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Impact of Alternative Fuels Present in Airports on Aircraft Rescue and Firefighting Response

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16. Abstract

Environmental pollution concerns and the prices of crude oil and kerosene-type jet fuels have driven government and industry leaders to research alternative fuel solutions. Each year, alternate fuels become more common, and they are being introduced into airports, bringing with them the potential for unknown dangers. This literature review was created to assess the integration of alternative fuels in airports and the possible new fire threats they might pose. The alternate fuels discussed here include synthetic paraffinic kerosene (SPK), biodiesel, green diesel, compressed natural gas (CNG), liquid petroleum gas (LPG), and electricity.

Alternative fuels are being introduced to airports through two different venues: aircraft and ground service equipment (GSE) vehicles. These venues are made possible through programs such as the Voluntary Low Emissions Program. Each year, airlines, such as United Airlines and Royal Dutch Airlines, are slowly increasing their use of SPK blends in their fleet to reduce their aircraft's greenhouse gas production. On the ground, airlines are retrofitting current (or buying new) GSE vehicles to run on various alternative fuels.

The introduction of these fuels means that aircraft rescue and firefighting personnel might have to address new potential dangers. Past research showed SPK fuel fires are similar to JP-8 fuel fires, though some SPK fuel blends have exhibited higher heat fluxes and faster material burnthrough times. Alcohol-resistant aqueous film-forming foam is the recommended agent for biodiesel fires; however, this extinguishing agent cannot be used in U.S. airports because it does not meet Federal Aviation Administration requirements. LPG and CNG fires pose great dangers because of the chance of storage tank explosion. Fire tactics for electric vehicle fires are still under development and little information is available.

In section 8 of this literature review, concerns and possible areas of research are presented. These range from analyzing fire extinguishment tests using SPK fuels to observing the fire behavior of lithium-ion batteries of electric GSE vehicles.

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LIST OF ABBREVIATIONS AND ACRONYMS

A	Amp
AC	Alternating current
B5	5% biodiesel blend
B20	20% biodiesel blend
B100	100% biodiesel
CO_2	Carbon dioxide
V	Volt
AFFF	Aqueous film forming foam
AGE85	Aviation grade ethanol
AOA	Airport operating area
AR-AFFF	Alcohol-resistant aqueous film-forming foam
ARFF	Aircraft Rescue and Firefighting
ATJ-SPK	Alcohol to jet synthetic paraffinic kerosene
AVGAS	Aviation gasoline
BLEVE	Boiling liquid expanding vapor explosion
BTL	Biomass to liquid
CAA	Clean Air Act
CAAFI	Commercial Aviation Alternative Fuels Initiative
CFR	Code of Federal Regulations
CHAdeMO	Trade name of quick-charging receptacle
CNG	Compressed natural gas
CTL	Coal to liquid
DEF STAN	United Kingdom Ministry of Defence
DGA	Direction Générale de l'Armement, French defense procurement agency
ERG	Emergency Response Guidebook
EV	All-electric vehicles
FAA	Federal Aviation Administration
FTS	Fischer-Tropsch synthesis
FT-SKA	Fischer-Tropsch synthetic kerosene with aromatics
FT-SPK	Fischer-Tropsch synthetic paraffinic kerosene
GA	General aviation
GHG	Greenhouse gas
GSE	Ground support equipment
GTL	Gas to liquid
HEFA-SPK	Hydroprocessed esters and fatty acids synthetic paraffinic kerosene
HEV	Hybrid electric vehicle
HRJ	Hydroprocessed renewable jet fuel
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
JAL	Japan Airlines
KLM	Royal Dutch Airlines
Li-ion	Lithium-ion
LL	Low lead
LPG	Liquid petroleum gas

MIL-SPEC	Military Specification
MOU	Memorandum of Understanding
MSDS	Material safety data sheet
NFPA	National Fire Protection Association
Ni-MH	Nickel-metal hydride
NIOSH	National Institute for Occupational Safety and Health
NLA	New large aircraft
PHEV	Plug-in hybrid electric vehicle
SAE	Society of Automotive Engineers
SAFUG	Sustainable Aviation Fuel Users Group
SKA	Synthetic kerosene aromatic
SPK	Synthetic paraffinic kerosene
STC	Supplemental type certificate
SWAFEA	Sustainable Way for Alternative Fuels and Energy for Aviation
Syngas	Synthetic gas
UK	United Kingdom
UL	Unleaded
UPS	United Parcel Service
U.S.	United States
VALE	Voluntary Airport Low Emission

EXECUTIVE SUMMARY

In 2008, crude oil and kerosene-type jet fuel prices skyrocketed incredibly high and negatively affected the economy. This price hike and its continuous instability have caused countries to consider using alternatives to replace crude oil. Environmental concerns from crude oil pollution have also driven countries to look at replacements. Because of these issues, governments and industry leaders have begun looking at alternative fuels as the solution. Alternative fuels are non-petroleum-based fuels that can substitute petroleum-based fuels. Each year, alternative fuels become more common in daily life, and they are being introduced into airports. This literature review was created to assess the integration of alternative fuels in airports and the possible new fire threats they might pose. The introduction of these fuels in airports brings potentially unknown dangers that must be addressed. The alternative fuels discussed in this literature review include synthetic paraffinic kerosene (SPK), biodiesel, green diesel, compressed natural gas (CNG), liquid petroleum gas (LPG), and electricity.

Alternative fuels are being introduced to airports through two different venues: aircraft and ground service equipment (GSE) vehicles. These venues are made possible through programs such as the Voluntary Low Emissions Program. Each year, airlines, such as United Airlines and Royal Dutch Airlines, are slowly increasing their use of SPK blends in their fleet to reduce their aircraft's greenhouse gas production. The pace that these new SPK fuels are introduced is greatly dependent on the approval of the processes from which they are made. On the ground, airlines have started retrofitting their current (or buying new) GSE vehicles to run on various forms of alternative fuels. New GSE fleets are now using CNG, LPG, and electricity as their alternate fuel sources.

Past research showed SPK fuel fires are similar to JP-8 fuel fires, but some SPK fuel blends did exhibit slightly higher heat fluxes during pool fire tests. This raises the question whether more extinguishment agent is needed for SPK fuels when compared to regular jet fuels. Research also showed that some SPKs had faster burnthrough times than JP-8 fuel. When combating biodiesel fires, it is recommended to use alcohol-resistant aqueous film-forming foam; however, this extinguishing agent cannot be used in U.S. airports. LPG and CNG pose great dangers because of the chance that a boiling liquid expanding vapor explosion could occur as fire is present near the storage tanks. Fire tactics to combat electric fires is fairly new, and more research on electric vehicle fires is suggested.

In section 8 of this literature review, concerns and possible areas of research were presented. These range from analyzing fire extinguishment tests using SPK fuels to observing the fire behavior of lithium-ion batteries of electric GSE vehicles.

1. INTRODUCTION.

In 2008, crude oil and kerosene-type jet fuel prices skyrocketed to incredibly high levels and negatively affected the economy. Figure 1 shows the constant uptrend of these prices and the reluctance of the prices to go down [1]. The increased fuel prices are not because of an oil shortage, but rather due to the high cost of exploring and drilling for new oil [2]. This price hike and continuous instability has caused countries to consider using alternatives to replace crude oil.

Environmental concerns regarding crude oil pollution have also motivated countries to look at oil replacements. Concerns regarding greenhouse gases (GHG), such as carbon dioxide (CO_2) pollution, have become popular subjects among environmental groups, and many nations have begun new efforts to reduce these gases. Because of these issues, governments and industry leaders have begun looking at alternative fuels as the solution.

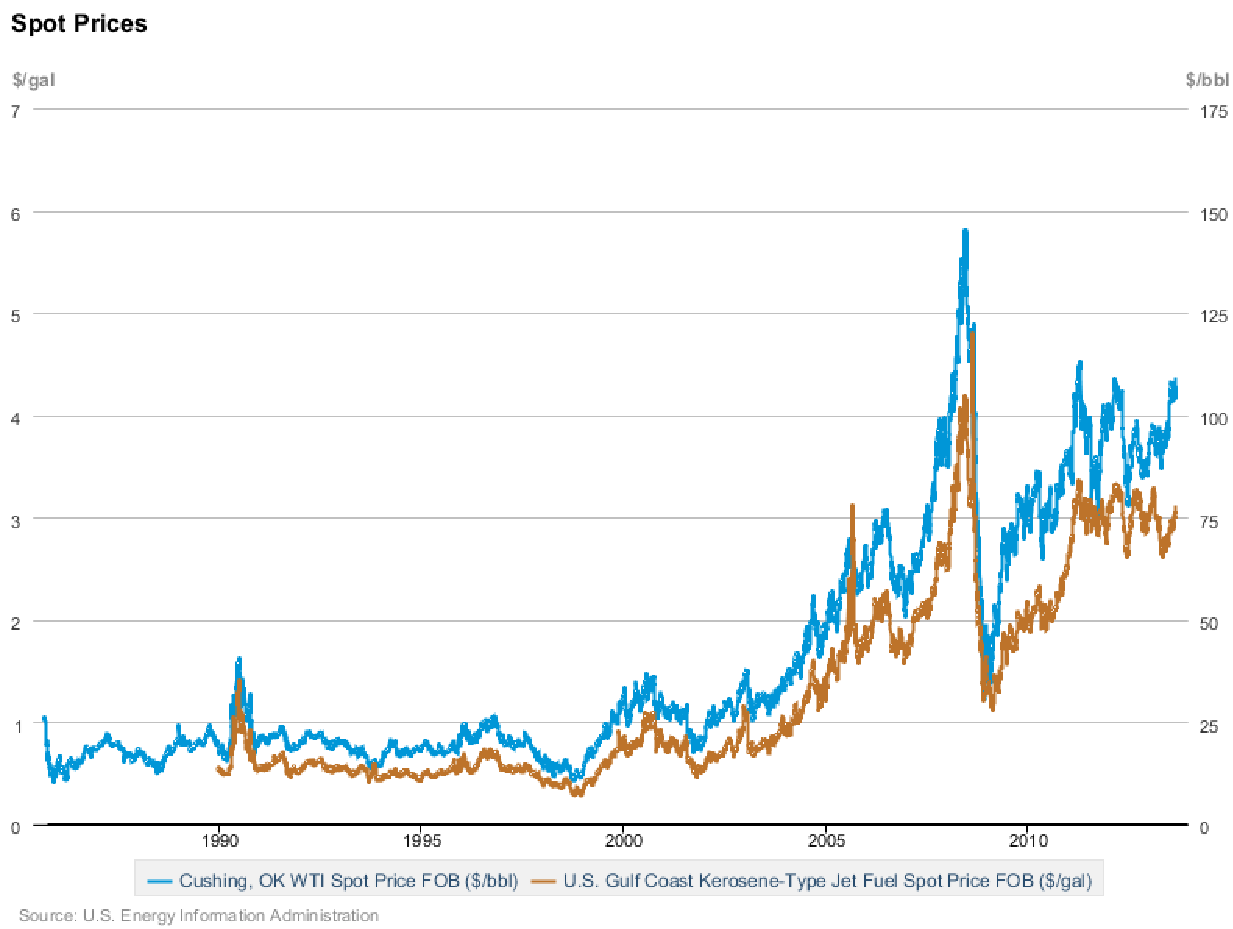


Figure 1. Crude Oil and Jet Fuel Prices From 1990 to 2013

Each year, alternative fuels become more common in daily life, and they are being introduced into airports. The introduction of these fuels in airports brings potentially unknown dangers that must be addressed. One of these potential dangers is how these fuels could react in fire incidents that Aircraft Rescue and Firefighting (ARFF) personnel must respond to. For this reason, members of the Federal Aviation Administration (FAA) Airport Technology Research and Development Branch have begun investigating the potential dangers of fire threats and how ARFF personnel might require training to combat these new dangers. The first step of this research effort was to launch a literature review, which investigates integrating alternative fuels in airports and the potential threats they might bring. The literature review also looked at past fire incidents, lessons learned from those incidents, and training involving these alternative fuels.

