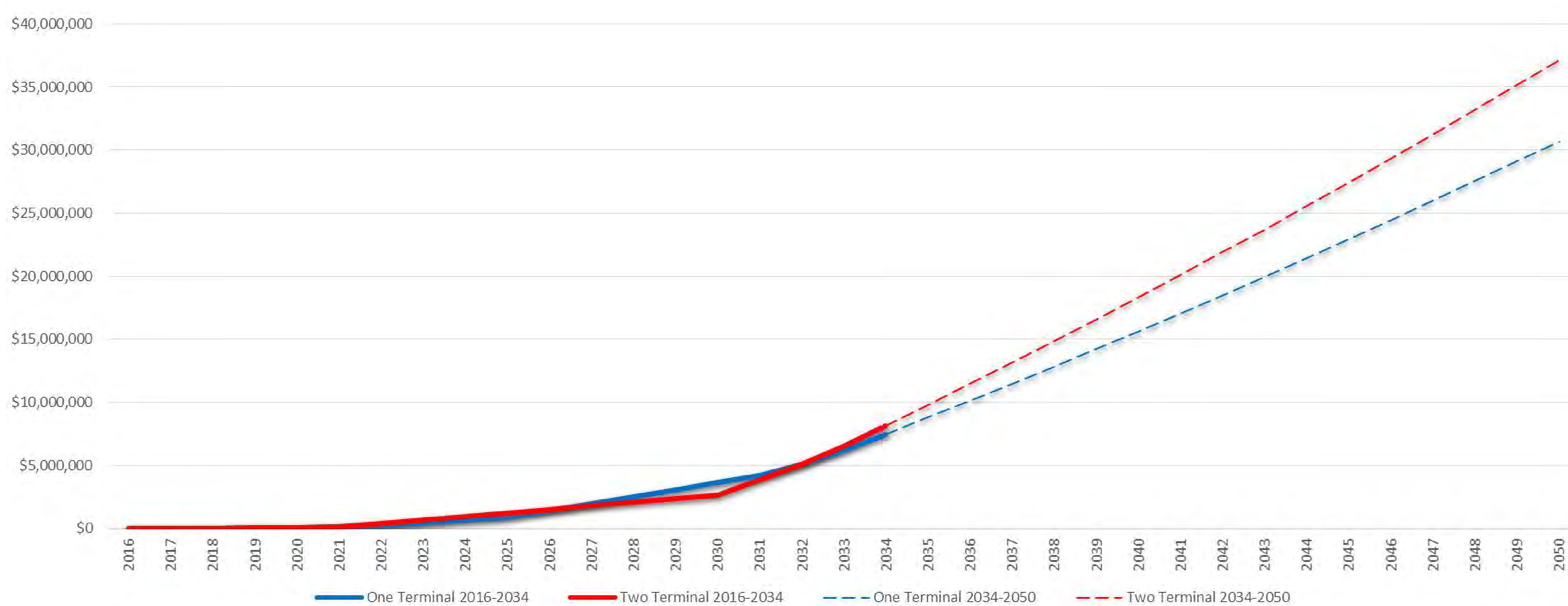
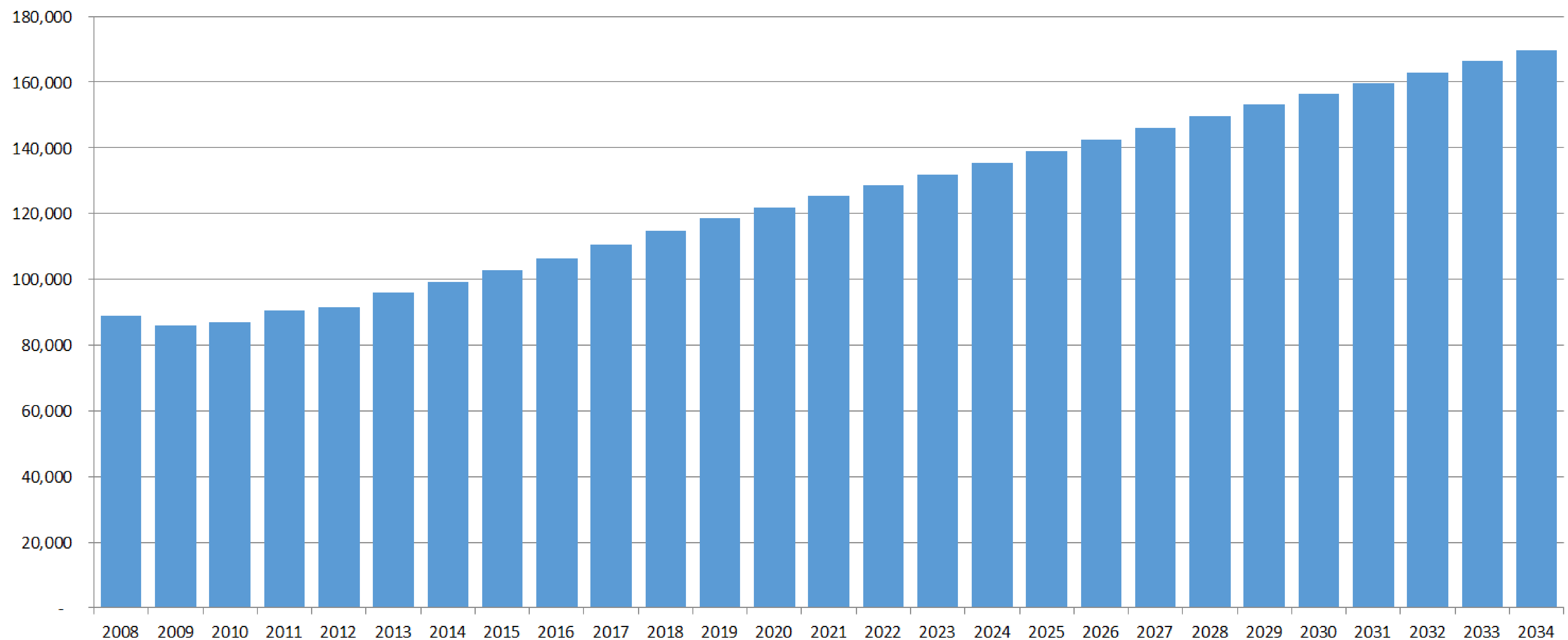


Chart 6-8
Annual Water Usage (Current and Proposed Build Out of Either Option) Based on Passenger Enplanement



2.7 Baseline Case: Energy Usage Comparison between Alternatives

In addition to costs, energy consumption was analyzed for both Alternatives. Each alternative was separately analyzed via the energy model to understand the incremental impacts that each would have on current consumption of electricity and natural gas. Like the current terminal, natural gas consumption is directly relational to the steam production for heating (comfort HVAC) and water heating. Likewise, chiller energy results in an increase to electricity consumption for the airport.

Refer to Chart 4-28 and Chart 4-29 for breakdown of current Terminal energy use.

2.7.1 Current demand plus energy for NorthSTAR and IAF

The first simulation adds the predicted electricity and natural gas consumption for the NorthSTAR (North Satellite) and IAF projects. This scenario uses expected passenger density for these areas and changes the overall footprint of the building to include the new expansions. Process and equipment loading is based on existing terminal. HVAC and lighting efficiencies based on documented requirements for these spaces.

Chart 6-9
Existing Terminal + NorthStar and IAF Energy Demand, by Use (Monthly)

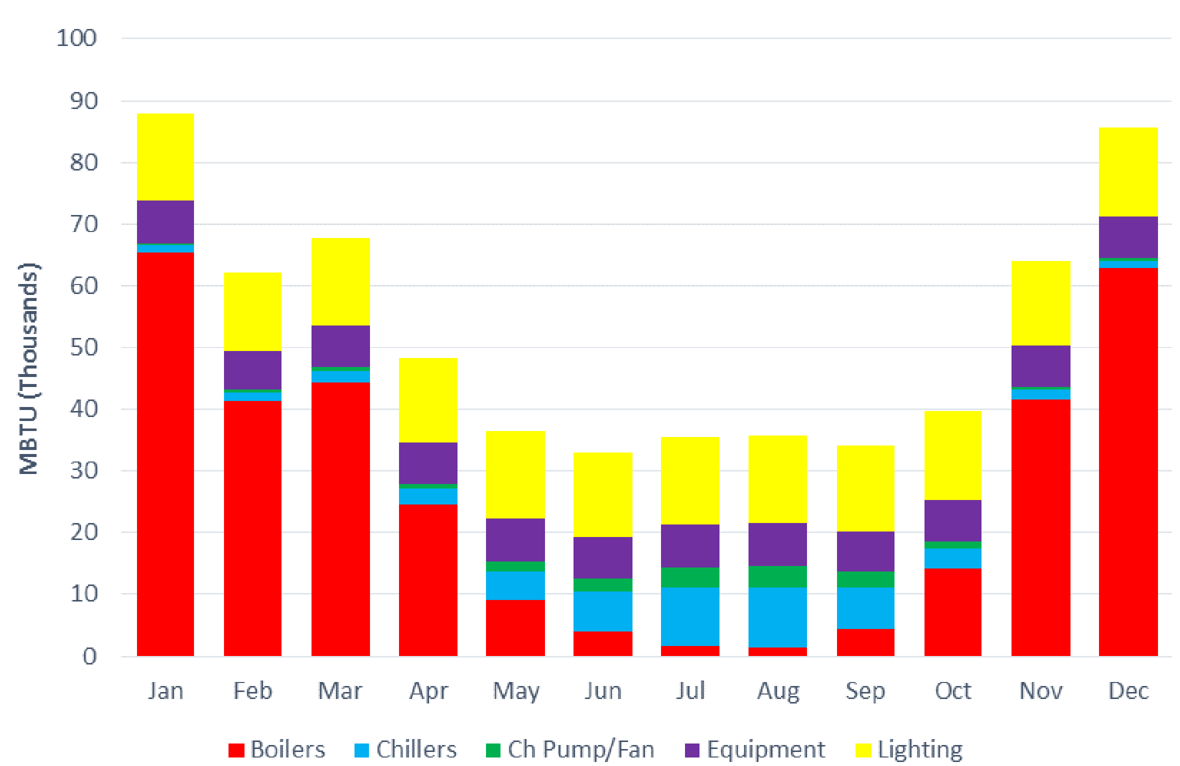
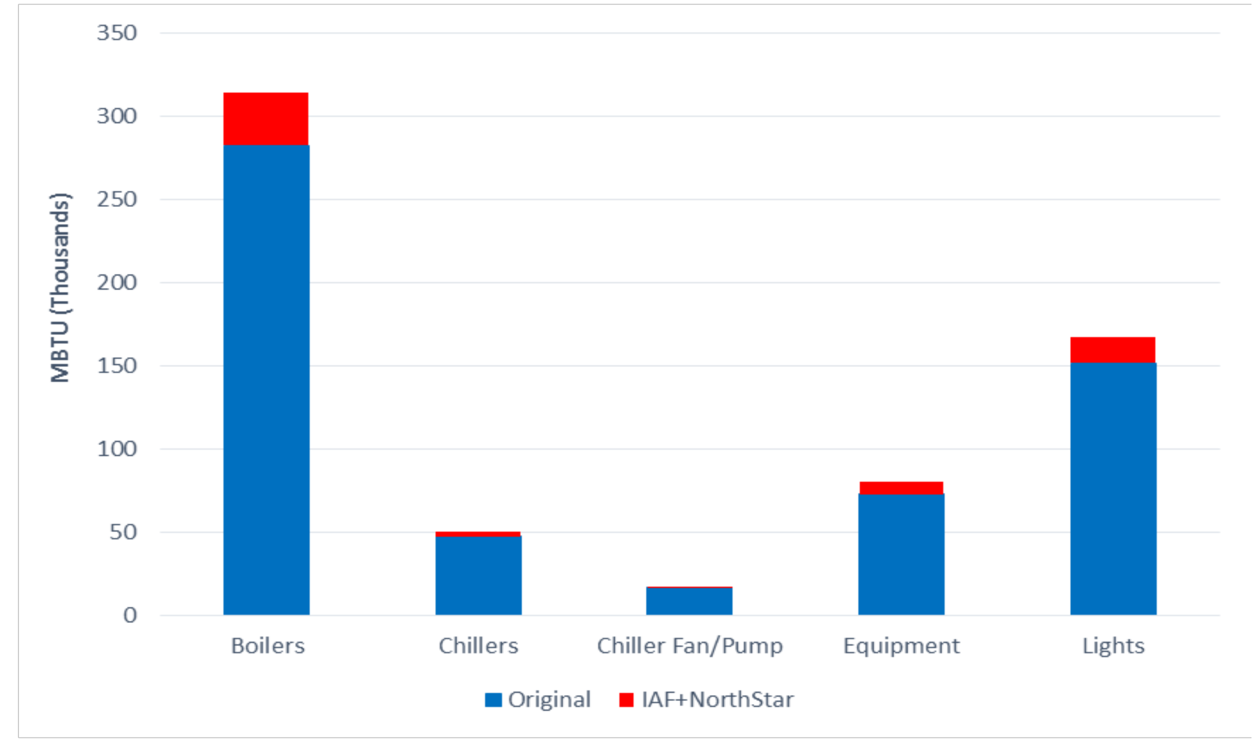
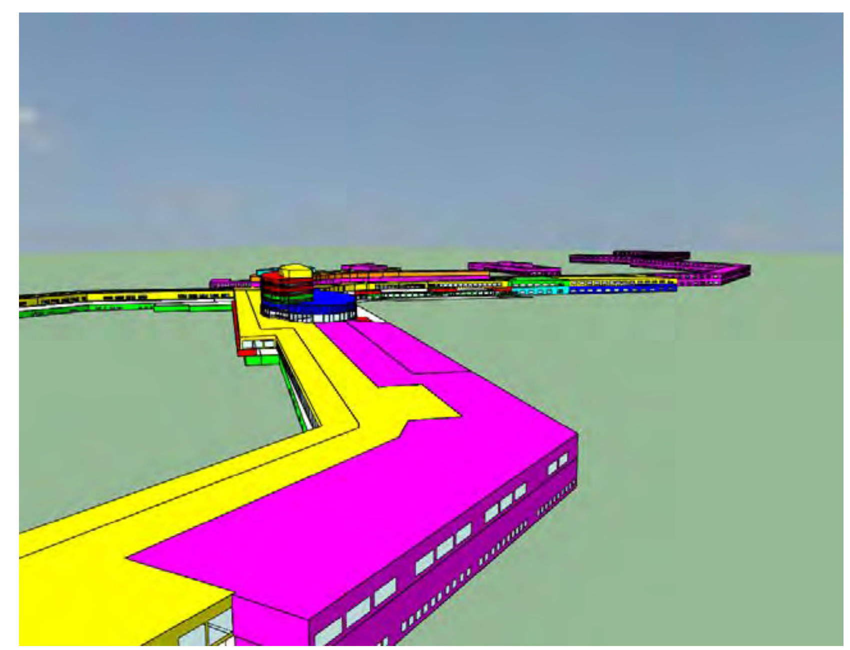


Chart 6-10
Existing Terminal + NorthStar and IAF Energy Demand (Annual)



2.7.2 Alternative: One Terminal



The next simulation forecasts the total energy requirement for the *One Terminal* alternative. The simulation includes energy demand for the current terminal, NorthSTAR renovation, IAF expansion, and all building modifications and additions for this alternative.

Chart 6-11
Existing Terminal + NorthStar and IAF + One Terminal Alternative Energy Demand, by Use (Monthly)

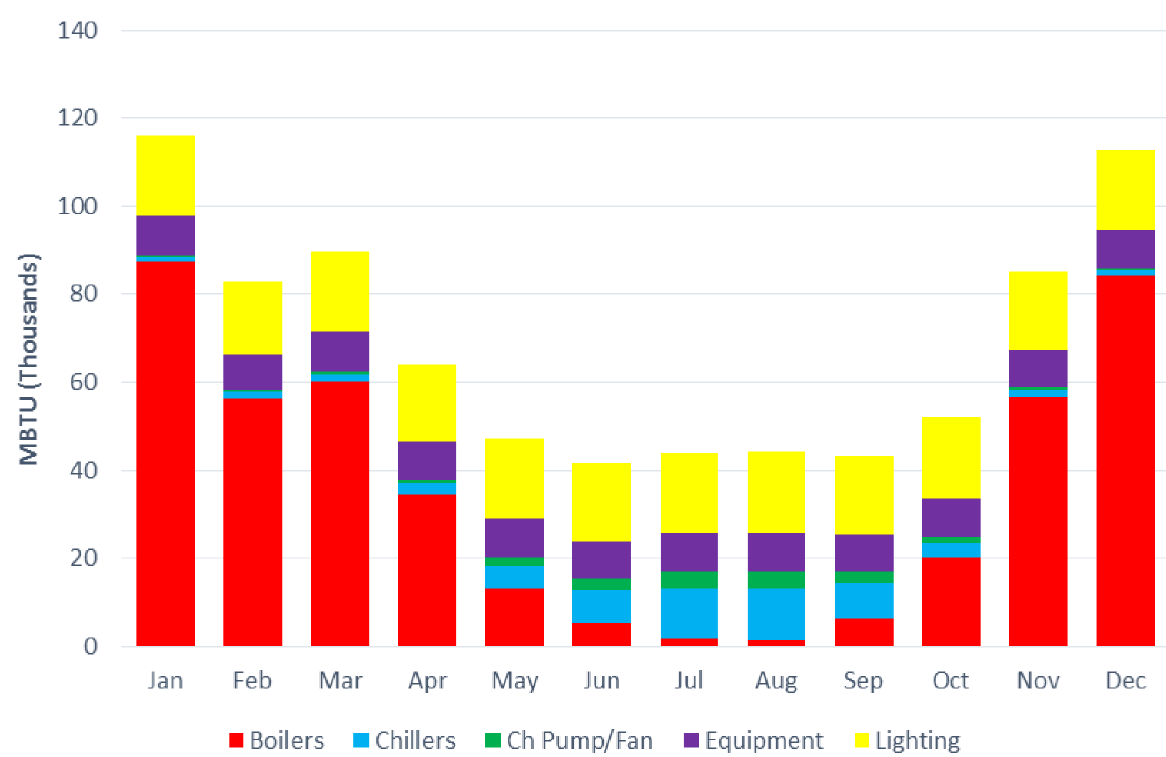


Chart 6-12
Existing Terminal + NorthStar and IAF + One Terminal Alternative Energy Demand (Annual)

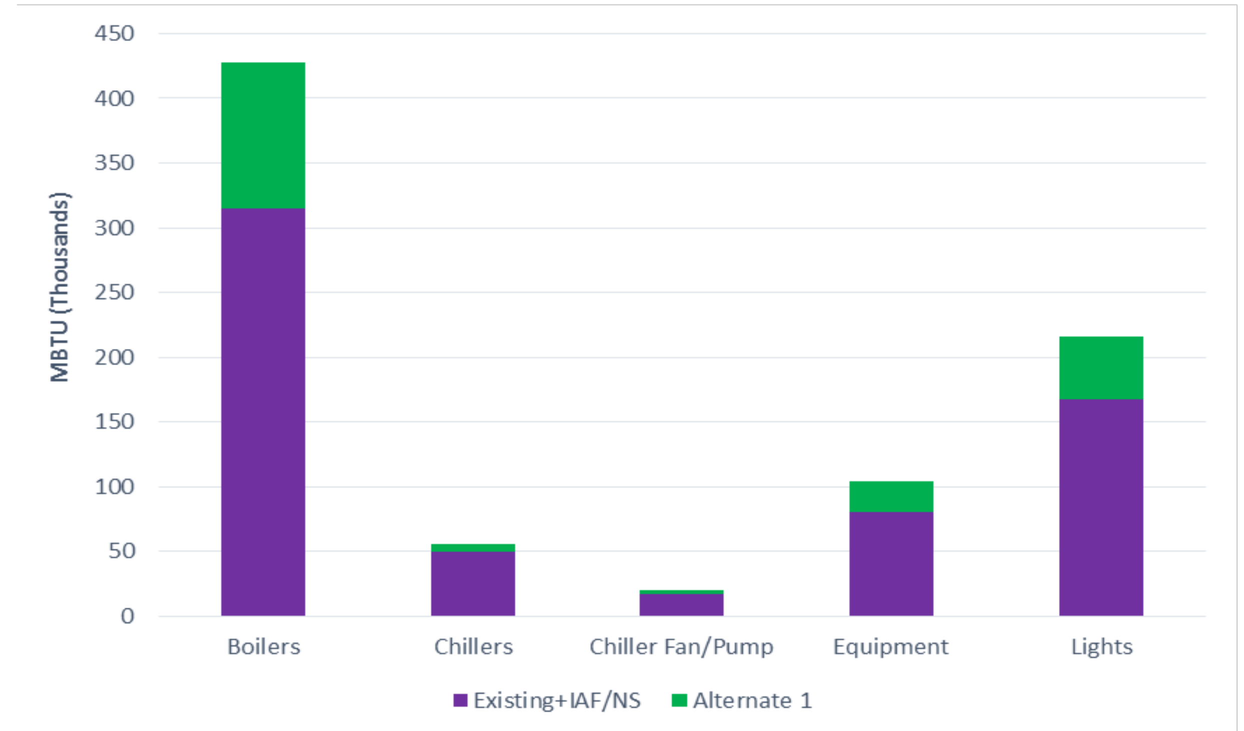


Chart 6-12 indicates that Alternative 1 (One Terminal) adds approximately 76% boiler energy, 12.5% chiller and fan/pump energy, and 27% equipment and lighting energy to the existing and near-term additions energy usage.

2.7.3 Alternative: Two Terminal

The next simulation forecasts the total energy requirement for the *Two Terminal* alternative. The simulation includes energy demand for the current terminal, NorthSTAR renovation, IAF expansion, and all building modifications and additions for this alternative.

Chart 6-14 indicates that Alternative 2 (Two Terminal) adds approximately 143% boiler energy, 23.6% chiller and fan/pump energy, and 49.5% equipment and lighting energy to the existing and near-term additions energy usage.

Chart 6-13
Existing Terminal + NorthStar and IAF + Two Terminal Alternative Energy Demand, by Use (Monthly)

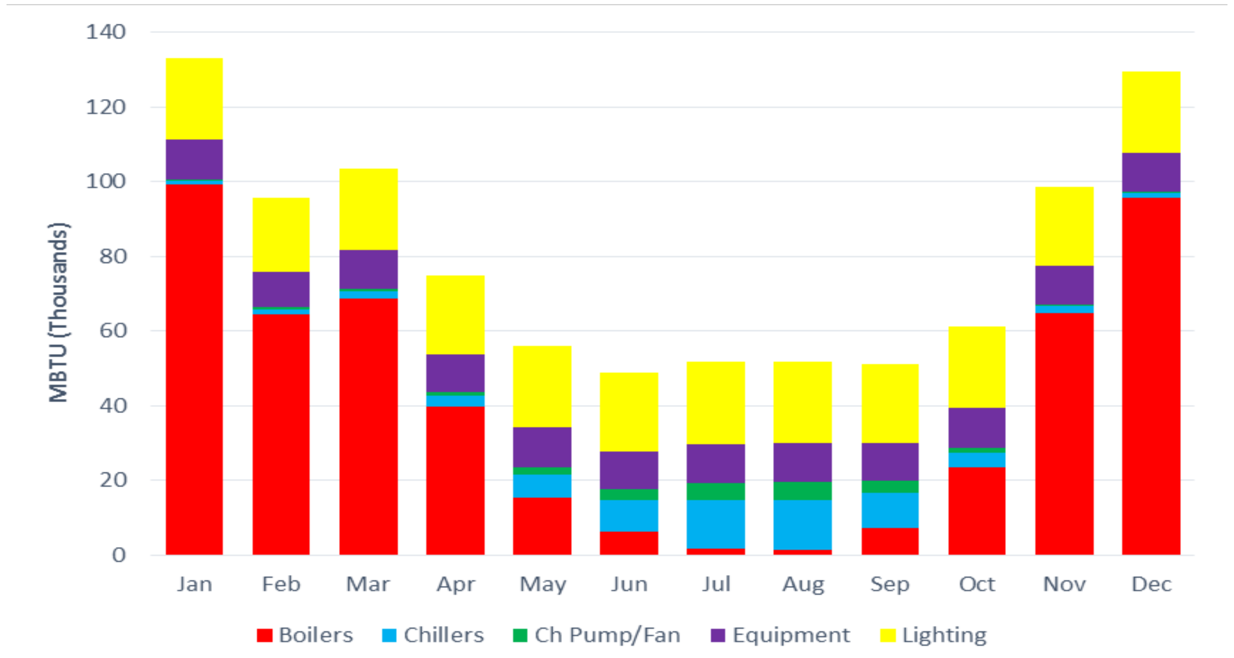
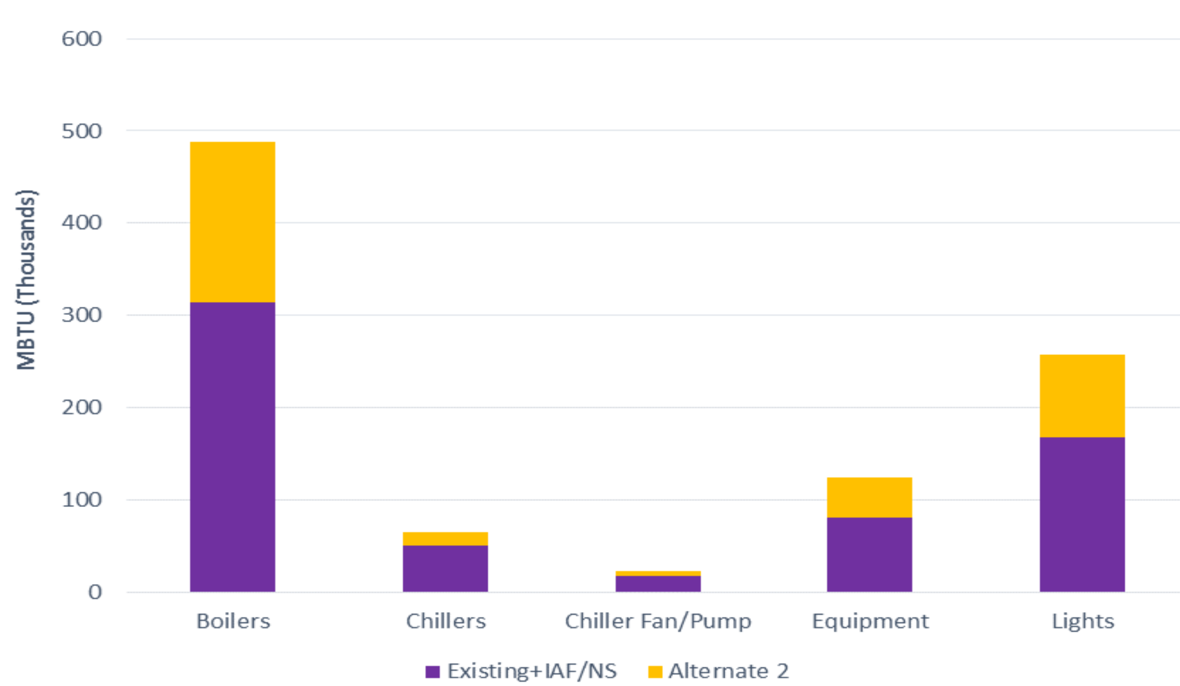
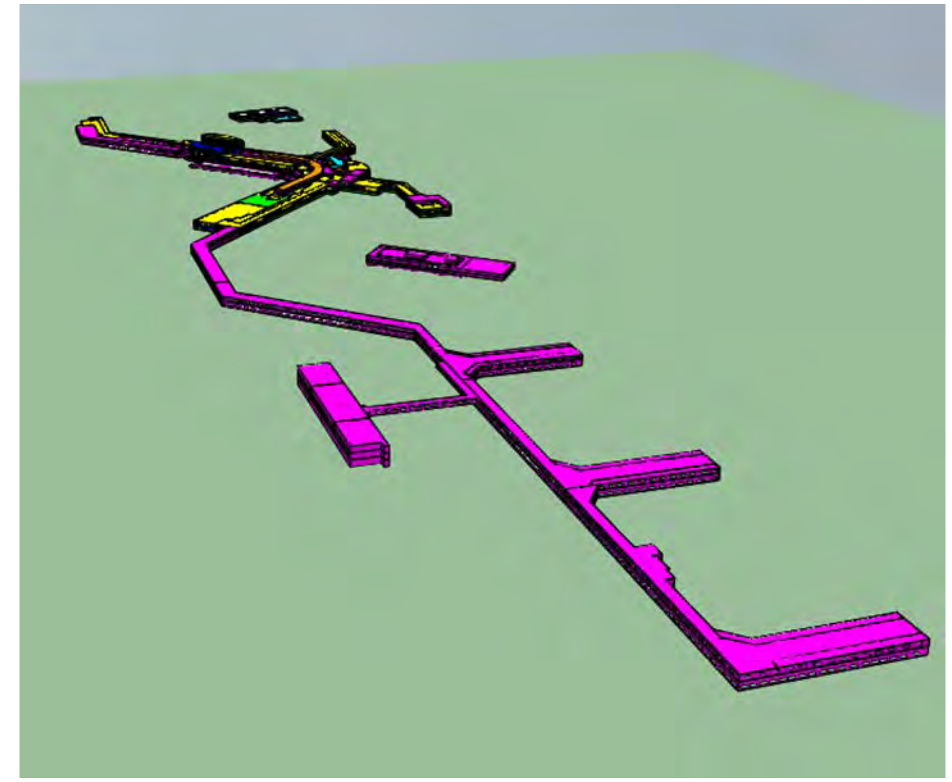


Chart 6-14
Existing Terminal + NorthStar and IAF + One Terminal Alternative Energy Demand (Annual)



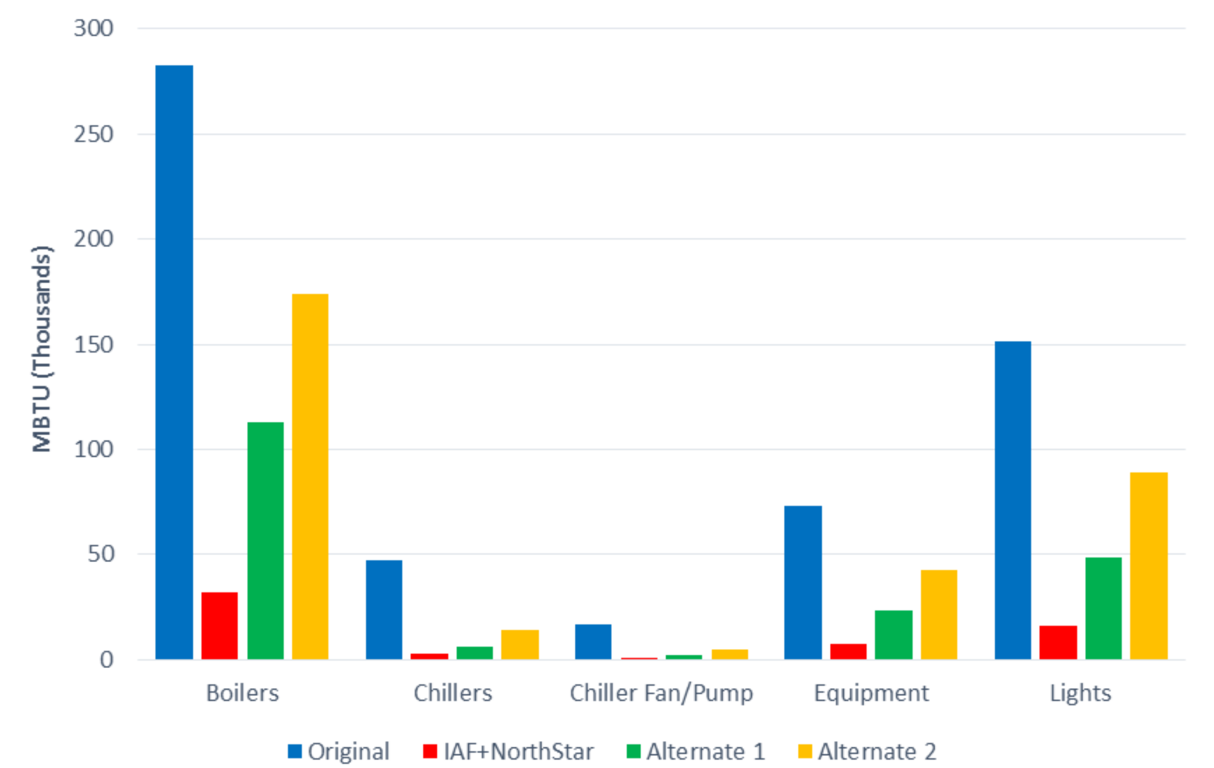


Two Terminal configuration

2.7.4 Alternative Comparison

Chart 6-15 compiles the simulation outputs for the two major options and displays them together for comparison.

Chart 6-15
Comparison of Annual Energy Demand: Alternative 1 vs. Alternative 2



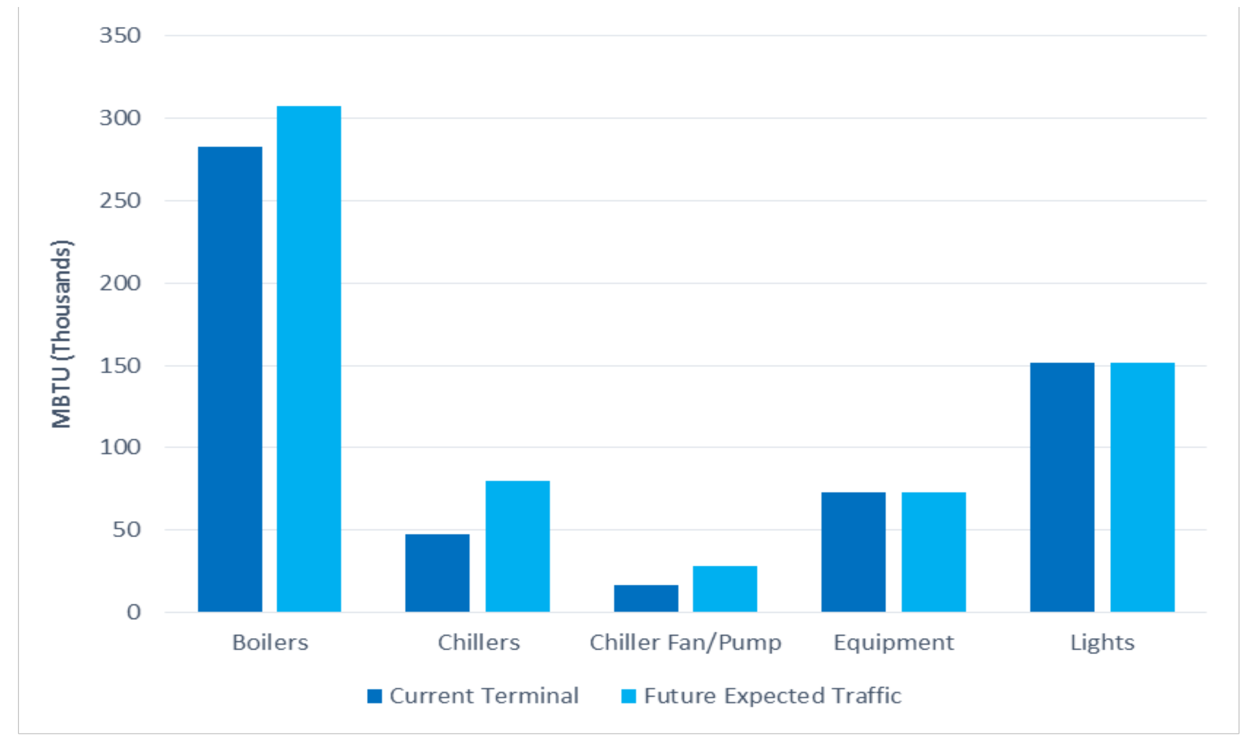
2.7.5 "No Expansion" Case

A final simulation was modeled to understand the impacts of the new passenger growth. The existing terminal was modeled with the proposed future passenger traffic of 66,000,000 to understand the energy impacts, assuming no new expansions or new construction. This scenario does not consider the code ramifications, existing infrastructure limitations (including HVAC), or egress considerations for the analysis. It is purely an analysis based on increasing passengers to sixty-six million on an annual basis.

Not expanding the facility to meet the ultimate passenger traffic load is not recommended. The infrastructure required to accommodate the increased passenger traffic is not currently built into the airport. Other than operational components, such as the transit, conveyance systems, gates, hold rooms, baggage handling systems, security checkpoints, etc., the HVAC system is undersized to handle the additional internal load. Increased power required for the operational systems and HVAC is not currently within the electrical infrastructure capabilities of the Terminal.

For the analysis, existing lighting and equipment energy is held constant. Increases in energy usage is directly related to increased HVAC requirements. Chart 6-15 shows the comparison. The boiler energy load increases slightly (due to increased ventilation load requirements). The chiller and fan loads increase significantly due to the increase in people. In fact, the increase in fan and chiller energy is greater than either the Alternative 1 or Alternative 2 options.

Chart 6-16
"No Expansion" Analysis



3 SUSTAINABLE MODEL

Development of a forecasting model for energy efficient construction involves re-evaluating the two alternatives and changing the inputs in the simulation model. For this analysis, a predicted 2030 LEED value was used to define lighting densities, equipment efficiencies, and envelope insulation values. The existing central plant is considered to remain as is for the existing terminal and the new decoupled heating plant used for the new portions of the building. Expanded use of daylighting and free cooling are also considered. Using the exact same model from above, these inputs were changed and the simulation modeled the new results. This represents a predictive approach for LEED in the future, based solely on LEED *Energy and Atmosphere* Prerequisite 2 and Credit 1 requirements. Other LEED aspects, such as environmental and social factors, controllability, and non-system related credits were not addressed.

The result is as shown in the following charts:

Chart 6-17
Exist. Terminal + NorthStar/IAF + Sustainable One Terminal Alternative Energy Demand, by Use (Monthly)

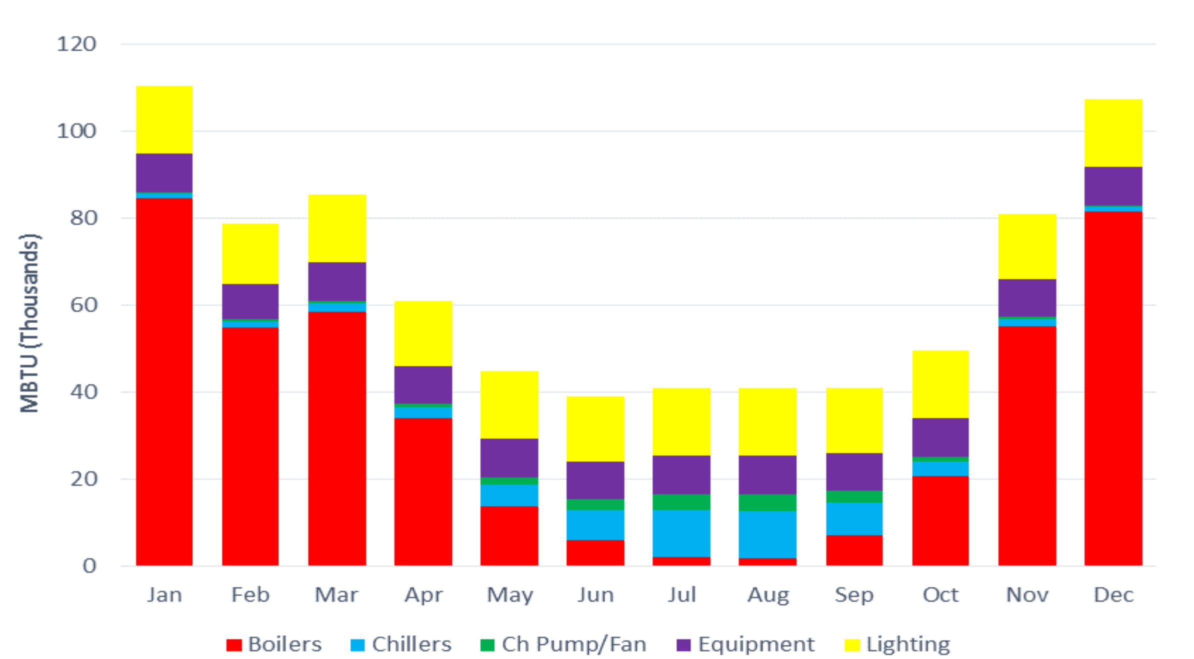


Chart 6-19
Exist. Terminal + NorthStar/IAF + Sustainable Two Terminal Alternative Energy Demand, by Use (Monthly)

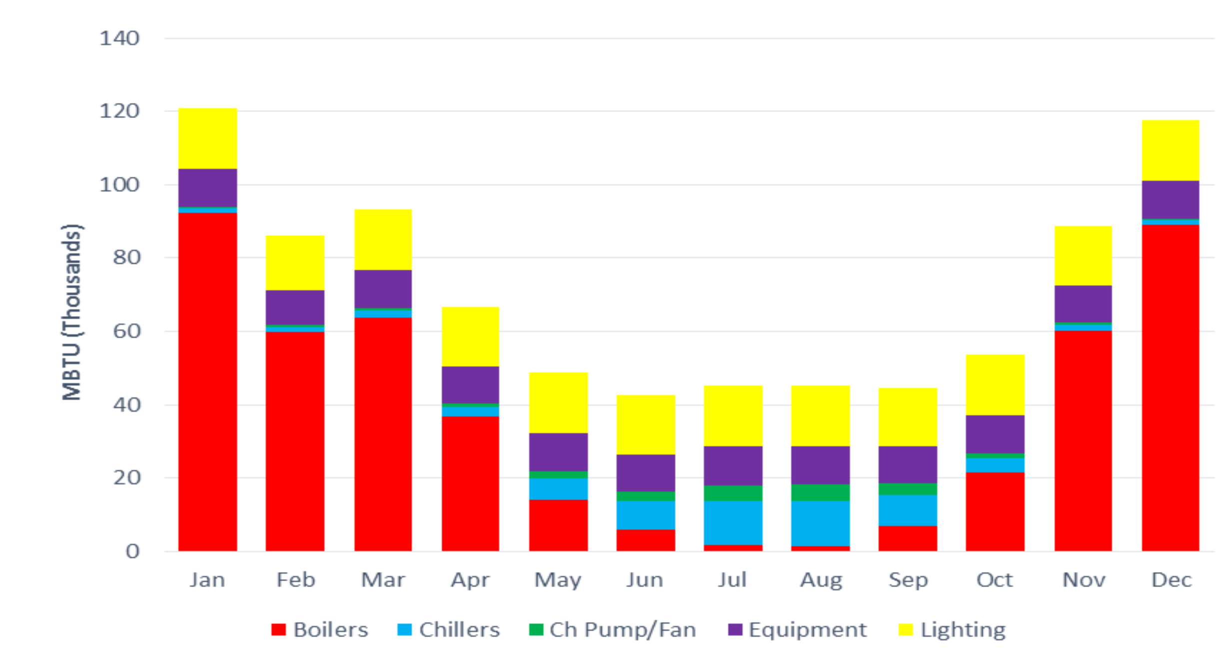


Chart 6-18
Existing Terminal + NorthStar and IAF + Sustainable One Terminal Alternative Energy Demand (Annual)

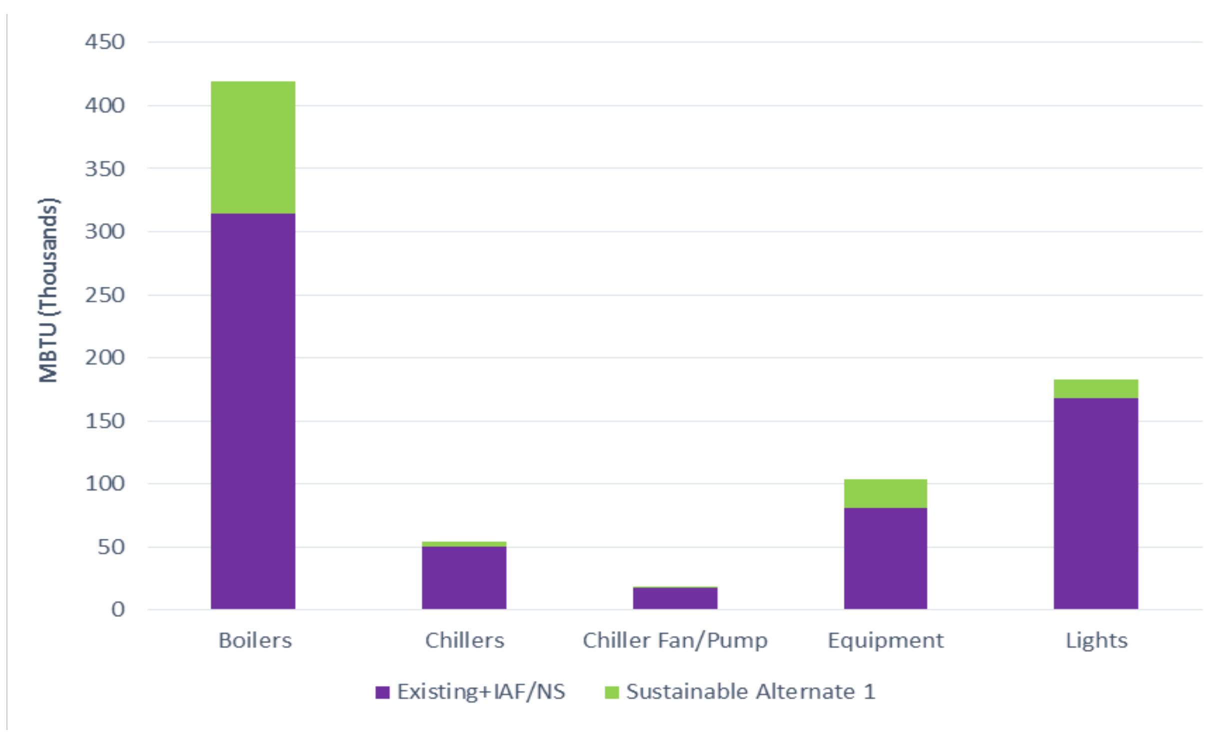


Chart 6-20
Existing Terminal + NorthStar and IAF + Sustainable Two Terminal Alternative Energy Demand (Annual)

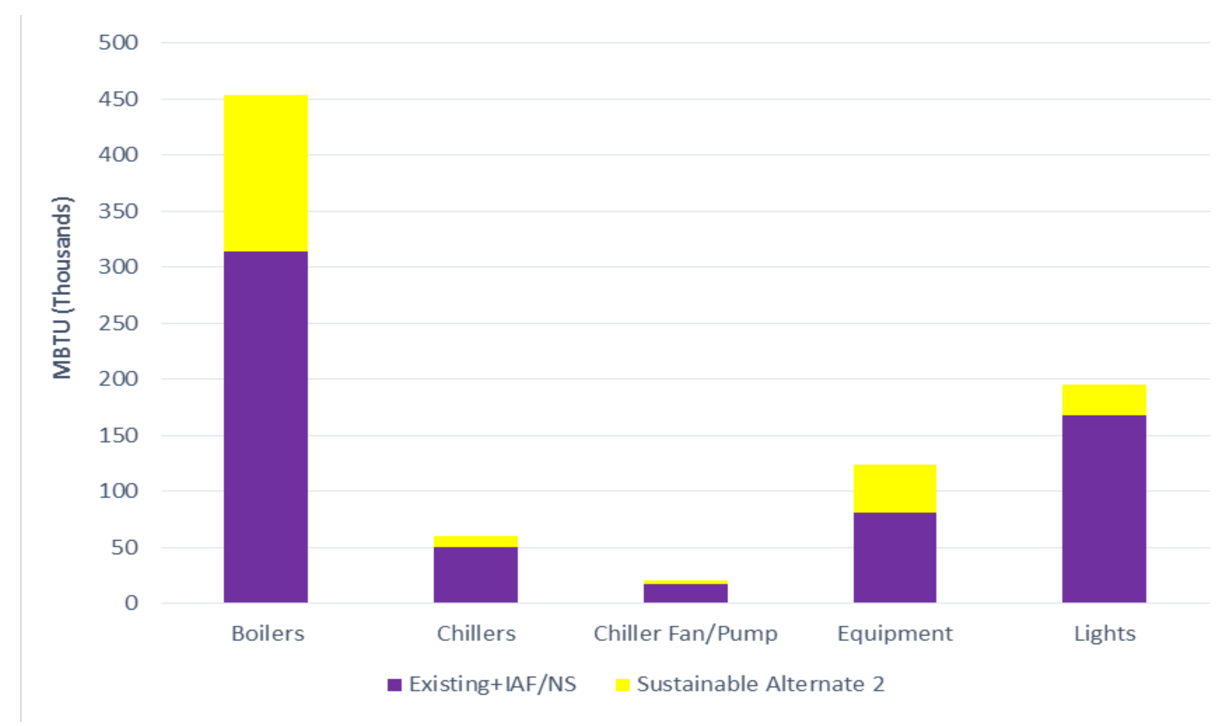


Chart 6-21
Comparison of Annual Energy Demand: Sustainable Alternative 1 vs. Sustainable Alternative 2

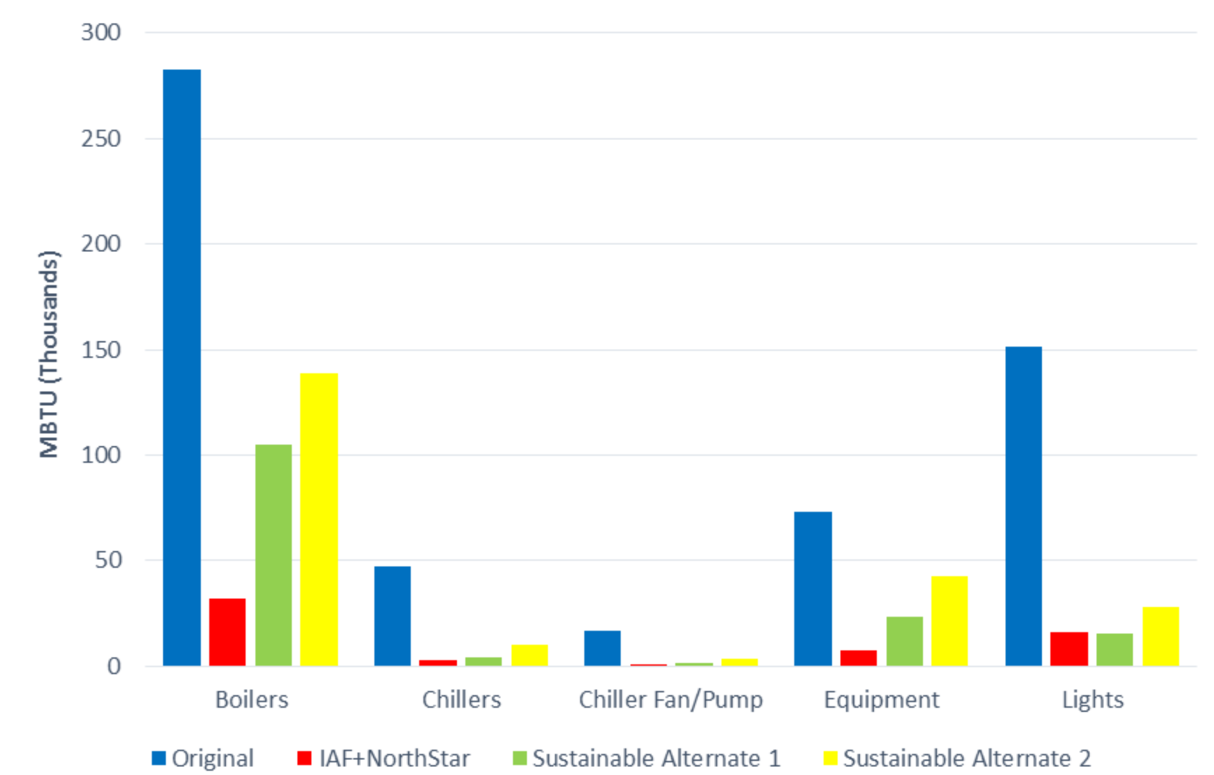
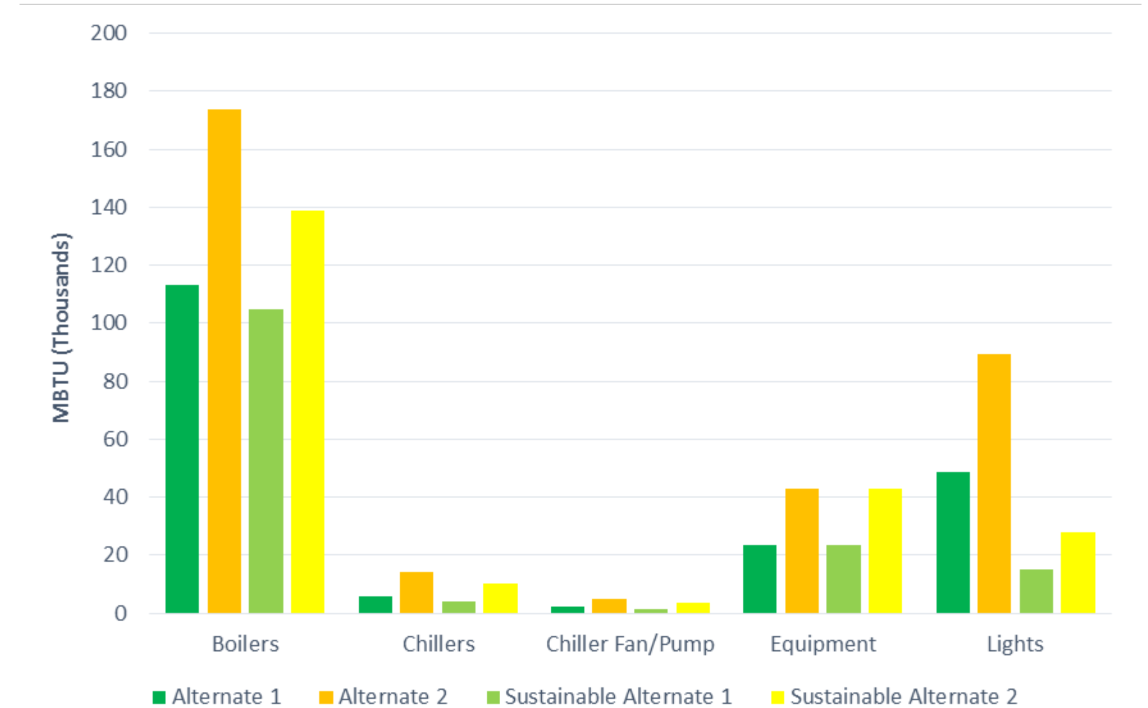


Chart 6-22
Comparison of Annual Energy Demand: Standard vs. Sustainable Alternatives



4 NET ZERO MODEL

One of the main challenges of a net zero approach is the ability to generate enough energy through renewable means. Using RETScreen V4 simulation, the total annual energy available from the use of solar PV covering the effective existing and proposed expansion roof areas was calculated. The simulation used modern PV panels (Sunpower SPR-320E-WHT mono-Si) in Seattle, based on the optimal angle for what maximum energy output could be produced. The analysis assumes a roof available area of 65% for terminals and 90% available for the garage (assuming solar canopies).

