ACRP Project 02-98
CONDUCT OF RESEARCH REPORT

Transportation Research Board
of
The National Academies of Sciences, Engineering, and Medicine

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CHAPTER 1

Introduction

Airport Energy Resiliency

Title 10 of the United States Code § 101(e)(6) defines energy resiliency to mean "the ability to avoid, prepare for, minimize, adapt to, and recover from anticipated and unanticipated energy disruptions in order to ensure energy availability and reliability sufficient to provide for mission assurance and readiness, including mission essential operations related to readiness, and to execute or rapidly reestablish mission essential requirements."

To provide more context for the development of an airport energy resiliency roadmap, this definition has been expanded to recognize that airport energy resiliency needs to incorporate short-, medium-, and long-term conditions as well as consider the potential causes of energy disruption. Airport energy resiliency, for the purposes of the roadmap development, is defined as the ability of an airport to prepare its energy resources to adapt to changing short-, medium-, and long-term conditions and to withstand and recover rapidly from disruptions, including the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents. Based on the research, the cost to provide energy should be part of the resiliency considerations.

Project Outcome

*The **goal of airport energy resiliency** is to plan and prepare to diversify and de-risk energy resources, while considering energy availability and the costs to maintain critical operations.*

The purpose of the ACRP 02-98 project was to provide guidelines to airport practitioners, including airport sponsors, senior management, staff, and consultants, for developing a customized roadmap for achieving energy resiliency. The primary project deliverables are *Airport Energy Resiliency: A Primer* (primer) and *ACRP Research Report 260: Airport Energy Resiliency Roadmap* (roadmap). The primer is intended to provide airport leadership with the tools to energize and support the development of an airport energy resiliency roadmap. At a high level, the primer addresses what is airport sustainability, why pursue it, who should be involved, and the key steps in the process.

ACRP Research Report 260 outlines a step-by-step process for airport staff members (or their consultants) to develop a roadmap customized for their airport and provide data to the airport's decision-makers. Since each airport and its setting are different, the roadmap is intended to identify the steps, considerations, and tools for developing an airport-specific roadmap.

Project Audience

Each of the project's products has a different intended audience. The primer is targeted to senior leadership, senior management, and other key decision-makers or influencers for the airport. This document is also anticipated to be useful for other airport staff that needs a high-level overview of airport sustainability.

The roadmap is intended to be used by staff or hired resources to prepare the airport's energy resiliency roadmap. Therefore, this document contains more technical information and resources.

Research Approach

The research approach has been threefold: data collection, data synthesis, and the production of deliverables.

Data Collection

The data collection started with the virtual kick-off meeting and panel's input on the amplified work plan and case study plan. The two primary data collection processes were the literature review and case study interviews. The results of the literature review are discussed in Chapter 2 and contained in Appendix A.

In addition to the overall literature review, a literature review was conducted on the case study subject airports or related entities prior to the case study. The results of this review were shared with the interviewee in advance of the meeting to help inform the case study discussion. These literature reviews, as applicable, are also in Appendix A. A literature review was also conducted on all medium-hub airports, per the request of the panel.

Seventeen case study interviews were conducted involving 17 airport operating entities, encompassing 20 airports, several community entities, and two military bases. One of the interviews was a central Florida complex community that included four airports and four community entities. This case study interview may be more appropriate to refer to as a focus group. This was the only in-person meeting, although some of the attendees participated virtually. After each case study, the responses to the questions and any additional discussion was summarized and provided to the participants for correction. A case study with two U.S. Navy bases involved in energy resiliency planning and implementation also occurred. The purpose of these interviews was to provide airports with a perspective of what similar facilities are doing regarding energy resiliency. Chapter 3 discusses the case studies.

Data Analysis

The data analysis commenced as soon as data was available from the interviews and literature review. The ongoing data analysis was used to inform the ongoing data collection. The data analysis also resulted in the key definitions white paper and initial gap analysis. Refined key definitions and are in included in the roadmap in Appendix B.

From the data collection and analysis, the research team identified two key insights related to airport energy resiliency.

1. There are two key time periods to airport energy resiliency: short-term, related to the ability to withstand and recover from an incident, and longer-term, related to the evolving aviation and ground transportation industries.
2. In both cases, the goal is to have an adequate, well-sourced system and backup system to meet the airport's energy demands.

Although there may be two different time frame considerations associated with airport energy resiliency, because the goal is the same, the process is similar. Therefore, both fit within the same roadmap.

Production of Deliverables

After addressing the panel's comments on the interim report, the project entered the production phase. In this phase, the information gathered and outlined during the previous phases was expanded into the primer and roadmap. The primer and roadmap are printed documents and PDFs, with links to readily available resources online, such as other ACRP products. Based on the research, the tools identified are available through their respective resources and included as links in the roadmap. Therefore, a WebResource was not recommended or prepared for this project.

During the production phase, this final report documenting the research process, summary of key findings, and implementation of research findings and products was prepared. The implementation of the research findings can also be promoted through the project flyer. The implementation plan details opportunities to promote the project through informing ACRP ambassadors who attend traditional aviation conferences, research team member presentations at subject matter conferences, and a concept for a pilot program.

CHAPTER 2

Annotated Bibliography

Literature Review

The literature review had two foci. The initial focus was to provide background information for the airports and other entities included in the case study interviews. The results of these literature reviews were provided to the case study interviewee in advance. The most pertinent items from the case study research are included in the general literature review.

The other focus was on airport energy resiliency. As part of this more general review, all the medium-hub airports were reviewed, per panel request, during amplified research plan webinar. The more general review included searches on the following terms and combination thereof as a starting point.

1. ACRP AND energy
2. Airport AND energy
3. Airport AND energy AND alternative
4. (Airport OR aviation OR aircraft) AND electric*
5. (Airport OR aviation OR aircraft) AND hydrogen
6. Airport AND geothermal
7. (Airport OR plane OR airplane OR aircraft) AND solar
8. Airport AND energy AND resiliency
9. Airport AND (all hazards OR all-hazards) AND energy
10. Airport AND contingency AND plan AND energy
11. Rental car AND electric
12. Hydrogen AND generation
13. Hydrogen fuel AND (storage OR distribution)
14. Geothermal AND heat pump
15. Geothermal AND building AND cooling
16. Electric AND storage AND (system OR technology)
17. eVTOL
18. Electric AND (urban OR air) AND mobility
19. (Airport OR aviation) AND ground AND equipment AND electric
20. Power AND alternative AND source
21. Airport AND energy AND (efficiency OR conserve OR LEED)
22. Airport AND energy AND vulnerable
23. Airport AND energy AND redundancy
24. Aviation AND projected AND energy AND (use OR usage OR demand)
25. Grants
26. State aviation office grants (esp. Florida)
27. Fuel tax
28. Airport Improvement Program (AIP) grants
29. Infrastructure Investment and Jobs Act (IIJA)
30. Bipartisan Infrastructure Law (BIL)

31. FAA grant assurances
32. Utility company rebates
33. Utility company incentive payments
34. Capital bonds
35. General revenue bonds
36. Loans
37. Non-aviation revenue
38. Concessionaire fees or rents
39. Parking revenues
40. Public-private partnerships (PPP)
41. Power sell-back to utilities
42. Power buy-back by utilities
43. Land leases
44. Tax rebates
45. Tax credits
46. Tax increment district financing for power distribution capital requirements and site utility upgrades
47. Monetization of carbon credits
48. Federal VALE grants
49. Application for newly available FAA sustainability grants for sustainability planning (a sub-sub section of the BIL legislation)
50. Federal green transition/EV grants that might be under department of energy or other related federal agency
51. ICAO reports; key words: energy resiliency, advanced air mobility, energy sustainability
52. Aviation week and space technology; key words: advanced air mobility, airport energy requirements
53. FAA white paper on advanced air mobility
54. IATA reports; advanced air mobility, airport energy resiliency, airport sustainability
55. eVTOL insider; airport energy requirements, microgrid planning
56. AW intelligence/advanced air mobility; airport energy requirements, microgrid planning
57. AAAE reports/white papers; advanced air mobility; airport energy resiliency

The initial literature review identified more than 500 resources. These resources were reviewed and refined to the most pertinent that are included by topic in Appendix A.

After the completion of the literature review, the team continued to review newly published information for application to the project. This included *ACRP Research Report 243: Urban Air Mobility: An Airport Perspective*, published in February 2023. The literature review included in Appendix A is as presented in the interim report.