2. PURPOSE.

Over the years, the alternative fuels movement has been growing worldwide and has been increasing its presence at airports through various sources. As these fuels increase their airport presence, ARFF personnel will need to familiarize themselves with the fuels and learn how to combat any potential fires they may create. This literature review aims to identify the alternative fuels that are becoming more prevalent at airports and the possible fire dangers they may present.

3. OBJECTIVES.

The objectives of this literature review were to

- identify the vehicles that operate inside an airport and the fuels they use.
- identify the alternative fuels that are being considered for integration with these vehicles.
- present examples of initiatives and accomplishments that have occurred at airports for each fuel.
- present past incidents and suggest training concerning alternatives fuels.
- present possible areas of research that pertain to ARFF.

4. BACKGROUND.

Alternative fuels are non-petroleum-based fuels that can act as substitutes for petroleum-based fuels. According to the Alternative Fuels Data Center of the United States (U.S.) Department of Energy, the following are considered examples of alternative fuels: biodiesel, electricity, ethanol, hydrogen, natural gas, and propane [3]. The resources used for the alternative fuels are known as feedstocks. Some alternative-fuel feedstocks are derived from nonrenewable sources such as gas deposits and mines, while other alternative-fuel feedstocks are derived from renewable sources such as wind and solar. There is a type of renewable feedstock that is known as biomass. Biomass refers to biological material that is used as a source of energy. Biomass can both refer to plant products such as corn, camelina, sugar cane, and wood as well as animal byproducts such as fats and waste. Currently, there is a growing push for new alternative energies, especially renewable sources that are sustainable since they pose a smaller threat to the environment and land use. Since these sources are renewable and sustainable, they could potentially offer an unlimited amount of fuel for the future.

4.1 ENVIRONMENTAL INITIATIVES.

Environmental initiatives have occurred at U.S. and international levels and have influenced the presence of alternative fuels at airports. Sections 4.1.1 and 4.1.2 describe U.S. and international environmental initiatives.

4.1.1 The U.S. Initiatives.

In 1970, the U.S. Congress passed the Clean Air Act (CAA), which regulates air emissions from stationary sources such as factories and mobile sources such as cars. This law also allowed the U.S. Environmental Protection Agency to establish air quality standards to protect public health and regulate air pollutants. In 1990, amendments were added to the CAA that required the reduction of emissions from hazardous air pollutants. [4]

In December 2003, the U.S. Congress passed the Vision 100—Century of Aviation Reauthorization Act, which helped establish a voluntary program with the purpose of reducing airport ground emissions. This law directed the FAA to issue a guidance report that describes what low-emission activities are eligible and how airport sponsors can demonstrate the benefits of these activities. To accomplish this, the FAA created the Voluntary Airport Low Emission (VALE) Program. The VALE program goal is "to help airport sponsors improve air quality in conjunction with regional efforts to meet health-based national Ambient Air Quality Standards." To meet its goal, VALE offers financial and regulatory incentives to airport sponsors so they may consider low-emission alternatives. [5]

The Energy Policy Act of 2005 aided emerging energy technologies to mature and combat GHG [6]. To do this, it provided loans to companies developing these new technologies [6]. This act also concentrated on renewable energies such as electricity, coal, and gases.

In 2006, the Commercial Aviation Alternative Fuels Initiative (CAAFI) was established by private industries (aircraft manufacturers, researchers), and government agencies such as the FAA [7]. The goal of CAAFI is to aid the development of alternative jet fuels to combat rising crude oil prices [7]. They also emphasize the environmental improvements that these fuels could supply.

4.1.2 International Initiatives.

In February 2009, the European Commission Directorate General for Mobility and Transport launched a study known as the Sustainable Way for Alternative Fuels and Energy for Aviation (SWAFEA) [8]. This study looked at the feasibility and impacts that alternative jet fuels could have in the aviation sector [8]. This was important since the European Commission has a goal to introduce 10% of renewable energy to its transportation sector by 2020 [9]. In 2011, the SWAFEA study found that biofuels could potentially help the aviation industry reach this goal [9].

In October 2010, the International Civil Aviation Organization (ICAO) adopted a resolution that would develop a CO_2 emission standard for aircraft by 2013 and increase fuel efficiency. Part of the ICAO effort to reduce CO_2 emissions is the use of alternative fuels for aircraft. Also, the

ICAO welcomed member states in the organization to submit plans on how they will meet the goals set by the resolution. [10]

5. AIRPORT VEHICLES AND FUEL STORAGE.

Airports are complex travel hubs made up of parking garages, maintenance facilities, terminals, fuel farms, and many types of vehicles. Each is a case where different fuels could be found, and ARFF personnel would need to know how to respond to a fire incident. Most vehicles found inside an airfield are classified under two categories: aircraft and GSE vehicles.

5.1 AIRCRAFT.

Many types of aircraft traffic through airports, and each aircraft uses a certain type of fuel that is carried in different quantities. Aircraft are categorized as follows: commercial, regional, general aviation (GA), corporate, military, and rotary.

Commercial aircraft transport large numbers of passengers for long distances. These aircraft typically have two or more jet engines as well as significantly sized fuel tanks that hold large amounts of Jet A fuel in different locations. These aircraft are categorized into three different types: narrow-body aircraft (single-aisle, small fuel tanks), wide-body aircraft (twin-aisle, large fuel tanks), and new large aircraft (NLA) (multideck, largest fuel tanks) [11]. For example, a commercial aircraft, such as the Boeing 747-400ER NLA, is capable of holding 63,705 gallons of Jet A fuel [12].

Regional aircraft, also known as commuter aircraft, carry a large number of passengers. These aircraft travel shorter distances than regular commercial aircraft and use Jet A fuel in either turboprop or jet engines. [11]

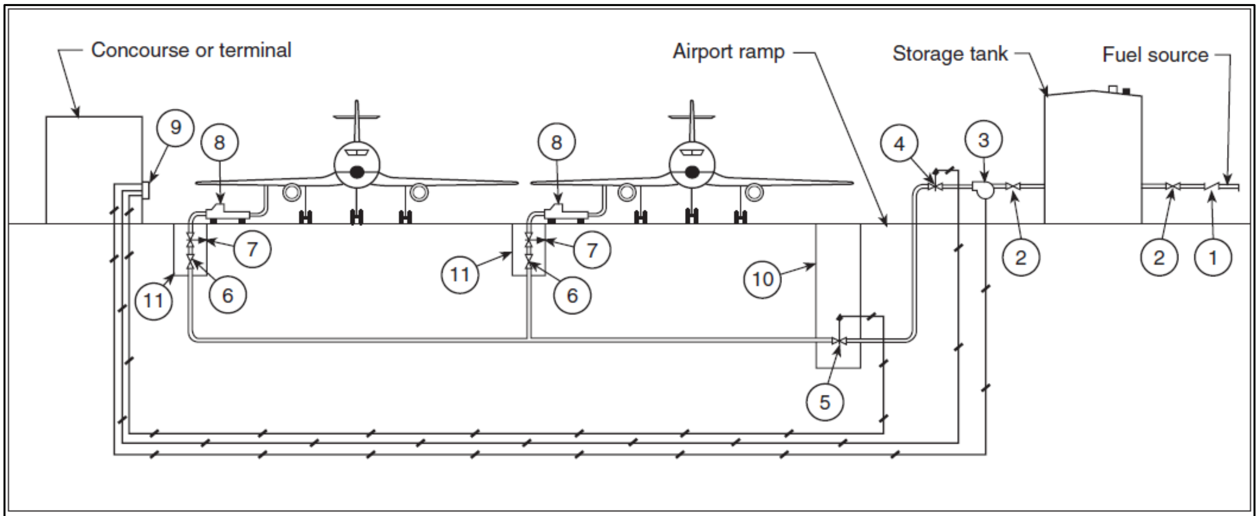
GA aircraft are used for training and leisure. These aircraft use either one- or two-piston engines and are fueled with aviation gasoline (AVGAS). The amount of AVGAS that these aircraft carry ranges from 90 to 500 gallons. [11]

Corporate aircraft are used for business purposes. The size of these aircraft can range from small, light planes to commercial aircraft. Corporate aircraft are usually pressurized and have jet engines and therefore use Jet A fuel. [11]

Many airports around the world share their runways and airspace with military bases. One example is the New Jersey Air National Guard, which operates at the Atlantic City International Airport, New Jersey. Military aircraft also present additional challenges to ARFF personnel since many of these aircraft could be carrying explosive ammunitions and use different types of jet fuels, typically JP-8.

Rotary aircraft, also known as helicopters, use either piston or jet engines; therefore, depending on the model, a rotorcraft could use either AVGAS or Jet A fuel. Helicopter fuel tanks carry from 90 to 1000 gallons of fuel. [11]

Aircraft fuels at airports are usually stored in large storage tanks located either above- or underground in an area often called the airport's fuel farm [11]. These tanks must comply with National Fire Protection Association (NFPA) 407, "Standard for Aircraft Fuel Servicing" [13]. Fuels can be transported from the fuel farm to the aircraft in one of three ways, which depends on the airport: fuel tankers, underground fueling systems, and fueling islands [11 and 13]. Fuel-carrying capacities of fuel tankers range from 500 to 10,000 gallons [11]. These tankers fill up at the airport's fuel farms and then drive through the airport operating area (AOA) to designated spots where they fuel the aircraft. Underground fueling systems run underground piping from the fuel storage tanks to hydrant pits at airport terminals or designated spots on the airport ramp [13]. A fuel service pumping vehicle then connects to a hose from the hydrant pit to the aircraft. Figure 2 illustrates the multiple components of an underground fueling system [13].



Note: No dimensional relationship exists between elements in this figure. Refer to this standard; NFPA 30, *Flammable and Combustible Liquids Code*; NFPA 70, *National Electrical Code;* and FAA Regulations for separations and clearances.

Key:

1. Check valve at tank inlet
2. Isolation valve at tank inlet/outlet
3. Pumping system
4. Pump discharge control valve or hydrant system shutoff valve (alternate location)
5. Hydrant system shutoff valve (alternate location)
6. Hydrant shutoff valve
7. Hydrant pit valve
8. Hydrant fueling servicing vehicle
9. Emergency fuel shutoff station
10. Valve box
11. Hydrant pit

Figure 2. Diagram of Underground Fueling System in Airports

Title 14 Code of Federal Regulations (CFR) Part 139.321, "Handling and Storing of Hazardous Substances and Materials," states that the certificate owner must inspect these facilities at least once every three consecutive months and provide training concerning the following: "(4) Fire safety in fuel farms and storage areas. (5) Fire safety in mobile fuelers, fueling pits and fueling cabinets" [14]. This training also falls under Advisory Circular 150.5230-4B, "Aircraft Fuel Storage, Handling, Training, and Dispensing on Airports" [15]. Fueling islands are gas pumps located around airports, most likely at airport ramps, where pilots self-serve their aircraft. These gas pumps are most commonly used by GA pilots.