Three models are generated: one for terminal only, one for garage only, and one for cargo only.

Table 6-5
Terminal Solar PV Potential Analysis

BUILDING	ROOF AREA SF	COVERAGE PV | ROOF %	PANELS NO.	POWER MWh	POWER KWh	POWER KBTU
TERMINAL						
TERMINAL ADMINISTRATION	22,400	65%	829	28	27,910	95,229
TERMINAL CONCOURSE A	210,900	65%	7,808	263	262,777	896,597
IAF EXPANSION	212,500	65%	7,868	265	264,771	903,399
TERMINAL CONCOURSE B	84,000	65%	3,110	105	104,662	357,108
TERMINAL CONCOURSE C	145,940	65%	5,403	182	181,839	620,433
TERMINAL CONCOURSE D	85,400	65%	3,162	106	106,407	363,060
TERMINAL TICKETING	255,900	65%	9,475	319	318,847	1,087,905
CENTRAL TERMINAL EXPANSION	77,600	65%	2,873	97	96,688	329,900
NORTH SATELLITE	93,200	65%	3,451	116	116,125	396,220
SOUTH SATELLITE	93,200	65%	3,451	116	116,125	396,220
TOTAL	**1,281,040**		**47,430**	**1,596**	**1,596,152**	**5,446,071**
TWO TERMINAL ALTERNATIVE	451,000	65%	16,698	562	561,938	1,917,331
TOTAL						
EXISTING TERMINAL	**1,281,040**		**47,430**	**1,596**	**1,596,152**	**5,446,071**
EXISTING + NEW	**1,732,040**		**64,128**	**2,158**	**2,158,090**	**7,363,402**

As is shown, the amount of power produced by PV is significantly less than the electrical power required to operate the terminal. The one terminal option has an electrical demand of 24 MWh at full buildout and the two terminal option has an electrical demand of 28 MWh at full buildout. These do not include natural gas energy or any energy required for the existing terminal. Therefore, the amount of power generated by installing PV over the effective roof of both the existing terminal and the new terminal would only power a fraction of the electrical requirement of the new terminal only.

Table 6-6
Garage Solar PV Potential Analysis

BUILDING	ROOF AREA SF	COVERAGE PV | ROOF %	PANELS NO.	POWER MWh	POWER KWh	POWER KBTU
PARKING						
MAIN PARKING GARAGE	642,500	90%	32,937	1,108	1,108,444	3,782,012
NEW NORTH TERMINAL PARKING	1,493,000	90%	76,538	2,576	2,575,731	8,788,395
TOTAL	**2,135,500**		**109,475**	**3,684**	**3,684,175**	**12,570,406**

For the garage, the 12,600,000 kBTU of energy produced is approximately 1/3rd of power required for existing garage (36,000,000 kBTU), but equals the power required for the new garage. As newer higher-performance PV panels become available, the use of PV for garage is feasible.

Table 6-7
Cargo Solar PV Potential Analysis

BUILDING	ROOF AREA SF	COVERAGE PV | ROOF %	PANELS NO.	POWER MWh	POWER KWh	POWER KBTU
CARGO						
AIR CARGO EXISTING	540,740	75%	23,101	777	777,406	2,652,510
AIR CARGO NEW		75%	0	0	0	0
TOTAL	**540,740**		**23,101**	**777**	**777,406**	**2,652,510**

The power produced for all of cargo is approximately 1/10th of the energy requirements of existing cargo. For all new cargo buildings, especially those without significant amounts of HVAC, the energy efficiency should be designed to take in consideration the amount of power consumed.

5 ALIGNMENT OF CAPITAL PROGRAMS TO SUSTAINABLE OBJECTIVES

Based on the outcomes of the analysis, comparisons can be made to determine how the different master planning options can meet the goals and objectives discussed in the *Background* Section. Information about forecasted energy and water consumption and potential use of renewable energy are used to gauge performance. Furthermore, connecting these predicted values to their key performance indicators will allow for ongoing comparisons of different sustainability and asset management possibilities.

5.1 Comparing Outcomes with Goals and Objectives

From the *Background* Section, the Port's Century Goals states "…zero additional energy use from 2012; future growth in energy usage is met through conservation and renewable sources".

This Report uses 2014 data as the baseline. 2012 used 6,988 MBTU less electricity and 289 MBTU more natural gas than 2012.

Based on the simulations, the increase due to the "one terminal" expansion would be 269,719 MBTU annually and the "two terminal" expansion would be 424,026 MBTU annually.

A future "LEED Silver" One Terminal alternative would require 158,513 MBTU more annually and the Two Terminal alternative would require 253,092 MBTU annually.

Based on full coverage of both existing and new terminal and garage with photovoltaic (assuming current efficiency), the maximum power produced for entire area would be 19,933 MBTU annually.

This deficit means that additional consumption reduction would be required in order to meet the Port Century Goal.

In regards to Airport energy and water objectives, the goals to reduce electricity and natural gas by 5% in 2020 based on 2012 baseline are also difficult due to the additions of the IAF and NorthStar expansions. These new spaces represent a forecasted increase of 77,087 MBTU of energy. Since 2012 and current water consumption rates are similar, the additional requirements for cooling will drive additional water requirements for the cooling towers.

The Airport's objective is to implement 3% of total electrical power through renewable energy and 50% use of biogas (renewable natural gas) from 2013 amounts. Using the full available roof of both the existing terminal and garage would result in approximately 9,228 MBTU of electricity generation, based on current PV panel efficiency. Three percent of the total current electricity of 384,000 MBTU use is just over 11,500 MBTU of energy. The electricity that Airport does procure is over 98% renewable hydropower. The use of biogas (renewable natural gas) is limited to contract terms. The amount of renewable natural gas would be just over 148,000 CCF annually.

5.2 Energy Use Metrics

In the *Objectives* Section, metrics and key performance indicators were discussed that are used with the Master Plan. This Section discusses outcomes of energy and water in terms of total consumed and costs based on a square foot basis. Per area consumption and costs are discussed, based not only on the two main alternatives – one vs. two terminal – but also based on level of sustainability.

In addition, energy use per passenger is an important metric that should be analyzed. Table 6-8 shows the comparison of the five scenarios on an annual energy consumed per passenger basis.

Table 6-8
Energy per Passenger (Annual BTU per Passenger)

OPTION	**TOTAL ENERGY (MBTU)**	**TOTAL PASSENGERS**	**BTU/PASSENGER (ANNUAL)**
CURRENT TERMINAL	622,332	37,488,267	16,601
CURRENT+IAF+NorthSTAR+ONE TERMINAL	892,051	66,000,000	13,516
CURRENT+IAF+NorthSTAR+TWO TERMINALS	1,046,358	66,000,000	15,854
CURRENT+IAF+NorthSTAR+ONE TERMINAL (LEED SILVER)	780,845	66,000,000	11,831
CURRENT+IAF+NorthSTAR+TWO TERMINALS (LEED SILVER)	875,424	66,000,000	13,264

The top category listed is based on the 2014 consumption of energy (primary, not including tenants, concessions, or other non-terminal or garage buildings) compared to total domestic and international passengers at Sea-Tac Airport. Forecasting the additional energy consumption for both the pending IAF expansion and NorthStar expansion, the simulated energy consumption for the one terminal alternative was added together on the second category. The third listed also included the IAF and NorthStar and the energy consumed for the two terminal alternative. Since the addition of the new terminal doubles the area of the one terminal option, the amount of energy consumed (primarily heating, process energy, and lighting) would increase accordingly. The fourth and fifth category are the same as the second and third, only using a predicted future LEED Silver level of sustainability (including central plant, lighting density, and materials of construction).

The only category that uses more energy per passenger is the non-LEED two terminal option. The additional terminal would require the additional energy consumed.

OTHER CONSIDERATIONS

In addition to energy efficient, sustainable construction methods, new campus-wide systems can be implemented in order to reduce overall environmental footprint, reduce energy consumption and cost, and provide more reliable power sources.

1 INTRODUCTION

Previous Sections looked at opportunities how energy and water can be reduced at a building level. This Section looks at additional opportunities at a campus-wide level. These strategies benefit the Airport through reduced energy consumption and cost and providing environmental benefit through reduced use of carbon-based fuels.

Two different types of strategies are focused within this Section: renewable energy and other energy strategies. The Renewable Energy paragraphs focus on solar electric, solar thermal, and wind. Other renewable energy options are not feasible, and therefore not discussed.

The "*Other Energy Strategies*" paragraph discusses energy transfer option, central plant options, metering strategies, and thermal storage.

Each of these strategies are discussed at a master planning level. Actual economics and sizing of the systems are only briefly discussed and further analysis would be required to determine feasibility and practicality of the options.

2 RENEWABLE ENERGY

As was discussed previously, renewable energy is a big step toward reducing overall energy consumption. Traditional renewable energy includes solar electric, solar thermal, wind, geothermal energy (not ground-source HVAC), low impact hydropower, biomass, and biofuel. Each of these different types of energy have limitations to amount of power or energy that be produced based on the available resources. In addition, where renewable energy systems reduce overall consumption and environmental impacts in comparison to traditional fossil fuel-based systems, they typically do not provide appropriate return on the investment to implement the systems.

Total cost of ownership for site-generated renewable energy outweighs the initial capital investment, the costs associated with modifying the distribution infrastructure, and the ongoing operational and maintenance costs associated with the equipment with the reduced energy cost. In many of these systems, offsetting CAPEX and OPEX costs with energy costs does not occur within the design life of the system. Without grants, many of these projects do not become feasible.

Using a combined approach based upon both TCO and sustainability goals, a renewable energy system becomes more favorable to implement. Many renewable energy projects may not have positive payback periods, but the overall environmental and social benefits may provide reasoning why it should be implemented. The beneficial reduction of greenhouse gases makes the use of renewable energy more attractive over a "cost only" decision approach. The use of renewable energy to replace natural gas consumption is a viable option, since on-site combustion of natural gas produces significant greenhouse gases. In contrast, the primary electrical provider for Sea-Tac is mostly hydropower based, and therefore both site and source emissions are minor.

As costs for installing renewable energy systems decrease, technology improves, and grants or incentives become more available, the cost benefits for installing renewable energy will follow, as well.

2.1 Solar

Of all "approved" site generated renewable energy systems, solar is the most feasible. Solar can be implemented in two different ways in order to reduce energy sourced from the public utility: electrical and thermal. Current technology, material costs, and the available solar resource in Seattle make solar electrical a difficult payback option at this time.

RETScreen V4 energy simulation model was used for all solar photovoltaic analysis for these models. RETScreen is a clean energy management and simulation tool developed by the government of Canada. It is used to determine amount of equivalent energy that can be produced annually, based on the Seattle solar resource. The following table includes the outputs based on a Sunpower mono-silicate photovoltaic panel with 20% efficiency.

Table 7-1
Solar Analysis for Seattle, Washington

Month	Daily solar radiation - horizontal	Daily solar radiation - tilted	Electricity exported to grid PER 1000 PANELS
	kWh/m²/d	**kWh/m²/d**	**MWh**
January	0.98	1.08	0.958
February	1.65	1.78	1.408
March	2.82	2.96	2.548
April	4.08	4.19	3.424
May	5.32	5.39	4.46
June	5.81	5.84	4.606
July	6.06	6.12	4.917
August	5.15	5.27	4.254
September	3.77	3.95	3.148
October	2.22	2.39	2.04
November	1.16	1.28	1.087
December	0.81	0.90	0.803
Annual	**3.33**	**3.44**	**33.653**

POWER | 1000 PANELS	33.653	MWh
AREA | 1000 PANELS	17556	SF
AREA | PANEL	17.556	SF
POWER | PANEL	0.034	MWh

Specific analysis for PV is shown in the previous Section. As technology improves, the amount of power generated from PV panels will increase, meaning that the more energy can be generated for the same roof area. The following NREL graphic shows historic, current, and emerging technologies for PV panels.

Figure 7-1
Best Research Cell Efficiencies (NREL Infographic)

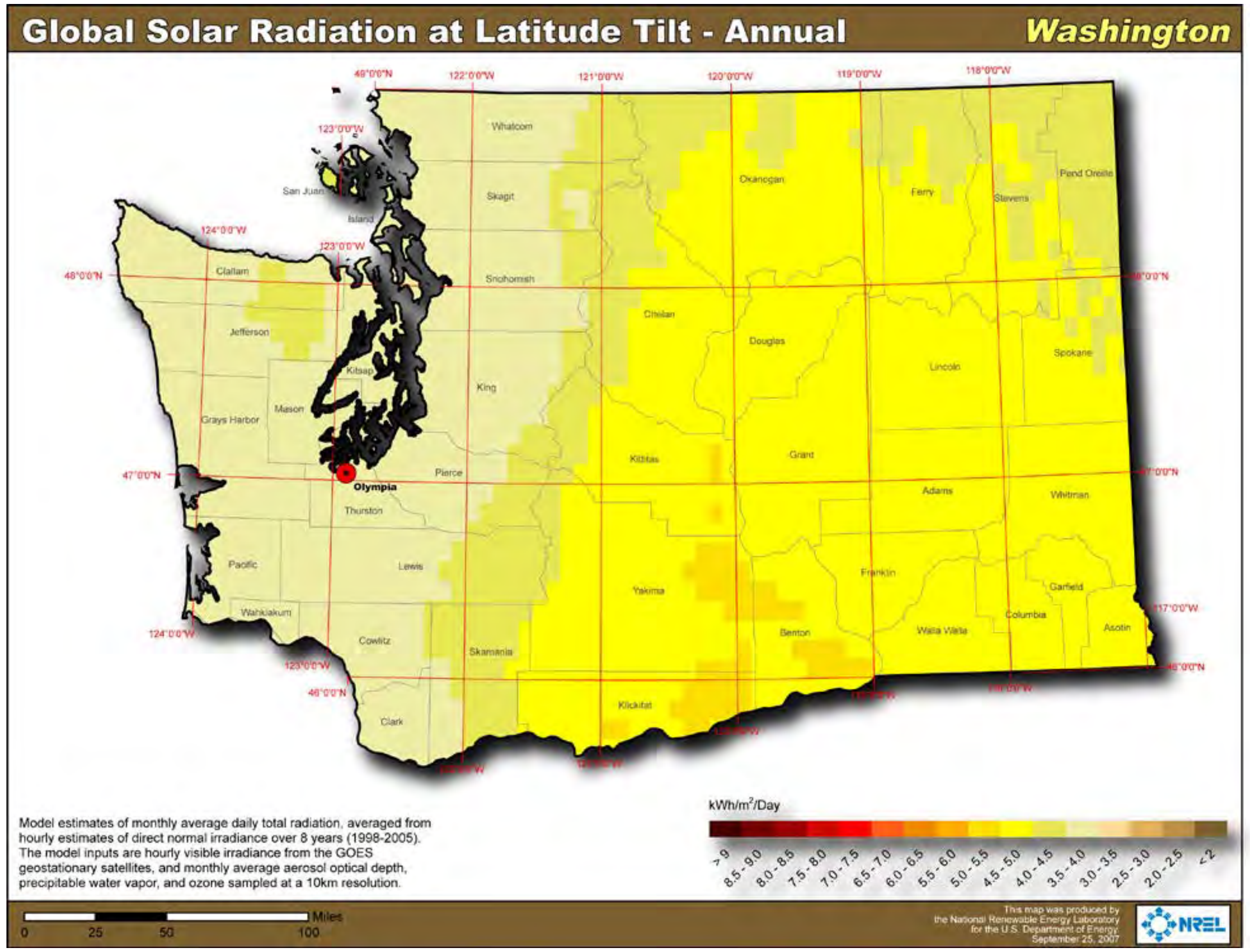
Another solar option is solar thermal. Solar thermal utilizes solar collectors to heat water. This water can be used for domestic or process/comfort heating purposes. Unlike photovoltaic panel systems, which convert sunlight into electricity, solar thermal systems stores heat in a collector to be used when the water needs to be heated. Gas or electric water heaters would supplement the solar thermal storage tank.

Photovoltaic energy has many advantages over solar thermal, such as overall efficiency, easier to install and maintain, less space for equivalent amount of heat produced, and the inability to freeze or overheat. Solar thermal systems, however, have lower first cost and therefore have simple payback of less than 20 years.

The analysis considers 7500 gallons of domestic water a day would need to be heated for all lavatory and service sink use at Sea-Tac. Solar data for Washington State was used in the assessment.

- Hot Water Temperature: 55°F heated to 140°F
- Collector: 42,400 BTU (assumed), 40 sq. ft., 850 required (36.3 MMBTU total output).
- Storage Tank: 42,500 Gal
- Annual Energy Saved: 4,675,000 kWh
- Annual Pounds of CO_2 saved: 225,250
- Estimated payback: 8-9 years

Figure 7-2
Washington State Solar Resource Map (NREL Infographic)



One of the concerns for solar photovoltaic at an airport is the effect of glare from the PV panel on pilots. The FAA wrote in Federal Register Vol. 78, No. 205 (October 23, 2013):

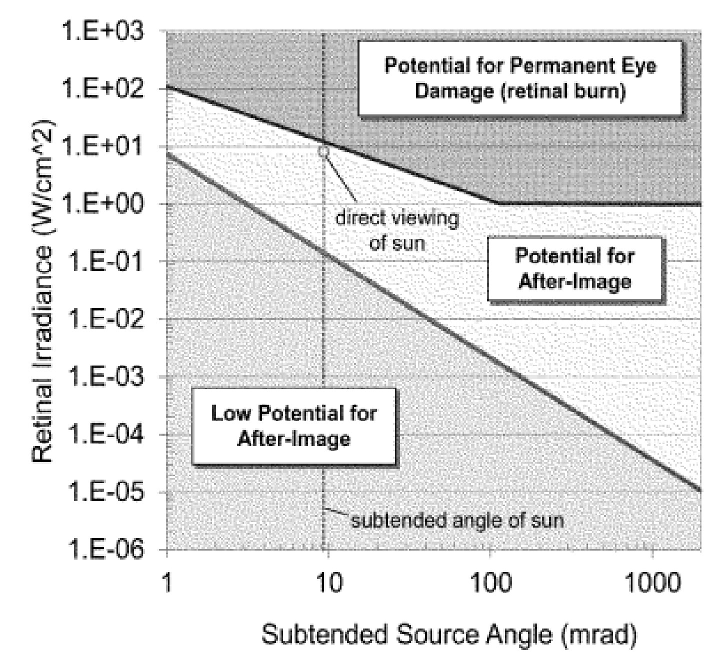
While solar PV or SHW systems (henceforth referred to as solar energy systems) are designed to absorb solar energy to maximize electrical energy production or the heating of water, in certain situations the glass surfaces of the solar energy systems can reflect sunlight and produce glint (a momentary flash of bright light) and glare (a continuous source of bright light). In conjunction with the United States Department of Energy (DOE), the FAA has determined that glint and glare from solar energy systems could result in an ocular impact to pilots and/or air traffic control (ATC) facilities and compromise the safety of the air transportation system. While the FAA supports solar energy systems on airports, the FAA seeks to ensure safety by eliminating the potential for ocular impact to pilots and/or air traffic control facilities due to glare from such projects.

Light absorption, rather than light reflection, is the main function of a photovoltaic panel. The absorbed solar radiation is converted to electricity. Modern PV panels are covered with anti-reflective coatings that allow as little as 2% of the light to reflect. This is similar to water (SEIA/Sandia study) and better than soil and wood shingles. Some of the concerns may be due to misconceptions of photovoltaic in comparison to concentrated solar power systems which use mirrors to reflect sunlight to heat water or other fluids.

There are solar installations near airports in fifteen different states and includes near airports in New York, San Francisco, Dallas, Denver, and Boston.

The FAA continues to monitor the impact to PV glare. The Interim Policy in Federal Register 78 requires that a "federally obligated airport" request a FAA review and approval to install solar on its ALP. The approval requires the use of the Solar Glare Hazard Analysis Tool (SGHAT) for all airport solar development. The tool, developed by Sandia National Laboratories, determines the potential ocular hazard based on subtended angle,

Figure 7-3
Subtended Source Angle vs. Potential for Glare Impact



The tool demonstrates that the solar installation meets the standard for measuring ocular impact.

2.2 Wind

Wind energy generating strategies were explored with this study to determine potential viability for use at Sea-Tac. Historic bio-climatic data delineating prevailing wind speed and direction was utilized as a foundational baseline in the discovery process. The predominant wind direction is from the south southwest (SSW) with speeds averaging approximately 8.7 MPH. An accompanying wind rose diagram visually illustrates the direction and intensities.

Several classes of wind turbines were explored to verify potential power generation, anticipated GHG emission reductions, return on investment (simple payback), equity payback, net present value, and internal rate of return information. Manufacturer provided performance data curves, relating power generation to various wind speeds were used in the calculations. A detailed summary overview of the findings is located in Table 05.

The study also investigated other airports experimenting with wind energy implementation at terminal buildings. Logan International Airport and Chicago Ohare International Airport have both implemented small building mounted turbines. These are small systems generating only modest returns and as a result are used primarily for educational and environmental messaging.

The study found that implementing wind technologies, given current installation economics, did not meet the Port baseline financial payback criteria. Simple return on investment for the smaller vertical axis turbines was in the 90 year payback range and the range for a larger turbine was approximately 39 years. Equity paybacks were between 59% for the smaller vertical axis type and 25 years for the larger units. It was interesting to note that the larger the system the more favorable the financial investment return.

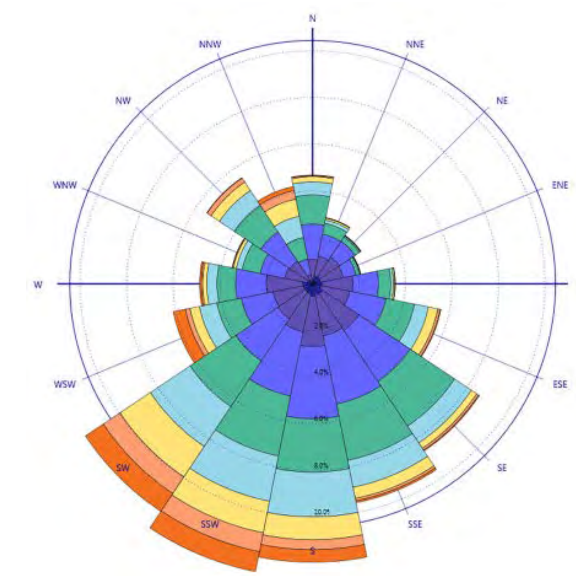
Smaller systems, with current technology, are incapable of producing sufficient power to solely provide net zero potential for most facilities, but could be considered for low power densities buildings, such as cargo warehouses or hangars. However, larger systems are capable of generating power sufficient to power the terminal facility when used in an array placed at a safe distance from the terminal buildings. This technology may hold some promise for a campus wide centralized approach as the economics become more favorable.

Implementing smaller independent site mounted vertical axis micro-turbine may provide a positive environmental messaging opportunity but will not make sense monetarily. Building mounted wind turbines are discouraged as they must mitigate the inherent structure borne acoustical transference issues associated with the placement.

The following systems were explored in the analysis.

- MICRO TURBINE: Localized site pole or building mounted 2.5 kW Vertical Axis wind turbine.
- SMALL TURBINE: Localized small site installed 375 kW propeller based wind turbine.
- MEDIUM TURBINE: Localized medium sized site installed 600 kW propeller based wind turbine.
- LARGE TURBINE: Localized large sized site installed 1000 kW propeller based wind turbine.
- MEGA TURBINE: Localized large sized site installed 2300 kW propeller based wind turbine.

Figure 7-4
Compass Rose Window Resource Map



Monthly historical wind speed and directional averages stay relatively constant throughout the year with velocities averaging around 8.7 MPH in a SSW directional pattern. The compass rose illustrated below in Figure 05 delineates predominant directional patterns and intensities.

Table 7-2
Wind Analysis

	Micro	Small	Medium	Large	Mega
POWER	2.5 KW	275 KW	600 KW	1000 KW	2300 KW
SYSTEM. POWER OUTPUT	25,000 W	275,000 W	600,000 W	1,000,000 W	2,300,000 W
SYSTEM. UNIT OUTPUT	2,500 W	275,000 W	600,000 W	1,000,000 W	2,300,000 W
SYSTEM.UNITS	10	1	1	1	1
COSTS					
CAPITAL COST	$150,000	$756,250	$1,500,000	$1,950,000	$4,485,000
MAINTENANCE. COST	$2,250	$11,345	$22,500	$29,250	$67,275
ENERGY					
PRODUCTION. kWh/Yr	17,250	110,000	271,000	407,000	1,212,000
PRODUCTION. $/Yr	$1,121	$7,150	$17,615	$26,455	$78,780
PRODUCTION. kWh/TERM	517,500	3,300,000	8,130,000	12,210,000	36,360,000
TAX INCENTIVES*					
FEDERAL	$45,000	$226,875	$450,000	$585,000	$1,345,500
INVESTMENT					
SAVINGS. AVERAGE $/YR	$1,770	$11,286	$27,804	$41,758	$124,350
SAVINGS. ANALYSIS.	$53,095	$338,576	$834,128	$1,252,731	$3,730,492
ROI. SIMPLE PAYBACK. YR	95.65	75.63	60.89	52.70	40.71
ROI. EQUITY PAYBACK. YR	60.60	47.91	38.57	33.39	25.79
NPV	$ (64,663)	$(269,148)	$(403,448)	$(389,437)	$(214,557)
IRR	-3.66%	-2.51%	-1.38%	-0.60%	0.88%

2.3 Others

Consideration was made to using bio-mass for the airport. Without large demands of heating and the low amount of suitable landfill waste, it was determined that bio-mass would not be a desirable pursuit for this project. In addition, several studies in the Pacific Northwest have noted that biomass uses more resources than not using biomass, due to the energy used to collect, transport, and use it.

2.4 Renewable Energy Certificates (Credits)

Renewable Energy Certificates (or Renewable Energy Credits, or REC) are non-tangible, tradable environmental commodities. They represent proof that one-megawatt (1 MW) of eligible renewable energy was generated and fed into the public grid. They are an approved production subsidy in the United States to incentivize producers of carbon neutral renewable energy to maximize production, even if their facility does not require the energy.

The buyer of the REC can use it for two purposes: regulatory/statutory requirements or for public recognition.

The purpose of a REC is to minimize power entering the grid that was generated by fossil fuel means. RECs can be purchased for production of energy from the following:

- Solar electric;
- Wind;
- Geothermal energy;
- Low impact hydropower;
- Biomass, biofuel, or landfill gas;
- Fuel cells or CHP (see below. Depending on state).

RECs favor locations where renewable energy is not feasible, such as lacking adequate or appropriate space, or due to low available resource. RECs do not lower energy costs. In fact, the purchase cost of the REC is on top of the energy spent to operate the facility. For these reasons, and because the majority of electricity purchased by the airport is significantly generated by hydropower, it is not recommended to purchase RECs. The airport should prioritize their own on-site generation, energy transfer, and energy efficiency prior to purchase of RECs.

3 OTHER ENERGY STRATEGIES

In addition to renewable energy strategies, there are other campus energy strategies that can reduce overall energy consumption, reduce energy costs, increase system efficiencies, or reduce impact to environment.

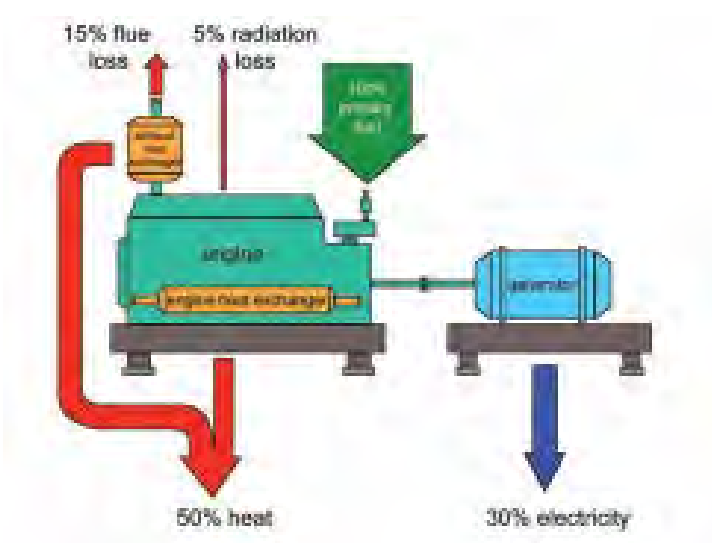
From site generation of power, to different methods of providing cooling and heating to the building, these strategies should be considered when analyzing new infrastructure requirements for the Master Plan.

3.1 Cogeneration/Trigeneration/Combined Heat and Power

“Combined heat and power” or “cogeneration” is the generation of thermal and electrical energy in a single process. Cogeneration installations can convert up to 90% of the energy of a fuel source into electrical power and heat for use in heating a building or water. This compares to conventional power generation which has a delivered energy efficiency of around 30-45% for fossil fuel sourced power plants.

Cogeneration installations can be fueled by natural gas, bio-gas or diesel. Reliability of CHP is generally good with availability factors of over 90% being common. The energy balance of a typical CHP plant is shown below.

Figure 7-5
Typical Cogeneration Diagram

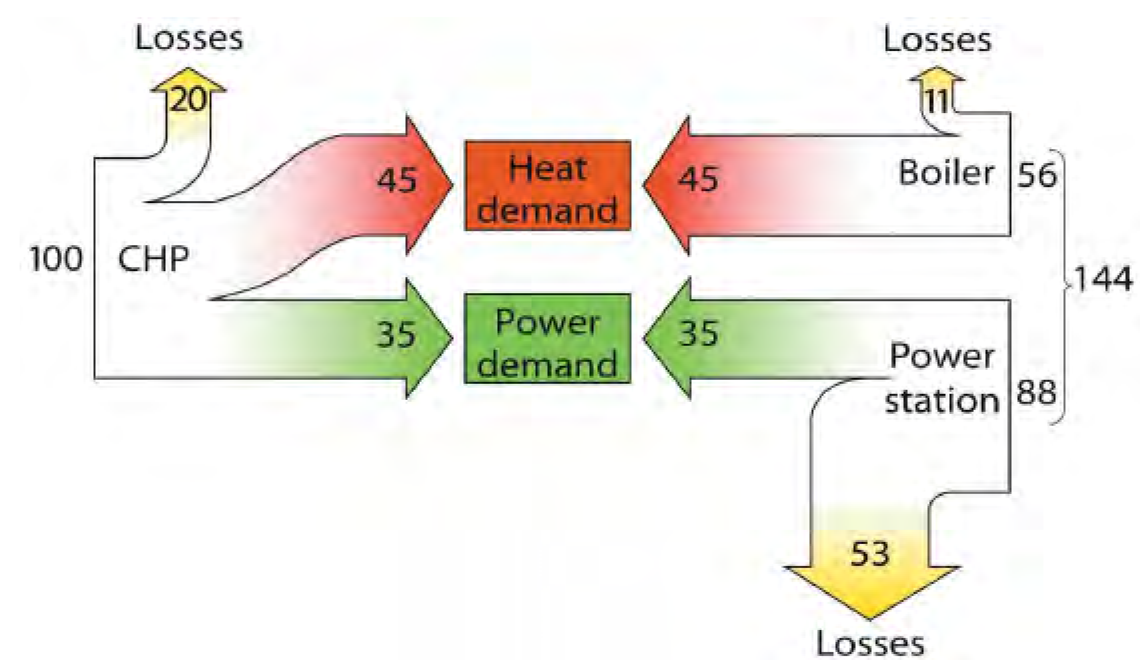


In lieu of 40-65% losses from traditional steam production and electrical production, the cogeneration system uses the waste heat from generating energy to produce steam.

This higher efficiency significantly reduces the amount of primary energy needed to generate the power and energy for a given thermal and electrical load. For high electrical costs, site energy cost can be reduced significantly using cogeneration. The delivered energy consumed on a site will increase due to CHP but overall primary energy consumption and CO2 emissions will decrease.

The amount of losses are demonstrated by the following energy flow diagram showing the comparison for cogeneration (left) and conventional fossil fuel-based utility power generation (right).

Figure 7-6
Energy Losses for Cogeneration (CHP) Compared to Traditional Electricity and Heat Generation



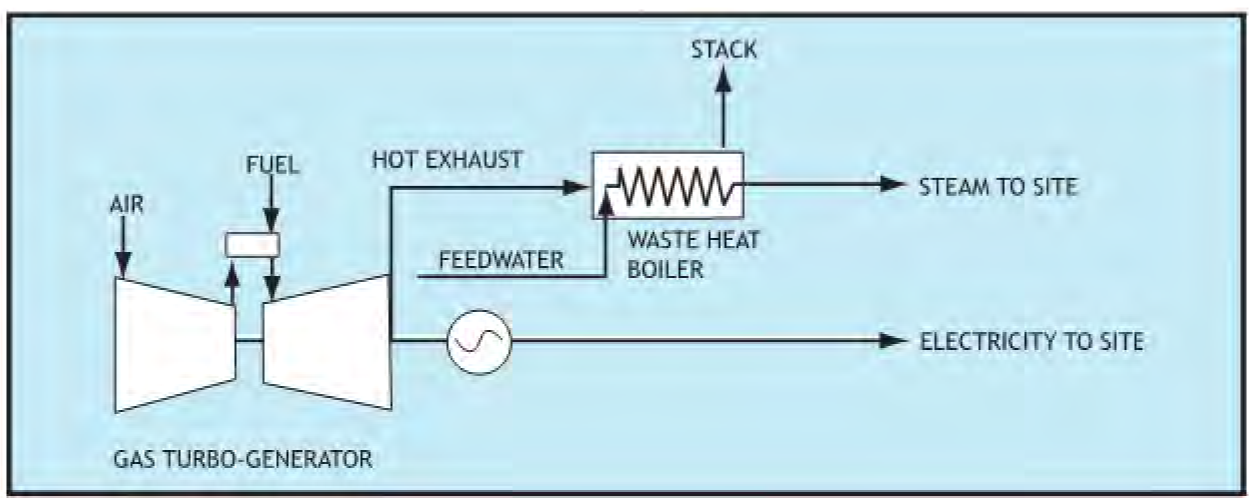
A cogeneration plant must operate for at least 5,000 hours or more per year and at least 14 hours per day to be economical, although this depends on the application. Cogeneration is specifically suited for large commercial or industrial facilities that operate continuously (24/7) and use large amounts of energy. Cogeneration is defined as producing multiple forms of energy with one energy source. In the case of the Sea-Tac facility, natural gas, or possibly a combination of natural gas and biogas could be the energy source. The gas is burned in a gas turbine to produce electricity and hot exhaust gases (from the turbine). The hot exhaust gases are normally passed through a heat recovery generator (HRSG) to generate steam. The steam is used directly for space heating, to generate hot water or to generate chilled water in an absorption chiller.

Many times, the operating cost is lower when a facilities' chilled water, hot water, steam and electricity is produced by a cogeneration system because the energy efficiency of the cogeneration system is higher than if separate pieces of equipment is used to generate the utilities. The cost for a facility to generate its own electricity is normally lower that the facility would pay to purchase the electricity from the utility. Facilities that can use all of the "free" waste heat that is generated by the gas turbines have higher efficiencies and better economics that a facility that cannot use all of the "free" waste heat. Reciprocating engines generate less waste heat that gas turbines for each megawatt (MW) of electricity produced but reciprocating engines generally have higher emissions. Gas turbines need higher gas pressures (typically around 300 psig) while reciprocating engines only need about 3 psig.

A cogeneration system normally uses a gas turbine or reciprocating engine. These engines are available about 95% of the time due to maintenance and the infrequent unexpected outage. For this reason it is common to use multiple smaller engines instead of one engine so that if an engine is unavailable the entire electrical load is not supplied by the utility, to minimize the monthly demand charge. These factors must be considered in economic calculations. A spare engine is normally nor used due to cost unless full back-up power is required. Cogeneration systems are advantages in areas where utility outages are common since they can be designed to run when the utility power is not available.

The cost of maintenance must be considered in the economics. Engine manufacturers offer a range of service contracts ranging from annual periodic inspections to performing all scheduled and or unscheduled maintenance. Normally if a facility employs maintenance personnel with gas turbine experience it is sufficient to perform most maintenance functions. For a fee, manufacturers can also supply a spare engine immediately form a pool of spares, which will allow the facility to minimize down-time. Manufacturers or 3rd parties will also finance, own and /or operate the facility.

Figure 7-7
Typical Cogeneration Flowchart



Advantages of Cogeneration

There are many advantages to cogeneration. For example:

- Overall energy cost *can* be reduced. Energy cost reductions are dependent on electrical and natural gas utility costs.
- Considering both site and source emissions, cogeneration has considerable environmental improvements over fossil fuel-based utility plants, such as power provided by Puget Sound Energy.
- Cogeneration system provides security of power. Primary electrical utility power becomes the standby power, with the CHP plant providing primary power, reducing chances for loss of power.
- They do not require power factor correction, and can reduce overall impacts caused by reactive power.
- Cogeneration can modulate output power and heat output over a wide range. The closer the thermal-to-power ratio, the more efficient the operation.
- The relative size requirement is small for the amount of power produced.
- No cooling water is required, since waste heat is used to produce steam.

Disadvantages of Cogeneration

There are also some disadvantages to cogeneration. They include:

- It adds complexity to the operation, requiring specialized staff.
- It increases the number of assets that must be managed and maintained.
- Noise and vibration can be a concern.
- The site emissions will increase.

Analysis

Using the 2014 data the relationship between the MAX and MIN steam loads which just happen to correspond to approximately the MIN and MAX electrical loads (December is the max steam load and the min electrical load, August is the min steam load and the max electrical load).

Table 7-3
Site Produced Energy via Cogeneration

Month	Electrical Load (MW)	Average Steam Flow (Lbs/Hr)	Approximate Steam Production with Two Type 1 Turbines with Unfired HRSG (Lbs/Hr)	Approximate Electrical Production with Two Type 1 Turbines (MW)	Approximate Steam Production with Two Type 1 Turbines with Unfired HRSG (Lbs/Hr)	Approximate Electrical Production with Two Type 1 Turbines (MW)
December	15.9	15,900	30,000	10	14,000	10
August	16.4	16,400	30,000	9	14,000	9
2014 Average	18.5	18,500	30,000		14,000	

Electrical load is projected to increase by about 6% once the one or two terminal expansion is completed, depending on overall efficiency of the buildings and equipment. Due to the inconsistencies of site steam requirements and main service electrical requirements happening concurrently, the best approach for consideration of cogeneration is to account for new electrical service for sizing and using the resulting steam production in both the new and existing facilities.

The best equipment fit for this scenario is either two Solar Mercury (5 MW each) or potentially two Solar Taurus gas turbines (5 MW each). Each turbine would have a heat recovery boiler (HRSG) and diverter valve. The Mercury turbines could have duct burners ahead of the HRSG's since the exhaust gas temperature is lower than the Taurus turbines (610ºF vs 900ºF). The Mercury turbines have recuperators which allow them to be one of the most efficient gas turbines available on the market today. As an added benefit, they also have very low emissions. These turbines do not require a Selective Catalytic Reduction (SCR) device to lower NO_X.

The turbines have an availability of about 95% and therefore the scheduled down time would be staggered for maintenance. The availability factor of a power plant is the amount of time that it is able to produce electricity over a certain period, divided by the amount of the time in the period. The availability of a power plant varies greatly depending on the type of fuel, the design of the plant and how the plant is operated. Everything else being equal, plants that are run less frequently have higher availability factors because they require less maintenance.

Using absorption chillers would increase the steam requirements for the cooling (summer) months, therefore improving the annual economics ("Trigeneration"). The use of absorption chillers would be necessary for Taurus turbines to make them economically viable.

Larger CHP plants (over 1MW) are typically natural gas driven reciprocating engines. Smaller CHP plants can use micro turbines with fuel cells as an alternative.

The natural gas service would need to be delivered at 300 PSIG. If that pressure was not available, gas compressors would be required, decreasing cost savings and increasing system complexity.

Other considerations for cogeneration include fuel infrastructure, plant space availability, noise and vibration concerns, complexity of equipment, additional staff required for operation, and added site emissions.

One option for cogeneration is an Energy Service Corporation (ESCO) owned and managed plant. The plant, located on the airport property, would be owned and operated by a third party ESCO. Power and steam generated by the plant would be "sold" to the airport at a negotiated rate. The amount of savings in comparison to owner-operated cogeneration plants is less, but without maintenance and operations costs, the life cycle costs can be favorable.

3.2 Fuel Cell Technologies

Fuel cell technology is a method of generating clean electricity from hydrogen to power buildings or vehicles, while emitting nothing but water. A fuel cell is like a battery. It uses energy stored in hydrogen and then via a chemical reaction with oxygen, produces water as a by-product.

First invented in the 19th century, fuel cells were used by NASA space vehicles to provide both power and drinking water. Recently, fuel cells provide critical backup power to facilities (especially high-reliability, industrial, or complex facilities), as well as provide primary power for remote facilities.

Hydrogen gas is fed into on side of a cell with air fed into the other side. The hydrogen atoms enter at the anode end of the fuel cell where a chemical reaction strips them of electrons. This produces a positively charged ionized hydrogen atoms. The release of the electrons provides the current (DC). Oxygen from the air entering at the cathode, combines with hydrogen ions to form water. An electrolyte is used to control the amount of ions passing between anode and cathode. Without this control, the chemical reaction would not occur and no current would be produced. Since the building power is alternating current based, the current must be converted through an inverter after it leaves the fuel cells. Individual fuel cells are stacked to provide more power. The taller the stack of cells, the more power is released.

Hydrogen is an energy "carrier", not an energy source. Hydrogen stores energy from the original source and is able to transfer it to be used in the fuel cell. There are two methods which hydrogen can be "energized". The first is by "splitting" water, thus isolating the hydrogen and oxygen atoms. The second method is to use hydrogen that are in hydrocarbons in a process known as "reforming".

Hydrogen is non combustion energy. Fuel cells are not subject to thermodynamic laws that limit conventional power plants. Although carbon dioxide is produced when hydrogen is removed from hydrocarbons, the process is significantly more efficient than standard combustion.

The key to performance for fuel cells is the technology and manufacturing practices required to build them, especially the choice for the electrolyte. The type of electrolyte (such as molten carbonate, phosphoric acid, proton exchange membrane) affects the quality of hydrogen required and will impact the catalyst material. Each type of electrolyte has both advantages and disadvantages compared to others, but none are inexpensive or can be scaled up to size needed to operate the airport.

One of the more popular electrolytes – molten carbonate – uses high temperature salts to produce the chemical reaction. It is capable of converting fossil fuels, such as methanol, syngas, diesel, or natural gas, to a hydrogen-rich gas. Some disadvantages to these types of fuel cells are that they take time to heat up to the temperature range required (excess of 600°F) and have short life spans since the high temperatures lead to corrosion of the platinum electrode catalysts. Some advantages are that these types of fuel cells are resistant to impurities and when combined with cogeneration (CHP), can produce 85% energy production if the heat from the molten sand is used for the CHP process. These systems can range between 300kW and 3MW.

In addition to buildings, several entities are producing fuel cell vehicles, including buses. These vehicles are essentially electric vehicles that use the fuel cell to produce the energy for the motor. Fuel cell buses are being tested in locations such as San Francisco and Oakland.

The major benefit for fuel cells is that it produces clean, non-combustion energy. The major drawbacks to fuel cells are the costs associated with the fuel cells, ongoing costs of expensive platinum electrodes, and the need for a steady supply of hydrogen.

For Sea-Tac, fuel cells are a good option if combined with a CHP plant that can pair the heat requirements of the electrolyte with the turbine and power generation of the CHP plant.

3.3 Metering Strategies

Although some systems are not well metered, Sea-Tac is currently improving the amount of metering that have for all energy and water utilities. Even though systems such as tenant energy, natural gas, and chilled water are well represented at the terminal, steam metering, water sub-metering, and electrical sub-metering have a ways to go.

Sub-metering allows for better functionality and control of costs. Sub-metering is used to reduce energy and water consumption and costs. Understanding the "real time" level of consumption (or cost) allows decisions to be made to reduce those costs. In addition, submeter data can provide a crucial diagnostic tool for operations and maintenance. If a system's energy unexplainably trends upward, it could indicate an energy-consuming asset is malfunctioning or requires calibration to operate more efficiently. Likewise, water consumption trends that exceed expectations can indicate leaks or malfunctioning fixtures. Known events such as weather, construction activities, passenger traffic, or other "documented" events can explain sudden spikes in energy or water usage. When these have not occurred, the submeters can indicate which system is the likely culprit. With a traditional overall meter, only the trend upward or spike in usage would be noticed. With submetering, the specific system or building areas that is causing the irregular reading can be determined. Once identified, the submters can also be used to track maintenance. In addition, submeters can be used to identify inefficient operations so that renewal plans can be developed to replace these assets.

Submetering can also be used to verify utility bills, especially in tenant situations. Currently, Sea-Tac submeters most of their tenants for natural gas and electricity. Use of submetering other locations in the airport can also help understand what areas and departments use energy.

Submetering can give opportunities for demand response or load shedding. Using a "smart" demand response system, individual assets can be classified based on their critical nature for airport operation and passenger comfort. Those assets that are not critical can be shut off during periods of high demand, if required either by public utility or the desire to operate the building using an alternative energy source such as renewable energy.

Finally, submetering can be used to benchmark performance and document overall improvement. Using data from submeters, sustainability goals can be measured and reported based on "real time" data. In addition, individual areas can be compared and benchmarked to determine realistic improvements. For example, if an area (such as a concourse) represents only 10% of total energy of the terminal, then an overall meter would not recognize a significant reduction of energy in this area. If the concourse reduced energy by 20% after a renovation focused on energy efficiency, the overall meter would only read as a 2% reduction overall. The submeter for the concourse would recognize that this reduction was due to the renovation.

Metering and submetering are not only becoming more popular in modern construction, especially in sustainable facilities, they are also being required by regulatory agencies. Both ASHRAE 90.1-2013 and LEED V4 have submetering requirements for buildings. Washington State Energy Code is currently based on ASHRAE 90.1-2010 and will likely adopt the 2013 standard in the next generation of the code. In addition, the Energy Policy Act of 2005 and Energy Independence and Security Act of 2007 both develop the framework for the regulatory requirement for metering. Buildings, like the airport, with multiple tenants will have more restrictive requirements than single-tenant buildings.

