EMERGING TRENDS IN ALTERNATIVE AVIATION FUELS

by

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Dedicated to my Grandparents

Donald and Alma Girton

Without whom I would never have had the opportunity of graduate school.

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Abstract

The days of petroleum-based aviation fuels are numbered. New regulations to be set in place in the coming years will force current fuels to be phased out in favor of cleaner fuels with less toxic emissions. The alternative fuel industry has already taken its foothold in other modes of transportation, and aviation will soon follow suit. Many companies have cropped up over the last decade, and a few have been around longer, that work hard to develop the alternative aviation fuels of the future. It is important, however, for the aviation community to know what to expect and when to expect it concerning alternative fuels. This study investigates where various companies in the alternative aviation fuel industry currently stand in their development and production processes, and how their products will affect aircraft owners and operators. By interviewing representatives from these companies and analyzing their responses to identify trends, an educated prediction can be made about where the industry is headed and when the aviation community can expect these fuel to be available. The findings of this study indicate that many companies are still in their developmental stages, with a few notable outliers, and that most of these companies expect to see production of their product by 2017. Also, the fuel manufacturers are dealing with all the legal hurdles regarding alternative fuels, so little to no effort will be required on the part of the consumer. These findings, along with their analysis, will enable the aviation community to make educated decisions concerning fuel and their aircraft, as well and do their part to help these beneficial fuels get to market.

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CHAPTER I: INTRODUCTION

A time is coming when today's "alternative" fuels will no longer be considered alternative. Whether the present society embraces them or not, sustainable and clean-burning fuels become more necessary each passing day as supplies of petroleum based fuels dwindle and the planet is subjected to increasing greenhouse gas levels. It may be decades before the full potential of sustainable fuel sources is realized, but research is ongoing and some options are already on the market. The majority of media coverage is directed to the largest fuel-consuming sector - automobiles. However, thousands of jetliners and general aviation aircraft fly overhead every day, guzzling jet fuel and avgas while leaving behind a carbon footprint of their own. Though comparatively their impact on the environment is small, lowering emissions for aircraft would be tantamount to taking millions of cars off the road. The success of air carriers is also a vital part of the economy and in order for aviation to thrive there must be a switch to cost effective sustainable fuels. There are currently many companies working on developing viable alternative fuels for aviation, both for jet fuel and avgas, but many obstacles hinder the adoption of these alternative fuels. Switching from the established platform of fossil fuels will take time, though legislation may soon mandate new fuel standards in some sectors of aviation. Whether the alternative fuel arrives by the pen of the lawmakers or by the wise choices of futurist aviators, the aviation industry is here to stay, but the fossil fuel is not.

Review of Literature

On August 28, 2012, President Barack Obama announced new automobile emissions standards for the United States to be enforced with gradually intensifying rigor

(Eilperin, 2012). The standards state that by the year 2025, U.S. automobiles must average 54.5 miles per gallon or better (Eilperin, 2012). The driving forces behind the new standards are the environmental concerns about the effects of toxic emissions and greenhouse gases, the finite supply of fossil fuels, as well as our nation's crippling dependency on foreign oil. Automobiles are not the only sector of transportation under the microscope; airliners account for 3% of all carbon emissions in the United States – a sizeable amount considering the number of airplanes compared to automobiles. For this reason, new efficiency and fuel standards for aviation will go into effect as soon as 2013. One way of reducing emissions is by increasing the efficiency of the engine, which often involves reducing its power output, but changing the type of fuel that the engine uses can also lower emissions. With aviation playing a pivotal role in commerce, high capacity, high speed, long distance flights are becoming more and more common. This essentially rules out the option of putting underpowered engines on smaller and slower airplanes to save fuel, not to mention the safety concerns that might present. Instead, developing and producing fuel from alternative, sustainable sources can lower emissions while maintaining power output. Though still in their adolescence, alternative fuels are inevitably coming, and there are many companies already in the game, each with their own idea for how to fuel the future of aviation.

Before delving too deeply into which alternative fuels will power the future of aviation, the reasons why the current standards will not suffice much longer should be clearly defined and consolidated. In very basic terms, aviation fuels are currently stratified into two broad categories: avgas (aviation gasoline) and jet fuels – the latter being much more varied. Both of these fuel categories are at least in part comprised of petroleum-derived gasoline. The problem with petroleum is that the world contains a finite amount of it and that much of it is harvested from the Middle East – a region whose ties with the United States are in a delicate political balance. Importing foreign oil is both expensive and temporary, for no matter where petroleum comes from, it will eventually dry up. It is the desire of the United States to lessen its dependence on foreign oil as well as develop sustainable, clean energy solutions for the future.

The second set of issues associated with traditional fuels is probably the main set of issues that most people think of first when pondering the evils of oil. This problem came to the forefront of the media in recent years and is the pollution factor associated with the burning of traditional fossil fuels. Many scientists fear that rising levels of CO_2 produced mainly from the burning of fossil fuels will have global consequences. Figure 1 on the following page depicts the percentages of various anthropogenic greenhouse gases released into the atmosphere, and Figure 2 shows the amount of CO_2 produced from various sources, including fossil fuels.

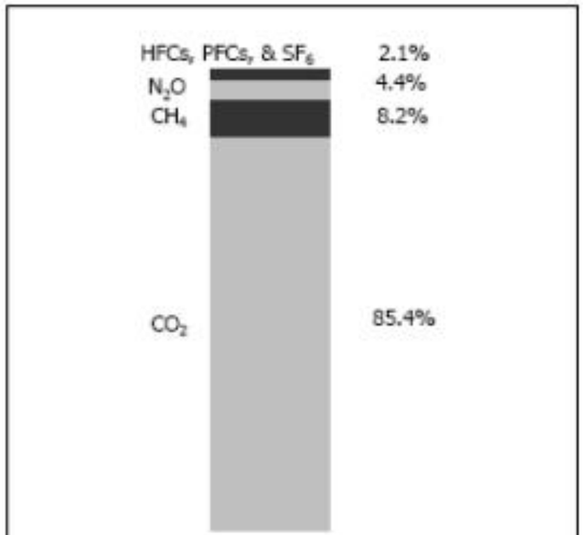

Figure 1: 2007 Greenhouse Gas Emissions by Gas (percents based on Tg CO2 Eq.) (Tg – teragram = 10^{12} g)

Figure 1. *Greenhouse Gas Emissions by Gas (Lesson 2 – Why do we need, 2009).*

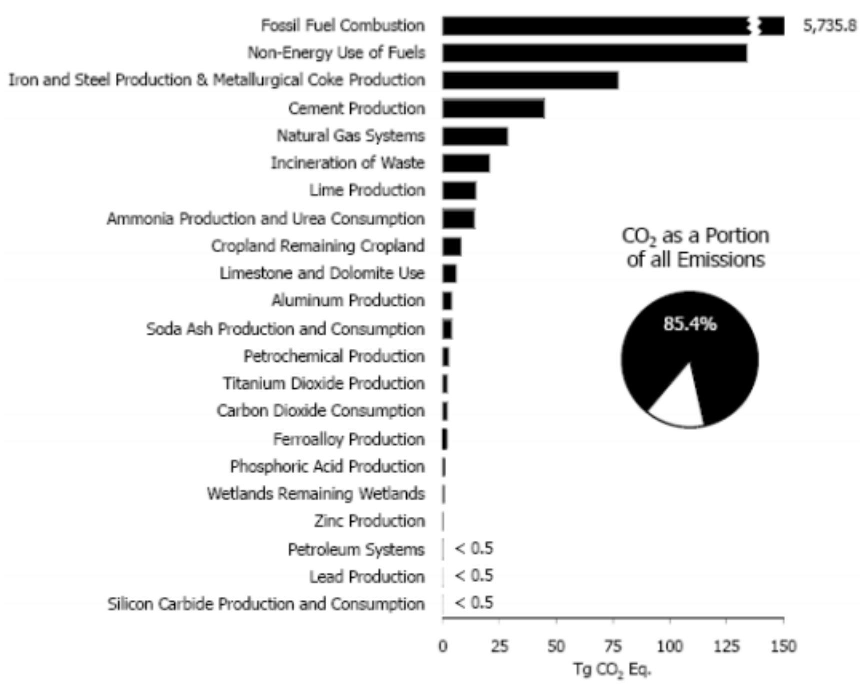

Figure 2. *CO_2 as a Portion of all Emissions (Lesson 2 – Why do we need, 2009).*