5.2 THE GSE VEHICLES.

In general terms, GSE vehicles are used to perform the following tasks:

- "Providing ground power and air conditioning to an aircraft;
- Moving an aircraft (e.g. out of a gate, to/from maintenance);
- Servicing an aircraft between flights (e.g., replenishing supplies, deicing, etc.);
- Loading/unloading passengers;
- Loading and unloading baggage and cargo; and
- Servicing the airport's ramps, runways, and other areas (e.g., snow removal and lawn maintenance equipment)." [16]

Appendix A describes the different types and functions of GSE vehicles that could be found inside airport property. The types of GSE vehicles actually present vary by airport since each airport has its own specific needs. Factors that amount to the airport's needs include the amount of daily aircraft traffic, aircraft size, and the type of airport. Weather also plays a role in what GSE vehicles are present [16]. For example, during the winter months, Logan International Airport needs snowplows to clear their runways, while Orlando International Airport needs lawnmowers to cut the grass along the runways. A busy airport like John F. Kennedy International Airport needs more baggage tugs than a smaller, less busy airport like Ontario International Airport.

GSE vehicles can either be fueled inside the airport property with diesel/gasoline storage, or at a fuel farm that could be located inside or outside the airport property. Fuel dispensing and storage facilities do not have to be inspected under 14 CFR Part 139.321 since this code only pertains to aviation facilities [17]. However, Advisory Circular 150.210-17B, "Programs for Training of Aircraft Rescue and Firefighting Personnel," states that airports must be provided with training on how to respond to special situations such as a fire at a GSE fuel storage facility [18].

6. ALTERNATIVE FUELS.

As more companies, governments, and institutions research alternative fuels, many new types of fuels and techniques have arisen. This literature review will only look at alternative fuels that have currently shown promise and are slowly being integrated into the airport environment. These fuels include "drop-in" jet fuels, AVGAS, biodiesel, green diesel, LPG CNG, and electricity. Literature has stated that the presence and types of alternative fuels at airports varies by region due to the availability of these fuels in the region.

6.1 DROP-IN JET FUELS.

When it comes to alternative jet fuel, industry has pushed for what is commonly called drop-in fuels. According to the International Air Transportation Association (IATA), drop-in fuels are "indistinguishable from conventional jet fuel" and with these fuels "no changes in any fuel system required," meaning that they can just be "dropped-in" to the existing fuel system [19]. This includes fuel characteristics such as freeze point, flash point, heating value, density, wear on fuel systems, and electrical conductivity [20]. Most drop-in fuel processes create SPK as their alternative fuel. SPK is a "jet fuel mainly containing of paraffinic chains (iso-, normal-, cyclo-), with zero or near zero aromatic content." [2] For airlines and aircraft manufacturers, drop-in fuels are best since no additional cost would be required to modify the aircraft engines and no changes would be needed for fuel storage facilities [21]. Organizations like the IATA and the Sustainable Aviation Fuel Users Group (SAFUG) have made it a priority that any drop-in fuel must come from a self-sustaining, renewable source and should aid in reducing GHG emissions in airports [19]. SAFUG, which was established in 2008, is composed of major international and domestic airlines such as Lufthansa and United Airlines. It established the following commitment concerning alternative drop-in fuels:

- "Jet fuel plant sources should be developed in a manner which is non-competitive with food and where biodiversity impacts are minimized; in addition, the cultivation of those plant sources should not jeopardize drinking water supplies.

- Total lifecycle greenhouse gas emissions from plant growth, harvesting, processing, and end-use should be significantly reduced compared to those associated with fuels from fossil sources.

- In developing economies, development projects should include provisions for outcomes that improve socioeconomic conditions for small-scale farmers who rely on agriculture to feed them and their families, and that do not require the involuntary displacement of local population.

- High conservation value areas and native eco-systems should not be cleared and converted for jet fuel plant source development." [22]

Drop-in jet fuels that would likely be used as a commercially available alternative to fossil jet fuels must be certified by one of two agencies: the American Standard for Testing and Materials, now known as ASTM International, and the United Kingdom (UK) Ministry of Defence (DEF STAN) [21]. At the time of this literature review's writing, there have only been two drop-in fuel processes approved by the ASTM and two other fuel processes that are close to being ASTM approved. While there are many other processes being investigated, they are nowhere near to starting the ASTM approval process. For this reason, this literature review only focused on the first four fuel processes: Fischer-Tropsch SPK (FT-SPK), Hydroprocessed Esters and Fatty Acids SPK (HEFA-SPK), Alcohol to Jet SPK (ATJ-SPK), and Fischer-Tropsch Derived Kerosene with Aromatics (FT-SKA).

6.1.1 The FT-SPK.

One of the first emerging technologies for replacing fossil jet fuel was creating an SPK through Fischer-Tropsch synthesis (FTS). FTS is the process in which liquid hydrocarbons, such as SPKs, are created from synthesis gases (syngas), which are carbon monoxide and hydrogen gas [23]. This process has been patented since 1935 and has been used to produce a variety of fuels. The original FTS process produced liquid hydrocarbons from coal (coal to liquid (CTL)) and natural gas (gas to liquid (GTL)), but over the past decade, biomass has become another feedstock used for the process as well (coal and biomass to liquid (BTL) [19]. Sasol, an energy and chemical company, has been using FTS to produce CTL hydrocarbons for over 60 years. Since 1999, Sasol provided the Tambo International Airport in South Africa with coal-derived FT-SPKs for their flights. This SPK was the only semi-synthetic fuel approved under DEFSTAN 91-91, "Turbine Fuel, Kerosine Type, Jet A-1" [24] and ASTM D1655, "Standard Specification for Aviation Turbine Fuels" [25] for many years. This fuel is used as a 50% blend because the SPK by itself does not produce the required level of aromatics.

When producing an SPK through BTL, the biomass first must go through a process known as gasification before going through FTS. Gasification is a "thermochemical conversion process that forms a syngas by reacting pyrolysis products with air or steam" [8]. Figure 3 illustrates the steps taken during a BTL FTS process [8]. All jet fuels created using biomass are also known as biojet fuels. In 2009, ASTM D7566, "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons" [26] was created, and this specification's Annex 1 certifies up to a 50% blend of FT-SPK produced through the BTL FTS process [8]. Similar to CTL and GTL, BTL is only allowed up to a 50% blend because it does not produce the required level of aromatics established by ASTM D1655 [25]. Because all these fuels required blending with fossil hydrocarbons, ASTM also established ASTM D4054, "Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives" in 2009 to ensure that all blends functioned well as drop-in fuels [27].

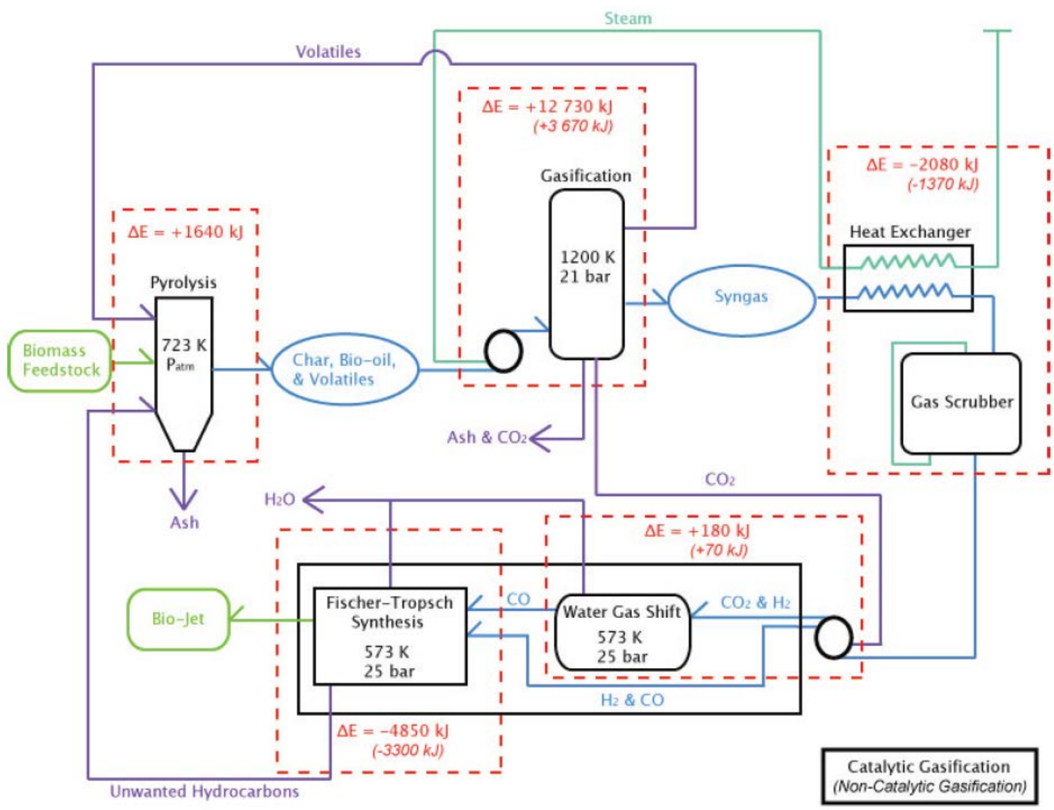


Figure 3. The BTL FTS Process

6.1.2 The HEFA-SPK.

HEFA-SPKs, also known as hydroprocessed renewable jet fuels (HRJ), are produced from tryglycerides and fatty acids that can be found in plant oils and animal fats [28]. HRJ production requires the following: "HRJ production first requires the removal of oxygen by reaction with hydrogen ('deoxygenation'). In a second step, the resulting hydrocarbon is further isomerized and cracked to reduce the carbon number into the jet range and achieve key jet fuel properties such as freeze and flash points" [28]. It is stated that the HRJ process is similar to FTS. In 2011, the HEFA-SPK process was approved under ASTM D7566 Annex 2 [9].

6.1.3 The ATJ-SPK.

Another process for drop-in jet fuel production that scientists have been investigating is the ATJ-SPK. This process takes carbon chains from alcohols like butanol and ethanol and converts them to longer alkane carbon chains that are found in jet kerosene [29]. The ATJ process has four steps: ethanol dehydration, alcohol oligomerisation, distillation, and hydrogenation [10, 30, and 31]. One primary feedstock used in this process is sugarcane, and because of the widespread availability of this feedstock, there has been a growing interest for this process [32]. Industrial microbiology has also emerged as a feedstock source for this process [10]. Certification for ATJ-SPK is expected to occur in 2014 [31 and 33].