Metering strategies for these different standards and policies breaks down the requirement between HVAC, electrical, and lighting. ASHRAE 90.1-2013, for example, requires individual metering for different buildings and areas within a building:

- Total electrical energy;
- HVAC;
- Interior lighting;
- Exterior lighting;
- Receptacle loads;
- Other energy resources (chilled water, steam, natural gas, diesel, hot water, etc.).

For electrical systems, ASHRAE requires that meters report data every fifteen minutes. For other resources, the meter will report data every hour.

ASHRAE 189.1-2011 adds additional requirements for metering. These include:

- District energy;
- Geothermal energy (including GSHP);
- On-site renewable electrical energy;
- On-site renewable thermal energy;
- Potable water;
- Reclaim water (from municipal or outside source);
- Harvested water.

LEED V4, *Advanced Energy Metering* credit requires additions metering. These include:

- Power factor (overall);
- Non-renewable energy sources (such as CHP);
- Chilled water systems (chillers, pumps);
- Condenser water systems (cooling towers, pumps);
- Hot water system – natural gas (boilers);
- Hot water system – electrical (pumps);
- Air handling systems (cooling and heating separate, if appropriate);
- Fans;

- Service hot water.

In developing a metering plan, it is important to prioritize how meters are implemented. Installing meters on existing systems can be an expensive task, especially if electrical panels and substations share multiple consumers of energy. Redistributing and consolidating these similar energy consumers can be expensive capital expenditure that needs to be weighed against the information provided with the meters. CAPEX costs associated with meters include the purchase of the meters themselves, ancillary devices (such as current transducers or safety switches), control system communication infrastructure modifications; control system interface modifications, and any aforementioned redistribution of power. OPEX costs include ongoing maintenance of meters, calibration of meters, and analysis of data. Data gathered should kept simple and only include what is deemed useful to properly diagnose, benchmark, and understand energy and water consumption and costs.

A recommended approach for implementation for new submeters, not already planned is as follows (in order of priority):

- All new construction or major renovations;
- Central plant equipment, especially steam;
- Site generation of electricity;
- Major distribution lines, especially at building entrances;
- Areas of the building that exceed 10,000 square feet (highest EUI first);
- Everything else.

3.4 Central Plant Strategies

The central mechanical plant (including both steam and chilled water systems) is one of the highest consumers of energy at the airport, rivaling the flightline charging/PCA systems, baggage handling, and the STS. The energy – electricity and natural gas – is converted to steam and chilled water that is used throughout the terminal for comfort HVAC, water heating, and freeze control.

As technology improves, steam and chilled water production equipment become more efficient. Driven by the rising costs of energy, the goals to reduce dependence on fossil fuels, and regulatory requirements that mandate both energy efficiency and environmental quality, new equipment is much more efficient than even the most recent generations.

Central plant strategies have been improved through research and development and technological advances from manufacturers, universities, research laboratories, sustainability-based organizations, and other large campus operators. Traditionally, airports only focused on providing the necessary performance to maintain the environmental conditions within the terminal and other buildings. Now, the reduction of energy, improvement of plant efficiency, improved reliability, and reduced impacts to the environment are additional primary goals of the operators.

New strategies provide the same performance while allowing the plant to use less resources and operate less often. For example, using free cooling opportunities in one example strategy that can reduce central plant energy consumption that Sea-Tac is already taking advantage of. Other strategies intended to increase efficiency, reduce losses, and reduce energy consumption are listed in the following paragraphs.

3.4.1 Decentralized vs. Centralized

One of the main considerations for the airport is whether to maintain the central plant approach as the airport develops for future growth, or transition to a decentralized approach. Long distances between buildings, mismatched performance requirements between buildings, likelihood of leaks, and potential for thermal losses in chilled water or steam systems all demonstrate that this comparison is necessary in order to maximum energy efficiency and lower overall costs of ownership.

Current HVAC trends include separation of ventilation system from the means for space cooling and heating, minimizing fan energy through use of multiple fan arrays, and using warmer chilled water or cooler heating water for space conditioning. Each of these trends can have impact to the centralized vs. de-centralized decision.

Central Heating

As shown in previous sections, the use of natural gas to produce steam is one of the largest components of the terminal's overall energy profile. Seattle's cooler and wet climate demands the need for nearly year-round heating and the ability to "dry out" the building. For this reason, the HVAC must produce a means to maintain comfortable temperature and dehumidify the terminal environment.

Modern HVAC systems rarely directly use steam in heating of spaces. Control of steam at a coil can be difficult and require continuous calibration to maintain operation. Most current HVAC systems use hot water through a coil to heat the space. The hot water flow is controlled to maintain the necessary performance.

A centralized boiler plant must generate a heating medium, such as steam, at a higher temperature and/or pressure than what is required at the coil. The higher temperature and pressure allows the steam to be distributed long distances with smaller distribution mains. This higher temperature and pressure is required to compensate for thermal and friction losses in the distribution over these long distances.

Energy to produce steam is very high, however. Additional energy must be used to generate steam than what is usable as hot water at the air handling equipment. Energy at boilers has many losses, such as production losses, radiation losses, distribution losses, condensate losses, and blowdown losses.

Production losses are those based on the efficiency of the boiler. Wasted energy ends up leaving the building through the stack. In addition, boilers constantly radiate energy (heat wasted through their shell), even when idle. These losses can range between one and four percent of the overall capacity, depending on load through the boiler.

Distribution losses are due to heat loss through the pipe as the steam (or hot water) is being transported to the buildings. Insulation slows down this continuous heat loss through the piping, but insufficient insulation, damaged insulation, or improperly installed insulation can result in considerable losses in heat.

For steam systems, condensate is returned back to the boiler to be regenerated as steam. Faulty steam traps, leaking pipes, improperly vented receivers all reduce the amount of condensate that returns to the boilers. This reduction in condensate requires additional makeup water to be required for the boilers. Additionally, steam systems build up concentrations of impurities that must be removed. In order to do this, part of the condensate is drained and replaced with clean water to maintain acceptable concentrations (referred to as “blowdown”). In addition to increasing demand for water, the makeup water is much cooler than the condensate and therefore requires additional energy to heat it to become steam.

Although steam production is a traditional method of providing “district heating” on a campus, the energy requirements have made some airports and similar facilities rethink the use of steam. Conversions from steam production to heating water solutions or other direct heating methods needs to be analyzed using a TCO process. Energy savings should be compared to CAPEX expenditures for renovation of existing facilities. Operational costs for steam systems should be compared against multiple heating systems throughout the Terminal. For new systems, considerations of alternative approaches should compare energy and operational costs against impacts to building footprint (additional space requirements for these alternate methods).

Central Cooling

Chillers are typically their most efficient at full load. Some modern chillers with variable speed drives are designed favoring part load conditions, but in general, chillers operate with the lowest electrical consumption per ton of refrigeration when they are at full load. For this reason, chiller plant strategy is to provide a group of chillers that meet the performance requirements of the facility, while allowing the chillers to operate efficiently most of the time. Chillers are staged based on actual load requirements, so that as multiple chillers are enabled, they are operated at their peak efficiency.

The major “losses” in a chiller plant come from three areas: thermal losses, frictional losses, and “low delta-T”.

Thermal losses are due to heat outside of a pipe radiating into the pipe, heating the chilled water. As before, insulation slows down this process, but damaged or improperly installed insulation allows more heat gain to the chilled water. This heat comes from heat built up in steam tunnels (from heat loss from steam pipes) or when pipe is in an environment warmer than the chilled water. Over the course of the pipe distribution to the various buildings, even a properly insulated chilled water system can increase by a few degrees over what it leaves the chiller. This increase in temperature results in energy spent without the benefit of cooling at by the end user (comfort HVAC), and therefore represents a thermal loss.

Distribution losses are due to friction in pipes. The longer the pumping distance, the higher the friction losses. These friction losses result in higher pumping energy required by the chilled water pumps. Higher horsepower pumps are less efficient than smaller pumps.

Finally, “low delta-T” syndrome is the condition where chilled water returns to the central plant only a few degrees warmer than what it was supplied. This small difference is due to operation of chillers at a higher load than the load in the building. Beyond operational and performance problems with “low delta-T”, energy usage is very inefficient due to chillers operating at their least efficient point and the pumping energy required.

Considerations

Ultimately, the objective for large campus HVAC systems is to provide the necessary performance to meet the building needs at the most appropriate CAPEX, OPEX, maintenance cost, and utility cost. Considerations should be given for:

- Building performance;
- Thermal performance;
- Availability for mechanical space (can be considerable);
- Efficiency;
- Noise control;
- Indoor environmental control;
- Reliability;
- Flexibility;
- Future replacement costs;
- Access to utilities required for system;
- Diversity.

For cooling systems, decentralized options include the use of direct expansion, smaller chilled water systems, ground source heat pumps, water source heat pumps, variable refrigerant systems, and others. For heating, some options include remote water boilers, direct or indirect heating, or solar thermal systems. Each has specific benefits and drawbacks for consideration.

Direct Expansion

From a cost standpoint, direct expansion (DX) is one of the least costly in terms of CAPEX. It can have a comparable OPEX to centralized chilled water systems and has a higher energy costs. Direct expansion is a system that uses refrigerant directly to cool a space. Although split systems are possible for smaller facilities, large DX rooftop units are traditionally used in this approach. From an energy standpoint, DX rooftop units can use significantly more energy than other approaches (as much as 300%). Ultra-efficient DX rooftop units are being produced by various manufacturers, but the energy use is still typically higher than an efficient chilled water system.

Since large mechanical spaces, piping, chases for piping, valves, insulation, and supports are not required, the initial capital cost (design, construction materials, and construction labor) is typically significantly less than a central chilled water system. Operational and maintenance costs are similar to a chilled water system. Even though DX rooftop units require less ongoing maintenance than a chilled water system, the compressors in them last only fifteen to twenty years. There are many compressors (from one to eight) in a DX rooftop unit, which exponentially increases service and renewal costs as these compressors wear out. Since the DX rooftop is located outdoors, service and maintenance would be outside in the weather. Rainy or winter weather can slow down maintenance.

Other considerations for DX rooftops include space considerations, noise, aesthetics, and reliability. Although DX rooftop units require no interior mechanical room space or chases to run piping, the ductwork from a DX rooftop is typically much larger than a chilled water VAV air handling unit, and therefore size of ceiling plenums to accommodate this ductwork must be considered. Central plants are typically remote of the terminal and therefore the noise and vibration from the large machinery does not impact the passengers. With DX rooftop units, the compressors are located on the roof, and therefore require special consideration to minimize noise and vibration. DX units on the roof can be very large (sizes up to twenty feet wide, ten feet high, and thirty feet long). For architectural roofs, this can be a challenge to conceal the DX units. Finally, a centralized chilled water system typically has multiple backup chillers and pumps for reliability. Although many large DX units have multiple compressors, each loss of a compressor results in a significant reduction in performance.

Certain DX units operating in reverse can provide heating to a space. This is referred to as a heat pump. Heat pumps provide limited heating to a space. Depending on the heating needs, supplemental heating is required, especially at perimeter spaces and near high infiltration areas.

Variable Refrigerant Flow

A variable refrigerant flow (VRF) system is special type of DX split system that uses a large remote compressor (condensing unit) piped to individual ducted and ductless indoor units for cooling. Each of the indoor units represent a single “zone” of cooling.

The benefit of a VRF system is that it balances the natural differences of heating and cooling within a space. For example, if an interior space requires cooling and a perimeter space requires heating, then heat from the interior space is “rejected” to the refrigerant and that heat is transferred to the perimeter space needing heat.

The compressor only operates when any additional cooling is required. Additional heating, like a conventional heat pump, is supplemented by other means, such as electrical resistance heat or hot water.

Benefits and drawbacks are similar to a conventional DX system. The energy usage for a VRF system is typically much lower than a DX system (and can be similar energy efficiency to a chilled water system) since the compressor only operates when the requirements of cooling and heating do not balance. Noise and size requirements are also much different than conventional DX. Since the VRF system uses a remote compressor, the largest noise source is separated from the passengers. VRF systems use small indoor units, and therefore ceiling plenum requirements are minimal.

The additional drawbacks of a VRF system are that they are typically small systems, they have length limitations, refrigerant piping is located in space, and added OPEX cost. VRF systems currently have size limitations that prevent them from being used for very large areas such as a concourse. Refrigerant piping has a limitation on distance, so remote compressors must be located somewhat near the indoor units. Refrigerant piping connecting between the compressor and indoor units is located above the ceiling plenum. A catastrophic failure of a refrigerant pipe would spill refrigerant oil into the space instead of water. Since the indoor units are small, there are exponentially more units in a VRF system that require ongoing preventative maintenance. Finally, unlike a chilled water system that uses multiple pumps or chillers for reliability, a loss of the compressor would result in loss of cooling or heating to all units attached to the system.

Small Chiller Plants

In lieu of a centralized chiller plant, several smaller satellite chiller plants can be used. Smaller chiller plants could be used specifically for a building or building area, instead of pumping chilled water from a single location.

Smaller chilled water systems could either use outdoor air-cooled chillers or indoor centrifugal or screw water-cooled chillers. The air-cooled chillers would have similar OPEX costs and utility costs to a DX system. From a performance standpoint, the air-cooled chiller would have similar performance as a conventional chiller system. Location of air-cooled chillers is one consideration.

Water-cooled chillers in smaller application would be 480V systems. Variable speed drives for this chiller size range that utilize the cooler Seattle temperatures to improve overall part load efficiency are economical, blending a small increase in CAPEX with a large potential for utility cost decrease. Other technologies, such as magnetic bearings, can together make the smaller chilled water system efficiencies similar to that of a large chiller plant.

The drawbacks of these systems include space considerations, cooling tower considerations, and operation/maintenance costs. More chiller plant locations require additional mechanical space to be built, therefore increasing building CAPEX costs. Friction losses if the cooling towers are not near the chillers are similar for the condenser water as the central plant is with chilled water.

Cooling towers, however, are open systems and lose some of the dynamic head advantages that a closed loop chilled water system has. Finally, the increased machinery has overall operational costs increases in the form of more preventative maintenance, more repair, and more personnel required to operate the facility.

One of the benefits of a small chiller plant is that, if connected to other plants, increases overall reliability of the system and reduces pumping requirements.

Water Source Heat Pumps

One variation of DX equipment is water source heat pumps (WSHP). Water source heat pumps are DX units that use water – typically from a cooling tower – to reject heat from a compressor to when cooling. From a cooling and heating standpoint, it operates the same way as a conventional heat pump. Instead of rejecting heat from the compressor to the air when cooling (or reverse when heating), it rejects or gains heat from the water. In turn, the efficiency of the refrigeration cycle is much more efficient than the air-source counterpart. Where air-cooled systems have efficiencies between 10 to 16 SEER (smaller ones even higher), water-cooled heat pumps can have efficiencies up to and exceeding 40 SEER.

Water source heat pumps range in size from less than a ton of cooling to over 100-tons of cooling per unit. This makes them comparable to conventional air handling units. The water-source heat pumps are typically larger, however, because the DX compressors are located in the unit.

The water source for a WSHP is typically from a cooling tower. Condenser water, instead of chilled water, is pumped to the WSHPs. WSHPs have similar benefits and drawbacks to DX systems: noise, OPEX costs, and duct sizing. WSHPs, since they use ambient temperature condenser water, are less prone to thermal losses of long lengths of piping.

Ground Source Heat Pumps

A specialized form of WSHP are ground source heat pumps (GSHP). They use the earth or a large body of water as a heat sink, eliminating the need for a cooling tower.

The use of GSHP, also called Geo-exchange systems, for large commercial projects, especially in institutional projects is an increasing trend. The potential for using GSHP to provide cooling and heating for the airport was reviewed within this study. At full load, these systems have similar efficiencies to cooling-tower water-sourced heat pumps (WSHP) and 20% to 50% better than air-sources heat pumps (ASHP). At part load or cooler temperatures, GSHP have a much better COP than their WSHP counterparts.

They have their best annual efficiency when cooling and heating requirements are balanced. In addition to heating water for coil usage for comfort heating, these systems can provide hot water which could be used to heat domestic water for restrooms. Since they are a closed loop system, they require virtually no chemical treatment and have a very small makeup water component.

CAPEX costs are higher than other systems, especially where ground space is not available or soil conditions are not favorable for boreholes. These systems also require considerable space for implementation. GSHP systems can raise ground temperature between 5°F -10°F in a 10-year period, especially in large systems with primarily cooling requirements. Any unbalanced loads affect total system efficiency.

There are four primary types of geothermal systems typically used in building, each with varying operational efficiencies, size requirements, and installation cost.

- Vertical ("borehole") closed loop: Ground-source piping is installed vertically. A looped pipe is installed in a "borehole". Approximately 250-650 square foot per ton is required for borehole field (one acre would provide 70-170 tons of cooling). Boreholes would range between180 to 400 foot of depth per ton. At over 7000 tons maximum for existing terminal, this would require 40 to 100 acres for the boreholes;
- Horizontal ("Trench") Closed Loop: Ground-source piping is installed horizontally in trenches. Approximately 2500 square foot per ton for trench field (one acre would provide about 17.5 tons, although "slinky" systems can reduce this size). Trenches typically 4-6 feet deep and trench lengths range between 125-300 feet per ton. Loop temperatures, which affect system efficiency, are higher than vertical installation. High water tables can improve efficiency and reduce size. For same 7000 tons maximum, the horizontal system requires up 400 acres;
- Surface Water ("Pond") Closed Loop: Piping is installed in a lake or large pond. The depth of pond must be 15-20 foot minimum. Provides 10 to 50 tons of cooling per acre of pond. Provides the coldest loop temperature (most efficient system). Resulting size requirement 140-700 acres of pond area;
- Open Loop ("Aquifer") System: Not a closed system. Draws water from aquifer, river, or lake to be used for cooling and deposits heated water back into the water. Typically only suitable for small systems due to amount of water volume required. Systems near large lakes or rivers can be larger. Requires considerable demineralization and water treatment. May require regulatory agency impact due to connection to public aquifer. Not practical for this application.

GSHP systems have COPs in the range of 3.5 to 5.0, depending on factors such as ground temperature, loop configuration, size of system, and balance of heating/cooling. This equates to 0.70 to 1.0 kw/ton.

Many factors go into the installed cost for a GSHP system. Larger systems have a greater cost. Vertical installations with deep boreholes have more costs than horizontal counterparts. Overall, the costs for a GSHP system (including all piping, pumps, heat pumps, exaction, and controls) range between $20 -$30 per square foot of conditioned space (ASHRAE Journal October 2012). Building area costs and additional system costs for other services in a decoupled plant will be additive to the GSHP system costs.

- Incentives are in form of Federal Income Tax credits and accelerated depreciation. It is assumed these would not apply to Seattle Tacoma International Airport.
- Actual soil conditions not provided: assume ground temperature of 55°F, soil conductivity of 1.1 BTU/(h*ft*°F), diffusivity of 0.75 ft^2/day.
- Piping is 1" SDR11 piping (HDPE), grout thermal conductivity of 0.80 BTU/(h*ft*°F)

High-level estimated CAPEX, OPEX, and energy costs were conceptually compared to the existing central plant. Overall energy consumption for the GSHP proved higher than the existing chiller and boiler plant. The overall annual chiller plant efficiency utilizing the plate-and-frame heat exchangers for free cooling is between 5.7 and 6.0. The annual GSHP efficiency lands between 3.5 and 5.0.

Overall, the existing central plant efficiency is comparable to the most efficient GSHP systems and more efficient than conventional GSHP systems. Additionally, the outside available areas is limited in space available for borehole wells necessary for GSHP. The airfield can be considered for bore hole fields, but the down time required to drill holes and install the loops could be restricitive. There are insufficient predicted energy savings to offset the capital cost for installing a new GSHP system and decoupling the central plant. Therefore, there is no possible payback for a GSHP system and is not recommended.

Recommendations

For the existing central plant, the ongoing audits and retrocommissioning have proven that the measures taken are beneficial in the form of reduced consumption and costs. The next audit – Stage 4 – should continue this trend of fine-tuning performance and energy efficiency.

As the chillers and boilers continue to age, the costs of maintaining the chillers and boilers added to utility costs should be compared against capital costs associated with replacing the chillers. Since the central plant is one of the largest consumers of energy and critical to the operation of the airport, careful planning should occur.

Based on the amount of energy used for both the existing steam boiler plant and chiller plants as well as the forecast from the simulation model, the recommendation for the current central plant and future HVAC is to retain the chiller plant, build a new chiller plant next to new piers and terminal, and phase out the use of centralized steam by generating hot water near where it is being used. This hybrid approach keeps the cooling centralized and de-centralizes the heating plant. The reason for this is that with the plate-and-frame heat exchanger, the chiller plant has a very good system efficiency. In addition, the operational costs with a single location are less than in most of the other options due to less installed assets centralized in a common location. It gives the airport the ability to focus environmental improvements on a single location, like what has been done with the retrocommissioning and energy audits. A single location allows both better reliability. The diversity of a central location occurs at multiple levels: unit, zone, area, building, and airport. Diversity can range between 0.60 to 0.80 in a centralized location versus decentralized layouts, requiring less installed capacity. A centralized chiller plant centralizes O&M.

Centralized chiller plants allow for more efficient use of the cooling towers. Cooling towers with close proximity can provide free cooling such as is currently being done for the existing plant. A centralized chiller plant improves possibility of integrating systems such as renewable energy, CHP, or thermal storage (see below) to the cooling side. A centralized chiller plant uses a single electrical room, allowing better implementation of submetering.

New chiller plants should consider siting to minimize impacts to passengers (such as aesthetics and noise) while optimizing performance and minimizing losses. A truly centralized chiller plant can optimize pumping strategies and distribution strategies based on equidistant relationships.

Pumping strategies for both the existing terminal and new expansions should consider tertiary pumps. Currently, the large chiller pumps must maintain enough head pressure to move chilled water through the most remote and highest restricting coil. This drives up horsepower that is not needed other than a small percentage of the end users. Tertiary pumps allow these large secondary pumps to be significantly unloaded and therefore use far less energy. These pumps would push the chilled water to the building, where the tertiary pumps would take over. The much smaller, more efficient tertiary pumps would boost pressure to meet the needs of the specific building.

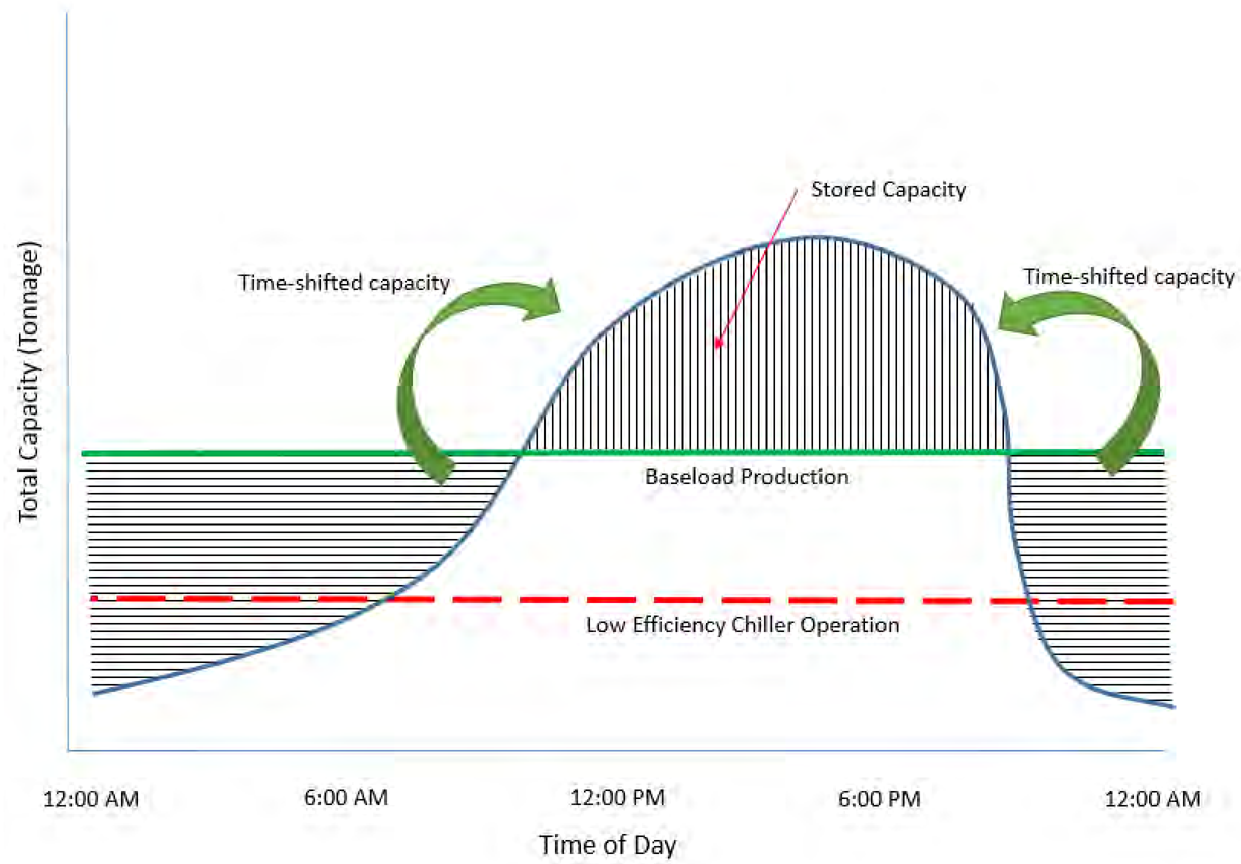
On the heating side, due to the large amount of energy and cost required to produce steam, decentralized heating plants should be considered. In lieu of steam, production of hot water near the building can be considered. For the existing terminal, existing steam-to-hot water heat exchangers can be removed and replaced with an efficient hot water boiler, such as a condensing boiler or heat pump boiler. For example, a full condensing natural gas hydronic 350-hp boiler with ultra-low emissions, up to 98% efficiency, and a 5:1 turndown ratio.

3.4.2 Thermal Storage

The use of thermal (ice) storage is currently used at Seattle for the PC Air plant.

Expanded use of thermal storage is one option for the airport. Unlike other energy strategies, thermal storage systems do not directly reduce energy consumption for a facility. Traditional central plants generate energy on an "as needed" basis. At peak cooling or heating periods, the chillers or boilers are operating at their highest load and highest energy consumption. Thermal storage allows the production of chilled water, hot water, or ice to be separated from the demand when these are needed. If a utility has a lower "non-peak" rate schedule that is favorable to overall energy costs, then thermal storage systems allow the energy spent to produce these medium to occur during these "off peak" hours. Thermal storage systems have additional benefits. For one, production and storage of the medium (such as chilled water) can provide additional reliability to a system. If a chiller needs to be shut down for a short period for maintenance, the stored water can be used to compensate for the offline chiller. Secondly, use of thermal storage allows for installation of a smaller chiller plant. Instead of only operating chillers when they are needed, a strategy can be developed to operate chillers continuously at their most efficient point and store water when not needed to be used when it is needed (see below).

Chart 7-1
Daily Usage vs. Thermal Storage



In the chart above, the chillers operate along the "baseload production" line throughout the day. This prevents the chillers from having to operate in less efficient modes for lower demand time periods, and uses the stored water during higher periods of demand. This strategy can reduce the size requirements of the chiller plant, since the plant no longer needs to be sized for maximum demand requirement.

FINAL RECOMMENDATIONS

Based on the findings within Task 6.12, this Section describes recommendations that should be implemented in the Master Plan.

1 SUMMARY

There are two major alternative options analyzed within Task 6.12. The first is determining whether expansion of the existing terminal or building a second terminal is the best approach to meet the 2034 passenger traffic expectations, based on energy consumption, water usage, and total costs of ownership. The second is determining the cost impacts of various levels of sustainability from minimum code compliant to net zero building.

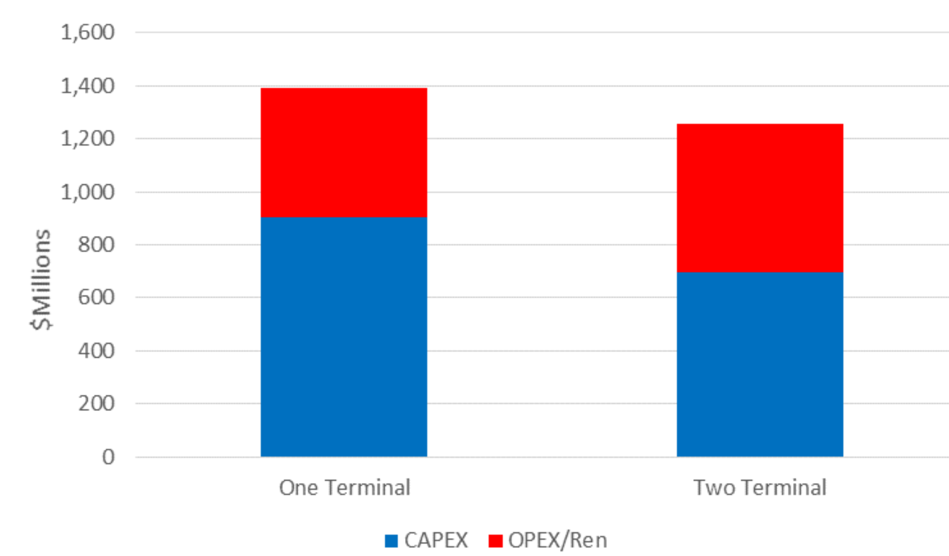
Based on the findings within this Task, the "two terminal" alternative has lower overall costs as compared the "one terminal" expansion approach. Section 6 goes into detail about the findings. Even though the "two terminal" option adds 2,901,000 square feet in comparison to the "one terminal expansion" option's 1,043,000 square feet, the total costs favor the "two terminal" option.

As a summary, the CAPEX for the one terminal option is significantly higher than the two terminal option. Using present day costs, the expansion of the current terminal would cost approximately $902M compared to the $696M cost to build a second terminal. Much of this cost is due to the staging and temporary services required to expand the operating terminal. The twenty-year OPEX, renewal costs, and utility cost is $87M for the one terminal expansion and $91M for the two terminal option. Extending that to forty-year OPEX, renewal cost, and utility cost, the one terminal cost is $490M, whereas the two terminal cost is $563M. This gives a total 20-year cost of $989M for one terminal and $787M for two terminals. The 40-year cost is $1.392B for the one terminal and $1.259B for the two terminal. This indicates that the two terminal cost is $133M less than the two terminal option.

Considering inflation and utility cost escalation, the one terminal cost is $1.234B (based on year each building is built) and the two terminal cost is $1.047B. The 20-year OPEX, renewal cost, and utility cost for the one terminal is $117M, while the two terminal cost is $123M. Moving up to 40-years, the OPEX, renewal cost, and utility costs increase to $829M and $958M, respectively. This gives a 20-year TCO (with inflation and utility cost escalation) to $1.351M for the one terminal option and $1.17B for the two terminal option. At 40-years, the inflation-impacted TCO is $2.063B for one terminal, and $2.005B for two terminals, at a difference of $58M.

The use of discounting gives the final comparison. The *discounted* one terminal option CAPEX is $617M and the two terminal is $402M. The 20-year OPEX, renewal cost, and utility cost is $45M and $46M, respectively. The 40-year OPEX, renewal cost, and utility cost is $161M and $181M, respectively. This gives a discounted TCO of $662M vs. $448M for twenty years and $778M vs. $583M for forty years, resulting in a $195M difference.

Chart 8-1
TCO (40-year comparison) of One vs. Two Terminal (current value)



Overall, based on the analysis, the recommendation for the passenger expansion is two terminal approach (based only on asset TCO costs and energy/water analysis – operational comparisons are reviewed in other reports) with a LEED prerequisite or LEED Silver standard.

Other recommendations based on the research, analysis, and discussion of this task are split into three categories: total cost, energy, and water.

Total Cost of Ownership/Asset Management Recommendations and Findings

1. OPEX and renewal costs are more significant than utility costs for current rate structure;
2. Consider environmental and social impacts along with TCO results in the asset selection and management decision making process. Develop a combined strategy for evaluating options during planning and implementation phases;
3. Using asset management tools, identify critical systems, their vulnerability to failure, and the consequence of the failure;
4. Develop a reliability centered maintenance program for these critical and important assets. Use asset management tools to track FCI and consider consequences of failure;
5. Develop strategy for maintenance spending for existing assets based on criticality, vulnerability, efficiency and reliability;
6. Consider leased equipment or ESCO operated systems.

Energy System Recommendations and Findings

1. Since LEED prerequisite and Washington State Energy Code mixed with Port of Seattle water efficiency policies are so similar, consider LEED prerequisite a standard for all Port owned and operated facilities;
2. Current heating plant uses significantly more energy than the cooling plant. Consider decoupling only the heating plant and replacing with high efficiency decentralized heating plants;
3. Alternatively, replace the existing natural gas-fired steam boilers with on-site generation (biofuel or natural gas fired CHP micro turbines) in order to produce much more efficiency steam and generate power, with similar environmental impact. Consider steam-fired absorption chillers;
4. Continue energy auditing/retrocommissioning program;
5. Use passive systems, such as natural ventilation to reduce energy requirements;
6. Maximize free cooling and economizer use;
7. Continue to improve lighting efficiency and controls;
8. Implement renewable energy, especially as technology improves, incentives become available, cost decrease, and size/efficiency improves;
9. Focus on control and reduction of energy required for plug loads and non-HVAC, non-lighting equipment;
10. Implement and improve current submetering strategies;
11. Implement solar thermal for domestic water heating;
12. Consider storage technologies, such as expanded thermal storage, fuel cells, etc.;

Water Recommendations and Findings

1. Document and manage construction water usage and other non-standard usage;
2. Water for non-potable uses (such as cooling tower, irrigation, or urinal/toilet flush) should be through harvested or gray water source first;
3. Implement and improve current submetering strategies, including harvested/gray water.

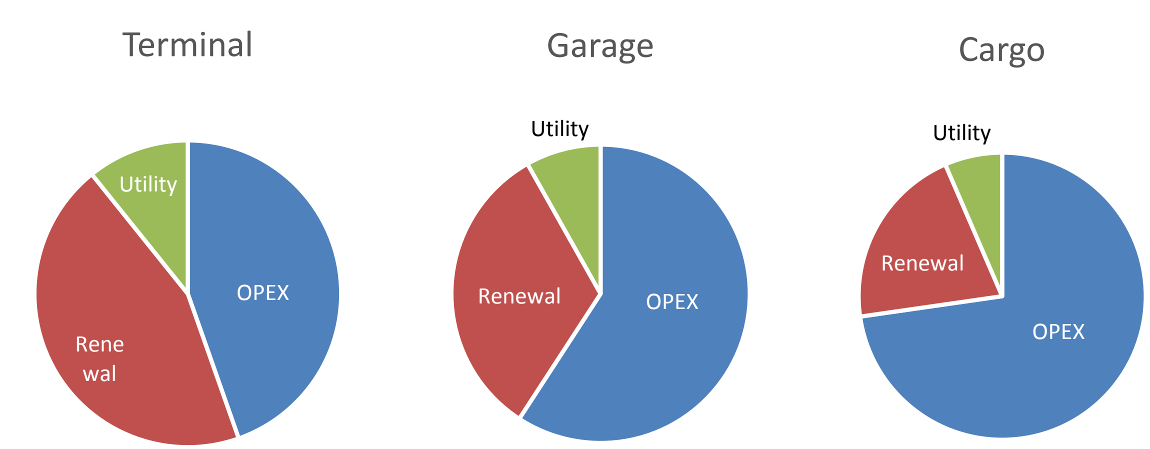
2 ASSET MANAGEMENT RECOMMENDATIONS AND FINDINGS

The Port already uses total cost of ownership analysis in comparing various initiatives during the planning process of various assets. The 2007 Port standard EX-15, *Sustainable Asset Management Policy*, dated 6/27/2007 with the 2013 goal workshop defined the need to evaluate potential projects and improvements based not only on their initial costs, but also on their ongoing operation, maintenance, utility, and renewal costs. Using tools such as PeopleSoft, Maximo and the F&I Asset Management System, many of the assets are currently tracked, or have the potential to be tracked through a robust asset management system. These systems allow the decisions that control costs to be available and understood throughout the service life of an asset. Understanding the asset's value to the operation allows for decisions to be made that affect service life or amount spent on maintenance.

2.1 OPEX and Renewal Costs are More Significant than Utility Costs for Current Rate Structure

As Charts 4-41, 4-42, and 4-43 demonstrate, significantly more costs are spent on the operation, maintenance, upkeep, and renewal of assets than on utilities. While this does not mean that utility costs do not matter, it does demonstrate – from a cost-only standpoint - that energy efficiency should not come at the price of increased operating costs or reduced service life. One of the primary facets of sustainability is minimizing the impact to the environment. While this obviously includes reduction of carbon-based energy, it also means the reduction of energy, materials, and waste required to maintain an asset or the energy required or waste produced from construction and replacement of the asset.

Chart 8-2
Comparing OPEX, Renewal Costs, and Utility Costs



2.2 Consider Environmental and Social Impacts When Determining Total Cost of Ownership

Outside of pure cost comparisons of various alternatives, it is important to understand the social and environmental impacts of the decisions. Although one option may be less expensive than another, the socioenvironmental impacts to that option may not make it a good choice. Technical Memorandum 7 describes these *triple bottom line* decisions, so that a combined strategy for evaluating options can be developed during planning and implementation phases of asset improvement projects.

2.3 Identify Critical Systems, Their Vulnerability to Failure, and the Consequence of Failure

Using asset management tracking and analysis tools, it is important to understand which systems and assets are the most critical in the operation of the airport. In addition to their importance, critical systems that are also vulnerable to weather, maintenance failure, overuse, terrorist or vandal failure, misuse, or other form of vulnerability should be identified along with the consequence of the failure. Ranking these based on both importance and vulnerability will provide the means for which OPEX budgets can be spent. Focus of maintenance spending on those systems which are the most critical, but also vulnerable to failure should be the first considered for renewal or improvement.

2.4 Develop a Reliability Centered Maintenance Program for These Critical and Important Assets

Once these critical and important assets are identified, development of a reliability centered maintenance (RCM) program is important. This approach helps define what the expected performance requirements of the asset are, and what ways that failure can occur, trying to identify specific events that can cause the failure that may lead to a predictive and proactive approach to preventing these failures. This approach will develop the failure mode effects analysis for these critical systems and apply the appropriate level of maintenance to prevent the failure from occurring during its expected service life. As the asset is continued to be reviewed during each maintenance cycle, the RCM program will fine tune the approach and adjust the maintenance based on what is learned through operation.

2.5 Also Consider Efficiency and Reliability in Maintenance Spending and Service Life

For all assets, whether considered critical or not, system efficiency and reliability should be noted and used to determine renewal requirements, maintenance spending, and expected service life. Assets that are inefficient, either by providing poor performance or by excessive use of energy, should be identified for replacement with more efficient and properly sized counterparts. Additionally, assets with poor reliability and high OPEX costs should be identified as potentially beyond their service life.

In each case, the amount of maintenance spent to extend these assets service life should be reduced. This reduced OPEX spending can be used to justify spending renewal costs to replace the asset with the more efficient counterpart.

In contrast, assets that operate efficiently and reliably should be considered for extended service life. Maintenance costs should be tracked and compared to the energy cost benefits and service life extended as long as it makes sense to do so.

2.6 Consider Leased Equipment or ESCO-Operated Systems

When implementing high CAPEX cost systems to reduce overall operating and utility costs for the airport, consideration should be made to use ESCO-operated or leased systems. ESCO, or *Energy Service Company*, is a company such as a public utility or private energy company that will build large energy systems, such as renewable energy power generation equipment, cogeneration plants, or central plants for large customers and then “sell” the power, heat, or chilled water to the customer to cover costs both of energy produces and lease payment on the equipment. Many ESCO contracts are incentive based, essentially guaranteeing certain energy rates or efficiencies of the built equipment. Many of these systems are also operated by the ESCO, therefore not requiring additional staff by the customer.

This approach provides several advantages. The first is that it eliminates CAPEX costs and significantly reduces OPEX costs. The second benefit is that it allows the airport to focus on operation of the airport instead of operating energy plants. The third benefit is that the ESCO main business focus is the reduction of energy. Therefore, the techniques that their system designers, contractors, and operators bring to the customer will focus on maximum energy reduction. Finally, once the contracted lease duration is over, the plant can be shut down, improved upon, expanded, or remain as is to meet the future needs of the airport.

3 ENERGY SYSTEM RECOMMENDATIONS AND FINDINGS

Sea-Tac has a strong culture in energy efficiency and sustainability among airports. Continued focus on energy efficiency and reduction will allow the Airport to meet its goals as passenger traffic grows in the next twenty years.

3.1 Adopting LEED Prerequisite as Minimum Standard

Since LEED prerequisite and Washington State Energy Code mixed with Port of Seattle water efficiency policies are so similar, LEED prerequisite should be considered the standard for most Port owned and operated facilities. Many federal, state, and local government buildings are mandated to be “LEED certifiable”, meaning that they are required to be built to a LEED standard of efficiency and sustainability, even if the building is not registered with the US Green Building Council. Additionally, buildings that receive government funding are many times required to be LEED Silver equivalent.

As the LEED standards advance beyond the current Version 4, it is assumed that the Washington State Energy Code requirements will advance in a similar manner. Using the LEED Prerequisite as the default standard (unless the building is a support building with high process loads) for all new Airport buildings.

3.2 Decoupling Only the Heating Plant and Replacing with High Efficiency Decentralized Heating Plants

The current chiller plant is efficient due to a combination of mild climate, use of waterside economizer, good part load efficiency, and improved building automation controls. In fact, the efficiency of the chiller plant is similar to the efficiency expected from the cooling side of a ground-source heat pump system. Other common decentralized cooling options will likely be less efficient and require more OPEX or have a long (or non-existent) payback as compared to the centralized chiller plant. The chiller plant only uses about 6% of the energy used by the terminal.

The boiler plant, however, uses 40-45% of the energy used by the terminal. Steam is an excellent method for providing heating to a large campus, but it tends to be much less energy efficient and environmentally friendly than other options. Steam must be superheated to build the heat and pressure required to transport it throughout the campus. Losses in improper or worn insulation, steam leaks, condensate return issues, and blowdown require significant amounts of extra energy to produce the required heat needed for the Airport. Other options, such as decentralized ultra-efficient condensing boilers or ground source heat pump boilers can be distributed throughout the airport to reduce transport distance required and improve overall heating efficiency of the infrastructure.

3.3 Replace the Existing Natural Gas-Fired Steam Boilers with On-Site Generation

Should centralized steam be preferred method to deliver heating to the terminal, replacing the heating-only natural gas-fired boilers with an on-site cogeneration combined heat and power plant would provide a much more efficient and environmental means to provide heat, while subsequently reducing power required from the public utility. This on-site cogeneration unit can be powered either by natural gas or through use of biogas ("renewable natural gas"). Whereas the existing boilers "waste" energy streams from their boiler stacks, the cogeneration unit uses the wasted heat in producing electricity to superheat water and produce steam thus using nearly 100% of the energy used for the process. The cogeneration plant, in this case, would be sized to meet the steam needs of the airport. The resulting power generated from the cogeneration system would reduce overall power requirements from public utilities and maintaining the Tier 1 rate structure for power.

3.4 Continue Energy Auditing/Retrocommissioning Program

Recent F&I energy efficiency and retrocommissioning audits have significantly reduced energy consumption of the Terminal, largely due to reductions in fan energy, improvements of central plant performance, and tuning of the preconditioned air cooling/heating system. Recently completed Stage 2 and Stage 3 improvements have demonstrated the recent improvements, while Stage 4 audit is currently in process.

Retrocommissioning is the process of tuning the performance of your various infrastructure energy systems (such as fans, chillers, boilers, cooling towers, pumps, and heating equipment) through both the normal operation and via the building automation system in order to optimize energy and output efficiency. As these equipment continue to operate, they experience a combination of wear, instrument *drift,* incorrect settings, non-working controls, and other factors that reduce equipment efficiency and do not allow them to operate at peak performance. Retrocommissioning is the process of "*resetting*" these systems, repair worn parts and fixing control issues. In turn, these systems will operate at their best energy efficiency, lowering energy consumption and cost.

As new assets are built, the process of continual planned retrocommissioning will keep the primary energy components operating at their peak energy efficiency. Other large energy assets, such as baggage handling equipment and satellite transit systems should also be reviewed on occasion to verify they are operating as intended and in the most efficient manner possible.

3.5 Use Passive Systems, Such as Natural Ventilation to Reduce Energy Requirements

Reduction of energy through passive architectural and mechanical systems is a primary method in reducing overall energy consumption and reducing energy costs. These passive systems are designed to meet their normal use, while minimizing the energy or impacts to the Airport.

Passive systems can be split into both architectural and mechanical systems. Architectural passive systems focus on the envelope to reduce energy. Solar heat gain through windows and skylights are a large component to the building's HVAC load. Consideration for the window placement, considering the best orientation for maximum lighting without direct impact from the sun is important in reducing these solar heat gains. Providing external shading for these windows or other means of solar control can also reduce influence of solar heat from the building.

For the building itself, consideration of the thermal mass of the building can be used to reduce the HVAC energy. Thermal mass is the storage of building heat to be used later. For example, heat from the daytime is stored in the building and used to reduce the energy required for heating at nighttime. In turn, the cooler temperatures at night release the heat from the building, allowing the materials to keep the building cooler and require less mechanical refrigeration. This is referred to as the "flywheel effect". Other architectural envelope considerations include development of the building footprint, orientation, and configuration to minimize the influence of the weather on the building environment, thus reducing HVAC system energy requirements.

In addition, "green" or vegetated roofs can be considered as a passive energy reduction system. Green roofs reduce the impact of solar heat gain on the roof, by planting plants on the roof. The plant systems take advantage of the rain and sun in order to promote growth and in turn reduce the amount of solar impact on the roof. The roof provides additional environmental benefits such as carbon reduction.

Finally, architectural consideration can be made for design of buildings that can freely implement renewable energy systems. Parking garages have large roof systems. Providing a canopy system on the roof, not only provides protection to passenger vehicles, but also provides a location for which to mount photovoltaic panels.

Mechanical passive systems include various means of ventilation and cooling/heating to reduce energy in the building. Radiant cooling and heating systems are one method to reduce energy. Active and passive chilled beams, for example, can provide a method for cooling large spaces while minimizing fan energy required for these spaces. Radiant heating can be more effective means than traditional convective heating.

Ventilation strategies such as natural ventilation, demand control ventilation, and displacement ventilation improve the air quality and reduce buildup of carbon dioxide, while reducing energy consumption. Natural ventilation takes advantage of the mild climate of Seattle by using the cooler temperatures available nearly year-round to cool the building. Demand control ventilation monitors carbon dioxide buildup in the building and controls the ventilation system to provide more outside air when the carbon dioxide levels are higher and reduces outside air when carbon dioxide levels are lower. This can reduce energy in summer and winter months, when the outside air would require additional heating, cooling, or dehumidification to be used within the space.

Placement of diffusers within the HVAC system can have adverse impacts to the energy consumption of the building. Traditional diffusers are located in the ceiling. When tall ceilings are located over high-intensity load spaces (such as ticketing areas, security checkpoints, hold rooms, and concession areas) excessive energy is required to deliver adequate air to the space to provide the necessary cooling or heating for the building occupants. Placement of the diffusers at levels closer to the occupant allows for more energy efficient method for delivery of HVAC airflow. Displacement ventilation systems discharge ventilation air cooled (or heated) through low velocity induction diffusers at occupant level and extracted from the space near the ceiling. This allows the coolest air in summer and warmest air in the winter to be used to condition the space for the passengers. Where this approach is impractical, large spaces benefit from the use of large ceiling high-volume low speed (HVLS) fans to increase the cooling effect of the air and to keep warmer air (in the winter) toward the passengers. Using HVLS reduces impacts of unwelcomed draftiness typical with jet-type diffusion systems required to throw large amounts of air from high ceilings.

Control of infiltration can considerably reduce energy during winter and summer periods when the outside temperatures are not favorable for indoor environment. The use of doors on baggage carousels and dropoff locations, vestibules at entrances, and control of gate doors can each have a big impact on reduction of uncontrolled infiltration.

Finally, where possible, the mechanical system should take advantage of heat recovery. Any system that produces heat should also include a method to capture the heat and use it to preheat water for domestic uses or preheat air from the outside in the winter.

3.6 Maximize Free Cooling and Economizer Use

Due to the mild weather of Seattle and Puget Sound Region, the Seattle-Tacoma International Airport does not typically see extreme temperatures, such as summer temperatures exceeding 90°F or winter temperatures below 35°F. As chart 4-2 shows, the use of airside economizers is favorable in the Seattle area over 5000 hours a year. The use of the economizer in these conditions will reduce energy consumption required by mechanical cooling.

3.7 Continue to Improve Lighting Efficiency and Controls

Lighting, as shown in Chart 4-29, is responsible for approximately 30-35% of the energy usage for the terminal. Recent lighting retrofits in the Terminal and Parking garage have significantly reduced the amount of energy required for these buildings.

As new buildings are being built and the current assets are being renovated or renewed, considerations should be made to use the most efficient lighting system possible. Recent comparisons between fluorescent and LED lighting have demonstrated that as LED lighting becomes more widespread, the cost for the lighting is nearing that of fluorescent. LED lighting has the additional benefit of extended service life over fluorescent lighting. As technology continues to improve performance and efficiency for these lighting systems and the costs for these systems decreases, the amount of energy spent on lighting should continue to decrease.

In addition to lighting methodology, effective lighting controls should be implemented with all new buildings and retrofitted where currently not present. Lighting controls includes both daylighting control of lighting using properly placed windows and skylights to minimize the need for daytime lighting, as well as systems that dim based on occupancy requirements. For example, connecting a hold room's lighting control system to the flight system will allow different gate hold rooms to change lighting levels (and therefore energy output required) based on whether the gate is active.

3.8 Implement Renewable Energy

Currently, renewable energy systems, such as photovoltaic systems, have long payback periods when grants and incentives are not available. As technology improves, these panels will become smaller or provide more power per square foot than existing panels. Current commercial panels are 20-25% efficient. Research and development of 40-50% efficient panels is currently being done through many manufacturers and the NREL. As these systems become more efficient, it will require less panels to produce the same amount of energy. This reduces not only the cost of the panel, but also the cost of roof structure and amount of labor cost to install the system. Consideration for renewable energy should be made during the planning for each new building or major renovation of an existing building. As technology improves and costs decrease, the return on investment will increase and TCO benefit of renewable energy will come more quickly.

Even if application of renewable energy is not considered for a building due to the costs and long payback periods associated with it, each building should be planned to include renewable energy infrastructure so it can be easier to implement in the future. During the planning process, locations for photovoltaic panels should be identified. Roofs should be built to accommodate the weights of these systems. Conduits and electrical infrastructure should be design to be able to integrate these systems in the future.