CHAPTER 3

Case Studies

Case Study Sites

Airports have been undertaking projects as steps toward energy resiliency. In addition, other industries have been pursuing energy resiliency. The Hanson team conducted 15 case study interviews with airport operating entities covering a range of projects at various sizes of airports, including two airports part of the Virgin Islands Port Authority and three airports part of the Columbus Regional Airport Authority. In addition, to use experience in other fields for airports, one of the airport case study interviews included a larger system of entities in central Florida, referred to as a complex community. The complex community study included representation by four airports and other energy users. Two case studies were conducted with U.S. Navy bases as a representation of what similar facilities are doing relative to energy resiliency.

The case study airports, including those in the central Florida case study, were selected to provide:

- Size distribution (three large hub [LH], two medium hub [MH], eight small hub [SH], three nonhub primary [NH-P], and four general aviation [GA])
- Geographical distribution, as a proxy for weather extremes (six Midwestern, eight Southern, three Western, three island)
- Resources available to the airport (to get a maximum spread of capital investment over the past five years; size category is a proxy for this)
- Governance (six municipal/county, 11 authorities)
- Publicized initiatives in the field of energy resiliency (e.g., LEED® recognition, publications)
- Reputation for innovation
- History of research cooperation
- Varying age of infrastructure (former military base to new development)

The airport case studies were completed between June and August 2022. All case studies were virtual, except for the central Florida complex community study, which was a hybrid study with in-person and virtual participants. The following participants were interviewed as part of the case studies.

Antonio B. Won Pat International Airport (GUM) – SH

- GUM is on a Pacific island. It is subject to extreme weather and requires the import of many energy supplies.

Bozeman Yellowstone International Airport (BZN) – SH

- BZN installed a geothermal system 10 years ago. It has been tracking the cost-saving data with the system.

Columbus Regional Airport Authority: John Glenn Columbus International Airport (CMH) – MH; Bolton Field Airport (TZR) – GA; Rickenbacker International Airport (LCK) – NH-P

- CMH, TZR, and LCK are part of a multiairport system operated by one entity that has a reputation for being highly proactive in its energy planning. CMH is planning a new terminal. TZR is classified by the FAA as a regional reliever airport. LCK is a very large general aviation airport classified by the FAA as a national airport; it also has enough annual enplanements to

be classified as a non-hub primary airport. LCK is an industrial aviation airport and the center of air cargo and logistics operations. It is also a former military facility.

Dallas Fort Worth International Airport (DFW) – LH

- DFW has a history of innovation and investment in efficiency and resiliency improvements. Among the airports in this study, it perhaps deals with the greatest weather extremes.

Eugene Airport (EUG) – SH

- EUG is beginning to look at options for energy resiliency. EUG is an innovation leader for airports in its region and size category and has a reputation for efficiency and engineering excellence.

Gerald R. Ford International Airport (GRR) – SH

- GRR is beginning to look at options for energy resiliency. GRR is an innovation leader for airports in its region and size category and has a reputation for efficiency and engineering excellence.

Virgin Islands Port Authority: Cyril E. King Airport, St. Thomas (STT) – SH and Henry E. Rohlsen Airport, Saint Croix (STX) – NH-P

- STT and STX are primary airports on Atlantic islands. STX completed a terminal expansion in 2022. Both airports are dependent on energy imports.

Los Angeles International Airport (LAX) – Tom Bradley International Terminal and Central Utility Plant (LEED Gold certified) – LH

- LAX has been undergoing massive construction, remodeling, and redevelopment for more than 12 years. The initial reason for its inclusion in this study is that the Tom Bradley International Terminal and Central Utility Plant are LEED Gold certified, but preliminary discussions revealed the wide-ranging energy sustainability initiatives at LAX. (Two interviews were conducted with LAX because of the complexity of their programs and to accommodate staff schedules.)

Memphis International Airport (MEM) – MH

- MEM is remarkable for its huge air cargo business and its close collaboration with its major tenant and the Tennessee Air National Guard. MEM just completed a terminal rebuild that included major energy conservation and resiliency improvements.

Savannah/Hilton Head International Airport (SAV) – SH

- SAV is beginning to look at options for energy resiliency. SAV is an innovation leader for airports in its region and size category and has a reputation for efficiency and engineering excellence.

Shawnee Regional Airport (SNL) – GA

- SNL is a municipally operated airport that the FAA classifies as a basic airport. It is beginning to look at infrastructure changes for resiliency, including energy resiliency.

South Bend International Airport (SBN) – SH

- SBN has been at the forefront of terminal geothermal. It also has a South Shore Line train station in the terminal that is a unique energy user. Like GRR, SBN is in a lake-effect snow belt.

Tallahassee International Airport (TLH) – NH-P

- TLH has a well-publicized large solar array installation on airport property. TLH exemplifies the challenges of energy resiliency in an area of extreme hurricane risk.

Central Florida complex community – a multientity focus group to recognize that airports are only a part of a community's critical user energy consumption. The criteria for selecting this complex community case study included:

- Strong established relationships with the main energy-using entities in the community
- LH, SH, and GA airports:
  - Orange County includes Orlando International Airport (MCO) – LH and Orlando Executive Airport (ORL) – GA operated by the Greater Orlando Airport Authority

(GOAA), as well as other major energy-dependent systems in the community — all of which allows the examination of the interactions among competing and cooperating energy users and of energy resiliency issues in a regional context. Getting the cooperation of such a large and diverse group of organizations was possible because most of them had or have relationships with Hanson. MCO has been engaged in major capital projects and is evaluating energy resiliency methods. (ORL was not discussed in detail during the case study, because GOAA was represented by consultants working on the new MCO terminal project. Therefore, ORL is not included in the count of case study airports.)

- MCO opened its new Terminal C in September 2022. It includes 15 additional domestic and international aircraft gates and offers top-of-the-line digital media and technology. Terminal C was designed for certification as one of the first LEED v4 airport campuses.
- Other airport participants representing central Florida included Orlando Sanford International Airport (SFB) – SH, Kissimmee Gateway Airport (ISM) – GA, and Lakeland Linder International Airport (LAL) – GA.

Due to the complexity of scheduling with the U.S. Navy, the base case studies were conducted in January 2023. Both bases interviewed are in Southern California. They are:

Naval Base Ventura County (NBVC)
Naval Air Facility El Centro

NBVC consists of three geographically separated facilities: Port Hueneme, Point Mugu, and San Nicholas Island.

The following table identifies the participants in the case studies. The research team is appreciative of the participants' time and willingness to share information regarding energy use and resiliency initiatives.

Summary of Case Study Participants

Antonio B. Won Pat International Airport (GUM)
Artemio "Ricky" Hernandez, Ph.D.
Austin Grant
Jean Arriola
Frank Santos
Victor Cruz
Bolton Field Airport (TZR)
Paul Kennedy
Bozeman Yellowstone International Airport (BZN)
Rhett Boerger
Cyril E. King Airport (STT)
Jerome Sheridan
Anise Hodge
Preston Beyer
Earl Thomas
Dallas Fort Worth International Airport (DFW)
Robert Horton
Jesse Dillard
Eugene Airport (EUG)
Cathryn Stephens
Gerald R. Ford International Airport (GRR)
Casey Ries

Michelle Baker
Henry E. Rohlsen Airport (STX)
Jerome Sheridan
Anise Hodge
Preston Beyer
Earl Thomas
John Glenn Columbus International Airport (CMH)
Paul Kennedy
Los Angeles International Airport (LAX)
Carter Atkins
Tina Backstrom Mike Christensen
Christine Salvaggio
Orange County
Keith Mutters (Orlando Utilities Commission)
Dr. Muthusamy Swami (University of Central Florida)
Robyn Dowsey (Eco-Build Strategies for MCO)
Tom Croff (Matern Professional Engineering for MCO)
Nicole Martz (SFB)
Shaun Germolus (ISM)
Adam Lunn (LAL)
Hector Clemente (Orange County Convention Center)
Dr. Katerina Chagoya (Orange County Convention Center)
Mike Hess (city of Orlando)
Memphis International Airport (MEM)
Thomas Wallace III
Lori Morris
Jack Jackson
Jerry Curle
Rickenbacker International Airport (LCK)
Paul Kennedy
Savannah/Hilton Head International Airport (SAV)
Andy Singhas
Shawnee Regional Airport (SNL)
Bonnie Wilson
South Bend International Airport (SBN)
Mike Daigle
Tallahassee International Airport (TLH)
Jim Durwin
Thomas Vergo
Eric Houge
Naval Base Ventura County
Richard John Mack (Civ)
Naval Air Facility El Centro
Bruce Delling (Civ)

Appendix A in the roadmap contains the interview questions and tables summarizing the findings from the case study interviews by category of activity. The tables cover the range of initiatives identified during

the case studies. Further, they provide the status by airport and an evaluation of maturity of technology, ease of implementation, and relative cost based on the information provided in the case study and the research team's professional opinion. Interviews conducted with multiairport operators are summarized under the largest airport in the system. **The tabular summaries were not intended to encompass all potential airport energy resiliency measures, but rather reflect the implementation efforts of the case study airports**.