Most people have heard about the harmful amount of CO_2 associated with fossil fuels and how that may or may not contribute to global warming, but there is another pollutant in avgas that may be even more dangerous. A toxic chemical called tetraethyl lead is required to achieve particular combustion properties specific to aviation fuels. Currently, emissions from the avgas 100LL contribute 45% of domestic atmospheric lead pollution (What is 100LL?). When the fuel is burned, the lead is released into the atmosphere, and studies have linked the inhalation of this airborne lead with problems in child brain development; even exposure to a small amount of tetraethyl lead may decrease the intellectual potential of a child. The threat is less for fully developed adults. Currently, about 30% of the general aviation community exclusively burns 100LL. A greatly reduced lead content or unleaded general aviation fuel will soon become mandatory because in October 2008 the EPA announced that airborne lead emissions must be reduced from 1.5 $\mu g/m^3$ to 0.15 $\mu g/m^3$ or 10% of their previous allowance by January, 2017 (What is 100LL?).

As far as CO_2 pollution from fossil fuels goes, the amount contributed by avgas-driven, general aviation airplanes is small. In fact, per volume, the combustion of avgas produces less CO_2 than automotive gasoline. In contrast, airborne pollutants released from commercial jets are higher per volume than automotive gasoline and contribute a full three percent of total airborne pollutants. The issues with pollution from jets are fortunately less psychological and more environmental. While three percent seems like a small number compared to all the pollution from cars, some of the alternative fuels in development could offer up to a 90% decrease in emissions without any alterations to the engines at all (Beyersdorf & Anderson, 2009). This will be discussed later, but the point remains that alternative fuels for commercial jets hold much promise and is a worthwhile investment for the planet.

The next several paragraphs reference historical data from an interview with Melanie Thompson. Mrs. Thompson is a chemist for a company called Baere Aerospace Consulting. She has personal experience with several methods of alternative fuel production for both alternative jet fuels and avgas. Her company works with many fuel suppliers to help them improve their fuel production methods. She has many years of experience and a broad knowledge of production methods that make her a reliable source of information on alternative fuels.

Moving forward, aviation fuels must be discussed one category at a time. It is difficult to know where alternative fuels are going without knowing what the standard is currently. For powering airplanes, fuel can be separated into two categories depending on the type of airplane: those using reciprocating engines and those using jet engines (M. Thompson, personal communication, October 6, 2011). Reciprocating engines are by far the most prominent power plant in general aviation aircraft. The fuel standard for many years now for reciprocating engines is called 100LL, which refers to its octane content, and "LL" stands for "low lead" (FAA OKs use of 100VLL, 2011). Lead is required in this fuel for this type of engine because it regulates the way the fuel burns in the combustion chamber and keeps the engine from "knocking" (M. Thompson, personal communication, October 6, 2011). Researchers are searching for ways to remove the lead altogether but currently unleaded alternatives are not available in any significant quantities. Alternative liquid fuels used in automobiles are also not an option because the many of these contain high levels of ethanol, which is made from corn. To use these fuels requires engine modification even in cars, but the engine modification required for aircraft would not even be worth the cost or effort, as the fuel is not powerful enough for the aircraft to perform safely (M. Thompson, personal communication, October 6, 2011). Scientifically speaking, every molecule of fuel has a particular amount of potential energy and not all fuels are created equal. Diesel fuel, for example, contains more potential energy per molecule than regular gasoline, which is why, gallon for gallon in similar sized vehicles, diesel vehicles get better gas mileage; each molecule of diesel pushes the vehicle farther than each molecule of gasoline would (M. Thompson, personal communication, October 6, 2011). With ethanol, there is less potential energy per molecule than there is even in gasoline, and with an airplane there are times when full throttle power is not just desirable, it is required for survival. Such an instance could be when trying to take off on a runway with limited space and an obstacle at the other end; if the airplane does not have enough power it will result in an unhappy ending for both pilot and plane. Needless to say, using fuels comprised of a majority of ethanol presents a risk that many people are not willing to take. This issue of power is one of the main factors that other, truly clean energy sources presently hold little promise as well.

The lead contained in the 100LL, however, is harmful to the environment when it is released in the plane's exhaust. That lead can get swept up by rain and washed into rivers, streams, and soil resulting in unfavorable conditions for plant growth, which could include edible crops (M. Thompson, personal communication, October 6, 2011). The fact of the matter is that something must be done to reduce the lead in general aviation emissions. As it so happens, simply incorporating less lead in the fuel is the current solution; the most effective alternative fuel for general aviation planes is merely a reduced-lead version of the already “low lead” 100LL. This reduced-lead version is appropriately called “100VLL” for 100 octane and “very low lead.” The FAA approved this new version of the fuel on September 14th, 2011 (FAA OKs use of 100VLL, 2011). According to the FAA, the 100LL variety “has the same minimum octane rating and will provide the same level of anti-knock performance as 100LL and 100 avgas grades,” (FAA OKs use of 100VLL, 2011, para. 3). The “anti-knock” property of the 100VLL gas is one of the unique properties of lead previously mentioned. It is very important that the properties of the fuel be the same as traditional fuels, as identical performance presents functional and economical advantages. Concerning 100VLL, the FAA also said it “meets all of the performance requirements of grades 80, 91, 100 and 100LL and will perform identically in existing aircraft and engines,” (FAA OKs use of 100VLL, 2011, para. 2).

In the world of alternative fuels, the ideal fuel would be one that is cleaner, cheaper, and provides equal or better performance with no necessary modifications to the aircraft. That last point echoes the concept of *identical* properties. Alternative fuels that can replace conventional fuels with no modification to the engine or loss in performance are known as “drop-in” fuels, implying that one can simply be dropped into the place of the other and everything would still run smoothly (M. Thompson, personal communication, October 6, 2011). 100VLL qualifies as a drop-in fuel, which makes perfect sense considering that the two fuels are truly identical in every way except that the alternative version merely has the least possible amount of lead.

Maintaining the ability to use an alternative fuel in an existing engine with minimal modification is important to pilots mainly for the financial implications.

100VLL is a great start, but the eventual goal of researchers and activists is to remove the lead from avgas altogether, as even a little exposure to tetraethyl lead is still harmful, particularly for children. An unleaded avgas alternative that performs as well as its leaded counterparts is greatly desired in the aviation community but would require extensive testing before its approval in the US market. This is shown to be true by the existence of unleaded aviation fuels in the Scandinavian general aviation market from as early as 1979. Back then there were only low-octane versions available but in 1991 a 91/97 UL avgas was developed and implemented in that same market. In November 2012, due to a good safety record, those same 91/97 UL fuels were approved for use by the European Aviation Safety Agency. The company producing that fuel is Hjelmco Oil (Hjelmco Oil, 2012). The existence of this fuel is little more than proof of concept for the US general aviation market though, as 30% of US general aviation airplanes can only run on 100LL or a compatible direct alternative. Fortunately, in February 2010, General Aviation Modifications announced the development of a fuel they call G100UL – an unleaded 100LL alternative safe for use in existing engines and even being mixed with 100LL during transition. Tests on this fuel are promising, even showing increased energy density (Hjelmco Oil, 2012. The challenge, as with all alternative fuels, is making the cost to the consumer competitive with the standard fossil fuel. While costs will come down over time, G100UL and other alternative fuels currently would cost more at the pump than the fuels they are designed to replace.

