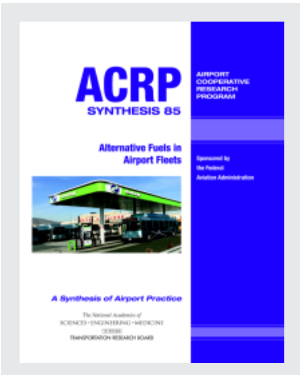

Alternative Fuels in Airport Fleets

DETAILS

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ACRP

SYNTHESIS 85

AIRPORT
COOPERATIVE
RESEARCH
PROGRAM

Alternative Fuels in Airport Fleets

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A Synthesis of Airport Practice

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AIRPORT COOPERATIVE RESEARCH PROGRAM

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Alternative Fuels in Airport Fleets

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA).

ACRP carries out applied research on problems that are shared by airport operating agencies and not being adequately addressed by existing federal research programs. ACRP is modeled after the successful National Cooperative Highway Research Program (NCHRP) and Transit Cooperative Research Program (TCRP). ACRP undertakes research and other technical activities in various airport subject areas, including design, construction, legal, maintenance, operations, safety, policy, planning, human resources, and administration. ACRP provides a forum where airport operators can cooperatively address common operational problems.

ACRP was authorized in December 2003 as part of the Vision 100—Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), Airlines for America (A4A), and the Airport Consultants Council (ACC) as vital links to the airport community; (2) TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academy of Sciences formally initiating the program.

ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for ACRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

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Primary emphasis is placed on disseminating ACRP results to the intended users of the research: airport operating agencies, service providers, and academic institutions. ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties; industry associations may arrange for workshops, training aids, field visits, webinars, and other activities to ensure that results are implemented by airport industry practitioners.

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Cover figure: Alternative fuel refueling station, San Francisco International Airport. *Courtesy:* Abubaker Azam.

FOREWORD

Airport administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to the airport industry. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire airport community, the Airport Cooperative Research Program authorized the Transportation Research Board to undertake a continuing project. This project, ACRP Project 11-03, "Synthesis of Information Related to Airport Practices," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an ACRP report series, *Synthesis of Airport Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Gail R. Staba
Senior Program Officer, Transportation Research Board

Airports own and contract fleets to transport passengers, staff, and goods by on- and off-road vehicles. Although most transportation fuels are consumed by aircraft, using alternative fuels in airport fleets is one opportunity airports have to control emissions and fuel costs and potentially reduce maintenance. Because of complex procurement, operational, and environmental decision making associated with alternative fuels, airport operators can be challenged when analyzing the options.

This synthesis of current airport practice compiles information on eight alternative fuels: biodiesel, renewable diesel, compressed natural gas (CNG), renewable natural gas, liquefied natural gas (LNG), liquefied petroleum gas (LPG), hydrogen, and electricity. Notably, ethanol and hybrid-electric vehicles (HEVs) are not included in this report because the driving experience and refueling operations associated with ethanol and HEVs are well understood and documented elsewhere.

Information used in this study was acquired through a review of the literature, an online survey completed by 33 airports (80% response), and 16 follow-up interviews with respondent airport operators.

Dr. Geoff Morrison, Damon Fordham, and Cian Fields, The Cadmus Group, Inc., collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on page iv. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

ALTERNATIVE FUELS IN AIRPORT FLEETS

SUMMARY

Alternative fuel use presents a valuable opportunity for airports to reduce emissions, manage fuel costs, reduce petroleum dependence, increase energy security, potentially reduce maintenance efforts, increase energy security, and strengthen their public image. However, navigating the complex procurement, operational, and environmental decision making associated with alternative fuels can be challenging for airports of any size or location. Although most transportation fuel used at airports is consumed by aircraft, airports often have sizable fleets of hundreds or even thousands of on- and off-road vehicles.

The objective of this synthesis report is to compile airport experiences using alternative transportation fuels in *airport-owned* or *airport-contracted* vehicles, including the following vehicle functional categories: shuttles, emergency response and security, and facility and maintenance. In total, 41 airports were sent a request to complete a comprehensive online survey. Of these, 33 airports completed the survey, a response rate of 80%. In addition, 16 of the respondent airports also participated in follow-up interviews by teleconference. This report is designed for use by airport senior management, fleet managers, airport environmental managers, procurement staff, and capital finance managers.

This synthesis report considers eight alternative fuels: biodiesel, renewable diesel, compressed natural gas (CNG), renewable natural gas, liquefied natural gas, liquefied petroleum gas, hydrogen, and electricity. Notably, ethanol and hybrid-electric vehicles (HEVs) are not included in this report because the driving experience and refueling operations associated with ethanol and HEVs are well understood and documented elsewhere. Figure 1 presents the airports that responded to the survey and their approximate fuel use mixes in airport-owned and airport-contracted vehicles. Greater detail on airport experiences can be found in chapter four, organized by fuel type, and chapter five, organized by vehicle type.

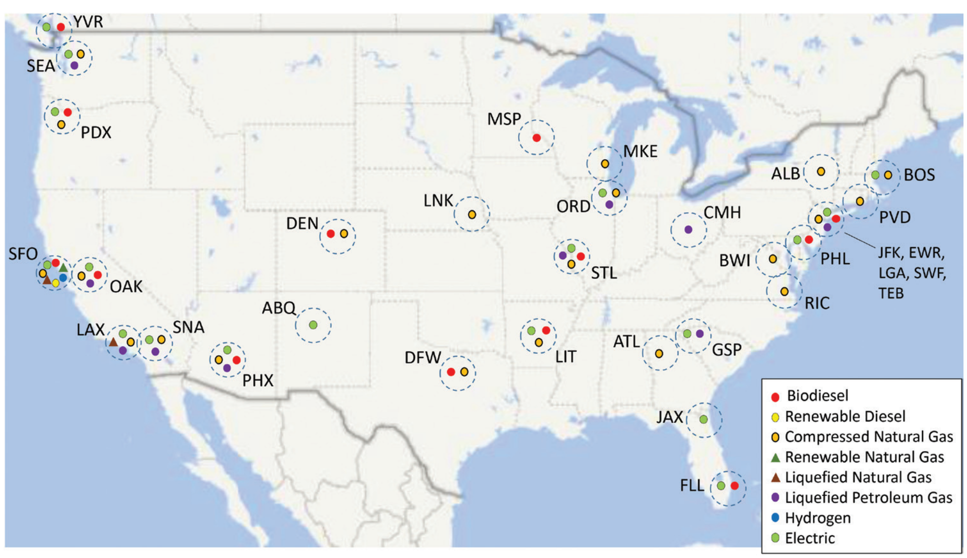

FIGURE 1 Map showing airport responses to online survey.

The online survey and phone interviews produced the following key observations:

- The use of alternative fuels has risen steadily in airport vehicle fleets since the early 1990s, in both the total number of airports using alternative fuels and the diversity of the fuel types used.
- Airports purchase alternative fuel vehicles for a variety of reasons, most notably to maintain an environmentally friendly image and to reduce greenhouse gas (GHG) emissions.
- Airports vary in their willingness to try new fuels. Phone interviews revealed the following factors explain much of that variation: (1) fuel availability in the airport's geographic region; (2) the airport's spatial footprint and the consequent driving distance between refueling stops; (3) the existence of tunnels, which preclude the use of certain gaseous fuels; (4) the frequency of extreme snow events; (5) the existence of policies that require the use of alternative fuels; (6) the existence of government incentives that lower the cost of alternative fuels; and (7) the degree of stakeholder and community involvement.
- Among the fuels considered in this synthesis report, CNG is used at the greatest number of airports (71% of airports surveyed). However, the fastest-growing fuel type in the past 5 years is electricity, used at 64% of airports surveyed.
- Buses and shuttle buses are often the first vehicle types that an airport considers good candidates for alternative fuels because (1) they create high levels of pollution near pedestrians; (2) they tend to have highly predictable duty cycles, which makes it relatively simple to plan refueling events; and (3) they are publicly visible, enabling airports to present an environmentally friendly image.
- A key concern airports expressed about the use of alternative fuels in buses and shuttle buses is the negative publicity that could be created if vehicles become inoperable or are out of service for extended periods.
- Most airports undertake the same three-step process when considering the use of a new alternative fuel: (1) identify available vehicle options that use a given fuel, (2) determine the costs and benefits of the alternative versus petroleum-based fuels, and (3) examine options for external and internal financing of vehicles, fuels, and infrastructure.
- Airports reported receiving a great amount of value from bi-fuel vehicles, such as vehicles that can use CNG or diesel/gasoline. Bi-fuel systems help ensure a vehicle's reliability when one of the fuels has an inoperable refueling station.
- The use of certain low-carbon fuels such as renewable natural gas and renewable diesel is limited in airport fleets, but the fuels are promising because of their competitive costs and their ability to dramatically decrease GHG emissions.
- Most alternative fuel dispensing stations are owned by private firms that operate both on- and off-airport. CNG and electric charging stations are exceptions; they are mostly airport-owned.
- Of the airports interviewed, 83% reported needing to construct new alternative fuel infrastructure when introducing a new alternative fuel, rather than being able to leverage existing infrastructure in the region.
- At some airports, a major barrier to alternative fuel use is the limited selection of vehicles in the procurement system resulting from (1) "Buy America" requirements, or (2) requirements to procure vehicles only from a given automaker (e.g., Ford).

A qualitative summary table (Table 1) depicts attributes of each fuel type. Further details about each attribute are provided in the report.

The interview results revealed several future research needs:

- Research on the lifetime durability of alternative fuel vehicles compared with conventionally powered vehicles. Survey respondents noted the lack of information on alternative fuels at the middle and end of vehicles' lifetime.
- Market assessment of emerging fuels associated with deep reductions in GHG emissions, such as electricity, renewable natural gas, renewable diesel, and hydrogen.

- A handbook or tool that helps airports conduct cost–benefit analyses on alternative fuel vehicles at their airports, and provides guidance on determining the environmental, social, and economic costs and benefits associated with vehicle procurement, maintenance, operation, and disposal.

TABLE 1

QUALITATIVE COMPARISON OF ALTERNATIVE FUELS

Passenger Car		Fuel Cost	Vehicle Cost	Fuel Availability	Vehicle Availability	GHG Emissions (*kg/mi*)	Air Quality (Tailpipe Emissions Only)			
							NOx (*g/mi*)	PM2.5 (*mg/mi*)	PM10 (*mg/mi*)	CO (*g/mi*)
	Gasoline[1]					0.31	0.12	4.78	5.41	2.7
	Hydrogen[2]			*		0.26	0	0	0	0
	Electric[3]					0.21	0	0	0	0

Heavy-Duty Pickup Truck		Fuel Cost	Vehicle Cost	Fuel Availability	Vehicle Availability	GHG Emissions (*kg/mi*)	Air Quality (Tailpipe Emissions Only)			
							NOx (*g/mi*)	PM2.5 (*mg/mi*)	PM10 (*mg/mi*)	CO (*g/mi*)
	Diesel[4]					0.62	1.15	21.89	25.22	0.46
	BD20[5]					0.53	0.94	10.89	11.84	0.37
	RD100[6]					0.44	0.94	10.89	11.84	0.37
	CNG					0.55	0.46	10.16	11.48	7.49
	LPG					0.55	0.46	10.16	11.48	7.49
	RNG[7]	No data		**		0.09	0.46	10.16	11.48	7.49

Transit Bus		Fuel Cost	Vehicle Cost	Fuel Availability	Vehicle Availability	GHG Emissions (*kg/mi*)	Air Quality (Tailpipe Emissions Only)			
							NOx (*g/mi*)	PM2.5 (*mg/mi*)	PM10 (*mg/mi*)	CO (*g/mi*)
	Diesel[4]					3.12	1.17	21.29	23.14	0.52
	BD20[5]					2.68	1.17	21.29	23.14	0.52
	RD100[6]					2.21	1.17	21.29	23.14	0.52
	CNG					3.31	0.59	21.29	23.14	23.00
	LNG					3.30	0.59	21.29	23.14	23.00
	RNG[7]	No data		**		0.55	0.59	21.29	23.14	23.00
	Electric[3]					1.50	0.00	0.00	0.00	0.00

Sources: Fuel cost: DOE 2017c; vehicle cost: ANL 2016b; fuel availability: DOE 2017b; vehicle availability: DOE 2017a; emissions: ANL 2016a; renewable natural gas GHG emissions: CARB n.d.

Key:

Worse than reference		Slightly worse than reference	Similar to reference / Reference fuel	Slightly improved over reference		Improved over reference

Colors should not be compared between vehicle types or columns.

Notes:

* Fuel currently available only in California.

**Fuel available mainly on West Coast of the United States.

1. E10 gasoline.
2. Gaseous hydrogen from natural gas reforming using conventional material.
3. Electricity produced using average U.S. grid mix.
4. Low-sulfur diesel.
5. Biodiesel from average Midwest soybeans and transesterification. Mixed with low-sulfur diesel at a ratio of 20-80 biodiesel-diesel.
6. Renewable diesel from hydrotreated pyrolysis oil from forest residues. Vehicle uses 100% renewable diesel.
7. Renewable natural gas from landfill gas, upgraded to pipeline quality.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Gasoline and diesel are the primary fuels used in the United States transportation sector, accounting for 93% of all energy use in light-, medium-, and heavy-duty vehicles (EIA 2016). Additionally, the transportation sector is a major contributor to greenhouse gas (GHG) and criteria pollutant emissions. A key strategy to address petroleum use and emissions from the transportation sector is to use alternative fuels (NAS 2013).

Fleet vehicles are widely viewed as attractive markets for alternative fuels for the following reasons (DOE 2001; Sperling and Nesbitt 2001):

- Certain fleet vehicles, such as buses and shuttle buses, often have higher mileage than privately owned vehicles, meaning the environmental benefits are amplified when shifting vehicles to alternative fuels.
- Fleet procurement processes tend to enable longer planning horizons than individual consumers typically use.
- Fleet vehicles often can be centrally fueled, reducing fuel infrastructure costs.
- Airport vehicle fleets often have predictable duty cycles with efficient refueling operations but long idle periods and frequent stops near pedestrians.

Although the costs and benefits of alternative fuels are fairly well understood, their use in airport fleets is not. This synthesis report compiles airport experiences with alternative fuels in airport-owned and airport-contracted vehicles, including shuttles, emergency response and security vehicles, and facility and maintenance vehicles. Insights provided in the report are designed to assist airports beginning new programs or modifying existing alternative fuel programs, and to help all airports understand the barriers and opportunities presented by alternative fuel use.

During report development, airports in the United States and Canada were surveyed about a range of topics involving alternative fuel vehicles, including fuel and vehicle costs, infrastructure, procurement, administrative considerations, environmental impact analysis, and future interests. Following completion of the online survey, 16 of the participating airports were interviewed via teleconference, giving additional details about their alternative fuel programs. Together, the online survey results and teleconference discussions provided an array of insights about how alternative fuels are being used in airport-owned and airport-contracted vehicles.

FUELS

This report considers eight alternative fuels, as described in Table 2. These fuels were chosen based on their potential to reduce emissions and petroleum use, and on whether the general population has a firm understanding of their costs and benefits. Notably, ethanol was not included in the study because it has been widely used in the market since the 1980s, and only minimal training is needed for personnel to understand the operation of flex-fuel vehicles (i.e., those capable of running on up to 85% ethanol by volume). Similarly, simple hybrid-electric vehicles were not included because the driving experience and refueling operations are the same as those of a petroleum-fueled vehicle. However, vehicles capable of running on grid electricity or in hybrid-electric mode are included [e.g., plug-in hybrid electric vehicles (PHEVs)]. Table 3 provides qualitative information on each fuel, allowing for easy comparison of each fuel's attributes and emissions. Chapter four discusses each of the fuels in greater detail.