Key Observations From Case Studies

The following are key observations from the case studies that influenced the airport energy resiliency guidelines developed through this project.

Relationship of Airport and Utility Provider

The relationship between an airport and its utility provider(s) is key, with far-reaching impacts. Some airports work closely with their utility provider and together have crafted a shared vision for their region's energy use and production. Others have a more passive relationship with minimal interactions, except when there are power outages. One airport seemed to have a very challenging relationship with its utility provider. The airport discovered the utility provider had given the airport a mandatory (and hard to reach) energy goal. This was only discovered when airport officials read an overarching strategic plan. The airport was not consulted in the deliberations around the strategy. Building a positive working relationship with representatives from the utility providers to be able to productively discuss resiliency, energy reduction, cost per unit, "greening" of energy, opportunities for rebates for efficiency investments, etc., is vitally important.

It is also vital for an airport to coordinate with its utility when considering energy conservation measures. Some utilities invoice higher use at a lower per-unit cost. When reducing usage, an airport could find itself paying more for less energy use, unless the rate is negotiated in advance of the energy reduction measures.

Information Asymmetry

The complexity of energy resilience creates an information asymmetry in which the airport staff members often feel like they are playing catch-up and looking to the experts, usually the consultants, to explain the myriad energy options the airport should consider. However, while consultants may be the experts, they may not be neutral experts, especially if associated with a specific product or service, and may advocate on behalf of the product or approach. It is challenging for airport staff members to trust that they are knowledgeable enough to make their own decisions or trust that the consultants are bringing forth and recommending the best options for their airport.

State and Federal Grant Opportunities

Many airports wished they had a better understanding of the federal funding landscape and the programs that are or will be funded as part of the Bipartisan Infrastructure Law, the Inflation Reduction Act, and/or future funding opportunities. There is not a recognized go-to source that houses and explains all the opportunities that exist, inclusive of agencies, application deadlines, etc.

Electric Vehicle Charging

Electric vehicles are being used by airport customers and tenants, and their use is anticipated to grow, particularly given the incentives in the recent federal legislation. Airports are working to identify the most appropriate type of charging station offerings and an associated rate structure. While out of the scope of this project, many airports cited this as a looming challenge, given how to address charging station requirements as part of parking standards, including the price and length of stay.

Establishing the Baseline

Calculating and understanding the airport's baseline energy use is vital to pursuing airport energy resiliency. This requires an inventory of all energy sources and uses. It is important to know the starting point to be able to gauge improvements. However, it is important to not only know the baseline but to understand its components, identify the major loads and know how they are served and to organize them by importance. This will allow an airport the flexibility to shed loads as part of its plan.

Design Considerations of High-Efficiency Systems

Orlando International Airport's new South Terminal Complex (OIA STC) contains a vast array of modern, state-of-the-art mechanical and electrical infrastructure equipment and associated baggage handling and people-moving systems designed to serve the needs of today's air-traveling public. These high-tech facilities require the careful consideration of the operating equipment and the potential effects that these systems can have on the supporting electrical infrastructure serving these types of facilities.

Baggage handling systems, for example, present a wide range of motors and associated variable-frequency (or variable-speed) drives (VFDs) necessary for the precise motor control required to efficiently operate the multitude of baggage conveyance equipment located throughout the OIA STC. During construction, following the energization of the electrical power distribution systems, the new baggage handling systems were energized for preliminary operation, and the baggage handling motor loads had an unanticipated effect on the electrical power systems in the form of negative kilovolt-amperes reactive (kVAR) readings recorded on various power quality monitoring systems installed in the complex. This condition has the effect of degrading, or lowering, the power factor of the electrical system, essentially resulting in poor energy efficiency. Addressing this negative kVAR situation can involve harmonic mitigation equipment or similar provisions, as well as the introduction of static VAR generators into the electrical power distribution system. Through the testing, the issues were addressed before full operation.

CHAPTER 4

Key Definitions

The key definitions for ACRP 02-98 are a compilation of those identified during the proposal process, with the addition of frequently heard terms in the case study interviews, coupled with literature review and research team member experience. The definitions encompass energy-related and -associated aviation terms. The resulting definitions are included in the glossary in Appendix B of the roadmap.

CHAPTER 5

Methodology for Vulnerability and Business Case Analyses

Vulnerability Assessment Methodology

The goal of airport energy resiliency is to have a well-sourced backup to address energy risks, whether those risks are short- or longer-term. Therefore, it is important to have tools to quantify the vulnerability due to various risks and evaluate the potential financial investment of improvements. One of the deliverables of ACRP 02-98 was a description of the approach to developing the vulnerability assessment.

There are several approaches to assess the vulnerability of systems or facilities, but the most widely used is the Threat and Hazard Identification and Risk Assessment (THIRA) developed and prescribed by the Federal Emergency Management Agency.[1] THIRA is one tool of the National Risk and Capability Assessment, which is a suite of assessment products that measures risk and capability across the nation in a standardized and coordinated process.[2]

THIRA is included in Chapter 3 of the roadmap as a tool to use in identifying resiliency gaps. An example is also in Appendix C.

Building the Business Case

Any energy resiliency measure should be the subject of a financial analysis. The effort will force a comprehensive determination of costs, an estimation of revenues, an estimation of future demand, an evaluation of the effects of doing nothing (the no-action alternative), and an estimation of the hard and soft benefits. Involving the full range of stakeholders at an airport will maximize the usefulness of the resulting benefit-cost analysis. The roadmap addresses three business case tools: return on investment, resiliency return on investment (ROI), and benefit-cost analysis.

Return on Investment

In several of the case studies, airports identified using ROI to evaluate or pursue energy resiliency-related projects. An ROI uses tangible costs (typically, the project cost) and benefits (typically, the expected savings from the project). An ROI can be a useful tool on projects for which the cost can be clearly identified and there are limited other factors. The simple ROI can be stated in total investment cost, less the actual cost savings, and stated in months or years for the cost savings to equal the investment; for example, a $100 investment with a $20-per-month cost saving equals five months to break even for the ROI.

Resiliency ROI

Resiliency ROI (RROI) has been more recently introduced for use in considering investment redundancy and other measures related to enhancing resiliency. The use of RROI allows for a recognition that resiliency

measures may need to be assessed over a longer period. Also, RROI can emphasize the soft benefits, such as to an airport's image or brand of staying operational[3]. Alternatively, an airport can choose to use a benefit-cost analysis that allows for the consideration of qualitative factors.

Benefit-Cost Analysis Methodology and Rationale

Benefit-cost analysis provides a means to consider tangible and intangible benefits and costs. Before considering whether and how to apply a benefit-cost analysis to airport energy resiliency, including meeting future demands, the pros and cons of the method should be considered. While benefit-cost can provide an added layer of clarity, including assessing the costs of no-action, if not careful, it can be used to validate preconceived beliefs due to subjectivity.[4]

Building the business case for airport energy resiliency projects is one of the activities that can be used to align airport energy resiliency strategies with other airport goals. Chapter 5 of the roadmap and Appendix D contain information on building the business case for airport energy resiliency projects.

Notes:

1. United States Department of Homeland Security Federal Emergency Management Agency. 2019. 2019 National Threat and Hazard Identification and Risk Assessment (THIRA): Overview and Methodology. https://www.fema.gov/sites/default/files/2020-06/fema_national-thira-overview-methodology_2019_0.pdf#:~:text=The%202019%20National%20Threat%20and%20Hazard%20Identification%20and,%28FEMA%29%20approach%20to%20completing%20a%20national-level%20risk%20assessment
2. United States Department of Homeland Security Federal Emergency Management Agency. 2021. National Risk and Capability Assessment. https://www.fema.gov/emergency-managers/risk-management/risk-capability-assessment
3. Gaille, B. "13 Benefit Cost Ratio Advantages and Disadvantages." Brandon Gaille Small Business & Marketing Advice (blog). June 27, 2018. https://brandongaille.com/13-benefit-cost-ratio-advantages-and-disadvantages
4. Smith-Woolwine, Inc. 2022. "Using Return on Investment and Resiliency Return on Investment for Preparedness." https://www.smith-woolwine.com/wp-content/uploads/2022/11/ROI-and-RROI_11-13-22.pdf

CHAPTER 6

Validation of Primer

Per the amplified research plan, after the research team prepared the draft final deliverables, but before the submission to ACRP for distribution to the panel, the primer was validated with three airports. To avoid bias, the case study and any panelist airports were not used for the validation. However, findings from the literature review and case studies were used to identify the candidate airports so that a range of sizes, experiences, and perspectives is represented for the primer validation. The selection of the validation airports was coordinated with the panel during the interim meeting to identify the final list of airports.