While this next fuel may not actually be alternative, it is a deviation from the usual trend of using 100LL or avgas: some small aircraft owners will power their planes using normal high-octane gasoline available at any gas station. The octane level is high enough to satisfy the needs of many planes, though some engine manufacturers do not honor engine warranties if the owner has not conformed to strict fuel-use guidelines (M. Thompson, personal communication, October 6, 2011). The reason for using the high-octane gasoline is simple – price. One trip to the avgas pump at any airport would be enough to make many people shy away from flying, as most places sell it for between four and five dollars per gallon, and most airplanes are not what many would consider "fuel efficient". For example, the Cessna 172, the best-selling general aviation aircraft of all time, manages between 7.5 and 9.5 gallons per hour (Skyhawk, 2011). At a cruising speed of around 122 knots (140 mph), that's around 16.5 miles per gallon, so about as fuel efficient as many SUV's or luxury cars even at highway speeds. Now imagine trying to fly a reasonable distance for an aircraft, such as to the next state, and paying $5.00 per gallon getting 16.5 mpg – it is easy to see why some aircraft owners choose the high-octane gasoline. The flip side to this option is that burning a fuel not certified for use in a particular engine means operating at one's own risk and would probably void any warranty on the engine parts involved. Also, in order for this practice to be legal, one would need a supplemental type certificate for the use of unleaded automotive fuel in an aircraft engine. These are obtained from the FAA and have been granted concerning fuel use as early as 1992 for aircraft such as the Waco YMF (Supplemental Type Certificate, 1992).

Continuing with the example of the Cessna 172, considering its popularity, it should be mentioned that in 2007, Cessna announced it plans to make a turbo-diesel powered variant of the classic plane (Niles, 2007). This is significant for the world of alternative fuels because diesel fuel can be made from a plethora of alternative sources

(Franchi, 2005). Many of these sources overlap with the production of alternative jet fuel, so this description of alternative diesel will be brief. Basically, almost all liquid alternative fuels fall under the umbrella of "biofuels." A biofuel is any fuel made from biological, organic sources (M. Thompson, personal communication, October 6, 2011). Technically speaking, even fossil fuels are biofuels because they come from ancient plant and animal materials, but fossil fuels come from a limited source and give off high levels of harmful emissions (Franchi, 2005). The popular alternative automobile fuel E85 (85% ethanol), which is made from corn, is a biofuel. Some of the more common sources of biofuels include corn, soybeans, switch grass, and algae. Fuels have even been made from things as extraordinary as chicken fat and human waste.

Alternative 100VLL and biodeisel account for a measureable amount of general aviation alternative fuel, but there are still other power sources harnessed by some airplanes, not in mass production, that show considerable promise and could give a glimpse of what the future of aviation might hold. One of these airplanes was seen very recently, in October of 2011, at NASA's annual Green Flight Challenge at the Ames Research Center at Moffett Field, California (Bergqvist, 2011). The team that won the challenge was the team from Pipstrel-USA.com flying their Taurus G4. The impressive part of their accomplishment was that their airplane was running on electric power. Just as modern electric cars receive an MPG equivalency rating, the Taurus G4 received an equivalent MPG rating as well – an incredible 403.5 passenger miles per gallon (Bergqvist, 2011). Adding to the glory, the Pipstrel team's aircraft carries two passengers, making it competitive with many light sport aircraft in the market today in terms of payload (Namowitz, 2011). The second place team, sponsored by Airbus, did not come close to Pipstrels' number, but still managed a respectable efficiency and did win an award for quietest aircraft (Bergqvist, 2011). One might expect that the aircraft makes some compromises in performance to achieve such efficiency, but the Green Flight Challenge guidelines actually require that all qualifying entries be able to fly at a speed of at least 100 miles per hour and use less than one gallon of fuel or the electrical equivalent per passenger. The distance travel by the Taurus G4 was 200 miles in just under two hours with two passengers on about a "half-gallon" of electrical power (Namowitz, 2011). What is important to take away from this is not the victory of one team or another though, it is the fact that there was a practical demonstration that airplanes can run on electric power, with no "tailpipe" emissions whatsoever, and travel a considerable distance at a decent speed (Namowitz, 2011). Compare the distance and speed to the averages mentioned for the Cessna 172 and suddenly electric-powered aircraft seem like a viable option for the future of general aviation.

So electric planes may have a place in the future of aviation, and they do not use any gas so it would seem they are an environmentally friendly fuel source sustainable in the event of a national crisis. However, those planes store their power in batteries which are often charged using electricity from a power plant, many of which still contribute pollution to the atmosphere (Manning, 1996). There is a way, however, to charge the batteries needed for electric flight without drawing energy from the grid. Although very little implementation into recreational flying exists, research on solar powered aircraft has been ongoing since the late 1970's when a company called AeroVironment, Inc. began development on solar-powered aircraft (Curry, 2008). Although not the first design of its kind, an aircraft called Pathfinder, developed and still operated by the same company, became part of a joint venture with NASA to develop a high-altitude, long-endurance, unmanned surveillance aircraft in the early 1980's (Curry, 2008). Since then, the government has cancelled the program to use these airplanes for surveillance, but those initial designs were influential in the development of other solar powered aircraft, such as the Pathfinder's successor, the Pathfinder Plus, which is now part of NASA's Environmental Research Aircraft and Sensor Technology project (ERAST) (Curry, 2008). These aircraft have a simple flying-wing design and several propellers that also provide directional guidance through variation of propeller speed on different sides of the plane. The power comes from a continuous strip of silicon solar cells across the top of the wing that is up to 19% efficient (Curry, 2008). This means that 19% of the solar energy that strikes the wing is converted to *useable* energy for propulsion of the aircraft and powering of onboard systems and sensors. There are onboard batteries in addition to the solar panels, but the power from the sun is enough to keep the aircraft aloft while charging these batteries for use after the sun goes down. When the sun does set, those batteries provide an additional two to five hours of flight time (Curry, 2008).

Comparatively, the 19% efficiency achieved by the solar cells is actually not bad. There is a theoretical limit for single layer solar cell efficiency of 37.7%, and some experimental cells have actually approached that limit (Fanchi, 2006). Fortunately, the technology is developing to make multilayer solar cells with a theoretical efficiency of up to 86% (Kruger, 2006). Similarly, some scientists have added a vertical component to existing solar cells by raising the surface into shallow honeycomb-shaped pockets, therefore increasing the surface area and improving the angle at which light strikes the cell. A third way to improve efficiency is to create darker silicon, which can absorb more of the light spectrum. Strides have recently been made in this area by German scientists who nearly doubled the efficiency of earlier solar cells in their research with newer, nearly pure black silicon (Matus, 2012).