6.1.4 The FT-SKA.

The IATA stated that one limiting factor for SPK use is meeting the minimum aromatic content of 8% for jet fuels [9]. For this reason, there has been a growing interest in synthetic kerosene aromatics (SKA) [9 and 28]. Currently, scientists have been able to produce SKAs through the FTS process with an iron-based catalyst and are known as FT-SKA [9]. Currently, this new FTS process is being reviewed by ASTM, and if approved, it could lead the way to 100% SPK blends [28].

6.1.5 Drop-in Jet Fuel Storage.

Because SPKs are considered drop-in fuels, they can be stored in the existing storage tanks located at the airports and can be transported in the same fuel trucks that transport fossil jet fuels [21]. Because drop-in fuels can only operate in blends, the SPKs and fossil jet fuels will be stored in separate tanks and then mixed together in another tank with the desired blend [21]. Figure 4 shows an HEFA/Jet A-1 blend storage tank in Mexico [9].

Figure 4. Fuel Storage Tank With HEFA/Jet A-1 Blend

<u>6.1.6 Drop-in Jet Fuel Initiatives and Accomplishments</u>.

Over the years, more airliners have become interested in different drop-in fuels and have begun initiatives to incorporate these fuels in their daily operations. They have also participated in conducting test flights using different SPKs. Table 1 presents a historical summary of some accomplishments and initiatives regarding drop-in jet fuels.

Table 1. Drop-in Jet Fuel Initiatives and Accomplishments

Year	Airport/Airline/Company	Summary
2007	Virgin Atlantic, Boeing, GE Aviation	In April 2007, Virgin Atlantic announced it would become the first commercial airline to use biojet as a fuel for a B-747 with GE engines for a demo flight. Virgin Atlantic hoped this demo flight would challenge the industry in accelerating the introduction of biofuels. This flight occurred in February 2008 [19].
2008	Boeing, Air New Zealand, Roll-Royce	In December 30, 2008, Air New Zealand flew a B-747 from Auckland, New Zealand, with a jatropha-derived 50% blend biofuel fueling one of the aircraft's engines. The biofuel did not create any adverse effects on the engine, and it performed as traditional jet fuel [8 and 34].

Table 1. Drop-in Jet Fuel Initiatives and Accomplishments (Continued)

Year	Airport/Airline/Company	Summary
2009	Continental Airlines	In January 2009, Continental Airlines flew a B-737-800 with one of its engines fueled with a jatropha/algae-derived 50% SPK blend. This flight occurred in Houston, Texas, and investigators found a 1.5% improvement in fuel flow [8].
2009	Japan Airlines (JAL)	In January 2009, JAL flew a B-747-300 with one of its engines fueled with a 50% camelina/jatropha/algae-derived SPK blend. The biofuel had no adverse effects on the engines and performed as well as traditional jet fuel [8].
2009	Royal Dutch Airlines (KLM), SkyNRG	In November 2009, KLM conducted a flight where one aircraft engine was fueled with a 50% camelina-derived SPK blend [35].
2009	Rentech	In December 2009, Rentech signed a nonbinding memorandum of understanding (MOU) with 13 airliners from around the world. The MOU states that the airlines could agree on the purchase of Rentech's GTL-SOK known as RenJet. Production rate of this fuel was expected to be 16,600 barrels per day [28].
2010	Rentech, United Airlines	In April 2010, United Airlines flew an Airbus 319 with one of its engines fueled with a 40% RenJet blend. This aircraft flew from Denver, Colorado, and the flight successfully validated the SPK performance [28].
2010	Sasol	In September 2010, Sasol fueled four passenger aircraft, a Hawk 4000, Beechcraft King Air 350i and P750, and a B-737-200, with 100% FT-SKAs. These aircraft flew successfully from Johannesburg, South Africa, to Cape Town, South Africa [9].
2011	InterJet, Mexican Federal Government	In April 2011, InterJet flew an A320 from Mexico City, Mexico, to Tuxtla Gutierrez, Mexico, with a 27% jatropha-derived HEFA-SPK blend supplied by the Mexican government [9].
2011	KLM, SkyNRG	In June 2011, KLM flew an aircraft fueled with bio-SPK from Amsterdam, Netherlands, to Paris, France. The bio-SPK was made from used cooking oil. A series of flights with the same fuel followed in September 2011 to prove the sustainability of the fuel [35].
2011	Lufthansa	In July 2011, Lufthansa dedicated an A321 for a loop route from Hamburg, Germany, to Frankfurt, Germany, where the starboard engine was fueled with a 50% HEFA-SPK blend. After 3 months of flying this route, a 1% drop in fuel burn was observed in the starboard engine. Ending in December 2011, a total of 1187 flights were flown using this route [9 and 31].

Table 1. Drop-in Jet Fuel Initiatives and Accomplishments (Continued)

Year	Airport/Airline/Company	Summary
2011	Aeromexico	In August 2011, Aeromexico flew the first commercial transoceanic flight on a B-777 with a 25% camelina-derived SPK blend from Mexico City, Mexico, to Madrid, Spain. This flight carried more than 250 passengers [9].
2011	Air France, SkyNRG	In October 2011, Air France flew "the greenest biofuel flight ever." It flew an A321 from Toulouse-Blagnac to Paris-Orly with a bio-SPK made from used cooking oil. The fuel was supplied by SkyNRG [9].
2012	Lufthansa	In January 2012, Lufthansa flew a B-747-400 from Frankfurt, Germany, to Washington, DC, USA, using a HEFA-SPK blend [31].
2012	KLM	In June 2012, KLM flew the longest biofuel flight from Amsterdam, Netherlands, to Rio de Janeiro, Brazil [31].
2012	British Airways	In December 2012, British Airways agreed to buy 50,000 tons of FT-SPK from Solena for a period of 10 years [36].
2013	KLM	In March 2013, KLM began a series of biofuel flights between Amsterdam, Netherlands, and New York, USA. This series ran as a 25-week pilot program that used a B-777-200 and has now ended. Two 10,000-gallon fuel tankers were dedicated to refueling this aircraft at John F. Kennedy International Airport [37].
2013	United Airlines, AltAir Fuels, Los Angeles International Airport	In June 2013, United Airlines signed an agreement with AltAir Fuels to buy 15 million gallons of biofuel for 3 years starting in 2014. The fuels will be delivered to and stored at Los Angeles International Airport [38].

6.2 THE AVGAS ALTERNATIVES.

Currently, the most common type of AVGAS used worldwide is AVGAS 100 low lead (LL), which is the largest contributor to lead in the atmosphere [39]. This type of fuel is specified by ASTM D910, "Standard Specification for Aviation Gasolines" [40] and UK DEF STAN 91-90 [41 and 42]. Because of its effect on the environment, companies have slowly started making different AVGAS to replace 100LL. ASTM D7547, "Standard Specification for Hydrocarbon Unleaded Aviation Gasoline" [43] and ASTM D6227, "Standard Specification for Unleaded Aviation Gasoline Containing a Non-hydrocarbon Component" [44] certify AVGAS fuels that contain hydrocarbons and nonhydrocarbons. Both hydrocarbon and nonhydrocarbon fuels are categorized as unleaded (UL). Examples of these fuels are AVGAS UL82, AVGAS UL87, and AVGAS UL91 [45]. The only issue with these fuels is that they do not work with all types of aircraft.

In July 1996, the University of South Dakota began researching a blend of aviation grade ethanol (AGE85) to see how effective it could be as a replacement for 100LL [39]. This research produced an FAA Supplemental Type Certification (STC) for the use of AGE85 on the Cessna

180 and 182 [39]. The FAA stated that it would not produce STCs for other aircraft until the fuel was certified by the ASTM [39]. To this day, AGE85 has not been certified, and even more interesting, ASTM D7547 and ASTM D6227 do not allow the use of alcohols, such as ethanol, to be used as part of a fuel blend [45]. However, alcohols can be used in low levels as anti-icing agents for the fuel system [41].

In 2005, Swift Fuels began research on a 100LL alternative-using biomass [46]. They developed a 102-octane unleaded AVGAS that has an ASTM Test Specification that was approved under ASTM D7719, "Standard Specification for High Octane Unleaded Test Fuel" [47] in March 2011. This is the only high-octane, unleaded AVGAS to obtain this approval [48].

On June 10, 2013, due to public health concerns, the FAA issued a request for unleaded candidates that can replace 100LL for all types of aircraft [49]. Under this program, the FAA will establish tests to certify the candidates and aid in deploying them into the market once they have been approved [49]. The FAA also included $5.6 million in its 2014 fiscal year budget to fund this research [50].

6.3 DIESEL ALTERNATIVES.

When it comes to reducing emissions from diesel-fueled GSE vehicles around airports, two technologies have emerged as possible diesel-replacements: biodiesel and green diesel.

6.3.1 Biodiesel.

Biodiesel is a "liquid fuel made up of fatty acid alkyl esters, fatty acid methyl esters, or long-chain mono alkyl esters" [51]. These esters are products from feedstocks such as pure vegetable oils, used cooking oils, animal fats, and algae [52] that are chemically altered through three different processes [53]:

> "Base catalyzed transesterification of the oil with alcohol.
> Direct acid catalyzed esterification of the oil with methanol.
> Conversion of the oil to fatty acids, and then to Alkyl esters with acid catalysis."

Figure 5 shows the different steps of the transesterification process [54].

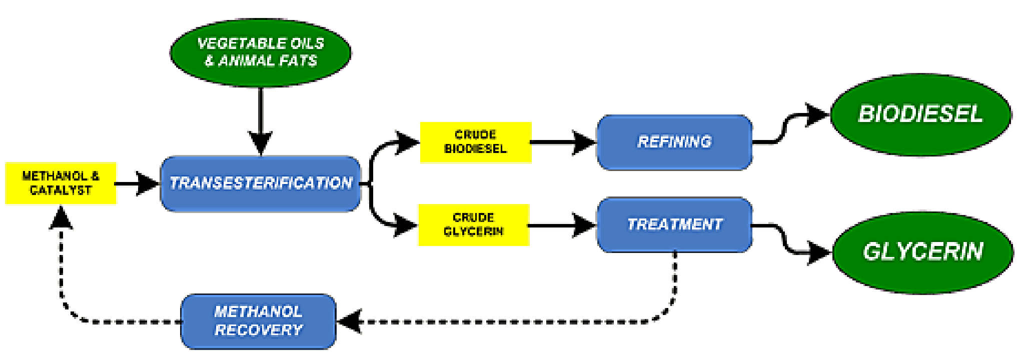


Figure 5. Biodiesel Transesterification Process

Currently, biodiesel is sold in three blend categories with each category having to meet a certain ASTM standard. The standard ASTM for regular diesel fuels, ASTM D975, "Standard for Specification for Diesel Fuel Oils" [55], allows for up to 5% of the fuel to be biodiesel. The most popular blend under this standard is 5%, also known as B5. Biodiesel blends ranging from 6% to 20% must meet quality standards stated in ASTM D7466, "Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20)" [56] in order to be sold as a biofuel. The most popular group of blends, and all biodiesel blends in the U.S., is 20% (B20) [57]. Blends ranging up to B20 require no engine modifications when used as a fuel replacement. The third blend category is for biodiesel blends of 100% (B100). Manufacturers that produce this blend must meet standards specified in ASTM D6751, "Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels" [58]. This blend cannot be used in regular diesel engines since it could cause corrosion and seal degradation [52]. This requires engine modifications to be made in order for this blend to be used. This blend is also known to be a poor performer at low temperatures [52] and has the tendency of gelling at approximately 32°F [16]. For these reasons, the U.S. Department of Energy and the National Energy Laboratory does not recommend this blend. As of 2011, there are approximately 613 biodiesel fueling stations around the country [16].