The validation airports were provided with a draft of the primer for review, a draft of the roadmap table of contents, and a review form to provide feedback and guide discussion. The research team held virtual meetings with representatives from each reviewing airport to enable a discussion of the questions and recommendations. The validation reviewers did not have a full roadmap, so their roadmap comments are based only on the table of contents and discussion during the interview.

The following airport representatives were part of the primer validation process:

Boston Logan International Airport (BOS) – Eastern large hub
Tyler Arrigo, Sustainability Project Manager
Kathy Ledoux, Senior Resiliency Manager
Shahbaz Soofi, Climate Strategy Manager

Jackson Hole Airport (JAC) – Western small hub
Dustin Havel – Deputy Director of Aviation – Operations
Megan Jenkins – Public Information Officer

Pittsburgh International Airport (PIT) – Midwestern medium hub
Tom Woodrow – Senior Vice President, Engineering and Intelligent Infrastructure

All three airports liked and strongly endorsed the draft primer and the roadmap table of contents. They suggested a few very useful changes and shifts in emphasis that we have incorporated, as noted below. The validation concept was sound and well worth the effort.

The following feedback was received from the validation process. The feedback is organized by review question, and the responses from the airports are summarized under the respective question.

1. Are the primer's content and tone appropriate to reach airport senior management and governing boards?

   Yes, but under role of leadership it might be good to recognize there are lots of pushing and pulling of leadership for other purposes (emergencies, SMS, other environmental initiatives, day-to-day operations, etc.); similar to the competing priorities included on Page 7 at the beginning of the funding section.

Yes.
Yes. Primer plays well with airport's drive for net zero.
Suggest a little more focus on benefits and maybe even how energy resiliency can support those other initiatives.
Leave the decades of work out and cover that in the roadmap and not the primer. The goal is to draw leaders in, not scare them away. Most leaders like a challenge, but the primer should be more as a sales pitch. *(Reference to decades removed.)*
Shift focus to benefits. (*Shifted to benefits focus*.)
With evolving technology programs like this, they are a journey, not a destination.
Maybe a little shorter document to get a higher probability of starting and finishing. (*Did not change length, because a full page could not be cut.*)
Like the exhibits.
Like the airport examples that are called out.

2. Does the primer make you want to read the guidebook to developing a roadmap to energy resiliency for your airport?
Maybe; sell the roadmap a little more. (Added more references to roadmap in primer.)
Yes.
Suggest sharing that resilience (reliability) will make you sleep better. (*Will keep in mind for presentations on the topic*.)
Have the ACRP report info on the front page. Maybe every page as a footer. (*Added in footer*.)
Like how it keeps referencing chapters, etc. to get more info.
Yes, suggest adding the hook of PIT savings of regional reduction of 6 million pounds of carbon and more than $1 million in operational savings in 2022. *(Added to PIT example in primer)*

3. Are any topics missing?
(roadmap, maybe primer) How to involve stakeholders, but not waste their time (efficient and productive conversations). Stakeholders want meetings that move us down the "road." (*Added productively to involve stakeholders in primer.*)
(roadmap) Maybe chat about the consensus a bit more. You won't get everyone on board, but don't let that stop you. (*Roadmap includes a stakeholder consensus discussion.)*
Emphasize using short-term actions to reach long-term goals. (*Addressed in roadmap.*)
Add usefulness of operational plans to promote resiliency, either alone or in conjunction with capital projects to primer and roadmap. (*Added more information on connection to operational plans in roadmap.*)
Bidirectional charging (reverse charging) from EVs. (*Added mention to roadmap.*)
Refueling issues – many emergency generators for many different buildings can result in access issues for fuel trucks and competing demands. (*Added text to roadmap to prioritize fuel deliveries in case of limitations.*)
How long should the airport be able to operate when the local grid goes down? Should the roadmap report recommend a minimum time? (*Roadmap recommends airports examine their situations and make appropriate plans and arrangements*.)
Documentation and analysis of looping of power supplies — are all essential buildings looped? (*Added all critical infrastructure needs, multiple feeds in roadmap*.)
Feasibility of rooftop solar for smaller buildings. (*Rooftop solar included in renewal energy solar photovoltaic section of roadmap*.)
Does roadmap address fuel cells — feasibility, space requirements, safety hazards? *(Roadmap mentions understanding space requirements for fuel and energy storage.)*

Different priorities for different EV users: ride-share, rental cars, airlines, parking garages, buses, GSE, airport vehicles, etc. (*Roadmap mentions multiple charging situations for airports to address. Separate ACRP study on EV charging is ongoing.*)
Induction charging of EVs for shuttle buses is becoming available. (*Added reference to induction charging in roadmap.)*
Importance of built-in redundancy. (Redundancy is one of the tools/levers and strategies.)
Take a campus approach. (Look at higher education for possible good examples). (*Complex Florida case study included a university.*)
PIT was able to develop its microgrid at zero cost to public, entirely financed by the private side of the partnership. PIT pays a monthly bill based on banded usage levels set in the contract. *(Added energy-as-a-service reference in primer to align with roadmap.)*
Add to improve overall safety for traveling public. *(Added public safety is ensured as a benefit in primer, roadmap, and summary of key findings.)*
Role of leader: add costs, returns on investment, cost efficiency — things that a leader must consider. *(Added cost reductions and return on investment to primer.)*
Add uninterrupted power supplies along with appropriately sized generators *(Added in primer.)*
For PIT, delete "and pipeline" *(Deleted "and pipeline" in primer.)*
Adjust fossil fuel generator for natural gas supporting sustainability, because natural gas has about 50% of greenhouse gas emissions compared to oil and coal. *(Changed reference from "will not support sustainability goals" to "may not support sustainability goals" in primer. Relationship to sustainability goals will vary with area of country.)*
Foundational goals – consider adding "leveraging natural resources on airport property," "sustainability." *(Added in tools/levers section of primer, because it may have a quantifiable metric.)*
"Energy service agreement" is PIT's wording *(Revised private funding options in primer to align with roadmap edits. Includes energy-as-a-service.)*
If interconnect maintained with local utility, may have to pay monthly fee to utility's equipment and maintenance. *(Added paragraph in roadmap in microgrid section on fee to maintain grid interconnect.)*

4. Should any topics be deleted or de-emphasized?
Assume primer and roadmap are intended to be used for years, look at Section 5 and do an appendix for the funding programs that might come and go. *(Moved current grant funding with specific time frame to an appendix in roadmap to make the body of the report more timeless.)*
Maybe reduce the primer to seven pages. (*Kept the same length, because there are no easy areas to cut a page of information*.)
No.
What is meant by grid resiliency in first page of key takeaways? Would omit — covered by energy resiliency. *(Removed grid resiliency bullet.)*
Suggest adding bullet on sustainability. *(Added bullet that resiliency complements sustainability.)*

5. Is the DoD callout box of interest, or would you rather see another airport example, even if the example scope is different?
DoD box is interesting.
No opinion.

6. What other changes do you recommend?
Maybe replace "resiliency" with energy redundancy or flexibility for more variety in text. (*A few substitutions were made in primer and roadmap.*)
The title could be changed to streamline. (*Shortened first heading*.)

Use of champion? Know the intent and what it is and difference from leadership. (*Clarified champion's role in primer and roadmap.*)
Partnership vs. just stakeholders. (Strengthened partnership language related to stakeholders in primer and roadmap.)
Move benefits to closer to top. (Moved sentence on role model for community up in primer.)
Move current special funding sources to appendix and emphasize that funding sources change with time. (Short-term funding sources moved to appendix in roadmap, with indication that airports should continually monitor for funding opportunities.)

7. Are any topics missing in the roadmap table of contents?
   Suggested revisiting issue in one to three years due to fast-evolving technology. (*Problem statement for further study of redundant or backup energy systems submitted to ACRP with panel's approval.*)
   No.

APPENDIX A

Literature Review Results

Energy Resiliency

"Airports, Take Note: How to Put Resilience First." *ARGS: Airline Routes and Ground Services*. November 20, 2019. https://airlinergs.com/issue-article/airports-take-note-how-to-put-resilience-first/

> Explores a report by Thornton Tomasetti and Resilience First on airport resilience, including energy, emerging alternate fuel sources for airplanes, and climate change.