It was mentioned earlier that the airplanes running solely on battery power did not have to make any performance compromises compared to other airplanes of similar size, but with solar power that is not true. In fact, the Pathfinder aircraft only flies between 15 and 25 miles per hour (Curry, 2008). Even with a flight time of over 15 hours that still covers only a few hundred miles at best. If higher levels of efficiency could be achieved in the solar panels though, the performance of the aircraft could improve dramatically and still improve the endurance. Consequently, the concept of a high altitude, multi-day, long range, and unmanned surveillance airplane would be easily realized. Multiple day flight for a solar aircraft is a feat only achieved twice in recent years and by much smaller and lighter aircraft, not large enough to carry any equipment (Curry, 2008). If advanced battery technology and high efficiency, multilayer silicon solar cells were combined, the prospect of flying a manned aircraft cross country on purely solar power would certainly be attainable. While the higher level of efficiency has not be achieved just yet, technology is making leaps and bounds every day, and in the future the need to actively fuel small aircraft, or even plug them in to charge their batteries, may be a thing of the past.

Flying cross-country on solar power and batteries may happen in the not-too-distant future, but flying cross-country on this next alternative fuel could be possible now. The task has not yet actually been achieved, but the technology to fly an aircraft several hundred miles, which qualifies as a “cross-country” flight, is already in place. Dr.

Clifford Ricketts of Middle Tennessee State University, a professor in the Agriculture Department, has demonstrated this successfully not in an airplane, but in a car. The differences in size and power between a mid-sized car and a small general aviation aircraft with a reciprocating engine are few enough to assume that the technology used in Dr. Ricketts vehicles could be applied to an aircraft with relative ease. Dr. Ricketts has been researching alternative fuel sources since the 1970's, and his motivation comes not from his love of the environment, but from a love for his country; while he does like the prospect of cleaner burning fuels with little to no environmental footprint, his true goal is to demonstrate to the world that the United States could be sustainable in the event of a national emergency that cuts off the supply of foreign oil (C. Ricketts, personal communication, October 11, 2011). Concerning his motivations, Dr. Ricketts said this: "I believe accomplishing this feat will have the following implications: A cleaner environment because of clean tailpipe emissions from the vehicle, energy self-sufficiency and renewability, less dependency on foreign oil and less of a trade imbalance because of the purchase of foreign oil" (Read, 2011). He demonstrated that his vision is possible first in 2010 with a 500-mile journey across the state of Tennessee, lengthwise, and in 2012 completed a coast-to-coast journey using less than ten "gallons" of hydrogen and 2.15 gallons of a gas/ethanol mixture in a modified Toyota Prius (Bro & Weiler, 2012).

Molecule for molecule, hydrogen is the most abundant element in the universe (Romm, 2004). As a fuel source, hydrogen is particularly appealing for two reasons: the first is that hydrogen, when burned in the same engine, provides about a 10% increase in efficiency over gasoline. Secondly, the only byproduct of combining H_2 with O_2 and energy (through combustion) is H_20 in the form of water vapor (C. Ricketts, personal communication, October 11, 2011). The hydrogen powered vehicle that Dr. Ricketts drives is a 1994 Toyota Tercel, and while it does have an admittedly small and efficient engine, it is still large enough to imagine that just a little more hydrogen would be enough for a small airplane. The engine modifications done to the Tercel are actually relatively few and inexpensive, mostly dealing with the electronic components involved (C. Ricketts, personal communication, October 11, 2011). Where it gets tricky though is the aspect of storing the hydrogen. Dr. Ricketts' Tercel used two specially made, carbon-wrapped tanks, similar in shape, but not size, to a conventional propane tank that might power a grill, to store the hydrogen, which was compressed to about 4000 PSI (C. Ricketts, personal communication, October 11, 2011). These two tanks are secured to the vehicle where the rear passenger seats would usually be. This high-pressure storage system enables each tank to store the equivalent of about four gallons of gasoline in hydrogen gas (C. Ricketts, personal communication, October 11, 2011). Together, that makes the capacity of the Tercel about the same as if it had eight gallons of gas in its tank, and with hydrogen being about 10% more efficient, the vehicle could travel 300 miles without having to refuel.

One of a few reasons why hydrogen has not taken off quite yet is the concerns about how flammable the gas is – people believe it is more dangerous than gasoline. It does not take long for disasters similar to the Hindenburg to come up when discussing hydrogen as a fuel source. It is true that hydrogen is one of the most flammable gasses in existence, but what people tend to forget is that the very gasoline pumping in cars everywhere every day is also gives off extremely volatile fumes. If gasoline spills, the fire flows wherever the gas does, but if a pressurized hydrogen tank spouts a leak then the fire is confined to a single plume (C. Ricketts, personal communication, October 11, 2011). Dr. Ricketts viewpoint on the matter is that all kinds of combustible fuels should be treated with respect, and if proper safety and storage practices are in place then the danger is no greater with hydrogen than it is every day at the gas pump (C. Ricketts, personal communication, October 11, 2011). Hydrogen, however, is not currently available at the local gas station.

Although it is the most abundant element in the universe, hydrogen in its pure gaseous state of H_2 is hard to come by (Romm, 2004). Dr. Ricketts has a truly revolutionary solution to this problem as well: sun and water. Over the years, Dr. Ricketts' interests have changed little by little, but his passion during the latter half of his career has been harvesting hydrogen from water molecules using a water electrolysis machine powered by the solar energy. The setup is ingenious: behind his garage at Middle Tennessee State University, Dr. Ricketts has a solar array about the size of one wall of a small house. These solar panels feed energy to the machine that separates the hydrogen from the oxygen in the water and then pumps the hydrogen into several large, pressurized storage tanks (C. Ricketts, personal communication, October 11, 2011). The best part is that when the solar array is not powering that machine it is feeding power back into the local power grid – a contribution that the power company actually pays Dr. Ricketts for (C. Ricketts, personal communication, October 11, 2011). So he is not just getting his fuel for free, he is making money from the process! This may not be the case for every American should the process become widespread, but it is an impressive way to get fuel and some extra cash when everyone else is still paying ridiculous prices at the pump.

The setup sounds perfect – harvesting a fuel from water that gives off water as its only byproduct (Romm, 2004). It seems like there should be a hydrogen plant on every corner for people to refill their carbon-wrapped tanks, but the force slowing the proliferation of alternative fuel is once again monetary (C. Ricketts, personal communication, October 11, 2011). The cost of building the plants and setting up the necessary infrastructure is too great for investment in the eyes of many fuel companies. Some production hydrogen vehicles do exist, most notably a few cars from Honda, Audi, Fiat, and Mercedes-Benz, and even a few airplanes such as one small aircraft that Boeing modified in 2008 for demonstration purposes, but widespread use of hydrogen in transportation, particularly aviation, is still a ways off (Boeing, 2008).

One last quality of hydrogen that makes it difficult to use for alternative fuel in aviation is the sheer size of the tanks needed to store it. In Dr. Rickett's Tercel, the two carbon-wrapped tanks take up the majority of the back seat area and still only hold the equivalent in energy to about eight gallons of fuel. This is with the hydrogen compressed to an amazing 4000 PSI as well, which is still 1000 PSI lower than the maximum pressure at which hydrogen can be stored, but that remaining 1000 PSI would actually make only a very small difference in the volume of the gas (C. Ricketts, personal communication, October 11, 2011). Imagine now that hydrogen is powering an airplane. The airplane most likely has a larger and less fuel-efficient engine as it is, and unless it has been modified to store the hydrogen in elongated, carbon wrapped wing tanks (a shape that is not ideal for high pressure storage), then the tanks would have to be placed elsewhere. They would probably be in the rear seats similar to Dr. Rickett's vehicle, and with a less efficient engine the tanks would have to be even larger to have the same range as the Tercel. This takes up usable space and limits the seating to two in most general aviation airplanes. It also affects the structural behavior of the plane since the weight of fuel in the wings is a factor taken into account in the design of an aircraft (Daggett, Haddaler, Hendricks, & Walther, 2006).