6.3.1.1 Biodiesel Storage.

Biodiesel can be stored in storage tanks similar to the ones used for diesel; however, it is recommended that the biodiesel should not be stored longer than 6 months because it is considered a solvent [5]. Because of this, it can cause corrosion in the storage tanks and pipe systems [21]. Also, since the fuel contains organic substances, it could lead to microbial growth such as algae [21 and 5]. It is recommended that the storage tanks used to store biodiesel be either isothermal or located underground to decelerate fuel degradation [5]. For fire protection, tanks storing biodiesel must abide with NFPA 30, "Flammable and Combustible Liquids Code" [59].

6.3.1.2 Biodiesel Airport Initiatives.

Biodiesel has made a presence in cities and highways, and now it is being integrated into airports. Table 2 presents historical examples of airport initiatives that involve biodiesel.

Table 2. Examples of Biodiesel Airport Initiatives

Year	Airport/Airline/Company	Summary
2006	Orlando International Airport	In August 2006, Orlando International Airport used B20 biodiesel to power 100 of its GSE vehicles, including tugs, buses, and trucks. These GSE vehicles were expected to use 1000 gallons of fuel a day. No updates were given on the success of this pilot program [60].
2011	Worldport Airport, United Parcel Service (UPS)	In April 2011, UPS installed 30,000- and 50,000-gallon biodiesel fuel tanks at Worldport Airport for its GSE vehicles [61].

Table 2. Examples of Biodiesel Airport Initiatives (Continued)

Year	Airport/Airline/Company	Summary
2011	Amsterdam Airport, KLM	In September 2011, approximately 40 GSE vehicles at the Amsterdam Airport Schiphol were powered by B100 biodiesel. Some of these vehicles were part of the KLM fleet located at the airport. They were part of a 4-month pilot program with the purpose of reducing CO_2 emissions. If the program proved successful, more vehicles would be converted to biodiesel [62].
2012	Brisbane Domestic Airport ,Virgin Australia	In May 2012, Virgin Australia announced it would use B20 to power one of its baggage tugs and one push-back vehicle in an 8-week period. This test took place at the Brisbane Domestic Airport, and if successful, Virgin Australia is expected to increase the number of GSE vehicle using B20. No updates on this test have been published [63].
2012	Lambert-St. Louis International Airport	In June 2012, it was reported that all stationary generators, construction equipment, and ARFF vehicles at the Lambert-St. Louis International Airport was being fueled with B20. This airport had been testing different blends of biodiesel since 1987 [64].
2012	Enterprise Holdings	In June 2012, Enterprise Holdings announced that the company had 70% of its airport shuttle bus fleet running on biodiesel blends and had the goal of increasing the number of buses using biodiesel to 80%. Most of these buses are driving on B5 but Enterprise wants to increase the number of buses that use B20 [65].
2012	Honolulu International Airport, Pacific Biodiesel Technologies	In December 2012, Pacific Biodiesel Technologies agreed to supply between 250,000 and 1 million gallons of biodiesel a year to Honolulu International Airport for its emergency power facility [66].

6.3.2 Green Diesel.

The second technology that has emerged as a diesel fuel replacement is a fuel known as green (synthetic) diesel. Green diesels are "diesel fuels produced from feedstocks other than conventional petroleum, for example, through an FT or HEFA process, either as a co-product of alternative jet fuel production or as the main output of the production process" [21]. Like the jet fuels produced by FT and HEFA processes, green diesel is also considered a drop-in fuel. This means no changes will have to be made to existing vehicles. They also meet ASTM D975 [55], which is the same standard used for regular diesel fuel [52]. According to Honeywell International Inc., a green diesel producer, green diesel emits 80% less pollution and can be blended in any proportion with existing diesel fuels [67]. They also claim that, when compared to biodiesel, green diesel has better cold-flow properties and oxidative stability [68].

6.3.2.1 Green Diesel Storage.

Since green diesel is considered a drop-in replacement, no modification will need to be made to existing storage tanks [21].

6.3.2.2 Green Diesel Airport Initiatives.

Green diesel is still an emerging fuel, and its presence in airports is expected as the technology for this fuel matures and processing costs go down. Table 3 presents the past airport initiatives that have involved green diesel.

Table 3. Examples of Green Diesel Airport Initiatives

Year	Airport/Airline/Company	Summary
2009	Los Angeles International Airport, American United, US Airways, Rentech	In August 2009, it was announced that eight airliners at the Los Angeles International Airport agreed to use green diesel to fuel their GSE vehicles starting in 2012 in cooperation with Rentech Inc. The airliners, which included American United and US Airways, agreed to purchase up to 1.5 million gallons a year from Rentech to power the airliners' luggage carts, food trucks, and other vehicles [69].
2012	Enterprise Holdings, National Car Rental, Louis Armstrong International Airport, Houston Hobby Airport, Mansfield Oil	In September 2012, Enterprise Holdings, owners of Enterprise Rent-A-Car and National Car Rental, announced they were conducting a pilot program where their airport shuttle buses at Louis Armstrong International Airport and Houston Hobby Airport would be powered by green diesel fuel provided by Mansfield Oil. This made Enterprise the first car rental company to use green diesel as a fuel for their airport shuttle fleet [70].

6.4 LIQUID PETROLEUM GAS.

LPG, commonly known as propane, is a mixture of gases that have been considered as an alternative fuel for GSE vehicles. LPG is a mixture of propane, propylene, butane, and butylene gases that become a liquid when pressurized [5]. Propane sometimes does not qualify as an alternative fuel because it is produced from natural gas processing and crude oil refining [5]. Approximately 45% of the LPG used in the U.S. comes from crude oil refining, and 55% comes from CNG processing [16]. LPG has been used as a motor fuel for over 80 years. As of 2011, 10 million on-road vehicles are powered by LPG [16], and 270,000 of those vehicles are being used in the U.S. [21]. LPG is almost a direct replacement to gasoline, and vehicles only need to be modified to meet emission standards [21]. There are also new bi-fuel vehicles that carry both gasoline and LPG and use separate systems for each fuel [21].

6.4.1 The LPG Storage and Distribution.

LPG is stored in large tanks that are connected to fueling stations. These tanks could be located either above or below ground. LPG tanks are filled via supply trucks [5].

Figure 6 shows an example of an LPG station [71] that could be present at airports. When being used by vehicles, LPG is stored and pressurized between 130 and 170 pounds per square inch [5]. Since LPG can expand at higher temperatures, the tanks are only filled to 80% capacity [5]. For fire protection, these storage facilities must comply with NFPA 58, "Liquefied Petroleum Gas Code" [72].

Figure 6. The LPG Fueling Station

6.4.2 The LPG Airport Initiatives.

Since LPG is easily available in certain areas, some airports have begun using it as an alternative fuel. Table 4 presents examples of airport initiatives that have involved LPG.

Table 4. Examples of LPG Airport Initiatives

Year	Airport/Airline/Company	Summary
2006	Austin-Bergtrom International Airport	Since 1999, Austin-Bergstrom International Airport has been using propane-powered vehicles, and in 2006, a 36,000-gallon propane vehicle station was installed at the airport [73].
2006	San Francisco International Airport	In 2006, San Francisco International Airport acquired and introduced retrofitted GSE vehicles fueled by LPG. These vehicles included 41 baggage tugs, 15 belt loaders, 23 van retrofits, 3 pickup trucks, and 1 lavatory truck [74].
2011	Louis Armstrong New Orleans International Airport	In April 2011, Louis Armstrong New Orleans International Airport added 27 LPG-powered vans to shuttle people to and from the airport [75].
2011	GO Riteway, General Mitchell International Airport	In November 2011, GO Riteway introduced 21 LPG-powered vans to General Mitchell International Airport. These vans are being used as ground transportation vehicles [76].

6.5 COMPRESSED NATURAL GAS.

Another popular alternative fuel that airports have been looking to replace gasoline and diesel is CNG. CNG is a mixture of odorless hydrocarbons, with methane gas having the highest concentration in the mixture [77]. Regarding energy consumption, CNG makes up approximately a quarter of the country's energy use [21]. It is commonly used for heaters, boilers, and electricity generation [21]; however, recently there has been an increase in the use of CNG as a fuel for light-weight to heavy-duty vehicles [78]. When compared to regular gasoline vehicles, CNG vehicles have shown an 80% reduction of ozone-forming emissions [78]. Additionally, burning CNG prevents the additional release of methane gas, which has been found to be 21 times stronger than carbon dioxide in terms of the greenhouse effect [79]. CNG comes from many different sources such as gas wells, oil wells, and coal bed methane wells [77].

All of these are nonrenewable sources; however, a new type of CNG, called Biogas, has emerged as a potential alternative fuel source. Biogas is made from biological sources, which include sewage; animal byproducts; and agricultural, municipal, and industrial waste. Compared to CNG, which contains about 70% methane, a biogas gas mixture contains from 50% to 80% methane. For this reason biogas must go through a refining process before it can be used as a fuel for vehicles. Currently, biogas powers more than half of Sweden's 11,500 CNG vehicles. [79]

6.5.1 The CNG Storage and Distribution.

Natural gas is distributed through a series of natural gas pipelines and can be stored in compressed storage tanks [21]. The size of the storage tanks can vary, reaching 20 inches in diameter and 23 feet in length [80]. An example of a CNG storage tank is shown in figure 7 [81]. Materials used to construct these tanks include steel, aluminum, and different types of composites [80]. When used as vehicle fuel, CNG is usually kept in compressed cylinders that are pressurized from 3000 to 6000 pounds per square inch [16]. When stored in cylinders, CNG is mixed with air and can only power vehicles when CNG makes up 5% to 15% of the content inside the cylinder [78]. Regarding fire protection, CNG dispensing systems and vehicles must comply with NFPA 52, "Vehicular Gaseous Fuel Systems Code" [82]; NFPA 57, "Liquefied Natural Gas (LNG) Vehicular Fuel Systems Code" [83]; and NFPA 59A, "Utility LP-Gas Plant Code" [84].

Figure 7. The CNG Storage Tanks

6.5.2 The CNG Airport Initiatives.

Since 2005, the presence of CNG at airports has been increasing. Table 5 shows examples of airport initiatives that have involved CNG.

Table 5. Examples of CNG Airport Initiatives

Year	Airport/Airline/Company	Summary
2005	Albany International Airport	In 2005, Albany International Airport received funding from VALE for two CNG shuttle buses and a CNG refueling station [85].
2010	Hamburg Airport	In January 2010, Hamburg Airport added 2 CNG-powered shuttle buses to its fleet. In total, the airport has 45 CNG-powered GSE vehicles, all of which are fueled using biogas [86].
2010	Dallas/Fort Worth International Airport	In January 2010, Dallas/Fort Worth International Airport, and Las Vegas Airport selected Clean Energy to build a CNG refueling station adjacent to the airport. These stations will support CNG-powered shuttle buses operating at the airports. It is also reported that 95% of Dallas Fort/ Worth International Airport's maintenance vehicles are powered by CNG [87].
2010	Logan International Airport	In 2010, Logan International Airport received funding from VALE to obtain eighteen 40-foot-long CNG buses for a new car rental facility [85].

