Project No. 02-10 **Copy No. ____**

PRACTICAL GREENHOUSE GAS EMISSION REDUCTION STRATEGIES FOR AIRPORTS

FINAL REPORT

Prepared for
Airport Cooperative Research Program (ACRP)
Transportation Research Board
of
The National Academies

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June 2011

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ABSTRACT

This report documents the research results focused on identifying practical greenhouse gas (GHG) reduction measures for use at airports. The project results include a Handbook and an interactive, electronic decision-support tool, called AirportGEAR (**Airport** **G**reenhouse Gas **E**mission **A**ssessment and **R**eduction), to aid airport operators in evaluating and selecting the GHG emission reduction measures that are best suited for their airport.

The list of practical GHG reduction strategies consists of 125 strategy in twelve categories, including airfield design and operations, business planning, carbon sequestration, construction, energy management, ground transportation, ground service equipment, materials and embedded energy, operations and maintenance, performance measurement, refrigerants and renewable energy. Each reduction measure was evaluated in accordance with eleven evaluation criteria, including estimated capital costs, estimated operation and maintenance (O&M) costs, estimated payback period, airport control, implementation timeframe, maturity of the measure, GHG reduction potential (in categories of Scopes 1 and 2 combined and Scope 3), and impacts to natural resources, the built environment regulatory compliance. Additional technical information for each strategy was also compiled, including applicability to various airport sizes and geographies, potential funding sources, challenges to implementation, and case study examples, among others. The evaluation criteria results and the technical information are presented in a four-page Fact Sheet for each strategy and serve as the foundation for the Handbook and AirportGEAR.

The Handbook also provides educational and background information, including topics such as emission sources, accounting principles, existing and emerging regulations, and the relationship between GHG emission reduction and other airport documents, processes and programs. Awareness training materials are also included in the Handbook.

The goal of AirportGEAR is to leverage the research findings. AirportGEAR provides a dynamic experience to evaluate and select appropriate GHG emission reduction strategies. Although the tool will not introduce any new information outside of the static Handbook content, it enables a more methodical evaluation of the strategies and allows the user to prioritize, select, and calculate emissions reductions based on airport-specific information.

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EXECUTIVE SUMMARY

ES.1 Introduction

Domestically and internationally, the airport and aviation industries are under pressure to address greenhouse gas (GHG) emissions and climate change, making this ACRP project a timely and much needed research topic. Growing pressures ranging from the international cap and trade debate to regional or local climate change goals and planning, coupled with the rising costs of energy and increasing public demand for protecting the environment, provide a backdrop for airport operators to focus on how to achieve tangible GHG emission reductions. However, even with a complete greenhouse gas emissions inventory, identifying appropriate and cost-effective reduction measures is daunting and can be a time-consuming effort. In addition, just providing a long list of greenhouse gas reduction strategies is not sufficient; a proven interactive tool to assist airports through the process of selecting alternatives for implementation is critical for evaluating and selecting strategies.

In embarking on this research, the oversight panel established the following purpose:

Document the wide range of strategies available to airport operators to reduce emissions of greenhouse gases associated with typical airport activity.

To achieve this objective and assist airports with evaluating various strategies, this project analyzed various greenhouse gas emission reduction strategies and compiled a list of one hundred and twenty-five (125) practices for use in the airport setting. Technical information is presented for each strategy to assist airport operators with selection and implementation of the strategies that are most appropriate for a specific airport. The strategies can be used to for both airport-wide greenhouse gas emission reduction initiatives (e.g. minimizing the use of auxiliary power units) as well as to reduce greenhouse gas emissions associated with a specific project (e.g. installing energy efficient equipment as part of a building renovation). The research results can be used by airport employees in all departments, whether they are in the initial stages of learning about greenhouse gas mitigation or already have greenhouse gas emission reduction activities underway.

ES.2 Findings

The findings of this research include:

- A list of 125 practical GHG reduction strategies in twelve categories, including airfield design and operations, business planning, carbon sequestration, construction, energy management, ground transportation, ground service equipment, materials and embedded

energy, operations and maintenance, performance measurement, refrigerants and renewable energy.

- Fact Sheets that summarize technical information for each strategy that will assist with evaluation, selection and implementation.
- A Handbook that includes educational and background information on GHG emission reduction in general, emission sources and their relative importance to airports, GHG emission accounting principles, existing and emerging regulations, the importance of coordinating with tenants, and the relationship between GHG emission reduction and other airport documents, processes and programs.
- An awareness training presentation that describes the findings of the research, which can be used by airport operators to gain support for GHG emission reduction initiatives.
- An interactive, electronic decision-support tool called AirportGEAR (**Airport** **G**reenhouse Gas **E**mission **A**ssessment and **R**eduction) that leverages the research results by providing a dynamic environment to evaluate the technical data for the GHG emission reduction strategies and select appropriate strategies for a specific airport.

The research findings will assist airport operators in understanding the broad topic of GHG emission reduction as well as the detailed strategies that can be implemented to reduce GHG emissions. The findings were developed to assist airport operators to reduce GHG emissions whether they are in the initial stages of learning about GHG mitigation or already have GHG emission reduction activities underway. AirportGEAR, the interactive decision-support tool, is designed to allow airport operators to evaluate the technical data for each strategy in order to determine which strategies are best suited for a specific airport based on local information.

ES.3 Conclusions

In addition to the technical research findings described in Section ES.2, the following four major conclusions resulted from the research.

1) *Varied Opportunities:* Various opportunities exist to reduce greenhouse gas emissions regardless of airport size, location, operating environment or resources. Strategies are available for all airports, whether they are in the initial stages of learning about greenhouse gas mitigation or already have greenhouse gas emission reduction activities underway. Greenhouse gas strategies can also be implemented by airport employees in all departments. This Handbook and AirportGEAR can assist an airport operator in selecting greenhouse gas reduction actions.