TABLE 2
DESCRIPTIONS OF FUEL TYPES INCLUDED IN STUDY

Fuel Type	Description
Biodiesel	Animal or vegetable oil–derived fuel made via transesterification process. Biodiesel is rarely used in its pure form (B100) and is often blended with conventional diesel (B2, B5, and B20, where the number following the "B" is the percentage of biodiesel blended). Typically, biodiesel is not blended at levels above 20% without modification to the fuel storage tank and engine. In this report, the term "Biodiesel" refers to B2, B5, and B20 unless otherwise stated.
Renewable Diesel	Fuel made from waste oils, fats, and vegetable oils that can be blended directly with conventional diesel up to 100% with no modification to the engine. Also known as "green diesel." Typically produced via hydrotreating process.
Compressed Natural Gas (CNG)	Fossil-based gaseous fuel, comprised mostly of methane.
Renewable Natural Gas	Fuel made from municipal solid waste and other bio-based feedstocks that is interchangeable with conventional natural gas and provides considerable greenhouse gas benefits, depending on the production process. Also known as "bio-methane." Typically sourced via anaerobic digestion of municipal solid waste.
Liquefied Natural Gas (LNG)	Conventional natural gas converted to liquid form through cooling.
Liquefied Petroleum Gas (LPG)	Fossil-based fuel created as by-product of natural gas and petroleum refining. Delivered and stored as liquid fuel. Also known as propane fuel.
Hydrogen	Gaseous fuel typically used in fuel cell or direct combustion.
Electricity	Fuel from the electricity grid, stored aboard vehicles in batteries. For this report, includes all-electric vehicles and plug-in hybrid electric vehicles.

VEHICLES

Airports own, lease, or contract a variety of vehicles that support daily operations. This synthesis report separates airport fleet vehicles into three functional categories: (1) shuttles, (2) emergency response and security, and (3) facility and maintenance. The vehicles within each category have similar duty cycles and administrative managers. The purpose of these groupings is to make this report as organized and user-friendly as possible. Within each functional category, several individual vehicle types are discussed, as described in Table 4. Large commercial service airports have up to hundreds or even thousands of vehicles in their fleets.

To demonstrate a "typical" airport-owned vehicle fleet portfolio, Figure 2 shows the makeup of the vehicle fleet at Oakland International Airport, a midsize commercial service airport. The fleet makeup is diverse; 15 vehicle types are represented. Pickup trucks and sedans account for more than 50% of all airport-owned vehicles.

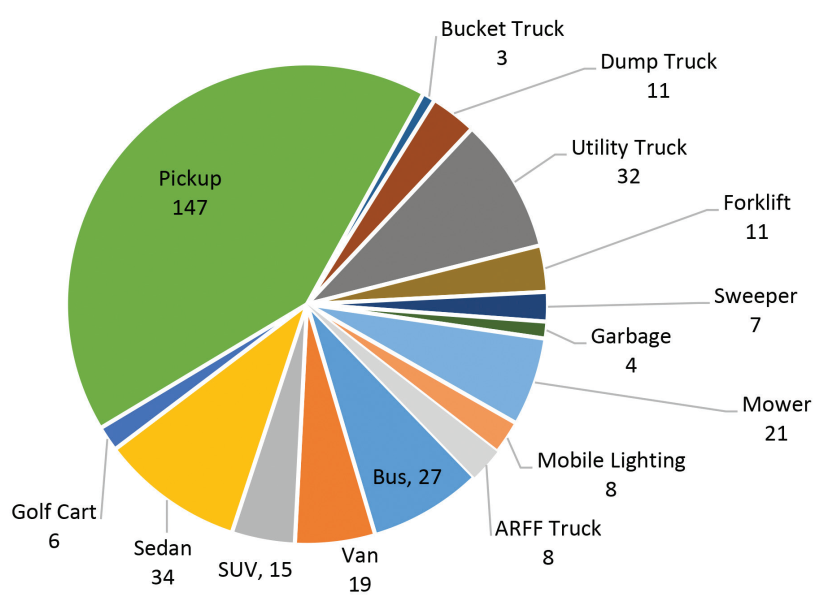

FIGURE 2 Example of "typical" airport-owned vehicle fleet (*Source*: Oakland International Airport).

Note that Figure 2 does not show stationary equipment that uses transportation fuels (e.g., diesel-powered pressure washers). In addition, the figure does not reflect the total fuel consumption of the vehicles—only the number of vehicles. In most airport fleets,

TABLE 3
QUALITATIVE COMPARISON OF ALTERNATIVE FUELS

Passenger Car	Fuel Cost	Vehicle Cost	Fuel Availability	Vehicle Availability	GHG Emissions (*kg/mi*)	Air Quality (Tailpipe Emissions Only)			
						NOx (*g/mi*)	PM2.5 (*mg/mi*)	PM10 (*mg/mi*)	CO (*g/mi*)
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Hydrogen[2]			*		0.26	0	0	0	0
Electric[3]					0.21	0	0	0	0

Heavy-Duty Pickup Truck	Fuel Cost	Vehicle Cost	Fuel Availability	Vehicle Availability	GHG Emissions (*kg/mi*)	Air Quality (Tailpipe Emissions Only)			
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CNG					3.31	0.59	21.29	23.14	23.00
LNG					3.30	0.59	21.29	23.14	23.00
RNG[7]	No data		**		0.55	0.59	21.29	23.14	23.00
Electric[3]					1.50	0.00	0.00	0.00	0.00

Sources: Fuel cost: DOE 2017c; vehicle cost: ANL 2016b; fuel availability: DOE 2017b; vehicle availability: DOE 2017a; emissions: ANL 2016a; renewable natural gas GHG emissions: CARB n.d.

Key:

Worse than reference		Slightly worse than reference	Similar to reference / Reference fuel	Slightly improved over reference		Improved over reference

Colors should not be compared between vehicle types or columns.

Notes:
* Fuel currently available only in California.
**Fuel available mainly on West Coast of the United States.
1. E10 gasoline.
2. Gaseous hydrogen from natural gas reforming using conventional material.
3. Electricity produced using average U.S. grid mix.
4. Low-sulfur diesel.
5. Biodiesel from average Midwest soybeans and transesterification. Mixed with low-sulfur diesel at a ratio of 20-80 biodiesel-diesel.
6. Renewable diesel from hydrotreated pyrolysis oil from forest residues. Vehicle uses 100% renewable diesel.
7. Renewable natural gas from landfill gas, upgraded to pipeline quality.

TABLE 4
DESCRIPTIONS OF VEHICLE TYPES FROM SURVEY RESPONDENTS

Functional Category	Description and Use
Shuttles	Vehicles used primarily to move people (e.g., employees, passengers, tenants) between terminals, parking lots, or other locations. Can be indoor or outdoor. Includes employee vehicle pool/car share vehicles. Vehicle types include buses (>40 passengers), shuttle buses (<40 passengers), cut-aways, and vans.
Emergency Response and Security	Vehicles used primarily by emergency services or security personnel. Vehicle types include Airport Rescue and Firefighting vehicles, pickup trucks or sport utility vehicles (SUVs), sedans, carts (e.g., golf carts, shuttles), and ambulances.
Facility/Maintenance	Vehicles used primarily for operational support of the airport. Vehicle types include pickup trucks or SUVs, sedans, bucket trucks, dump trucks, utility trucks, forklifts, snow removal vehicles, sweepers, and garbage trucks.

the vast majority of fuel is used in the buses, shuttles, and vans, even though they represent a small percentage of the fleet. These vehicles have relatively low fuel economies and high vehicle miles traveled compared with other vehicles in the airport fleet.

LITERATURE REVIEW

Understanding Life-Cycle Costs

To evaluate the true cost of ownership of vehicles, airport fleet managers should consider estimating the life-cycle cost of ownership, typically in $/mi. This formula incorporates upfront vehicle costs, fuel costs, maintenance and repair costs, infrastructure costs, and vehicle disposal costs. Additionally, the life-cycle costs should capture differences in the training requirements, permitting, or management of the vehicles, if needed.

Several publicly available websites and documents provide useful comparisons across alternative fuel and vehicle categories. For example, the U.S. Department of Energy's (DOE's) Alternative Fuel Data Center provides data on all the fuels included in this report, including fuel costs, refueling station locations, and tools for fleet managers (DOE 2016a). A recent study by the National Academies of Science, Engineering, and Medicine (NAS) provides an all-encompassing examination of transitions to alternative fuels, including future performance of alternative fuel vehicles, costs, and barriers to implementation (NAS 2013).

Alternative fuel studies that focus exclusively on fleet vehicles are less common. DOE (2001) summarized alternative fuel use at three case study airports and concluded that although some fuels can lead to cost savings compared with equivalent diesel vehicles, external funding for alternative fuel programs is critical to their success. *ACRP Synthesis 24: Strategies and Financing Opportunities for Airport Environmental Programs* (Molar 2011) provides a wealth of information on funding opportunities and strategies available to airports and applicable to alternative fuels. Sperling and Nesbitt (2001) examined the decision-making process of fleet managers and found that the most compelling attributes of alternative fuels—such as the ability to reduce emissions—are not important motivators for fleet managers, who are more likely to prioritize minimizing the cost for a given level of service. In addition, the authors observed that fleets often have short-term budgets relative to other larger organizations, making vehicles with long payback periods less appealing.

Relatively little research has been conducted on the emissions benefits of alternative fuels at airports. One report, *ACRP Web-Only Document 13: Alternative Fuels as a Means to Reduce PM2.5 Emissions at Airports* (Pearce et al. 2012), investigates the potential PM2.5 (particulate matter with a diameter of 2.5 micrometers or less) emissions reductions from 18 different alternative fuels in aircraft, ground support equipment (GSE), and road vehicles. The report findings show that, at five case example airports, parking vehicles contribute a maximum of 2.0% of on-airport PM2.5 emissions (San Diego International Airport), and other non-GSE vehicles contribute a maximum of 3.0% (Hartsfield Atlanta International Airport).

Airport GHG inventories also provide valuable data on emissions. They indicate that airport-owned and airport-contracted vehicle emissions contribute to a sizeable portion of the emissions over which an airport has direct control. Typically, inventories divide emissions into Scope 1, 2, and 3 (Kim et al. 2009):

- **Scope 1** emissions are those under the direct control of the airport and include airport fleet vehicles.
- **Scope 2** emissions result from electricity consumed by the airport but generated off-airport.
- **Scope 3** emissions include all other emissions attributable to, but not directly generated by, the airport, such as those from aircraft, GSE, and employee commuting (WRI 2012).

How Important Are Greenhouse Gas Emissions from Fleet Vehicles?

At the Philadelphia, Los Angeles, and Minneapolis–Saint Paul International Airports, fleet vehicles account for 38%, 43%, and 45% of Scope 1 emissions, respectively.

Fleet managers at airports have several tools at their disposal to compare alternative fuel emissions, learn about financing alternative fuels, and determine associated cost savings. These tools are highlighted in Table 5 along with additional tools that are not specific to determining the emissions or economics of alternative fuels, but nevertheless may be useful for airport managers.

ORGANIZATION OF THE REPORT

The following chapters present results and analysis from the online survey and interviews. Chapter two describes the methodology for recruiting airports. Chapter three provides an overview of the findings and examines broad, cross-cutting topics.

Chapter four highlights interview results and findings for each of the fuel types. Chapter five discusses user experiences for three vehicle categories. Chapter six concludes this synthesis report with a summary of the study findings and next steps.

TABLE 5
TOOLS FOR ALTERNATIVE FUELS IN AIRPORT FLEETS

Tool Name	Description	URL
	Emissions Tools	
Greenhouse Gas Regulated Emissions and Energy Use in Transportation Model (GREET)	This model enables users to easily perform life-cycle analysis simulations of alternative transportation fuels and vehicle technologies.	https://greet.es.anl.gov/
Aviation Environmental Design Tool (AEDT)	AEDT is a software system that dynamically models aircraft performance in space and time to simulate fuel burn, emissions, and noise.	https://aedt.faa.gov/
MOtor Vehicle Emission Simulator (MOVES)	This emission modeling system estimates emissions for mobile sources at the national, county, and project levels for criteria air pollutants, GHGs, and air toxins.	https://www.epa.gov/moves
EMission FACtor (EMFAC)	This emissions model is developed and used by the California Air Resources Board to assess emissions from on-road vehicles including cars, trucks, and buses in California.	https://www.arb.ca.gov/msei/categories.htm
How Clean Is Your Electric Vehicle?	This calculator allows users to compare emissions of plug-in hybrid electric and battery electric vehicles to gasoline-only vehicles, by ZIP code.	http://www.ucsusa.org/clean-vehicles/electric-vehicles/ev-emissions-tool#.WJC2aUn2bct
	Economic Tools	
Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool	This tool helps users examine both the environmental and economic costs and benefits of alternative fuel and advanced vehicles.	https://greet.es.anl.gov/afleet
Alternative Fuel Price Report	The *Clean Cities Alternative Fuel Price Report* provides regional alternative and conventional fuel prices for biodiesel, compressed natural gas, ethanol, hydrogen, propane, gasoline, and diesel.	http://www.afdc.energy.gov/fuels/prices.html
VICE 2.0: Vehicle and Infrastructure Cash-Flow Evaluation (VICE) Model	The VICE model version 2.0 is the second generation of the financial model developed by the National Renewable Energy Laboratory for fleet managers, to assess the financial soundness of converting their fleets to run on CNG.	http://www.afdc.energy.gov/vice_model/
Vehicle Cost Calculator	This tool uses basic information about driving habits to calculate total cost of ownership and emissions for makes and models of most vehicles, including alternative fuel and advanced technology vehicles.	http://www.afdc.energy.gov/calc/
Electric Vehicle (EV) Charging Financial Analysis Tool	This tool was developed to evaluate the financial viability of EV charging infrastructure investments involving multiple private and public sector partners.	https://www.c2es.org/publications/business-models-financially-sustainable-ev-charging-networks
Electric Vehicle Explorer	This tool enables users to determine whether an EV is right for them by comparing the costs of several vehicles.	http://gis.its.ucdavis.edu/evexplorer/#!/locations/start
	General Tools	
Alternative Fueling Station Locator	This interactive map enables users to find alternative fueling stations near an address or ZIP code or along a route in the United States.	http://www.afdc.energy.gov/locator/stations/
Petroleum Reduction Planning Tool	This planning tool helps vehicle fleets reduce petroleum consumption and GHG emissions.	https://www.afdc.energy.gov/prep/
Database of Federal and State Laws and Incentives	This database enables users to search incentives and laws related to alternative fuels and advanced vehicles by jurisdiction.	http://www.afdc.energy.gov/laws/search

CHAPTER TWO

METHODS

SELECTION OF AIRPORTS

A list of airports to survey and potentially interview was compiled from a variety of sources including the list of airports in the FAA Voluntary Airport Low Emissions (VALE) Program (FAA 2016), DOE's alternative fuel station locator database (DOE 2016a), correspondence with members of the ACI-NA Environmental Affairs Committee, and correspondence with panel members and consultants. The final list of 41 airports invited to take the survey represented a range of sizes of airports and a large portion of FAA regional offices. The lack of randomization and the relatively small sample size make it impossible to generalize the statistical results beyond descriptive statistics. Additionally, most airports are in the commercial service category—smaller general aviation and reliever airports may differ in the costs and benefits they can expect from alternative fuels.