Table 5. Examples of CNG Airport Initiatives (Continued)

Year	Airport/Airline/Company	Summary
2011	Houston Airport System, George Bush Intercontinental Airport	In April 2011, Houston Airport System announced that a fleet of CNG-powered shuttle buses would be operating at the George Bush Intercontinental Airport. These shuttles are expected to transport 676,000 people annually and reduce fuel costs by $2.00 per gallon [88].
2012	San Francisco International Airport	In 2012, San Francisco International Airport had almost 500 CNG-powered vehicles inside the airport [89].
2012	Tampa International Airport, Clean Energy	Between March and December 2012, Tampa International Airport used 49,900 gallons of CNG to power 16 shuttle buses and 8 other vehicles from a CNG station located at the airport. This station, operated by Clean Energy, opened in March 2012 and is expected to help the airport save about $1 million over the next 5 years [90].
2012	Lambert-St. Louis International Airport	In 2012, it was reported that Lambert-St. Louis International Airport was equipped to serve 60 CNG-powered GSE vehicles [16].
2012	Portland International Airport	Portland International Airport has been replacing its GSE vehicles with CNG-powered counterparts since 1997. In 2012, Portland International Airport had 46 CNG-powered vehicles [16].
2012	Atlanta Hartsfield International Airport	In 2012, Atlanta Hartsfield International Airport received funding from VALE for the conversion of 18 GSE vehicles to CNG-powered counterparts [85].
2013	Phoenix Sky Harbor International Airport	As of 2013, over 100 transit buses and over 100 GSE vehicles are powered by CNG vehicles at the Phoenix Sky Harbor International Airport [91].
2013	Mineta San Jose International Airport	As of 2013, Mineta San Jose International Airport reports that 25% of its fleet of vehicles is powered by CNG [92].

6.6 ELECTRICITY.

One of the cleanest alternative fuels that airports have been adopting is electricity. Electricity is a popular option since it can be produced from numerous sources. These sources include oil, coal, nuclear energy, and renewable sources like hydropower, natural gas, wind energy, and solar energy [93 and 94]. Figure 8 shows the distribution of electricity production in the U.S. as of 2011 [94]. Unlike other alternative fuels that need combustion, mechanical power from electricity is derived directly from the source itself [5]. Vehicles that use electricity as their main power source come in three different categories: hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and all-electric vehicles (EV) [95]. HEVs have the ability to alternate between an internal combustion engine and an electrical motor [95]. The electrical motor is powered by a battery that is charged through regenerative braking and through the combustion engine [95]. PHEVs are similar to HEVs with the only difference being that their battery is charged by plugging it in to some type of electrical source [95]. EVs are only powered by batteries that are charged by plugging them in to some type of electrical source [95]. Another reason why these vehicles have become popular is that when driven in electrical mode, they produce no emissions [94]. These vehicles are known to require less maintenance compared to their gasoline-powered counterparts [16].

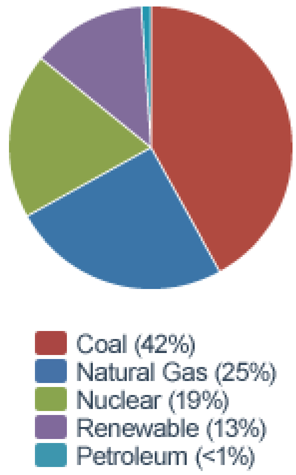


Figure 8. Distribution of Electricity Production

6.6.1 Electricity Storage and Distribution.

The most common energy storage medium for electrical vehicles is batteries, which come in different types: lithium-ion (Li-ion), lithium-polymer, nickel-metal hydride (NiMH), lead-acid, and ultra-capacitors. Li-ion batteries are popular because they have high energy efficiency, high power-to-weight ratio, and low self-discharge. NiMH batteries are known to have longer life cycles than lead-acid batteries and are known to have good specific energy. Today, most PHEVs and EVs use Li-ion batteries, and HEVs widely use NiMH batteries. [96]

To recharge these batteries, different types of charging stations were created. Currently, there are three different types of charging stations established by the National Electric Code that are used to charge PHEVs and EVs [16]. Level 1 chargers provide power through a 120-volt (V) alternating current (AC) connection [97]. The plug used to connect to the vehicle is a J1772 standard connector that was developed by the Society of Automotive Engineers (SAE) [97]. Level 1 chargers usually come in a cordset where one end of the cord is a standard NEMA 5-15 three-prong plug and the other end is a J1772 connector [98]. This cordset can be plugged into any standard 15-amp (A) 120V outlet and can charge a vehicle in 10 or more hours [16]. Level 1 chargers usually come with all plug-in vehicles [97]. Level 2 chargers use the same J1772 connector but require a 30-A 240V circuit [98]. This type of charger requires the installation of charging equipment and a dedicated circuit [97]. Power to these charging stations can come from an electric source or directly from renewable energy sources such as solar energy (shown in figure 9) [97]. Vehicles that use Level 2 charging stations can take 4-8 hours to be fully charge [16]. A Level 3 charging station uses a 480-VAC, 3-phase transformer and converts it to 500V direct current [98]. This type of charging station is known as a fast charging station since it can recharge a battery to 80% in about 1 hour [98]. Batteries using this type of charging method will not reach 100% because of heat buildup [98]. For this type of station, a CHAdeMO connector is used [94]. This type of connector has not yet been certified by the SAE [97].

Figure 9. Solar Electric Charging Station

Figure 10 shows a vehicle that can use both J1772 and CHAdeMO connections [97]. Using Level 2 and Level 3 charging stations is suggested for airports since they have the lowest charging times [5]. Level 3 stations are especially valuable for airports that have a consistently high amount of traffic [5]. For the charging stations, the wiring must abide with NFPA 70, "National Electrical Code®" [99].

Figure 10. The J1772 and CHAdeMO Connections

6.6.2 Electricity Airport Initiatives.

As of 2012, 10% of GSE vehicles are electric [16]. Table 6 offers examples on how electric vehicles have been incorporated into airports.

Table 6. Examples of Airport Initiatives Involving Electricity

Year	Airport/Airline/Company	Summary
2005	San Francisco International Airport, United Airlines, SkyWest Airlines, and Continental Airlines	As of September 2005, San Francisco International Airport used an Inherently Low-Emission Airport Vehicle grant to purchase 54 electrical GSE vehicles consisting of baggage tugs, belt loaders, and pushback tractors for three airlines that operated in the airport. These airlines were United Airlines, SkyWest Airlines, and Continental Airlines [74].
2008	Westchester County Airport	In 2008, Westchester County Airport received a VALE grant to purchase 9 electrical baggage tugs, 5 electric belt loaders, 3 electric pushback tractors, and 13 dual-port rechargers [85].
2008, 2009	Philadelphia International Airport, US Airways, United Airlines	In both 2008 and 2009, Philadelphia International Airport received VALE grants to build charging stations for 224 electric GSE vehicles that were purchased by US Airways and United Airlines [85].
2010	Logan International Airport, Delta Airlines	In September 2010, Delta Airlines received a loan from the Massachusetts Port Authority to purchase electric GSE vehicles for their terminal at Logan International Airport. With this loan, Delta purchased 50 electric baggage tugs, 25 electric belt loaders, and charging stations for these vehicles. With the purchase of these vehicles, Delta increased the number of electric GSE vehicles in Logan International Airport to 1200. In that same year, Delta had a fleet of over 1200 vehicles throughout all the airports that it operated in [100 and 101].
2010	Lehigh Valley International Airport	In 2010, Lehigh Valley International Airport received a VALE grant to purchase eight electric GSE vehicles, six electric hybrid SUVs, and six rechargers [85].
2011	Chicago O'Hare International Airport	In 2011, Chicago O'Hare International Airport received a VALE grant to purchase three hybrid pickup trucks [85].
2011	United Airlines	As of November 2011, about 25% of United Airlines' GSE fleet is powered electrically or by an alternative fuel [102].

Table 6. Examples of Airport Initiatives Involving Electricity (Continued)

Year	Airport/Airline/Company	Summary
2012	American Airlines	As of 2012, 30% of American Airlines baggage tractors and belt loaders were converted to electrical power [16].
2013	Spirit Airlines	In March 2013, Spirit Airlines purchased 21 lithium battery retrofit kits for their baggage tractors. They expect to reduce their fuel consumption by 25,000 gallons per year and reduce maintenance cost for these vehicles [103].
2013	Alaska Air	In 2013, 22% of Alaska Air's GSE fleet was powered by electricity [104].

7. PAST RESEARCH AND INCIDENTS.

In the past, researchers have studied the burning characteristics of these emerging fuels, and firefighters have responded to incidents involving these fuels as well.

7.1 THE SPK RESEARCH.

Since 2008, the U.S. Air Force has been researching the fire suppression efforts for SPK fuel fires and the burning characteristics of SPKs [105-108]. For the suppression evaluations, researchers compared suppression attempts of FT-SPK and HEFA-SPK fuels and their blends with suppression attempts on JP-8 fuel using Military Specification (MIL-SPEC) MIL-F-24385F [109]. MIL-SPEC MIL-F-24385F is used to evaluate various aqueous film-forming foam (AFFF) agents and their ability to extinguish fuel pool fires. It evaluates two aspects of the AFFF agents: how much time an agent is required to extinguish a pool fire of a certain size and the burn-back resistance of the AFFF agents [109]. Researchers wanted to see if MIL-SPEC AFFF agents would have the ability to suppress SPKs within set MIL-SPEC times.

Research showed that both FT-PSK and HEFA-SPK fuel fires were extinguished within the required 30 seconds [105-107]. An interesting observation was that HEFA-SPKs had burn-back times similar to JP-8 fuel, but FT-SPK had longer burn-back times [107]. This meant that, theoretically, FT-SPK fuel would be safer than regular fuel in the event of a fire [105 and 106]. However, when observing the average heat flux values of these pool fires from all the fuels, FT-SPKs and their blends exhibited the higher values [107]. Heat flux is the amount of heat transferred through a surface unit area. Researchers also looked at the flame propagation speeds of these fuels and found that both FT-SPK and HEFA-SPK have similar propagation speeds to JP-8 [108].

The U.S. Navy has also researched fire extinguishment efforts involving different bio-derived SPKs. This research effort examined different bio-SPKs and a blend of each fuel. The first bio-SPK was derived from camelina (HRF76) and its blend HRF76-F-76, and the SPK was derived from algae (HRJ5) and its blend HRJ5/JP-5. These fuels were compared with the Navy's two standard fuels: JP-5 and F-76. For extinguishment efforts, gaseous agents, foam agents, and water were used as the extinguishing agents. Cup burner tests with the SPK fuels and blends were run when gaseous agents were used. These tests revealed that bio-SPKs and their blends were a bit more difficult to extinguish then their petroleum counterparts. [110]

For AFFF agents, MIL-F-24385F tests were run with the bio-SPK fuels and blends. These tests showed that the AFFF agents passed the MIL-SPEC tests with these fuels [110].