2) *Greenhouse Gas Accounting Principles are Critical:* Understanding greenhouse gas accounting principles and an airport's greenhouse gas inventory is imperative to selecting appropriate greenhouse gas reduction strategies. One size does not fit all.

3) *Integrated Solutions:* Successful implementation of a greenhouse gas reduction program includes integration of reduction concepts into all departments and business processes in addition to discrete application of technological solutions in projects and stand alone programs.

4) *Lifecycle Emissions are Important:* The results presented in this research do not reflect life cycle emissions associated with producing materials. Airports should be cognizant of life cycle emissions when looking at emission reduction strategies.

ES.4 Recommendations

The findings and conclusions of this research may be used to assist airport operators in enhancing the GHG emission reduction initiatives currently underway by the airport industry as a whole. Airport operators of varying levels of progress in GHG emission reduction and airport size, location, operating environment or resources can use the findings to begin reducing GHG emissions for projects and operations. In addition, the research results may be used to increase awareness of the importance of GHG emission reduction and the opportunities available to achieve emission reduction goals.

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CHAPTER 1 BACKGROUND

Domestically and internationally, the airport and aviation industries are under pressure to address greenhouse gas (GHG) emissions and climate change, making this ACRP project a timely and much needed research topic. Growing pressures ranging from the international cap and trade debate to regional or local climate change goals and planning, coupled with the rising costs of energy and increasing public demand for protecting the environment, provide a backdrop for airport operators to focus on how to achieve tangible GHG emission reductions. However, even with a complete greenhouse gas emissions inventory, identifying appropriate and cost-effective reduction measures is daunting and can be a time-consuming effort. In addition, just providing a long list of greenhouse gas reduction strategies is not sufficient; a proven interactive tool to assist airports through the process of selecting alternatives for implementation is critical for evaluating and selecting strategies.

In embarking on this research, the oversight panel established the following purpose:

Document the wide range of strategies available to airport operators to reduce emissions of greenhouse gases associated with typical airport activity.

To achieve this objective and assist airports with evaluating various strategies, this project analyzed various greenhouse gas emission reduction strategies and compiled a list of one hundred and twenty-five (125) practices for use in the airport setting. Technical information is presented for each strategy to assist airport operators with selection and implementation of the strategies that are most appropriate for a specific airport. The strategies can be used to for both airport-wide greenhouse gas emission reduction initiatives (e.g. minimizing the use of auxiliary power units) as well as to reduce greenhouse gas emissions associated with a specific project (e.g. installing energy efficient lighting). The research results can be used by airport employees in all departments, whether they are in the initial stages of learning about greenhouse gas mitigation or already have greenhouse gas emission reduction activities underway.

The research results include: 1) a Handbook and 2) an accompanying decision-support tool, called AirportGEAR (**Airport** **G**reenhouse Gas **E**mission **A**ssessment and **R**eduction). The Handbook also provides educational and background information, including topics such as emission sources, accounting principles, existing and emerging regulations, and the relationship between GHG emission reduction and other airport documents, processes and programs. An awareness presentation is also included as part of the Handbook. AirportGEAR is an interactive, electronic decision-support tool that can be used to leverage the research findings. AirportGEAR provides a dynamic experience to evaluate and select appropriate GHG emission reduction strategies. Although AirportGEAR does not introduce new information outside of the static Handbook content, it enables a more methodical evaluation of the strategies and allows the user to prioritize, select, and calculate emissions reductions based on airport-specific information.

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CHAPTER 2 RESEARCH APPROACH

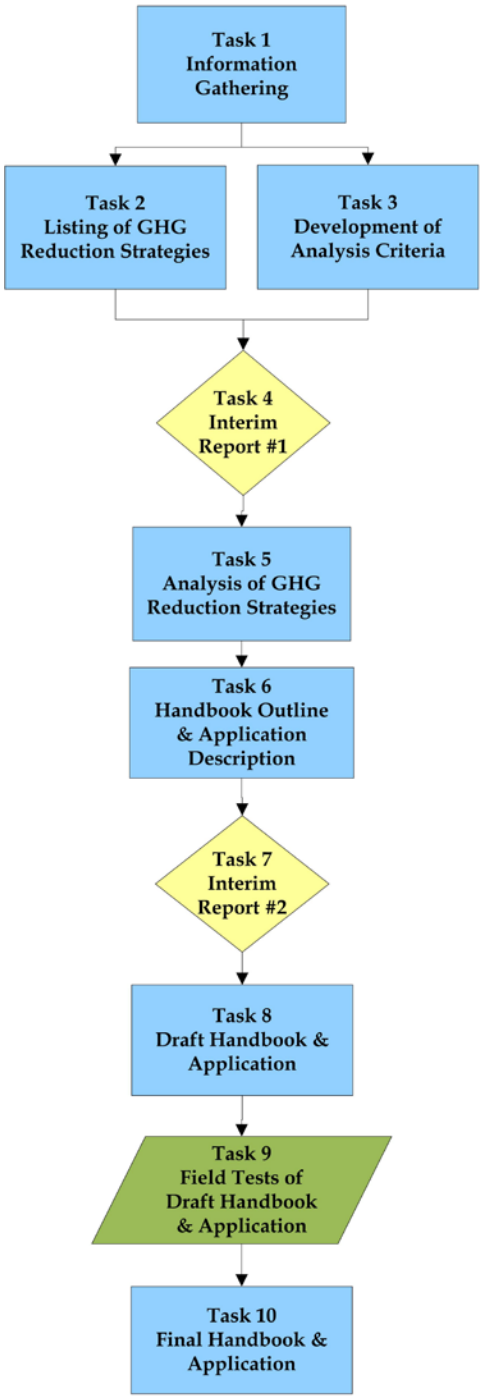
This chapter presents the methodologies used to conduct the research associated ACRP Project 02-10: *Practical Greenhouse Gas Emission Reduction Strategies for Airport*. The scope of this Project consisted of ten (10) tasks to achieve the objectives of the research, as depicted in **Figure 2-1**. A summary of the tasks is presented in the following paragraphs and detailed information regarding the methodologies employed for the tasks is included in the following subsections.