Chiu, Bill, Anjan Bose, Scott Brown, Babu Chalamala, Darcy Immerman, Amin Khodaei, Jay Liu, Jim Mazurek, Damir Novosel, Aleksi Paaso, Farnoosh Rahmatian, Julio Romero Agüero, and Marianna Vaiman. "Resilience Framework, Methods, and Metrics for the Electricity Sector (TR83)." IEEE Power and Energy Society. October 29, 2020.

> "This report provides an overview of resilience definitions, including its relationship with reliability, the existing frameworks for holistically defining resilience planning and implementation process, and the metrics to evaluate and benchmark resilience. It provides recommendations on how to use those frameworks and metrics and evaluates technologies, tools, and methods to improve electrical system resilience."

Clark, Corrie E., Richard J. Campbell, and D. Andrew Austin. "Potential Options for Electric Power Resiliency in the U.S. Virgin Islands." Congressional Research Service. R45105. February 14, 2018. https://sgp.fas.org/crs/row/R45105.pdf

> Discusses the solar energy facility at Cyril E. King International Airport and microgrid at Henry E. Rohlsen Airport as part of greater electric power resiliency for the U.S. Virgin Islands in the wake of hurricanes Maria and Irma in 2017.

Federal Energy Management Program. "Resilience Planning and Implementation." https://www.energy.gov/eere/femp/resilience-planning-and-implementation

> FEMP resource page for resilience planning includes links for training courses, including Technical Resilience Navigator.

Karaim, Reed. "Co-op Tech: Military Resilience." *Rural Electric Magazine.* October 23, 2019. https://www.cooperative.com/remagazine/articles/Pages/co-op-tech-military-resilience.aspx.

> Explores Naval Submarine Base New London and the Department of Defense's partnership with the Connecticut Municipal Electric Energy Cooperative to increase energy resiliency at the base, including through its microgrid project. "[E]nergy is the Pentagon's single largest operating cost at its bases—in 2017, the DOD spent $3.5 billion to heat, cool, and provide power to

installations—and the military is looking for ways to cut its energy bill through improved efficiency and other measures. To that end, Jan Ahlen, NRECA director for energy solutions, notes that in addition to greater resilience, 'the military installations are really pushing for self-sufficiency.' Electric co-ops, he says, are well positioned to help the military with that push because of their growing involvement and experience with microgrids."

Moore, Ben and Terry Kagler. "How the PEER Standard Can Prioritize Airport Energy Resiliency." *Aviation Pros.* November 4, 2021. https://www.aviationpros.com/airports/article/21243227/how-the-peer-standard-can-prioritize-airport-energy-resiliency

Discusses the wave of electrical power loss in 2021 at airports such as Denver, Los Angeles, and airports throughout Texas before moving on to discuss Performance Excellence in Electricity Renewal (PEER), "a newer certification developed by the Green Building Certification Institute that focuses on electrical and energy resiliency." PEER sets standards for system performance across four outcome categories: reliability and resiliency, energy efficiency and environment, operational effectiveness, and customer contributions.

Roege, Paul E., Zachary A. Collier, James Mancillas, John A. McDonagh, and Igor Linkov. "Metrics for Energy Resilience." *Energy Policy.* April 5, 2014. https://recias.inl.gov/SiteAssets/SitePages/NSRCI/Energy%20Resilience%20Metrics%20EP%202014.pdf

Microgrids, Energy Distribution, Energy Storage, and On-Site Energy Generation

Booth, Samuel, James Reilly, Robert Butt, Mick Wasco, and Randy Monohan. *Microgrids for Energy Resilience: A Guide to Conceptual Design and Lessons from Defense Projects*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-72586. January 2020. https://www.nrel.gov/docs/fy19osti/72586.pdf

Henrikson, Carmen, Mathew Marshall, and Jim Zoellick. "Redwood Coast Airport Microgrid: Advancing a Resilient and Clean Energy Future." Clean Coalition. Webinar. September 17, 2020. https://clean-coalition.org/news/webinar-redwood-coast-airport-microgrid-sep-2020/

Recorded hourlong webinar and slide deck covering in-depth the technical design, operations agreement, business model, and project build of the Redwood Coast Airport microgrid.

Klauber, Adam, Joey Cathcart, Lauren Shwisberg, Isaac Toussie, Adib Naslé, Kelsey Fahy, Scott Mitchell, Zack Pecenak, Michael Stadler, Wilson Rickerson, Meredith Pringle, Steve Barrett, and James Crites. *ACRP Research Report 228: Airport Microgrid Implementation Toolkit.* Washington, D.C.: Transportation Research Board, 2021.

Mallery, Janice, Douglas L. Van Bossuyt, and Anthony Pollman. "Defense Installation Energy Resilience for Changing Operational Requirements." *Designs.* 6, no. 28. March 2022. DOI:10.3390/designs6020028.

Includes case study for Naval Submarine Base New London's microgrid.

Nolan, Paul. "Pittsburgh International Boosts Energy Resiliency, Reliability." *Airport Improvement Magazine.* October 2021. https://airportimprovement.com/article/pittsburgh-int-l-boosts-energy-resiliency-reliability

Osit, Steven L. and Sarah M. Keane. "Microgrids: Opportunities and Challenges for US Airports." *Journal of Airport Management*. 15, no. 4. 322-332. September 1, 2021.

Great airport-targeted overview of microgrids, featuring the Pittsburgh microgrid.

Poudel, Bikash, Timothy R. McJunkin, Ning Kang, and Jim T. Reilly. "Net-zero Microgrid Program Project Report: Small Reactors in Microgrids." Idaho National Laboratory. November 10, 2021. https://doi.org/10.2172/1829672

Includes section on commercial application of microgrids at airports that features Pittsburgh and Redwood as well as a figure of a small-reactor-based microgrid for commercial application in airports.

Smith, David J. "Airports, Microgrids and Resilient Power." Burns Engineering. July 18, 2018. https://www.burns-group.com/blog/2018/07/airports-microgrids-and-resilient-power/

United States Department of Energy New England CHP Technical Assistance Partnership. "Bradley Airport Energy Center 5.8-MW CHP System." February 2016. https://chptap.ornl.gov/profile/22/BradleyAirportpp.pdf

"Bradley International Airport in Windsor Locks, Connecticut has a central energy plant with Combined Heat and Power (CHP) that provides electricity, heating, cooling and hot water for the main passenger terminals at the airport. The CHP facility has been in operation since 2002, at which time it featured three Waukesha engine generators. Waste heat from the engines is used for heating and also to power a 500-ton Trane single-stage hot water absorption chiller, which supplies chilled water year round for the airport. In 2010, the facility started the process of adding a fourth engine, a 2 MW Waukesha APG2000, natural gas-fired internal combustion engine (IC) and heat recovery hot water boiler. Thermal energy is recovered from the jacket cooling water of the four engines and exhaust heat of the old and new engines (800°F and 1200°F, respectively), in order to generate 220°F hot water used by the airport."

Walton, Rod. "The EnergyTech Mission Critical Microgrid Series Part 2: The Pittsburgh International Airport Microgrid." *EnergyTech.* May 2, 2022.

Part of an in-depth, three-part series that highlights the Redwood and Pittsburgh microgrids. Article explains that microgrids fall into three categories, based primarily on the nature of the end user of the power, but all three types are designed to sustain mission-critical systems. The Pittsburgh microgrid is built for resilience and sustainability. Its 20-megawatt energy plant is driven by five 4-megawatt Jenbacher engines for primary, baseload generation. "The air travel industry is catching on to the resiliency attributes of the secure, wholly contained power generation system. Most have had on-site power gen-sets, but only a few are evolving to capture 100 percent resiliency and greenhouse gas reduction goals in one package."

Emerging Trends in Energy Demand and Usage

Federal Aviation Administration. *Urban Airport Mobility (UAM): Concept of Operations. V1.0.* June 26, 2020. https://nari.arc.nasa.gov/sites/default/files/attachments/UAM_ConOps_v1.0.pdf

The FAA shared this UAM concept of operations with internal and external stakeholders in June 2020.

Frithiof, Mattias, Philip Jonat, and Gaël Le Bris. "Electrification of Airports from Landside to Airside." WSP. May 25, 2022. https://www.wsp.com/en-us/insights/electrification-of-airports-from-landside-to-airside

Looks at emerging trends and the changing landscape of electrification of landside and airside transportation at airports and the infrastructure needed to generate and store the electricity needed for such increased demand.

Hedden, Carole Rickard. "AAM Services Sector To Include Retrofit Kits." *Advanced Air Mobility Report.* March 2, 2022.