For the water agent test, researchers used water mist to combat a compartment containing a 4-Megawatt fuel spray fire. Only SPK blends and their petroleum counterparts were used for this fire scenario. Results showed that the blends only took a couple of seconds longer to extinguish than the petroleum-based fires. Overall, researchers concluded that these fuels posed no new threats to Navy firefighters [110].

In France, the Direction Générale de l'Armement (DGA) (responsible for France's Department of Defense procurement) Aeronautical Systems, in conjunction with the French Institute of Industrial Environment and Risks, conducted several tests to evaluate the potential changes alternative jet fuels could pose on fire safety. In these tests, they evaluated four different alternative fuels with different aromatic concentrations; one fuel contained an oxygenated compound. These fuels were then compared with the fire performance of JP-8 fuel. The DGA evaluated these fuels using three tests: fire resistance test of materials (Park Burner tests), burnthrough tests (NextGen Burner test), and heat flux tests using a 2-m^2 fuel pan. For the Parker Burner tests, researchers found the fuels that produced less soot and smoke exhibited the best performances (longer failure times on aluminum sheets). For the burnthrough tests, the alternative fuels that produced the highest levels of smoke and soot had quicker burnthrough times. These times were quicker than the times recorded with JP-8 fuel. Heat flux tests revealed that there was no significant difference in the flame temperatures read by thermocouples. Looking at heat flux readings from outside the fuel pan showed that most SPKs registered slightly lower readings compared to JP-8 fuel. The DGA found significant differences with some alternative jet fuels' fire performance compared to JP-8 fuel. Soot and smoke production played a major role in the fire performance. [111]

7.2 BIODIESEL INCIDENTS AND SUGGESTED PROCEDURES.

In April and July 2007, incidents were reported where biodiesel-soaked rags, which were used to handle biodiesel in storage facilities, caused chemical reactions that produced small fires [112]. These incidents show that, given the right temperatures, even the smallest amount of biodiesel could self-combust.

On June 12, 2009, the National Biodiesel Board, in a partnership with the U.S. Department of Energy and the International Association of Fire Chiefs, released a training package that educates firefighters on how to combat biodiesel fires [113]. The training material includes presentations and videos that discuss topics such as what foams are preferred to extinguish a biodiesel fire [113]. Their training material suggests using alcohol-resistant AFFF (AR-AFFF) to extinguish a biodiesel fire [114]. The issue with using AR-AFFF is that ARFF personnel in the U.S. are not allowed to use this agent since it is not MIL-SPEC qualified. FAA Cert Alert 06-02 states:

> "Any AFFF purchased after July 1, 2006 by an airport operator certificated under Part 139 must meet the Mil Spec as mentioned above. There are several reasons

for this requirement. First of all, AFFF has to be compatible when mixed. AFFF manufactured by different manufacturers, although meeting the UL 162 standard, may not be compatible. AFFF meeting the Military Specification will always be compatible with other Military Specification AFFF no matter the manufacturer. Second, AFFF meeting the military specification requires less agent than AFFF meeting UL 162 to extinguish the same size fire. Finally, the requirement to use Mil Spec is in concert with the National Fire Protection Association National Fire Code 403, paragraph 5.1.2.1." [115]

When reviewing biodiesel's material safety data sheet (MSDS), it states that foam, dry chemical, and gaseous agents could be used to extinguish small fires involving biodiesel. When dealing with large fires, foam agents are recommended. The MSDS also recommends that fire personnel may have to withdraw from large fires and allow the tank to burn [116].

7.3 THE LPG INCIDENTS AND RECOMMENDED PROCEDURES.

On April 9, 1998, 20 volunteer firefighters responded to a propane fire at a turkey farm that was 2.5 miles away from the fire department in Iowa [117]. The cause of the fire was an all-terrain vehicle struck a pipe that was adjacent to an 18,000-gallon LPG storage tank [117 and 118]. This pipe fed LPG to a device known as a vaporizer, which converts the LPG from a liquid state to a gaseous state [117]. The gas leaked from this pipe, reached a pilot flame, and ignited. When firefighters reached the turkey farm, the storage tank was engulfed in fire and was venting from two pressure release valves [117]. Firefighters decided to allow the tank to burn itself out, and they sprayed water on surrounding buildings [117]. Eight minutes after firefighters arrived, a boiling liquid expanding vapor explosion (BLEVE) occurred [117 and 118]. This explosion separated the tank into four parts, which were launched in four different directions [117 and 118]. This flying debris killed two firefighters who were 105 feet away from the tank and injured seven other personnel [118]. On April 15, 1998, investigators from the National Institute for Occupational Safety and Health (NIOSH) arrived at the scene to investigate the incident [118]. After reviewing all of the evidence and testimony from the incident, NIOSH made the following recommendations [117]:

1. "Fire Departments should follow guidelines as outlined in published literature and guidebooks for controlling fire involving tanks containing propane.
2. Emergency personnel should adhere to the procedure outlined in 29 CFR 19.10.120(q) - Emergency response to hazardous substance release.
3. All firefighters should be educated to the many dangers associated with BLEVE." [117]

They recommended reviewing the emergency procedures stated in the Emergency Response Guidebook (ERG). The ERG states that when combating an LPG fire, firefighters should follow these procedures: [119]

"Small Fire

- Dry chemical or CO_2.

Large Fire

- Water spray or fog.
- Move containers from fire area if you can do it without risk.

Fire Involving Tanks

- Fight fire from maximum distance or use unmanned hose holders or monitor nozzles.
- Cool containers with flooding quantities of water until well after fire is out.
- Do not direct water at source of leak or safety devices; icing may occur.
- Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank.
- ALWAYS stay away from tanks engulfed in fire.
- For massive fire, use unmanned hose holders or monitor nozzles; if this is impossible, withdraw from area and let fire burn." [119]

On July 6, 2007, an LPG line at an ARFF training facility at Salt Lake City International Airport started leaking and caused a fire near the facility's 12,000-gallon LPG storage tank. Because ARFF personnel were concerned about the risk of a BLEVE, they evacuated personnel from the surrounding buildings. The tanks were equipped with safety shutoff valves that automatically closed when the fire was detected, so flow to the LPG line was stopped, and the fire was starved. At the same time, ARFF personnel soaked the storage tank with water to keep the tank cool and prevent a BLEVE. [120]

7.4 THE CNG INCIDENTS AND RECCOMENDED PROCEDURES.

In March 2012, firefighters responded to a multiple-vehicle fire at a government holding lot [121]. One vehicle that caught on fire was a Honda GX, which was powered by CNG [121]. As firefighters approached the GX, the vehicle exploded; at this time firefighters were 50-75 feet away from the vehicle [122]. Debris from the explosion was ejected in all direction as far as 100 feet [122], and the CNG tank landed 95 feet away from the vehicle [122]. Recommendations from this incident were to approach the vehicle from 45° angles, be able to identify CNG vehicles, and consider cooling streams from a distance [122].

In October 2012, a CNG-operated bus caught on fire in the Netherlands [123 and 124]. The passengers and driver evacuated from the bus after failing to extinguish the fire [123]. The blaze reached the CNG tanks stored in the roof of the bus and set them on fire [124]. Heat from the fire caused the cylinders' main valve to break, which caused up to 15-meter-long, horizontal flames [123 and 124]. Because of the horizontal flames, firefighters were not able to combat the fire [123]. If the main valves had not broken, a BLEVE could have occurred [125].

When combatting a CNG fire, the ERG suggests using the same procedures that are used when dealing with an LPG fire [119].

7.5 ELECTRIC VEHICLE FIREFIGHTING TRAINING.

Electric vehicles are different from other types of vehicles, since their fuel source varies depending on the vehicle. Some have a combination of a fuel tank and a battery, and others only have a battery. Therefore, ARFF personnel should know how to combat fires in both types of electric vehicles.

In May 2010, the Fire Protection Research Foundation published a report detailing the different hazards that each type of electrical vehicle presented. It was emphasized in this report that firefighters should have some basic knowledge on the wiring of these vehicles. Also, while water, foam, dry chemical, and gaseous agents could be used to extinguish electric vehicle fires, more research on the behaviors of these fire types should be done. Further reported was that one of the more challenging areas where firefighters would have to respond is the fleet charging stations, especially indoor stations. [126]

On July 26, 2012, NFPA launched an online training course, known as Electric Vehicle Safety Training, which was designed for first responders dealing with electric vehicle fires [127]. This self-paced course teaches firefighters how to identify different electric vehicles, understand basic electrical concepts, respond to vehicle and battery fires, and other topics [127]. ARFF personnel with electric vehicles in their airports are encouraged to take this training course.

7.6 FUEL FARM INCIDENTS.

Fuel farms pose a threat to ARFF personnel because the farms can produce significant-sized fires due to the amount of fuel they store.

In November 1990, ARFF personnel combatted a fire at Stapleton International Airport's fuel farm that had started at two 400,000-gallon jet fuel storage tanks and spread to an 800,000-gallon storage tank [128]. It took ARFF personnel over a day to control the fire, which by the second day had burned about 2.8 million gallons of fuel [129].

In March 2011, the fuel farm at Miami International Airport caught fire. It took ARFF personnel more than 2 hours to extinguish the fire, which damaged the pumps used for the underground fueling system at the airport [130].

7.7 FUEL TANKER INCIDENTS.

Since fuel tankers constantly operate around the airport, they also add to the types of hazards that ARFF personnel need to respond to.

In January 2013, strong winds blew a B-737 into a parked fuel tanker at Buffalo Niagara International Airport [131]. The aircraft nose was damaged, but no fuel leak occurred [131]. If this tanker had caught fire, it would have posed the threat of igniting the aircraft fuel tank as well.

In August 2013, a fuel truck at Southwest Florida International Airport caught fire. ARFF personnel were able to extinguish it using foam agent. The fire occurred on a road used to access the airport's fuel farm. [132]

8. CONCERNS/FUTURE AREAS OF RESEARCH.

After reviewing past incidents and training recommendations by different organizations, some areas of concern were found that should be considered for future research efforts.

8.1 THE SPK FUELS.

SPK firefighting research has only been documented since 2008, and the research has been limited [105-108]. Moreover, research has only been performed using military-grade aviation fuels and not commercial fuels. The research only looked at small fires through the MIL-SPEC tests (10 gallons of fuel) and other small test setups [105-108]. Although this research noted that MIL-SPEC foams could adequately extinguish SPK fires, it did specify some SPK exhibited higher heat fluxes [107]. This could become an issue when dealing with large pool fires. This implies that the bigger the area, the more heat is transferred. Since some SPK have higher heat fluxes, more heat will be transferred compared to JP-8 fuels. This is of great concern when dealing with aircraft pool fires, since the amount of heat being transferred by SPK fuels could evaporate liquid-based agents before they can extinguish the fire. For this reason, large-pool SPK fire research is necessary to observe and evaluate the effectiveness of MIL-SPEC AFFF in extinguishing it. This type of research will aid researchers in determining if the amount of AFFF present in an airport is sufficient to respond to an SPK fire. These large pool fires should not focus only on aircraft crashes, but also on fuel tankers and fuel farms, since SPK fuel will be stored in them.