In the first four tasks of the research, available resources were investigated and reviewed to gather information on proven and innovative measures for reducing airport-related GHG emissions. During the resource review, data pertaining to each emission reduction measure, such as cost and example applications, were also recorded. The data were used to compile a list of GHG reduction measures and to develop a set of proposed evaluation criteria that were used to analyze each reduction strategy for cost effectiveness, ease of implementation, and resource impact. Upon completion of these tasks, progress was reported to and reviewed by the Oversight Panel.

Upon receipt and incorporation of comments from the Oversight Panel, the next three tasks focused on the analysis of the reduction measures in accordance with the evaluation criteria, developing a draft outline of the Handbook and developing a draft description of the decision-support tool, AirportGEAR. These results were then presented to the Oversight Panel and an Interim Meeting was held to discuss their comments and the remaining tasks of the research.

Following the Interim Meeting, the final tasks of the Project were executed. The last three tasks included writing the Handbook based on the approved outline and developing AirportGEAR based on the approved application description. Upon completion of the first version of AirportGEAR, a field test was conducted with domestic airports of diverse sizes and geographies to test the tool and provide suggestions for improvement. Following the field tests, the Handbook and AirportGEAR were finalized and presented to the Oversight Panel for review.

Figure 2-1
Summary of Tasks



SUBTASKS	OUTCOME
▪ Literature review ▪ Research institutions ▪ Vendor information ▪ Trade organizations ▪ Governmental agencies	Compendium and reference list of applicable information from previous 10 years as well as emerging information during the course of the research.
▪ Categorize strategies by impact on Scope 1, 2 and/or 3 emissions ▪ Create a template for ranking strategies ▪ Design analysis around application development	Comprehensive list of reduction strategies and a template to analyze and rank the strategies.
▪ Conference call with Research Team and ACRP Panel	Consensus and buy-in on work done to date and the plan to move forward.
▪ Use and adjust ranking template ▪ Develop quality control protocol for analysis ▪ Create fact sheets Update list of strategies	Fact sheets for each strategy including full analysis and example highlights
▪ Update the Handbook Outline included in this Working Plan. ▪ Develop protocol for integrating fact sheets into application.	Handbook outline, application description and awareness training material outline.
▪ Plan for field testing the Handbook & application ▪ Conference call with Research Team and ACRP Panel	Consensus and buy-in on Handbook outline, application description, and training materials as well as the field testing plan.
▪ Develop awareness training materials ▪ Develop quality control protocol for Handbook & application	Draft Handbook, application and training materials
▪ Develop a survey and reporting template to collect feedback ▪ Develop and provide training sessions for participating airports	Feedback from airports regarding clarity and usability of Handbook, application and training materials.
▪ Incorporate field test feedback into the Handbook, application and training materials.	Final Handbook, application and training materials

Research Team Research Team & ACRP Panel Research Team, ACRP Panel & Selected Airports

2.1 Information Gathering and Listing of Greenhouse Gas Emission Reduction Strategies

A comprehensive literature review was conducted to initiate the information gathering activities for this Project. The literature was systematically organized according to the set of subject categories presented in **Table 2-1,** which effectively became a way of identifying the type of emission reduction measures. During the review, the subject matter of the literature was monitored to ensure that publications in all categories were collected and a broad base of emission reduction measures was established.

Table 2-1
Draft Categories of Greenhouse Gas Emission Reduction Measures

Airfield Design and Operations (AF)	Ground Service Equipment (GS)
Business Planning (BP)	Materials and Embedded Energy (ME)
Carbon Sequestration (CS)	Operations and Maintenance (OM)
Construction (CN)	Performance Measurement (PM)
Energy Management (EM)	Refrigerants (RF)
Ground Transportation (GT)	Renewable Energy (on-site) (RE)

Source: CDM January 2010.

In addition to the literature review, internet resources were investigated to collect information. Information sources included the airport trade associations (AAAE, ACI, and ACC, domestic and international airports, International Civil Aviation Organization (ICAO)), airport users (ATA), federal agencies (USEPA and USDOT), and California Climate Action Registry (CCAR). Pertinent research from the Transportation Research Board (TRB) was also included in the information gathering. One significant international data source was collected: "AIRCLIP – Airports and Climate Preservation" and its accompanying database of airport-related greenhouse gas reduction measures that was developed through a survey facilitated by ACI-World and ACI-NA. A complete list of resources is included in the **REFERENCES** section.

Following collection of available resources, the research team assembled a protocol for consistently distilling the information that was collected. A web-based application was used to efficiently develop a database of reduction strategies and relevant technical data. The web-based application allowed the Research Team to share their results in real-time and collaborate accordingly. The database served as the foundation for the Handbook and AirportGEAR.

Upon completion of the information gathering activities for this Project, a list of practical GHG reduction strategies was developed. The emission reduction strategies were organized

according to the categories listed in **Table 2-1**. The categories allow users of the Handbook and AirportGEAR to focus on a specific area that may be of particular importance (e.g. energy management).