DEVELOPMENT AND IMPLEMENTATION OF FULL ONLINE SURVEY

An online survey was developed to gather insight into airport experiences with alternative fuels. The survey was designed to quickly and efficiently capture basic information about the airport's alternative fuel use, and identify barriers to and unanticipated outcomes of using alternative fuels in airport-owned and airport-operated vehicles. The survey achieved 33 unique responses across the United States and Canada, representing a response rate of 80%. The survey was built using the web-based SurveyGizmo tool. In some cases, the survey was saved by one user and completed by another user from the same airport, owing to the breadth of topics covered.

The logic paths within the survey guided participants to questions relevant and specific to their indicated alternative fuel usage. For example, a user who indicated that the airport in question used biodiesel would be prompted to indicate whether the airport blends that biodiesel with conventional diesel, and at what ratio. Participants who did not indicate biodiesel usage would never see this question. These branching pathways aided in minimizing survey completion time and user fatigue while still allowing the gathering of highly detailed information on each airport.

The survey began by requesting basic information about the airport, followed by descriptive information about its use of alternative fuel (e.g., types and number of vehicles, purchase dates, and infrastructure required for fueling), and then more detailed questions (e.g., ownership breakdown, procurement strategies, funding, satisfaction, and experience with implementing use of the fuel). The survey also included questions specific to the fuels the respondent reported using (e.g., biodiesel blend). Snapshots of the online survey can be seen in Figure 3.

DEVELOPMENT OF FOLLOW-UP INTERVIEW

On completion of the survey portion of this project, follow-up interviews were conducted with 16 of the airports that participated in the survey. These interviews were conducted by teleconference and lasted between 30 min and 1.5 h. The interviewees had varying positions and roles at their respective airports: Some were environmental managers; others were fleet managers or consultants who supported an airport. Although airport interest in participation was limited, the study team strived to achieve a diversity of geographic regions and airport classifications (i.e., large/small commercial service, reliever, and general aviation).

The follow-up phone interviews also varied in content and structure, based on the airport's survey responses. The interviewer usually began by asking what was driving the airport to adopt alternative fuels. The interviewer then invited any insight the interviewees could offer and any experience they had gained that would be valuable to others who are beginning to implement alternative fuels. The interviews were used as an opportunity to clarify points of confusion or scarcity of detail

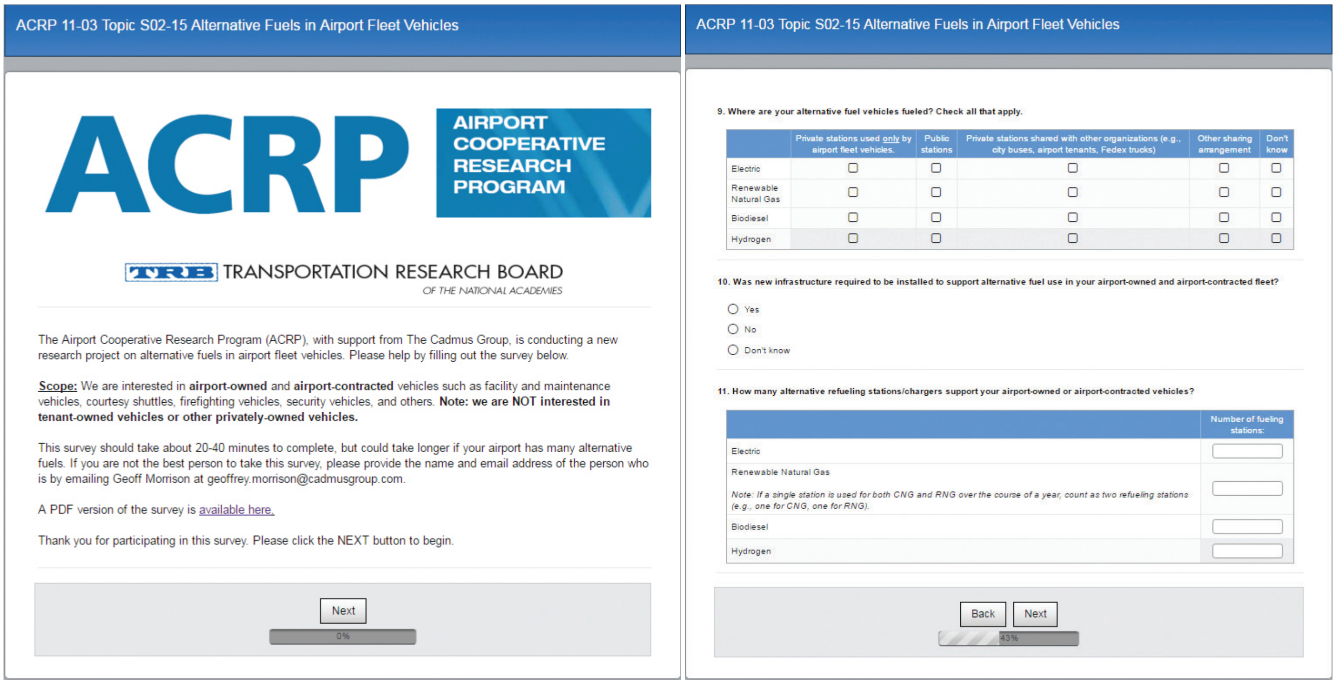


FIGURE 3 Snapshot of cover page of the online survey (left) and of questions within online survey (right).

in the survey responses. (Frequently, the interviewer invited greater detail about the owner/operator breakdown, because the answers were typically more complex than the survey instrument allowed.)

The survey asked about a range of topics relevant to airports planning alternative fuel use, including

- Accessory equipment
- Employee engagement
- Weather impacts
- Training requirements
- Emission reductions
- Fleet size
- Fuel costs
- Vehicle costs
- Procurement process
- Operations and maintenance
- Project financing
- Refueling infrastructure
- Safety
- Policy

The full survey questionnaire can be found in Appendix A. The list of airports that responded to the survey and that participated in phone interviews is featured in Appendix B.

CHAPTER THREE

OVERVIEW OF ALTERNATIVE FUEL USE IN AIRPORT FLEETS

HISTORICAL USE OF ALTERNATIVE FUELS AT AIRPORTS

Airports that responded to the online survey reported having launched alternative fuel vehicle programs as early as 1991. Over the subsequent 25 years, greater numbers of airports began to use alternative fuels in airport-owned and airport-contracted vehicles (see Figure 4). Note that this figure indicates the number of airports using alternative fuels, not the *volume* of alternative fuels or their *environmental benefits*. Today, across the 33 airports surveyed for this report, the most common alternative fuels are compressed natural gas (CNG) and electricity. Of the airports surveyed, 71% use CNG; 64% use electricity. Biodiesel and liquefied petroleum gas (LPG) are less common—48% of the airports use biodiesel; 42% use LPG. The remaining fuel types included in this study—renewable diesel, renewable natural gas, and hydrogen—are used at less than 5% of responding airports.

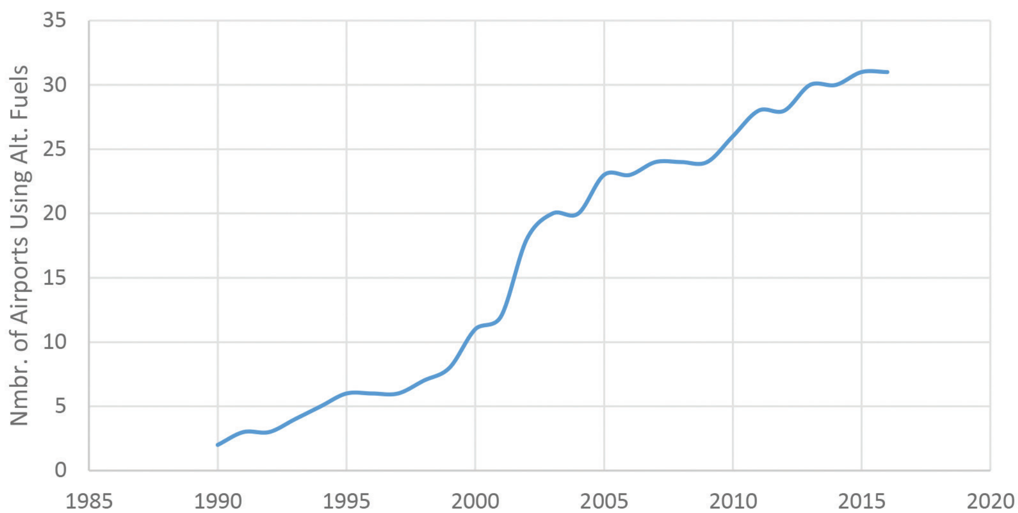


FIGURE 4 Growth of alternative fuels used at airports participating in the online survey ($n = 31$); y-axis shows the number of airports using alternative fuels over time. (Figure does not reflect the total fuel volume used at the airport. Figure omits airports that did not know what year they began using alternative fuels.)

Figure 5 provides an image of which fuels are used at which airports. Please note that this figure indicates which fuels are employed but not the *volume* of alternative fuels or their *environmental benefits*.

DRIVERS OF ALTERNATIVE FUEL USE AT AIRPORTS

Airports were asked to rate six factors—petroleum reduction, local air pollution reduction, GHG reduction, image of environmental conscientiousness, cost savings, and compliance with regulation—according to importance in driving a decision to shift to alternative fuel vehicles. Responses varied from "not important" to "extremely important." The results are shown in Figure 6.

Maintaining an environmentally conscientious image was rated "extremely important" by the highest percentage of respondents. These airports are willing to pay a premium and to accept reduced travel range, cargo and passenger capacity,

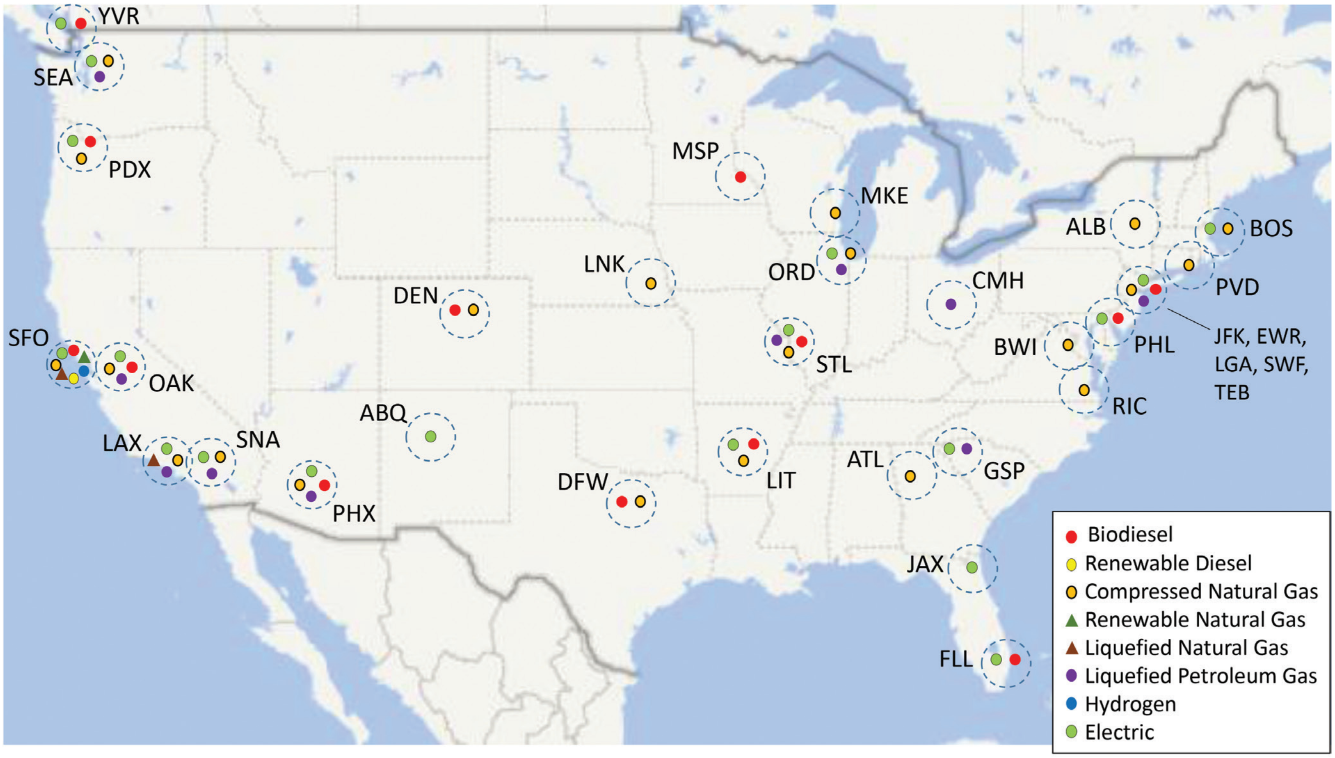


FIGURE 5 Alternative fuels used at airports in online survey.

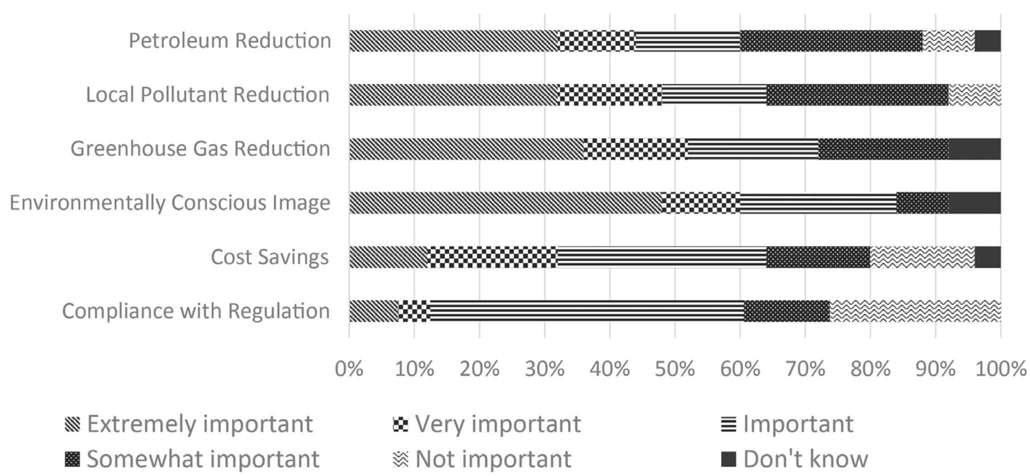


FIGURE 6 Drivers of alternative fuel use at airports (n = 33).

and refueling opportunities, to acquire vehicles and/or use fuels that they believe convey an image of environmental stewardship. GHG reductions were also widely considered important. Compliance with regulation was the factor least frequently rated "extremely important."

ROLE OF AIRPORT DECISION-MAKING PROCESS

The survey and interviews highlighted the large number of personnel, airport departments, and airport partners needed to successfully implement alternative fuel programs. Respondents discussed the innate challenge of coordinating across multiple decision makers including vehicle operators, fleet procurement officials, infrastructure decision makers, maintenance personnel, environmental managers, and senior airport management. Additionally, at some airports, the local municipality or port authority serves as the final decision maker on issues related to vehicle and infrastructure procurement.

Sperling and Nesbitt (2001) offer a valuable framework for understanding how administrative differences between airports affect alternative fuel vehicle adoption. The authors classified vehicle fleet decision making using a conceptual map along two dimensions: formalization and centralization (Figure 7). *Formalization* is the extent to which formal rules govern fleet decision making. *Centralization* is the degree to which fleet decision making occurs within a single office or organization. From this structure, four quadrants emerge: hierarchic, autocratic, bureaucratic, and democratic.