Discusses retrofit kit companies like ZeroAvia and Universal Hydrogen and their current orders (currently over 300 kits or aircraft across the industry). "[W]ith new AAM aircraft, the aftermarket is destined to look much different as services focus on battery exchanges, hydrogen fuel cells, loading and basic inspections versus the massive overhauls associated with legacy engines. Among the services is the retrofit of existing aircraft with new propulsion technologies designed to deliver lower costs and zero emissions."

International Civil Aviation Organization. "eVTOL and Urban Air Mobility – A New Systemic and Sustainable Approach for Air Travel." Webinar. June 4, 2021. https://www.icao.tv/videos/stocktaking-2021-evtol-urban-air-mobility

A nearly two-hour webinar featuring nine speakers from ICAO, Airports Council International, the Aerospace Technology Institute, and the industry on eVTOL and urban air mobility. Includes discussion of changing ground infrastructure requirements and evolving battery needs.

Le Bris, Gaël, Loup-Giang Nguyen, Beathia Tagoe, Philip Jonat, Cedric Y. Justin, Eugene Reindel, Katherine B. Preston, and Phillip J. Ansell. *ACRP Research Report 236: Preparing Your Airport for Electric Aircraft and Hydrogen Technologies.* Washington, D.C.: Transportation Research Board, 2022.

Norris, Guy. "Eviation on Track for All-Electric Alice Completion." *Advanced Air Mobility Report.* October 27, 2021.

Discusses Eviation's all-electric regional aircraft Alice's development, DHL contract, and agreement with Clay Lacey to provide electric ground-charging facilities at its locations. The nine-passenger aircraft is designed for feeder runs and has an estimated 30-minute charging time.

Oakleaf, Brett and Scott Cary. "Current Technological Trends in Sustainable Aviation." National Renewable Energy Laboratory. https://www.nctcog.org/nctcg/media/Transportation/DocsMaps/Plan/Aviation/2021/UAS_TaskForcePresentations_113021.pdf

This presentation covers advanced air mobility, sustainable aviation fuels, electrified aviation, infrastructure peak loads for electrified aviation, and ground infrastructure for complex unmanned aircraft system operations.

Qui, Rui, Shuhua Hou, and Zhiyi Meng. "Low Carbon Air Transport Development Trends and Policy Implications Based on a Scientometrics-Based Data Analysis System." *Transport Policy*. 107. 1-10. 2021. doi.org/10.1016/j.tranpol.2021.04.013

> "This study analyzes low carbon air transport development trends using a scientometrics-based data analysis system that evaluates all relevant scientific papers, and explores policy implications."

Warwick, Graham. "Engineers Envision Hydrogen Regional Aircraft of the Future." *Advanced Air Mobility Report.* October 27, 2021.

Sustainability, Energy Conservation, and Energy Use Efficiency

Albuquerque International Sunport. "Sustainable Airport Master Plan: Executive Summary." March 4, 2020. https://www.abqsunport.com/wp-content/uploads/2020/12/ABQ_Executive_Summary-ReducedSize.pdf

> Includes inventory and baseline data for energy and other requirements. In 2014, Albuquerque International Sunport's on-site photovoltaic solar provided 2,480,000 kilowatt-hours of electricity – baseline.

Dixon, Brandy M. "AEA Awarded $21 Million BUILD Grant for Anchorage Airport Project." Alaska Energy Authority. September 16, 2020. https://www.akenergyauthority.org/Portals/0/2020_09_16%20AEA%20Awarded%20%2421%20Million%20BUILD%20Grant%20Press%20Release.pdf

> U.S. Department of Transportation program to build airport facilities to promote economic development. This project at Ted Stevens Anchorage International Airport is for a cold-storage warehouse that will "make the building a showpiece in energy-efficiency."

Galloway, John, Tom Green, Katie Lamond, Stephanie Meyn, Chad Reese, and Erik Herzog. "Creating Sustainability at Airports." Environmental Protection Agency. Webinar. June 5, 2019. https://www.epa.gov/sites/default/files/2019-06/documents/epa-sw-airports-webinar-2019-06-05_0.pdf

> Slide deck for EPA presentation on sustainability at airports featuring presenters from San Francisco International Airport, Seattle-Tacoma International Airport, the Port Authority of New York and New Jersey, San Diego County Regional Airport Authority, and EPA discussing decarbonization, zero-emission vehicle readiness, energy resiliency, carbon neutrality, distributed energy resources, plane electrification, climate adaptation, green buildings, and fast-charging hubs.

Haberl, Jeff S., Zilbershtein, Gali, Baltazar, Juan-Carlos, Mao, Chunliu, Ugursal, Ahmet, Nelson, Ian, Parker, Patrick, Yazdani, Bahman L., Martinez, Joseph T., Cho, Soolyeon, Stratakes, Travis, Jiang, Anjie, Dong, Lining, and Hussain, Marshall. *ACRP Web-Only Document 27: Methodology to Develop the Airport Terminal Building Energy Use Intensity (ATB-EUI) Benchmarking Tool*. Washington, D.C.: Transportation Research Board, 2016. https://doi.org/10.17226/23495

> Outlines the overall data collection and analysis process for developing airport terminal building benchmarks for energy use intensities.

Lytle, Scott. "2019 Environmental Section Summary Report." Ted Stevens Anchorage International Airport. https://dot.alaska.gov/anc/business/environmental/environmental-summary-2019.shtml

> "Over the last several years ANC has been implementing measures to reduce the energy consumption at all airport facilities. Improvements and upgrades to heating, cooling and electrical lighting systems combined with operational efficiencies have reduced the electrical and natural gas consumption and are expected to save the State of Alaska thousands of dollars.
> Some of these ongoing measures such as replacing older lighting fixtures and lamps with LED bulbs will continue to reduce our environmental footprint and energy costs."

Morrison, Geoff, Damon Fordham, Elise Emil, Cian Fields, Kelly Blynn, Toral Patel, James Schroll, Katherine Preston, Adam Klauber, Kristin Lemaster, and Alexander Epstein. *ACRP Research Report 220: Guidebook for Developing a Zero- or Low-Emissions Roadmap at Airports*. Washington, D.C.: Transportation Research Board, 2021.

RTAA (Reno-Tahoe Airport Authority) Annual Sustainability Report 2020.
https://www.renoairport.com/wp-content/uploads/2022/07/RTAA-Annual-Sustainability-Report-2020.pdf

> "Target: Secure FAA funding and airline participation to install, using FAA funding, 20 dual-part electric charging stations to support airline-owned electric-powered ground support equipment (eGSE) at RNO. Achievement: In partnership with Southwest Airlines and United Airlines, the RTAA's VALE eGSE Charging Station's Project, provided the charging infrastructure to switch to e-vehicles. Annual emissions reductions will be reported in future annual reports."
> "Target: Participate in the ReEnergize Reno initiative to help reduce energy and water usage in large buildings and reduce climate pollution. Achievement: Formally joined the ReEnergize Reno initiative and actively participated in the effort, signifying the RTAA's strategic commitment to improving building energy usage, water efficiency, reducing climate pollution."

Renewable Energy, Energy Demand, and Energy Pricing and Costs

Barrett, Stephen B. *ACRP Synthesis 110: Airport Renewable Energy Projects Inventory and Case Examples.* Washington, D.C.: Transportation Research Board, 2020.

> Case studies include the anaerobic digester at Brunswick Executive Airport, solar at Denver International Airport, St. Louis-Lambert, and San Diego International Airport , geothermal at Eastern Iowa Airport and Nashville International Airport, and the biomass boiler at Ketchikan International Airport.

Barrett, Stephen B., Philip M. DeVita, Julie E. Kenfield, Bradley T. Jacobsen, and David Y. Bannard. *ACRP Report 151: Developing a Business Case for Renewable Energy at Airports*. Washington, D.C.: Transportation Research Board, 2016.

International Civil Aviation Organization. "A Focus on the Production of Renewable Energy at the Airport Site: ECO Airport Toolkit." https://www.icao.int/environmental-protection/Documents/Energy%20at%20Airports.pdf

> Discusses energy demand mitigation, case study airports, and renewable energy sources, including wind, solar, biomass, geothermal, and hydro.

Jacobs, Kasey R., Stephen J. Fain, Stevie Henry, Wayne Archibald, and William A. Gould. *Synthesis of Climate Change Related Knowledge and Information in the United States Virgin Islands: An Institutional Analysis*. Report Presented to the U.S. Department of the Interior, Office of Insular Affairs. April 2016. http://ess-caribbean.com/wp-content/uploads/2018/08/Synthesis-of-Climate-Change-Related-Knowledge-and-Information-in-the-United-States-Virgin-Islands.pdf

> "The Virgin Islands Port Authority has constructed one of the largest solar energy panel systems in the U.S. Virgin Islands at the Cyril E. King Airport on St. Thomas to help reduce the airport's monthly utility costs."