2.2 Development of Evaluation Criteria

During the resource review, criteria commonly used to evaluate the effectiveness of various environmental measures were compiled. The members of the Research Team also drew on previous experience in airport operations, GHG management, rating and ranking systems, and decision-making processes to supplement the list of potential evaluation criteria. Over a course of two months, these criteria were discussed, debated, and refined by the Research Team until a consensus-based set of evaluation criteria was established.

As the evaluation criteria were being developed, the visions of the how the Handbook and the decision-support tool are used were also considered. The Handbook is a paper document that includes a Fact Sheet for each reduction measure. The Fact Sheets are organized so that the user can quickly and ***visually*** assess critical information from the evaluation criteria results. A visual rating system for the established evaluation criteria are used to convey this key information. The Fact Sheets are organized in the Handbook by the reduction strategy's category and include detailed information that is needed for practical implementation. The user may focus in on a specific area (e.g. energy management) or may flip through the Fact Sheets to identify measures that have certain evaluation criteria results, such as short payback period, large GHG reduction potential, or no impact on regulatory status.

AirportGEAR uses the information included in the Fact Sheets to develop a customized list of reduction strategies based on the user's input. For AirportGEAR, the rating system is ***numerical*** instead of the visual system employed in the Handbook, and scores are computed based on the established evaluation criteria. High scores indicate preferred reduction strategies.

Based on these visions for the Handbook and the tool, two rating systems for the evaluation criteria were developed. Two different rating systems are needed depending on whether these systems are used in the Handbook or AirportGEAR. For the Handbook, the results of the evaluation criteria are communicated visually through the use of symbols. For example, one to four dollar signs ($ to $$$$) are used to communicate to the reader the estimated capital cost of the reduction strategy, with one dollar sign ($) indicating a lower capital cost. For AirportGEAR, a series of numerical scores are generated from the rating system to assist the user in selecting reduction measures for implementation.

In some cases, the number of symbols presented in the Handbook are the inverse of the score assigned in the tool to resolve the differences between how the "mind's eye" evaluates the visual data in the Handbook and the need for a consistent numerical scoring system in the tool that uses high scores for preferable measures. For example, a measure with a high capital cost will show four dollar signs ($$$$) in the Handbook, which is the maximum number, because the

mind's eye will automatically perceive more symbols as being more expensive. In the tool, a high capital cost are assigned a score of "1", which is the minimum number, because the most expensive measures are not as preferable as less expensive measures and the tool uses a scoring system where high scores indicate preferable measures. Due to this divergence, two rating systems were developed for the consensus-based list of criteria: one for the Handbook and one for the decision-support tool.

2.3 Evaluation of GHG Reduction Strategies

Following review of the draft list of reduction measures and evaluation criteria, the reduction measures were analyzed using the evaluation criteria. Analysis of the reduction strategies was completed in four steps:

1) ***Planning***: A team of experts was established and a quality assurance/quality control (QA/QC) plan was developed. The team consisted of seventeen (17) subject matter experts. Each team member was assigned between five (5) and twelve (12) reduction measures to analyze. The QA/QC plan, as well as regular team communication, was used to ensure that the reduction strategies were evaluated consistently.

2) ***Evaluation***: The team of experts analyzed the reduction measures and recorded the information in an on-line database. During the evaluation, weekly conference calls with the team members were conducted to discuss questions and collaboration opportunities, share resources and troubleshoot issues. The Fact Sheets were generated directly from the database and include the results of the criteria analysis as well as pertinent information needed for implementation. The database will also serve as the foundation and source data for the decision-support tool.

3) ***Technical Review #1***: All Fact Sheets were reviewed by the Principal Investigator and comments were incorporated into the database by the team members. This review focused on content and consistency across all Fact Sheets.

4) ***Technical Review #2***: The Technical Review Committee, a team of seven (7) senior experts, reviewed the Fact Sheets in their area of expertise and the comments were incorporated into the database.

During the evaluation of the reduction strategies, the original list of reduction measures was refined. In some cases, reduction measures were eliminated after the evaluation showed that they were not practical for airports to implement. In other cases, one reduction strategy was split into two or more strategies to increase usability of the information.

The technical information that resulted from evaluation of the reduction strategies serves as the foundation of the Handbook and AirportGEAR. The technical information is organized and presented in a 4-page Fact Sheet for each strategy. In developing the Fact Sheets, the emission

reduction strategies were categorized and evaluated relative to a number of attributes, including:

- Category of the strategy - such as business planning, ground transportation
- Evaluation criteria -- representing issues likely of interest or concern to airports
- Other relevant information, including favorable implementation areas, geographic regions and airport sizes
- Ranking Guidance - the variables that uses can use to help identify strategies that would meet their needs.

2.4 Development of the Handbook and AirportGEAR

Handbook

An initial Handbook outline was included in the Amplified Work Plan (AWP) for this project (dated May 2009) and was used as the starting point for development of the Handbook. Comments received by the Oversight Panel were used to update the outline. Following approval of the outline, the Handbook was prepared.

AirportGEAR

The description of AirportGEAR was developed through a series of workshops and meetings with both GHG and information management experts within the Research Team. During the workshops and meetings, functionality and features of AirportGEAR was developed. Following, the team members responsible for building the tool distilled the information into a "Software Requirements Specification" (SRS) that described in detail how AirportGEAR functions. The SRS was presented to the Oversight Panel during a webinar and their comments were incorporated into the final description of the tool. Following, the tool was developed, tested and prepared for the field tests.