		Formalization	
		High	Low
Centralization	High	Hierarchic	Autocratic
	Low	Bureaucratic	Democratic

FIGURE 7 Vehicle fleet decision-making conceptual map (*Source*: Sperling and Nesbitt 2001).

These structures vary in the degree of ease with which airports can begin a new alternative fuel program. For example, in bureaucratic vehicle fleets (high formalization, low centralization), decisions are dispersed among several individuals or departments. Addressing broad societal or environmental problems such as greenhouse gas emissions or petroleum dependency becomes "someone else's problem" and often goes unaddressed. As a result, uptake of alternative fuels or vehicles may be slow or even impossible without a strong and/or clear government mandate or policy. On the other hand, hierarchical structures (high formalization, high centralization) tend to place decisions in the hands of a small number of decision makers who possess the authority to pursue promising emerging fuels.

Sperling and Nesbitt (2001) argue that hierarchical structures are the most effective circumstances for the adoption of alternative fuels because the few individuals with power can directly align the other levels of decision making to a single set of objectives. In the case of alternative fuel adoption, the objective of fleet managers is to use vehicles with the lowest cost and shortest payback periods, whereas upper management's objectives are broader and include air quality and public relations.

Airports that participated in this survey vary considerably in their formalization and centralization. Using a set of survey questions and typology similar to those used by Sperling and Nesbitt (2001), the survey revealed that decision making in airports fleets is most often bureaucratic or, somewhat less often, hierarchical. Few airports were classified as democratic, and in only one instance was an airport classified as autocratic. Table 6 summarizes the approach used to categorize airport decision making. (Note: Respondents who answered "Don't know" to questions in Table 6 were removed. As noted previously, hierarchical decision-making structures have been observed to be the most conducive to alternative fuel adoption.)

TABLE 6
SURVEYED AIRPORTS' APPROACH TO VEHICLE PROCUREMENT

Question Types	Question*	Percentage of Airports Responding "Yes"	Percentage of Airports Responding "Somewhat"	Percentage of Airports Responding "No"
Formalization Questions	Formal written rules guide vehicle procurement decisions? ($n = 22$)	64	27	9
	Detailed cost analyses are used before vehicle procurement process? ($n = 19$)	53	37	11
	Emissions analyses are used before vehicle procurement decisions? ($n = 22$)	32	45	23
	Final vehicle choices are made after soliciting bids? ($n = 21$)	67	24	10
Centralization Questions	Vehicle procurement decisions are made by only 1 or 2 individuals? ($n = 22$)	36	18	45
	Senior management decides which fuels and how many vehicles are procured? ($n = 24$)	54	38	8

Source: Analysis of survey results.
*Respondents who answered "Don't know" were removed from the total used to calculate percentages.

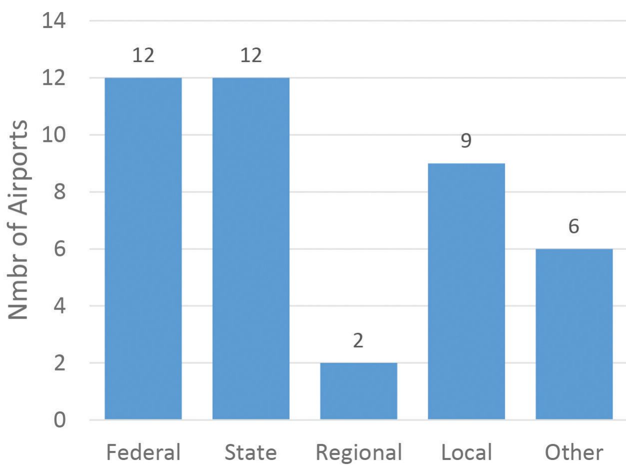
PROCUREMENT OF ALTERNATIVE FUEL VEHICLES

Minneapolis–Saint Paul International Airport Fleet Planning

As part of its new fleet management strategy to target efficiency, Minneapolis–Saint Paul International Airport (MSP) is using a formal process to determine when to adopt a new alternative fuel. This system incorporates a return on investment (ROI) calculation based on the expected vehicle, fuel, infrastructure, and maintenance costs. The predetermined ROI threshold triggers the purchase of an alternative fuel vehicle when a given fuel's ROI reaches the threshold. For example, MSP seeks fuels with ROIs of 7 years or less.

Airports, cities, and port authorities typically have dedicated procurement offices that write specifications for each vehicle based on usage requirements, and then post a vehicle procurement for bidding by vendors. Of the 33 airport respondents, 67% operate in this way. During the interviews, several airports mentioned that it is standard practice for them to take the lowest bid vehicle option without accounting for fuel price differences. This tactic proves problematic for alternative fuel powertrains, which tend to have higher upfront costs but lower operating costs that can offset the purchase cost premium over the course of the vehicle's lifetime. Payback periods vary based on fuel type, vehicle usage characteristics, and many other factors. It is important for airports to consider lifetime costs, but not all airports do.

Many airports reported financing as a barrier to using alternative fuel vehicles. To overcome the higher upfront costs typical for an alternative fuel deployment, many airports pursue external or alternative funding approaches including rebates, tax credits, and grants. As noted, *ACRP Synthesis 24: Strategies and Financing Opportunities for Airport Environmental Programs* (Molar 2011) can serve as a useful resource for airports looking to fund an alternative fuel initiative. Figure 8 reflects data on the form and sources, respectively, of funding used by the airports surveyed.



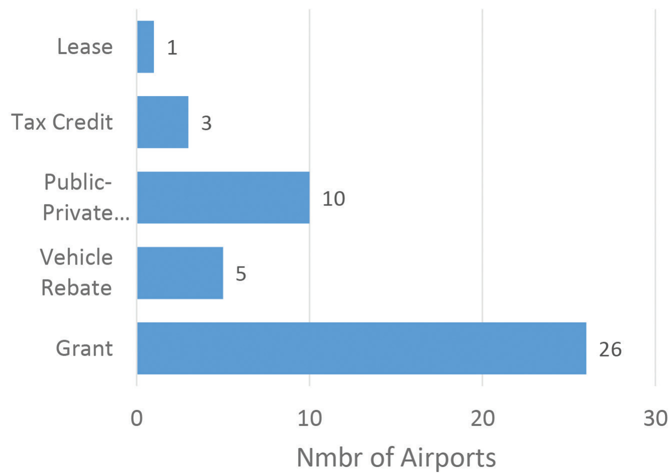


FIGURE 8 Locality of funding for alternative fuels (left) and source of funding (right).

During the interviews, multiple airports also acknowledged the advantages of VALE grants but noted the significant time and cost associated with the detailed application process. FAA's Zero Emission Vehicle Pilot Program is considered to have an easier application process, with only a five-page checklist application.

Beyond financial barriers, airports reported administrative impediments. Several airports noted difficulties in procuring alternative fuel vehicles because the procurement process was entirely controlled by a separate municipal entity. Airports have unique vehicle operating characteristics and needs, and the nuanced way in which an alternative fuel can benefit an airport may be unfamiliar to an external procurement office. At least two airports also cited the stipulations of the Buy America Act as limiting their vehicle options in the already narrow alternative fuel vehicle market. Other airports commented on the cyclical nature of vehicle procurement and grant offerings and their effects on attempts to implement alternative fuels. In many cases, the cycles do not line up—for example, an airport needs a new vehicle but the grant is not being offered, or funding is available but there's no immediate need for a new vehicle—resulting in needs going unmet or opportunities being missed.

VEHICLE AVAILABILITY

When airports consider adopting alternative fuels, they often follow a basic three-step process: (1) identify viable vehicle makes and models, (2) assess the costs of those vehicles versus a conventionally powered vehicle, and (3) identify external funding sources and methods for leveraging existing infrastructure.

Near-term consideration of an alternative fuel vehicle is possible only if a vehicle type is readily available on the market. Figure 9 shows the vehicle-fuel combinations that existed in the 2016 U.S. vehicle market. Green indicates the vehicle is widely available. Orange indicates limited availability or use in demonstration projects in the United States. Red indicates no availability.

		Fuel Type							
Vehicle Category	Vehicle Type	Biodiesel	Renewable Diesel	Compressed Natural Gas	Renewable Natural Gas	Liquefied Natural Gas	Liquefied Petroleum Gas	Hydrogen	Battery-Electric
Shuttles	Bus, Shuttle Bus	▯	▯	▯	▯	~	▯	~	▯
	Van	▯	▯	▯	▯	~	▯	X	~
Emergency Response and Security	Pickup or SUV	▯	▯	~	~	X	~	X	~
	Sedan	▯	▯	▯	▯	X	▯	~	▯
	Airport Rescue and Firefighting (ARFF)	▯	▯	▯	▯	X	X	X	X
	Ambulance	▯	▯	▯	▯	X	▯	X	X
Facility / Maintenance	Pickup or SUV	▯	▯	~	~	X	~	X	~
	Sedan	▯	▯	▯	▯	X	▯	~	▯
	Bucket, Dump, Tow, Utility Truck	▯	▯	▯	▯	~	▯	X	X
	Forklift	▯	▯	▯	▯	X	▯	▯	▯
	Snow Removal	▯	▯	▯	▯	~	▯	X	X
	Sweeper	▯	▯	▯	▯	~	▯	X	X
	Garbage Truck	▯	▯	▯	▯	▯	▯	X	~

Key:
- ▯ Widely Available (Green)
- ~ Limited Availability/Demonstration Only (Orange)
- X No Availability (Red)

FIGURE 9 Vehicle availability types in the United States.

FUEL AND INFRASTRUCTURE COST

Fuel delivery is one of the great barriers to alternative fuel adoption. Government estimates of the cost of new refueling stations vary widely—from $12,000 to $18,000 for electric charging stations (DOE 2016a), up to more than $1,000,000 for new hydrogen stations (CARB 2016). Notably, some fuels, such as renewable diesel, are drop-in fuels; therefore, they do not require new infrastructure. This compatibility helps airports avoid the cost of new infrastructure.

A key strategy for reducing infrastructure costs is to leverage the existing refueling infrastructure in the region. In the United States today, there are almost 17,000 refueling stations for biodiesel, renewable diesel, CNG, liquefied natural gas (LNG), hydrogen, electricity, and propane/LPG, of which approximately 15,000 are electric charging stations. However, airports in the online survey reported using existing refueling stations only 13% of the time, suggesting that either airports are too far from many of the existing refueling stations or fleet managers prefer having their own dedicated refueling stations.

Airports have also relied on external grants to help fund alternative fuel infrastructure. For example, Congestion Mitigation and Air Quality Improvement funding is not restricted to vehicle acquisition; it can also be used for infrastructure development, parking facility construction, and related activities. VALE grants have also been used to fund infrastructure construction or improvements, such as the upgrades to existing CNG stations at Albany International Airport. Table 7 provides a brief list of federal/national funding programs that can be used for alternative fuels in fleet vehicles at airports.

TABLE 7
FUNDING PROGRAMS AVAILABLE FOR ALTERNATIVE FUELS IN AIRPORT FLEET VEHICLES

Program Name	Funder
Clean Diesel National Grants	U.S. Environmental Protection Agency
FAA Voluntary Airport Low Emission Program	Federal Aviation Administration
Congestion Mitigation and Air Quality Improvement Program	Federal Highway Administration and the Federal Transit Administration. Funds are distributed locally through metropolitan planning organizations.
Department of Energy, Clean Cities	U.S. Department of Energy
Zero Emissions Airport Vehicle Program	Federal Aviation Administration
VW Settlement Zero Emission Vehicle Investment	Volkswagen AG

Fuel price is a major component of the total cost of vehicle ownership. A key advantage of alternative fuels is that they are less prone to dramatic price fluctuations. However, because many alternative fuels have not reached market maturity, costs are uncertain and often higher than those of conventional fuels. Table 8 shows airport response results to the question of whether the alternative fuels used at their airports had become less or more expensive compared with conventional fuels over the past 2 years.

TABLE 8
SURVEYED AIRPORTS' ALTERNATIVE FUEL COSTS (RELATIVE TO CONVENTIONAL FUELS)

	Total Responses	Less Expensive	About the Same	More Expensive	Don't Know
Biodiesel	14	14%	29%	14%	43%
Renewable Diesel	1	0%	100%	0%	0%
CNG	15	80%	0%	13%	7%
LNG	0	n/a	n/a	n/a	n/a
LPG	6	17%	33%	0%	50%
Renewable Natural Gas	1	100%	0%	0%	0%
Hydrogen	1	0%	0%	100%	0%
Electric	17	35%	12%	12%	41%

The higher fuel costs of many alternative fuels and the upfront cost of infrastructure pose challenges to airports. Fuel costs can account for a major portion of the total cost of ownership of conventionally powered vehicles when annualized over the vehicles' lifetime. Airports were asked to estimate whether the alternative fuels used at their airports were less or more expensive than conventional fuels, or about the same. Unsurprisingly, the two fuels that the highest percentage of respondents said were less expensive were CNG and electricity, at 80% and 35%, respectively. Table 9 gives the average costs of fuels for each of the alternative fuels in this report.

Last, another strategy for financing alternative fuel infrastructure is partnering with airport tenants. Forty-two percent of airports in the online survey reported either having a joint airport-tenant alternative fuels program or engaging tenants in some way on alternative fuels. The most common activities are to team with tenants on grant funding or to co-host vehicle demonstrations. Additionally, multiple airports reported having programs with ground transportation operators, such as Clean Taxi programs and alternative fuel requirements for shared-ride vans. Overall, airports stated they had more influence over ground transportation than airline GSE.

TABLE 9
NATIONAL AVERAGE FUEL PRICE BETWEEN OCTOBER 1 AND OCTOBER 31, 2016

Fuel	Cost	Source
Diesel	$2.48/gallon	(DOE 2016a)
Gasoline	$2.22/gallon	(DOE 2016a)
Biodiesel (B20)	$2.46/gallon	(DOE 2016a)
Renewable Diesel*	~$0.15/gallon above petroleum diesel	(Ernst 2016)
CNG	$2.06/gasoline gallon equivalent (GGE)	(DOE 2016a)
Renewable Natural Gas	No data	No data
LNG	$2.43/diesel gallon equivalent	(DOE 2016a)
LPG	$2.68/gallon	(DOE 2016a)
Hydrogen	$13/kg or $5.3/GGE**	(DOE 2016c)
Electricity	$0.13/kWh or $1.45/GGE***	(DOE 2016a)

*California only in 2016.
**Assumes 2.5 times higher efficiency of hydrogen fuel cell electric vehicles compared with internal combustion vehicles.
***Assumes 3.0 times higher efficiency of electric vehicles compared with internal combustion vehicles.

CHAPTER FOUR

AIRPORT EXPERIENCE WITH ALTERNATIVE FUELS—BY FUEL TYPE

This chapter presents information gathered from airports during the survey and interviews about each fuel type used. It also includes information on fuel infrastructure and cost. Notable highlights include the following:

- Airports have observed that biodiesel's cold weather performance improves with the use of a winter additive.
- Airports report unique issues encountered with CNG, such as expensive and unexpected replacement of tanks.
- Airports have experienced difficulty securing funding for electric vehicle infrastructure because it typically is not included or anticipated in vehicle procurement budgets.

BIODIESEL

Nine of the 33 airports that participated in the survey reported using B20 fuel derived from soybean feedstock, and an additional four reported using B5. Of those airports using B20, eight (or 89%) reported being "satisfied" or "extremely satisfied" with the fuel (Figure 10). B20 is popular because it balances several benefits—low cost, low emissions, cold weather performance, materials compatibility, and ability to act as a solvent.