None of these obstacles are insurmountable, though. Everything mentioned above assumes that the airplane in question is an existing gas-powered plane modified to run on hydrogen, which would currently be possible with the above configuration on short distance flights. However, a plane designed from the ground up to run on hydrogen is certainly feasible. Such a plane could exist in two ways: the first is that it would have to be a very efficient engine and low drag design, with the maximum amount of space possible used for hydrogen storage. The second makes use of a newer, experimental way of storing hydrogen. When hydrogen comes in contact with magnesium, iron, and manganese in a special tank known as a metal hydride tank, it condenses down to a solid, which take up significantly less space (C. Ricketts, personal communication, October 11, 2011). When heat is applied to the hydrogen solid however, it quickly reverses back to a gaseous state and combusts (C. Ricketts, personal communication, October 11, 2011). This is actually a technology used originally in rocketry, which is currently its best application because once the reaction starts, it continues until all the fuel is used up. That is perfect for rocketry since the scientists know exactly how far up the rocket needs to go before its fuel is exhausted and they can provide the correct amount of fuel accordingly. Distances in general aviation are less predictable, as weather could develop, or air traffic control could change a routing and therefore increase the distance traveled. Research to find a way to cut that reaction short is currently ongoing. When the solution is developed, the problem of storing the fuel will be a thing of the past and hydrogen will be a perfectly viable alternative fuel for general aviation and potentially even larger, long-range aircraft.

The larger, long-range aircraft mentioned above specifically refers to jetliners. Despite the lengthy discussion above on alternative fuels for general aviation, the real concern of scientists, environmentalists, and politicians for alternative fuels in aviation is with jetliners. The amount of greenhouse gasses emitted by general aviation aircraft is negligible when compared to total overall amount of emissions each year, but jetliners actually account for a substantial three percent (M. Thompson, personal communication, October 6, 2011). This number may seem small but it continues to grow. From 1990 to 2006 for example, the total amount of greenhouse gas emissions from commercial aviation increased by 87% (Warren, 2007). Currently, the average high-altitude, long-range jetliner on a trip from New York to Los Angeles produces over 4,200 pounds of CO_2 per passenger (Warren, 2007). That can sometimes mean millions of pounds of emissions per trip at that distance. So 3% may seem like a small amount, but reducing that percentage would make a profound environmental impact.

Almost all of the previously discussed alternative fuels at their current level of development could not provide the energy needed to propel a jetliner across the country. The most promising form of alternative energy for jetliners is biofuels, and fortunately there is plenty of research ongoing for the development of biofuels from companies such as BAER Aerospace Consulting. In an interview with Melanie A. Thompson, a chemist working for BAER, she explains that biofuels can be synthesized from practically anything so long as it contains hydrogens and carbons (2011). To put it in the simplest terms possible, she says that if molecules were made of Tinkertoys, and hydrogen Tinkertoys were colored red and carbon Tinkertoys were colored blue, then with the modern knowledge of chemistry, any substance containing red and blue Tinkertoys can be broken down into more basic parts and reconstructed into a biofuel (2007). These are known as synthetic biofuels, and they have been successfully made from a plethora of materials, from dead leaves raked up in a yard, to human excrement extracted from sewage (M. Thompson, personal communication, October 6, 2011). The construction of biofuels from otherwise useless material is not a new idea – NASA and the US Air Force have been researching it for many years and as a demonstration in 2009 they successfully flew a DC-8 on a biofuel synthesized from hydro-treated, recycled chicken fat (M. Thompson, personal communication, October 6, 2011). In another test, they flew an F-22 at supersonic speeds powered by a 50-50 mixture of chicken fat synthetic biofuel and regular jet fuel (Beyersdorf & Anderson, 2009). All of this research and experimentation is part of NASA's Alternative Aviation Fuel Experiment (AAFEX). In the study, the DC-8 was flown at several different power settings from idling on the ground to 100% throttle in flight. Their findings show that the alternative fuel was at least 99% as effective as a conventional jet fuel (JP-8 in this case) and that the environmental impact was reduced by up to 90% in the lower power ranges above idle, and still by around 60% even at full power (Beyersdorf & Anderson, 2009). The measure of environmental impact is reflected as one number representing both CO_2 emissions and aerosol emissions that NASA refers to as the CO_2 Emissions Indices (EI). Figure 3 on the next page shows the level of emissions across the full range of power for the alternative fuel, regular JP-8, and a blend of the two. The F-T line represents the alternative fuel and is labeled as that way because the fuel is produced through a process known as the Fischer-Tropsch process (Beyersdorf & Anderson, 2009).

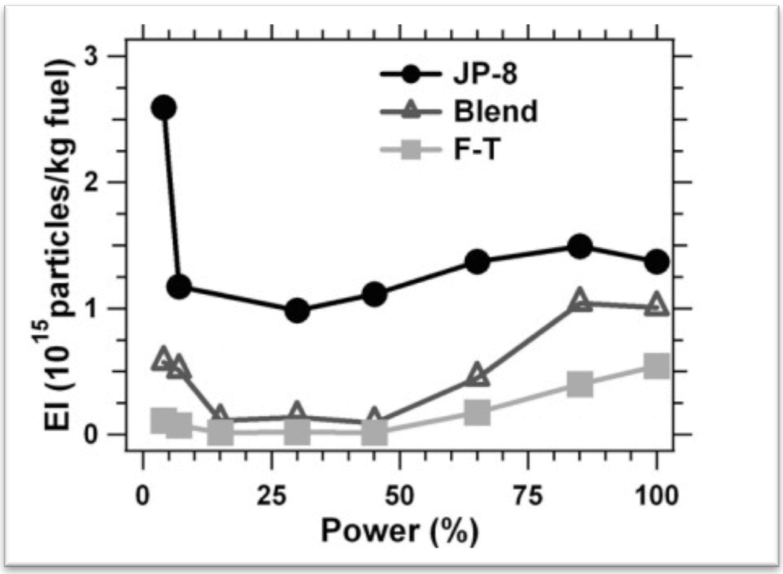

Figure 3. *Emissions Comparison (Beyersdorf & Anderson, 2009)*

The Fischer-Tropsch process is no new development – it has been around since the 1920's when Franz Fischer and Hans Tropsch developed it to assuage a petroleum shortage in Germany by converting coal to synthetic fuel (Siuru, 2008). It is the same process used by Baere and is the most common method of producing synthetic biofuels today (M. Thompson, personal communication, October 6, 2011). As the graph above shows, the alternative fuel demonstrates a significant decrease in harmful emissions to the environment in the AAFEX experiment. Utilizing chicken fat falls under a category of F-T fuels referred to as BTL, which stands for Bio-to-Liquid. Some of the other intriguing applications of the process are CTL (Coal-to-Liquid) and GTL (Gas-to-Liquid)

(Cassedy, 2000). The GTL method is particularly promising because the gas used is natural gas, a relatively common naturally occurring methane gas that is often burned off wastefully when it is released as a byproduct of drilling for petroleum oil.