2.5 Field Tests of AirportGEAR

Twelve airports participated in the field tests:

1) Van Nuys Airport, CA
2) Phoenix Sky Harbor Airport, AZ
3) Lincoln Airport, NE
4) San Francisco International Airport, CA
5) Dekalb Peachtree Airport, GA

6) Boeing Field-King County Airport, WA
7) Columbus Airport, OH
8) Boston Logan International Airport, MA
9) Portland International Jetport, ME
10) Port Authority of New York and New Jersey
11) Lambert-St. Louis, MO
12) Dulles International Airport, DC

Tulsa International Airport and Charleston International Airport declined to participate. Anchorage International Airport did not return phone calls or emails regarding participation in this project.

The field tests commenced with a kick-off conference call on September 21, 2010. Prior to the kick-off meeting, materials were sent to the participants, including a copy of the AirportGEAR installation package, a three-ring binder containing the Fact Sheets, and the User's Manual for AirportGEAR. During the kick-off meeting, the background of the project was presented and the expectations of the field tests were discussed.

After the kick-off meeting, the Research Team followed up with the participants to resolve any installation issues. Two progress calls were held in October to provide a forum for the airports to discuss their experiences with each other and to ask the Research Team questions about AirportGEAR. Both progress calls were well attended and informative initial feedback was received. Other than the progress calls, the field test participants used AirportGEAR on their own to simulate a user who will access the tool from the Transportation Research Board following publication.

At the end of the testing period, all participants but two had successfully installed AirportGEAR. The installation issues encountered by those two airports were rooted in the version of the platform that user had installed on the testing computer. Specifically, 64-bit technology was introduced into the market in April 2010 and the structure of this first version of AirportGEAR was not designed to be compatible with this kind of platform. It appears that additional, different installation packages will be needed for brand new computers (those issued after April 2010 to accommodate the 64-bit technology) and older computers (prior to 2002 that utilize Microsoft Service Package 2); this update was incorporated in AirportGEAR for version 2.

The field tests were extended to November 19, 2010 (original completion date was November 5, 2010) to accommodate the schedules of several of the participants. Comments from the field test participants were collected via a comprehensive survey on SurveyMonkey.

Of the 10 participants that were able to successfully install AirportGEAR, 8 submitted comments, including:

1) Van Nuys Airport, CA
2) Phoenix Sky Harbor Airport, AZ
3) San Francisco International Airport, CA
4) Columbus Airport, OH
5) Boston Logan International Airport, MA
6) Port Authority of New York and New Jersey
7) Lambert-St. Louis, MO
8) Dulles International Airport, DC

The comments received by the field test participants were meaningful and proved helpful in improving the tool. Specifically, many of the comments focused on the user interface and aesthetics of the site to enhance usability. In addition, the participants recommended additional information that should be added to AirportGEAR to make it more educational for users.

2.6 Completion of the Handbook and AirportGEAR

Handbook
A draft copy of the Handbook was prepared submitted to the Oversight Panel for review in April 2011. Comments were received in May 2011 and integrated into the final Handbook.

AirportGEAR
The comments received from the field test participants were used to develop a plan for improving AirportGEAR. The plan was executed and version 2 of AirportGEAR was developed. The installation package for AirportGEAR was provided to the Oversight Panel for review and a webinar was conducted to demonstrate the capabilities of the tool to the Oversight Panel. Comments were received during the webinar and as part of written comments received in May 2011. The comments were integrated into the final version of AirportGEAR.

CHAPTER 3 FINDINGS AND APPLICATIONS

3.1 Information Gathering and List of Greenhouse Gas Reduction Strategies

Based on the information gathering, 125 emission reduction strategies were compiled to assist airport operators to reduce airport-related greenhouse gas emissions. This list represents a broad range of opportunities to reduce greenhouse gas emissions associated with airport activity. The list of strategies is presented in **Table 3-1** on the following pages.

3.2 Development of Evaluation Criteria

Three proposed categories of evaluation criteria were developed; 1) Financial Considerations, 2) Implementation Considerations, and 3) Potential Impacts. Evaluation criteria addressed within each category are summarized in **Table 3-2**.

Table 3-2
Summary of Evaluation Criteria

Financial Consideration
Estimated Capital Costs
Estimated Operation and Maintenance Costs
Estimated Payback Period
Implementation Considerations
Airport Control
Implementation Timeframe
Maturity of Strategy
Potential Impacts
Greenhouse Gas Reduction Potential: Scopes 1 & 2
Greenhouse Gas Reduction Potential: Scope 3
Impacts to Natural Resources
Impacts to the Built Environment
Impacts to Regulatory Compliance

Source: CDM January 2010.

Table 3-2
List of Practical Greenhouse Gas Emission Reduction Strategies for Airports

Airfield Design and Operations	
AF-01	Provide Infrastructure for Pre-Conditioned Air (PCA) and Ground Power
AF-02	Minimize the Use of Auxiliary Power Units (APUs)
AF-03	Design Airside Layout to Reduce Aircraft Delay and Surface Vehicle Congestion
AF-04	Design Runways, Taxiways, Ramps & Terminals to Reduce Aircraft Taxiing Distances
AF-05	Consider Longer Runways to Reduce the Use of Reverse Thrust
AF-06	Install or Expand Hydrant Fueling System
AF-07	Provide Fixed Gate Infrastructure for Aircraft Underground Supply and Evacuation Systems
AF-08	Create Partnerships with Intercity Rail Services to Optimize Passenger and Cargo Movement
AF-09	Implement Emission-based Incentives and Landing Fees
AF-10	Install a Jet Fuel Pipeline
AF-11	Support Optimized Departure Management on Existing Runways
AF-12	Support Modernization of Air Traffic Management (ATM)
AF-13	Support the Development of Alternative Fuels for Aircraft
AF-14	Support Single/Reduced Engine Taxiing
AF-15	Support Alternative Passenger Boarding Procedures
AF-16	Support Push Back Tugs to Transport Planes to Taxiways, Runway Ends, and/or Take-off Areas
AF-17	Support Fuel Efficiency Targets for Aircraft
AF-18	Support the Use of Paperless Ticket Technology
Business Planning	
BP-01	Use Greenhouse Gas Impact Evaluations as Decision-Making Criteria
BP-02	Develop an Airport Expansion and Development Greenhouse Gas Emission Policy
BP-03	Develop a Climate Action Plan (CAP)
BP-04	Develop Climate Change and Energy Communication Materials and/or Information Center
BP-05	Create a Carbon Offset Purchasing Strategy
BP-06	Develop and Apply or Sell Carbon Offsets
BP-07	Offer Voluntary Carbon Offsets for Passengers
BP-08	Use Airport-Specific Sustainable Planning, Design, and Construction Guidelines
BP-09	Participate in a Greenhouse Gas Registry and/or Accreditation Program
BP-10	Set a Policy for Green Building Certification for Buildings
BP-11	Support the Use of Customer Self-Service Equipment in Terminal Design