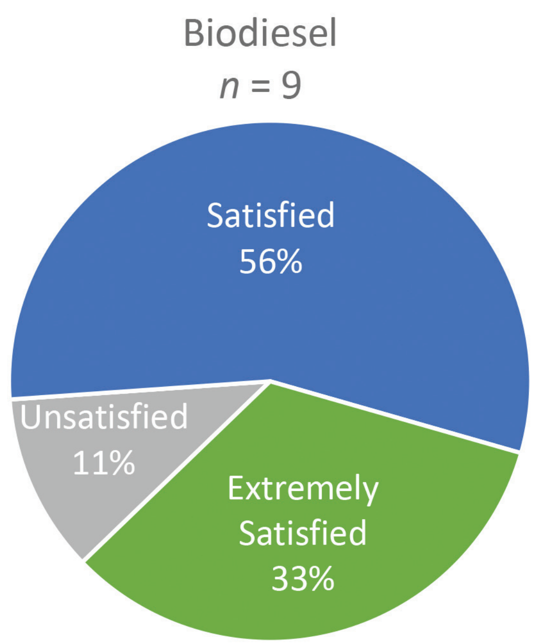


FIGURE 10 Surveyed airports' overall level of satisfaction with biodiesel.

By total volume, biodiesel is the most common diesel replacement fuel in the United States, with 2 billion gallons consumed per year across all on- and off-road vehicles (EIA 2016). Pure biodiesel made from soybeans (the most common feedstock) reduces GHG emissions by 12% compared with conventional diesel (ANL 2016a). Biodiesel produced from other pathways, such as from waste oils, can reduce GHG emissions by up to 88% on a life-cycle basis, but these types are not common (ANL 2016a). Most diesel fuel in the United States is blended with up to 2% biodiesel by volume—known as B2. The next most common blends are B20 (6% to 20% biodiesel) and B5 (2% to 5% biodiesel). B100 (pure biodiesel) is rarely used in its pure form. To qualify as an alternative fuel under the Clean Air Act of 1970, the blend must be B20 or higher (DOE 2016b).

The most commonly cited issue with biodiesel is the clogging of fuel filters (reported by three airports in the survey). Pure biodiesel from soybeans begins to form ice crystals when the temperature drops below 0°C (32°F), whereas diesel fuel does not form crystals until it reaches −45°C to −7°C (−49°F to 19°F) (DOE 2016b). Biodiesel also begins to gel in cold weather. Multiple airports reported that the use of a winter additive prevents gelling. Lambert–Saint Louis International Airport uses biodiesel in its fleet of snow management vehicles (Figure 11). One airport reported not using the fuel in Airport Rescue and Firefighting vehicles because of reliability concerns. Last, survey respondents noted that biodiesel tends to have more maintenance requirements and is slightly more expensive per gallon than diesel fuel.

FIGURE 11 Biodiesel snowplows and blowers (*Source*: Lambert–Saint Louis International Airport).

Most airports that use biodiesel reported having only one refueling station on site. Minneapolis–Saint Paul International was the only exception with two refueling stations. Almost all reported that their on-airport biodiesel dispensers were private stations. Little Rock International Airport was the only respondent to report using a public station for B20 refueling.

RENEWABLE DIESEL

Renewable diesel is a hydrocarbon fuel that offers performance similar to that of conventional diesel, but it is produced from such renewable feedstocks as fats and oils. As a "drop-in" fuel, renewable diesel requires no replacement of infrastructure or engine, and can be blended with diesel at ratios of up to 100% (Ernst 2016). Life-cycle analyses suggest that renewable diesel reduces GHG emissions by as much as 80% compared with emissions for conventional diesel, reduces nitrogen oxides (NOx) by 14%, and reduces particulate matter by a small fraction. Across the United States, approximately 560 million gallons of renewable diesel were used in 2016, representing less than 1% of road transportation fuel use (EIA 2016).

Today, renewable diesel is being used at San Francisco International Airport (SFO) at blends of 99% (i.e., 99% renewable diesel, 1% diesel) in all formerly diesel-powered vehicles. The airport reported being "extremely satisfied" with the fuel's performance, cost, and emissions. The city of San Francisco and several neighboring cities also use renewable diesel in their city fleets, so they already have a foundation of knowledge and distribution from which airports can learn.

However, availability is much more limited outside California, owing to a lack of incentives and limited distribution. This limited availability appears to contribute to a general lack of knowledge among airport fleet managers about renewable diesel. Most of the airports interviewed for this report could not define renewable diesel and could not distinguish it from biodiesel.

COMPRESSED NATURAL GAS

CNG is the most commonly used alternative fuel in airport-owned and airport-operated vehicles. Of respondent airports, 71% reported using CNG in at least one vehicle type—typically buses and shuttle buses. DOE estimates that GHG emissions resulting from CNG are 11% lower than those emitted by diesel (ANL 2016a). However, another key advantage of CNG over diesel is the reduction in local air pollutants, namely NOx and particulate matter. Across the United States, CNG accounts for just 2% of road transportation fuel use (EIA 2016).

Overall, 76% of the airports that use CNG reported being "satisfied" or "extremely satisfied" with the fuel (Figure 12). The most commonly cited advantages of CNG versus diesel are lower fuel costs, less intensive maintenance requirements, reductions in criteria pollutant emissions, more predictable fuel prices, greater existing infrastructure and distribution, reduced odor from exhaust, and reduced noise from the engine.

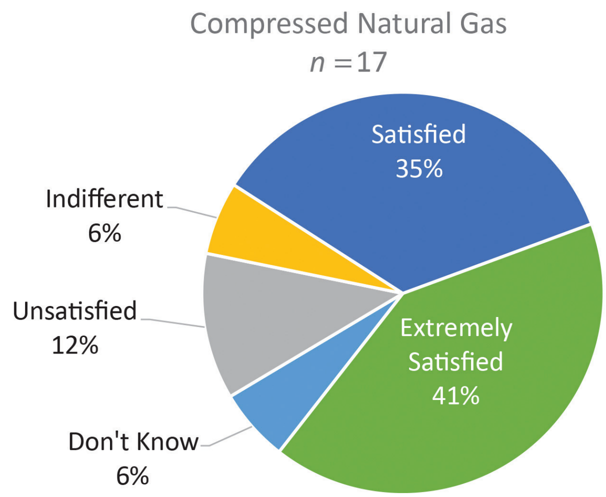


FIGURE 12 Surveyed airports' overall level of satisfaction with CNG.

Many airport fleets also discussed limitations of CNG, such as the following:

- Slow-fill CNG stations take much longer for refueling, so planning around the duty cycle is required.
- Few vehicle models are available on the market.
- Low energy density relative to other fuels necessitates larger storage tanks to achieve the same range. This size difference creates problems for vehicles that lack excess space capacity, such as some vocational vehicles.
- Compared with gasoline vehicles, engine spark plugs in CNG-fueled vehicles require more frequent replacement because of a higher combustion temperature.
- CNG pickup trucks, sedans, SUVs, and facility and maintenance vehicles require aftermarket conversion.
- If the on-airport refueling station is out of commission, drivers must refuel several miles away, adding to labor and fuel costs.
- Onboard CNG fuel tanks typically expire at the midpoint of the vehicle's lifetime, imposing substantial downtime and replacement costs (up to $15,000 per shuttle bus).
- Airports report difficulty finding replacement parts for CNG engines.

Last, a key benefit of CNG vehicles that airport respondents identified was that many vehicle types can be bi-fuel, meaning that they can run on CNG or gasoline/diesel. Airports found that the ability to use either of two fuels provided the following advantages over a dedicated fuel system: (1) vehicle operators could drive longer distances off-airport if needed, including to places without CNG refueling stations; (2) vehicles could continue normal operations if an airport CNG station became temporarily inoperable; and (3) vehicles could continue operation if repair parts for the CNG engine were unavailable.

RENEWABLE NATURAL GAS

Renewable natural gas is a renewable substitute for fossil-based natural gas. It is made from waste gases at landfills, municipal solid waste facilities, dairy farms, and water treatment facilities. After it is processed, renewable natural gas uses the same distribution pipeline and dispensing stations as CNG.

Limited environmental assessments of renewable natural gas have been performed, but the current literature suggests that the fuel can achieve promising reductions in GHG emissions. For example, recent analyses for the State of California estimate that some renewable natural gas pathways achieve greater than 100% reductions in GHG emissions by displacing methane emissions at the production sites and displacing fossil fuel in vehicles (CARB 2016). However, other studies note that, owing to data limitations, many uncertainties exist about the fuel's environmental benefits (Han et al. 2011).

As with renewable diesel fuel, producers of renewable natural gas receive incentives for selling fuel in California (CARB 2016). These incentives appear to influence a fuel's availability in non-California regions. In an interview, Seattle–Tacoma International Airport reported briefly starting a renewable natural gas program, but the program quickly ceased when the fuel distributor moved all fuel to California markets. SFO was the only airport surveyed that uses renewable natural gas. Its program began in 2014; SFO now uses renewable natural gas in 26% of its airport-owned and airport-operated vehicles. SFO allows the use of waste products in the production of renewable natural gas (by an off-airport producer).

Only 28% of airport respondents reported being "interested" or "extremely interested" in using renewable natural gas as fuel in the future. More than half said they were "not interested"—the highest degree of disinterest among all the fuel types.

LIQUEFIED NATURAL GAS

LNG is rarely used in airport fleets; it is typically reserved for specialized equipment. Of the airports surveyed, only 26% said they were "interested" or "extremely interested" in using LNG in the future. As described by DOE, the main barriers to using LNG are the higher fuel cost compared with CNG (DOE 2016a) and the need for special storage tanks capable of maintaining the cryogenically cooled fuel in liquid form. Additionally, the life-cycle emissions and petroleum consumption of LNG are higher than those of CNG because of the compression stage. Airports at which LNG may make economic sense are those near marine terminals where LNG is already imported or exported. This proximity eliminates the need for the airport to compress the fuel. Overall, however, the prospects for greater LNG expansion in airport fleets appear to be limited because of low interest and high costs compared with other fuels.

LIQUEFIED PETROLEUM GAS

The use of LPG, also known as propane, is limited at airports. Of the 33 airport respondents, LPG was used only in forklifts and other material-handling equipment. Availability of vehicles remains a primary barrier to greater adoption of this fuel. According to DOE (2016a), in U.S. markets the only types of LPG vehicles are forklifts, buses, and garbage trucks, which are used in a limited number of city fleets. Although some airports in the survey expressed interest in LPG fuel, one respondent (Denver International Airport) noted that LPG cannot be used in tunnels because of fire codes. Additionally, LPG fuel costs are higher than those of diesel—since 2000, LPG has averaged about $0.20 more per gallon of diesel equivalent. Overall, the prospect of greater LPG use in airport fleets is limited.

HYDROGEN

Hydrogen fuel has zero tailpipe emissions and the potential for zero life-cycle emissions if the hydrogen is created from renewable energy. Therefore, hydrogen fuel has great potential for supporting a long-term strategy for mitigating emissions and petroleum use. However, the technology is still in relatively early stages, and fuel and vehicle availability remain key barriers. Other barriers and costs have been detailed elsewhere by DOE (2016a) and others.

Of the airports surveyed for this report, only SFO reported using hydrogen in its vehicle fleet—specifically, in two mobile lighting structures that were partially funded by DOE. The airport fleet manager reported that the fuel is expensive and currently delivered in bottles, but the airport is seeking access to a hydrogen fueling station off-airport, which could lower costs and enable airport personnel to also fuel other vehicle types. However, the airport fleet manager also stated that he did not think hydrogen was practical in large vehicles owing to the high vehicle and fuel costs.

ELECTRICITY

Survey responses showed that electricity was the fastest-growing alternative fuel over the previous 5 years. Forty-five percent of surveyed airports reported having battery-electric vehicles (BEVs), whereas 18% of airports reported having PHEVs. As detailed elsewhere (e.g., DOE 2016a), two key advantages of these powertrains over petroleum-fueled vehicles are the low fuel costs and stable fuel prices. Additionally, BEVs and PHEVs have zero tailpipe emissions when running on batteries, which can be a major benefit in areas where vehicles operate near airport workers and passengers. On a life-cycle basis, the amount of GHG emissions caused by BEVs and PHEVs depends largely on the source of the electricity, but it is lower than petroleum fuels in every U.S. state (DOE 2016a). Additionally, BEVs have the potential for zero emissions on a life-cycle basis if the electricity is produced by renewable resources.

Overall, 55% of airports reported being "extremely satisfied" or "satisfied" with their BEVs and PHEVs. However, 11% reported being "unsatisfied" (Figure 13) and several airports also reported challenges with the vehicles. The main concern expressed by airports is the higher upfront vehicle cost of BEVs and PHEVs compared with traditional vehicles. Although some airports said that employees were enthusiastic about BEVs, others reported barriers to employee acceptance. Additionally, the electric charging stations are not typically covered under fleet expenses, meaning fleet managers must be creative in finding financing solutions. A BEV at the Port of Seattle is shown in Figure 14.

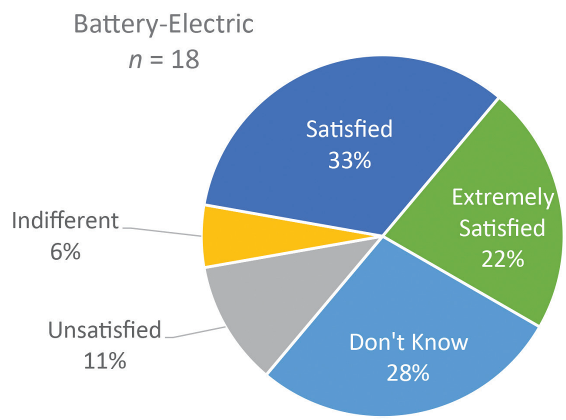


FIGURE 13 Surveyed airports' overall level of satisfaction with battery-electric.

FIGURE 14 Battery-electric vehicle (*Source*: Port of Seattle)

One airport expressed concerns about unanticipated costs from the BEVs' lengthy refueling time. Specifically, the airport managers said that BEVs can be out of service for an entire day if drivers or maintenance personnel forget to plug in the vehicle overnight, creating problems for fleet readiness. PHEVs, which can run on gasoline or electricity, would mitigate this concern.

FUTURE INTEREST IN ALTERNATIVE FUELS

The final question in the online survey asked airports about their future interest in each alternative fuel over the next 5 years. Respondents expressed the greatest interest in electricity, with about 80% of airports saying they were "interested" or "extremely interested" (Figure 15). The next-highest amount of interest was shown for CNG, with 67% of airports indicating that they are "interested" or "extremely interested."

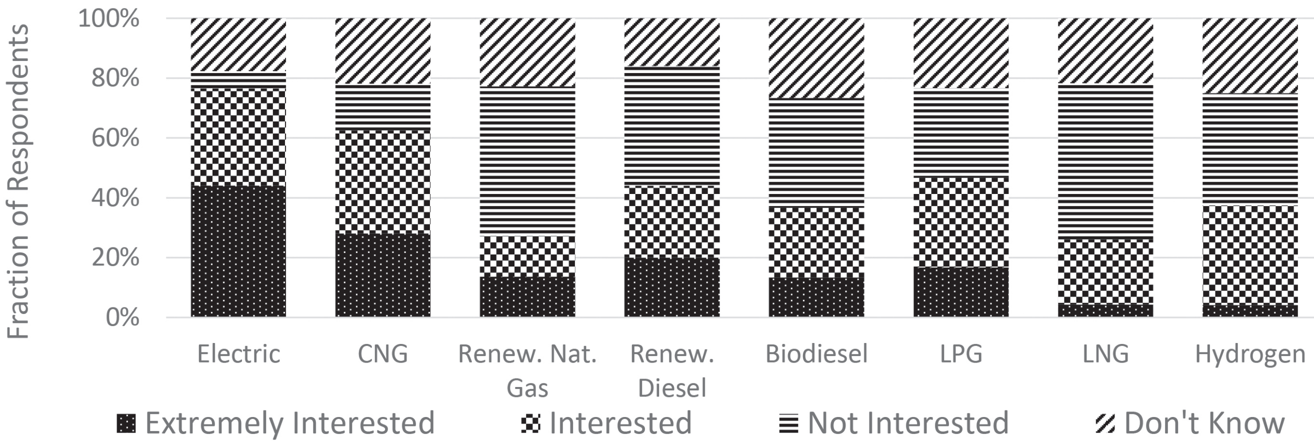


FIGURE 15 Surveyed airports' interest in future use of alternative fuels.