3.9 Focus on Management and Reduction of Energy Required for Plug and Process Loads

Plug loads and process loads represent a large percentage of the total electricity used for the terminal. These include all equipment not associated with lighting, HVAC, or water heating, which includes baggage handling equipment, security equipment, scanning equipment, office computers and equipment, satellite transit system, etc. The analysis should focus especially on large consumers of energy, as small changes to the efficiency of large systems can have a larger impact to overall energy consumption and cost than big changes to smaller systems.

Procurement of this equipment should not only focus on the performance, but also on the energy required to operate this equipment. Purchase of EnergyStar appliances and office equipment, premium efficiency motors, high efficiency conveyance systems, and other considerations can reduce the impact that these systems have to the overall energy consumption of the building.

3.10 Implement and Improve Current Submetering Strategies

The Port of Seattle is currently improving their legacy metering for many of the energy systems for the terminal. Major substations have power centers that are used to track electricity use at major distribution points (building) level. Chilled water usage is metered in various concourses. The PCA plant is metered for all energy used.

As new buildings and major renovations occur, considerations for an effective submetering strategy should be included. Submetering for all energy systems should occur at each unique building. Electricity should be metered separately for lighting, HVAC, water heating, and plug loads. Natural gas usage should be metered for each building. Chilled water and heating water usage at each major air handling unit should be monitored. Steam consumption at each steam-to-hot water generator should be submetered.

In doing this, a complete understanding of each system's energy use will be available to the airport. Should any system display unexplained increases in energy consumption, that system can be reviewed for faulty, unbalanced, or improperly controlled equipment. This assists in not only diagnosing where the problem is occurring, but also does so before the system fails completely. An increase in energy consumption is typically a sign of impending failure of a piece of equipment. Finding the equipment prior to the failure will prevent costly unplanned downtime situations.

Additionally, submetered systems can be used to track energy efficiency. Energy conservation measures put in place can get direct results on how they are performing. Submeters would confirm the expected energy reduction resulting from the replacement of inefficient equipment. If competing energy systems are being monitored within a building (such as chilled water and steam), it could indicate an HVAC with competing control strategy and an opportunity to further reduce energy consumption.

3.11 Implement Solar Thermal for Domestic Water Heating

Where solar electric (photovoltaic) systems currently have a sixty year or longer payback, solar thermal systems at eight to nine year payback may be more optimal to implement in the present time. Solar thermal collectors differ from photovoltaic panels in the method that they are used. Their size is much smaller than photovoltaic, and their orientation is less critical. For these reasons, they are simpler and less expensive to implement than photovoltaic panels.

Solar thermal systems for domestic hot water should be implemented at the airport. The solar thermal system would "preheat" the water, reducing the amount of electricity, steam, or natural gas that is required to heat it to final temperature.

3.12 Consider Storage Technologies

Although not considered an energy conservation strategy, thermal storage can be used to reduce energy costs by allowing the equipment that produces the chilled water or heating water to operate during non-peak periods which may be less expensive due to time-of-day or demand-based rate structures. In addition, thermal storage systems allow for smaller central plants and provide immediate backup of chilled water or heating water should a portion of the infrastructure have an unexpected failure. Currently, the PCA plant produces ice (a form of thermal storage) that is used for cooling of the preconditioned air. Thermal storage for the main central plant should be considered for new central plants associated with the second terminal.

Another type of storage that should be considered is energy storage systems. Fuel cells are currently available to store energy efficiently for future use. The fuel cell uses the hydrogen in various ways for energy. For example, molten carbonate type fuel cells use hydrogen from natural gas or other fuels in a non-combustion method to extract the energy. This energy can be used for backup power or for direct use of the electricity released, such as with a cogeneration plant.

4 WATER MANAGEMENT RECOMMENDATIONS AND FINDINGS

Water usage at the airport is directly related to passenger traffic. As expected passenger traffic through the airport continues to grow, the amount of water used in the restrooms or by the cooling towers through increased cooling requirements will continue to increase. Means to decrease the dependency on public water supply are needed to reduce costs and improve the sustainability of the airport. The Port of Seattle has an aggressive water efficiency standard that currently improves upon the required LEED water efficiency prerequisite. Current legacy restrooms are being retrofitted. Newly remodeled or constructed restrooms should meet this standard, and therefore reduce the amount of water needed per passenger.

4.1 Document and Manage Construction Water Usage and Other Non-Standard Usage

While the amount of water used by the cooling tower is metered and the amount of water used in the restrooms is predictable, the amount of non-tenant water used for "process" needs can be difficult to estimate and predict. Spikes in water usage, for example, can be seen on utility bills when major construction is happening at the airport. In some cases, this increase in water consumption can be significant.

Makeup water to boilers, cooling towers, and other equipment should continue to be monitored. Process water for “back-of-house” uses should be metered, as well. During periods of construction, procedures should be implemented to control construction water waste in similar manner as solid waste is managed.

4.2 Water for Non-Potable Uses Should be Harvested or Gray Water Source

Other than establishing and implementing a water efficiency standard at the airport, the other major method of reducing the amount of water used from the public utility is to use harvested (stored) rain water and/or gray water.

Since treating water to potable standards is complex, expensive on a private basis, and requires specialized operators, this procedure is not recommended for the airport. Instead, it is more cost effective and simpler to use harvested or gray water for non-potable purposes. Water for non-potable uses (such as cooling tower, irrigation, or urinal/toilet flush) should be through these source first, and only use potable water if the stored water is insufficient to meet the airport’s needs.

There are several considerations for implementing a stored water program. Rain water can be captured from both site and roof sources, although roof sources are typically cleaner than site sources and may require less filtration to be used for non-potable uses. Infrastructure would need to be put in place to distribute both non-potable (“purple pipe”) and potable water (“blue pipe”) to the building users. Cooling towers treatment and “cycles of concentration” should be reviewed to determine if the new water source has adverse effects to the performance, requiring more frequent blowdown cycles.

4.3 Implement and Improve Current Submetering Strategies

Water metering is currently present at the main building entry. Some submetering is done for tenants (especially cooking concessions) and for large consumers of water (such as cooling tower makeup).

Water submetering should be expanded, much in same way as the energy systems. Each building should be individually submetered. All large consumers of water, such as cooling towers, boilers, fountains, cafeterias, equipment and vehicle cleaning facilities, and irrigation should be independently submetered.

Submetering each of these allows for trending to occur. Unexplained increases in water consumption can be tracked down to one of the large consumers or building from which it is occurring. From there, leaks can be discovered and repaired, or operations changed to reduce eater usage to original rate. This provides benefit, not only in utility cost reduction, but also in OPEX costs, since the time required to discover and repair faulty water infrastructure can be reduced and small leaks can be discovered before major (very expensive) failure occurs.

Attachment A

Definitions, Acronyms, Legend, and Abbreviations

Definitions

The following definitions are included to refer to terms used within this document:

AAAE	American Association of Airport Executives
ACEEE	American Council for an Energy-Efficient Economy.
ACI	Airports Council International
ACRP	Airport Cooperative Research Program. The aviation portion of the Transportation Research Board. Has developed many papers on airport sustainability.
ACRP 09-10	Study for benchmarking airport energy consumption
AEDG	Advanced Energy Design Guides. Developed by ASHRAE to represent a 30% savings from ASHRAE 90.1-1999 in order to promote NZEB.
ALP	Airport Layout Plan
AM	Asset Management
APM	Automatic People Mover. Also referred to as STS for Sea-Tac.
Architecture 2030	Advocacy group developed by Edward Mazria in 2003 to promote reduction in greenhouse gases due to buildings. Challenge 2030 program reduces GHG to carbon neutral in 2030.
ARFF	Airport Rescue and Fire Fighting
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASHRAE 90.1	Energy Standard for Buildings Except Low-Rise Residential Buildings
ASHRAE 189.1	Standard for the Design of High Performance, Green Buildings Except Low-Rise Residential Buildings
ASHRAE Vision 2020	Program developed by ASHRAE to have a NZEB by 2020.
BAS	Building Automation System. May also be referred to as BEMS, EMCS, BCS, etc. Control system that operates and monitors HVAC, electrical, lighting, and other systems and is responsible for managing energy specific strategies within those systems (such as free cooling).
BCE	Business Case Evaluation
Benchmark	A standard or point of reference against which things may be compared or assessed.
BPA	Bonneville Power Authority (utility provider)
CBECS	Commercial Buildings Energy Consumption Survey. A national sample survey managed by EIA that collects information on the stock of U.S. commercial buildings, including their energy-related building characteristics and energy usage data (consumption and expenditures)
CAPEX	Capital Expenditure, Capital Expense. Funds used to acquire or upgrade physical assets such as property, buildings or equipment. These expenditures can include everything from repairing a roof, purchasing a piece of a equipment, or building a brand new building.
CMS	Cost Management Services
CONRAC (or RAC)	Consolidated Rental Agency Complex
DDC	Direct Digital Controls
DoE	United States Department of Energy
EIA	United States Energy Information Administration. Principal agency of the U.S. Federal Statistical System responsible for collecting, analyzing, and disseminating energy information to promote sound policymaking, efficient markets, and public understanding of energy and its interaction with the economy and the environment
ECI	Energy Cost Index
ENERGY SYSTEM	Specific to electricity and natural gas
EUI	Energy Use Intensity. EUI is expressed as energy per square foot per year. It's calculated by dividing the total energy consumed by the building in one year (measured in kBtu or GJ) by the total gross floor area of the building.
FCI	Facility Condition Index
HRSG	Heat Recovery Steam Generator
IECC	International Energy Conservation Code
IFMA	International Facility Management Association.
IGCC	International Green Construction Code
IOA	Initiatives, Opportunities, and Actions. Refer to Technical Memorandum 7.

KPI Key Performance Indicators

LBC Living Building Challenge. International sustainable building certification program created in 2006 by the non-profit International Living Future Institute. Launched by the Cascadia Green Building Council (a chapter of both the U.S. Green Building Council and Canada Green Building Council). More rigorous system than LEED

LBNL Lawrence Berkeley National Laboratory. One of the national laboratories funded by Department of Energy whose focus is on energy efficiency research.

LCC Life Cycle Costing. The process, similar to TCO, for discovering the cost of an asset over its life cycle.

LCA Life Cycle Assessment.

LEED Leadership in Energy and Environmental Design. Program developed by USGBC (United States Green Building Council) in 1998 to recognize energy efficient and environmentally-friendly buildings. A 110-point Rating System determines level of certification from "certified" to "Platinum". New construction for airports would comply with the Green Building Design & Construction: LEED for New Construction rating system. Current generation is LEED version 4, introduced in November, 2013. Until October 31, 2016, new projects may choose between LEED 2009 and LEEDv4. New projects registering after October 31, 2016 must use LEEDv4.

M&R Maintenance and Renewal

NREL National Renewable Energy Laboratory. One of the national laboratories funded by Department of Energy whose focus is on renewable energy research.

NZEB Net Zero Energy Building. A building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is roughly equal to the amount of renewable energy created on the site.

Types:

• Zero net site energy use In this type of ZNE, the amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building. In the United States, "zero net energy building" generally refers to this type of building.

• Zero net source energy use This ZNE generates the same amount of energy as is used, including the energy used to transport the energy to the building. This type accounts for losses during electricity transmission. These ZNEs must generate more electricity than zero net site energy buildings.

• Net zero energy emissions Outside the United States and Canada, a ZEB is generally defined as one with zero net energy emissions, also known as a zero carbon building or zero emissions building. Under this definition the carbon emissions generated from on-site or off-site fossil fuel use are balanced by the amount of on-site renewable energy production. Other definitions include not only the carbon emissions generated by the building in use, but also those generated in the construction of the building and the embodied energy of the structure. Others debate whether the carbon emissions of commuting to and from the building should also be included in the calculation.

• Net zero cost In this type of building, the cost of purchasing energy is balanced by income from sales of electricity to the grid of electricity generated on-site. Such a status depends on how a utility credits net electricity generation and the utility rate structure the building uses.

• Net off-site zero energy use Abuilding may be considered a ZEB if 100% of the energy it purchases comes from renewable energy sources, even if the energy is generated off the site.

• Off-the-grid Off-the-grid buildings are stand-alone ZEBs that are not connected to an off-site energy utility facility. They require distributed renewable energy generation and energy storage capability (for when the sun is not shining, wind is not blowing, etc.). An energy autarkic house is a building concept where the balance of the own energy consumption and production can be made on an hourly or even smaller basis. Energy autarkic houses can be taken off-the-grid.

• Net zero-energy building Based on scientific analysis within the joint research program "Towards Net Zero Energy Solar Buildings" a methodological framework was set up which allows different definitions, in accordance with country's political targets, specific (climate) conditions and respectively formulated requirements for indoor conditions: The overall conceptual understanding of a Net ZEB is an energy efficient, grid connected building enabled to generate energy from renewable sources to compensate its own energy demand.

OPEX	Operational Expenditure, Operational Expense. Ongoing cost to operate a building, including wages for employees, janitorial and office supplies, third party services (such as janitorial), routine maintenance costs, repair costs, and cost of supplies to operate building (such as water treatment chemicals, HVAC filters, etc.).
PdM	Predictive Maintenance
PSE	Puget Sound Energy
PNNL	Pacific Northwest National Laboratory. One of the United States Department of Energy national laboratories, managed by the Department of Energy's Office of Science. The main campus of the laboratory is in Richland, Washington.
RCM	Reliability Centered Maintenance
RENEX	Renovation Expenditure or Renewal Expenditure. Costs associated with major repair/replacement of equipment or assets. Typically higher in costs than initial capital cost (CAPEX) due to the nature of repairing/replacing work in an active building and the costs of downtime. Renewal costs are estimated as a percentage increase over initial capital costs for this study.
"SHOEBOX" MODEL	A term used by ASHRAE and International Building Performance Simulation Association to represent an architectural massing model used to develop a high-level planning thermal model from. Includes basic geometric form with zoning split to each exposed exterior directions and a single core zone. Internal thermal loading (people, lighting, and equipment) is density based and represents general conditions within the overall space, not individual space conditions.
SAMP	Sustainable Airport Master Plan
SCL	Seattle City and Lights (electricity provider)
SGHAT	Solar Glare Hazard Analysis Tool. Tool developed at Sandia Labs to determine amount of glare from a photovoltaic panel or panels. The tool determines that amount of glare that could impair pilot vision.
SEIA	Solar Energy Industries Association
TCO	Total Cost of Ownership. The total amount of cost spent to plan, design, build, commission, operate, maintain, energize, renew, replace, and demolish an asset, accounting for residual value at end of life.
TMY (or TMY3)	Typical Meteorological Year. Standard weather information for a given location based on historical trends. Distributed by NREL. Used for simulation of energy simulations. TMY3 is the third generation of the standard.
TRACON	Terminal Radar Approach Control
TRB	Transportation Research Board. Parent organization of ACRP.
UNIFORMAT	Standard for classifying building specifications, cost estimating, and cost analysis in United States and Canada. Used to provide consistency in economic evaluation of building projects. Created by American Institute of Architects and US General Services Administration and is recognized as ASTM Standard. Level 1 categories include (A) Substructure, (B) Shell, (C) Interiors, (D) Services, (E) Equipment and Furnishings, (F) Special Construction and Demolition, and (F) Building Sitework.
UNIFORMAT LEVEL 2 –	Major components within Uniformat structure. Elements perform a given function, regardless of design specification, construction method, or material used.
USGBC	United States Green Building Council. Private organization that founded and manages the LEED Rating System for buildings
UTILITY/UTILITIES –	Includes electricity (both from public utility and site generated), natural gas (both primary and renewable, or biogas), fuel (diesel, propane, etc.), chilled water (generated by Central Plant), steam (generated by Central Plant), heating water (converted from steam), water (domestic, process, and collected), and sewer (sanitary and storm)
WBDG	Whole Building Design Guide. A program of the National Institute of Building Sciences, funded by Department of Defense, NAVFAC, Army Corps of Engineers, US Air Force, US General Services Administration, Department of Veteran Affairs, NASA, and Department of Energy. Focused on sustainable construction of buildings.
WLC	Whole Life Cost. Another term for TCO
WSEC	Washington State Energy Code
WUI	Water Use Intensity. WUI is expressed as water consumed per square foot per year. It's calculated by dividing the total water used or consumed by the building in one year (measured in 1000 gallons) by the total gross floor area of the building.

Attachment B

References and Standards

ASHRAE

- ASHRAE Guideline 0 – *The Commissioning Process*, 2013
- ASHRAE Guideline 1 – *The HVAC Commissioning Process*, 1996
- ASHRAE Standard 55 – *Thermal Environmental Conditions for Human Occupancy*, 2013
- ASHRAE Standard 62.1 – *Ventilation for Acceptable Indoor Air Quality*, 2013
- ASHRAE Standard 90.1 – *Energy Standard for Buildings Except Low-Rise Residential Buildings*, 2007, 2010, 2013
- ASHRAE Standard 100 – *Energy Efficiency in Existing Buildings*, 2015
- ASHRAE Standard 169 – *Climatic Data for Building Design Standards*, 2013
- ASHRAE Standard 189.1 – *Standard for the Design of High-Performance Green Buildings*, 2014
- ASHRAE *Fundamentals* Handbook, 2013
- *Advanced Energy Design Guides*
- ASHRAE *Combined Heat and Power Design Guide*
- *ASHRAE GreenGuide: Design, Construction, and Operation of Sustainable Buildings*, Fourth Edition
- *Ground Source Heat Pumps*
- *Performance Measurement Protocols for Commercial Buildings: Best Practices Guide*

USGBC

- LEED V4 Rating System Reference Guide

Others

- Washington State Energy Code
- National Institute of Building Sciences *Whole Building Design Guide*
- International Code Council – *International Energy Conservation Code*, 2009, 2012, 2015
- EPA EnergyStar Program

References

- ACRP. *Airport Energy Efficiency and Cost Reduction*. Washington D.C: Transportation Research Board; 2010.
- ACRP. *Evaluating Impacts of Sustainability Practices on Airport Operations and Maintenance*. Washington D.C: Transportation Research Board; 2014.
- ACRP. *Guidebook for Energy Facilities Compatibility with Airports and Airspace*. Washington D.C: Transportation Research Board; 2014.
- ACRP. *Guidebook for Incorporating Sustainability into Traditional Airport Projects*. Washington D.C.: Transportation Research Board; 2012.
- ACRP. *Prototype Airport Sustainability Rating System--Characteristics, Viability, and Implementation Options*. Washington D.C.: Transportation Research Board; 2014.
- Airports Council International - North America. Minimizing Airport Environmental Impacts. *Going Greener*.
- Alarie, Don. "Intelligent design for facility asset management." *Journal of Airport Management* 1, no. 4 (2007): 357-369.
- Anthony, Nicholas, and John Hastings. "*ISO 55000 Series Standards.*" In Physical Asset Management, 505-525. Springer, 2015.
- ASHRAE Vision 2020 Ad Hoc Committee. *Producing Net Zero Energy Buildings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers; 2008.
- Association of Higher Education Facilities , Federal Facilities Council, Holder Construction Company, International Facility Management Association, and National Association of State Facilities Admin. *Asset Lifecycle Model for Total Cost of Ownership: A framework for facilities lifecycle cost management.*
- Association of Higher Education Facilities Officers/APPA. *Asset Lifecycle Model*.
- Barrilleaux J, Morgan C, Stilson D. Airport Sustainability. 2015.
- Baker, Jaap, and Joris Volwerk. "Life Cycle Tenders for Infrastructure Projects." In *Life-Cycle and Performance of Civil Infrastructure Systems*, by Hyo-Nam Cho, Dan Frangopol, & Alfredo H-S. Ang, 103-110. London, United Kingdom: Taylor & Francis/Balkema, 2007.
- Bhutta, M. Khurrum S. "Supplier Selection Problem: Methodology Literature Review." *Journal of International Technology & Information Management* 12, no. 2 (2003): 53-72
- Bodehed, Erika. *Developing a model of total cost of ownership for evaluation of purchases at Saab Microwave Systems*. Lund, Sweden: Department of Industrial Management and Logistics, 2008
- Bonneville Power Administration. "Facility Asset Management Strategy." City of Bonneville, 2012
- Bourke, Kathryn, Vijay Ramdas, Shillpa Singh, Andy Green, Andrew Crudgington, and Das Mootanah. Achieving Whole Life Value in Infrastructure and Buildings. Building Research Establishment (BRE); Transport Research Laboratory (TRL); Faithful & Gould; Institution of Civil Engineers (ICE); Construction Industry Research and Information Association (CIRIA), Watford, UK: Building Research Establishment (BRE) Press, 2005, 62.
- Brommer M, Flikweert J, Lawton P, Roca M, Simm J. *Assessment And Measurement Of Asset Deterioration Including Whole Life Costing*. Bristol, UK: Environment Agency; 2009.
- Brothers, Bond. *Asset Management: The Critical Component in Meeting Long Term Sustainability Goals*. Boston: Harvard Allston Development Group, 2008.
- BSI Standards. *Building and Constructed Assets - Service Life Planning BS ISO 15686-1:2011*. United Kingdom: BSI Standards, 2011
- Caplehorn, Peter. *Whole Life Costing - A New Approach*. New York, USA: Routledge, 2012.
- Cartlidge, Duncan. *Procurement of Built Assets*. Elsevier Butterworth-Heinemann, 2004.
- CDi Mazzetti. *North Satellite Mechanical Design*. SeaTac, Washington; 2014.

- Chartered Institute of Procurement & Supply. *P&SM: Whole Life Costing*. UK: CIPS, 2013.
- Cincinnati/Northern Kentucky International Airport. *Cincinnati Northern Kentucky International Airport 2035 Master Plan.* Hebron, 2013.
- City College of San Francisco. *Total Cost of Ownership - Facilities Management Standard.* San Francisco: City College of San Francisco, 2014.
- Clift, Mike, and Kathryn Bourke. *Study on Whole Life Costing.* London, UK: BRE Publications, 1999.
- Connell J. North Satellite Expansion – Ground Source Heat Pump System Potential. 2014.
- Dan Turner W. *Model for Improving Energy Use in U.S. Airport Facilities*. Airport Cooperative Research Program; 2007.
- Davis Langdon Management Consulting. *Life Cycle Costing (LCC) As a Contribution to Sustainable Construction: A Common Methodology*. 2007.
- Degraeve, Zeger , Eva Labro, and Filip Roodhooft. *Total Cost of Ownership Purchasing of a Service: The Case of Airline Selection at Alcatel Bell*. N.d.
- Department of Energy. *Cost Estimating Guide*. Washington, D.C: Department of Energy; 2011.
- Department of Energy. *O&M Best Practices Guide*.; 2010.
- Dundee City Council, Perth & Kinross Council, and Angus Council. *Procurement Strategy* (2008-2011). Tayside Procurement Consortium, 2007.
- Elite Line Service Inc. *Equipment Maintenance Procurement - What is the Total Cost for Low O&M?* Carrollton, TX: ELS Inc, 2011.
- El-Haram, Mohamed A., Sasa Marenjak, and Malcolm W. Horner. *Development of a generic framework for collecting whole life cost data for the building industry.* (Journal of Quality in Maintenance Engineering) 8, no. 2 (2002): 144-151.
- Ellingham, Ian, and William Fawcett. *Whole Life Sustainability*. London, UK: RIBA Publishing, 2013.
- Ellram, Lisa. "*A Structured Method for Applying Purchasing Cost Management Tools.*" International Journal of Purchasing and Materials Management 32, no. 1 (1996): 11-19.
- Ellram, Lisa. "*A Taxonomy of total cost of ownership.*" Journal of Business Logistics, 1994: 171-191.
- Ellram, Lisa. *"The Supplier Selection Decision in Strategic Partnership*." Journal of Purchasing and Materials Management, 1990: 8-14.
- Ellram, Lisa. *"Total Cost of Ownership - Elements and Implementation."* International Journal of Purchasing and Materials Management 29, no. 4 (1993): 3-11.
- Ellram, Lisa. *"Total Cost of Ownership: An Analysis Approach for Purchasing."* International Journal of Physical Distribution & Logistics Management, 1995: 4-23.
- Ellram, Lisa, and Amelia Carr. *"Strategic Purchasing - A History and Review of the Literature."* International Journal of Purchasing and Materials Management 30, no. 2 (1994): 10-19.
- Ellram, Lisa, and Sue P. Siferd. *"Total Cost of Ownership - A Key Concept in Strategic Cost Management Decisions."* Journal of Business Logistics 19, no. 1 (1998): 55-84.
- Emerson Reliability Consulting. *Capital Projects Operational Readiness and Business Risks: Maximizing Returns on New Assets.* August 2014.
- Ethical Trading Initiative. *Step-by-Step Guide to Reviewing and Improving Purchasing Practices.* London, United Kingdom: ETI, 2010.
- Ferrin, Bruce G., and Richard E. Plank. *"Total Cost of Ownership: an exploratory study."* Journal of Supply Chain Management 38, no. 3 (2002).
- Gales, Tony. "*Pump Reliability in the Food & Beverage Sectors*." Maintenance Online -. Conference Communication, n.d. Web. 25 Apr. 2016.
- Garfamy, Reza Mohammady. *"A Data Envelopment Analysis Approach Based on Total Cost of Ownership for Supplier Selection."* Journal of Enterprise Information Management 19, no. 6 (2006): 662-678.
- Government Procurement Branch. *Total Cost of Ownership - An Introduction to Whole-of-Life Costing.* New Zealand: Ministry of Business, Innovation & Employment, 2013.
- Gram, Markus, and Werner Schroeder. *"Evaluating The Life Cycle Costs of Plant Assets – A Multi-dimensional View –."* Serbian Journal of Management 7, no. 2 (2012): 287-298.
- Grussing, Michael N. "*Life Cycle Asset Management Methodologies for Buildings*." Journal of Infrastructure Systems (American Society of Civil Engineers) 20 (2014).
- Guckert, Donald J., and Jeri Ripley King. *"Designing for Stewardship: Aligning Project Decisions with the Total Cost of Ownership ."* Facility Manager Magazine, 2006: 28-31.
- Hartsfield-Jackson Atlanta International Airport. *Sustainable Management Plan*. Atlanta, GA: Hartsfield-Jackson Atlanta International Airport, 2011.
- Hilber P. *Component Reliability Importance Indices for Maintenance And Optimization Of Electrical Networks*. Stockholm, Sweden: Royal Institute of Technology; 2016.
- Hooper, Rebecca, Robert Armitage, Andrew Gallagher, and Tom Osorio. *Whole-life Infrastructure Asset Management: Good Practice Guide for Civil Infrastructure.* London, UK: CIRIA, 2009.
- Horkan, Sean. "*Making Every Journey Better - Now Heathrow's Airport Asset Management Improvement Plan is off the Ground.*" (Institute of Asset Management) February (2014).
- Howards S. *Improving Building Efficiency At Seattle-Tacoma International Airport*. Washington, D.C: Department of Building Efficiency and Renewable Energy; 2004.
- Hurkens, Krisje, Wendy van der Valk, and Finn Wynstra. *"Total Cost of Ownership in the Services Industry - A Case Study."* Journal of Supply Chain Management, Winter 2006: 27-37.
- Kaiser H. *Capital Renewal and Deferred Maintenance Programs*. Alexandria, Virginia: APPA; 2016.
- Kangaroo Island Council, Australia. *Airport Infrastructure and Asset Management Plan*. Kangaroo Island, Australia: Kangaroo Island Council, 2010.

- Kim, Gu-Taek, Kyoon-Tai Kim, and Du-Heon Lee. *"Development of a life cycle cost estimate system for structures of light rail transit infrastructure."* Automation in Construction (ELSEVIER) 19 (2010): 308-325.
- Klinghoffer O, Papworth F, Barnes R. *Durability Design Using Risk Assessment And Monitoring*. Denmark: Force Technology; 2016.
- Korpi, Eric, and Timo Ala-Risku. *"Life cycle costing: a review of published case studies."* Managerial Auditing Journal (Emerald Group Publishing, Limited) 23, no. 3 (2008): 240-261.
- Leavitt E., Stanton L. Strategy for a Sustainable Sea-Tac. 2015.
- Lingegårda, Sofia, Mattias Lindahl, and Andreas Syberg. *"Life-cycle Cost Strategies for Harbors - A Case Study."* (ELSEVIER) 30 (2015): 317-322.
- Liverpool Plains Shire Council. *Airport and Facilities Asset Management Plan*. Liverpool Plains Shire Council, 2011.
- Love, Peter E.D., Ian Simpson, Andrew Hill, and Craig Standing. "*From justification to evaluation: Building information modeling for asset owners."* (ELSEVIER) 35 (2013): 208-216.
- Love, Peter E.D., Jane Matthews, Ian Simpson, Andrew Hill, and Oluwole A. Olatunji. "*A benefits realization management building information modeling framework for asset owners."* Automation in Construction (ELSEVIER) 37 (2014): 1-10.
- Love, Peter E.D., Junxiao Liu, Jane Matthews, Chun-Pong Sing, and Jim Smith. "*Future proofing PPPs: Life-cycle performance measurement and Building Information Modelling."* Automation in Construction (ELSEVIER) 56 (2015): 26-35.
- Lu L. The Relationship between Maintenance and Service Planning. 2003.
- Martinez J. Application of Reliability-Centered Maintenance in Facility Management. 2007.
- Miami International Airport. *"Commissioning Requirements (section 01810) - Miami International Airport."* Miami, 2002.
- Mote P., Snover A. Northwest. In: Capalbo S, Eigenbrode S, Glick P, Littell J, Raymondi R, Reeder S, ed. *Climate Change Impacts In The United States: The Third National Climate Assessment*. 3rd ed. Global Research Change Project; 2014.
- Naguib, Ramez. "*Total Cost of Ownership for Air-Cooled and Water-Cooled Chiller Systems."* American Society of Heating, Refrigerating and Air Conditioning 51 (2009): 42-48.
- National Aeronautics and Space Administration. *RCM Guide: Reliability-Centered Maintenance Guide for Facilities and Collateral Equipment*. NASA; 2008.
- New Jersey Department of Environmental Protection. *Asset Management Guidance and Best Practices*.
- Nicosia, Nancy, and Nancy Moore. *Implementing Purchasing and Supply Chain Management – Best Practices in Market Research.* Air Force, United States: RAND, 2006.
- Office of Asset Management, Federal Highway Administration U.S. Department of Transportation. *Life Cycle Cost Analysis - The Pennsylvania Experience.* Washington, DC: FHWA, 2003, 10.
- Office of Asset Management, FHWA, US DOT. *Life-Cycle Cost Analysis - The Georgia Experience*. Georgia DOT, Washington , DC: FHWA, 2007, 12.
- Office of Government Commerce. *Procurement Guide 07 - Whole-Life Costing and Cost Management.* United Kingdom: Office of Government Commerce, 2003.
- Ozbay, Kaan, Neville Parker, Dima Jawad, and Sajjad Hussain. *Guidelines for Life Cycle Cost Analysis.* Washington, DC: Federal Highway Administration, 2003.
- Palmer C., Laurent C. *Solar and Glare*. Boston, MA: Meister Consultants Group; 2014.
- Parida A., Kumar U. *Maintenance Productivity and Performance Measurement*. 1st Ed.
- Parkhi, Shilpa Shekhar. *Total Cost of Ownership (TCO).* Nashik, India: THINK-LINE, 2013.
- Parrish, Kristen, and Mikhail Chester. *"Life-Cycle Assessment for Construction of Sustainable Infrastructure."* Practice Periodical on Structural Design and Construction (American Society of Civil Engineers) 19, no. 1 (2014): 89-94.
- Perera, Oshani, Barbara Morton, and Tina Perfrement. *Life Cycle Costing in Sustainable Public Procurement: A Question of Value*. Winnipeg, Canada: International Institute for Sustainable Development, 2009.
- Pihl K. North Satellite Project 30% Design Phase Photovoltaic System Preliminary Evaluation. 2014.
- Procurement and Property Branch. *Best Practices for Maintenance of Building Assets - Procurement Practices Manual.* Tasmania, Australia: State of Tasmania, Department of Treasury and Finance, 2013.
- Rabetino, Rodrigo, Marko Kohtamäki, Heini Lehtonen, and Hanna Kostama. *"Developing the Concept of Life-Cycle Service Offering."* Industrial Marketing Management (ELSEVIER) In Press (2015).
- Radziwill, Nicole M., and Ronald F. DuPlain. *"Using Value Based Total Cost of Ownership Measures to Inform Subsystem Tradeoffs."* International Society for Optical Engineering. Proceedings of SPIE, 2010
- Robert Alfert, Jr., Karen M. Ryan, and Roy Block. *ACRP 11-01 Procurement of Airport Development and Planning Contracts.* Airport Cooperative Research Program, Washington, DC: Transportation Research Board, 2012.
- Roda, Irene, and Marco Garetti. *"TCO Evaluation in Physical Asset Management: Benefits and Limitations for Industrial Adoption."* In Advances in Production Management Systems. Innovative and Knowledge-Based Production Management in a Global-Local World, by IFIP Advances in Information and Communication Technology, 216-223. Springer Berlin Heidelberg, 2014.
- Ruitenburg, R.J. (Richard), A.J.J. Braaksma, and L.A.M. van Dongen. *"A multidisciplinary, expert-based approach for the identification of lifetime impacts in Asset Life Cycle*

Management." 3rd International Conference on Through-life Engineering Services. ELSEVIER, 2014. 204-212.

- Safi, Mohammed, Hakan Sundquist, and Raid Karoumi. *"Cost-Efficient Procurement of Bridge Infrastructures by Incorporating Life-Cycle Cost Analysis with Bridge Management Systems."* Journal of Bridge Engineering (ASCE) 20, no. 6 (2015): 12.
- Salt Lake City Department of Airports, and Carter & Burgess. *Making the Business Connection to Airport Sustainability.* Salt Lake City: Salt Lake City Department of Airports, 2006.
- San Francisco Water Power Sewer. *San Francisco Municipal Buildings*. San Francisco: San Francisco Public Utilities Commission; 2013.
- Schuman, Charles A., and Alan C. Brent. *"Asset life cycle management: towards improving physical asset performance in the."* International Journal of Operations & Production Management (Emerald Insight) 25, no. 6 (2005): 566-579.
- Scottish Procurement Directorate. *Sustainable Procurement Action Plan for Scotland.* Scotland, United Kingdom: Scottish Government, 2009.
- Seattle-Tacoma International Airport. *Concession Design Guidelines*.
- Seattle-Tacoma International Airport. *2014 Progress Report*. Seattle, Washington; 2014.
- The Association of Cost Engineers. *Whole Life Costing - A Systems Engineering Approach.* The Association of Cost Engineers, 2014.
- The Boston Group. *Strategic Infrastructure - Steps to Operate and Maintain Infrastructure Efficiently and Effectively.* World Economic Forum, 2014.
- The National Institute of Building Sciences. *A Common Definition for Zero Energy Buildings*. 2015.
- TOO, Eric G. *"Infrastructure Asset Management: The Challenges and Approaches."* The 8th International Conference on Construction and Real Estate Management. Brisbane, Queensland, Australia: China Architecture & Building Press, 2010.
- Transportation Research Board. *ACRP 01-16: Asset and Infrastructure Management for Airports (Report 69).* Aviation Cooperative Research Program, Washington, DC: Transportation Research Board, 2012.
- Transportation Research Board. *ACRP 139: Optimizing Airport Building Operations and Maintenance Through Retro-commissioning: A Whole-Systems Approach.* ACRP, Washington, DC: Transportation Research Board, 2015.
- U.S. General Services Administration. *The Federal Strategic Sourcing Initiatives*. GSA, n.d.
- U.S Green Building Council. *Treatment of District or Campus Thermal Energy in LEED V2 and LEED 2009 - Design & Construction.*; 2016.
- United Kingdom Government, Cabinet Office. *Total Cost of Ownership - Things to Consider*. United Kingdom Government, 2011.
- Woodward, David G. *"Life cycle costing—Theory, information acquisition and application."* International Journal of Project Management (ELSEVIER) 15, no. 6 (1997): 335-344.
- Wouters, Marc. *"Beyond the Acquisition Price - Total Cost of Ownership for Supporting Purchase Decisions."* n.d.
- Wouters, Marc, James Anderson, and Finn Wynstra. *The adoption of Total Cost of Ownership for sourcing decisions – A structural equations analysis.* University Park, PA, 2004.
- Yavas, Burhan. *"Strategic Sourcing: A Comparative Study across Two Industries."* International Journal of Business and Management 6, no. 4 (2011): 3-15.

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1 Port of Seattle Strategic Goals
2 Port of Seattle Century Goals
3 Port of Seattle Policy EX-15, *Sustainable Asset Management Policy*, adopted 2/6/2013

Attachment D

Cost Matrix

			ASSET MANAGEMENT									
				Construction			Operation			Renovation		
			Expected Service Life	Construction Cost/SF	Airport Cost Premium (%)	Total Const Cost/SF	OPEX Cost/SF	Minimum OPEX (%)	Maximum OPEX (%)	Replacement Value (%)	Demolition Cost (%)	Disposal Cost (%)
Terminal Administration Building	*A Substructure*	A10 Foundations										
Overall Square Footage:		A20 Basement Construction										
124,000	*B Shell*	B10 Superstructure	50	$82.50	15%	$94.88	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$55.00	15%	$63.25	$0.54	80%	125%	120%	20%	5%
22,400		B30 Roofing	35	$8.19	20%	$9.83	$0.08	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$22.00	15%	$25.30	$0.83	80%	125%	120%	20%	5%
		C20 Stairs	50	$3.00	15%	$3.45	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$28.50	18%	$33.63	$0.98	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	8.50	15%	$9.78	$0.25	80%	125%	120%	20%	5%
		D20 Plumbing	30	$8.50	20%	$10.20	$0.39	80%	125%	120%	20%	5%
		D30 HVAC	28	$57.95	20%	$69.54	$2.19	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$7.10	20%	$8.52	$0.39	80%	125%	120%	20%	5%
		D50 Electrical	27	$60.00	20%	$72.00	$2.68	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment	20	$5.00	20%	$6.00	$0.07	80%	125%	120%	20%	5%
		E20 Furnishings	15	$10.00	15%	$11.50	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$341.33		$400.11	$8.13					
Terminal Concourse A	*A Substructure*	A10 Foundations	50	$29.65	15%	$34.10	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction										
228,600	*B Shell*	B10 Superstructure	50	$73.25	15%	$84.24	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$36.95	15%	$42.49	$2.89	80%	125%	120%	20%	5%
210,900		B30 Roofing	35	$20.48	30%	$26.62	$0.17	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$8.85	15%	$10.18	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50	$3.20	15%	$3.68	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$69.02	18%	$81.44	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$38.08	30%	$49.50	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$4.80	30%	$6.24	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$68.18	30%	$88.63	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$7.66	30%	$9.96	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$77.42	30%	$100.65	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment	20	$32.10	20%	$38.52	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings	15	$13.66	15%	$15.71	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$478.83		$586.59						
IAF Expansion (2017)	*A Substructure*	A10 Foundations	50	$42.50	15%	$48.88	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction										
425,000	*B Shell*	B10 Superstructure	50	$145.00	15%	$166.75	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$50.14	15%	$57.66	$2.89	80%	125%	120%	20%	5%
212,500		B30 Roofing	35	$27.68	30%	$35.98	$0.17	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$17.25	15%	$19.84	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50	$4.75	15%	$5.46	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$48.50	18%	$57.23	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$21.75	30%	$28.28	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$9.68	30%	$12.58	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$68.23	30%	$88.70	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$9.26	30%	$12.04	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$68.95	30%	$89.64	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment	20	$63.81	20%	$76.57	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings	15	$6.98	15%	$8.03	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$545.12		$660.28						

				ASSET MANAGEMENT								
				Construction			Operation			Renovation		
			Expected Service Life	Construction Cost/SF	Airport Cost Premium (%)	Total Const Cost/SF	OPEX Cost/SF	Minimum OPEX (%)	Maximum OPEX (%)	Replacement Value (%)	Demolition Cost (%)	Disposal Cost (%)
Terminal Concourse B	*A Substructure*	A10 Foundations	50	$29.65	15%	$34.10	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction										
84,000	*B Shell*	B10 Superstructure	50	$73.25	15%	$84.24	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$46.19	15%	$53.12	$2.89	80%	125%	120%	20%	5%
84,000		B30 Roofing	35	$20.48	30%	$26.62	$0.17	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$8.85	15%	$10.18	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50	$3.20	15%	$3.68	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$69.02	18%	$81.44	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$1.61	30%	$2.09	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$4.80	30%	$6.24	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$68.18	30%	$88.63	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$7.66	30%	$9.96	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$77.42	30%	$100.65	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment	20	$4.50	20%	$5.40	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings	15	$6.50	15%	$7.48	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$418.42		$510.50						
Terminal Concourse C	*A Substructure*	A10 Foundations	50	$29.65	15%	$34.10	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction										
172,900	*B Shell*	B10 Superstructure	50	$73.25	15%	$84.24	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$46.19	15%	$53.12	$2.89	80%	125%	120%	20%	5%
145,940		B30 Roofing	35	$20.48	30%	$26.62	$0.17	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$8.85	15%	$10.18	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50	$3.20	15%	$3.68	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$69.02	18%	$81.44	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$1.61	30%	$2.09	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$4.80	30%	$6.24	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$68.18	30%	$88.63	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$7.66	30%	$9.96	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$77.42	30%	$100.65	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment	20	$4.50	20%	$5.40	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings	15	$6.50	15%	$7.48	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$410.61		$501.04						
Terminal Concourse D	*A Substructure*	A10 Foundations	50	$29.65	15%	$34.10	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction										
89,550	*B Shell*	B10 Superstructure	50	$73.25	15%	$84.24	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$46.19	15%	$53.12	$2.89	80%	125%	120%	20%	5%
85,400		B30 Roofing	35	$20.48	30%	$26.62	$0.17	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$8.85	15%	$10.18	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50	$3.20	15%	$3.68	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$69.02	18%	$81.44	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$1.61	30%	$2.09	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$4.80	30%	$6.24	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$68.18	30%	$88.63	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$7.66	30%	$9.96	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$77.42	30%	$100.65	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment	20	$4.50	20%	$5.40	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings	15	$6.50	15%	$7.48	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$416.10		$507.69						

				ASSET MANAGEMENT								
				Construction			Operation			Renovation		
			Expected Service Life	Construction Cost/SF	Airport Cost Premium (%)	Total Const Cost/SF	OPEX Cost/SF	Minimum OPEX (%)	Maximum OPEX (%)	Replacement Value (%)	Demolition Cost (%)	Disposal Cost (%)
Terminal Ticketing	*A Substructure*	A10 Foundations	50	$29.65	15%	$34.10	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction										
448,850	*B Shell*	B10 Superstructure	50	$267.09	15%	$307.15	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$46.19	15%	$53.12	$2.89	80%	125%	120%	20%	5%
255,900		B30 Roofing	35	$20.48	30%	$26.62	$0.17	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$13.50	15%	$15.53	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50	$13.25	15%	$15.24	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$63.49	18%	$74.92	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$22.45	30%	$29.19	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$8.56	30%	$11.13	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$68.18	30%	$88.63	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$8.56	30%	$11.13	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$77.42	30%	$100.65	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment	20	$21.20	20%	$25.44	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings	15	$19.16	15%	$22.03	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$634.19		$760.08						
Terminal Central Terminal Expansion	*A Substructure*	A10 Foundations	50	$68.00	15%	$78.20	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction										
138,800	*B Shell*	B10 Superstructure	50	$126.00	15%	$144.90	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$72.50	15%	$83.38	$2.89	80%	125%	120%	20%	5%
77,600		B30 Roofing	35	$31.00	30%	$40.30	$0.17	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$23.00	15%	$26.45	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50		15%	$0.00	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$66.00	18%	$77.88	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$0.00	30%	$0.00	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$10.50	30%	$13.65	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$76.00	30%	$98.80	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$8.56	30%	$11.13	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$80.00	30%	$104.00	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment	20	$5.00	20%	$6.00	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings	15	$10.50	15%	$12.08	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$533.41		$644.51						
North Satellite	*A Substructure*	A10 Foundations	50	$19.16	15%	$22.03	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction						80%	125%	120%	20%	5%
211,000	*B Shell*	B10 Superstructure	50	$77.84	15%	$89.52	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$48.00	15%	$55.20	$2.89	80%	125%	120%	20%	5%
91,500		B30 Roofing	35	$14.22	30%	$18.49	$0.17	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$11.50	15%	$13.23	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50	$2.85	15%	$3.28	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$71.62	18%	$84.51	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$9.28	30%	$12.06	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$5.50	30%	$7.15	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$67.00	30%	$87.10	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$7.61	30%	$9.89	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$76.92	30%	$100.00	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment		$32.63	20%	$39.16	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings		$12.05	15%	$13.86	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$434.71		$529.57						

			ASSET MANAGEMENT									
			Expected Service Life	Construction			Operation			Renovation		
				Construction Cost/SF	Airport Cost Premium (%)	Total Const Cost/SF	OPEX Cost/SF	Minimum OPEX (%)	Maximum OPEX (%)	Replacement Value (%)	Demolition Cost (%)	Disposal Cost (%)
South Satellite	*A Substructure*	A10 Foundations	50	$19.16	15%	$22.03	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction						80%	125%	120%	20%	5%
317,600	*B Shell*	B10 Superstructure	50	$77.84	15%	$89.52	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$48.00	15%	$55.20	$2.89	80%	125%	120%	20%	5%
93,200		B30 Roofing	35	$14.22	30%	$18.49	$0.17	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$13.50	15%	$15.53	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50	$2.85	15%	$3.28	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$71.62	18%	$84.51	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$9.28	30%	$12.06	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$5.50	30%	$7.15	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$67.00	30%	$87.10	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$7.61	30%	$9.89	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$76.92	30%	$100.00	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment		$32.63	20%	$39.16	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings		$12.05	15%	$13.86	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$432.03		$526.19						
Terminal Baggage Level/Bridge Level	*A Substructure*	A10 Foundations	50	$28.47	15%	$32.74	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction		$5.50								
1,067,700	*B Shell*	B10 Superstructure	50	$73.25	15%	$84.24	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$44.00	15%	$50.60	$2.89	80%	125%	120%	20%	5%
812,350		B30 Roofing										
	C Interiors	C10 Interior Construction	29	$10.99	15%	$12.64	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50	$3.85	15%	$4.43	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$61.33	18%	$72.37	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$12.46	15%	$14.33	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$4.45	20%	$5.34	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$57.39	20%	$68.87	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$7.50	20%	$9.00	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$68.00	20%	$81.60	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment		$56.45	20%	$67.74	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings		$7.08	15%	$8.14	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$413.33		$486.86						
Terminal Satellite Transit Level	*A Substructure*	A10 Foundations	50	$25.00	15%	$28.75	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction		$110.00	15%	$126.50	$0.00	80%	125%	120%	20%	5%
405,350	*B Shell*	B10 Superstructure	50	$80.00	15%	$92.00	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$5.00	15%	$5.75	$2.89	80%	125%	120%	20%	5%
405,350		B30 Roofing										
	C Interiors	C10 Interior Construction	29	$15.00	15%	$17.25	$2.62	80%	125%	120%	20%	5%
		C20 Stairs	50	$7.50	15%	$8.63	$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$65.00	18%	$76.70	$0.93	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$10.50	15%	$12.08	$1.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$3.50	20%	$4.20	$0.77	80%	125%	120%	20%	5%
		D30 HVAC	28	$59.00	20%	$70.80	$5.02	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$8.50	20%	$10.20	$0.78	80%	125%	120%	20%	5%
		D50 Electrical	27	$80.00	20%	$96.00	$2.13	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment		$16.00	20%	$19.20	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings		$12.50	15%	$14.38	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$485.75		$568.91						

			ASSET MANAGEMENT									
				Construction			Operation			Renovation		
			Expected Service Life	Construction Cost/SF	Airport Cost Premium (%)	Total Const Cost/SF	OPEX Cost/SF	Minimum OPEX (%)	Maximum OPEX (%)	Replacement Value (%)	Demolition Cost (%)	Disposal Cost (%)
Central Plant	*A Substructure*	A10 Foundations			15%		$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction										
	B Shell	B10 Superstructure			15%		$2.57	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure			15%		$8.58	80%	125%	120%	20%	5%
		B30 Roofing										
	C Interiors	C10 Interior Construction			15%		$0.29	80%	125%	120%	20%	5%
		C20 Stairs			15%		$0.04	80%	125%	120%	20%	5%
		C30 Interior Finishes			18%		$3.59	80%	125%	120%	20%	5%
	D Services	D10 Conveying			15%		$0.00	80%	125%	120%	20%	5%
		D20 Plumbing			25%		$0.63	80%	125%	120%	20%	5%
		D30 HVAC			25%		$2.29	80%	125%	120%	20%	5%
		D40 Fire Protection			25%		$0.81	80%	125%	120%	20%	5%
		D50 Electrical			20%		$2.58	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment			20%		$0.00	80%	125%	120%	20%	5%
		E20 Furnishings			15%		$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$0.00		$0.00						
Main Parking Garage (excluding Central Plant)	*A Substructure*	A10 Foundations	50	$9.60	5%	$10.08	$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction										
5,140,000	*B Shell*	B10 Superstructure	50	$43.64	5%	$45.82	$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	38	$2.50	5%	$2.63	$0.01	80%	125%	120%	20%	5%
		B30 Roofing	30	$1.19	5%	$1.25	$0.00	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$1.73	5%	$1.82	$0.00	80%	125%	120%	20%	5%
		C20 Stairs	50	$1.71	5%	$1.80	$0.07	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$2.47	5%	$2.59	$0.17	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30	$4.73	5%	$4.96	$0.69	80%	125%	120%	20%	5%
		D20 Plumbing	30	$0.95	5%	$1.00	$0.03	80%	125%	120%	20%	5%
		D30 HVAC	28	$0.44	5%	$0.46	$0.00	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$1.24	5%	$1.30	$0.13	80%	125%	120%	20%	5%
		D50 Electrical	27	$10.68	5%	$11.21	$0.43	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment		$0.56	5%	$0.59	$0.00	80%	125%	120%	20%	5%
		E20 Furnishings			5%	$0.00	$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$81.43		$85.50						
Air Cargo/Warehouse	*A Substructure*	A10 Foundations	50	$33.41	10%		$0.00	80%	125%	120%	20%	5%
Overall Square Footage:		A20 Basement Construction										
	B Shell	B10 Superstructure	50	$42.48	10%		$0.00	80%	125%	120%	20%	5%
Footprint Square Footage:		B20 Exterior Enclosure	35	$31.68	10%		$2.51	80%	125%	120%	20%	5%
		B30 Roofing		$18.00	10%		$0.23	80%	125%	120%	20%	5%
	C Interiors	C10 Interior Construction	29	$7.92	10%		$0.07	80%	125%	120%	20%	5%
		C20 Stairs	50	$0.36	10%		$0.00	80%	125%	120%	20%	5%
		C30 Interior Finishes	15	$6.12	10%		$4.74	80%	125%	120%	20%	5%
	D Services	D10 Conveying	30		10%		$0.00	80%	125%	120%	20%	5%
		D20 Plumbing	30	$10.80	10%		$0.41	80%	125%	120%	20%	5%
		D30 HVAC	28	$12.24	10%		$5.76	80%	125%	120%	20%	5%
		D40 Fire Protection	23	$5.76	10%		$0.98	80%	125%	120%	20%	5%
		D50 Electrical	27	$29.52	10%		$2.57	80%	125%	120%	20%	5%
	E Equipment and Furnishings	E10 Equipment		$11.52	10%		$0.00	80%	125%	120%	20%	5%
		E20 Furnishings		$2.16	10%		$0.00	80%	125%	120%	20%	5%
	TOTAL (AVERAGE)			$0.00		$0.00						

Attachment E

Additional Information

INTRODUCTION

This section provides additional information that supplements sections within the main body of the report.