Table 3-2
List of Practical Greenhouse Gas Emission Reduction Strategies for Airports

Construction	
CN-01	Use Warm Mix Asphalt (WMA) in place of Hot Mix Asphalt
CN-02	Recycle and Reuse Construction and Demolition Materials
CN-03	Implement a Construction Vehicle Idling Plan
CN-04	Specify Low-emission Construction Vehicles and Equipment
CN-05	Specify Energy Efficient Temporary Lighting During Construction
Carbon Sequestration	
CS-01	Install Sustainable, Long-term Vegetation
CS-02	Add Mineral Carbonation Systems to Exhaust Streams
CS-03	Implement or Support Carbon Dioxide Capture and Storage Processes
CS-04	Invest in Terrestrial Carbon Sinks
Energy Management	
EM-01	Develop a Strategic Energy Management Plan
EM-02	Specify Energy Efficiency Requirements for Equipment in Contract Agreements
EM-03	Develop Energy Performance Contracting Partnerships
EM-04	Enter into a Green Power Purchasing Agreement
EM-05	Evaluate "Take or Pay" Contract Provisions
EM-06	Develop and Market an Energy Conservation Program for Building Users
EM-07	Evaluate Fuel Mix
EM-08	Use Thermal Imaging to Identify Energy Losses
EM-09	Improve Insulation of Building Envelope
EM-10	Change Set Points or Exclude Selected Zones from Heating and Cooling
EM-11	Restrict Heating and Cooling to Lowest 10 ft of Indoor Space
EM-12	Install Green Vegetated Roofs for Greater Building Insulation
EM-13	Install a Cool Roof
EM-14	Design Building Orientation for Energy Use Reduction
EM-15	Apply Solar Reflective Paint
EM-16	Apply Thermochromic Coatings on Buildings
EM-17	Install LED Runway and Taxiway Lighting
EM-18	Implement a Lighting System Energy Conservation Program
EM-19	Install a Building Automation System (BAS)
EM-20	Periodically Re-commission HVAC Systems and Control Systems

Table 3-2
List of Practical Greenhouse Gas Emission Reduction Strategies for Airports

Energy Management (cont.)	
EM-21	Install High-Efficiency Equipment and Controls
EM-22	Integrate Thermal Storage into Heating and Cooling Systems
EM-23	Evaluate and Upgrade the Central Plant and Distribution System Equipment
EM-24	Install Variable Speed Drives (VSD) and Optimize Controls of Pumps for Air Handling Units
EM-25	Install Evaporative Cooling Systems
EM-26	Install Energy Efficient Chillers
EM-27	Install Ultraviolet-C (UVC) Lights in Air Handling Units (AHUs) for Continuous Coil Cleaning
EM-28	Install a Heat Recovery System
EM-29	Design for Larger Diameter Piping
EM-30	Reduce Transmission Losses in Electrical Wires
EM-31	Purchase ENERGY STAR Equipment
EM-32	Enhance Piping Insulation
EM-33	Construct a Cogeneration or Trigeneration Energy System
EM-34	Use Methane from Anaerobic Bioreactor Treatment Systems for Deicing Fluids
EM-35	Install Energy Efficient Elevators, Escalators, and Autowalks
EM-36	Optimize Passenger and Baggage Handling System
EM-37	Incorporate Use of Natural Ventilation and Economizer Control
EM-38	Install Window Awnings or Sunshades
EM-39	Utilize Sophisticated Energy Models for Building Design
Ground Service Equipment	
GS-01	Support Alternatively Fueled Ground Service Equipment (GSE)
Ground Transportation	
GT-01	Provide Priority Vehicle Parking for Emissions Friendly Vehicles
GT-02	Provide Preferential Car/Vanpool Parking for Employees
GT-03	Promote Public Transit to the Airport
GT-04	Provide Transit Fare Discounts and/or Alternative Mode Subsidies
GT-05	Increase Mass Transit Access to the Airport
GT-06	Alter Parking Pricing Structures for Employees and Passengers

Table 3-2
List of Practical Greenhouse Gas Emission Reduction Strategies for Airports