The project to fuel the fleets of the US Air Force on chicken fat never fully came to fruition and merely stood as a demonstration for what possibilities exist, but synthetic biofuels are still in production on a relatively small scale and the fuel does not normally come from chickens. Through the Fischer-Tropsch process, BTL fuels can come from a variety of sources. Over the years the source of the organic matter has changed as people discover the pros and cons to each source. For instance, at one point corn was thought to be an ideal source of organic material for making biofuels. While it is true that corn is still a main contributor to the popular E85 ethanol fuel, using corn for fuel increases the demand and drives up the price to the point where E85 offers little savings to the consumer at the pump. The same is true for jet fuels derived from corn. Another downside to corn is that making fuel out of corn takes an otherwise edible product out of hungry mouths elsewhere; there is hunger everywhere and it is impossible to say that an alternative fuel is doing more good for the world by reducing emissions when it could save a child from starvation (C. Ricketts, personal communication, October 11, 2011). The same problem exists with soybeans, which are another popular source of alternative fuel. Fortunately, as mentioned earlier, the fuel can be made from any organic source. So, a solution currently in use by some fuel makers is to use saw blade grass as the source. The grass is inedible, so hungry mouths do not miss it, it grows in arid environments, therefore not taking up the fertile farmland, and it is an annual crop as opposed to a perennial (C. Ricketts, personal communication, October 11, 2011). Crops like these are ideal for producing synthetic biofuels, but in order to make enough of the fuel to power the world's jetliners the amount of land required would be vast.

There is still another method to get the required material for making the alternative fuel. Though many scientists still consider it somewhat obscure, the cultivation of various forms of green algae shows great promise in terms of producing a larger quantity of alternative fuel for a given space (Walton, 2008). The reason is that over 50% of each algae cell is made of useable oils useful for conversion into fuel (Walton, 2008). Also, algae grow very fast in almost any environment as long as there is water and sun (Walton, 2008). Land that is unusable for anything else could be converted into an algae growth field with little more than some light flooding and a little algae to start the growth. In fact, it would only take one hundred square miles of desert land to be flooded and used to grow algae in order to produce enough biodiesel to run all of the trucking fleets in America each year (C. Ricketts, personal communication, October 11, 2011). Considering the vast amounts of unused desert land in the western United States, this could be a reachable goal, but one hundred square miles is still a lot of land to monitor while growing the algae. Fortunately, a company called Valcent Products in conjunction with Global Green Solutions, a Canadian alternative energy company, has developed a system that they call Vertigro to better utilize available space for growing algae (Walton, 2008). The Vertigro system is set up in a structure that is essentially a greenhouse and green algae is grown between sheets of plastic with moisture in between that are suspended from the ceiling. By using this vertical design, they are able to produce an amazing 100,000 gallons of fuel per acre, which is over 3,000 times more than can be produced from an acre of corn (Walton, 2008). While fuel derived from green algae is still a developing science, it could eventually play a key role in solving the energy crisis in America and around the world.

So there are many sources from which alternative jet fuel can be made. With seemingly miraculous energy solutions like the Vertigro system in existence, it is a wonder why all fuel for both aviation and ground transportation is not produced right here in the United States. The fact of the matter is that an object at rest tends to stay at rest, and it is the same with the established system of fossil fuels. It is not that it is so expensive to build a greenhouse full of algae or grow a field full of switch grass, but developing the refineries to carry out the Fischer-Tropsch process on a grand enough scale would be very costly. It may be because current operations are small scale, but the Fischer-Tropsch process itself also holds no economic benefit over the refining of fossil fuels (M. Thompson, personal communication, October 6, 2011). In time it may be something that the government will invest in for the benefit of the environment, the creation of jobs, and also the severance of dependence on the foreign oil, but for now it seems the cost to the consumer too great. One other thing slowing the process is the sheer amount of fuel needed to power a fleet of jets. Jets burn billions of gallons of fuel each year, and with many sources of biofuel, only 20% to 30% of the material ends up as fuel (M. Thompson, personal communication, October 6, 2011). This is why algae holds so much promise, particularly in the Vertigro environment. With 50% of each algae cell becoming fuel, and a potential 100,000 gallons of fuel per acre, algae could solve the problem of quantities once this system becomes more developed and more widespread (Walton, 2008).

To achieve optimal efficiency with the least impact on the environment, multiple alternative energy sources should be harnessed to power different parts of an airplane. While a truly zero-emissions jetliner is still in the realm of science fiction, a jetliner running on biofuels could be made even more efficient if any auxiliary systems on the aircraft, such as on-board entertainment systems or cabin pressurization, were powered by one of the other alternative fuel methods previously discussed (Warren, 2007). Similar in concept to how hybrid cars use both electric energy and gas, a hybrid jetliner would be even more efficient than one running all systems on the energy generated by the biofuel engines (Warren, 2007). Solar panels on the wings or hydrogen tanks powering a generator are just a few examples.

Research Questions

This study seeks to evaluate the current state of the alternative fuel industry. In the pages above, several methods of production, and companies utilizing these methods, have been mentioned. Also, a few airplanes designed to make use of alternative fuel sources were discussed briefly. Through a series of interviews and research, the major players in alternative energy for aviation and their methods will be identified as well as any large-scale production, alternatively powered aircraft. The research questions to be addressed by this study are as follows:

- Who are the major manufacturers of alternative aviation fuels?
- What problems may slow the adoption of alternative fuels in aviation?
- What is the status of the viable production methods of alternative fuels?

Inevitably alternative fuels are the future of transportation. Every alternative fuels source mentioned above has been put to use in aviation with, at the very least, a working demonstration. In some cases, alternative fuel use is actually starting to spread into the aviation population on a larger scale; 100VLL recently received approval from the FAA and should find its way into more airplanes every day. G100UL is in development and will become very popular when new legislation on the use of lead in avgas goes through. Concerning jetliners, which have a far greater environmental footprint than general aviation, the use of biofuels produced through the Fischer-Tropsch process is currently in practice on some commercial flight. In November 2011, Continental and Alaska Airlines both flew their first commercial, domestic flights, with passengers, under the power of alternative fuels (Bogart, 2011). These flights were successful, and as more pressure is put on airlines to become environmentally friendly in the future, biofuels should eventually become the fuel of choice. Whether for general aviation or commercial flight, alternative fuels are on the rise and should be embraced. Supplies of fossil fuels are finite and come from a land where there is much political tension. In order to leave a healthy planet and a strong, sustainable country for future generations, many steps must be taken, and the development and adoption of alternative fuels is a major piece of that puzzle.

CHAPTER II: METHODOLOGY

Participants

The participants in this study include a selection of companies currently working on alternative fuel solutions for the aviation industry. In order to be considered, a participant had to be a legally established company with reasonable proof of their legitimacy as a company. For the purposes of this study, reasonable proof could be a website with published data on their work, association with an official regulatory group, or a referral from another notable company. These qualifications made most companies easy to identify through a simple Google search. Shortly after beginning the search for participants, an organization called CAAFI appeared several times in search results. CAAFI is the acronym for the Commercial Aviation Alternative Fuels Initiative, and they are an organization that works with airlines, manufacturers, researchers, and government agencies to proliferate the use of alternative fuels in aviation. Their goal, as stated on their website, is as follows:

> CAAFI's goal is to promote the development of alternative jet fuel options that offer equivalent levels of safety and compare favorably on cost with petroleum based jet fuel, while also offering environmental improvement and security of energy supply for aviation. (CAAFI, 2012, para. 2)

The CAAFI website provides a list of 41 fuel suppliers with whom they co-operate. For the purposes of this research, every manufacturer listed on the CAAFI website was a potential participant. However, all of the manufacturers on that list deal in jet fuel only, and this study also deals with manufacturers of 100LL avgas alternatives.

The search process for fuel suppliers making 100LL alternatives also began with a Google search. This search provided the names of several companies as well, the two most prevalent being Swift Fuels and Hjelmco Fuels. Both of these companies deal in unleaded aviation gasoline. In an effort to locate more potential participants, two questions were added to the end of the interview questions list that asked about each participant's major partners and competitors. Upon performing the interview with Swift Fuels, that question provided one lead to a company called GAMI, which stands for General Aviation Modifications, Inc. All three avgas companies were contacted, but interviews only came to fruition from Swift and Hjelmco.