UNDERSTANDING TOTAL COST OF OWNERSHIP

3.1.1 Types of Cost

Total cost of Ownership is all of the costs associated with an asset. These costs are broken down into capital expenditures, operation expenditures, renewal expenditures, end-of-life expenses, and income.

Capital expenditures (CAPEX) include all costs associated with acquiring and constructing the asset. These include non-construction costs, such as purchase of land, lease, finance costs, program management fees, architectural and engineering costs, regulatory costs (such as permit or inspection fees), as well as all site and building construction costs, including materials, labor, and project management costs. It includes planning costs, such as the costs associated with assembling the Project Team (both design and construction) and the cost of Airport employees' involvement with the program. It includes startup and commissioning costs and fit-out costs for equipment, fixtures, and furnishings.

Operation expenditures (OPEX) primarily includes six components: operations, maintenance, repairs, replacement, alterations, and utility costs.

Operational costs are those related to normal operation of the Airport. These include continual taxes and fees associated with the asset, janitorial, waste management, security, insurance, compliance with regulatory requirements (inspections), and management of the assets. For services such as HVAC, electrical, and plumbing, operation costs include operation of equipment and the materials such as chemical treatment needed to operate the machinery.

Maintenance costs are those necessary to maintain the expected design service life of a fixed asset. These include ground maintenance, regular planned maintenance, preventative maintenance, and cost of all personnel, contracts, and equipment necessary for this maintenance.

Repair costs is work required to restore assets to normal operating condition. These include unplanned maintenance (responding to a fault), maintenance management, and includes costs associated with equipment/asset downtime. Repairs are reactive where maintenance is preventative.

Replacement costs are those associated with a single fixed asset. It is a direct replacement for another asset and performs the same function.

Alteration costs are those associated with a change in physical or operational requirements of a facility. These include costs associated with modifying or upgrading decorations, furnishings, or equipment to meet its current intended purpose or to adapt it to its new use. These are typically overlooked in budgeting for facility needs.

Utility costs include all fees associated with energy, water, and other utilities necessary to operate the building. This may apply to energy or water supplied by a public utility or through the upkeep and operation of site-generated utilities.

Renewal expenses (RENEX) includes major systematic replacement or refurbishment of a group of assets intended to extend the overall life and retain useful benefit of the facilities and systems. This not only includes costs associated with replacement of the asset, but also the shutting down operation in order to complete the work. This may include lost revenue during the periods where construction prevents normal operation.

End-of-life expenses (DISPEX) include all expenses related to demolition of the asset and disposal of the waste produces by demolition. It would include all fees associated with decommissioning and any costs associated with restoring the space or site to suitable condition.

Also considered in a TCO calculation is any income generated by the asset. This may include third party income (such as rent generated by concessions) or the sale of salvaged materials or sale of land at the end of life.

Together these costs represent the overall cost to build, own, operate, and remove assets related to the Airport.

3.1.2 Understanding Life of an Asset

Understanding the asset's life-cycle is important in discussions regarding total cost. This can be determined and defined in many different ways, depending on the asset and the purpose of the discussion.

"Useful Life" or "Service life" (sometimes called "physical life") is the period of time over which an asset is expected to last before it needs to be replaced or rehabilitated. This is the definition used throughout the report in discussions on TCO. Some assets do not reach this point before they are demolished or replaced due to program or economic changes.

"Functional life" is the period of time which the need for the asset is anticipated. If an asset can no longer function as intended, it is at end of its functional life.

"Economic life" is the period of time until the asset is no longer the most economical solution among all proposed alternatives. Rising energy costs can contribute to shorter economic life.

"Technological life" is the period of time until an asset is technologically obsolete. Newer and better technological solutions dictate replacement of the asset. For example, computers may have a long service life, but technology makes them obsolete in a much shorter span of time.

“Social Life” or “Legal Life” are terms for the period of time until an asset should be replaced for reasons other than economic ones. These may include changes to codes, health and safety concerns, or public perception.

“Contract Life” is the period of time for fixed date assets. These may include assets that are leased or built to span a temporary period of time.

“Arbitrary Life” or “Study Life” is the term used to describe a period of time for which a study occurs, that does not necessarily reflect actual life expectancy for the asset.

Anticipated or expected useful life of an asset provides a good prediction of the actual life expectancy of the asset, assuming routine maintenance has occurred and the asset is being operating as intended. Premature failure, improper installation, reduced or improper maintenance, overuse, and use beyond intended performance can all reduce the expected life of the asset. If the life-cycle of an asset is less than the intended useful period needed for the asset, then renewal costs are required to rehabilitate, renovate, or replace the asset for continued operation. Since renewal costs are many times more expensive than their initial capital costs, it is important to understand how O&M and installation affect the asset’s life.

3.1.3 Future Value of Money

In terms of *Total Cost*, it is important to understand several primary terms that allow a comparison of how much an asset costs in terms of present day and actual cost over time.

The possibility of trading the initial capital expenditures against future operational cost savings is one of the main purposes of TCO. Many times, an increase in capital expenditures results in more reliability and reduced maintenance costs.

The *Time Value of Money* considers both inflation and opportunity costs to determine how much money will be spent in the future. For cash assets or existing capital, *opportunity cost* is equivalent to the benefit the cash could have achieved had it been spent differently or invested. For funded assets (those borrowed), opportunity cost is the cost of borrowing that money such as the rate of the loan.

Inflation reduces the value or purchasing power of money over time. It is a result of the gradual increase in the cost of goods and services due to economic activity.

Nominal Rate is the rate of interest before the adjustment for inflation.

The following formula factors inflation out of any nominal rate:

$$Actual\ Rate = \frac{1 + Nominal\ Rate}{1 + Inflation\ Rate} - 1$$

If inflation rates for all asset costs are known or considered to be equal, inflation can be excluded. However, if certain assets or costs have known inflation rates that are considerably different, then inflation should be included.

Cost *Discount* are asset costs and revenue that occur at different points in the life of a building, so therefore cannot be compared directly (due to the time value of money changes). This is based on the value of money being greater at present than in the future, due to earning power on that money between the future and present dates. To understand the present value, these future costs are “discounted” to their present value through the appropriate equations. The discount rate is defined in terms of opportunity cost. Present Value represent costs accruing in the future that have been discounted to account for the fact that they are worth less at the time of the calculation.

The basic discount equation is as follows:

$$Present\ Value = \frac{Future\ Value\ (in\ year\ x)}{(1 + Discount\ Rate)^{Number\ (x)\ of\ Years\ in\ Future}}$$

Discounting to present value makes an adjustment to the future costs of an asset that takes account of inflation and the real earning power of money, allowing them to be compared and evaluated on the same basis as costs incurred at the present.

Having a “zero” discount rate suggests that there is no future earning power of money. Therefore, the timing of costs such as renewal or major repair does not matter in the decision. It provides the best case scenario for favoring higher initial CAPEX costs to generate better savings in the service life of an asset.

In comparison, a high discount rate suggests that future cost of money is significant and therefore, lower upfront CAPEX costs, short service life, and more recurring costs are shown to have a lower overall total cost. This methodology argues that current decisions are more important than future considerations.

Although all assets or services do not have the same rate of inflation, the average rate of increase for products, services and labor is called *Escalation*. Where the real escalation rate is close to zero or zero, the escalation rate for that asset is essentially the same as the inflation rate.

The formula for calculating the future cost of an item with a known cost today and a known escalation rate is:

$$COST_{In\ Future\ Year\ X} = COST_{Present}(1 + Escalation\ Rate)^{Number\ (X) of\ Years\ in\ Future}$$

3.1.4 Understanding Reliability

The significance of reliability as compared to service life is apparent, but it is necessary to establish how much reliability is truly needed for an asset. Each system needs to determine which assets are most critical to the Airport. In addition, understanding the vulnerability of both the asset and the outcome of the asset’s failure is important in determining the true requirement for reliability.

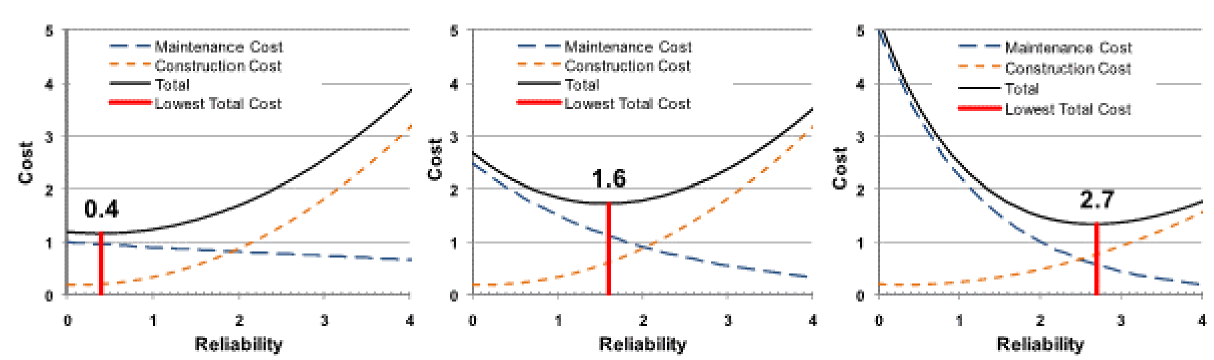
Critical assets that are vulnerable – such as to weather, sabotage, terrorism, or early failure – and could compromise the effective operation of the Airport should be considered a primary candidate for higher reliability construction. The critical asset/group of assets should have a high reliability in order to perform the work as designed and intended for the defined level of service. A reliable system does not necessarily have to have a longer service life. Take for example a security system or PLC.

If the construction cost of added reliability is high and the added reliability only marginally affects the maintenance cost, then lower reliability gives a lower overall cost. This assumes that future maintenance costs are discounted and therefore are less impacted based on present value. This results in any repair up to the service life being less costly than the original capital investment.

If the construction cost to increase reliability is low, but results in a significant savings in overall maintenance costs (such as a protective coating in a corrosive environment), then reliability is more important and assets should be designed and constructed for long service life.

The problem is that contractors minimize construction costs in order to win "low bid" construction contracts. Any increase to construction cost either results in less profit for the contractor or failure to win the bid. Since the maintenance cost is paid by the airport, this lower capital cost can result in higher operational costs throughout the service life. For this reason, understanding the total cost of operation is important when determining asset requirements.

Figure 1-2
Examples of Reliability Based on its Influence on Construction and Maintenance Costs



These examples show that low reliability systems have lower initial capital costs, but have higher operation and maintenance cost in the long term. Likewise, highly reliable systems have a higher capital cost, but have a lower ongoing O&M cost.

It is important to understand the different types of maintenance available for an asset. Each type of maintenance has both benefits and drawbacks that affect the overall cost and service life of an asset. These maintenance types are:

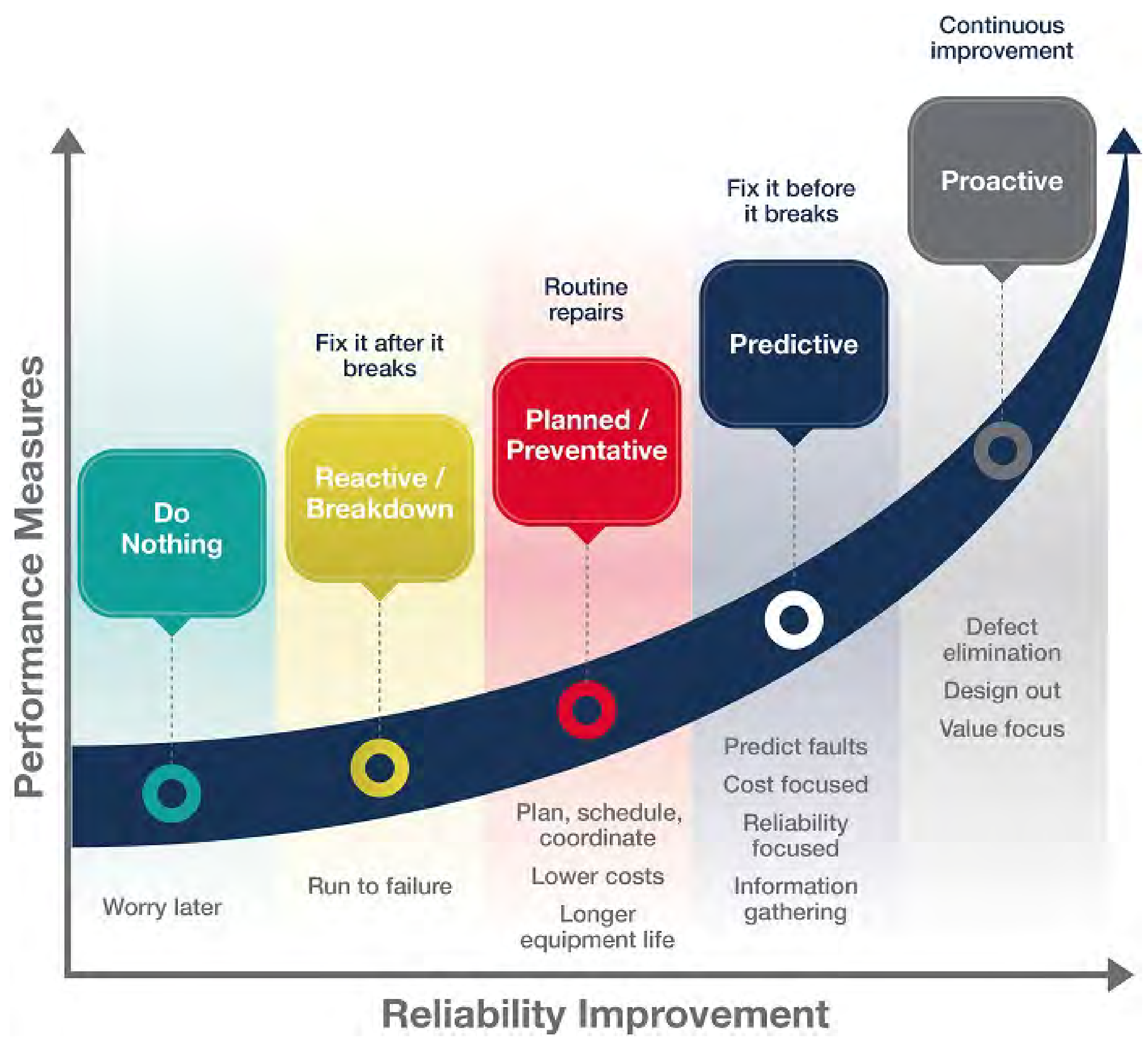
Reactive Maintenance – this technique assumes that no maintenance occurs until an asset fails. This "run until it breaks" model is typical for many applications. This technique has a low cost and requires less maintenance staff, but failure can happen more frequently and be costlier than other options. This can also cause unplanned and disruptive downtime and the potential for secondary equipment failure. Since this technique necessitates a smaller maintenance staff, outside resources are typically required to provide the service.

Preventative Maintenance – this technique assigns maintenance tasks on a time-based or run-hour-based system. This technique aims to extend service life through consistent observation and rehabilitation of the asset in order to minimize the potential for more significant failure. It can be cost effective for many capital-intensive processes and allows scheduling among many types of assets. It can result in extended life and energy efficiency, since system defects and inefficiencies are discovered in a timely basis. Preventative maintenance can have a 12% to 18% savings of total cost over reactive maintenance since the chance of catastrophic failure is significantly reduced. The downside of preventative maintenance is that catastrophic failure still occurs. It can require a larger maintenance staff in order to provide the PM. Finally, it can result in maintenance that is not necessary, which could result in potential damage while the unnecessary maintenance is occurring.

Predictive Maintenance – this technique uses measurements from sensors, controls, and other means to detect when performance is degrading over time. The slight degradations signify the need to perform maintenance. Once repaired, the asset is brought back to its normal operating state. In lieu of time-based maintenance (preventative), predictive maintenance analyzes the actual condition of the asset. This can lead to increased operational life and availability of the asset by decreasing the time that the asset is down for maintenance. It decreases the amount of labor required to maintain the assets. It renews setpoints and sets the asset for optimal energy efficiency. It can result in a 8% to 12% cost reduction as compared to preventative maintenance. The drawbacks are that it requires additional capital expenditures to invest in diagnostic sensors and equipment to monitor the asset. The maintenance staff must be trained to use this diagnostic equipment and be able to recognize degrading performance.

Reliability Centered Maintenance – this technique utilizes the efforts of the asset management program to define which maintenance technique is appropriate for which asset. It recognizes that not all assets require full preventative or predictive maintenance. Some assets have lower probability of failure or the consequences of failure are not significant. RCM focuses maintenance on the most critical and vulnerable assets.

Deferred Maintenance – Maintenance work that has been deferred on a planned or unplanned basis to a future budget cycle or postponed until funds are available. Known repairs that are deferred have a more significant risk of premature failure and shorter life cycle.

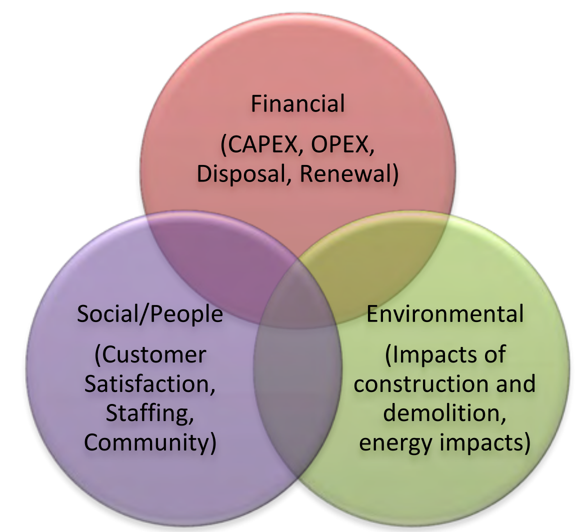


Gales, Tony. "Pump Reliability in the Food & Beverage Sectors." Maintenance Online -. Conference Communication, n.d. Web. 25 Apr. 2016.

STRATEGIC ASSET MANAGEMENT OBJECTIVES

Traditional master planning considers overall performance and growth needs for an organization and develops a financial plan to meet those needs, not subjective issues such as occupant comfort or impact to the environment. This financial plan typically considers only initial capital investment to make important decisions of which path should be taken. Understanding how each decision affects the operational and financial aspects of the organization is important to developing the appropriate decision. These costs go well beyond the initial capital investment, however. The asset will have new staff that will operate the commercial side, as well as staff to operate and maintain the building. The asset will require energy and water to operate. Differing levels of maintenance will be required as the asset ages. As the asset ages toward the end of its service life, additional costs are realized in demolition and disposal costs and renewal costs to rebuild the asset. The asset – during construction, during operation, and with the demolition and disposal – have an environmental impact. The most cost-effective solution is not always the most environmentally ideal choice. For example, a building system might consume very little energy but cost more to maintain than it saves in energy costs.

Essentially, each new asset has three primary components that are considered: a cost component, a people component, and an environmental component. This is referred to as the "Triple Bottom Line", a term first described by the Brundtland Commission in 1987, to describe the accounting philosophy of sustainable development having financial, social, and environmental impacts. Environmental represents issues related to air quality, land use, transportation impacts, greenhouse gas emissions, biodiversity, and use of natural resources such as energy, water, and raw materials. The people, or social, component represents community health and welfare, customer satisfaction, and the job satisfaction, health, and welfare of the staff working at Sea-Tac and its tenants.



The Port of Seattle Master Planning efforts are focused on this philosophy – using this process to understand the links between overall "total cost of ownership", sustainability, and delivering customer satisfaction for the planned growth. The objectives of developing the plan includes considerations for all three components.

Use of TCO for these comparisons allows for good decision making resulting in efficient use of the asset in both cost savings and environmental impact. Even if environmentally favorable decisions do not save money, TCO may reveal that the additional cost is minimal in comparison to their health and welfare benefits. Balancing economic (financial) concerns with human concerns (health and comfort) and environmental concerns (resource use, carbon impacts, ecological decisions).

Some sustainability issues are difficult to measure and to incorporate into a TCO analysis, however. There are methods and approaches to assessing environmental impacts that are of concern, but difficult to quantify. While a number of approaches for understanding environmental impact are available, ISO Standards 14040 and 14044 recommend Life Cycle Assessment (LCA). LCA calculates the potential environmental impacts by scoring and rating on environmental criteria to assist on which asset to purchase. Even though some environmental factors can be referred to in terms of cost (such as waste and remediation costs, other environmental factors have no currently agreed methodology for quantifying in cost terms.

Asset Management (AM) objectives should follow ISO 55000 standards. The objectives should be:

- Specific and measurable outcomes or achievements of the asset or group of assets to implement the AM policy(s) and strategy(s) to meet the airport's Strategic Master Plan
- Detailed and measurable levels of performance required by the assets
- Specific and measurable outcomes required of the AM framework

Within the airport's asset management there are two main themes or drivers:

1. Organization structure and function, and
2. Lifecycle process and practices.

Addressing and implementing the related objectives would assist the airport in developing a sustainable AM program and enhances the reliability of its assets. These themes/drivers deal with the operational and financial aspects of the airport. They are in place to reduce the airport's lifecycle costs by operating more efficiently, pursuing cost-effective investment strategies, and optimizing investment choices.

The related objectives to the organization structure and function for an airport are the following:

- Creation of a consolidated group that drives AM performance across the airport business divisions
- Level of service agreements between the asset management decisions and the other business units within the airport such as IT, operations, procurement, etc. to drive asset performance strategies
- Utilization of database as part of the staff operational procedures by modifying data entry portals to suit individual roles, provide training and ongoing support, and formalize and record asset management procedures

The related objectives to lifecycle process and practices are the following:

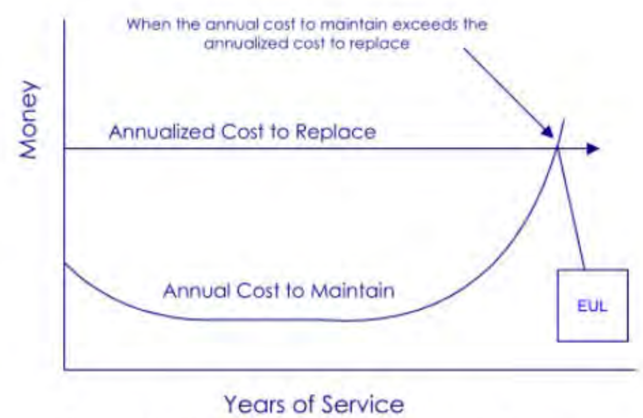
- Fully implement asset management system across the asset classes
- Integrate asset management awareness and requirements as part of the leadership programs at Sea-Tac
- Review and benchmark the operations and maintenance performance
- Develop metrics to help in measuring the airport's performance to improve its system's efficiency and reliability
- Develop and implement a risk management plan (assessments, registers, and mitigation). The tolerable risk limits are identified and quantitatively determined using dollar values.
- Identify and manage the gaps in the capital asset procurement siloes throughout the asset's lifecycle (Repair and replacement planning, design, construction, O&M, and repair and replacement investment decisions over time). The gaps include - but not limited to- very limited upfront O&M input in design, design is not executed with Total Cost of Ownership (TCO) as a decision making guide, commissioning process is disjointed and incomplete, and BIM information, record drawings, PM's, warranty data, and CMMS bridge are incomplete.

These gaps can be managed by – but not limited to – developing project team, using TCO in capital asset decision making, BIM standards, project teams work with contractor during the commissioning process, and solid CMMS data provides baseline for TCO decision making.

This will assist in minimizing the cost of ownership, while maintaining the required levels of service and sustaining the airport's infrastructure.

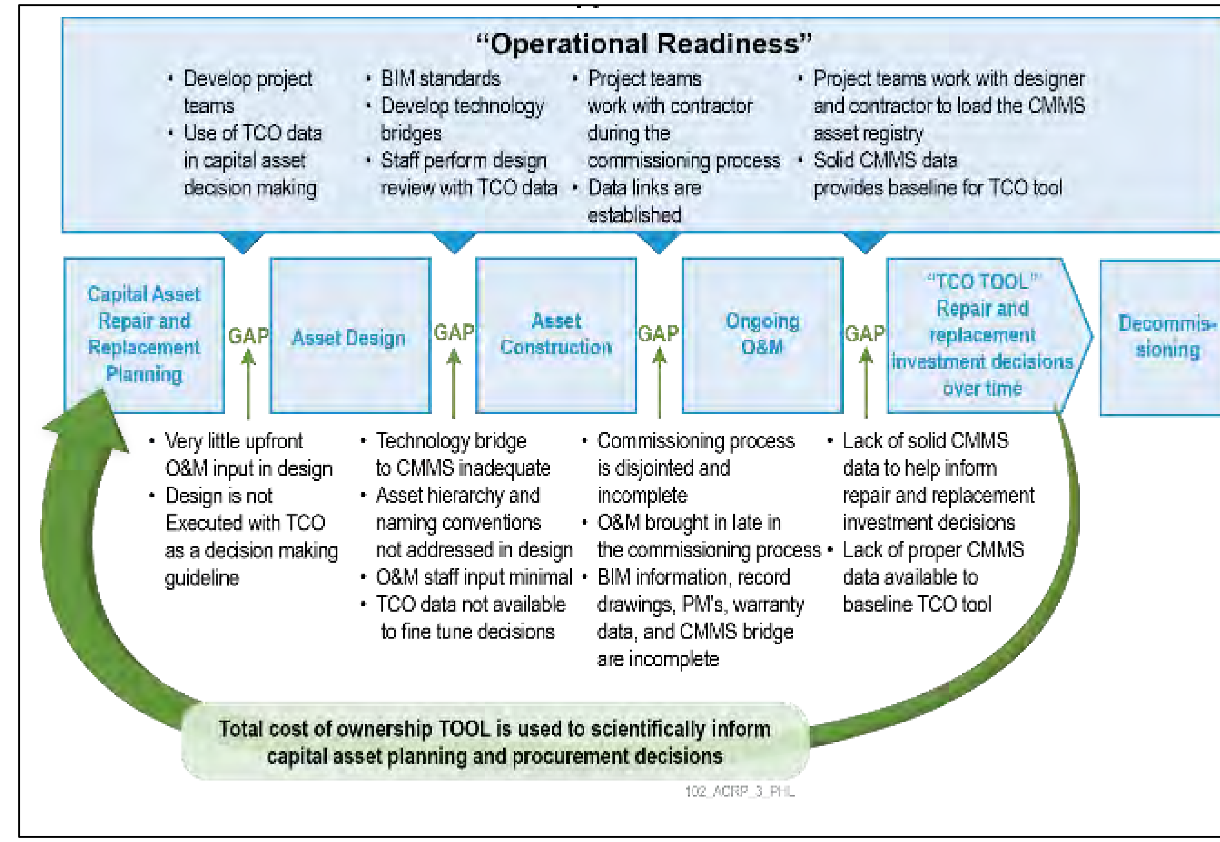
- Justification and prioritization of capital funds based on strategic objectives, risk, revenue, and service-level performance
- Integration of AM system with GIS, BIM, and financial systems
- Reduce critical assets' downtime by implementing predictive maintenance (PdM) and reliability-centered maintenance (RCM) "best practices" to improve on the system's reliability and performance
- Identify any performance shortfalls or indicators of prospective gaps and have mitigation action plans in place that can be implemented
- Identify, establish, or update asset policies with defined reliability, availability, maintainability, and safety requirements aligned to asset systems
- Identify, establish, or update policies incorporating sustainable development and in alignment with priority work in the risk-based maintenance program

- Establish maintenance interventions for medium to low criticality assets, based on cost and risk
- Develop and implement a maintenance strategy for the critical assets. These assets are managed based on the optimal point of repair and replacement cost, risk exposure, and not allowed to run to failure
- Integrate decision support system with maintenance management systems to improve timely decisions and minimize the downtime and impact on the system's (asset or group of assets) performance



Source: Graphic Systems Facility Management Technology Consultants, *Federal Real Property Association: Best Practices in Developing Asset Management Plans*

- Utilize the asset management database as the repository of the asset data register including replacement cost, remaining useful life, depreciation schedules, service level assessments, operating costs, resource allocation, and services
- Comply with all legislative requirements related to the airport operations such as facility audits (in compliance by a given percentage)
- Identify the risk levels for the assets that have been considered in the service levels and operation and maintenance plans
- Minimize and sustain the maintenance and renewal (M&R) gap to a certain percentage over 20 years. M&R Gap is the difference between estimated budgets and projected expenditures for maintenance and renewal of assets totaled over a defined time 5, 10, or 20 years, based on Port of Seattle's bonds and debt cycle
- Minimize and sustain the maintenance and renewal sustainability index to a certain percentage over 20 years. This is the ratio of estimated budget to projected expenditure for maintenance and renewal of assets over a defined time 5, 10, or 20 years, based on Port of Seattle's bonds and debt cycle



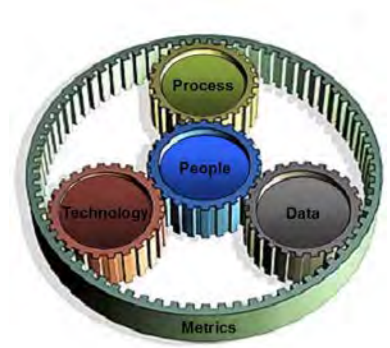
ASSET MANAGEMENT INTERVIEWS

A gap assessment exercise was conducted for the Seattle-Tacoma International airport (SEA). The gap assessment objectives were to identify the gaps/needs between the existing asset management practices and the future state that is being sought, along with high level improvement recommendations. The results of this assessment was intended to inform the Sustainable Airport Master Planning (SAMP) capital expansion effort of future business process and technology needs to support a robust asset management / operational sustainability program.

This Asset Management Gap Assessment entailed on-site interviews with six (6) SEA staff representing various functional departments including Facilities and Capital Programs (F&I) and

Planning & Environmental Programs. Specifically, the interviewees represented Maintenance, Facilities and Infrastructure, Continuous Process Improvement, and Environmental.

- ***Assessment Methodology*** - Today's asset management programs are built on several key elements that can help maximize asset life, reduce energy/utility consumption, and optimize costs and risks. Successful program implementation supports sustainable business practices and provide today's asset managers easy access to information required to support sound business and planning decisions. For these programs to be successful they must be part of an overall Asset Management strategy built on five (5) focus areas that include:
    - People – organization framework with documented roles and responsibilities
    - Process – published work flow policies and procedures
    - Data – data quality assurance/control programs
    - Technology – facilities staff have appropriate technology and training
    - Metrics – regular department reporting against performance measures/metrics



- ***Interview Methodology*** - A group of six key stakeholders were identified by SEA management to participate in one-on-one interviews where each interviewee was asked the same set of twenty-two (22) probing (i.e., open ended) questions in the five key areas of; people, process, data, technology, and metrics. In total, 132 interview responses were reviewed, analyzed, and consolidated into a list of findings and recommendations.

  The following is a list of key stakeholders that participated in the Asset Management Gap Assessment interview process.
    - Steve Rybolt, Environmental Management Specialist, Environmental
    - Stuart Matthews, General Manager, Aviation Maintenance
    - Deb Sorensen, Asset Manager, Aviation Maintenance
    - Brendalynn Taulelei, CMMS Manager, Aviation Maintenance
    - Wes Henrie, Manager, Continuous Process Improvement
    - Mike Smith, General Manager, Facilities and Infrastructure

- Interview Questions - The following is the list of interview questions used in this assessment:

  Asset Management Survey (Context: Input into a 20-Year Master Planning Project)

Staff Interview Questionnaire

General Questions:

- Asset Management Program – In your own words - please describe the SEA-TAC's AM Program:
    - How long has it been in place?
    - Are there guiding documents such as an Asset Management Policy/Framework/Roadmap (including Mission/Vision/Values)?
    - Is there a cross-functional steering committee (planning, facilities, operations, finance, etc.)?
    - Does SEA-TAC have an interest in the new ISO 55000 standard for Asset Management?
    - Can you highlight 2-3 general strengths of the Asset Management Program?
    - Can you highlight 2-3 areas for opportunity for the Asset Management Program?

5-Key Elements Questions/Comments (People, Process, Data, Technology, and Metrics):

- People/Organizational – Do you have any organizational/staffing thoughts to improve the Asset Management functions? (i.e., centralized vs de-centralized staffing, competencies and training needs, etc.)
- Process – Are there published asset management policies and procedures (i.e., SOP's, workflows) in a book/binder? Is there formal training for each?
- Process – Regarding the Maintenance Work Order, Preventive Maintenance and Corrective Maintenance processes? Can you identify any "pain points" that could use some attention?
- Process – Regarding the Capital Planning processes? Can you identify any "pain points" that could use some attention (Whole Life Costing, robust Business Case Evaluation (BCE) process, etc.)?
- Data – A few questions regarding physical assets:
    - Do you have a good asset register?
    - Do you have a good sense of their condition?
    - Do you have a good Preventive Maintenance program for critical assets?
    - Can you describe any Predictive Maintenance programs at SEA-TAC?
    - Is there a good process that links the condition and PM program data to the CIP process?
    - Are there staff dedicated to performing data analysis / asset failure analysis?
- Data – Please explain any data quality programs that are in place to protect the data being entered into SEA-TAC software systems.
- Technology – What 2 or 3 things would you improve with Maximo and/or PeopleSoft?
- Technology – Is there an Asset Management focused Information Technology (IT) Master Plan?

- Metrics – Is there a comprehensive suite of a) Customer Service Levels and/or 2) Performance Measures in place to measure effectiveness of Asset Management or Preventive Maintenance programs?
- Metrics – Are Asset Management programs results / benefits being captured and communicated to staff?
- Overall - Are there any other thoughts, suggestions or comments you may have in improving Asset Management needs in the context of this 20-year Master Planning effort?

Existing Information

Currently, Seattle-Tacoma International Airport uses several methods to track and manage their assets:

- **PeopleSoft**: All assets owned by the Port of Seattle, having a useful life of 3 years or more and a total capital project cost of $20,000 or more. This includes machinery, equipment, property, buildings, structures, vehicles, servers, software applications and other items/components or related systems that have a distinct and quantifiable business function.

- **Maintenance Maximo**: Any tangible property or component that requires regular maintenance and/or upon failure gets repaired; regardless of value.

- **F&I Asset Management System**: Assets managed by the Facilities and Infrastructure Group

Asset registry information was provided from Maximo for use in data collection for this analysis. Some costing and quantity considerations were used from this registry data.

Quantifying Relationship between Asset Design Life and Maintenance Spend

Facility Condition Index (FCI) represents the ratio of existing maintenance, repair, and replacement deficiencies of the facility to the current replacement value of the facility. This value provides the asset management team and airport leadership with an index to compare the asset/facility performance to expectations. This index is a benchmark used to compare the relative condition of a group of assets. Additionally, FCI can provide standardized metrics for total cost of ownership/whole life cycle costs, can reduce risks by identifying and prioritizing needs, and can identify areas for sustainability impacts.

The FCI value is presented on a 0 to1 scale or 0% - 100%. The higher the value of the FCI, the poorer the asset's or facility's overall condition. For traditional buildings, a good asset or facility usually has a FCI score of less than 5%, fair between 5% and 10%, and poor has a score of more than 10%.

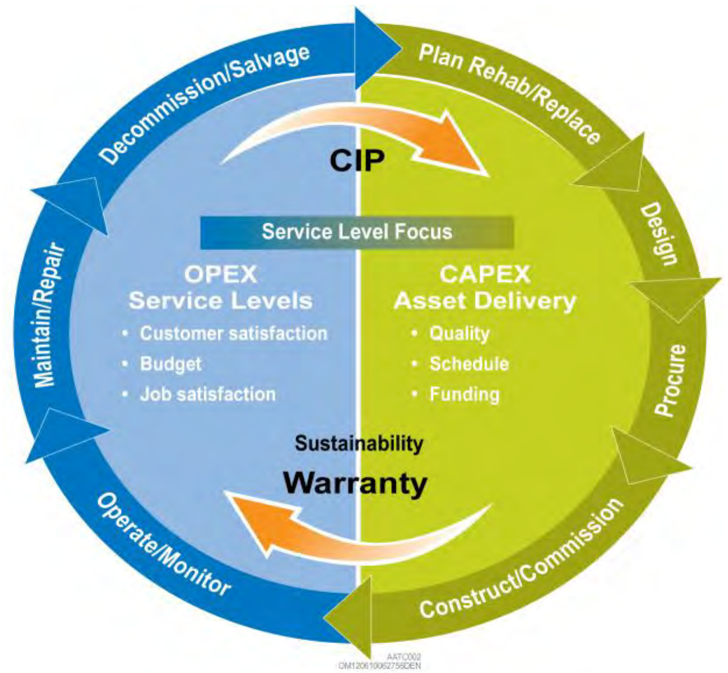
The following typical FCI elements are considered for a forward-looking condition assessment:

- Document the condition of the facility based on assessment (Backlog)
- Identify the probable wear and tear on the facility over an identified period of time (deterioration rate)
- Identify the projected continued deterioration of existing deficiencies of the facility (Backlog deterioration rate)
- Identify the projected maintenance and repair of the facility over an identified period of time (maintenance and repair rate)
- Project/predict changing demands on the facility that could impact its functional use
- Put a facility preservation plan in place in the event that the asset is not used within the identified period

Summary of Findings

Seattle-Tacoma International Airport (SEA) is in a unique situation in the airport industry. The staff interview results indicated that Asset Management practices and principles have been evolving for many years and that foundational elements of a successful program are in place at SEA. There are pockets of cross-collaboration, ongoing process improvements, development of data standards, technology advancements, and informal performance measures. They point to the need for director-level leadership, a holistic approach linking these ad-hoc elements together, coupled with a clear path forward.

SEA has taken an innovative approach to the traditional master planning process by adding an asset management review component as a key input. Effective asset management programs can be an important catalyst to a robust and successful sustainability program helping to maximize asset life, reduce energy/utility consumption, and optimize costs and risks. Holistic and effective asset management programs offer to link best practices across each phase of a facilities lifecycle. Effectively bridging the well-known industry gap between Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) functions, processes, and technologies.



Presently at SEA, there is staff concern that the new CAPEX program being developed under the SAMP will solely focus on improvements to the physical capital assets. And that the present OPEX functions, processes and technology gaps identified in this assessment could remain unchanged negatively impacting the goals set forth in the SAMP and the Century Agenda. The challenge for SEA is ensure a dual and concurrent focus to fund and execute both a sustainable capital plan and an asset management / sustainable operations plan. Thus effectively closing the CAPEX / OPEX gap at SEA. This two-pronged approach represents a robust, world-class, solution to sustainable planning and asset management best practices across the globe.

6.2 Summary of Findings

The following sections provide an overview of the interview findings and recommendations in three formats:

Common Themes
Master Planning Linkages to Asset Management
Gap Assessment Findings and Recommendations

6.2.1 Common Themes

The open-ended / probing questions varied somewhat in their responses, but a few common themes were generated as summarized below by category.

People / Organizational:

- There was a proactive program in place until the leader left SEA and efforts have stalled.
- There is a need for director-level leadership, with a holistic approach linking ad-hoc elements together, coupled with a clear plan forward.
- Dedicated staff needed to execute the plan since current staff are busy with normal workloads.
- Inter-departmental involvement on improvement teams to ensure sustainable change.

Process / Procedures:

- There is an existing Sustainable Asset Management Policy (EX-15) that needs to be reviewed and updated.
- Existing Asset Management, Maintenance, CIP, and New Asset Turnover Standard Operating Procedures (SOPs) need to be reviewed and updated.
- The Condition Assessment process needs; a more timely execution plan, and data / information linkages established to appropriate SOPs.
- The Preventive Maintenance Optimization program pilot was a success and needs to be re-launched.

Data:

- Asset register lists needs to be validated.
- Data and asset naming / numbering schemes should be reviewed and standardized across groups.
- Identify “minimum asset information” requirements

Technology:

- There is a need for a PeopleSoft / Maximo interface
- Decision on “system of record” for asset information (i.e., Maximo, PeopleSoft, Excel spreadsheets)
- Use of Maximo mobile field tools has improved data collection and should be rolled out to all appropriate staff.

Performance Metrics:

- There are a variety of KPI measures in place in some groups
- There is no formal or consistent performance management system in place.

General:

- There are a need to co-invest in business process improvements (i.e., asset management / operational sustainability) while also investing in the capital infrastructure to ensure a robust sustainability model.

Master Planning Linkages to Asset Management

The master planning process relies heavily on existing airport information/data typically collected through a variety of asset management related business processes. Table 1 below provides a summary review of findings when comparing the master planning process needs with the current SEA asset management program elements.

Master Planning Step	General Finding	Comment
Facilities Inventory	3 different databases 3 different asset definitions	Inventory information informs current capacity analysis.
Demand & Capacity Review	Assessed condition on 15% of assets	Condition information informs current capacity analysis.
Review of Alternatives	Total Cost of Ownership (TCO) Process: a) pockets of good historical data b) no formal process Business Case Evaluation (BCE) Process: a) in place, but could be updated to reflect current best practices	TCO process and information used in alternatives decision making process. BCE process used to select best appropriate project alternative(s).
Costing of Preferred Alternatives	Whole Life Cost (WLC) Modeling Process: a) no current process, WLC added to SAMP scope.	WLC modeling used to run scenarios in an effort to select best appropriate project alternative(s).
Airport Layout Plan (ALP)	Sustainable Operations Plan (OPEX functions, processes and technology): a) no current plan	A Sustainable Operations Plan ensures that new capital plan is supported by appropriate staffing/skills, business processes, and technologies / training.
CIP Projects	New Asset Turnover Process: a) in place, but could be updated to reflect current best practices	A New Asset Turnover Process ensures that the Facilities Inventory remains current and that a preventive maintenance plan is defined to protect the investment, maximize life, control costs and risks.

Gap Assessment Findings

The following table presents findings (identified issues / opportunities) and recommendations.

Identified Issue / Opportunity	Recommendation
People:	
There was a proactive program in place until the asset management program leader left SEA. There is a need for director-level leadership, with a holistic approach coupled with a clear path forward.	Consider identification of a director-level staff member to sponsor an inter-departmental asset management program. Consider the creation and formal chartering of an inter-departmental steering team.
The asset management functions are being done in an ad-hoc manner and in staff's spare time.	Conduct an organizational review to understand gaps and needs. Develop formal roles and responsibilities for required functions.
There is a need for asset management training across SEA in an effort to ensure alignment across the organization.	Provide formal asset management training for all SEA departments.

Identified Issue / Opportunity	Recommendation
Process:	
Policy EX-15 Sustainable Asset Management requires an update review.	Convene an interdepartmental committee to review and update Policy EX-15.
Some key standard operating procedures require an update review.	Convene an interdepartmental committee to review and develop an SOP review and update plan. SOP categories identified include the following: ▪ Asset Management ▪ Maintenance ▪ Capital Improvement Planning including Life Cycle Costing (LCC), Whole Life Cost (WLC) modeling, and Business Case Evaluation (BCE). ▪ New Asset Turnover
The Condition Assessment process needs a more timely execution plan.	Conduct a status review and develop a Condition Assessment program execution plan.
The Preventive Maintenance Optimization (PMO) program pilot was a success and needs to be re-launched.	Conduct a status review and develop a PMO program execution plan.
Data:	
There are various formal and informal asset registers with varying degrees of information and accuracy.	Convene an inter-departmental committee to review the various asset registers to determine the following: ▪ Definition of an asset ▪ Asset data/information requirements ▪ Asset register ownership, management, data/information standards, and integration requirements. ▪ Asset data/information linkages to Key Performance Indicators (KPIs). (see Measures below)
Technology:	
There are various "systems of record" for asset information making it difficult to establish a formal asset register.	Convene an inter-departmental committee to review the various systems of record (i.e., Maximo, PeopleSoft, Excel spreadsheets) and develop a "system of record plan" that meets asset management objectives. (See Data above)
There is a need for a Maximo / PeopleSoft interface.	Convene an interdepartmental committee to review and develop a Maximo / PeopleSoft interface plan to meet asset management objectives.
Use of Maximo mobile field tools has improved data collection and should be rolled out to all appropriate staff.	Review current status of Maximo mobile field tool usage and develop rollout execution plan.
Measures:	
There are a variety of key performance indicators (KPIs) in place in some groups within SEA, but there is no formal or consistent performance management process/system in place.	Convene an inter-departmental committee to review and recommend the following: ▪ Appropriate asset management service level definitions and associated KPIs ▪ A formal performance management process/system.
Other:	
There are a need to co-invest in business process improvements (i.e., asset management / operational sustainability) while also investing in the capital infrastructure to ensure a robust sustainability model.	Convene an inter-departmental committee led by a director-level staff member to conduct a review of the current SAMP to identify investment and program requirements to support a robust asset management / operational sustainability program.

Recommended Next Steps

1. Conduct a formal review of the Asset Management Gap Assessment report with the SEA management team including key stakeholder representation from departments such as; Facilities and Capital Programs, Planning & Environmental Programs, and Aviation Operations.
2. Develop a multi-year Asset Management Program and Implementation Plan including recommended action plans.

3. Communicate and engage executive leadership as plan sponsors.
4. Develop a formal communication plan/strategy to explain the study results and implementation plan to all stakeholder groups (trade/services departments, customer community, and management).
5. Identify organizational enhancements to ensure successful execution of the action plans.
6. Establish clear goals and success factors to measure progress.
7. Consider a "team-based" approach for implementation and create a steering committee, tactical team and sub-teams to monitor and execute the work. The teams-based approach builds creates involvement and change ownership leading to sustainable practices. Example roles/responsibilities of this framework follow:

- Steering Committee – management team to set goals, remove obstacles and monitor progress
- Tactical Team – day-to-day core team focused on managing Sub-teams towards goals and objectives. Report monthly progress to the Steering Committee.
- Sub-teams – cross-functional teams with focused optimization effort (ex. SOP improvement teams, Maximo / PeopleSoft integration team, Condition Assessment best practices team)

Appendix B
Climate Change Research Synthesis

Appendix B
Climate Change Research Synthesis

The Port of Seattle adopted a goal of completing a risk analysis of potential climate change impacts and implications for the Airport, and developing a strategy plan for avoiding/mitigating potential climate change risks. This section documents the current state of the understanding of expected changes to the climate and actions already underway locally to adapt to those conditions. The section concludes with an identification of the infrastructure at risk due to the anticipate climate change effects.

B.1 Findings of Climate Change Research

For this Sustainable Airport Master Plan, research was reviewed to identify current predictions concerning how the climate is expected to change in the future relative to current conditions. The following sections discuss the state of the research, indicating how the climate has changed in the last century and then identifies predictions of further climate changes at a national level, and then regional/state/local level. While the majority of the scientific community supports the belief that human activities, particularly the generation of greenhouse gases, are causing the greatest changes in the climate, this section notes that conclusion, but does not summarize that portion of the research.

It is important to note that climate predictions represent general trends that might be expected in the climate. Such predictions are largely based on the underlying assumptions, as discussed in Section B.1.1 (*Climate Prediction Methodologies*). While the regional models are capable of predicting to smaller (relative to global models), the Puget Sound Region has diverse topography which can materially affect the results. Thus, the information presented in this synthesis is intended to identify regional and state trends and how these trends may affect conditions in the Airport vicinity. Then, in conducting airport planning, the trends can be used to identify contingencies that the Port of Seattle may wish to consider relative to future development and operational scenarios.

B.1.1 *Climate Prediction Methodologies*

Significant study has occurred concerning potential changes in the climate that may occur over time. Because the conclusions depend upon these assumptions, this section was prepared to synthesize the prediction methodologies and specifically identify the leading models that are referenced in many of the studies considered in this synthesis. Key factors that have been identified as affecting future climate predictions are:

- The rate at which levels of greenhouse gas concentrations change (continue to increase or decrease, and if they decrease, at what levels);
- How strongly features of the climate (e.g., temperature, precipitation, and sea level) respond to the expected changes in greenhouse gases; and
- Natural influences on climate (e.g., volcanic activity, sun intensity) and natural processes within the climate system (e.g., changes in ocean circulation patterns)

As modeling capabilities have improved in the last decade, scientists have modified their approaches to considering climate change and added various scenarios, thus accounting for the evolution of the modeling scenarios. Examples of modeling scenarios commonly referenced in research are shown in **Table B-1**

TABLE B-1
Summary of SRES Modeling Results – Temperature and Sea-Level Rise Changes

IPCC Special Report on Emissions Scenario (SRES)	Temp Change (°C) relative to 1980-1999 (best estimate)	Sea Level Rise (m relative to 1980-1999)
Constant year 2000 concentrations	0.3-0.9 (0.6)	NA
B1 Scenario	1.1-2.9 (1.8)	0.18-0.38
A1T scenario	1.4-3.8 (2.4)	0.20-0.45
B2 Scenario	1.4-3.8 (2.4)	0.20-0.43
A1B Scenario	1.7-4.4 (2.8)	0.21-0.48
A2 Scenario	2.0-5.4 (3.2)	0.23-0.51
A1FI Scenario	2.4-6.4 (4.0)	0.26-0.59

Note: the assumptions associated with the scenarios noted above are identified in Section B.1.1.
Source: Point of departure. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*

These scenarios were defined by IPCC and are noted in their Special Report on Emissions Scenarios (SRES). There are 40 different SRES scenarios, each making different assumptions for future greenhouse gas pollution, land-use, and other driving forces. Assumptions about future technological development as well as the future economic development were made for each scenario. The following briefly identify the characteristics of the major SRES family/scenarios, which are noted here for context relative to the climate projections are grouped into four families:

- SRES A1 scenarios describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The SRES A1 scenarios describe alternative directions of technological change in the energy system: fossil-intensive (SRES A1FI), non-fossil energy sources (SRES A1T), or a balance across all sources (SRES A1B) (where balance is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).
- SRES A2. These scenarios describe a heterogeneous world, involving self-reliance and preservation of local identities. Fertility patterns across regions would converge very slowly, which would result in continuously increasing global population. Economic development would be primarily regionally oriented and per capita economic growth and technological change would be more fragmented and slower than other scenarios.
- SRES B1. This set of scenarios describes a convergent world with the same global population, that would peak in mid-century and then decline (as in SRES A1), but with a rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis would be on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- SRES B2. The B2 scenarios describe a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. Global population would increase at a rate lower than SRES A2, and intermediate levels of economic development and less rapid and more diverse technological change relative to SRES B1 and SRES A1 would occur. While the SRES B2 scenarios were oriented towards environmental protection and social equity, they would focus on local and regional levels.