Ground Transportation (cont.)	
GT-07	Implement "On-foot" Payment for Parking
GT-08	Implement a Traffic Management System
GT-09	Allow Telecommuting for Employees
GT-10	Allow Flexible Work Schedules for Employees
GT-11	Build a Consolidated Rent-A-Car Facility (ConRAC)
GT-12	Construct a Personal Rapid Transit (PRT) System
GT-13	Promote Bicycle Use by Employees
GT-14	Convert Airport Fleet Vehicles to Alternatively Fueled Vehicles
GT-15	Support Conversion of Tenant Fleet Vehicles to Alternatively Fueled Vehicles
GT-16	Support Alternatively Fueled Vehicles for Rental Cars and Commercial Vehicles
GT-17	Support Alternatively Fueled Taxis
Materials and Embedded Energy	
ME-01	Develop an Integrated Solid Waste Management Plan
ME-02	Start or Enhance a Waste Reduction or Recycling Program
ME-03	Start or Enhance a Green Procurement Program (GPP)
ME-04	Separate and Compost Food Waste
Operation and Maintenance	
OM-01	Create a Detailed Operations and Maintenance Manual
OM-02	Develop a Measurement and Verification Plan
OM-03	Use a Computerized Maintenance Management System (CMMS)
Performance Measurement	
PM-01	Conduct Regular Greenhouse Gas (GHG) Emission Inventories
PM-02	Perform Energy Audits
PM-03	Install Tenant Energy Sub-Metering Systems
PM-04	Track Energy Use
PM-05	Work with Airport Industry to Develop Benchmarking Databases

Table 3-2
List of Practical Greenhouse Gas Emission Reduction Strategies for Airports

Renewable Energy (on-site)	
RE-01	Install Building Integrated Photovoltaic (BIPV) Panels
RE-02	Install Building-mounted or Ground-mounted Solar Photovoltaic (PV) Panels
RE-03	Install Solar Thermal Systems for Hot Water Production
RE-04	Use Solar Desiccant Air Conditioning Systems
RE-05	Use On-site Biomass Energy Systems
RE-06	Install Ground-Source or Geothermal Heating and Cooling System
RE-07	Install a Geothermal Snow and Ice Melting System
RE-08	Use Seawater and Natural Water Bodies for Cooling
RE-09	Install Building-Mounted Wind Turbines
RE-10	Install a Waste-to-Energy System
RE-11	Install a Tidal Energy System
RE-12	Install Sewer Heat Recovery Systems
RE-13	Construct a Hydrogen Fueling and Generation Station
RE-14	Utilize Local Landfill Gas
Refrigerants	
RF-01	Replace Refrigerants with Natural or Lower Global Warming Potential (GWP) Gases
RF-02	Incorporate Intelligent Fault Diagnosis for HVAC Refrigerant Systems
RF-03	Use Hydronically Coupled Vapor-Compression Heat Pumps
RF-04	Install Microchannel Components and Heat Exchangers

Source: CDM September 2010.

As discussed in Chapter 2, the proposed rating systems for the evaluation criteria are different depending for the Handbook and AirportGEAR because these two resources are used differently. For the Handbook, the evaluation criteria are communicated visually through the use of symbols. For example, one to four dollar signs ($ to $$$$) are used to communicate to the reader the estimated capital cost of the reduction strategy, with one dollar sign ($) indicating a lower capital cost. For AirportGEAR, a series of numerical scores are generated from the rating system to assist the user in selecting reduction measures for implementation.

In some cases, the number of symbols presented in the Handbook are the inverse of the score assigned in AirportGEAR to resolve the differences between how the "mind's eye" evaluates the visual data in the Handbook and the need for a consistent numerical scoring system in the tool that uses high scores for preferable measures. For example, a measure with a high capital cost will show four dollar signs ($$$$) in the Handbook, which is the maximum number, because the mind's eye will automatically perceive more symbols as being more expensive. In AirportGEAR, a high capital cost are assigned a score of "1", which is the minimum number, because the most expensive measures are not as preferable as less expensive measures and the tool uses a scoring system where high scores indicate preferable measures. Due to this divergence, two rating systems were developed for the consensus-based list of criteria: one for the handbook and one for the application tool, as presented in **Table 3-3**.

For AirportGEAR, the maximum potential score for each category (Financial Considerations, Implementation Considerations and Potential Impacts) is equal so that emphasis is not placed on one category over the others. As part of the decision-support tool, the user will have the ability to weight each of the criteria according to the relative importance at the airport in order to incorporate individual user preferences.

Table 3-3
Evaluation Criteria

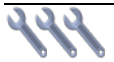
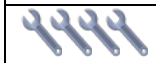
Financial Considerations				
Criterion	*Definition*	*Rating Values*		
		Icon	*Numerical Score in AirportGEAR**	*Rating Value Definitions*
Estimated Capital Costs	Upfront costs to plan, design and/or construct the reduction action.	$	1	< $10,000
		$$	2	$10,000 - $100,000
		$$$	3	$100,001 - $1,000,000
		$$$$	4	> $1,000,000
Estimated Annual Operations and Maintenance Costs	Annual costs for continued implementation of the reduction action.		1	< $5,000
			2	$5,000 - $50,000
			3	$50,001 - $100,000
			4	> $100,000
Estimated Payback Period*	The time required for the return on an investment to "repay" the capital and operations and maintenance costs.		1	< 2 years
			2	2 - 5 years
			3	6 - 10 years
			4	> 10 years

Table 3-3
Evaluation Criteria

Implementation Considerations				
Criterion	*Definition*	*Rating Values*		
		Icon	*Numerical Score in AirportGEAR*	*Rating Value Definitions*
Airport Control***	The level of financial and logistical control of the airport operator to implement the reduction action.	✈	1	Airport operator has no ownership, control, or influence over implementation of the strategy
		✈✈	2	Airport operator has no ownership, or control, but can influence the reduction of GHG emissions through policy, procedures or training
		✈✈✈	3	Airport has no ownership, or control, but can influence the reduction of GHG emissions through infrastructure improvements
		✈✈✈✈	4	Airport operator has complete control over implementation of strategy
Implementation Timeframe	The time period required to implement the action and reduce GHG emissions.		1	Immediate: < 1 yr
			2	Short-term: 1 - 5 yrs
			3	Medium-term: 5 - 10 yrs
			4	Long-term: > 10 yrs
Maturity of Strategy	Past demonstration that the reduction action is implementable and effective.	★	1	Conceptual stage
		★★	2	Trial tested
		★★★	3	Proven
		★★★★	4	Proven at airports