Sinha, Kapil, Nusrat Ali, and E. Rajasekar. "An Agent-Based Dynamic Occupancy Schedule Model for Prediction of HVAC Energy Demand in an Airport Terminal Building." *Proceedings of the 16th International Building Performance Simulation Association International Conference and Exhibition.* 2019. http://www.ibpsa.org/proceedings/BS2019/BS2019_211133.pdf

> Models heating, ventilating and air conditioning and energy grid performance for peak energy demand at a medium-sized airport in Visakhapatnam, India, located in a warm and humid climate zone.

Ecological Stressors and Severe Disruption

GRA, Inc., LMI, RFMarchi Aviation Consulting, AECOM, and CHPlanning. *ACRP Research Report 199: Climate Resilience and Benefit–Cost Analysis: A Handbook for Airports*. Washington, D.C.: Transportation Research Board, 2019.

ICF, Gresham, Smith and Partners, and Faith Group, LLC. *Airport Cooperative Research Program Research Report 188: Using Existing Airport Management Systems to Manage Climate Risk.* Washington, D.C.: Transportation Research Board, 2018.

International Civil Aviation Organization. "Climate Resilient Airports: ECO Airport Toolkit." https://www.icao.int/environmental-protection/Documents/Climate%20resilient%20airports.pdf

> Discusses resilience planning, risk and exposure, aviation climate impacts, increasing energy consumption from climate change, airport energy independence, and examples of action by airports on climate resilience, including Honolulu's solar energy field. "In essence, creating resilient airports is not just about protecting infrastructure and operational assets from flooding caused by sea, rivers, and storms. It is also about enabling airports to become more sustainable and improve local water, climate, and energy management - something that airports will have to embrace if they want to continue thriving."

International Civil Aviation Organization. "On Board: A Sustainable Future." Environment Report 2016. https://www.icao.int/environmental-protection/Documents/ICAO%20Environmental%20Report%202016.pdf

> Chapter 7 focuses on climate change adaptation and resilience in aviation and airports.

Government Funding, Regulation, and Legislation and Effects of Energy Regulatory Policies

American Association of Airport Executives. "Airport Alert: Airport Energy Resiliency and Renewable Energy Act Introduced." August 3, 2022.

No further action has yet been taken on this bill since its Senate introduction on Aug. 2, 2022. More information available at https://www.govinfo.gov/app/details/BILLS-117s4727is/.

Federal Aviation Administration. "United States 2021 Aviation Climate Action Plan." 2021. https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

Chapter 6 covers "FAA Leadership on Climate, Sustainability, and Resilience," including current activity and proposed actions.

"Inflation Reduction Act of 2022 Includes Many Provisions Related to Energy Transition and Renewable Energy." *Tax News Update.* August 2, 2022. https://taxnews.ey.com/news/2022-1169-inflation-reduction-act-of-2022-includes-many-provisions-related-to-energy-transition-and-renewable-energy

The Inflation Reduction Act of 2022 contains airport-specific provisions boosting sustainable aviation fuels, the Voluntary Airport Low Emissions Program, and microgrid energy storage solutions.

National Association of Regulatory Utility Commissioners. *Private, State, and Federal Funding and Financing Options to Enable Resilient, Affordable, and Clean Microgrids.* January 2021. https://www.naseo.org/Data/Sites/1/naseo_microgrid.pdf

Discusses energy savings performance contracts used as private-sector funding model for Naval Submarine Base New London, as well as a range of funding models, including state and federal funding for microgrids.

Warwick, Graham. "Special Report: Industry Needs Quick Answers on FAA's eVTOL Shift." *Advanced Air Mobility Report.* May 18, 2022.

Discusses the federal regulatory landscape for eVTOLs and the adjusted projected timeline to service entry (originally projected for as early as 2024) in the wake of recent change in FAA communication. "Industry was expecting an FAA policy statement saying winged eVTOLs would be certified under existing Part 23 regulations as airplanes with the ability to take off and land vertically. Instead, the FAA called manufacturers individually to tell them their vehicles will now be certified as powered-lift aircraft under Part 21.17(b) 'special class' rules."

Energy Security

Azzuni, Abdelrahman and Christian Breyer. "Global Energy Security Index and Its Application on National Level." *Energies.* May 15, 2020. https://www.mdpi.com/1996-1073/13/10/2502/pdf?version=1590041356

Contextualizes airport energy security in a broader context of global and national energy security.

Shetland, Andrew and Phil Damicis. "Leveraging Contracting Vehicles for Energy Security." *The Military Engineer.* 113, no. 732. March–April 2021. https://www.noresco.com/media/TME-Submarine-Base-New-London_tcm23-116225.pdf

Discusses energy security at Naval Submarine Base New London, including its fuel cell and microgrid upgrades.

APPENDIX B

Gap Analysis and Further Research

Based on the literature review and information shared during case study interviews, initial gaps in airport energy resiliency have been identified. The gaps identified are divided into those addressed in the roadmap and those that are beyond this project's scope and budget and are identified for further research. The gaps identified for further research have been correlated to ACRP research roadmaps.

Gaps Addressed in Roadmap

How Airports Identify, Assess, and Prioritize Risks

Short- and long-term energy resiliency requires new thinking by airport management about how to identify, assess, and prioritize risks. Without a clear risk and hazard assessment, decisions on the rest of the gaps to be addressed in the roadmap cannot be appropriately targeted.

Energy Resiliency Best Practices Used by Airports

One of the case study questions asked, "What would be useful in an energy resiliency roadmap for your airport?" A very common response was that the airport is interested in assessing for its use the energy resiliency best practices of other airports where best practices include not only physical facilities and systems, but also governance and decision-making. The data gathered from the case studies and literature review were used to address this gap in the roadmap.

Role of Surrounding Community in Sustainability/Resiliency Management Plans

When formulating its airport energy resiliency plan, an airport should understand the influence of the surrounding community. This influence can range from mandates to limited or no support. The roadmap includes guidance on identifying the airport's energy resiliency role within the community setting. The airport should also understand ways in which it can participate in community resiliency and sustainability planning.

Relationship Between Airport and Utility Provider

Another potential influence on an airport's energy resiliency plan is the relationship between an airport and its utility provider(s). How stable is the service provided to the airport? What is the utility doing to address its resiliency? Is the utility supportive of an airport's energy reduction efforts? Are there grants or incentive programs offered by the utility that an airport can use? Is negotiation needed before an airport's energy-reducing project to avoid paying higher per-unit costs for lower usage, potentially increasing the operating cost when reducing usage? Is there a special case for city-owned electric utilities? The roadmap identifies considerations for building a relationship with the airport's utility providers.

Generational Change in Airport Leadership

A generational change in airport leadership is underway. Leaders who have generally been more conservative are giving way to millennials who see the validity of climate change, greening an airport and the self-sufficiency of airports through innovation. The roadmap was prepared to be appealing and understandable to all generations in the workforce and provide tools to assist with communication. One such tool is identifying the return on investment or benefit-cost analysis.

Airport Electric Vehicle Charging

While electric aircraft are regularly in the news and need to be part of an airport's future planning, airports are already experiencing the use of electric ground vehicles by tenants or for their own operations. Considerations in the transition to more electric vehicles include whether there is sufficient infrastructure to support the increased charging, charging tenants for increased electrical usage if not separately metered, and time-of-day demands and utility pricing. As electric vehicle usage increases, another area of planning is preparing for electric battery fires. The roadmap includes considerations and refers to other sources for further guidance. *ACRP Research Report 236: Preparing Your Airport for Electric Aircraft and Hydrogen Technologies* is one resource to address this gap. Additional resources focused on ground vehicles, especially charging parked cars, are identified and used to address this gap.

Generator Alternate Fuel Sources

Generators are one of the most common means to back up some to all of an airport's operations. However, the generators depend on a reliable source of fuel, most commonly diesel, that is delivered to an airport by truck. Airports need to consider how much fuel is needed to provide the desired period of generator operations to meet the airport's resiliency goals. Also, airports are exploring other fuel options such as Jet A, which may have larger storage capacities at an airport, or natural gas. However, diesel and Jet A are not directly interchangeable. Considerations for alternative fuel use for generators are identified in the roadmap.