CHAPTER FIVE

AIRPORT EXPERIENCE WITH ALTERNATIVE FUELS—BY VEHICLE TYPE

INTRODUCTION

This chapter presents the results of the survey and interviews conducted with airports about various vehicle functions (or "type"). Successful adoption of alternative fuels in airport-owned or airport-contracted vehicles requires coordination across vehicle types and duty cycles. Figure 2 shows the makeup of the Oakland International Airport vehicle fleet, reflecting a typical airport-owned vehicle fleet portfolio.

Adoption of a new fuel at an airport also requires coordination across several components of airport planning, including the procurement, operation, and maintenance of vehicles. Many airports administer these components separately. Some airports pay per mile for service, contracting all components to a third party. Some procure the vehicles but contract their operations, whereas others maintain control over all components. Ownership of refueling stations adds another layer of complexity. Refueling stations are sometimes owned by the airport; other times they are owned by a third party that pays the airport to lease land.

Vehicles are divided into three functional categories: shuttle vehicles, emergency response and security vehicles, and facility and maintenance vehicles.

SHUTTLES

Airport-owned and airport-contracted buses, shuttle buses, and vans move passengers and employees between terminals, parking lots, and office buildings, both on- and off-airport. Based on the responses of the 33 airports surveyed, buses, shuttles, and vans were the most likely vehicle types to use alternative fuels. Alternative fuels were used in buses at 21 airports, in shuttles at 16 airports, and in vans at 13 airports. As shown in Figure 16, CNG and biodiesel are the two alternative fuels most often used in airport shuttle vehicles.

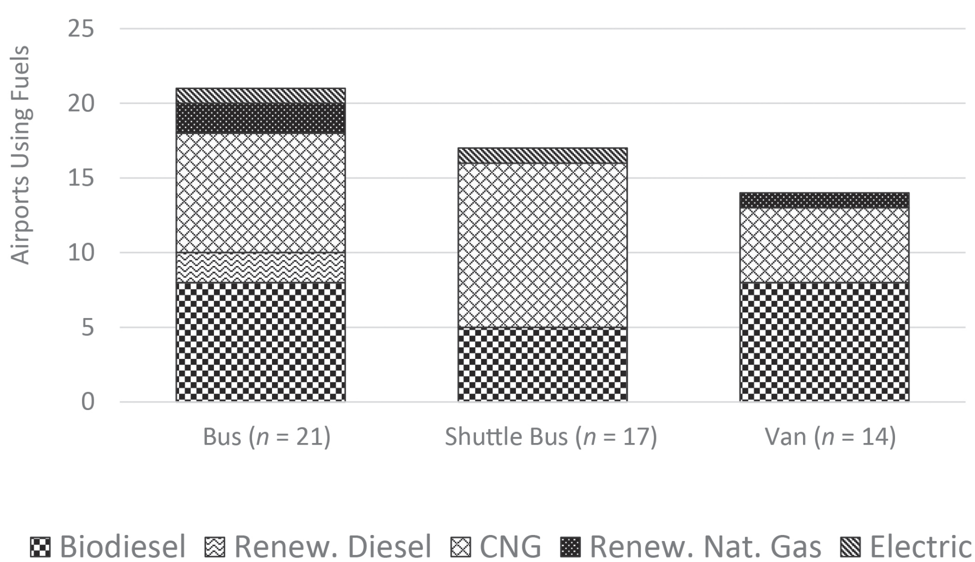


FIGURE 16 Frequency of alternative fuels in buses, shuttle buses, and vans in surveyed airports (n = 33).

Online survey respondents were asked to indicate who has direct control over the operation of these vehicles. Third-party operation appears to be more common than direct airport control for buses, shuttle buses, and vans. The survey did not inquire about the degree to which this third-party operation creates a barrier to alternative fuel adoption.

Respondents noted that the public visibility of these vehicles and the opportunity to project an environmentally friendly image were the two main benefits of using alternative fuels. However, as one survey respondent noted, the public visibility of buses, shuttle buses, and vans also poses a risk to the airport's public image if major issues or delays are associated with the vehicles. The same respondent suggested that airports interested in adopting an untested fuel should do so in passenger cars or pickup trucks, which are less visible to the public and have the added benefit of having a lower upfront cost of ownership than buses, shuttle buses, and vans. Respondents also noted that the shuttle vehicles have high mileage compared with other vehicle categories, which presents refueling challenges—especially for fuels that have range limitations such as CNG, renewable natural gas (RNG), and electricity. Respondents acknowledged that better planning could mitigate those challenges.

Respondents also discussed the relative costs of alternate fuel buses, shuttle buses, and vans to airports. Most respondents said that the upfront costs of these vehicles were higher than those for the equivalent fossil fuel–based vehicles. These results largely followed the fuel types. For example, respondents using CNG, RNG, or electricity reported higher upfront costs, whereas respondents using biodiesel tended to say costs were about the same.

EMERGENCY RESPONSE AND SECURITY VEHICLES

Emergency response and security vehicles are less frequently powered by alternative fuels. As shown in Figure 17, airports rarely use fuels with limited range in emergency response and security vehicles. Overwhelmingly, airports expressed the need for "ready" vehicles—ones they could quickly and easily refuel and put into operation. Golf carts were the only vehicle category with a high use of electricity. The duty cycles of emergency response and security vehicles are characterized by long periods spent traveling routine pathways and idling, and far fewer periods of intensive driving, sometimes at high speeds. These periods of intensive driving were the main reason airport respondents wanted ready vehicles.

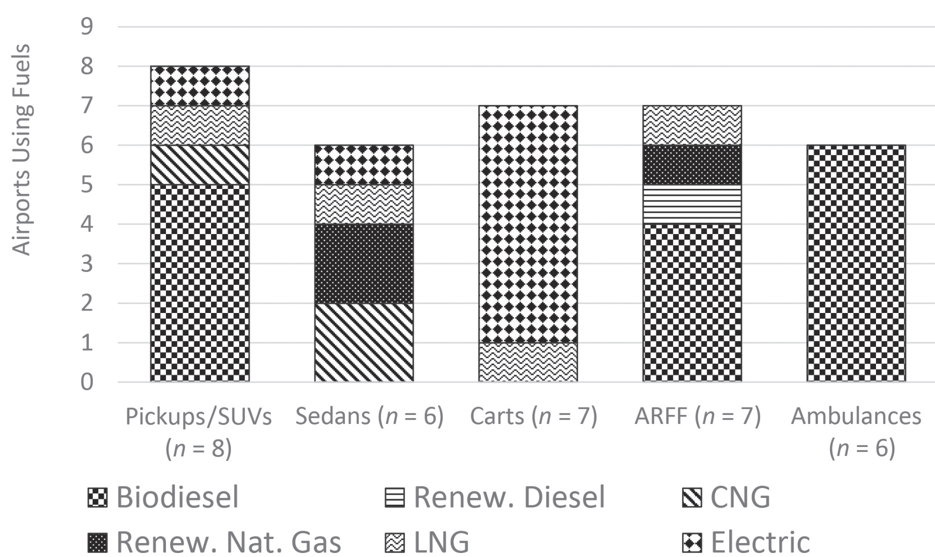


FIGURE 17 Frequency of alternative fuel use in emergency response and security vehicles (n = 33).

Another barrier to alternative fuel adoption in emergency response and security vehicles is the structure of oversight for these vehicles. At many airports, vehicle procurement, operation, and refueling are overseen by the security and police department rather than by the general airport fleet, which typically oversees other vehicles. This structure poses problems of scale because emergency response and security vehicle fleets tend to be smaller than those of other fleets (e.g., facility and maintenance fleets).

Concerns about using alternative fuels in Airport Rescue and Firefighting vehicles and ambulances were similar to those about use in security and police vehicles—namely, that reliability had to take priority. Interviewees articulated a reluctance to try a new or untested fuel.

FACILITY AND MAINTENANCE VEHICLES

Hydrogen Mobile Lighting at San Francisco International Airport

The only instance of an airport in the online survey or interviews using hydrogen fuel is San Francisco International Airport's (SFO's) hydrogen mobile lighting unit. This clean, quiet lighting unit replaced a high-emission, aging diesel unit in 2010. As noted in chapter four, SFO reports that hydrogen fuel is very expensive and currently delivered in bottles, but the airport is seeking access to a hydrogen fueling station off-airport, which could lower costs and enable airport personnel to also fuel other vehicle types.

Facility and maintenance vehicles encompass several vehicle types that include work trucks and material handling equipment, among others. These vehicles have a wide range of duty cycles, from long periods of non-operation (e.g., snow plows or mowers) to regular daily use (e.g., forklifts). As shown in Figure 18, the use of alternative fuels in these vehicles varies by vehicle type. CNG and renewable natural gas are used most often in pickups and sedans, and their use is limited in other vehicle types. B20 is used in most vehicle types, especially dump trucks, sweepers, and utility trucks.

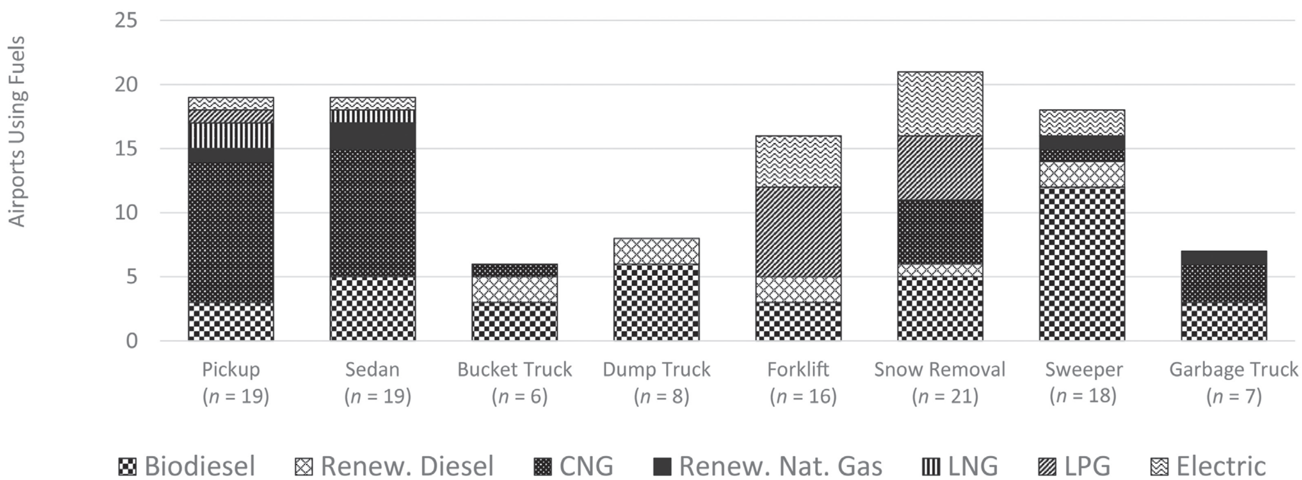


FIGURE 18 Frequency of alternative fuel use in maintenance and facility vehicles (*n* = 33).

Airports were asked about the upfront procurement cost of alternative fuel powertrains for facility and maintenance vehicles, versus gasoline or diesel internal combustion engines. All respondents familiar with vehicle procurement costs relayed that costs were either more expensive or about the same. No respondent reported a lower upfront cost. As discussed earlier, the high upfront cost poses a major barrier to alternative fuel adoption.

Multiple survey respondents and interviewees noted that snow removal vehicles present several barriers to alternative fuel use at airports. At some airports, the vehicles sit in non-operational states for much of the year but are essential to the broader airport's mission in an extreme snow event. Airports report being very reluctant to use untested alternative fuels in snow removal equipment, where reliability is paramount.

One innovative strategy used at Chicago O'Hare International Airport was to replace mowers and other landscaping vehicles with goats, sheep, and llamas. Compared with other methods, grazing animals are only cost-effective in areas that are difficult to reach with standard equipment, such as steep hillsides.

Although this chapter represents the majority of vehicles used in airport-owned and airport-contracted vehicle fleets, airport fleets also rely on other types of vehicles and equipment. Examples include pressure washers, compressors, lifts, gardening equipment, and boats. These less common vehicles and equipment also primarily use gasoline or diesel, and thus have the potential to shift to alternative fuels. However, the main limitation to alternative fuel use is the availability of engines and powertrains that can run on those fuels. Drop-in fuels such as renewable diesel can play an important role in shifting away from petroleum fuels, because no engine replacement is needed.

CHAPTER SIX

CONCLUSIONS AND FURTHER RESEARCH

This report summarizes results from an online survey of 33 airports and phone interviews with 16 airports on their experience with using alternative fuels in airport fleet vehicles. As previously stated, airports differ in their mix of vehicles, mix of fuels, geography, and ultimate goals—all of which contribute to great diversity among their experiences with these fuels. The following are observations and considerations to support other airports in moving forward with alternative fuel programs.

GENERAL OBSERVATIONS

- **Rationale for alternative fuels.** Airports purchase alternative fuel vehicles for a variety of reasons, most notably to reinforce an environmentally conscious image and to reduce greenhouse gas (GHG) emissions.
- **Compressed natural gas (CNG) and electricity are the two most common fuels.** The use of alternative fuels has steadily risen in airport vehicle fleets since the early 1990s, in both the total number of airports using alternative fuels and the diversity of fuel types used. Among the fuels considered in this synthesis report, CNG is used at the most airports (71% of airports surveyed). However, the fastest growing fuel type in the past 5 years is electricity, used at 64% of airports surveyed.
- **Increasing availability of low-cost alternative fuels.** The use of certain low-carbon fuels, such as renewable natural gas and renewable diesel, is limited in airport fleets, but the fuels are promising because of their competitive costs and their potential to dramatically reduce GHG emissions.
- **Role of airport administrative structure.** Airports tend to be either bureaucratic or hierarchical in how they make decisions related to alternative fuel adoption. According to Sperling and Nesbitt (2001), a hierarchical structure is especially conducive to the adoption of alternative fuels because it has relatively few decision makers and because cross-cutting initiatives that involve multiple divisions or departments at the airport can be centrally planned and delegated.
- **Advantages of bi-fuel vehicles.** Airports reported receiving great value in bi-fuel vehicles, such as vehicles that can use CNG or diesel/gasoline. A primary advantage of bi-fuel powertrains is the vehicle's reliability when one of the fuels has an inoperable refueling station.
- **Possible infrastructure modifications.** Most alternative fuel dispensing stations are owned by private firms, operating both on- and off-airport. CNG stations are an exception; they are mostly airport-owned. Of the airports interviewed, 83% reported needing to construct new alternative fuel infrastructure when introducing a new alternative fuel, rather than being able to leverage existing infrastructure in the region.