Table 3-3
Evaluation Criteria

Potential Impacts				
Criterion	*Definition*	*Rating Values*		
		Icon	*Numerical Score in AirportGEAR*	*Rating Value Definitions*
GHG Reduction Potential: *Scopes 1 & 2***	The magnitude of the reduction in Scope 1 & 2 GHG emissions (Direct and Indirect emissions) as a result of the action.	*None*	0	Does not decrease Scopes 1 &2 emissions
			1	Low: reduction of Scopes 1 & 2 emissions is always relatively low
			2	Medium: there is potential for the reduction of Scopes 1 & 2 emissions to range from low to high depending on implementation details
			3	High: reduction of Scopes 1 & 2 emissions is always relatively high
GHG Reduction Potential: *Scope 3****	The magnitude of the reduction in Scope 3 GHG emissions (Other emissions) as a result of the action.	*None*	0	Does not decrease Scope 3 emissions
			1	Low: reduction of Scope 3 emissions is always relatively low
			2	Medium: there is potential for the reduction of Scope 3 emissions to range from low to high depending on implementation details
			3	High: reduction of Scope 3 emissions is always relatively high

Table 3-3
Evaluation Criteria

Potential Impacts (Cont.)				
Criterion	*Definition*	*Rating Values*		
		Icon	*Numerical Score in AirportGEAR*	*Rating Value Definitions*
Impacts to Natural Resources	Impacts or secondary benefits to natural resources.		2	Adverse impacts to natural resources (i.e. stormwater)
			0	No benefit or impact to natural resources
			-2	Benefit to natural resources (i.e. reduces criteria pollutants)
Impacts to the Built Environment	Secondary benefits for the built environment and local communities.		2	Adverse impacts to the built environment
			0	No adverse or positive impacts to the built environment
			-2	Positive impact to the built environment
Impacts to Regulatory Compliance	Impact on the airport operator's compliance status with regulations.		2	May trigger a change to regulatory compliance status
			0	Does not change regulatory compliance status
			-2	May facilitate compliance with a regulation

Table 3-3
Evaluation Criteria

* For "Estimated Capital Cost", "Estimated O&M Cost" and "Estimate Payback Period", AirportGEAR transforms the numerical scores shown here to complete the calculation of the overall numerical score for the strategy. When computing the overall numerical score for the strategy, AirportGEAR reverses the scores for these criteria (e.g. one dollar sign is represented at "4" in the overall numerical score calculation instead of "1") to reflect that higher scores are more desirable. The user does not need to do anything different based on this information; this reversal of scores is done in the background of the tool and is represented in the overall numerical score for the strategy. The user should use the numerical scores shown in this table when interpreting or changing the rating values for these evaluation criteria in AirportGEAR.

** Does not consider financial incentives such as grants, rebates or tax incentives or the cost of carbon.

*** Ranking scale is representative of a majority of airports, but may not fit the control and operation structure for every airport

3.3 Evaluation of GHG Reduction Strategies

The results of the evaluation of the reduction strategies are presented in the compilation of Fact Sheets included in the Handbook. The Fact Sheets include the following information:

- A description of the reduction action
- The results of the criteria analysis with explanations for how the ratings were determined
- GHG emission sources impacted by the reduction measure
- Impacts of geography and airport size on implementation
- Space requirements
- Airport activities impacted by the reduction measure (e.g. planning, construction, airside operations)
- Implementation area
- Recommended stakeholder engagement
- Funding opportunities
- Case studies
- On-line resources
- Key references
- Related reduction measures

3.4 Handbook and AirportGEAR

The Handbook associated with this Project is included as a separate file and includes the Fact Sheets, the AirportGEAR User's Manual and an Awareness Training presentation. The AirportGEAR installation package is also included as a separate set of files.

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CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

In addition to the technical research findings, the following four conclusions resulted from the research.

1) *Varied Opportunities:* Various opportunities exist to reduce greenhouse gas emissions regardless of airport size, location, operating environment or resources. Strategies are available for all airports, whether they are in the initial stages of learning about greenhouse gas mitigation or already have greenhouse gas emission reduction activities underway. Greenhouse gas strategies can also be implemented by airport employees in all departments. This Handbook and AirportGEAR can assist an airport operator in selecting greenhouse gas reduction actions.

2) *Greenhouse Gas Accounting Principles are Critical:* Understanding greenhouse gas accounting principles and an airport's greenhouse gas inventory is imperative to selecting appropriate greenhouse gas reduction strategies. One size does not fit all.

3) *Integrated Solutions:* Successful implementation of a greenhouse gas reduction program includes integration of reduction concepts into all departments and business processes in addition to discrete application of technological solutions in projects and stand alone programs.

4) *Lifecycle Emissions are Important:* The results presented in this research do not reflect life cycle emissions associated with producing materials. Airports should be cognizant of life cycle emissions when looking at emission reduction strategies.

4.2 Recommendations

The findings and conclusions of this research may be used to assist airport operators in enhancing the GHG emission reduction initiatives currently underway by the airport industry as a whole. Airport operators of varying levels of progress in GHG emission reduction and airport size, location, operating environment or resources can use the findings to begin reducing GHG emissions for projects and operations. In addition, the research results may be used to increase awareness of the importance of GHG emission reduction and the opportunities available to achieve emission reduction goals.

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