A total number of 44 alternative aviation fuel suppliers were identified, but due to a lack of contact information, or a functioning website for some, only 27 companies were contacted. Prior to contact, IRB approval was received for this study, as can be seen in Appendix A. The list of companies contacted is provided below:

List of Contacted Companies

Swift Fuels	Hjelmco Oil
Air BP	American Clean Coal Fuels
Amyris	Applied Research Associates
Baard Energy	Biofuels Technologies Enterprises
BioJet	Clean Energy Fuels Ltd.
Diversified Energy	Exponent
Gas Technology Institute	GE Aviation

Great Plains Oil & Exploration	GEVO
JetE	RenTech
Saphire Energy	Shell Aviation
SkyNRG	Solena Fuels
Solazyme	Terasol Energy
Terrabon	Velocys

Due to the limited number of potential participants, there was no sampling necessary; the whole population of willing participants was pursued for an interview. Approximately half of the companies contacted responded to the contact request, though only 10 of those responded with a willingness to participate in an interview. From there, due to scheduling issues and an inexplicable halt to communications, only five companies actually ended up participating in an interview for the study. The participating companies actually did provide a fairly even sampling of companies working on various fuels, as two of them were avgas companies and the other three dealt in jet fuel alternatives. Additionally, they covered a spectrum of where various companies in the industry stand, ranging from experienced companies with 32 years of experience to start ups formed less than two years ago.

In order for the study to be more accurate, information from more than just five companies was desirable. Fortunately, many of the questions used in the interview would be answered using pubic data from company websites. After the interviews were complete, several company website were searched for data that pertained to the research questions of this study. Therefore, data collection in this study came from both personal interviews and online research.

Instruments Used

The instruments used in this study are few and simple. In order to collect the data, the only instruments required were a computer with an Internet connection, a sound recorder, a telephone, an IRB consent form, a contact request letter, and an interview question list. As mentioned in the previous section, the initial data collection process began with participant selection, and that began with a simple Internet search. After locating potential participants online, particularly through the CAAFI website, companies with available contact information were emailed a contact request letter, which can be seen in Appendix B.

The contact request letter served merely to reach out to the companies for a representative that they felt was knowledgeable enough about work with alternative fuel to answer interview questions. Upon establishing a contact with a representative from a company, an interview time was arranged via email. Though about ten companies expressed interest in participating in an interview, only five of them were willing to remain in contact long enough to actually schedule the interview; several companies simply stopped responding to requests for an interview time without explanation.

Before the interview could be conducted, each participant had to provide consent to participate, either verbally on the recording or by signing the form itself. To fulfill this requirement, the consent form was either read aloud over the phone before the interview or emailed to the participant beforehand. A copy of the consent document can be found as part of the IRB approval seen in Appendix A. Some of the participants also requested to see the list of questions prior to the interview, at which point that list was emailed to them as well.

The questions used in the interview were designed to get a broad feel for where each company is in the alternative fuel industry. Some of the questions were to find general information about each company, such as what product they make and how long they have been making it. Other questions dealt with the financial side of the industry and sought to find out how cost effective the fuel is for both manufacturer and consumer. Still, there were other questions that might pique the interest of the pilots and aircraft owners in the general aviation community. Those questions dealt more with the legal aspects of alternative fuels. In general the questions can be grouped into three major categories: questions dealing with general information, questions dealing with product consequences (whether good or bad), and questions concerning information useful to the consumer. There are also a few miscellaneous questions designed to provide a more thorough answer to the research questions, and some simply to further the reach of the study. These questions are important because they touch on all the major factors that might determine the success or failure of alternative fuels as a business, ranging from their cost, to environmental impact, to ease of adoption by consumers. The answers to these questions should provide a clear picture of where each participating company is in their work with alternative fuels. A copy of the full interview questionnaire can be found in Appendix C.

The interviews themselves were conducted over the phone at the prearranged times. The first order of business was to read the consent document if that had not been taken care of via email. After that, the interviewee was asked the list of 18 questions, and all answers were recorded. The answers were actually recorded twice to ensure successful capture of the data: once on the computer using a program called Audacity, and again on the phone itself by running a voice recorder application while the interviewee was on speaker phone. By recording the answers, all attention could be focused on the performing the interview and the entire answer could be recorded instead of the paraphrasing that would result from trying to write or type the answers as they were spoken. Ultimately, the recorded answers as presented in this report would be paraphrased anyways, but by having a recording one can listen to answers multiple times and ensure that participants' true intent is captured in the paraphrase.

Study Design

This study is of a qualitative design that uses interviews to probe companies in the industry for information. The ultimate goal is to be able to assess where the industry currently stands and to make predictions as to where the industry is going. With that information, it will be possible for pilots and aircraft owner/operators to make educated decisions about the future of their business in aviation.

There are several quantitative aspects to this otherwise qualitative study, such as cost of production and cost to consumer. However, there are so many factors that play into the monetary numbers of aviation fuels that price alone is not a fair means for comparison. One thing is for certain about price, and it is that in order for an alternative fuel to overtake traditional fuels, it must be at least equal in price at the pump. Because of this fact, though many companies find ways to cut costs here and there the end product in each case will generally cost about the same. There may be some differences between the price of avgas and jet fuel when compared to their petroleum based counterparts, but generally price alone is not the best way to differentiate between two similar products in this industry.

Another reason why a quantitative method is not useful in this study can be taken from the research questions. The purpose of the study is not to find who can make alternative fuels cheapest or even cleanest, but instead to see what the major trends across the industry are in order to predict what the future standard might be. For instance, instead of saying that Company X makes a cheaper product than Company Y, this study focuses on the methods that Companies X and Y use to make their products and tries to find overarching similarities. Basically a qualitative method is the proper method for this study because it focuses on the industry trends instead of comparing companies numerically. There are questions in the interview that deal with values such as quantity of production and fuel price, but these will be used more to draw conclusions about when the alternative fuel industry might challenge petroleum.

Procedures Utilized

The procedures used in analyzing data in this study are as straightforward as the data collection itself. After all of the interviews were completed, the recorded answers were transcribed from the recording onto a document for presentation in this report. This was done by replaying the recorded audio through a program called “Quicktime”, which is standard software on any Apple computer like the one used for this analysis. The software allows the user to start and stop the audio by pressing the spacebar and the on-screen window is small and nonintrusive, therefore leaving plenty of space to manage the interview answers document.

By replaying the audio one response at a time, the data was accurately paraphrased into a more succinct and manageable answer. Then, additional information pertaining to the study was gleaned from several of the websites belonging to the companies; when a company was not available or willing to participate in an interview, the first part of their website searched was usually the Frequently Asked Questions section. Many questions from the questionnaire can be found in a similar format in many companies' FAQs. Questions on product cost and whether aircraft modification is required are issues at the forefront of the aviation community's mind, so this information is usually readily available. Typically, the information gathered from company websites was not used to establish any new trends, but instead used to see if that company fit the trend that was already apparent from the interviews.

When as much data as possible had been collected, the information was laid out in an organized manner for cross comparison. This involved placing the answers to each question directly below the question itself in the interview answers document such that every piece of information could easily be paired with the question it answered. While conducting the interviews, and again while transcribing the interviews, a preconception of trends that might exist began to form. This was helpful for immediately identifying several trends simply from hearing the interviews multiple times already. Using the transcribed interviews, all data was compared using a multi-window feature on a computer for quick navigation between different transcriptions. The computer used during data analysis was a base model MacBook, and the multi-window feature is called "Exposé." This feature allows the user to display all open windows with a single gesture and can be set up through the standard System Preferences software. One can then easily select which documents they would like to view and place them side-by-side. With this capability, each set of transcribed interview answers was compared side-by-side to find similarities or differences between corresponding questions. Each company was analyzed and compared to the other companies to find overarching trends between them.