OBSERVATIONS BY FUEL TYPE

- **Biodiesel.** Eighty-nine percent of airports reported being "satisfied" or "extremely satisfied" with biodiesel. Airports use biodiesel in most vehicle applications that also use diesel. The main challenges expressed with biodiesel include fuel filter fouling in lower temperatures (however, this challenge was overcome by either adding solvents or changing the fuel supplier).
- **Renewable diesel.** Renewable diesel is currently used at San Francisco International Airport. Airport managers expressed extreme satisfaction with the fuel's cost competitiveness and operating characteristics.
- **Compressed natural gas.** CNG is the most commonly used alternative fuel in airport-owned and airport-operated vehicles. The U.S. Department of Energy (DOE) estimates that GHG emissions resulting from CNG are 11% lower than those emitted by diesel, in addition to important reductions in nitrogen oxides and particulate matter emissions (ANL 2016a).
- **Renewable natural gas.** RNG is a renewable substitute for fossil-based natural gas. Limited environmental assessments of RNG have been performed, but the current literature suggests that the fuel can achieve promising reductions in GHGs.

- **Liquefied natural gas (LNG).** LNG is rarely used in airport fleets; it is typically reserved for specialized equipment. The main barriers to using LNG are the higher cost compared with CNG (DOE 2016a) and the need for special storage tanks capable of maintaining the cryogenically cooled fuel in liquid form. Additionally, life-cycle emissions and petroleum consumption of LNG are higher than for CNG because of the compression stage.
- **Hydrogen.** Hydrogen fuel has zero tailpipe emissions and the potential for zero life-cycle emissions if the hydrogen is created from renewable energy. Although it's in the early stages of development, hydrogen fuel has potential to support a long-term strategy for mitigating emissions and petroleum use.
- **Electricity.** Electricity is the fastest-growing alternative fuel among survey respondents in the past 5 years. Two key advantages of these powertrains over petroleum-fueled vehicles are the low fuel costs and stable fuel prices.

OBSERVATIONS BY VEHICLE TYPE

- **Shuttles.** These vehicles are often the first vehicle type that an airport considers for alternative fuels and are good candidates for alternative fuels because (1) they operate near pedestrians and could limit negative health and environmental impacts; (2) they tend to have highly predictable duty cycles, which helps in planning the refueling events; and (3) they are publicly visible, creating an opportunity for airports to present an environmentally friendly image. Airports often use grant funding to help finance the refueling stations. A key concern expressed by airports regarding the use of alternative fuels in buses, shuttle buses, and vans is the potential for negative publicity in the case of a failed vehicle deployment.
- **Emergency response and security vehicles.** Emergency response and security vehicles are less frequently powered by alternative fuels. Barriers to alternative fuel adoption in these vehicles include the need for them to be "ready," and the structure of oversight required for them. At many airports, the vehicle procurement, operation, and refueling are overseen by the security and police department, rather than by the general airport fleet, which typically oversees other vehicles.
- **Facility and maintenance vehicles.** Few clear, overarching themes emerged for this class of vehicles, due primarily to the variation among the individual vehicles and the resulting usage needs. To address these unique challenges, airports relied on their historically innovative abilities, such as using goats for vegetation management in hard-to-reach areas.

KEY CONSIDERATIONS

- **Fuel and vehicle availability.** Rapid growth in the alternative fuel industry in recent years means airports have an increasing ability to adopt alternative fuels. Figure 9 shows the fuel-vehicle combinations that are currently available on the market or in the demonstration phase.
- **Barriers to alternative fuel adoption.** Airports vary in their willingness to try new fuels. Phone interviews revealed the following key barriers: (1) higher fuel, vehicle, or infrastructure costs for certain alternative fuels; (2) unavailability of fuel or vehicles in the airport's geographic region; (3) inadequate refueling infrastructure as a result of the airport spatial footprint; (4) failure to meet the necessary fuel requirements of the vehicle duty cycle; (5) tunnels prohibit the use of certain gaseous fuels; and (6) equipment reliability concerns owing to the frequency of extreme weather.
- **Funding opportunities.** The primary external funding source for alternative fuels in airport fleets is such federal grants as Voluntary Airport Low Emissions grants. Airports also rely on state grants. To a lesser degree, airports use public–private partnerships and federal and state vehicle rebates.
- **Procurement restrictions.** At some airports, a major barrier to alternative fuel use is the limited selection of vehicles in the procurement system as a result of (1) Buy America requirements, or (2) requirements to procure vehicles only from a given automaker (e.g., Ford).

FUTURE RESEARCH NEEDS

- **Synthesize literature** on the lifetime durability of alternative fuel vehicles compared with conventionally powered vehicles. Survey respondents noted the lack of information on alternative fuels at the middle and end of the life of vehicles.
- **Conduct a market assessment** of certain emerging fuels associated with deep reductions in GHG emissions, such as electricity, RNG, renewable diesel, and hydrogen.
- **Develop a handbook** that helps airports conduct cost–benefit analyses on alternative fuel vehicles at their airports. Such a handbook would include the environmental, social, and economic costs and benefits associated with vehicle procurement, maintenance, operation, and disposal. Additionally, the handbook could provide guidance on innovative financing models that would enable airport fleets to take advantage of federal and state tax incentives for the purchase of alternative fuel vehicles.

REFERENCES

Argonne National Laboratory (ANL), "The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model," ANL, Washington, D.C., 2016a [Online]. Available: https://greet.es.anl.gov/ [accessed Dec. 19, 2016].

Argonne National Laboratory (ANL), "The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model," AFLEET Tool, ANL, Washington, D.C., 2016b [Online]. Available: https://greet.es.anl.gov/ [accessed April 18, 2017].

California Air Resources Board (CARB), "Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline," California Environmental Protection Agency, Sacramento, n.d. [Online]. Available: https://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf [accessed Dec. 19, 2016].

California Air Resources Board (CARB), *LCFS Pathway Certified Carbon Intensities,* California Environmental Protection Agency, Sacramento, 2016 [Online]. Available: https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm [accessed Dec. 23, 2016].

Ernst, S., "What You Need to Know About Renewable Diesel," 2016, *Government Fleet News Media* [Online]. Available: http://www.government-fleet.com/article/story/2016/03/what-you-need-to-know-about-renewable-diesel.aspx [accessed Dec. 21, 2016].

Federal Aviation Administration (FAA), "Voluntary Airport Low Emissions Program (VALE), Airports," FAA, Washington, D.C., 2016 [Online]. Available: https://www.faa.gov/airports/environmental/vale/ [accessed Dec. 21, 2016].

Han, J., M. Mintz, and M.Q. Wang, *Waste-to-Wheel Analysis of Anaerobic-Digestion-Based Renewable Natural Gas Pathways with the GREET Model*, 2011 [Online]. Available: https://greet.es.anl.gov/publication-waste-to-wheel-analysis [accessed Dec. 22, 2016].

Kim, B., L.A. Waitz, M. Vigilante, and R. Bassarab, *ACRP Report 11: Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories,* Transportation Research Board of the National Academies, Washington, D.C., 2009, 53 pp. [Online]. Available: http://www.trb.org/Main/Blurbs/160829.aspx [accessed Dec. 19, 2016].

Molar, B., *ACRP Synthesis 24: Strategies and Financing Opportunities for Airport Environmental Programs,* Transportation Research Board of the National Academies, Washington, D.C., 2011, 218 pp.

National Academies of Sciences, Engineering, and Medicine (NAS), Committee on Transitions to Alternative Vehicles and Fuels, Board on Energy and Environmental Systems, Division on Engineering and Physical Sciences, *Transitions to Alternative Vehicles and Fuels,* National Research Council, Washington, D.C., 2013 [Online]. Available: https://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels [accessed Dec. 19, 2016].

Pearce, H., et al., *ACRP Web-Only Document 13: Alternative Fuels as a Means to Reduce* $PM_{2.5}$ *Emissions at Airports,* Transportation Research Board of the National Academies, Washington, D.C., 2012, 175 pp.

Sperling, K. and D. Nesbitt, "Fleet Purchase Behavior: Decision Processes and Implications for New Vehicle Technologies and Fuels," *Transportation Research Part C: Emerging Technologies,* Vol. 9, No. 5, Oct. 2001, pp. 297–318 [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0968090X00000358 [accessed Dec. 22, 2016].

U.S. Department of Energy (DOE), Clean Cities Program, Alternative Fuels Data Center, "Alternative Fuels Data Center," 2016a [Online]. Available: http://www.afdc.energy.gov/ [accessed Dec. 21, 2016].

U.S. Department of Energy (DOE), Clean Cities Program, *Biodiesel Handling and Use Guide,* 5th Ed., 2016b [Online]. Available: http://www.afdc.energy.gov/uploads/publication/biodiesel_handling_use_guide.pdf [accessed Dec. 21, 2016].

U.S. Department of Energy (DOE), Hydrogen and Fuel Cells Program, "Program Records," 2016c [Online]. Available: https://www.hydrogen.energy.gov/pdfs/16011_h2_delivery_cost_2015.pdf [accessed Dec. 24, 2016].

U.S. Department of Energy (DOE), Clean Cities Program, Alternative Fuels Data Center, "Alternative Fuel and Advanced Vehicle Search," 2017a [Online]. Available: http://www.afdc.energy.gov/vehicles/search/ [accessed April 18, 2017].

U.S. Department of Energy (DOE), Clean Cities Program, Alternative Fuels Data Center, "Alternative Fueling Station Locator," 2017b [Online]. Available: http://www.afdc.energy.gov/locator/stations/ [accessed April 18, 2017].

U.S. Department of Energy (DOE), Clean Cities Program, Alternative Fuels Data Center, "Fuel Prices," 2017c [Online]. Available: http://www.afdc.energy.gov/fuels/prices.html [accessed April 18, 2017].

U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, Clean Cities Program, "Alternative Fuel Niche Markets," *Alternative Fuel Information Series,* 2001 [Online]. Available: http://www.afdc.energy.gov/pdfs/airportafvfleets.pdf [accessed Dec. 19, 2016].

U.S. Energy Information Administration (EIA), *Annual Energy Outlook 2016* [Online]. Available: http://www.eia.gov/outlooks/aeo/ [accessed Dec. 22, 2016].

World Resources Institute (WRI), Greenhouse Gas Protocol, Washington, D.C., 2012 [Online]. Available: http://www.wri.org/our-work/project/greenhouse-gas-protocol [accessed Dec. 20, 2016].

BIBLIOGRAPHY

California Air Resources Board (CARB), *2015 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development,* California Environmental Protection Agency, Sacramento, 2015 [Online]. Available: https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2015.pdf [accessed Dec. 19, 2016].

California Air Resources Board (CARB), *Draft Technology Assessment: Medium- and Heavy-Duty Fuel Cell Electric Vehicles,* California Environmental Protection Agency, Sacramento, 2015 [Online]. Available: https://www.arb.ca.gov/msprog/tech/techreport/fc_tech_report.pdf [accessed Jan. 30, 2017].

City of New York website, "Climate Week: Mayor de Blasio Announces NYC Fleet Now Operates More Than 500 Electric Vehicles," 2016 [Online]. Available: http://www1.nyc.gov/office-of-the-mayor/news/759-16/climate-week-mayor-de-blasio-nyc-fleet-now-operates-more-500-electric-vehicles [accessed Dec. 22, 2016].

U.S. Department of Energy (DOE), *Plug-In Electric Vehicle Handbook for Public Charging Station Hosts,* 2012 [Online]. Available: http://www.afdc.energy.gov/pdfs/51227.pdf [accessed Dec. 20, 2016].

U.S. Environmental Protection Agency (EPA), *MOVES2014a: Latest Version of MOtor Vehicle Emission Simulator (MOVES)*, 2014 [Online]. Available: https://www.epa.gov/moves/moves2014a-latest-version-motor-vehicle-emission-simulator-moves [accessed Dec. 22, 2016].

ACRONYMS

BD	Biodiesel
BEV	Battery-electric vehicle
CARB	California Air Resources Board
CNG	Compressed natural gas
DOE	Department of Energy
EIA	Energy Information Administration
GGE	Gasoline gallon equivalent
GHG	Greenhouse gas
GSE	Ground support equipment
HEV	Hybrid-electric vehicle
Kg	Kilogram
kWh	Kilowatt-hour
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas (propane)
NOx	Nitrogen oxides
PHEV	Plug-in hybrid electric vehicle
RNG	Renewable natural gas
VALE	Voluntary Airport Low Emissions

APPENDIX A

Survey Questionnaire

This appendix presents the questionnaire used in the online survey for this report. Answers for each question are given as they appeared in the survey.

Question 1: State your name, title, and airport code.

Question 2: Do you currently use alternative fuels in any of your airport-owned or airport-contracted vehicles?

- ☐ Yes
- ☐ No

Question 3: Which of the following alternative fuels do you currently use in your airport-owned or airport-contracted vehicles?

- ☐ ELECTRIC—includes all-electric or plug-in hybrid electric vehicles (does not include hydrogen fuel cell electric vehicles).
- ☐ COMPRESSED NATURAL GAS—fossil-based gaseous fuel, mostly comprised of methane.
- ☐ RENEWABLE NATURAL GAS—originates from bio-based feedstock and is interchangeable with conventional natural gas.
- ☐ RENEWABLE DIESEL—also known as "green diesel," renewable diesel is made from waste oils, fats, and vegetable oils and can be blended directly with conventional diesel up to 100% with no modification to the engine.
- ☐ BIODIESEL—animal or vegetable oil–derived fuel made via transesterification process. Typically, not blended above 20% with diesel without modification to fuel storage tank and engine.
- ☐ PROPANE/LIQUEFIED PETROLEUM GAS—fossil-based fuel created as by-product of natural gas and petroleum refining. Delivered and stored as liquid fuel.
- ☐ LIQUEFIED NATURAL GAS—conventional natural gas converted to liquid form through cooling.
- ☐ HYDROGEN—gaseous fuel typically used in fuel cell or direct combustion.

Question 4: [If usage of biodiesel indicated] Specify the primary type of biodiesel used.

Note: If the blend changes over the course of the year, mark the most common blend used.

- ☐ B20 Biodiesel (20% biodiesel, 80% diesel)
- ☐ B85 Biodiesel (85% biodiesel, 15% diesel)
- ☐ B100 (100% biodiesel)
- ☐ Don't know
- ☐ Other type (specify):

Question 5: [If usage of renewable diesel indicated] Specify the primary blend of renewable diesel used.

Note: If the blend changes over the course of the year, mark the most common blend used.

- ☐ RD5 Renewable Diesel (5% RD, 95% diesel)
- ☐ RD20 Renewable Diesel (20% RD, 80% diesel)
- ☐ RD100 Renewable Diesel (100% RD)
- ☐ Don't know
- ☐ Other type (specify):

Question 6: [If usage of electric vehicles indicated] Specify the type of electric vehicles in use.

Note: OK to mark multiple answers.

- ☐ All-electric (runs exclusively on grid power)
- ☐ Plug-in hybrid electric (can run on grid power or as a gasoline/diesel-hybrid electric vehicle)
- ☐ Don't know
- ☐ Other type (specify):

Question 7: What percentage of your airport-owned and airport-contracted vehicles use each of these alternative fuels on a regular basis? Leave blank if not known. [answered separately for each fuel type]

Question 8: What year did your airport first use alternative fuels in your airport-owned or airport-contracted vehicle fleet? [answered separately for each fuel type]

Question 9: Describe any surprises, issues, or initial/recurring problems in using the alternative fuels in your airport-owned or airport-contracted vehicles. Possible topics include: fuel availability, cold/warm weather impacts, maintenance challenges, warranty issues, driver training, employee acceptance, employee health, reduced vehicle range compared with equivalent conventionally powered vehicles, auxiliary equipment needed to support the vehicle's operation, safety, codes, and standards. [answered separately for each fuel type]

Question 10: Where are your alternative fuel vehicles fueled? [answered separately for each fuel type]

- ☐ Private stations used only by airport fleet vehicles
- ☐ Public stations
- ☐ Private stations shared with other organizations (e.g., city buses, airport tenants, FedEx trucks)
- ☐ Other sharing arrangement
- ☐ Don't know

Question 11: Was new infrastructure required to be installed to support alternative fuel use in your airport-owned and airport-contracted fleet? [answered separately for each fuel type]

- ☐ Yes
- ☐ No
- ☐ Don't know

Question 12: How many alternative refueling stations/chargers support your airport-owned or airport-contracted vehicles? [answered separately for each fuel type]

Question 13: SHUTTLE: Identify the types of alternative fuel vehicles in your airport-owned or airport-contracted vehicles.