After researching the amount of AFFF needed to put out a large SPK pool fire, future research should also investigate the amount dry chemical agent or clean agent needed to extinguish fires of this nature. To do this, researchers should investigate three-dimensional fires using SPK fuels. As the past research suggests, more clean agent might be needed to combat SPK fires than the amount used to combat Jet A fuel fires. Researchers should also investigate if SPK fuels can be used with the FAA NextGen burner, and if successful, use SPK fuels for various material fire tests such as burnthrough tests. The tests conducted by the DGA indicated that some SPKs have quicker burnthrough times [111], which is of great concern if a pool fire were ever to occur next to an aircraft. For these burnthrough tests, researchers should not only look at aluminum skins but also the next composite skins that aircraft manufacturers are incorporating into their new aircraft.

8.2 THE AVGAS ALTERNATIVES.

AVGAS alternatives are still in their infant stages, but as these technologies mature, researchers should begin to investigate their burn characteristics. To do this, certified AVGAS fuels should be used in the MIL-F-24385F tests [109]. With this test, researchers will know how much agent will be needed to extinguish a pool fire involving alternative AVGAS fuels. Another area researchers should investigate is how to respond to a potential fire that could occur at fuel islands holding AVGAS alternatives located around the airport.

8.3 THE DIESEL ALTERNATIVES.

Extinguishing biodiesel and green diesel vehicle fires should be similar to extinguishing diesel fires, but the greater concerns are the storage tanks where the diesel fuel is stored. Literature has shown that biodiesel is a solvent that could corrode the storage tank and leak from the tanks [5 and 21]. As previously stated, biodiesel fuel could go through chemical reactions and self-combust [112]. If biodiesel leaks from a storage tank and self-combusts, this could cause the storage tank to catch on fire. Because of this danger, researchers should look at more tactics that could be used in combating storage tank fires.

8.4 THE CNG AND LPG STORAGE TANKS.

Regarding CNG and LPG, the greatest dangers are the storage tanks in which the fuels are contained. These are not only the large storage tanks kept on airport property, but also the tanks that are installed in GSE vehicles. These tank fires are difficult to control, and they could be potentially dangerous to ARFF personnel. As past incidents have shown, these storage tanks could undergo BLEVE [117, 118, 121, and 122]. The blast range from these tanks could reach 100 feet or more. Since GSE vehicles operate at airport gates and ramps, explosions of these ramps could put not only personnel in danger, but they could also potentially damage aircraft or structures. Large storage tanks could be located near fuel farms, and this could place these farms in danger. When on fire, these storage tanks could create craters if they explode, or even more dangerous, the tanks could explode and spread the fire to the adjacent fuel farms. For these reasons, research should be conducted to determine what tactics will be effective when combating CNG and LPG storage tank fires.

8.5 ELECTRIC VEHICLES.

Development of Li-ion batteries has helped increase the presence of electric vehicles not only on roads and highways but also at airports. Because of the potential dangers of Li-ion battery fires [126 and 127], researchers should consider investigating potential fires that could occur with electric GSE vehicles operating at the AOA. Locations of these batteries should be investigated, as well as the potential of these batteries launching shrapnel at ARFF personnel or other vehicles. One topic to consider for future research is whether ARFF personnel will need to set a perimeter around the vehicles, or if the fire dangers will not be that significant.

Past literature states that electric vehicle charging stations are usually placed next to each other, meaning vehicles will be adjacent when charging [95-98]. Also, depending on the traffic and type of charging station, many airports might leave electric GSE vehicles charging overnight, which could increase the chance of thermal runaway. Since the vehicles are charging together side-by-side, an electric GSE vehicle fire could spread from one vehicle to another, which would mean that multiple Li-ion batteries could catch fire. With known Li-ion's highly reactive nature, this type of fire could pose a great danger to ARFF personnel, vehicles, and structures around these GSE vehicles.

9. SUMMARY.

This literature review looked at the types of alternative fuels that are being integrated into airports and how these fuels are being integrated. AVGAS alternatives are still fairly new and will require future research. To be certified as a jet fuel drop-in, SPK fuels must pass ASTM D1655 and ASTM D7566. Currently, two SPKs have been approved by ASTM, and two are on their way to be approved. Biodiesel is only available up to B20 blends, and it will need special care when being stored. LPG and CNG must both be stored in compressed storage tanks and burn cleanly, thus helping to lower emissions. Electric vehicles come in three different versions, and they are a popular choice when it comes to replacing GSE vehicles.

Part of this literature review also looked at fire research and tactics recommended for combating alternative fuel fires. Research showed that SPK fuel fires are similar to JP-8 fuel fires, but some SPK fuel blends did exhibit slightly higher heat fluxes during pool fire tests. Research also showed that some SPKs had faster burnthrough times than JP-8 fuel. When combating biodiesel fires, it is recommended to use AR-AFFF, but this extinguishing agent cannot be used in airports under Cert Alert 06-02 because AR-AFFF is not MIL-SPEC-certified. LPG and CNG pose great dangers because of the chance that a BLEVE could occur, because the fire would be near the storage tanks. If a compressed storage tank is on fire, it is recommended that ARFF personnel try to cool down the tank to prevent a BLEVE. Fire tactics for combating electric fires is fairly new, and more research must be done on electric vehicle fires.

Section 8 of this literature review presented areas where ARFF researchers should invest their time when looking at alternative fuels. For each alternative fuel and storage area, concerns and scenarios were presented as possible future research efforts. This ranged from testing fuels with different agents to possible scenarios occurring at airports.

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APPENDIX A—EXAMPLES OF GROUND SUPPORT EQUIPMENT VEHICLES

The following ground support equipment (GSE) vehicle examples were obtained from ACRP Report 78 [A-1].

Category	Category Description	GSE	GSE Description
Ground power/air conditioning	Used to help start the engines, operate instruments and provide for passenger comfort (e.g., lighting, air conditioning) while an aircraft is on the ground.	Air starter 	Vehicle with a built-in engine which, when aircraft engines are started, provides air for the initial rotation of a large engine.
		Ground power unit (GPU) 	Mobile generators that provide power to parked aircraft when an aircraft's engines are not in use. Typically not used when an airport has gate power systems [i.e., 400 Hertz (Hz)]. Can also be used to start aircraft engines.
		Air conditioning units 	Also referred to as air carts, these units provide conditioned (i.e., cooled and heated) air to ventilate parked aircraft. At some larger airports, individual packaged assemblies or centralized electrical-powered pre-conditioned air (PCA) systems are used.
Aircraft movement	Although an aircraft's engines are capable of moving an aircraft in reverse, this is not typically done for aircraft with jet engines due to the resulting "jet blast" that would occur at the back of the aircraft. For this reason, and others, pushback tugs/tractors are used to maneuver aircraft away from (i.e., out of) gates.	Pushback tugs/tractors 	Used to move an aircraft out of a gate when a pilot is given clearance to taxi to a runway. May also be used to move an aircraft to various locations on an airport (e.g., maintenance hangars). There are two types of pushback tugs/tractors: (1) conventional and (2) towbarless. Conventional tugs use towbars that are connected to an aircraft's noise wheel. Towbarless tractors scoop up the noise wheel and lift it off the ground.
Aircraft service	Aircraft service activities include replenishing supplies and aircraft refueling.	Catering truck 	Typically owned and operated by airlines and companies that specialize in airline catering (e.g., preparing and supplying packaged food). Services provided include removal of unused food/drinks and loading of these items for the next flight.
		Cabin service vehicles 	The main cabin service activities are cleaning the passenger cabin and replenishing items such as soap, pillows, and blankets.

Category	Category Description	GSE	GSE Description
		Lavatory service vehicles 	Used to flush aircraft lavatory systems. Small commuter and regional aircraft used for short flights may not be equipped with on-board lavatories.
		Potable water trucks/carts 	These trucks provide drinkable water to an aircraft.
		Aviation fuel trucks, hydrant dispenser trucks/carts 	Two methods are used to fuel aircraft. The first dispenses fuel from a fuel truck/tanker directly to an aircraft's tank(s). The second method of dispensing fuel is used at airports with underground fueling systems and employs hydrant trucks/carts as "connectors" between the underground fueling system and aircraft.
		Hydrant pit cleaners 	Used at airports with underground fueling systems. Flushes and cleans hydrant pits.
		Maintenance vehicles 	Various types of vehicles are used to provide aircraft maintenance service. These vehicles are used by airport and/or airline employees to travel to/from maintenance facilities and an aircraft in need of repair.
		Deicers 	Vehicles that are used to transport, heat, and spray deicing fluid on an aircraft prior to departure.
Passenger loading/ unloading	Methods vary depending on airport, aircraft, and available airport equipment/facilities. Two methods are used to board passengers onto large aircraft—boarding stairs and jet bridges.	Boarding stairs 	Whether towed, pushed into position, or fixed to a truck, boarding stairs provide a means of loading and unloading passengers at hardstands (i.e., remote parking positions) and in the absence of jet bridges.
		Buses 	On the airside of a large airport, buses may be used to transport passengers and employees from terminal to terminal (or aircraft). Referred to as "people movers," "mobile passenger lounges," and "moon buggies."

Category	Category Description	GSE	GSE Description
Baggage/cargo handling	Passenger baggage/some cargo must be transferred to/from gates and from gate to gate. Cargo-only aircraft typically have one or more large doors to facilitate loading/unloading of goods.	Baggage tugs 	Most recognizable type of GSE at an airport. These vehicles are used to transport luggage, mail, and cargo between an aircraft and the airport terminal and/or processing/sorting facilities.
		Belt loaders 	Used to load and unload baggage and cargo into/from an aircraft.
		Cargo/container loaders 	Used to load and unload the cargo on an aircraft that is within a container or on a pallet.
		Cargo transportation/ tractors 	Used to load and unload cargo but are primarily used to move cargo from one airport location to another.
		Forklifts 	Cargo is moved primarily by forklifts within airport cargo handling facilities.
		Conveyors	At larger airports, there has been a recent trend to move baggage between concourse collection areas and to/from the concourse collection areas and the terminal baggage claim areas using conveyor systems. Installation of such conveyor systems can significantly reduce the run time for baggage tugs and/or reduce the number of baggage tugs at an airport.
Airport service	Various types of GSE are used by ground crews (airline and/or airport) to service airports.	Snow removal equipment 	Airports use snow removal equipment to keep runways, taxiways, and ramp areas free of snow and ice. Can include snowplows, snow sweepers, and snow blowers. Snow sweepers, typically used in areas with low snow tolerance (i.e., runways), use brushes to remove thin layers of snow from pavement services. Snow blowers are sometimes used instead of snowplows. This type of vehicle uses spinning blades that force the snow out of a "funnel" on the top of the blower.

Category	Category Description	GSE	GSE Description
		Foreign object debris (FOD) removal 	The removal of FOD can be accomplished using mechanical systems (power sweeper trucks, vacuum systems, and jet air blowers) and non-mechanical systems (e.g., tow-behind trailers equipped with brushes, magnetic bars).
		Bobtail trucks	A bobtail is an on-road truck that has been modified to tow trailers and equipment. Bobtails are also used at some airports to plow snow.
		Miscellaneous equipment 	Includes the non-road equipment used by an airport's ground crew to maintain the airport airside environs. This GSE includes generators and lawn mowers. Select on-road equipment such as tow trucks (pictured) can also fall into this category.

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