Simulations of 21st century climate require projections of future greenhouse gases and sulfate aerosols (which reflect sunlight and also promote cloud formation). Three of these SRES scenarios were commonly chosen for purposes of testing their effect in Global climate models: SRES B1, SRES A1B, and SRES A2. The changes noted by of all scenarios is similar until about 2020 owing primarily to the long lifetime of coal fired electric power plants and their contribution to greenhouse gases. SRES Scenario A2 produced the highest climate forcing by the end of the century, but before mid-century. None of the scenarios were consistently the highest.

Globally, scientists are examining various continued greenhouse gas emission rates to consider how the climate may change over time. The two most common scenarios identified throughout this research (referred to as SRES B1 and SRESA2) consider the effects if substantial emission reductions are achieved, as well as scenarios of higher emission rates (higher than present rates) respectively. These two scenarios seem to reflect the bookends of the range of climate change effects identified by the SRES scenarios.

For purposes of the State Climate Assessment, the State used SRES scenario A1B. The State Assessment referenced later in this synthesis indicates that it was chosen because "more modeling groups ran SRES A1B than SRES A2, and since our focus for this study was on midcentury change".

With IPCC Fifth Assessment Report issued in 2013, the development of scenarios fundamentally changed from the SRES process which had preceded. The new structure for scenarios called Representative Concentration Pathways (RCPs) uses updated models with the intent to provide a "flexible, interactive, and iterative approach" to climate change scenarios. A key difference between the SRES and RCP scenarios is that under the RCPs there are no fixed set of population growth, economic growth, and technology assumptions, as scientists expressed concern that the net of these assumptions affects emissions and radiative forcing which is believed to be more directly related to climate change. The four RCPs that were selected by IPCC represent a range of greenhouse gas concentrations and climate forcing. These scenarios are identified by their approximate radiative forcing (RF, W m–2) reflecting the effect that greenhouse gases have on climate. The RCPs indicate levels that could be reached during or near the end of the 21st century and are referred to as RCP2.6,[1] RCP4.5, RCP6.0, RCP8.5.[2] **Table B-2** summarizes the conclusions of the RCP scenarios.

TABLE B-2
SUMMARY OF GLOBAL RCP CONCLUSIONS

Scenario	Atmospheric carbon dioxide concentrations in 2100 (used as input for most model simulations)	Temperature increase to 2081-2100 relative to a 1850-1900 baseline		Global mean sea level rise for 2081-2100 relative to a 1986-2005	
		Average	Likely range	Average	Likely range
RCP2.6	421ppm	1.6°C	0.9-2.3°C	0.40m	0.26-0.55m
RCP4.5	538ppm	2.4°C	1.7-3.2°C	0.47m	0.32-0.63m
RCP6.0	670ppm	2.8°C	2.0-3.7°C	0.48m	0.33-0.63m
RCP8.5	936ppm	4.3°C	3.2-5.4°C	0.63m	0.45-0.82m

1 Some research refers to RCP2.6 as RCP3DP - where 'PD' stands for Peak and Decline.

2 Burkett, V.R., et al, 2014: Point of departure. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 169-194. Available at http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap1_FINAL.pdf

Source: Representative Concentration Pathways Fact Sheet, Australian Government Department of the Environment

Through the modelling scenarios, scientists noted that because of lags in the climate system (for instance, ocean uptake of heat), if concentrations of greenhouse gases in the atmosphere were stabilized, warming would still continue for decades. Sea level rise would continue for centuries as the warming ocean continued to expand. As a result, the scientific community has begun to use the RCP scenarios.

The RCPs represent:

- **RCP2.6**: The emission pathway is representative of scenarios that lead to very low greenhouse gas concentration levels. Research indicates it is a "peak-and-decline" scenario; its radiative forcing level first reaches a value of around 3.1 W/m2 by mid-century, and returns to 2.6 W/m2 by 2100. To reach these radiative forcing levels, 2050 global greenhouse gas levels would need to be reduced by 50% relative to 1990 levels, and be near or below zero net emissions post 2050. Another report indicates that greenhouse gas levels would need to remain at today's levels until 2020, then decline, with concentrations peaking in 2050, but become negative in 2100.
- **RCP 4.5**: This scenario is generally a stabilization scenario in which global greenhouse gas concentrations and total radiative forcing is stabilized by 2100 and some believe is generally consistent with ambitious emission reductions. In this scenario, greenhouse gas emissions increase slightly before they begin to decline after 2040.
- **RCP6**: This scenario, considered another intermediate level, is another stabilization scenario in which greenhouse gas emissions and radiative forcing are stabilized by 2100. In this scenario, greenhouse gases peak in 2060 at 75% above today the decline to 25% by 2100.
- **RCP 8.5**: This RCP is characterized by increasing greenhouse gas emissions over time and is generally considered a business as usual scenario.

There is some difficulty in relating/comparing the various scenarios (SRES to RCP), since the SRES scenarios are based on population/growth and emission changes, whereas RCP is based on the end result of radiative forcing. However, IPCC has compared the results so far. Relative to temperature change, IPCC notes that RCP8.5 is close to SRES scenario A2, but below SRES scenario A1FI. RCP4.5 follows SRES scenario B2 up to 2060, but then drops to track SRES scenario B1. RCP6.0 has lower temperature change to start, following SRES scenario B1, but then increases toward SRES scenario B2 by 2100. In general, SRES scenarios A1B, A1T, and B2 lie in the large gap between RCP8.5 and RCP4.5/6.0. The RCP8.5 scenario compares generally to SRES A1FI in the later timeframe. The RCP2.6 temperature change stabilizes at about 1°C above the reference period (1986–2005) and the results do not compare to SRES scenarios. **Figure B-1** compares the results of SRES scenarios to the RCPs.

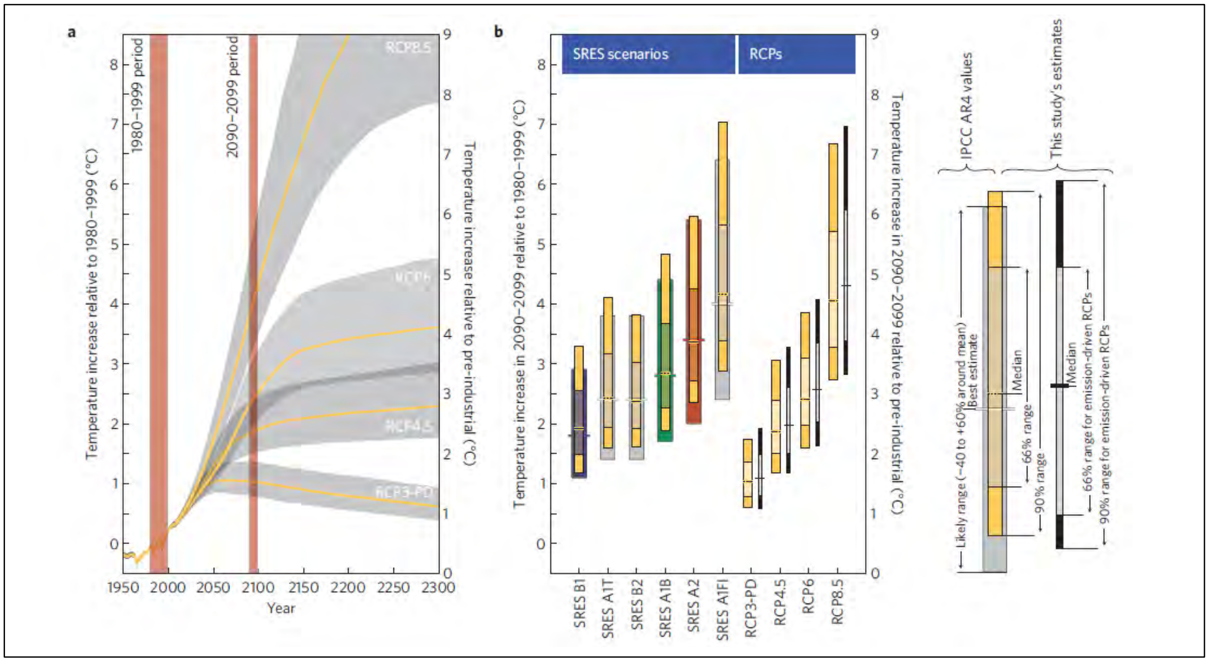
B.2 National Climate Change Predictions

The following sections summarize the national level results of the SRES and RCP scenarios noted in the preceding section. These evaluations, as well as other independent lines of investigation, demonstrate that the world is warming and that the primary cause of this warming is human activity. From the warming, changes in the climate over time are predicted to include: shorter duration of ice on lakes and rivers, reduced glacier extent, earlier melting of snowpack, reduced lake levels due to increased evaporation, lengthening of the growing season, changes in plant hardiness zones, increased humidity, rising ocean temperatures, rising sea level, and changes in some types of extreme weather.

As noted in the 2014 National Climate Assessment,[3] several conditions are most noteworthy:

[3] U.S. Global Change Research Program, 2014 National Climate Assessment available on the web at http://nca2014.globalchange.gov/

FIGURE B-1RELATIONSHIP BETWEEN SRES and RCPs



Source: Rogelj, G*lobal Warming Under Old and New Scenarios using IPCC Climate Sensitivity Range Estimates*; Nature Climate Change Letters; 2-2013

- Continued warming and an increased understanding of the U.S. temperature record, as well as multiple other sources of evidence, have strengthened scientific confidence in the conclusions that the warming trend is clear and primarily the result of human activities. For the contiguous United States, the last decade was the warmest on record, and 2012 was the warmest year on record.
- The increasing temperatures are expected to continue to shrink glaciers across western and northern North America, decrease the amount of water in spring snowpack in western North America, and shift to earlier peak flow in snow dominated rivers in western North America.
- Heavy precipitation and extreme heat events are increasing in a manner consistent with model projections; the risks of such extreme events is expected to rise in the future. Since 1900, the average annual US precipitation rate has increased about 5%. More winter and spring perception is projected for the northern US, and less for the Southwest.
- The sharp decline in summer Arctic sea ice has continued, is unprecedented, and is consistent with human-induced climate change. A new record for minimum area of Arctic sea ice was set in 2012.
- Increase in wildfire activity fire frequency and duration, and burnt area in forest in the western US, coupled with insect infestations in forests.
- Changed migration and survival of salmon in Pacific.
- A longer and better-quality history of sea level rise has increased confidence that recent trends are unusual and human-induced. Limited knowledge of ice sheet dynamics leads to a broad range for projected sea level rise over this century.

The National Climate Assessment confirms that temperatures at the Earth's surface, in the troposphere,[4] and in the oceans have all increased over recent decades. Closer to the poles, the largest increases in temperature are occurring especially in the Arctic. Atmospheric water vapor is increasing in the lower atmosphere because a warmer atmosphere can hold more water. Sea level is increasing because water expands as it warms and because melting ice on land adds water to the oceans. Changes in other climate-relevant indicators such as growing season length have been observed in many areas. Worldwide, the observed changes in average conditions have been accompanied by increasing trends in extremes of heat and heavy precipitation events, and decreases in extreme cold.

The United States has retained weather records since approximately 1895. Since that time, the U.S. average temperature has increased by 1.3°F to 1.9°F; records indicate that most of this increase has occurred since about 1970. The most recent decade (2000-2010) was the nation's warmest on record. Because human-induced warming is superimposed on a naturally varying climate, the temperature rise is not expected to be uniform or smooth across the country or over time.

In general, the following changes are expected in the future in the United States:

- Average temperatures nationwide would increase and the changes will vary regionally. Under a lowered greenhouse gas emissions scenario, by 2100, emissions would increase less than 5°F. With the higher emissions scenario (SRES A2), temperatures could increase 5-9°F in the continental U.S.
- Soil moisture changes in the U.S. would decrease across much of the western U.S.[5] West of the Mississippi River, soil moisture would decrease anywhere from 1 to 10% by the end of this century.
- Seasonal precipitation would not change much under the lower emissions scenario. In general, the northern part of the U.S. is projected to see more winter and spring precipitation, while the southwestern U.S. is projected to experience less precipitation in the spring. Summer drying is projected for parts of the U.S., including the Northwest and southern Great Plains.
- Also evaluated was changes to the maximum number of consecutive dry days (non-precipitation days). That evaluation shows that other than in the northern Great Plaines, substantial increases are expected in the number of consecutive dry days (as much as 20% in some areas).
- Hurricanes and tropical storms are expected to become more intense, with stronger winds as a result of higher ocean temperatures. As sea surface temperatures rise, developing storms will contain more energy.
- The frost-free season is lengthening, with the largest increases occurring in the Western United States and the growing season projected to continue to lengthen.
- Sea level is expected to rise 0.7 to 6.6 feet by 2100 (with most studies predicting 1 to 4 feet). The larger projected range reflects uncertainty about how glaciers and ice sheets will react to the warming ocean, the warming atmosphere, and changing winds and currents.

B.3 Pacific Northwest, State of Washington, Puget Sound Region, and Local Climate Change Predictions

4 The active weather layer extending up to about 5 to 10 miles above the ground.

5 Modeling was not done for the eastern United States.

This section documents a number of studies and reports that have been prepared to consider the effects of climate change on regional and local conditions. The following section summarize the regional, state, and local efforts to predict future changes. However, as was noted earlier, a number of climate scenarios have been considered and thus, it is important to note which scenario was used in the prediction to understand any underlying assumptions. As is shown, there are general consistent conclusions of these studies (increased temperatures, particularly during the summer; increased precipitation, with increased summer droughts, etc.) and the magnitudes vary based on the modeling scenario assumptions (as discussed in a prior section). Some of the mentioned climate predictions are also noted as a basis for the adaptation efforts presented in Section B.2.

In 2007, the University of Washington's *Uncertain Future* document noted the following climate change conclusions:

- Average annual temperature in the Puget Sound region warmed 2.3°F (1.3°C) during the 20th century, a rate substantially greater than the global warming trend.
- Projected 21st century average warming rates for the Pacific Northwest are on the order of 1.8°F (1.0°C) by the 2020s and 3.0°F (1.7°C) by the 2040s, relative to 1970-1999 average temperature. Even the lowest estimated global warming would change Pacific Northwest climate significantly. The climate models projected an average warming rate for the Pacific Northwest of 0.6°F per decade for the period 1990s-2040s. The lowest rate of warming was about 0.5°F per decade, and the highest was 0.9°F per decade.
- Puget Sound river and stream flows are changing in ways consistent with projected climate change impacts.
- Glaciers in the Cascade and Olympic Mountains have been retreating for over 50 years.
- Lake Washington has warmed substantially and there is evidence of rising temperatures in the Strait of Juan de Fuca.
- Scientists project that Puget Sound waters will warm in the future, potentially putting many species at risk including plankton, the foundation of Puget Sound's food web.
- Most models suggest modest (0-20%) increases in winter precipitation and in annual precipitation by mid-21st century. Simulated changes in summer precipitation tended to be slightly negative (reduced), though changes in precipitation were smaller than the increases in evaporation. More of the region's winter precipitation was found to likely fall as rain rather than snow, increasing flooding in Puget Sound watersheds. Relative to precipitation, the underlying report notes "None of these changes stands out above background variability, and model simulations have large interdecadal variability so that the ten-year averaged changes commonly reported are not necessarily indicative of a monotonic trend or of anthropogenic influence.
- The rate of sea-level rise in the Pacific Northwest is projected to be faster than the global average, and is likely to increase both the pace and extent of the erosion and near shore habitat loss already affecting Puget Sound shorelines, especially in south Puget Sound.
- Puget Sound salmon are likely to be further stressed by lower summer and fall stream flows, warmer water temperatures, and an increased potential for winter flooding.
- The potential for harmful algal blooms and low oxygen concentrations in bottom waters may increase due to warmer water temperatures, increased temperature stratification, and other factors.

These predictions are based upon two SRES scenarios (A2 and B1), representing high-growth and low growth scenarios. The 2007 report noted that as of that time increases in CO_2 concentrations from 1970 to 2000 averaged 0.40% per year, though other gases had different rates. Continued increase at 0.4% per year would lead to a concentration of 456 parts per million by volume (ppmv) in 2050, below that of the SRES scenarios.

As noted earlier, global climate change models are not able to simulate regional climate at a precise location basis. However, with a large number of simulations conducted, these predictions can assist with understanding potential regional changes and these simulations combined with regional climate models enable a more refined characterization at a local level. According to the *Climate Change in the Northwest – Implications for our Landscapes, Waters, and Communities* the Regional Climate Change Assessment Program and Regional Climate prediction.net has conducted modelling relative to SRES A2 (continued growth in emissions – see the section B.1.1) and has a resolution of approximately 50 km (31 miles) when predicting through 2070. Other models use these simulations and predict at 25 km (16.5 miles) area.[6]

In 2009, the University of Washington's Climate Impacts Group (CIG) completed the *Washington State Climate Change Impacts Assessment*. From that study, CIG prepared a summary table of anticipated climate changes. That table is reproduced at the end of this document (see 11 page table). Six average climate change scenarios were created by averaging the model output for the Pacific Northwest region for each of the model runs during each time period of interest, i.e., 2020s medium emissions scenario (A1B), 2020s low emissions scenario (B1), 2040s medium emissions scenario (A1B), 2040s low emissions scenario (B1),and so on for the 2080s. To make the composite climate scenarios suitable for locally-specific climate impacts analysis, they were "downscaled" to create higher resolution climate projections in the Pacific Northwest.

The results noted here from the 2009 assessment are based on averages across all of the models. Increases in annual temperature are projected to be, on average, 2.0°F by the 2020s, 3.2°F by the 2040s, and 5.3°F by the 2080s (compared to 1970 to 1999). Projected changes in annual precipitation are small (+1 to +2%), but some models projected an enhanced seasonal precipitation cycle with changes toward wetter autumns and winters and drier summers, similar to the other studies cited previously. Increases in extreme high precipitation in western Washington and reductions in Cascades snowpack are key projections that are consistent among different projections of a high resolution regional climate model.

The most recent regional predications (noted in *Climate Change in the Northwest – Implications for our Landscapes, Waters, and Communities* 2013) indicate higher end of century temperatures than earlier predictions. The projections indicate that century-scale warming (the average over the years 1970-2099 after deducting 1970 through 1999) could be a change of 6.1 °F (3.4 °C) based on SRES A1B. For SRES B1, the models predict a 4.5 °F (2.5 °C) change by 2070. Projected warming varied from 3.3 to 11 °F across individual models and SRES scenarios, and the temperature change is projected to be largest in summer.

Annual average precipitation was also projected in the regional models. Averaged over the Northwest, a change of 3–5% with a range of -10% to +18% for 2070–2099 was identified. Seasonally, model projections were found to range from small decreases to large increases in winter, spring, and fall. Projections of precipitation have larger uncertainties than those for temperature. However, as noted in the report, one aspect of seasonal changes in precipitation is largely consistent across climate models: summer precipitation is projected to decrease by as much as 30% by the end of the century. The consequences of unusually dry summers include: low stream flow west of the Cascades which affects salmon and other natural conditions, and greater wildfires throughout the region (in frequency, breadth, and duration).

The newer RCP scenarios have also been considered at the regional level. By 2100, RCP 4.5's assumed greenhouse gas concentration effects most closely resembles the radiative forcing of SRES B1 (substantial greenhouse gas reductions), whereas RCP8.5 most closely follows SRES A1FI (very high growth) outpacing that of SRES A2 (continued growth). Projected changes in temperature are a bit

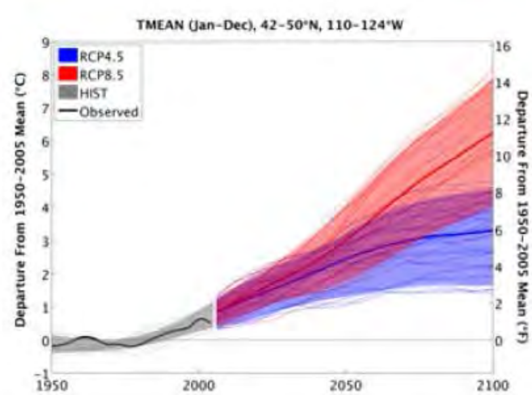
[6] Dalton, M; *Climate Change in the Northwest: Implications for our Landscapes, Waters, and Communities* (edited by Meghan Dalton, Philip Mote, and Amy Snover), Washington DC Island Press; 2013

higher for the RCP runs than for the SRES scenarios, especially for RCP8.5, although the SRES timeline was 2070 whereas the RCP is 2100, accounting for some of the differences. However, the report notes that the spread in results is substantial: a factor of at least two for the annual mean and three or more for most seasons. All models project warming of at least 0.9 °F (0.5 ° C) in every season. In summer, the projected warming is somewhat larger than for other seasons, especially for the RCP8.5 very high growth scenario, which projects changes of between 3.4 °F and 9.4 °F (1.9 °C and 5.2 °C).

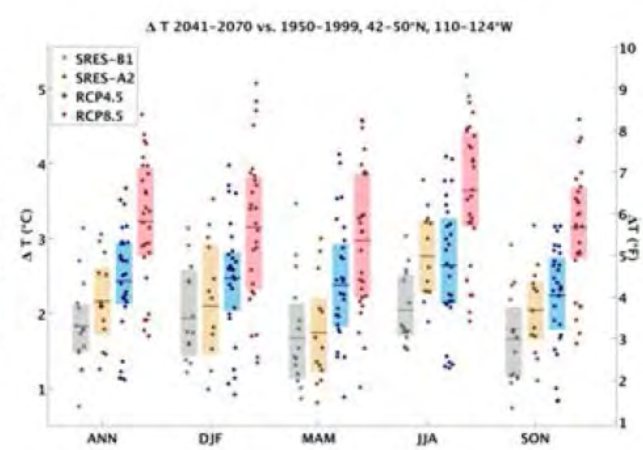
Figures B-2a and B-2b illustrate the results. In **Figure B-2a,** the observed (1950–2011) regional mean temperature and simulated (1950–2100) regional mean temperature are shown for scenarios RCP4.5 (dashed curves, dark shading) and RCP8.5 (solid curves, light shading). In the adjacent **Figure B-2b**, changes in annual mean and seasonal temperature (2041–2070 minus 1950–1999) averaged across the Northwest are shown from specific SRES and RCP scenarios. Each symbol represents one simulation by one model, and the shaded boxes indicate the interquartile range (25th to 75th percentiles). Means are indicated by horizontal lines in the boxes.

Figure B-2
Climate Change in the Northwest – Regional Temperature Prediction Summary

a



b



Source: *Climate Change in the Northwest – Implications for our Landscapes, Waters, and Communities, 2013*

The scenarios have less consensus for precipitation than for temperature: some project increases and some decreases in each season. All scenarios project increases at high latitudes and decreases in low latitudes, but vary in middle latitudes. A majority of scenarios project increases in precipitation during winter, spring, and fall, and a majority project decreases in summer. There is a strong relationship between projected summertime changes in temperature and precipitation: the scenarios/models that project the largest warming also project largest decreases in summer precipitation.

Regionally averaged changes are similar between the global and regional models and scenarios, indicating that while accounting for land-atmosphere interactions at a smaller scale than can be represented at global models grid scales may result in finer spatial patterns, it does not substantially change the regionally averaged climate response predicted by the models. The spatial pattern of change in regional models displays some "regional texture" - for instance, warming in the winter is largest in the Snake River basin (southern Idaho), and warming in summer is smallest west of the Cascades, consistent with the marine influence and lower rates of warming over ocean.

The climate models and scenarios are unanimous that measures of heat extremes will increase and measures of cold extremes will decrease. For the frost-free period and number of days below cold thresholds, the global changes are substantially larger than the regional model standard deviations of those variables. This indicates that although all measures are consistent with an overall warming trend, the largest changes relative to the natural variability are occurring and will occur in variables measuring low temperature extremes.

TABLE B-3 SUMMARY OF REGIONAL PREDICTIONS OF CHANGE (2040 through 2070)

Variable Name	Mean Change	Standard Deviation of Change
Freeze-free period	+35 days	6 days
# days Tmax > 32 °C (90 °F)	+8 days	7 days
# days Tmax > 35 °C (95 °F)	+5 days	7 days
# days Tmax > 38 °C (100 °F)	+3 days	6 days
# days Tmin < 0 °C (32 °F)	-35 days	6 days
# days Tmin < -12 °C (10 °F)	-15 days	7 days
# days Tmin < -18 °C (0 °F)	-8 days	5 days
Consecutive days > 35 °C (95 °F)	+134%	206%
Consecutive days > 38 °C (100 °F)	+163%	307%
Heating degree days	-15%	2%
Cooling degree days	+105%	98%
Growing degree days (base 10 °C [50 °F])	+51%	14%

Note: Mean change: 2041–2070 mean minus 1971–2000 mean, for continued growth emissions scenario SRES-A2 relative to 1950-2011.
Source: *Climate Change in the Northwest: Implications for our Landscapes, Waters, and Communities*; 2013

The data in the table above will form the basis of the assumptions concerning climate change that will be used in the Sea-Tac Sustainable Airport Master Plan.

It can also be informative to consider the climate predictions that are being used by other local agencies. Seattle Public Utilities is currently (2014) using the following climate predictions:[7]

Sea-Level Rise: Mean projections indicate that Seattle will experience 7 inches of sea-level rise by 2050, and 24 inches by 2100.[8] SPU notes that sea-level rise impacts will first be noticed episodically with more frequent tidal flooding events. Water levels associated with storm surges and "king tides" (annually occurring extreme events) today will eventually become monthly, even daily events.

Extreme Precipitation: SPU notes that identifying the magnitude of extreme precipitation change in Seattle has been difficult to model because of many factors including areas the complex terrain.

Extreme Heat: Seattle has averaged only a handful of 90°F days per year during the past few decades. By the end of this century, such events are expected to become more common, with more than two weeks of 90°F days likely each summer. Also certain to increase are nighttime temperatures and humidity. Increased temperatures will likely increase water demand.

Hydrology: Pacific Northwest winters are projected to become warmer and wetter, and summers warmer and drier. That means more rain than snow falling on the Cascade Mountains and eventually more prolonged periods of drought. It also likely means changing forests, stressed salmon habitat, and wildfires.

Other local effects that have been identified by the City and/or County[9] are:

- Increases in runoff during storm events;

7 Seattle Public Utilities web site http://www.seattle.gov/util/AboutUs/SPU_&_the_Environment/ClimateChangeProgram
8 SPU notes that the highest projections for sea level rise are 19 to 56 inches by 2050 and 2100, respectively.
9 http://www.kingcounty.gov/environment/climate/climate-change-resources/impacts-of-climate

- Declines in summer runoff due to glacier loss;
- Lowering of groundwater levels;
- Increases in urban heat island effects;
- Losses or increases in losses of wetland and near shore habitat acreage;
- Changes in the timing and duration of growing season;
- Decreases in species abundance and increases in species morbidity; and
- Increases in biological invasions and occurrences of harmful algal blooms.

Figure 4-3
City of Seattle Climate Change Predictions

	Projected Changes	
	Near Term Changes (through 2050)	**Long-Term Changes (through 2100)**
Temperature	Average annual temperature projected to increase within the range of 1.5°F to 5.2 °F by 2040s with summer temperature increasing as much as 7.9 °F.' The frequency and duration of extreme heat events (days over 92 °F) is projected to increase.	Average annual temperature projected to increase within the range of 2.8°F to 9.7 °F by 2080s with average summer temperature increasing as much as 12.5°F.' The frequency and duration of extreme heat events (days over 92 °F) is projected to increase.
Precipitation	Average annual change in precipitation likely to be small (+1% to +2%) but wetter winters and drier summers are likely. More precipitation expected to fall as rain rather than snow at mid and low elevations, contributing to a projected statewide reduction in average spring snowpack of about 26% by the 2020s and about 40% by the 2040s. Stream flows likely to be higher in autumn, winter and early spring, and lower in late spring and summer, especially in rivers fed by snow melt.	Projected decrease in average snowpack of about 60% by the 2080s. Projected increase in average annual precipitation of +4%, wetter winters and drier summers are likely. Stream flows likely to be higher in autumn, winter and early spring, and lower in late spring and summer, especially in rivers fed by snow melt. Potential for more extreme precipitation events continues
Sea Level	Base Sea Level Rise: Estimates for the increase in base sea level range up to 9 inches by the 2030s and up to 19 inches by the 2050s. Episodic Sea Level Rise: In addition to base sea level rise, storm surges and high tides will continue to periodically increase sea level. The highest observed water level was 38 inches above mean higher-high water, as an "everyday" high tide.	Base Sea Level Rise: Estimates for the increase in base sea level range up to 56 inches by 2100. Episodic Sea Level Rise: planning estimates for episodic sea level rise factors remain the same in 2100: 38 inches.
Source: City of Seattle, Climate Action Plan (2013), Climate Change Impacts		

B.4. Climate Change and Adaptation Activities

The prior section presented a brief summary of the extensive research that has been conducted about potential changes in climate. Since scientists generally agree that the climate is already changing, and that it will continue to change over time in response to past and present human activity, substantial research and discussion is also occurring about how these changes/effects can be addressed. There are generally two categories of potential responses to human-induced climate change:

- Mitigation (reducing activities that cause climate change) and
- Adaptation (adjust the practices, systems, and structures to reduce the negative consequences and take advantage of the opportunities of beneficial changes).

Since the prior section of this report discusses the efforts designed to reduce greenhouse gases, this chapter focuses on adaptation efforts. The section begins with the efforts being undertaken at a national level, followed by regional and local efforts.

B.4.1 National Efforts

Many of the federal agencies have adopted plans and programs designed to address their respective areas to climate change. On June 25, 2013, President Obama announced a US Climate Action Plan that is designed to reduce greenhouse gas emissions and improve national climate preparedness and resiliency. President Obama established the Interagency Climate Change Adaptation Task Force, co-chaired by the Council on Environmental Quality (CEQ), the Office of Science and Technology Policy (OSTP), and the National Oceanic and Atmospheric Administration (NOAA), and including representatives from more than 20 Federal agencies.

Adaptation elements of the President's Climate Action Plan include:

- *Building Stronger and Safer Communities and Infrastructure*
  - Directing Agencies to Support Climate-Resilient Investment
  - Establishing a State, Local, and Tribal Leaders Task Force on Climate Preparedness
  - Supporting Communities as they Prepare for Climate Impacts
  - Boosting the Resilience of Buildings and Infrastructure
  - Rebuilding and Learning from Hurricane Sandy
- *Protecting our Economy and Natural Resources*
  - Identifying Vulnerabilities of Key Sectors to Climate Change
  - Promoting Resilience in the Health Sector
  - Promoting Insurance Leadership for Climate Safety
  - Conserving Land and Water Resources
  - Maintaining Agricultural Sustainability
  - Managing Drought, Reducing Wildfire Risks, Preparing for Future Floods
- *Using Sound Science to Manage Climate Impacts*
  - Developing Actionable Climate Science
  - Assessing Climate-Change Impacts in the United States
  - Launching a Climate Data Initiative
  - Providing a Toolkit for Climate Resilience

Executive Order 13653 *Preparing the United States for the Impacts of Climate Change* directs Federal agencies to take a series of steps to make it easier for American communities to prepare for impacts of climate change. Specifically, the Executive Order instructs agencies to modernize Federal programs to support climate-resilient investments; plan for climate change related risks to Federal facilities, operations, and programs; and provide the information, data, and tools that state, local, and private-sector leaders need to make smart decisions to improve preparedness and resilience.

In 2012 the U.S. Department of Transportation adopted a Climate Adaptation Plan. Within this plan are priority items for the FAA that include:

- Airport sustainability planning, such as the FAA funding of the Port of Seattle's SAMP
- Navigation Infrastructure assessment: examining the vulnerability of navigation resources to a combination of storm surge impacts that occur with a changing climate
- NextGen Network Enabled Weather: cost effective access to weather information

In 2007 the FAA formulated the Aviation Climate Change Research Initiative (ACCRI). As a part of its five-pillar plan to meet NextGen environmental goals, the FAA developed the ACCRI with participation from NASA, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Environmental Protection Agency (USEPA). The main objective of ACCRI is to identify and address key scientific gaps and uncertainties regarding climate impacts while providing timely scientific input to inform optimum mitigation actions and policies. To date, ACCI has produced valuable research concerning the effects of aircraft emissions in the upper atmosphere, contrails, and metrics for assessing the effect of aviation on climate change.[10]

B.4.2 Pacific Northwest Efforts, State, and Puget Sound Region Efforts

In 2012, the State of Washington completed *Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy*.[11] The plan identifies the following response strategies:

Protect people and communities most vulnerable to climate impacts by increasing state and local public health capacity to monitor, detect, plan, and respond to emerging threats and climate-related emergencies. Also increase awareness of climate risks among the public and health-care providers.

Reduce risk of damage to buildings, transportation systems, and other infrastructure. Identify vulnerable areas and take proactive steps to reduce risks to infrastructure, avoid climate risks when siting new infrastructure and planning for growth, and enhance capacity to prepare for more frequent and severe flooding, rising sea levels, wildfires, and changes in energy supply and demand.

Reduce risks to ocean and coastlines. Help communities prepare for rising sea levels and storm surge and protect people and property. Prevent the degradation of habitats and create opportunities for upland habitat creation. Reduce shellfish vulnerability by reducing land-based contributions of carbon and polluted runoff to the marine environment.

Improve water management by promoting integrated approaches that consider future water supply and address competing water demands for irrigated crops, fish, municipal and domestic water needs, and energy generation. Implement enhanced water conservation and efficiency programs and incorporate climate change realities into agency decision-making.

Reduce forest and agriculture vulnerability by enhancing surveillance of pests and disease. Promote and transition to species that are resilient to changing climate conditions, conserve productive and adaptive forest and farmland, and reduce forest and wildland fire risk in vulnerable areas.

Safeguard fish, wildlife, habitat, and ecosystems and improve the ability of wildlife to migrate to more suitable habitat as the climate shifts. Protect and restore habitat and sensitive and vulnerable species. Reduce existing stresses from development, pollution, unsustainable harvest, and other factors.

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10 https://www.faa.gov/about/office_org/headquarters_offices/apl/research/science_integrated_modeling/accri/

11 Washington Department of Ecology, *Preparing for a Changing Climate Washington State's Integrated Climate Response Strateg*y, April 2012.

Support the efforts of local communities and strengthen capacity to respond and engage the public. Identify existing and new funding mechanisms to support adaptation work at the local level, and ensure a coordinated and integrated approach among levels of government and society. Support research and monitoring and ensure scientific information is accessible and responds to needs of decision-makers.

Relative to infrastructure, the State plan notes that climate change effects infrastructure could include: increased maintenance and repair costs, public safety effects, interruptions in critical evacuation routes and energy supplies, create travel delays and disruptions, disrupt economic activity, and degrade quality of life.

The following infrastructure specific recommendations were identified:

- Protecting infrastructure by strengthening dikes and levees and by using other hard or soft structural approaches.
- Strengthening infrastructure to better withstand climate impacts (such as flooding or extreme heat) through improved materials, design, and construction techniques.
- Raising or elevating infrastructure to protect it from flooding.
- Relocating, decommissioning or abandoning selected infrastructure where the costs of protection and maintenance outweighs the benefit.
- Care must be taken to avoid approaches that have negative impacts on fish and wildlife or cause unintended consequences.

Through the County's and City's sustainability planning processes, the local agencies have undertaken the implementation of programs to reduce greenhouse gas (improved transportation/bussing, promoting smart growth, implementing energy efficiency actions). From an adaptation perspective, the County, in association with ICLEI, was one of the first local governments to develop guidance[12] on how to consider climate change, and has adopted resiliency plans and initiatives to address flooding. Similarly, the City of Seattle has implemented adaptation measures described in the following paragraphs.

King County code (KCC 18.50.010) requires annual reporting on the County's climate change, energy, green building, and environmental purchasing programs. In 2012, the King County Executive and King County Council collaborated to develop and adopt a Strategic Climate Action Plan (SCAP). The SCAP synthesizes and focuses King County's most critical goals, objectives, and strategies to reduce greenhouse emissions and prepare for the impacts of climate change. According to the 2013 Sustainability Report, the County has developed programs and projects to help reduce the impacts of floods, support farm and forest owner action to address climate change impacts, and begin to prepare the region for the effects of climate change on storm water, public health, and emergency response. King County is required by Council Ordinance 17270 to conduct a comprehensive update of the SCAP by June 30, 2015. Ordinance requirements for the update include work to further identify community level actions the County can take to reduce climate pollution and prepare for the impacts of climate change, and direction to formally combine and integrate the King County Energy Plan into the SCAP. In addition, King County has formed the King County-Cities Climate Collaboration and Sustainable Cities Roundtable to share climate change expertise and coordinate activities with other local parties.

According to the 2013 Sustainability progress report, the County has adopted one climate adaptation-related goal and associated performance measures and targets.

Goal O.5: King County will plan and prepare for the likely impacts of climate change on County owned facilities, infrastructure and natural resources.

PERFORMANCE MEASURE 1: Number of key facilities and natural resource assets and programs assessed for vulnerability to climate change impacts

[12] King County, Univ. Washington, and ICLEI, *Preparing for Climate Change: A Guidebook for Local, Regional and State Governments,* September 2007

Target 1: A target will be established as part of the 2015 SCAP update.

PERFORMANCE MEASURE 2: Number of key facilities and natural resource assets and programs vulnerable to climate change impacts that implement a plan for reducing likely impacts

Target 1: A target will be established as part of the 2015 SCAP update.

Examples of actions the County has implemented to address facility vulnerabilities to climate change are associated with sea level rise impacts to the wastewater infrastructure. In 2013, Wastewater Treatment Division's climate change program assessed its wastewater conveyance system and performed a hydraulic analysis of sea-level rise impacts on essential facilities in the conveyance system. The analysis indicated that 20 facilities are at risk of saltwater inflow because their weir elevations are lower than the highest predicted tides. The assessment concluded that the West Point treatment facility is adequately protected against flooding from sea-level rise, both now and in the foreseeable future, because of the past construction of large landscaped walls and earthen berms around the plant. A pump station in West Seattle is being upgraded to protect Puget Sound and the surrounding environment from sewer overflows and likely sea-level rise impacts are being incorporated into its design.

In 2013 the City of Seattle adopted its climate action plan.[13] As the City notes, the purpose of the plan was to identify city actions that reduce greenhouse emissions and also support vibrant neighborhoods, economic prosperity, and social equity as well as actions to enable infrastructure resiliency. The Climate Action Plan (CAP) has an extensive listing of greenhouse as emission actions. The City of Seattle does not have a comprehensive adaptation strategy, as noted in the 2013 CAP but notes that a citywide strategy is needed The CAP notes that such a strategy should employ an integrated and interdisciplinary approach and maximizes co-benefits such as fostering healthy communities, natural systems, social equity, and prosperity.

The City anticipates implementing the following by 2015:

1. Conduct a citywide assessment of the impacts of temperature, precipitation, and sea level rise on City infrastructure, operations, facilities, and services, including human health with special attention to vulnerable communities.
2. Develop a comprehensive adaptation strategy that integrates the City's planning efforts across all relevant departments and considers both the cost of implementing actions to improve our ability to adapt and the potential cost of inaction. Engage residents in developing the strategy.
3. Apply the planning methodology detailed in the City of Seattle Sea Level Rise Planning Guidance for Capital Projects to projects projected to be impacted by sea level rise.

In addition, the CAP notes plans relative to: natural systems, utility systems (water, electricity, and drainage), land use, transportation, buildings, public health, emergency planning, and food systems.

Separately, SPU has developed RainWatch, a tool that uses advanced technology to predict and monitor rainfall. Over time, as data is added to build up data over consecutive seasons, the City expects to use the information holistically as a tool to prepare, or adapt, to climate change. Although changes in precipitation likely to occur from climate change in Seattle are uncertain, climate models point to an increase in frequency and intensity of precipitation events.

[13] City of Seattle, *Climate Action Plan*, June 2013.

Figure 4-5
County Progress on Climate Goals

County Goal Area	County Services	County Operations
Overarching Climate Change Targets	King County shall partner with its residents, businesses, local governments and other partners to reduce countywide greenhouse gas emissions by at least 80 percent below 2007 levels by 2050.	King County shall reduce total greenhouse gas emissions from government operations, compared to a 2007 baseline, by at least 15 percent by 2015, 25 percent by 2020, and 50 percent by 2030.
Transportation and Land Use	King County will reduce the need for driving and provide and encourage the use of sustainable transportation choices such as public transit, alternative technology vehicles, ridesharing, walking and bicycling.	King County will increase the efficiency of its vehicle fleets and minimize their greenhouse gas emissions.
Energy and Green Building	King County will help reduce energy use by its residents, business and other partners and will support development of increasing amounts of local renewable energy.	King County will reduce energy used in government operations.
Forests and Agriculture	King County will support healthy, productive farms and privately owned forests that maximize biological carbon storage, promote public health, and are resilient to changing climate conditions.	King County will acquire, manage and restore its parks and other natural lands in ways that maximize biological carbon storage and are resilient to changing climate conditions.
Consumption and Materials Management	King County will encourage and support behaviors, purchasing, and waste management strategies that account for and minimize the life-cycle impacts of consumption and materials.	King County will minimize operational resource use, maximize reuse and recycling, and chose products and services that have low environmental impacts.
Preparing for Climate Change Impacts	King County will work with local cities and other partners to prepare for the effects of climate change on the environment, human health, and the economy.	King County will plan and prepare for the likely impacts of climate change on County-owned facilities, infrastructure and natural resources.

KEY	Meeting or approaching goal	Opportunity to improve	Significant work necessary

Source: King County's 2013 Climate Change, Energy, Green Building and Environmental Purchasing Programs

References

Publisher	Author	Title	Date
City of Seattle	web	Climate web site (adaptation, changes, research)	2014
City of Seattle		Sustainability Report 2013 Accomplishments Report	undated
City of Seattle		Climate Action Highlights 2010	undated
Climate Vulnerability Org	web	Pacific Northwest Climate Change Vulnerability web site	2014
IPCC		Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation	2012
IPCC		Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press	2014
Island Press	Dalton, Meghan et al	Climate Change in the Northwest: Implications for our Landscapes, Water, and Communities	2013
Journal of Climate	Duliere, V	Changes in Twentieth-Century Extreme Temperature and Precipitation over the Western United States Based on Observations and Regional Climate Model Simulations*	2013
Journal of the American Water Resources Association	Tohver	Impacts of 21st century climate change on hydrologic extremes in the Pacific Northwest region of North America	2014
King County	Map	Vashon-Maury Island Coastal Flood Hazard Mapping Evaluation of Potential Impacts of Sea Level Rise	2011
King County		King County Sustainability Report - Climate Change Energy Green Building Envir Purchasing Programs	2013
King County		Policy Brief - Confronting Climate Change	2014
King County		Climate Change Infographic	2013

Publisher	Author	Title	Date
North Cascadia Adaptation Partnership	Raymond, C.L. et al	Draft Climate Change Vulnerability and Adaptation in North Cascades Region Washington	2013
Oregon State University		Scientific Consensus Statement on the Likely Impacts of Climate Change on the Pacific Northwest - Exec Summary	2004
REACCH		Regional Approach to Climate Change web site	2014
Univ of Oregon		An Overview of Potential Economic Costs to Washington of a Business-As-Usual Approach to Climate Change	2009
Univ of Oregon	Steve Adams, et al	Additional Analysis of the Potential Economic Costs to the State of Washington from Business as Usual Approach to Climate Change: Lost snowpack water storage and Bark Beetle Impacts	2010
University of Oregon		Preparing PacNW for Climate Change A framework for Integrative Preparation Planning for Natural, Human, Built, and Economic System	2008
US F&WS	US F&WS	Climate change in the Pacific Region	2014
University of Washington		Uncertain Future: Climate Change and its effects on Puget Sound	2007
University of Washington		Uncertain Future: Climate Change and Its Effects on Puget Sound – Foundation Document	2007
University of Washington CIG		Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Executive Summary	2009
US Global Change Research Information Office GCRIO		The Potential Consequences of Climate Variability and Change -Pacific Northwest	2004
US Global Change Research Program		National Climate Assessment	2014
USEPA	USEPA	Climate Change & Air Quality	2014
USEPA	USEPA	Climate Change in the Pacific Northwest - web	2014

Publisher	Author	Title	Date
UW CIG		Comprehensive Hydrologic Data Base Incorporating IPCC Climate Change Scenarios to Support Long-Range Water Planning in the Columbia River Basin (The Columbia Basin Climate Change Scenarios Project)	2010
UW CIG	web	Overview of Climate Change Scenarios web	2014
UW CIG	table	Summary of Projected Changes in Major Drivers of Pacific Northwest Climate Change Impacts	2012
UW CIG		Washington Climate Change Impacts Assessment - Evaluating Washington's Future in a Changing Climate	2007
UW CIG	Snover, AK	State of Knowledge Report Climate Change Impacts and Adaptation in Washington State - Technical Summaries for Decision Makers 2013	2013
UW CIG	Salathé, Department of Interior, Pacific Northwest Climate Science Center	Uncertainty and Extreme Events in Future Climate and Hydrologic Projections for the Uncertainty and Extreme Events in Future Climate and Hydrologic Projections for the Pacific Northwest	2013
WDOE		Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy	2012

Appendix C
ACROS Tool Results

APPENDIX C
Climate Risk Analysis – ACROS Tool Results

Projected climate change risks were modeled using the ACROS tool, provided by the ACRP Report 147. The tool requires several user inputs, including reporting existing Airport assets and operations, and their associated *criticality* and *vulnerability* values. User inputs are required in three sections: (1) Assets, (2) Criticality, and (3) Vulnerability.

Assets

Assets and operations at the Airport that can be potentially affected by climate change risks were selected. A list of the physical assets and operations/processes selected in the ACROS tool are summarized in Table C-1 and Table C-2, respectively.

TABLE C-1
Summary of Selected Physical Assets in ACROS Tool

Service	**Asset/Operation/Process**
Aircraft/GSE	Ground Support Equipment (GSE)
Airfield/Airspace	Navigational Aids
Airfield/Airspace	Runways, Taxiways, and Holding Areas
Cargo	Air Cargo Buildings
Cargo	Cargo - Aprons
Cargo	Cargo - Loading/Unloading Equipment
Commercial Passenger Terminal Facilities	Commercial Passenger Terminal Facilities
Commercial Passenger Terminal Facilities	Aprons
Commercial Passenger Terminal Facilities	Curbside Amenities
Commercial Passenger Terminal Facilities	Gates
Commercial Passenger Terminal Facilities	Passenger Boarding Bridges
General Aviation Facilities	Aircraft Parking Aprons
General Aviation Facilities	General Aviation Facilities
General Aviation Facilities	Hangars
General Aviation Facilities	Loading/Unloading Equipment
General Aviation Facilities	Transient Aircraft Parking Apron Areas
Ground Access, Circulation, and Parking	Access Roads
Ground Access, Circulation, and Parking	Parking Facilities
Other	Regional Infrastructure
Support Facilities	Aircraft Fuel Storage
Support Facilities	Airline Maintenance Facilities
Support Facilities	Airport Administrative Areas
Support Facilities	Airport Maintenance Facilities
Support Facilities	FAA Facilities (Air Traffic Control Tower)
Support Facilities	Flight Kitchens
Utilities	On-Site Electrical Infrastructure
Utilities	Stormwater Drainage
Utilities	Water Distribution Systems

TABLE C-2 Summary of Selected Operations or Processes in ACROS Tool	
Service	**Asset/Operation/Process**
Aircraft/GSE	Aircraft Performance
Aircraft/GSE	Demand and Capacity
Environmental and Safety	Bird and Wildlife Hazard Management
Environmental and Safety	Environmental (Noise, Air Quality, and Water Quality and Quantity)
Environment and Safety	Snow and Ice Control (Deicing)
Other	Personnel and Passengers
Other	Construction Activities
Other	Grounds and Landscaping
Support Facilities	Aircraft Rescue and Fire Fighting (ARFF)
Utilities	Communications

Criticality

ACROS defines criticality as the consequence of failure for an individual asset or operation, rated on a scale from 1 to 3, where 1 indicates that loss of the asset/operation would have a negligible impact on the Airport, and 3 indicates that the loss of the asset/operation would significantly impair the Airport. ACROS defines vulnerability as the likelihood of the asset/operation failure in response to impacts based on current conditions.

Default values for the criticality of Airport assets/operations were used. According to the ACRP Report 147, default values represent a preliminary estimate based on subject matter expert input.

Vulnerability

Like criticality, vulnerability is rated on a scale from 1 to 3, where a 1 indicates that the asset/operation is unlikely to be affected by the climate risk impact, and a 3 indicates that the asset/operation will be significantly impaired or disabled by the climate risk impact.

Default values for the criticality and vulnerability of Airport assets/operations were used. According to the ACRP Report 147, default values represent a preliminary estimate based on subject matter expert input.

The following material provides the raw output report from the ACROS tool using the assumptions and methodology described previously.

Airport Climate Risk Operational Screening Tool Report

Airport: SEATTLE-TACOMA INTL

FAA Region: ANM

Section I: Climate

Summary of climate data changes

Summary of Historical Record and Projected Changes (Days/Year)								
Climate Vector	Units	2013	2030			2060		
		Baseline	25th Percentile	Median	75th Percentile	25th Percentile	Median	75th Percentile
HotDays	days per year	2.3	3.1	6.4	12	4.3	12.4	26.5
VeryHotDays	days per year	0	0	1.6	4.8	0.1	4.2	12.9
FreezingDays	days per year	10.1	1.7	5.5	8.7	0	1.9	6.6
FrostDays	days per year	80.2	64.8	68.8	71.9	41.7	51.7	59.4
HotNights	days per year	0	0.1	0.8	1.4	1.6	5.2	12.8
HumidDays	days per year	0	0	0.1	0.2	0.8	1.1	1.3
SnowDays	days per year	8.3	3.4	4.8	5.5	0	0.6	1.2
StormDays	days per year	42.4	42.7	43.5	44.5	43.1	45.3	47.8
HeavyRain1Day	days per year	13.4	13.7	14	14.5	14.2	15	16.1
DryDays	days per year	27.2	28.5	29.6	30.6	30.4	33.2	35.6
SeaLevelRise	days per year	0	0	0	0	0	0	0
CoolingDays	days per year	69.1	75.3	80.6	80.8	84.6	98	98.3
HeatingDays	days per year	244.8	230.2	231.3	234.6	208.2	211.1	219.2

Summary of Historical Record and Projected Changes (Various Unit)								
Climate Vector	Units	2013	2030			2060		
		Baseline	25th Percentile	Median	75th Percentile	25th Percentil e	Median	75th Percentile
CoolingDegreeDays	yearly accumulation	63.4	88.6	122.7	203.1	126.3	211.6	412.7
HeatingDegreeDays	yearly accumulation	3537.3	3242.9	3287.2	3341.2	2801.3	2912	3046.9
HeavyRain5Day	inches	4.8	4.9	5	5.1	4.9	5.2	5.4
SeaLevelRise_BaseFloodElevat ion	feet	0	0	0	0	0	0	0

Climate Projections (Days/Yr)

The majority of the climate vectors in the report are shown in units of days per year. By using a common unit, it is possible to provide a risk estimate across multiple climate vectors. Additional explanatory vectors are available below.