- ☐ Bus (>40 passengers)
- ☐ Shuttle bus (<40 passengers)
- ☐ Vans
- ☐ Pickup trucks or SUVs
- ☐ Sedans
- ☐ Carts (e.g., golf-carts, shuttles)

Question 14: EMERGENCY RESPONSE AND SECURITY: Identify the types of alternative fuel vehicles in your airport-owned or airport-contracted vehicles.

- ☐ Pickup or SUVs

- ☐ Sedans
- ☐ Carts (e.g., golf-carts, shuttles)

Question 15: FACILITY/MAINTENANCE: Identify the types of alternative fuel vehicles in your airport-owned or airport-contracted vehicles.

- ☐ Pickup or SUVs
- ☐ Sedans
- ☐ Bucket trucks
- ☐ Dump trucks
- ☐ Utility trucks
- ☐ Forklifts
- ☐ Snow removal vehicles
- ☐ Sweepers
- ☐ Garbage trucks

Question 16: OTHER VEHICLES: Identify the types of alternative fuel vehicles in your airport-owned or airport-contracted vehicles.

- ☐ Mobile lighting
- ☐ Airport Rescue and Fire Fighting
- ☐ Ambulances

Question 17: Who owns the alternative fuel vehicles in your airport-owned or airport-contracted vehicle fleet? [answered separately for each vehicle identified in Q13–16]

- ☐ Airport
- ☐ Third party
- ☐ Both
- ☐ Neither

Question 18: Who decides the vehicle makes, models, and fuel types used in your airport-owned and airport-contracted vehicle fleet? [answered separately for each vehicle identified in Q13–16]

- ☐ Airport decides
- ☐ Third party decides
- ☐ Don't know
- ☐ Other—Write in:

Question 19: Describe the decision-making process for the procurement of the alternative fuel vehicles in your airport-owned and airport-contracted fleet (Yes/Somewhat/No/Don't know).

- ☐ Formal written rules guide vehicle procurement decisions
- ☐ Detailed cost analyses are used before vehicle procurement process
- ☐ Emissions analyses are used before vehicle procurement decisions
- ☐ Final vehicle choices are made after soliciting bids
- ☐ Vehicle procurement decisions are made by only 1 or 2 individuals
- ☐ Senior management decides which fuels and how many vehicles are procured

Question 20: Are your alternative fuel vehicles retrofits (i.e., aftermarket conversion)?

- ☐ All are retrofits
- ☐ None are retrofits
- ☐ Some are retrofits, some are not
- ☐ Don't know

Question 21: Who operates the alternative fuel vehicles at your airport? [answered separately for each vehicle identified in Q13–16]

- ☐ Airport
- ☐ Third party
- ☐ Don't know

Question 22: Does your airport participate in alternative fuel programs with tenants (airlines, ground transportation providers, professional service consultants, others)?

- ☐ Yes
- ☐ No
- ☐ Don't know

Question 23: Please describe the nature of the alternative fuel program with tenants (what are the program's goals, how is it administrated, has it resulted in increased alternative fuel use, etc.):

Question 24: Select the types of financial resources that were important in funding your airport's alternative fuel vehicles and/or the refueling stations:

- ☐ Grant (National, State, Regional, Local, Other?)
- ☐ Vehicle rebate (National, State, Regional, Local, Other?)
- ☐ Public–private partnership (National, State, Regional, Local, Other?)
- ☐ Low interest loan (National, State, Regional, Local, Other?)
- ☐ Fee waiver (National, State, Regional, Local, Other?)
- ☐ Tax credit (National, State, Regional, Local, Other?)

Question 25: Provide the name(s) of the funding source(s), if applicable. (Skip question if not known)

- ☐ Grant
- ☐ Vehicle rebate
- ☐ Public–private partnership
- ☐ Low interest loan
- ☐ Fee waiver
- ☐ Tax credit
- ☐ Other

Question 26: Have emissions of the alternative fuel vehicles been quantified and tracked?

- ☐ Yes
- ☐ No
- ☐ Don't know

Question 27: Indicate the emissions model(s) or program(s) used to estimate the emissions from your airport vehicle fleet:

- ☐ AEDT model (FAA)
- ☐ EDMS model (FAA)
- ☐ MOBILE/MOVES model (EPA)
- ☐ GREET model (DOE)
- ☐ EMFAC (CARB)
- ☐ OFFROAD model (CARB)
- ☐ Don’t know

Question 28: How important were each of the following considerations in the decision to use alternative fuels at your airport? (Not important, Somewhat important, Important, Very important, Extremely important, Don’t know?)

- ☐ Compliance with regulation
- ☐ Cost savings
- ☐ Airport’s “green” image
- ☐ Greenhouse gas reduction
- ☐ Local pollutant reduction
- ☐ Petroleum reduction

Question 29: For alternative fuel vehicles that are purchased new at your airport, how do the costs of the vehicle procurement compare to the equivalent conventionally powered vehicle? [answered separately for each vehicle identified in Q13–16]

- ☐ Less expensive
- ☐ About the same
- ☐ More expensive
- ☐ Don’t know

Question 30: How do the fuel costs compare to the equivalent conventionally powered vehicle? [answered separately for each vehicle identified in Q13–16]

- ☐ Less expensive
- ☐ About the same
- ☐ More expensive
- ☐ Don’t know

Question 31: Describe your overall level of satisfaction with using alternative fuels in your airport-owned or airport-contracted fleet. [answered separately for each vehicle identified in Q13–16]

- ☐ Extremely unsatisfied
- ☐ Unsatisfied
- ☐ Indifferent
- ☐ Satisfied
- ☐ Extremely satisfied
- ☐ Don’t know

Question 32: Describe your airport's level of interest in using the following fuel types in the next 5–10 years.

- ☐ Not interested
- ☐ Interested
- ☐ Extremely interested
- ☐ Don't know

Question 33: Please provide any further comments on your alternative fuel vehicle program at your airport for the researchers of this project.

Questions 34 through 36 gather information regarding an airport's willingness to participate in follow-on phone interviews.

APPENDIX B

List of Survey Respondents

Table B1 provides a summary of the participating airports, including information on their sizes, categories, and geographies. The categories reflect those in the National Plan of Integrated Airport Systems. The "P" category is for primary airports, which are commercial service airports that have more than 10,000 passenger boardings each year. The "R" category is for reliever airports, which are airports designated by the FAA to relieve congestion at commercial service airports and to provide improved general aviation access to the overall community. Interview column indicates airports with whom the authors of this report held a follow-up phone interview.

TABLE B1
AIRPORTS IN ONLINE SURVEY AND FOLLOW-UP PHONE CALL, LISTED WITH NUMBER OF ENPLANEMENTS IN 2015

Airport	Code	Airport Category	City	State/Region	Enplanements (CY 2015)	Interview?
Albany International Airport	ALB	P	Albany	NY	1,276,793	
Albuquerque International Airport	ABQ	P	Albuquerque	NM	2,323,883	
Atlanta International Airport	ATL	P	Atlanta	GA	49,340,732	Yes
Baltimore–Washington International Airport	BWI	P	Baltimore	MD	11,738,845	
Clinton National Airport	LIT	P	Little Rock	AR	958,510	
Dallas–Fort Worth International Airport	DFW	P	Irving	TX	31,589,839	
Denver International Airport	DEN	P	Aurora	CO	26,280,043	Yes
Fort Lauderdale–Hollywood International Airport	FLL	P	Fort Lauderdale	FL	13,061,632	
General Mitchell International Airport	MKE	P	Milwaukee	WI	3,229,897	
Greenville–Spartanburg International Airport	GSP	P	Greenville	SC	955,097	
Jacksonville International Airport	JAX	P	Jacksonville	FL	2,716,473	
John F. Kennedy International Airport	JFK	P	Queens	NY	27,782,369	Yes
John Glenn Columbus International Airport	CMH	P	Columbus	OH	3,312,496	
John Wayne Airport, Orange County	SNA	P	Santa Ana	CA	4,945,209	Yes
LaGuardia Airport	LGA	P	Queens	NY	14,319,924	Yes
Lambert–St. Louis International Airport	STL	P	Saint Louis	MO	6,239,248	Yes
Lincoln Airport	LNK	P	Lincoln	NE	160,525	
Logan International Airport	BOS	P	Boston	MA	16,290,362	Yes
Los Angeles International Airport	LAX	P	Los Angeles	CA	36,351,272	
Minneapolis–Saint Paul International Airport	MSP	P	Saint Paul	MN	17,634,273	Yes
Newark Liberty International Airport	EWR	P	Newark	NJ	18,684,818	Yes
Oakland International Airport	OAK	P	Oakland	CA	5,506,687	Yes
O'Hare International Airport	ORD	P	Chicago	IL	36,305,668	Yes
Philadelphia International Airport	PHL	P	Philadelphia	PA	15,101,349	Yes
Phoenix Sky Harbor International Airport	PHX	P	Phoenix	AZ	21,351,504	
Portland International Airport	PDX	P	Portland	OR	8,340,252	
Richmond International Airport	RIC	P	Richmond	VA	1,740,391	Yes
San Francisco International Airport	SFO	P	South San Francisco	CA	24,190,560	
Seattle–Tacoma International Airport	SEA	P	Seattle	WA	20,148,980	Yes
Stewart International Airport	SWF	P	New Windsor	NY	142,603	Yes
T. F. Green Airport	PVD	P	Warwick	RI	1,763,676	
Teterboro Airport	TEB	R	Teterboro	NJ	7,951	Yes
Vancouver International Airport	YVR	N/A	Richmond	BC	10,150,000	
				Average:	**13,038,990**	

APPENDIX C

Fuel Properties

Table C1 provides information on the properties of the fuels discussed in this report.

TABLE C1
PROPERTIES OF FUELS IN THIS REPORT

Fuel Type	Fuel Material (Feedstocks)	Gasoline/Diesel Gallon Equivalent	Physical State	Cetane Number	Octane Number
Gasoline (E10)	Crude Oil	100%	Liquid	N/A	84-93
Low Sulfur Diesel	Crude Oil	113% of the energy of 1 gal of gasoline	Liquid	40–55	N/A
Biodiesel	Fats and oils from sources such as soybeans, waste cooking oil, animal fats, and rapeseed	B100 has 103% of the energy in 1 gal of gasoline or 93% of the energy of 1 gal of diesel. B20 has 109% of the energy of 1 gal of gasoline or 99% of the energy of 1 gal of diesel.	Liquid	48–65	N/A
Renewable Diesel	Fats and oils from soybeans, waste cooking oil, animal fats, and rapeseed	1 gal of renewable diesel has 113% of the energy of 1 gal of gasoline.	Liquid	70	N/A
CNG	Underground reserves	5.66 lb or 123.57 cu ft of CNG has 100% of the energy of 1 gal of gasoline. 6.38 lb or 139.30 cu ft of CNG has 100% of the energy content of 1 gal of diesel.	Compressed gas	N/A	120+
Renewable Natural Gas	Biogas	5.66 lb or 123.57 cu ft of renewable natural gas has 100% of the energy of 1 gal of gasoline. 6.38 lb or 139.30 cu ft of renewable natural gas has 100% of the energy content of 1 gal of diesel.	Compressed gas	N/A	120+
LNG	Underground reserves	5.38 lb of LNG has 100% of the energy of 1 gal of gasoline and 6.06 lb of LNG has 100% of the energy of 1 gal of diesel.	Cryogenic liquid	N/A	120+
Propane/ LPG	By-product of petroleum refining or natural gas processing	1 gal of propane has 73% of the energy of 1 gal of gasoline.	Pressurized liquid	N/A	105
Hydrogen	Natural gas or renewables	1 kg or 2.198 lb of hydrogen has 100% of the energy of 1 gal of gasoline.	Compressed gas or liquid	N/A	130+
Electricity	Coal, nuclear, natural gas, hydroelectric, and wind and solar	33.70 kWh has 100% of the energy of 1 gal of gasoline.	Electricity	N/A	N/A

APPENDIX D

Fuel Use by Airport in Online Survey

TABLE D1
ALTERNATIVE FUEL USE BY AIRPORT

Airport	Code	City	State/ Region	Electric Vehicle (BEV)	Biodiesel	Compressed Natural Gas (CNG)	Hydrogen	LNG	LPG	Renewable Diesel	Renewable Natural Gas
Albuquerque International Airport	ABQ	Albuquerque	NM	X							
Albany International Airport	ALB	Albany	NY			X					
Atlanta International Airport	ATL	Atlanta	GA			X					
Logan International Airport	BOS	Boston	MA	X		X					
Baltimore–Washington International Airport	BWI	Baltimore	MD			X					
John Glenn Columbus International Airport	CMH	Columbus	OH						X		
Denver International Airport	DEN	Aurora	CO		X	X					
Dallas–Fort Worth International Airport	DFW	Irving	TX		X	X					
Fort Lauderdale–Hollywood International Airport	FLL	Fort Lauderdale	FL	X	X						
Greenville–Spartanburg International Airport	GSP	Greenville	SC	X					X		
Jacksonville International Airport	JAX	Jacksonville	FL	X							
John F. Kennedy International Airport, Newark; Liberty International Airport; LaGuardia Airport; Stewart International Airport; Teterboro Airport	JFK, EWR, LGA, SWF, TEB	Queens, Newark, Queens, New Windsor, Teterboro	NY, NJ	X	X	X			X		
Los Angeles International Airport	LAX	Los Angeles	CA	X		X		X	X		
Clinton National Airport	LIT	Little Rock	AR	X	X	X					
Lincoln Airport	LNK	Lincoln	NE			X					
General Mitchell International Airport	MKE	Milwaukee	WI			X					

Airport	Code	City	State/ Region	Electric Vehicle (BEV)	Biodiesel	Compressed Natural Gas (CNG)	Hydrogen	LNG	LPG	Renewable Diesel	Renewable Natural Gas
Minneapolis–Saint Paul International Airport	MSP	Saint Paul	MN		X						
Oakland International Airport	OAK	Oakland	CA	X	X	X			X		
O'Hare International Airport	ORD	Chicago	IL	X		X			X		
Portland International Airport	PDX	Portland	OR	X	X	X					
Philadelphia International Airport	PHL	Philadelphia	PA	X	X						
Phoenix Sky Harbor International Airport	PHX	Phoenix	AZ	X	X	X			X		
T. F. Green Airport	PVD	Warwick	RI			X					
Richmond International Airport	RIC	Richmond	VA			X					
Seattle–Tacoma International Airport	SEA	Seattle	WA	X		X			X		
San Francisco International Airport	SFO	South San Francisco	CA	X	X	X	X	X		X	X
John Wayne Airport, Orange County	SNA	Santa Ana	CA	X		X			X		
Lambert–St. Louis International Airport	STL	Saint Louis	MO	X	X	X			X		
Vancouver International Airport	YVR	Richmond	BC	X	X						

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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