LED Lighting

There is a general lack of documented savings gained by switching to LED lighting. Are there operational limitations on LED lighting for runways — for example, compatibility with night vision systems? How much savings from life cycle and maintenance costs are associated with LED lights? LED lighting for buildings varies in quality and can affect electrical systems. What features should an airport consider to identify high-quality LED lighting? Factors to evaluate when considering LED or other lighting are identified in the roadmap.

Solar Farms and Installations

There is an inconsistent understanding among many airports regarding the current FAA guidance for the placement of solar farms on airport property. Can an airport gain financial or other advantages from a joint solar development with a city or utility company? How successful have public-private partnerships been for the installation and operation of solar farms? What is the state of electricity storage from photovoltaic (PV) systems? Evaluation factors for PV systems are identified in the roadmap.

Geothermal

What is the expected useful longevity of geothermal installations, and is there a difference between vertically and horizontally drilled holes? What is the minimum distance from other land use needed to

protect the longevity of an airport's system? What ongoing maintenance or periodic replacement should be planned to manage a geothermal system? Lessons learned from airports with geothermal systems are included in the roadmap.

Facilities

Which energy resiliency features are best built into new designs or construction? Which are best suited for renovated, remodeled, or rehabilitated structures? Lessons learned from case studies and the literature review are highlighted in the roadmap.

Costs

What is the current cost per unit of energy of each alternative source? What trends are expected during the next 10 years? Energy cost trends or a means to evaluate them included in the roadmap.

Usage

One of the challenges faced by the case study airports is establishing a baseline. It is common for airports to have multiple service meters and constantly changing conditions due to ongoing development. While airports indicated they are assessing potential use and reduction options on a project basis, a process for establishing an overall baseline would benefit airports. This baseline could assist airports in understanding where they are starting, especially as it relates to a goal to reduce or limit the growth in energy use. Identifying the need to establish the baseline and outline its process is included in the roadmap. However, more complex situations are beyond this project's budget.

In addition to a baseline, how can an airport project future usage by types, sources, and costs of energy? Methods or strategies to evaluate current and future energy usage are part of the roadmap.

Vulnerability

What are the environmental threats to energy resiliency? Human-caused threats? Threats from evolving tenant demands? Rising costs? An outline of potential threats for an airport to consider is identified in the roadmap. Because each airport is unique, the actual vulnerability must be identified by each airport based on its situation.

Grant Funding: Federal and State

Many case study airports wished they had a better understanding of the federal funding landscape and the programs that exist or are coming soon as a result of the passage of the Bipartisan Infrastructure Law and the Inflation Reduction Act. An overview of potential funding sources to consider or investigate is part of the roadmap.

Gaps Anticipated to Be Addressed in Upcoming ACRP Study

Electric Passenger/Customer Vehicle Charging

Electric automobiles are being used by airport customers, and their use is anticipated to grow. Further, some communities have started to establish charging station requirements as part of parking standards. The airport customers' lengths of stay vary widely, from short-term meet and greets to day trips to extended travel. Airports are working to identify the most appropriate type of charging stations and an associated rate structure. While the roadmap recognizes planning for future electrical vehicle use, the specifics related to establishing an electric vehicle charging program, with considerations for parking options and pricing, are better addressed as a standalone study to allow for sufficient detail. ACRP Project 03-71," Guidance for Planning for Future Electric Vehicle Growth at Airports," was announced as a fiscal year 2023 study.

Gaps to Be Addressed in Future Research

Finding, Using, and Relying on Consultants

Energy resilience is a complex topic and, at times, airports question whether they have the most up-to-date information, given the ever-evolving landscape. This includes technology and funding sources. While consultants are available to explain concepts and options, there is concern that consultants may have an ulterior motive to sell a particular solution and may not be objective regarding the airport's best interests. Additionally, the use of consultants means the airport is not building its own institutional knowledge. It can also be challenging to identify the right consultant for the right job.

This topic does not directly fit within any of ACRP's roadmaps but can support several of them, including these emerging issues selected by ACRP's Thought Leader Forum: the impacts of innovative and emerging technologies, the challenges and opportunities for the airport business model, and airport workforce development. When focused on consultants for energy resiliency or emerging issues, this topic could start as a synthesis project to identify current airport practices. When considering consultant selection for a broader range of projects, it may be best addressed through a research project.

Redundant or Backup Energy Systems Evaluation

The identification of the range of redundant or backup energy systems used by airports or similar entities is part of the roadmap. However, a deep dive into all potential systems, selecting a system, the pros and cons of various systems, the benefit-cost analysis of system versus mitigated risk, and financial planning for such resiliency is beyond the budget of this study and warrants further research. This topic also encompasses the speed and effectiveness of automatic switching gear and the ability to avoid electricity quality issues that affect critical systems, such as screening machines, access controls, baggage handling systems, and airline gate terminals.

This topic fits within ACRP's identified emerging issue of enhancing the resiliency of airports and interrelated systems. It may also cross over into an issue for the Program for Applied Research in Airport Security, to the extent that it would deal with disruptions to airport security systems. This topic is most appropriate as a research project.

Problem Statement Submitted

With panel support, the following problem statement was submitted during ACRP 02-98.

Subprogram – Research

Title – Airport Redundant or Backup Energy Systems Evaluation

Background – While ACRP 02-98: Airport Energy Resiliency Primer and Roadmap identifies the range of redundant or backup energy systems used by airports or similar entities for consideration by airports in the roadmap, a deep dive into all potential systems, selecting a system, the pros and cons of various systems, the benefit-cost analysis of system versus mitigated risk, and financial planning for such resiliency is beyond the budget of ACRP 02-98 and warrants further research. This topic should also encompass the speed and effectiveness of automatic switching gear and the ability to avoid electricity quality issues that affect critical systems, such as screening machines, access controls, baggage handling systems, and airline gate terminals.

This topic fits within ACRP's identified emerging issue of enhancing the resiliency of airports and interrelated systems. It may also cross over into an issue for the Program for Applied Research in Airport Security, to the extent that it would deal with disruptions to airport security systems.

Objective – The outcome of this project is anticipated to be a guidebook that airports can use to assist in their evaluation of redundant or backup energy systems from functional, feasible, and financial perspectives.

Research Approach – Airports are continuing to invest in redundant or backup energy systems. Much of this investment is occurring at larger airports. The lessons learned from the existing and planned systems would benefit the overall airport industry. It is anticipated that this research project will include case studies of different types of systems in use at airports and other industries if an airport example is not available. It should also capture energy efficiency and resiliency considerations of airports that have or are developing new terminal facilities. The case studies would be augmented by a literature review. The research team may also wish to contact the vendors of redundant or backup energy systems to identify the most recent evolution of equipment to better identify factors an airport should consider. To maintain neutrality among the vendors, the systems would not be evaluated but, rather, the features and data an airport should have to evaluate various systems would be identified.

Cost Estimate and Backup – To allow for sufficient case study data gathering and potentially some site visits, the project budget is estimated at $500,000.

Related Research

ACRP 02-98: Airport Energy Resiliency Primer and Roadmap. The products of this study identify potential types of systems, but a more detailed guide is needed to assist airports in evaluating and comparing options.

ACRP Research Report 228: Airport Microgrid Implementation Toolkit. This is a good toolkit for airports to evaluate the use of a microgrids, but more detailed information is also needed on other types of redundant and backup systems. Also, several airports have implemented microgrids since the publication

of this study, so airport microgrid case studies can now be captured. The primary case studies in the publication are military bases.

ACRP Synthesis 91/TCRP Synthesis 137: Microgrids and Their Application for Airports and Public Transit. This study was published in 2018 and includes considerations and case studies. Additional airport case studies are now available, and microgrid technology continues to advance.

ACRP Research Report 220: Guidebook for Developing a Zero- or Low-Emissions Roadmap at Airports. While focused on reducing emissions, airports may have multiple goals of low emissions and energy resilience.

ACRP Research Report 199: Climate Resilience and Benefit–Cost Analysis: A Handbook for Airports. Some of the evaluation criteria may apply to energy resiliency projects.

ACRP Report 151: Developing a Business Case for Renewable Energy at Airports. Redundant or backup energy systems may involve renewable energy, especially if airports also have low or zero carbon emission goals and need a business case.

ACRP Synthesis 110: Airport Renewable Energy Projects Inventory and Case Examples. This contains some airport case studies that would be useful for follow-up on success and options to microgrids.

Federal Energy Management Program "Resiliency Planning and Implementation" website: https://www.energy.gov/eere/femp/resilience-planning-and-implementation. An FEMP resource for resilience planning that includes links for training courses, including Technical Resilience Navigator. Includes tools for calculating the cost of a grid outage and other tools to evaluate resilience options.

Topic Areas – Emergency management, financial/economic, operations, sustainability