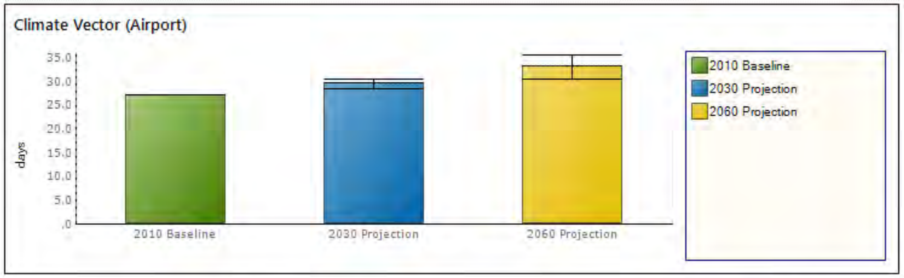
Dry Days
CONFIDENCE: Moderate

DryDays

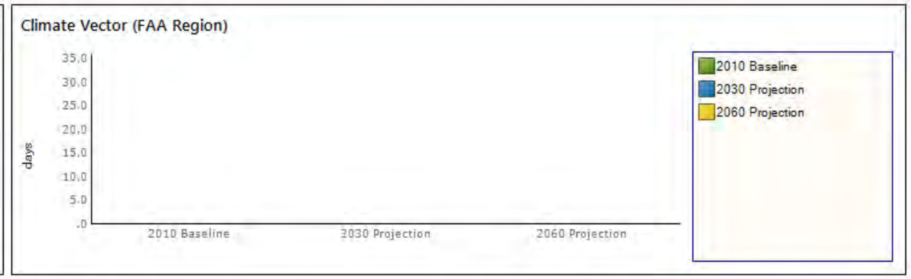
CONFIDENCE: MODERATE

A Dry Day is a day with a rainfall accumulation less than 0.03 inches. Dry Days are measured in days per year.

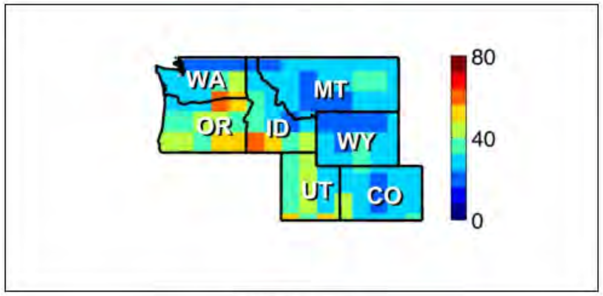
Climate Vector (Airport)



Climate Vector (FAA Region)

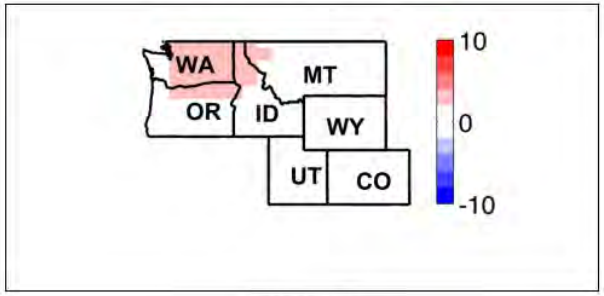


Number of Days



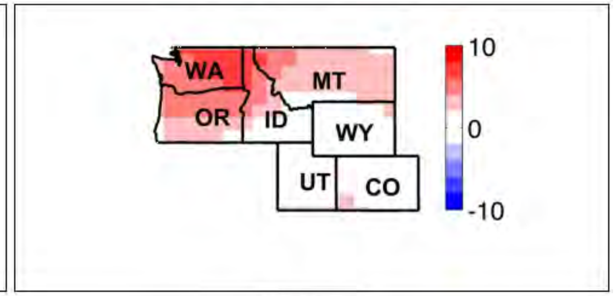
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



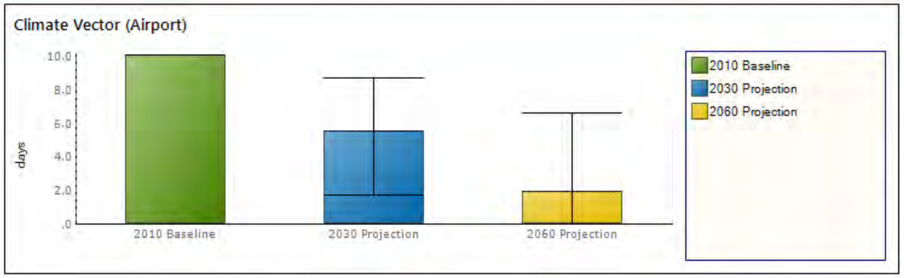
2060 (Median)

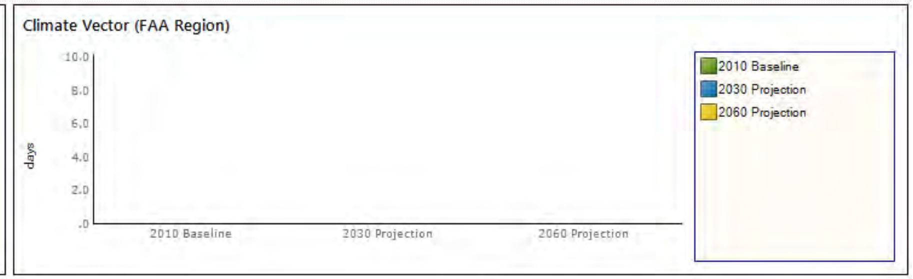
Freezing Days
CONFIDENCE: High

FreezingDays

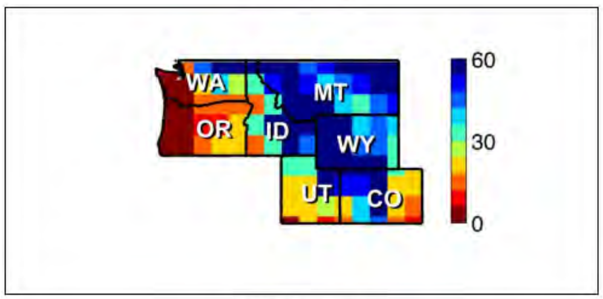
CONFIDENCE: HIGH

A Freezing Day is a day with a high temperature at or below 32°F. Freezing Days are measured in days per year.



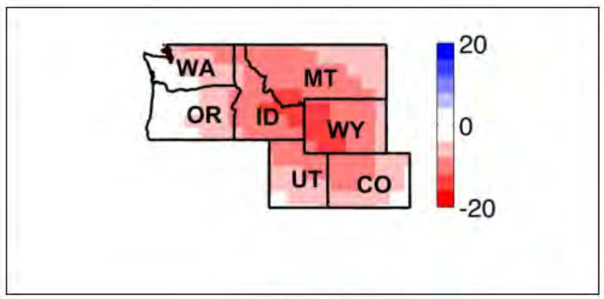


Number of Days



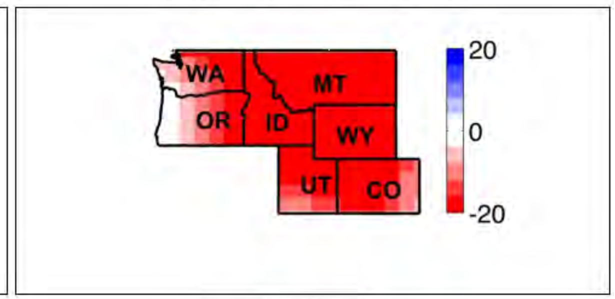
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

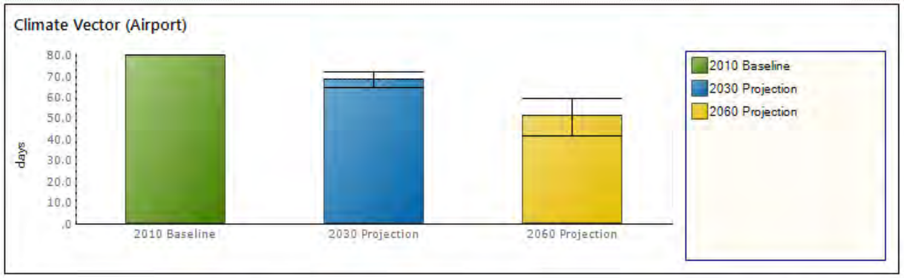
Frost Days

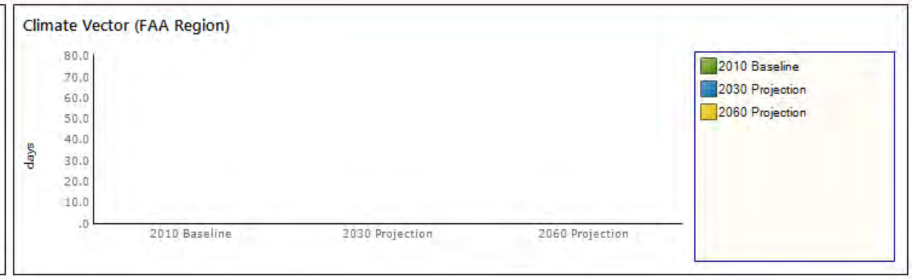
CONFIDENCE: High

FrostDays

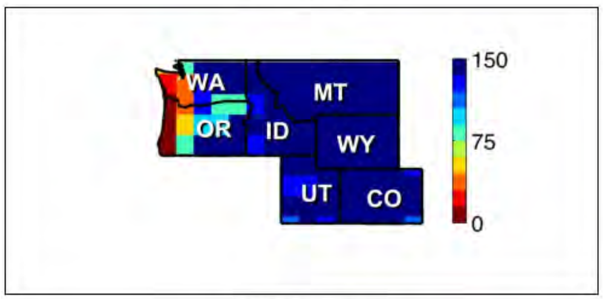
CONFIDENCE: HIGH

A Frost Day is a day with a low temperature at or below 32°F. Frost Days are measured in days per year.



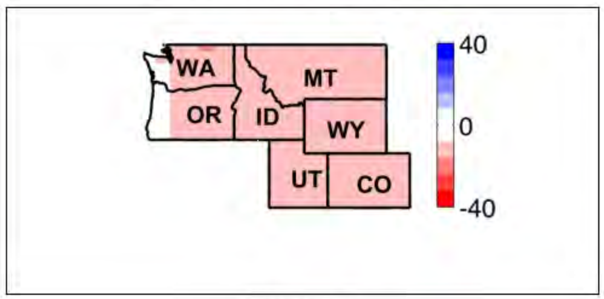


Number of Days



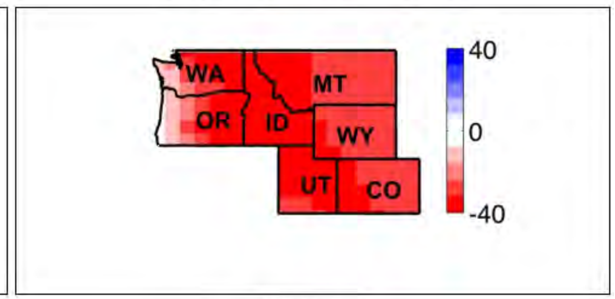
2010 (Baseline)

Change from Baseline in Number of Days



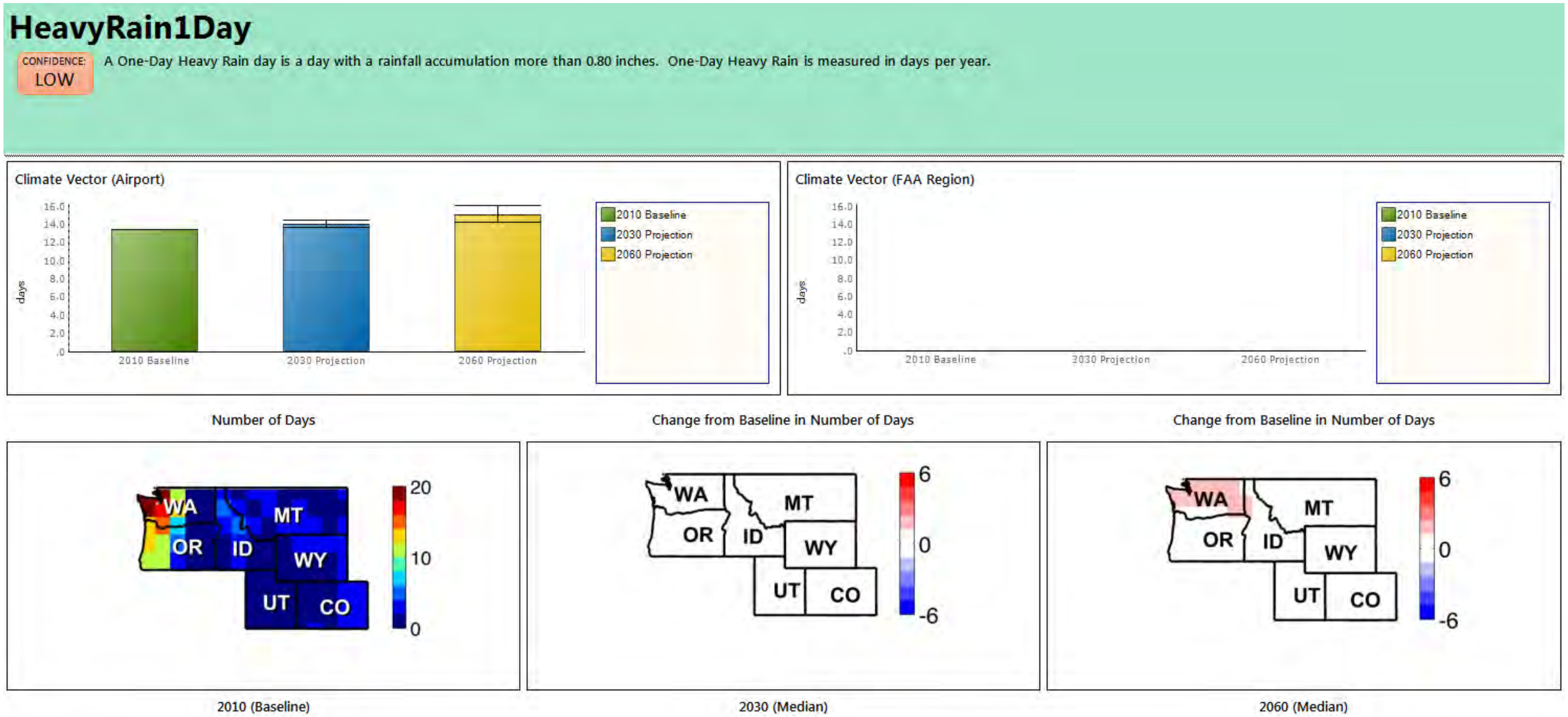
2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

Heavy Rain (1 Day)
CONFIDENCE: Moderate



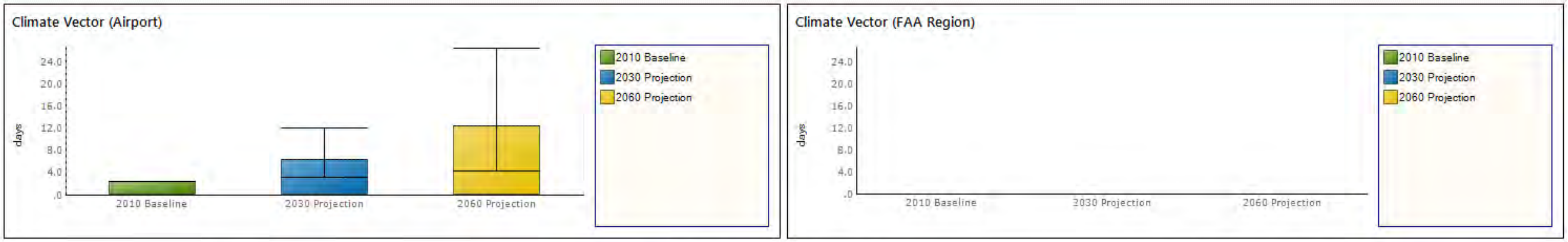
Hot Days

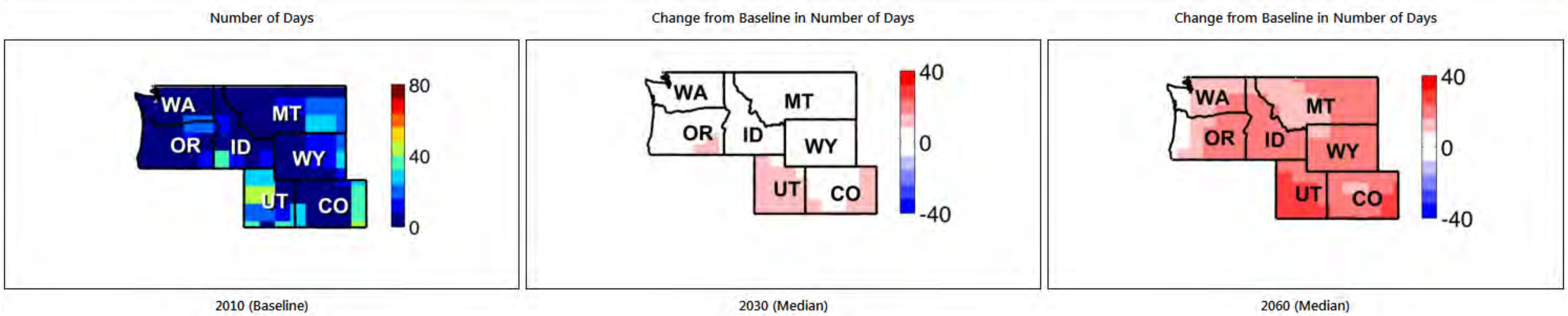
CONFIDENCE: High

HotDays

CONFIDENCE: HIGH

A Hot Day is a day with a high temperature at or above 90°F. Hot Days are measured in days per year.



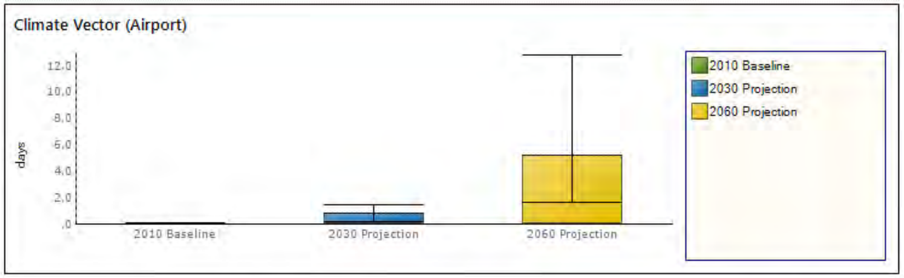


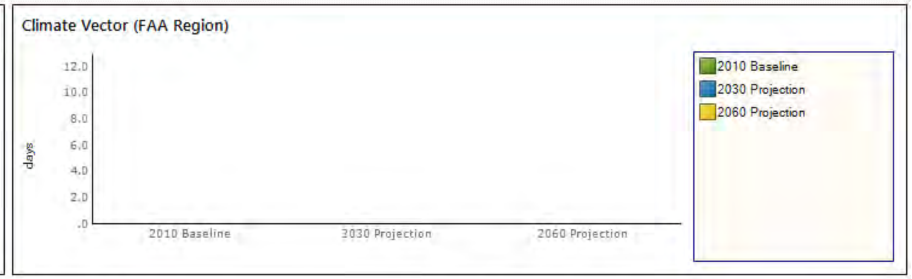
Hot Nights
CONFIDENCE: High

HotNights

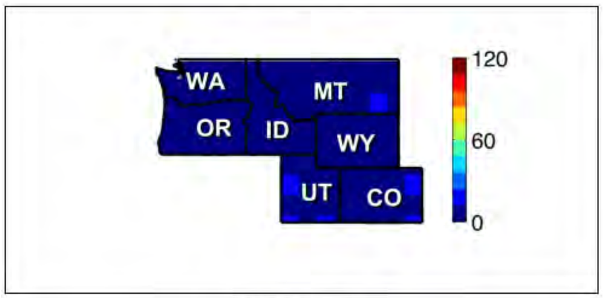
CONFIDENCE: HIGH

A Hot Night is a night with a low temperature at or above 68°F. Hot Nights are measured in nights per year.



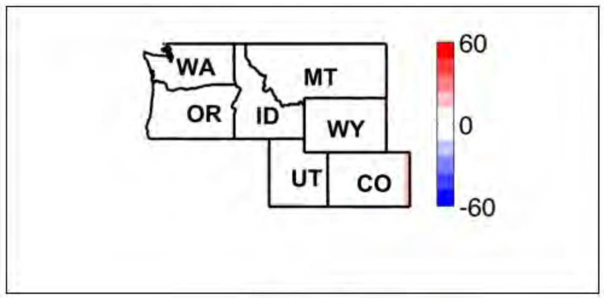


Number of Days



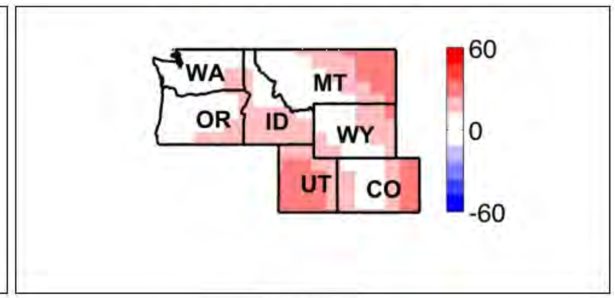
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

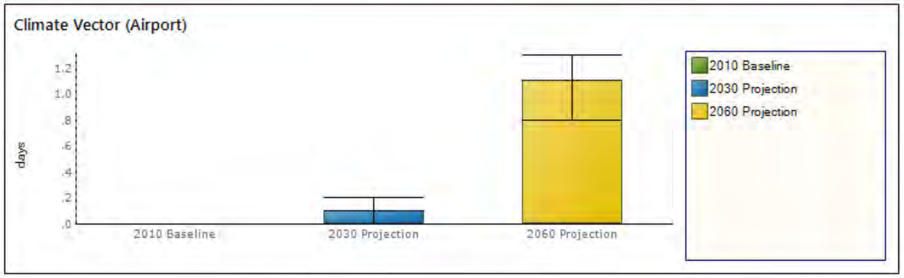
Humid Days

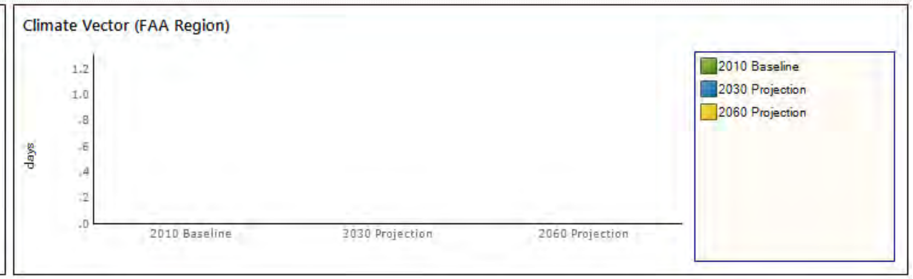
CONFIDENCE: High

HumidDays

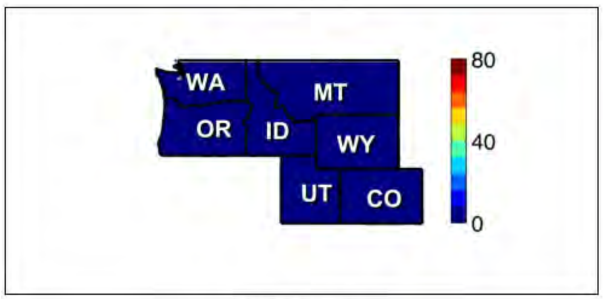
CONFIDENCE: HIGH

A Humid Day is a day with an average dewpoint temperature above 65°F. The dewpoint temperature is the temperature at which water vapor in the air condenses into dew. Humid Days are measured in days per year.



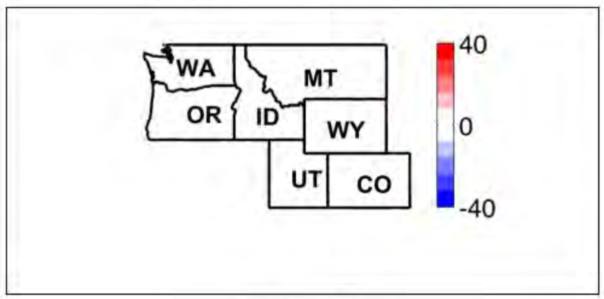


Number of Days



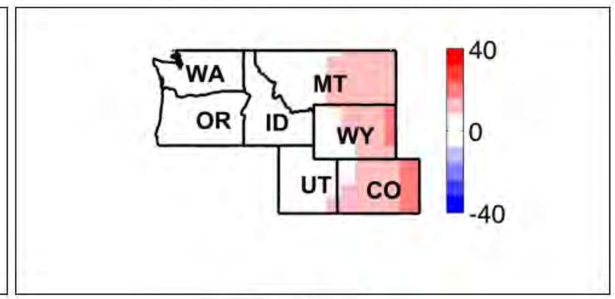
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

Snow Days

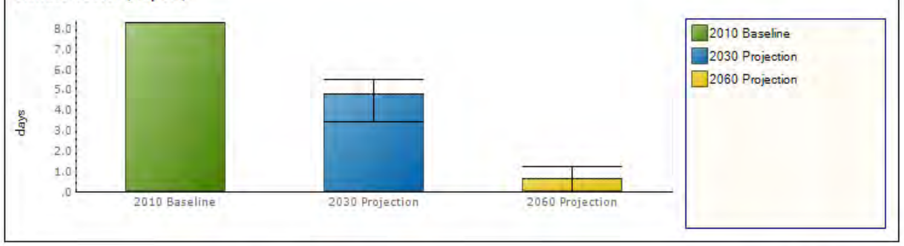
CONFIDENCE: Moderate

SnowDays

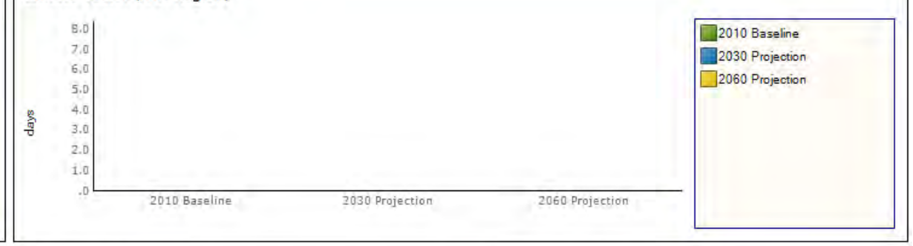
CONFIDENCE: MODERATE

A Snow Day is a day with a snowfall accumulation more than 2 inches. Snow Days are measured in days per year.

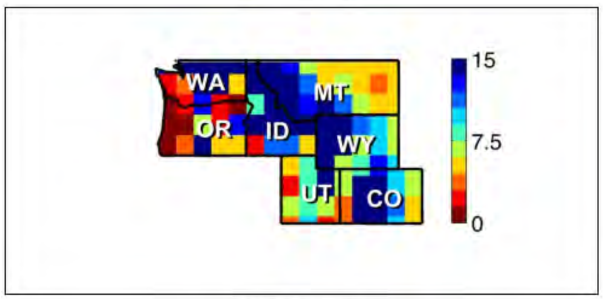
Climate Vector (Airport)



Climate Vector (FAA Region)

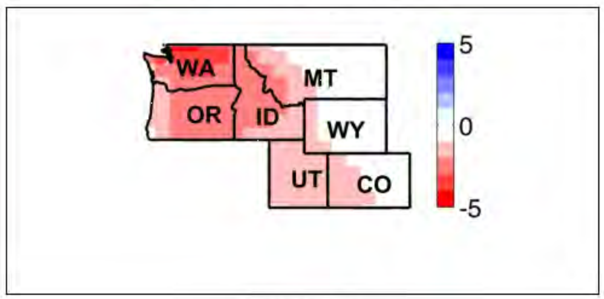


Number of Days



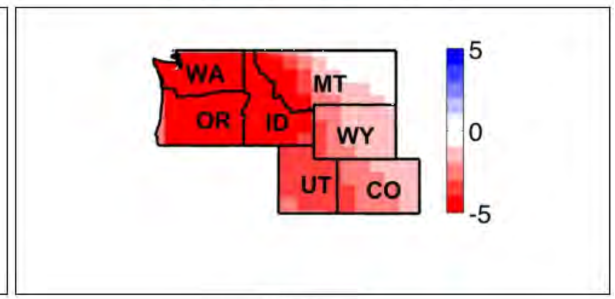
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



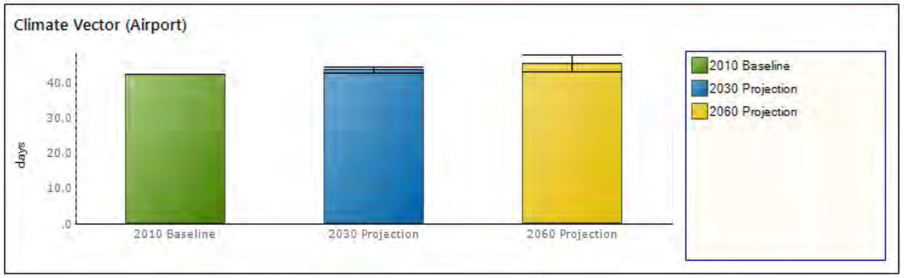
2060 (Median)

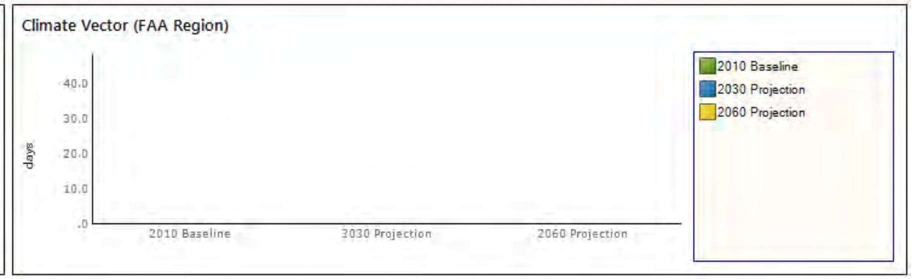
Storm Days
CONFIDENCE: Low

StormDays

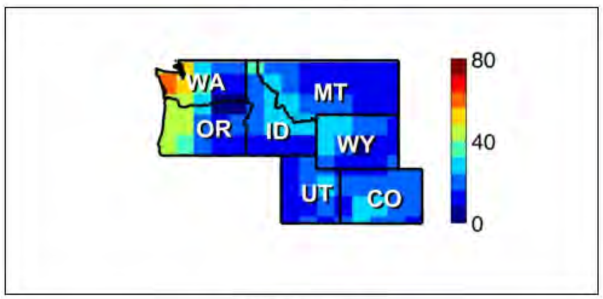
CONFIDENCE: LOW

A Storm Day is a day with a thunderstorm rainfall accumulation more than 0.15 inches. May include high wind events and hail. Storm Days are measured in days per year.



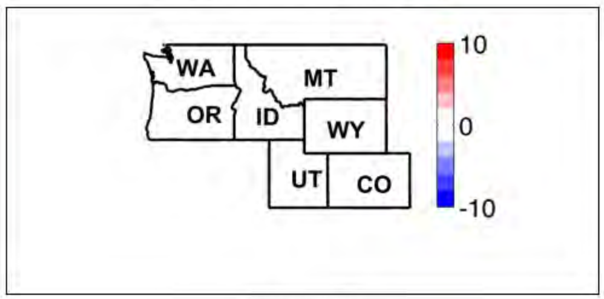


Number of Days



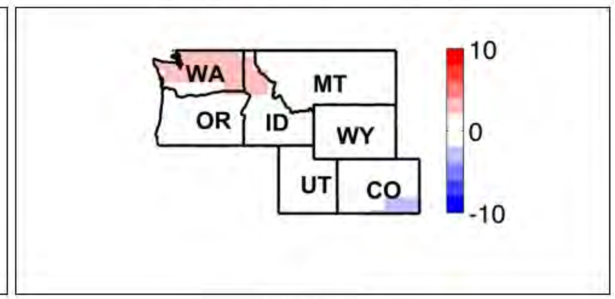
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

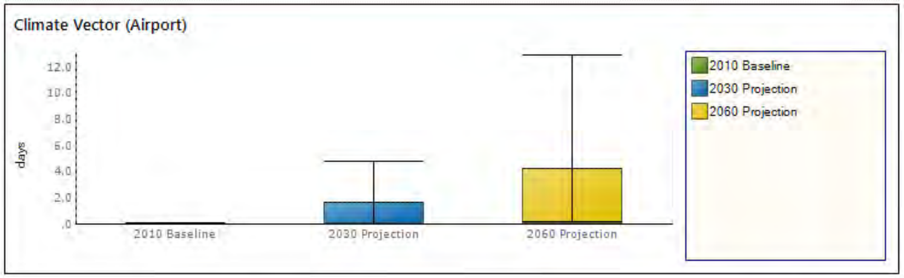
Very Hot Days

CONFIDENCE: High

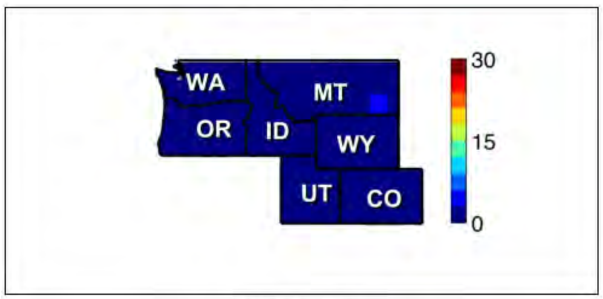
VeryHotDays

CONFIDENCE: HIGH

A Very Hot Day is a day with a high temperature at or above 100°F. Very Hot Days are measured in days per year.

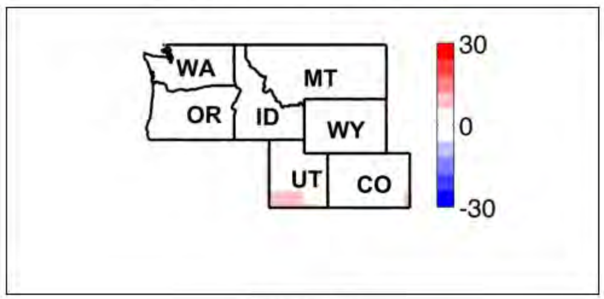


Number of Days



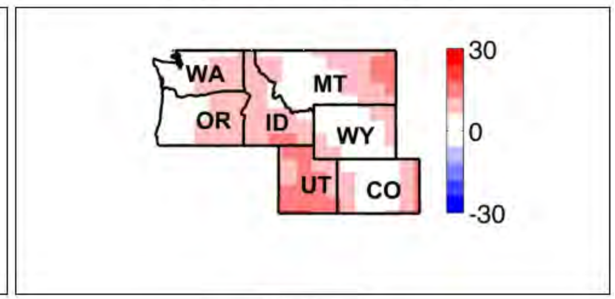
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

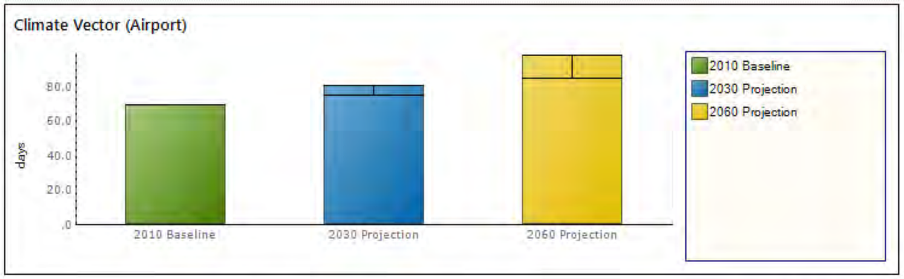
Cooling Days

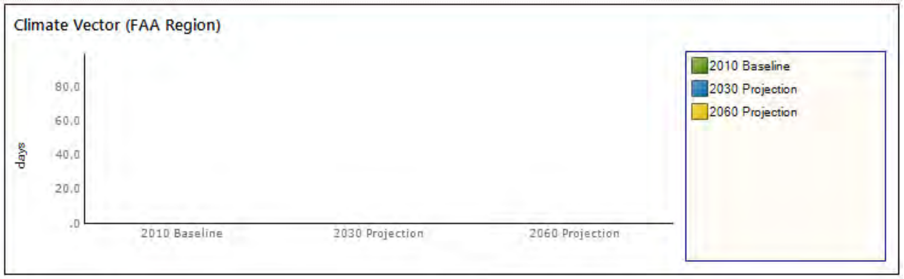
CONFIDENCE: High

CoolingDays

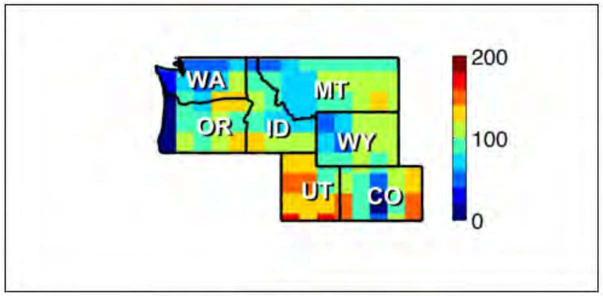
CONFIDENCE: HIGH

A Cooling Day is a day with an average temperature at or above 68°F. Cooling Days are measured in days per year.



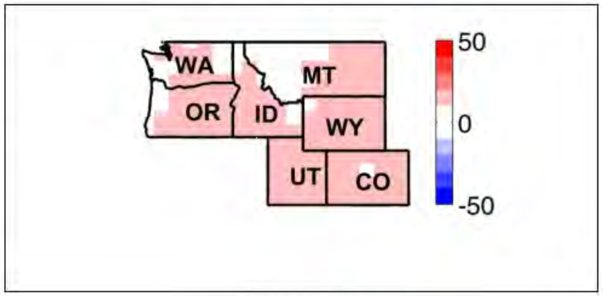


Number of Days



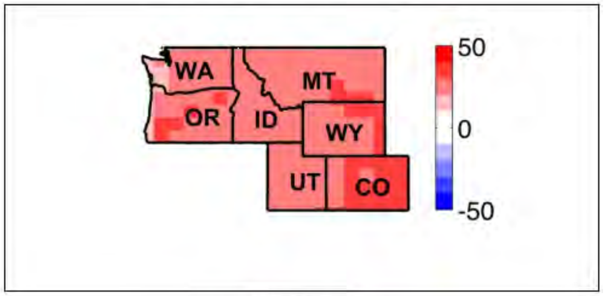
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

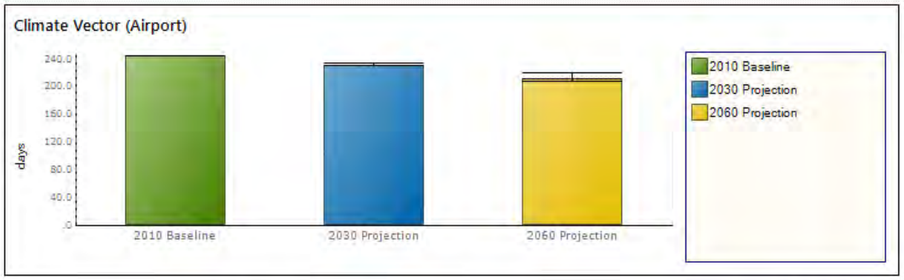
Heating Days

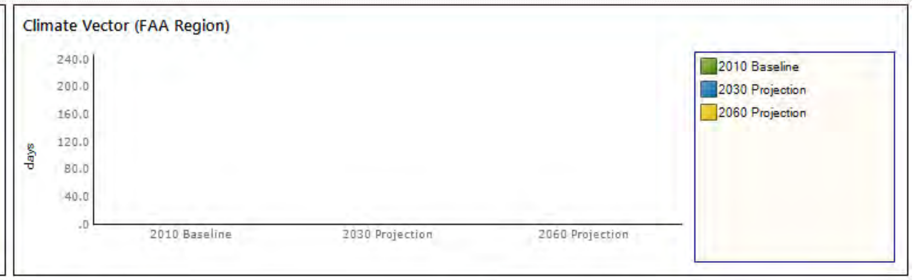
CONFIDENCE: High

HeatingDays

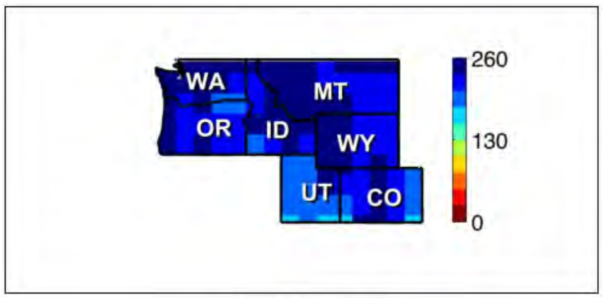
CONFIDENCE: HIGH

A Heating Day is a day with an average temperature at or below 62°F. Heating Days are measured in days per year.



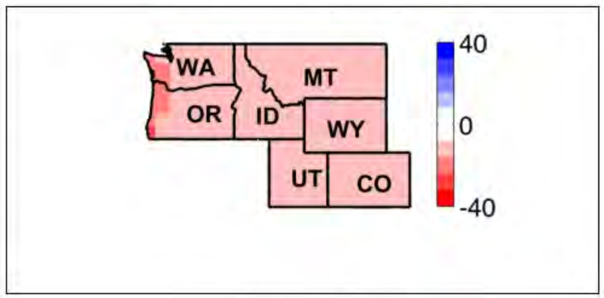


Number of Days



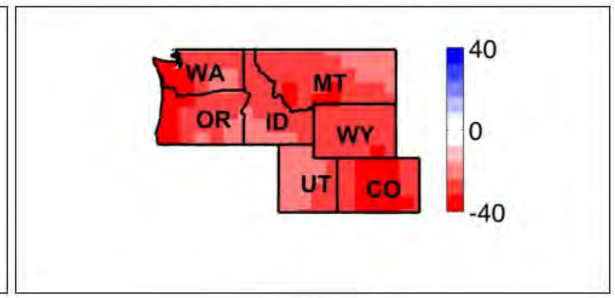
2010 (Baseline)

Change from Baseline in Number of Days



2030 (Median)

Change from Baseline in Number of Days



2060 (Median)

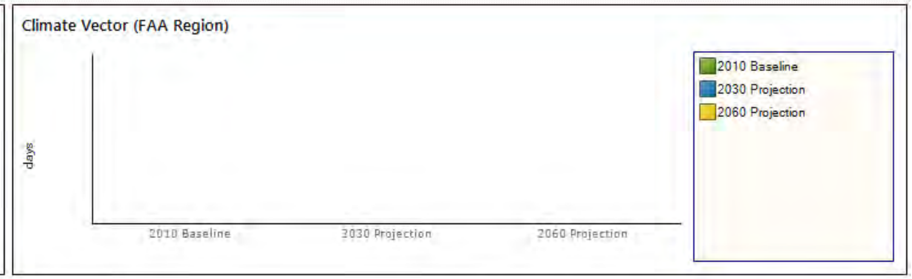
Sea Level Rise

CONFIDENCE: High

SeaLevelRise

CONFIDENCE: HIGH

Sea Level Rise measures the number of days per year where the runway elevation is inundated by tidal flooding. Runways protected by levees at OAK and MSY airports are flagged as inundated to emphasize the importance of maintaining flood protection.



Number of Days

2010 (Baseline)

Change from Baseline in Number of Days

2030 (Median)

Change from Baseline in Number of Days

2060 (Median)

Additional Climate Projections (Various units)
The climate vectors below are reported in various units. While these cannot be accounted for in the risk estimate (which requires comparison across the same unit of change), these vectors are shown to provide additional information.

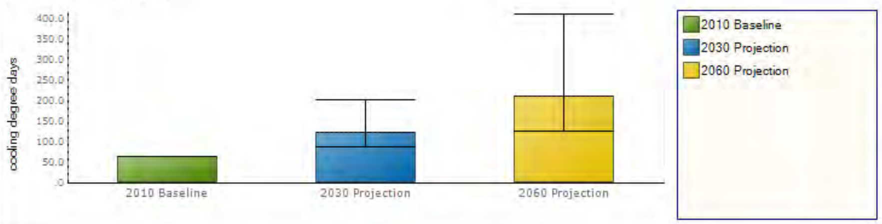
Cooling Degree Days
CONFIDENCE: High

CoolingDegreeDays

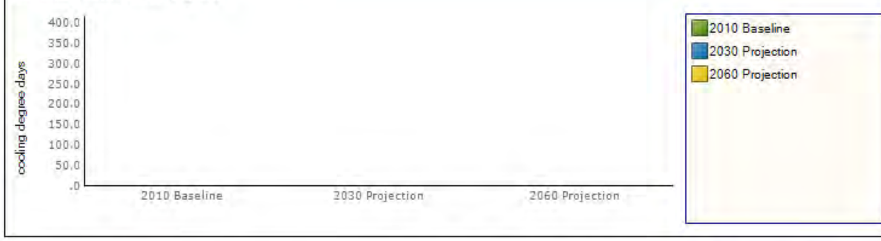
CONFIDENCE: HIGH

A Cooling Degree Day (CDD) is a unit of measure that reflects the energy demand needed to cool a building. The daily CDD is calculated by subtracting 65 from the day's average temperature. Daily CDDs are summed to obtain the accumulated CDD per year.

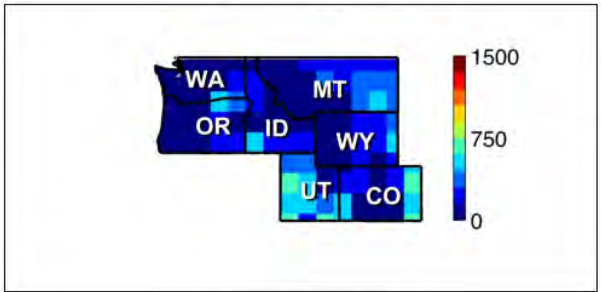
Climate Vector (Airport)



Climate Vector (FAA Region)

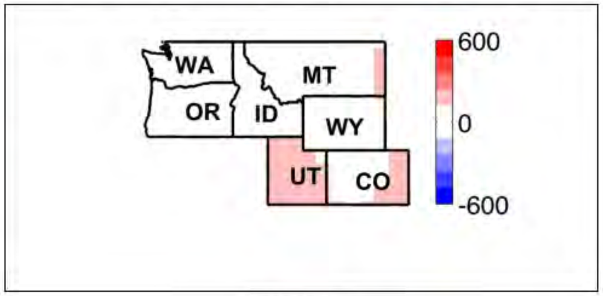


Yearly Accumulation of Degree-Days



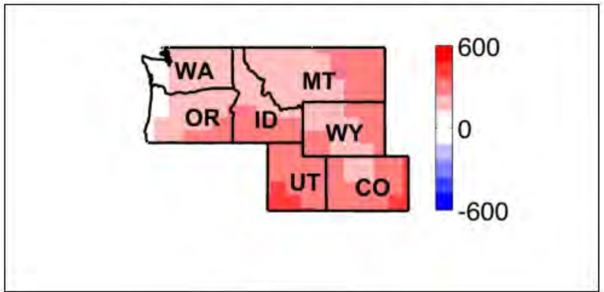
2010 (Baseline)

Change from Baseline in Yearly Accumulation of Degree-Days



2030 (Median)

Change from Baseline in Yearly Accumulation of Degree-Days



2060 (Median)

__Heating Degree Days__

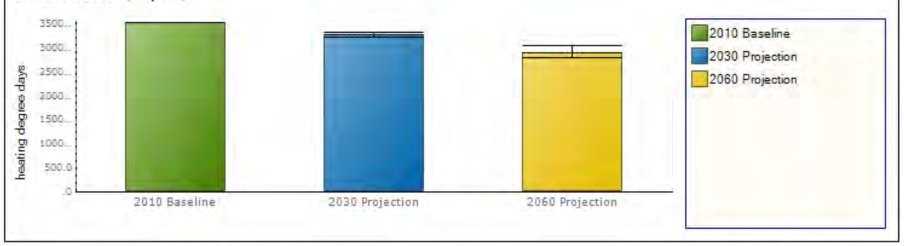
CONFIDENCE: High

HeatingDegreeDays

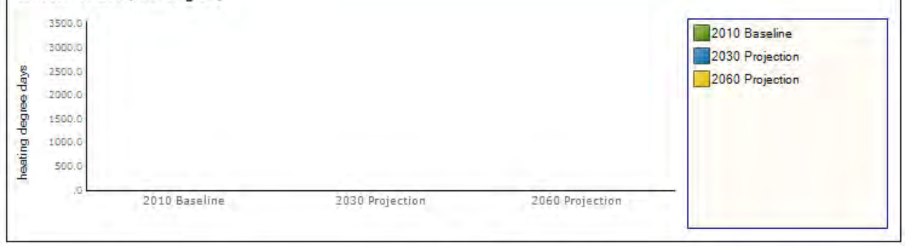
CONFIDENCE: HIGH

A Heating Degree Day (HDD) is a unit of measure that reflects the energy demand needed to heat a building. The daily HDD is calculated by subtracting the day's average temperature from 65. Daily HDDs are summed to obtain the accumulated HDD per year.

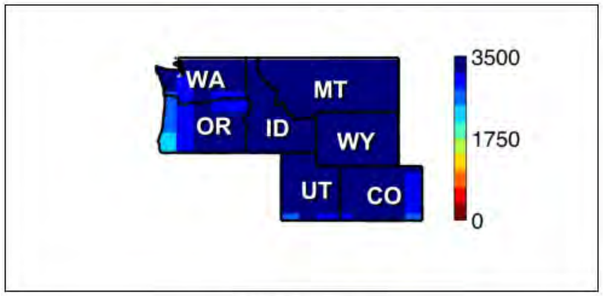
Climate Vector (Airport)



Climate Vector (FAA Region)

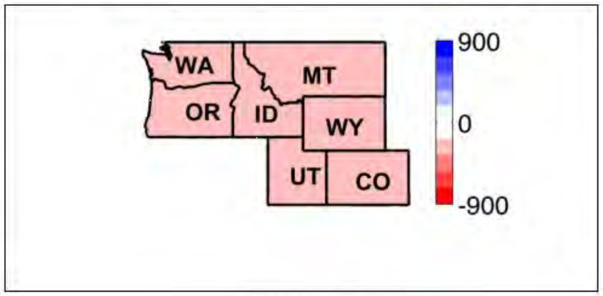


Yearly Accumulation of Degree-Days



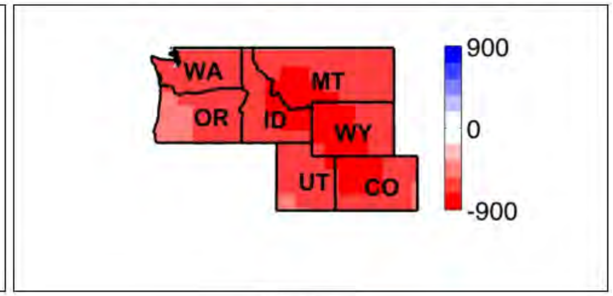
2010 (Baseline)

Change from Baseline in Yearly Accumulation of Degree-Days



2030 (Median)

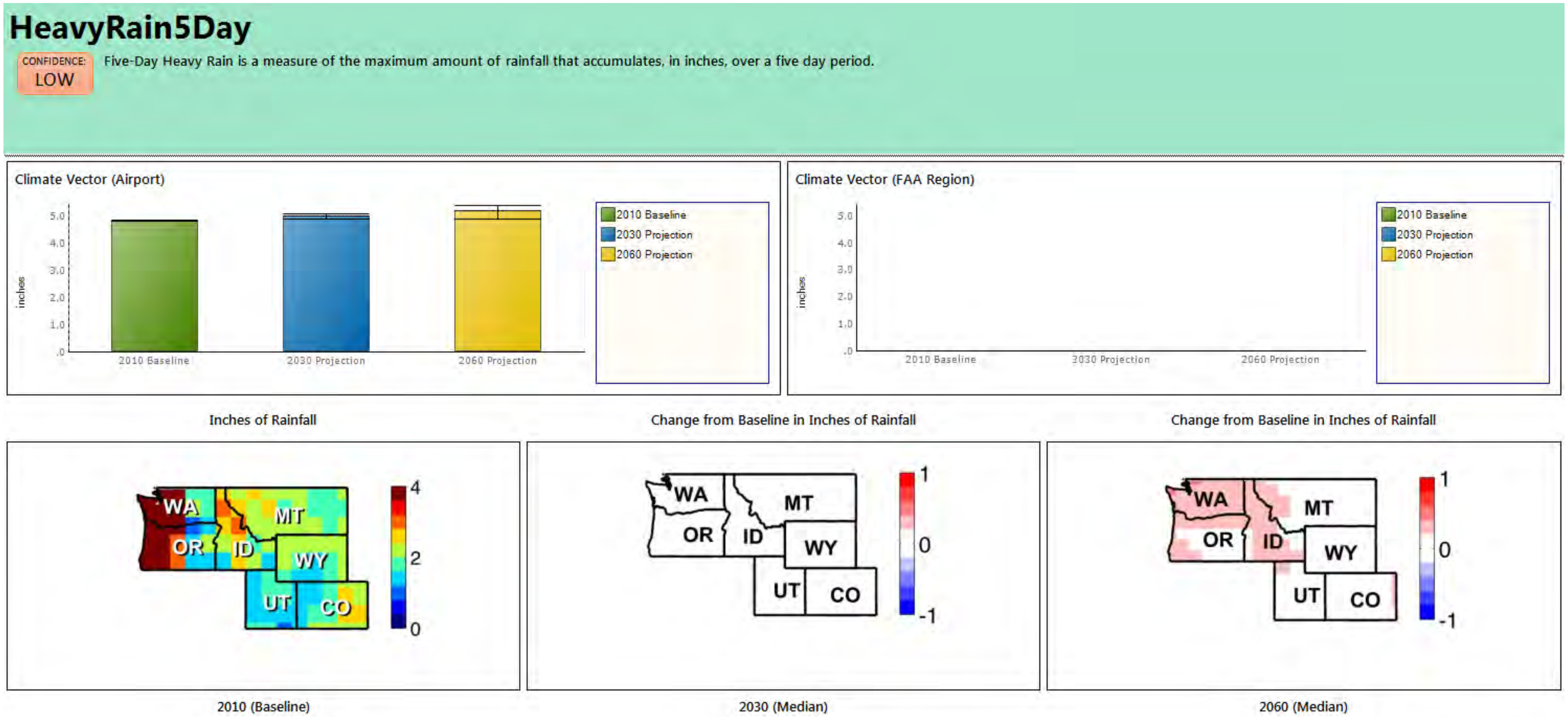
Change from Baseline in Yearly Accumulation of Degree-Days



2060 (Median)

Heavy Rain (5 Day)

CONFIDENCE: Low



__Sea Level Rise BFE__
CONFIDENCE: High

SeaLevelRise_BaseFloodElevation

CONFIDENCE: HIGH

The Base Flood Elevation (BFE) estimates the height to which floodwater is anticipated to rise during a 100-year flood event. BFE is measured in feet relative to the North American Vertical Datum of 1988 (NAVD88).

Base flood elevation (feet)

2010 (Baseline)

Change from Baseline in Base flood elevation (feet)

2030 (Median)

Change from Baseline in Base flood elevation (feet)

2060 (Median)

SCREENING

Relative to the selected airport, risk is categorized as:

● (red) = High Risk ● (yellow) = Medium Risk ● (blue) = Low Risk

Section II: Risk (2030)

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	Commercial Passenger Terminal Facilities					**Gates**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		3	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		3	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		3	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		3	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		3	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)

						• Improve Drainage Infrastructure
	🔵	3	1	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	🔵	3	1	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
	🔵	3	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	🔵	3	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	🔵	3	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
	🔵	3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🔴	**Commercial Passenger Terminal Facilities**					**Commercial Passenger Terminal Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🔴	3	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	🟡	3	2	StormDays HeavyRain1Day HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies

		3	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		3	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		3	2	DryDays StormDays HeavyRain1Day HotDays	Decreased Food Resources	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		3	1	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		3	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope • Improve Drainage Infrastructure
		3	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		3	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		3	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		3	2	StormDays	Failure of Drainage Systems	• Upgrade Capacity • Elevate Facilities
		3	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers

						• Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		3	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		3	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		3	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		3	2	StormDays	External Facility Damage Due to Flooding	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Use Disposable Flatware and Plates • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Commercial Passenger Terminal Facilities					**Gates (Passenger Boarding Bridges)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	2	HotDays	Roofing Material and Exterior Seals (Roof and	• Upgrade Roof with High Heat and Reflective Products

					Walls) Degradation	
	●	2	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
	●	2	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
	●	2	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
	●	2	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	2	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	2	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
	●	2	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	2	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	2	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material

	●	2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Support Facilities**					**Airport Maintenance Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
	●	2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
	●	2	1	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
	●	2	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
	●	2	1	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	2	1	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing

						Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	2	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
	●	2	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	2	1	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	2	1	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
	●	2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	2	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
	●	2	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
	●	2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Aircraft / GSE**					**Demand and Capacity**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	2	HotDays HotNights HumidDays StormDays	Reduced Throughput Capacity (Number of Planes	• Plan for Fluctuations in Throughput Capacity

				HeavyRain1Day DryDays CoolingDays	Operating Out of the Facility)	
	🟡	2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Change in Tourism and Seasonal Enplanements	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	🔵	2	1	VeryHotDays	Increased Fire Hazards May Impede Flight Operations	• Plan for Increases in Fires • Assess Fire Main Capacity
	🔵	2	2	StormDays	Increased Delays Due to Inability to Have People on Ramp	• Plan for Weather-Related Delays in Passenger Movements • Communicate with Community about Transportation Delays
	🔵	2	1	HotDays HeavyRain1Day	Reduced Ability of Some Airports to Take Certain Aircraft	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	🔵	2	2	HeavyRain1Day StormDays	Delays, Cancellations and Other Effects of Systemic Changes and Increased Irregular Operation	• Develop IROP Protocols • Communicate with Community about Transportation Delays

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🟡	**Cargo**					**Apron**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🟡	3	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
	🔵	3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material
	🔵	3	2	DryDays	Water-Reliant Maintenance	• Install Gray Water Systems • Develop Water Conservation Protocols

					Curtailed	
		3	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Install Erosion Control Structures • Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or
		3	2	StormDays HeavyRain1Day	Flooding	• Change Alignment • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment
		3	2	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
		3	1	HeavyRain1Day StormDays	Debris and Foreign Object Damage	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Ground Access, Circulation, and Parking					**Access Roads**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	HotDays DryDays	Reduced Visibility	• Travel at Slower Speeds • Increase Lighting
		3	1	HotDays	Thermal Expansion	• Replace Expansion Joints
		3	3	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
		3	1	StormDays HeavyRain1Day	Ramp Flooding	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		3	1	HeavyRain1Day	Changes in the Normal Flow of Traffic	• Communicate with Regional Authorities • Cooperate with Regional Planners to Develop Adaptations
		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

		3	3	StormDays HeavyRain1Day	Flooding	• Change Alignment • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment
		3	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations
		3	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		3	1	StormDays	Debris and Foreign Object Damage	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations
		3	1	StormDays HeavyRain1Day	Electrical Failures	• Install On-Site, Raised and Protected Backup Power Supplies and Lighting
		3	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Install Erosion Control Structures • Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**On-Site Electrical Infrastructure**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	3	HotDays	Insufficient Capacity Due to Increased Demand	• Generate Power Onsite • Increase Size of Electrical Service • Use Demand-Limiting Measures

	🟡	2	3	HotDays	Decreased Reliability of External Utility	• Add a Secondary Feed from an Additional Utility • Add or Increase Capacity for Onsite Generation • Arrange An Uninterruptable Power Rate • Use Demand-Limiting Measures
	🔵	2	1	StormDays HeavyRain1Day	Flooding	• Implement Barrier System • Install On-Site, Raised and Protected Backup Systems
	🔵	2	2	HeavyRain1Day StormDays	Loss of Power	• Install On-Site, Raised and Protected Backup Power Supplies
	🔵	2	2	DryDays	Soil Expansion-Contraction	• Modify Fill Material at Underground Utilities to Alleviate Expansion
	🔵	2	2	StormDays	Damage Due to Electrical Voltage Spikes	• Add TVSS to All Critical Systems
	🔵	2	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
	🔵	2	2	VeryHotDays	Transformer Failure	• Install Supplemental Fans • De-Rate and Replace Or Supplement Transformer

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🟡	**Ground Access, Circulation, and Parking**					**Parking Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🟡	3	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
	🔵	3	1	StormDays	Damage to Cars	• Offer More Covered Parking Facilities
	🔵	3	1	HotDays DryDays	Reduced Visibility	• Travel at Slower Speeds • Increase Lighting
	🔵	3	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	🔵	3	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems

						• Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations
	🔵	3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material
	🔵	3	1	HotDays	Increased Pavement Temperature	• Offer More Covered Parking Facilities
	🔵	3	2	StormDays HeavyRain1Day	Flooding	• Change Alignment • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment
	🔵	3	1	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	🔵	3	1	StormDays	Wind Damage	• Offer More Covered Parking Facilities
	🔵	3	3	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
	🔵	3	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Install Erosion Control Structures • Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🟡	**General Aviation Facilities**					**Aircraft Parking Aprons**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🟡	3	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
	🔵	3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material
	🔵	3	2	StormDays HeavyRain1Day	Flooding	• Change Alignment • Install Flood Barriers • Move Paved Area

						• Assess Noise Impacts from Changes in Use or Alignment
		3	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Install Erosion Control Structures • Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or
		3	2	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
		3	2	HeavyRain1Day StormDays	Debris and Foreign Object Damage	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**Water Distribution Systems**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
		3	1	StormDays HeavyRain1Day	Flooding	• Provide on Site Storage for Temporary Operation • Increase Capability for Disinfection
		3	1	StormDays HeavyRain1Day	Surface Water Contamination	• Provide on Site Storage for Temporary Operation • Increase Capability for Disinfection
		3	1	DryDays	Reduced Water Availability Due to Drought	• Utilize Water Conserving Fixtures and Landscaping
		3	1	DryDays	Less Water Main Flushing	• Continue Monitoring and Disinfection of Water Supply System

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**Sanitary Sewer**
	Impact	***Criticality***	***Vulnerability***	***Climate***	***Impacts***	***Adaptation Options***

	Risk			Vectors		
		3	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
		3	3	StormDays HeavyRain1Day	Increased Combined Sewer Overflow Events	• Provide Onsite Storage for Temporary Operation • Increase Capability for Disinfection
		3	2	StormDays HeavyRain1Day	Flooding	• Implement Barrier System • Increase Conveyance and Capacity • Temporarily Route Discharge to Alternate Location

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	General Aviation Facilities					**Hangars**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		1	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		1	1	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		1	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		1	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure

						• Develop IROP Protocols
		1	1	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		1	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		1	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
		1	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		1	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		1	1	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		1	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		1	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		1	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		1	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL	**SERVICE:**	**ASSET/OPERATION:**

RISK						
	Support Facilities					**Airport Administrative Areas**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		2	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	1	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		2	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	1	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the

						Building
		2	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
		2	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		2	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		2	1	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	General Aviation Facilities					**General Aviation Terminal Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		1	2	HotDays HotNights	Increased HVAC Demand and	• Design for Incremental Change (e.g. Modular Systems)

				HumidDays	Duration	• Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
	●	1	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
	●	1	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
	●	1	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	1	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	1	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	1	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
	●	1	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols • Coordinate With FEMA
	●	1	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	1	1	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA

						• Prioritize Assets and Develop A Redundancy Plan
		1	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		1	1	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		1	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		1	1	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Support Facilities					**Flight Kitchens**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		1	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		1	1	HotDays	Increased Water Demand	• Plan for Increased Water Consumption
		1	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		1	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		1	2	StormDays HeavyRain1Day HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies

	●	1	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Use Disposable Flatware and Plates • Install Gray Water Systems • Provide Onsite Storage for Operational Needs
	●	1	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
	●	1	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	1	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
	●	1	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
	●	1	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
	●	1	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
	●	1	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
	●	1	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
	●	1	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment

						• Elevate Structure • Develop IROP Protocols
		1	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		1	2	DryDays StormDays HeavyRain1Day HotDays	Decreased Food Resources	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Cargo					**Air Cargo Buildings**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		2	1	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	1	StormDays	Damage to Transport Vehicles	•
		2	1	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		2	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		2	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		2	2	StormDays HeavyRain1Day	External Facility Damage Due to	• Improve Building Envelope (Incorporate Flood-

					Driving Rain	Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	2	1	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	2	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
	●	2	1	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols • Coordinate With FEMA
	●	2	1	StormDays	External Facility Damage Due to Flooding	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	2	1	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	2	1	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
	●	2	1	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
	●	2	1	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
	●	2	2	StormDays	Failure of Drainage Systems	• Upgrade Capacity • Elevate Facilities

		2	1	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	1	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Use Disposable Flatware and Plates • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Personnel and Passengers**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Human Migration	• Plan for Changes in Magnitude and Timing of Passenger Travel
		2	1	HotDays	Heat Exposure	• Educate Employees about Heat Injuries • Schedule Cooling Breaks • Improve Temperature Control and Monitoring Strategies (Shades on Windows, Window Films, Covered Waiting Area, Misting Station, setc.) •
		2	1	HotDays	Limitation on Outdoor Maintenance and Services	• Use Longer Season to Absorb Work Delays Due to Weather and Air Quality
		2	1	StormDays HeavyRain1Day HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies
		2	1	StormDays	Threat to Maintenance Workers	• Schedule Work Around The Forecast
		2	1	StormDays HeavyRain1Day HotDays	Change in Tourism and Seasonal Enplanements	• Plan for Changes in Magnitude and Timing of Passenger Travel

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	Environmental and Safety					**Bird and Wildlife Hazard Management**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Changes in Ecosystems and Distributions of Pests / Wildlife	• Use Appropriate Wildlife and Landscape Management Techniques
		2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Increased Risk of Bird Strikes From Ecosystem Changes	• Use Appropriate Wildlife and Landscape Management Techniques
		2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Potential Increase in Wildlife Attractants	• Monitor Wildlife • Use Appropriate Wildlife and Landscape Management Techniques
		2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Wildlife Changes	• Use Appropriate Wildlife and Landscape Management Techniques

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	Support Facilities					**Airline Maintenance Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals)	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)

					and / Or Mold Vulnerability	
		1	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		1	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		1	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs
		1	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		1	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		1	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		1	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		1	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		1	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		1	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure

		1	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		1	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		1	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		1	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Support Facilities					**FAA Facilities (Air Traffic Control Tower)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		2	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	1	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)

					Vulnerability	
	●	2	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
	●	2	1	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	2	1	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	2	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	2	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
	●	2	2	StormDays HeavyRain1Day	Flooding	• Cooperate with FAA to Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	2	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
	●	2	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
	●	2	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material

		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	General Aviation Facilities					**Loading and Unloading Equipment / Operation**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays DryDays	Wildfire Smoke	• Develop Personal Protective Strategies • Limit Activities During Poor Air Quality
		2	1	StormDays HeavyRain1Day	Reduced Level of Service	• Expand Canopy Coverage
		2	1	HotDays HotNights HumidDays	Increased Level of Insect Activity	• Modify The Effective Lighting Color Temperature and Improve Insect Intrusion Prevention Design Solutions.
		2	1	StormDays HeavyRain1Day	Flooding	• Install Erosion Control Structures • Move Runway • Assess Noise Impacts from Changes in Runway Alignment
		2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	1	StormDays	Damage Due to Electrical Voltage Spikes	• Add TVSS to All Critical Systems
		2	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		2	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**Communications**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***

	●	2	1	StormDays	Disruption in Airport Operations	• Install On-Site, Raised and Protected Backup Power Supplies
	●	2	1	StormDays	Loss of Power	• Install On-Site, Raised and Protected Backup Power Supplies
	●	2	1	StormDays HeavyRain1Day	Flooding	• Flood Resistance Measures
	●	2	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Commercial Passenger Terminal Facilities**					**Curbside Amenities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	3	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
	●	3	1	HotDays HotNights HumidDays	Increased Level of Insect Activity	• Modify The Effective Lighting Color Temperature and Improve Insect Intrusion Prevention Design Solutions.
	●	3	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
	●	3	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	3	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	3	1	StormDays HeavyRain1Day	Reduced Level of Service	• Expand Canopy Coverage
	●	3	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure

						• Develop IROP Protocols
		3	1	HotDays DryDays	Reduced Visibility	• Increase Lighting
		3	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		3	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		3	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Commercial Passenger Terminal Facilities					**Apron**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material
		3	2	StormDays HeavyRain1Day	Flooding	• Change Alignment • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment
		3	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Install Erosion Control Structures • Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or
		3	1	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
		3	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of	• Use Hard Stands • Replace Pavement

					Pavement	
	●	3	1	HeavyRain1Day StormDays	Debris and Foreign Object Damage	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations

OVERALL RISK	SERVICE:					ASSET/OPERATION:
●	**Support Facilities**					**Aircraft Rescue and Fire Fighting (ARFF)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	3	1	HotDays	Increase in Emergency Medical Situations	• Optimize Accessibility to Emergency Personnel
	●	3	1	StormDays	Fires Due to Lightning Strikes	• Plan for Increases in Fires • Assess Fire Main Capacity
	●	3	2	StormDays HeavyRain1Day	Emergency Response Situations	• Provide Appropriate Training for Disaster Response
	●	3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	SERVICE:					ASSET/OPERATION:
●	**Environmental and Safety**					**Snow and Ice Control (De-Icing)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	2	DryDays	Less Runoff Results in High Deicer Concentrations	• Improve Deicing Collection, Storage, and Treatment

OVERALL RISK	SERVICE:	ASSET/OPERATION:
●	**Utilities**	**Stormwater Drainage**

	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
	●	2	1	HotDays	Permit Compliance Issues Due to High Pollutant Loads	• Monitor and Adjust Outdoor Water Use With Respect to Pollutant Loading
	●	2	2	DryDays StormDays HeavyRain1Day	Permit Compliance Issues	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment
	●	2	1	StormDays HeavyRain1Day	Increased Discharge Quantity and Degraded Quality	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment
	●	2	1	DryDays StormDays HeavyRain1Day	Dryer Soils Lead to Reduced Vegetation and Increased Erosion	• Replace Vegetation With Drought Resistant Vegetation Or Structural BMPs.
	●	2	1	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
	●	2	1	StormDays HeavyRain1Day	Flooding	• Implement Barrier System
	●	2	1	StormDays	Blocked Drains Due to Debris	• Increase Monitoring, Maintenance and Cleaning of Stormwater System
	●	2	1	StormDays HeavyRain1Day	Increased Demand on Existing Drainage	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment
	●	2	1	DryDays	Decreased Discharge Quantity and Impaired Quality	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Airfield / Airspace**					**Runways, Taxiways, and Holding Areas**
	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
	●	2	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material
	●	2	2	StormDays HeavyRain1Day	Flooding	• Change Alignment • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or

						Alignment
		2	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment
		2	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		2	1	HotDays HotNights HumidDays	Reduced Rate of Climb	• Lengthen Runway • Reduce Payload
		2	2	StormDays HeavyRain1Day	Debris and Foreign Object Damage	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Regional Infrastructure**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	StormDays	Loss of Power	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		2	1	StormDays HeavyRain1Day	Tail Water Effects Reduce Stormwater Drainage Capacity	• Increase Conveyance and Capacity
		2	1	HotDays	Reduced Rate of Climb	• Cooperate with Regional Planners to Adjust Height Restrictions
		2	1	StormDays HeavyRain1Day	Reduced Transportation Capacity	• Plan for Weather-Related Delays in Passenger Movements • Communicate with Community about Transportation Delays

		2	1	StormDays	Disruption in Airport Operations	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		2	1	DryDays	Subsidence of Foundations	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		2	1	StormDays	Wind Damage	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		2	1	HotDays	Thermal Expansion	• Cooperate with Regional Planners to Adjust Height Restrictions
		2	1	StormDays HeavyRain1Day	Flooding	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Construction Activities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	2	StormDays HeavyRain1Day HotDays DryDays	Construction Delays	• Schedule Work Around The Forecast

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Cargo					**Loading and Unloading Equipment / Operation**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	StormDays	Wind Damage	• Protect Exposed Utilities and Structures
		2	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		2	1	HotDays HotNights HumidDays	Increased Level of Insect Activity	• Modify The Effective Lighting Color Temperature and Improve Insect Intrusion Prevention Design Solutions.
		2	1	HotDays DryDays	Reduced Visibility	• Increase Lighting
		2	1	StormDays HeavyRain1Day	Reduced Level of Service	• Expand Canopy Coverage

		2	1	StormDays	Damage Due to Electrical Voltage Spikes	• Add TVSS to All Critical Systems
		2	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	1	HotDays DryDays	Wildfire Smoke	• Develop Personal Protective Strategies • Limit Activities During Poor Air Quality
		2	2	StormDays HeavyRain1Day	Flooding	• Install Erosion Control Structures • Move Runway • Assess Noise Impacts from Changes in Runway Alignment

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Aircraft / GSE					**Ground Service Equipment**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	HotDays	Non-Attainment of Air Quality Standards	• Transition GSE Fleet to Alternate Fuel Equipment
		2	2	StormDays HeavyRain1Day	GSE Operation Impairment	• Raise or Relocate Pavement • Install Flood Control Structures (e.g. Levees)

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Grounds and Landscaping**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	2	DryDays HotDays	Increased Water Demand for Landscaping	• Modify Landscaping Methods and Elements

OVERALL RISK	**SERVICE:**	**ASSET/OPERATION:**
	Aircraft / GSE	**Aircraft Performance**

	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*
		2	1	StormDays	High Winds Interfere with Landings and Takeoffs	• Communicate with FAA to Establish Greater Aircraft Separation
		2	2	StormDays	Disruption in Airport Operations	• Plan for Fluctuations in Throughput Capacity
		2	1	HotDays	Foreign Object Damage (Tires and Deteriorated Pavement)	• Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations
		2	1	HotDays HotNights HumidDays	Reduced Rate of Climb	• Provide More Fuel and Maintenance • Reduce Payload • Increase Payload Fees • Lengthen Runway
		2	2	StormDays HeavyRain1Day	Reduced Braking Performance	• Lengthen Runway • Install Transverse Grooves
		2	1	StormDays	Damaged Electrical Systems	• Cooperate with Airlines in Investigating Electrical Damage Reduction
		2	1	HotDays	Weathering of Fleet (Tires)	• Change Tires More Frequently • Clean Runways More Frequently
		2	1	StormDays	Greater Turbulence	• Provide More Fuel and Maintenance • Reduce Payload • Increase Payload Fees • Lengthen Runway
		2	2	StormDays	Wind Damage	• Require Tie-Downs for Larger Aircraft • Increase Strength of Tie-Down Connection
		2	1	StormDays	Increased Fuel Consumption	• Provide More Fuel and Maintenance • Reduce Payload • Increase Payload Fees • Lengthen Runway
		2	2	StormDays	Damage to Aircraft	• Offer Covered Holding Areas
		2	2	StormDays HeavyRain1Day	Reduced Visibility	• Plan for More Instrument-Reliant Navigation

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Airfield / Airspace					**Navigational Aids**
	Impact Risk	*Criticality*	*Vulnerability*	*Climate Vectors*	*Impacts*	*Adaptation Options*

	Impact Risk	Criticality	Vulnerability	Climate Vectors	Impacts	Adaptation Options
	●	2	1	StormDays HeavyRain1Day	Flooding	• Cooperate with FAA to Install Flood-Resistant Elements
	●	2	1	DryDays	Soil Expansion-Contraction	• Replace NAVAID Foundations

OVERALL RISK	SERVICE:					ASSET/OPERATION:
●	**Support Facilities**					**Aircraft Fuel Storage / Fueling**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	1	2	HeavyRain1Day	Jet Fuel System Valves, Pumping and Controls Equipment Located in Underground Vaults on the Ramp Become Submerged and Potentially Inoperable	• Raise Vaults
	●	1	1	VeryHotDays	Potential Increase In Fire Risks (Flashpoint of Aviation Fuel Is 100°F)	• Plan for Increases in Fires • Assess Fire Main Capacity
	●	1	2	StormDays HeavyRain1Day	Flooding	• Raise or Relocate Parking Facilities
	●	1	1	HeavyRain1Day	Lifting and Rupturing of Buoyant Underground Tanks	• Increase Burial Depth Or Amount of Pavement Above UST • Anchor UST • Equip Fuel Lines With Automatic Shut-Off Valves
	●	1	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	1	1	HotDays HotNights	Increased Fuel Consumption	• Expand On-Site Storage Capacity
	●	1	2	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
	●	1	1	DryDays	Subsidence of Foundations	• Modify Fill Material

		1	2	StormDays HeavyRain1Day	Submerged Jet Fuel Systems	• Raise Vaults
		1	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems

Section II: Risk (2060)

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	Commercial Passenger Terminal Facilities					Gates
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		3	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		3	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		3	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		3	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		3	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure

		3	1	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		3	1	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		3	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		3	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		3	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Commercial Passenger Terminal Facilities					**Commercial Passenger Terminal Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	2	StormDays HeavyRain1Day HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies
		3	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling

						• Improve Building Envelope • Replace Equipment According to Climate Zone
		3	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		3	2	DryDays StormDays HeavyRain1Day HotDays	Decreased Food Resources	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
		3	1	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		3	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope • Improve Drainage Infrastructure
		3	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		3	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		3	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		3	2	StormDays	Failure of Drainage Systems	• Upgrade Capacity • Elevate Facilities
		3	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols

		3	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		3	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		3	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		3	2	StormDays	External Facility Damage Due to Flooding	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Use Disposable Flatware and Plates • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Commercial Passenger Terminal Facilities					**Gates (Passenger Boarding Bridges)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		2	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and

						Cleaning of Stormwater Systems
		2	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
		2	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		2	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational

						Needs

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	Support Facilities					**Airport Maintenance Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		2	1	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		2	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		2	1	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	1	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	1	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor

						Barriers / Retarders, etc.) • Improve Drainage Infrastructure
		2	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	1	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		2	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Aircraft / GSE					**Demand and Capacity**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Reduced Throughput Capacity (Number of Planes Operating Out of the Facility)	• Plan for Fluctuations in Throughput Capacity

	🔵	2	1	VeryHotDays	Increased Fire Hazards May Impede Flight Operations	• Plan for Increases in Fires • Assess Fire Main Capacity
	🟡	2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Change in Tourism and Seasonal Enplanements	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	🔵	2	1	HotDays HeavyRain1Day	Reduced Ability of Some Airports to Take Certain Aircraft	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	🔵	2	2	StormDays	Increased Delays Due to Inability to Have People on Ramp	• Plan for Weather-Related Delays in Passenger Movements • Communicate with Community about Transportation Delays
	🔵	2	2	HeavyRain1Day StormDays	Delays, Cancellations and Other Effects of Systemic Changes and Increased Irregular Operation	• Develop IROP Protocols • Communicate with Community about Transportation Delays

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
🟡	**Cargo**					**Apron**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🟡	3	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
	🔵	3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material
	🔵	3	2	DryDays	Water-Reliant Maintenance Curtailed	• Install Gray Water Systems • Develop Water Conservation Protocols
	🔵	3	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Install Erosion Control Structures • Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or
	🔵	3	2	StormDays	Flooding	• Change Alignment

				HeavyRain1Day		• Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment
	●	3	2	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
	●	3	1	HeavyRain1Day StormDays	Debris and Foreign Object Damage	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Ground Access, Circulation, and Parking**					**Access Roads**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	3	2	HotDays DryDays	Reduced Visibility	• Travel at Slower Speeds • Increase Lighting
	●	3	1	HotDays	Thermal Expansion	• Replace Expansion Joints
	●	3	3	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
	●	3	1	StormDays HeavyRain1Day	Ramp Flooding	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	●	3	1	HeavyRain1Day	Changes in the Normal Flow of Traffic	• Communicate with Regional Authorities • Cooperate with Regional Planners to Develop Adaptations
	●	3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material
	●	3	3	StormDays HeavyRain1Day	Flooding	• Change Alignment • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment
	●	3	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and

						Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations
		3	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		3	1	StormDays	Debris and Foreign Object Damage	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations
		3	1	StormDays HeavyRain1Day	Electrical Failures	• Install On-Site, Raised and Protected Backup Power Supplies and Lighting
		3	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Install Erosion Control Structures • Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**On-Site Electrical Infrastructure**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	3	HotDays	Insufficient Capacity Due to Increased Demand	• Generate Power Onsite • Increase Size of Electrical Service • Use Demand-Limiting Measures
		2	3	HotDays	Decreased Reliability of External Utility	• Add a Secondary Feed from an Additional Utility • Add or Increase Capacity for Onsite Generation • Arrange An Uninterruptable Power Rate • Use Demand-Limiting Measures
		2	1	StormDays HeavyRain1Day	Flooding	• Implement Barrier System • Install On-Site, Raised and Protected

						Backup Systems
		2	2	HeavyRain1Day StormDays	Loss of Power	• Install On-Site, Raised and Protected Backup Power Supplies
		2	2	DryDays	Soil Expansion-Contraction	• Modify Fill Material at Underground Utilities to Alleviate Expansion
		2	2	StormDays	Damage Due to Electrical Voltage Spikes	• Add TVSS to All Critical Systems
		2	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
		2	2	VeryHotDays	Transformer Failure	• Install Supplemental Fans • De-Rate and Replace Or Supplement Transformer

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Ground Access, Circulation, and Parking					**Parking Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		3	1	StormDays	Damage to Cars	• Offer More Covered Parking Facilities
		3	1	HotDays DryDays	Reduced Visibility	• Travel at Slower Speeds • Increase Lighting
		3	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		3	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations
		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

		3	1	HotDays	Increased Pavement Temperature	• Offer More Covered Parking Facilities
		3	2	StormDays HeavyRain1Day	Flooding	• Change Alignment • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment
		3	1	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		3	1	StormDays	Wind Damage	• Offer More Covered Parking Facilities
		3	3	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
		3	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Install Erosion Control Structures • Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**Water Distribution Systems**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
		3	1	StormDays HeavyRain1Day	Flooding	• Provide on Site Storage for Temporary Operation • Increase Capability for Disinfection
		3	1	StormDays HeavyRain1Day	Surface Water Contamination	• Provide on Site Storage for Temporary Operation • Increase Capability for Disinfection
		3	1	DryDays	Reduced Water Availability Due to Drought	• Utilize Water Conserving Fixtures and Landscaping
		3	1	DryDays	Less Water Main Flushing	• Continue Monitoring and Disinfection of Water Supply System

OVERALL RISK	SERVICE:					ASSET/OPERATION:
🟡	**Utilities**					**Sanitary Sewer**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🟡	3	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
	🔵	3	3	StormDays HeavyRain1Day	Increased Combined Sewer Overflow Events	• Provide Onsite Storage for Temporary Operation • Increase Capability for Disinfection
	🔵	3	2	StormDays HeavyRain1Day	Flooding	• Implement Barrier System • Increase Conveyance and Capacity • Temporarily Route Discharge to Alternate Location

OVERALL RISK	SERVICE:					ASSET/OPERATION:
🟡	**General Aviation Facilities**					**General Aviation Terminal Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	🔵	1	1	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
	🟡	1	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	🔵	1	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
	🔵	1	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	🔵	1	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration,

						Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	1	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	1	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
	●	1	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols • Coordinate With FEMA
	●	1	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	1	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
	●	1	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
	●	1	1	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
	●	1	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
	●	1	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
	●	1	1	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational

						Needs

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	General Aviation Facilities					**Hangars**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	1	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		1	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		1	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		1	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		1	1	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		1	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		1	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
		1	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers

						• Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		1	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		1	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		1	1	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		1	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		1	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		1	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		1	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Cargo					**Air Cargo Buildings**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	1	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor

					Seals) and / Or Mold Vulnerability	Barriers / Retarders, etc.)
		2	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		2	1	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		2	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	1	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	1	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	1	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols • Coordinate With FEMA
		2	1	StormDays	External Facility Damage Due to Flooding	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope

	●	2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
	●	2	1	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
	●	2	1	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
	●	2	1	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
	●	2	2	StormDays	Failure of Drainage Systems	• Upgrade Capacity • Elevate Facilities
	●	2	1	StormDays	Damage to Transport Vehicles	•
	●	2	1	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Use Disposable Flatware and Plates • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Support Facilities**					**Airline Maintenance Facilities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	1	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	1	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
	●	1	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational

						Needs
	●	1	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	1	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	1	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
	●	1	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	1	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
	●	1	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	1	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
	●	1	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
	●	1	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan

		1	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		1	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		1	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Support Facilities					**Airport Administrative Areas**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		2	1	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		2	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.)

						• Select Different Equipment on or Outside of the Building
		2	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
		2	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	1	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		2	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		2	1	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**	**ASSET/OPERATION:**

	Support Facilities					**Flight Kitchens**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		1	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		1	2	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		1	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		1	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		1	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		1	2	StormDays HeavyRain1Day HotDays	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies
		1	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Use Disposable Flatware and Plates • Install Gray Water Systems • Provide Onsite Storage for Operational Needs
		1	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		1	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols

		1	2	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		1	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		1	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		1	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
		1	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		1	1	HotDays	Increased Water Demand	• Plan for Increased Water Consumption
		1	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		1	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		1	2	DryDays StormDays HeavyRain1Day HotDays	Decreased Food Resources	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Other					**Personnel and Passengers**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	StormDays HeavyRain1Day	Outbreak of Contagious Diseases	• Develop Biological, Chemical and Personal Protective Strategies

				HotDays		
		2	1	HotDays	Heat Exposure	• Educate Employees about Heat Injuries • Schedule Cooling Breaks • Improve Temperature Control and Monitoring Strategies (Shades on Windows, Window Films, Covered Waiting Area, Misting Station, setc.) •
		2	1	StormDays HeavyRain1Day HotDays	Change in Tourism and Seasonal Enplanements	• Plan for Changes in Magnitude and Timing of Passenger Travel
		2	1	HotDays	Limitation on Outdoor Maintenance and Services	• Use Longer Season to Absorb Work Delays Due to Weather and Air Quality
		2	1	StormDays	Threat to Maintenance Workers	• Schedule Work Around The Forecast
		2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Human Migration	• Plan for Changes in Magnitude and Timing of Passenger Travel

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Environmental and Safety					**Bird and Wildlife Hazard Management**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Changes in Ecosystems and Distributions of Pests / Wildlife	• Use Appropriate Wildlife and Landscape Management Techniques
		2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Increased Risk of Bird Strikes From Ecosystem Changes	• Use Appropriate Wildlife and Landscape Management Techniques

		2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Potential Increase in Wildlife Attractants	• Monitor Wildlife • Use Appropriate Wildlife and Landscape Management Techniques
		2	1	HotDays HotNights HumidDays StormDays HeavyRain1Day DryDays CoolingDays	Wildlife Changes	• Use Appropriate Wildlife and Landscape Management Techniques

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Support Facilities					**FAA Facilities (Air Traffic Control Tower)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	DryDays	Subsidence of Foundations	• Increase System Redundancy • Perform BCA • Prioritize Assets and Develop A Redundancy Plan
		2	1	HumidDays CoolingDays	Failure of Building Envelope (Roofing Materials, External Seals) and / Or Mold Vulnerability	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
		2	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		2	1	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	1	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)

		2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	2	StormDays	Internal Facility Damage Due to Driving Rain	• Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.) • Improve Drainage Infrastructure
		2	2	StormDays HeavyRain1Day	Flooding	• Cooperate with FAA to Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		2	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	2	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		2	2	HotDays	Roofing Material and Exterior Seals (Roof and Walls) Degradation	• Upgrade Roof with High Heat and Reflective Products
		2	2	HotDays DryDays	Potential for Drawing in Smoke Through Outdoor Air Handling Systems	• Use Smoke Detector at OA to Override OA Unit
		2	2	HotDays HotNights HumidDays	Increased HVAC Demand and Duration	• Design for Incremental Change (e.g. Modular Systems) • Perform Energy Modeling • Improve Building Envelope • Replace Equipment According to Climate Zone
		2	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
		2	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	General Aviation Facilities					**Loading and Unloading Equipment / Operation**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
		2	1	StormDays HeavyRain1Day	Reduced Level of Service	• Expand Canopy Coverage
		2	1	HotDays HotNights HumidDays	Increased Level of Insect Activity	• Modify The Effective Lighting Color Temperature and Improve Insect Intrusion Prevention Design Solutions.
		2	1	StormDays HeavyRain1Day	Flooding	• Install Erosion Control Structures • Move Runway • Assess Noise Impacts from Changes in Runway Alignment
		2	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		2	2	HotDays DryDays	Wildfire Smoke	• Develop Personal Protective Strategies • Limit Activities During Poor Air Quality
		2	1	StormDays	Damage Due to Electrical Voltage Spikes	• Add TVSS to All Critical Systems
		2	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems

OVERALL RISK	SERVICE:					ASSET/OPERATION:
	Commercial Passenger Terminal Facilities					**Apron**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		3	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material

		3	2	StormDays HeavyRain1Day	Flooding	• Change Alignment • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment
		3	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Install Erosion Control Structures • Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or
		3	1	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
		3	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		3	1	HeavyRain1Day StormDays	Debris and Foreign Object Damage	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Utilities					**Communications**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	StormDays	Disruption in Airport Operations	• Install On-Site, Raised and Protected Backup Power Supplies
		2	1	StormDays	Loss of Power	• Install On-Site, Raised and Protected Backup Power Supplies
		2	1	StormDays HeavyRain1Day	Flooding	• Flood Resistance Measures
		2	3	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion

OVERALL RISK	SERVICE:					ASSET/OPERATION:
●	Commercial Passenger Terminal Facilities					Curbside Amenities
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	3	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
	●	3	1	HotDays HotNights HumidDays	Increased Level of Insect Activity	• Modify The Effective Lighting Color Temperature and Improve Insect Intrusion Prevention Design Solutions.
	●	3	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
	●	3	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	3	2	HumidDays HeavyRain1Day	Building Moisture Damage; Mold	• Schedule More Frequent Inspections • Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / Retarders, etc.)
	●	3	1	StormDays HeavyRain1Day	Reduced Level of Service	• Expand Canopy Coverage
	●	3	2	StormDays HeavyRain1Day	Flooding	• Increase Water Removal Capacity • Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
	●	3	1	HotDays DryDays	Reduced Visibility	• Increase Lighting
	●	3	2	StormDays	Wind Damage	• Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square Foot, Sheeting, etc.) • Select Different Equipment on or Outside of the Building
	●	3	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.)

						• Select Different Equipment on or Outside of the Building
	●	3	2	StormDays HeavyRain1Day	Foundation Heave	• Modify Fill Material
	●	3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Support Facilities**					**Aircraft Rescue and Fire Fighting (ARFF)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	3	1	HotDays	Increase in Emergency Medical Situations	• Optimize Accessibility to Emergency Personnel
	●	3	1	StormDays	Fires Due to Lightning Strikes	• Plan for Increases in Fires • Assess Fire Main Capacity
	●	3	2	StormDays HeavyRain1Day	Emergency Response Situations	• Provide Appropriate Training for Disaster Response
	●	3	2	DryDays	Reduced Water Availability Due to Drought	• Install Battery Backup-Powered Low-Flow Equipment • Install Gray Water Systems • Provide Onsite Storage for Operational Needs

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Utilities**					**Stormwater Drainage**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	1	HotDays	Permit Compliance Issues Due to High Pollutant Loads	• Monitor and Adjust Outdoor Water Use With Respect to Pollutant Loading
	●	2	2	DryDays StormDays HeavyRain1Day	Permit Compliance Issues	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment
	●	2	1	StormDays HeavyRain1Day	Increased Discharge Quantity and Degraded Quality	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment
	●	2	1	DryDays StormDays	Dryer Soils Lead to Reduced Vegetation	• Replace Vegetation With Drought Resistant Vegetation Or Structural BMPs.

				HeavyRain1Day	and Increased Erosion	
	●	2	1	DryDays	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
	●	2	1	StormDays HeavyRain1Day	Flooding	• Implement Barrier System
	●	2	1	StormDays	Blocked Drains Due to Debris	• Increase Monitoring, Maintenance and Cleaning of Stormwater System
	●	2	1	StormDays HeavyRain1Day	Increased Demand on Existing Drainage	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment
	●	2	1	DryDays	Decreased Discharge Quantity and Impaired Quality	• Improvement to Conveyance, Detention, BMPs, and Deicing Treatment

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Environmental and Safety**					**Snow and Ice Control (De-Icing)**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	2	DryDays	Less Runoff Results in High Deicer Concentrations	• Improve Deicing Collection, Storage, and Treatment

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Airfield / Airspace**					**Runways, Taxiways, and Holding Areas**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	2	DryDays	Soil Expansion-Contraction	• Modify Sub-Base Material
	●	2	2	StormDays HeavyRain1Day	Flooding	• Change Alignment • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment
	●	2	2	StormDays HeavyRain1Day	Erosion, Scouring and Undermining of Pavement	• Plant Resilient Infield Vegetation • Improve Hydrologic Design • Install Flood Barriers • Move Paved Area • Assess Noise Impacts from Changes in Use or Alignment

		2	1	HotDays	Loss of Pavement Integrity (e.g. Melt), Decreased Utility of Pavement	• Use Hard Stands • Replace Pavement
		2	1	HotDays HotNights HumidDays	Reduced Rate of Climb	• Lengthen Runway • Reduce Payload
		2	2	StormDays HeavyRain1Day	Debris and Foreign Object Damage	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems • Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris Removal Operations

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
	Cargo					**Loading and Unloading Equipment / Operation**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
		2	1	StormDays	Wind Damage	• Protect Exposed Utilities and Structures
		2	1	StormDays	Damage from Direct Lightning Strikes	• Protect Structures and Conductors by Installing Advanced Lightning Protection for Envelope
		2	1	HotDays HotNights HumidDays	Increased Level of Insect Activity	• Modify The Effective Lighting Color Temperature and Improve Insect Intrusion Prevention Design Solutions.
		2	1	HotDays DryDays	Reduced Visibility	• Increase Lighting
		2	1	StormDays HeavyRain1Day	Reduced Level of Service	• Expand Canopy Coverage
		2	1	StormDays	Damage Due to Electrical Voltage Spikes	• Add TVSS to All Critical Systems
		2	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems
		2	2	StormDays	Damage from Hail	• Upgrade Structure (Windows, Roof Materials, Cladding, Sheeting, etc.)

						• Select Different Equipment on or Outside of the Building
	●	2	1	HotDays DryDays	Wildfire Smoke	• Develop Personal Protective Strategies • Limit Activities During Poor Air Quality
	●	2	2	StormDays HeavyRain1Day	Flooding	• Install Erosion Control Structures • Move Runway • Assess Noise Impacts from Changes in Runway Alignment

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Other**					**Regional Infrastructure**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	1	StormDays	Loss of Power	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	●	2	1	StormDays HeavyRain1Day	Tail Water Effects Reduce Stormwater Drainage Capacity	• Increase Conveyance and Capacity
	●	2	1	HotDays	Reduced Rate of Climb	• Cooperate with Regional Planners to Adjust Height Restrictions
	●	2	1	StormDays HeavyRain1Day	Reduced Transportation Capacity	• Plan for Weather-Related Delays in Passenger Movements • Communicate with Community about Transportation Delays
	●	2	1	StormDays	Disruption in Airport Operations	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	●	2	1	DryDays	Subsidence of Foundations	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	●	2	1	StormDays	Wind Damage	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan
	●	2	1	HotDays	Thermal Expansion	• Cooperate with Regional Planners to Adjust Height Restrictions
	●	2	1	StormDays HeavyRain1Day	Flooding	• Develop Adaptations in Cooperation with Regional Planners • Incorporate Adaptations in Master Plan

OVERALL RISK	**SERVICE:**	**ASSET/OPERATION:**

●	Aircraft / GSE					Ground Service Equipment
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	1	HotDays	Non-Attainment of Air Quality Standards	• Transition GSE Fleet to Alternate Fuel Equipment
	●	2	2	StormDays HeavyRain1Day	GSE Operation Impairment	• Raise or Relocate Pavement • Install Flood Control Structures (e.g. Levees)

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Other**					**Construction Activities**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	1	2	StormDays HeavyRain1Day HotDays DryDays	Construction Delays	• Schedule Work Around The Forecast

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Other**					**Grounds and Landscaping**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	1	2	DryDays HotDays	Increased Water Demand for Landscaping	• Modify Landscaping Methods and Elements

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Aircraft / GSE**					**Aircraft Performance**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	1	StormDays	High Winds Interfere with Landings and Takeoffs	• Communicate with FAA to Establish Greater Aircraft Separation
	●	2	2	StormDays	Disruption in Airport Operations	• Plan for Fluctuations in Throughput Capacity
	●	2	1	HotDays	Foreign Object Damage (Tires and Deteriorated Pavement)	• Replace Pavement • Replace Expansion Joints • Plan for Increased Foreign Object Debris

						Removal Operations
	●	2	1	HotDays HotNights HumidDays	Reduced Rate of Climb	• Provide More Fuel and Maintenance • Reduce Payload • Increase Payload Fees • Lengthen Runway
	●	2	2	StormDays HeavyRain1Day	Reduced Braking Performance	• Lengthen Runway • Install Transverse Grooves
	●	2	1	StormDays	Damaged Electrical Systems	• Cooperate with Airlines in Investigating Electrical Damage Reduction
	●	2	1	HotDays	Weathering of Fleet (Tires)	• Change Tires More Frequently • Clean Runways More Frequently
	●	2	1	StormDays	Greater Turbulence	• Provide More Fuel and Maintenance • Reduce Payload • Increase Payload Fees • Lengthen Runway
	●	2	2	StormDays	Wind Damage	• Require Tie-Downs for Larger Aircraft • Increase Strength of Tie-Down Connection
	●	2	1	StormDays	Increased Fuel Consumption	• Provide More Fuel and Maintenance • Reduce Payload • Increase Payload Fees • Lengthen Runway
	●	2	2	StormDays	Damage to Aircraft	• Offer Covered Holding Areas
	●	2	2	StormDays HeavyRain1Day	Reduced Visibility	• Plan for More Instrument-Reliant Navigation

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Airfield / Airspace**					**Navigational Aids**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***
	●	2	1	StormDays HeavyRain1Day	Flooding	• Cooperate with FAA to Install Flood-Resistant Elements
	●	2	1	DryDays	Soil Expansion-Contraction	• Replace NAVAID Foundations

OVERALL RISK	**SERVICE:**					**ASSET/OPERATION:**
●	**Support Facilities**					**Aircraft Fuel Storage / Fueling**
	Impact Risk	***Criticality***	***Vulnerability***	***Climate Vectors***	***Impacts***	***Adaptation Options***

		1	2	HeavyRain1Day	Jet Fuel System Valves, Pumping and Controls Equipment Located in Underground Vaults on the Ramp Become Submerged and Potentially Inoperable	• Raise Vaults
		1	1	VeryHotDays	Potential Increase In Fire Risks (Flashpoint of Aviation Fuel Is 100°F)	• Plan for Increases in Fires • Assess Fire Main Capacity
		1	2	StormDays HeavyRain1Day	Flooding	• Raise or Relocate Parking Facilities
		1	1	HeavyRain1Day	Lifting and Rupturing of Buoyant Underground Tanks	• Increase Burial Depth Or Amount of Pavement Above UST • Anchor UST • Equip Fuel Lines With Automatic Shut-Off Valves
		1	2	StormDays HeavyRain1Day	External Facility Damage Due to Driving Rain	• Improve Building Envelope (Incorporate Flood-Resistant Structural Elements) • Install Flood Barriers • Elevate Critical Equipment • Elevate Structure • Develop IROP Protocols
		1	1	HotDays HotNights	Increased Fuel Consumption	• Expand On-Site Storage Capacity
		1	2	StormDays HeavyRain1Day	Pavement Heave	• Replace Pavement • Modify Sub-Base Material
		1	1	DryDays	Subsidence of Foundations	• Modify Fill Material
		1	2	StormDays HeavyRain1Day	Submerged Jet Fuel Systems	• Raise Vaults
		1	1	StormDays HeavyRain1Day	Debris	• Protect Exposed Utilities • Plan for Increased Debris Removal Operations • Increase Monitoring, Maintenance and Cleaning of Stormwater Systems