Trends observed were written down based on the three major question categories previously listed, and were then analyzed on a deeper, question-by-question basis as needed. A trend was indicated if a majority of interviewees provided a similar response. An example of a trend could be that many companies are still in the developmental phase of their product, or perhaps have only what they refer to as a “pilot plant” for small-scale production for research purposes. However, it was also worth noting that there was a few outliers did not fit the trend but whose actions were significant to the state of alternative fuel development.

In order to properly complete the study, one must recall the research questions proposed in Chapter One. The research questions sought to find out who is actively making alternative fuels, what has slowed their progress, and what the status of their current methods is. With those questions in mind, each interview and supporting data was analyzed to find specific answers. After the research questions were thoroughly answered, the information was used to make an educated prediction on the direction of the industry such that any interested parties in aviation may plan accordingly, or at least know what to expect.

CHAPTER III: RESULTS

Presentation of Data

The data for this study comes from the five interviews conducted with representatives from companies in the alternative aviation industry. Supplementary data for determining trends was gathered from the websites of some of the companies listed on the CAAFI list of alternative aviation fuel suppliers. Simplified transcripts of the interviews can be found in Appendix D.

Analysis

For such a large amount of qualitative data, the approach to data analysis must be clear and organized. To achieve this high degree of organization, the questions from the interview question list have been grouped into similar categories. As a reminder, a copy of the questions list can be found in Appendix B. The organization of the questions consists of three groups: basic questions about the product, questions about product consequences, and questions that interest the end user. There were also a few miscellaneous questions that will be discussed at the end. The basic questions about product information simply address the what, where, when, etc. of each fuel. These questions will help paint a brief picture of each company as well. The questions about product consequences are the most in depth section of the analysis. Each company touts their own reasons for why their product is best, but there are trends evident of recurring benefits and drawbacks for all of the products that will likely persist as the industry develops. Lastly, the questions of interest to the customer are any that deal with the aircraft requirements, legal requirements, and of course, the fuel price. Each set of questions will be analyzed to find commonalities between sources and to make an assessment of the current state of the industry.

Products

In general, aviation fuels are divided into two distinct categories: avgas and jet fuel. However, at a molecular level, both fuels share several characteristics. As mentioned in Chapter 1, hydrogen and carbon are the basic building blocks of fuel, and that holds true for both avgas and jet fuel. The concerns with traditional, petroleum-based fuels come not only from the dirty and finite feedstock, but also from the myriad of chemicals required to make the fuel work properly. For instance, in traditional leaded avgas, there is a dangerous chemical known as the "scavenger" that is designed to remove lead from the engine components after combustion. While there is much controversy over the tetraethyl lead itself, which is still very harmful, the scavenger chemical is also even more toxic, even in small amounts. With unleaded avgas, removing the lead eliminates both problems, for without the lead, a scavenger chemical is no longer needed.

So now let's identify the trends that exist in the companies working on these solutions. For avgas manufacturers, the trend is to produce a completely unleaded aviation gasoline that is stripped down to its basic hydrocarbon parts, leaving a very clean burning fuel as the end product. Octane levels for American-made unleaded avgas are unanimously at 100. The two biggest players in American-made unleaded avgas are Swift Fuels and GAMI, the former having the most promising report. Each of these companies makes their own version of the 100 octane unleaded avgas and each gives it their own name: 100SF and G100UL respectively. Across the Atlantic Ocean, in

Sweden, Hjelmco Oil has been making a similar product for over thirty years. Their product is also fully unleaded but tops out at 98 octane, which may or may not be enough to entice the appropriate U.S. agencies to approve its use in America. According to their reports, their fuel is perfectly capable of running in about 90% of the world's piston-powered fleet, and 75% in the U.S. However, red tape in the American government and difficulties with receiving approval from all required parties have prevented Hjelmco from expanding into America as of yet. From a production standpoint, Hjelmco has more capacity and experience than any other unleaded avgas manufacturer by far, which would certainly be beneficial to the American market. According to their founder, whether their business moves to America or not is up to the folks on Capitol Hill.

In the jet fuel realm, the trending product is easily identifiable. While each company has their own slightly tweaked version, every company that was interviewed and ultimately many more produce a Synthetic Paraffinic Kerosene, or SPK fuel. This is the same type of fuel that was tested by the military and NASA in 2011 with such promising results. Those tests were little more than research and proof-of-concept, but the methods and the fuel itself have been established for some time. In fact, one company in South Africa, SASOL, has been making this fuel since before alternative fuels required certification. The SPK fuel, like its avgas alternative counterpart, is also lacking in many of the harmful, toxic, metallic chemicals found in traditional aviation fuels. The reason why so many companies are making basically the same end product is because the regulatory agencies are comfortable with this fuel now and it is already certified for use in a 50/50 blend for commercial aviation. What does vary between companies is the feedstock. Moving forward, the word "feedstock" will be used frequently. Despite it sounding as it refers to an edible crop, this is not necessarily the case. The fact is that a feedstock is simply whatever source a company utilizes to harvest their hydrogen and carbons. There is a lot of differentiation that can be derived from a company choosing a particular feedstock, and they each have their own ideas as to why their particular feedstock is best.

Production

The trend in products is towards a simplified, 100-octane, unleaded avgas, and towards Synthetic Paraffinic Kerosene jet fuel blended 50/50 with traditional jet fuels. All of that is very well, but the alternative fuel industry will never challenge big oil without competitive levels of production. Unfortunately, the trend in production scale is largely towards companies in the developmental stages of production. Many companies, for both avgas and jet fuel, have a very promising product, but any semblance of major production is a minimum of five years away. There are several outliers from the trend though. For example, Hjelmco Oil in Sweden has been in large-scale production for several decades now and sells their fuel all across Scandinavia and even in Japan. Likewise, Shell Oil recently invested in a large-scale production facility for Fischer-Tropsch derived SPK jet fuels. SASOL, in South Africa, also has a production facility producing over 100,000 barrels per day. However, most of the companies working with alternative avgas and those on the Commercial Aviation Alternative Fuels Initiative list may have as much as a pilot production facility, generally producing around 10 barrels per day, but not much more than that.

Given that most companies are trending towards SPK fuels, it is no surprise that the methods used for production also show a trend. The most popular method of production, used in one variation or another by every alternative jet fuel company interviewed and several more, is the Fischer-Tropsch process. The process involves several complicated steps beginning with the feedstock and finishing with a product that needs little extra treatment before it is ready for blending and use. Each company has their own take on the finer details of the process, but the basic structure remains intact across the board. A more detailed description of the process itself can be found in the transcriptions of the interviews. The largest area where companies differ is with their feedstock. Some companies use forestry waste, some use coal, and still others use waste straight out of landfills. There are even methods of harvesting feedstock from pollutants in the atmosphere, therefore helping the environment twofold. Concerning unleaded avgas, the processes are much the same as they are in producing traditional avgas, except none of the harmful or caustic chemicals are used in the mix. It sounds like a easy process and one might wonder why this as not achieved sooner, but it is more complicated than that. Lars Hjelmberg, of Hjelmco Oil, simplified the explanation by stating that the process and equipment are essentially the same as with traditional aviation gasoline, just refined and tweaked for a significantly cleaner end result.

The last question on general product information deals with the amount of time each company has been producing their product. In general, there is no commonality in the answers to this question. Some companies, such as Hjelmco Oil and SASOL, have been producing their products for decades. Others have only been in business for about ten years, and some were formed as recently as last year (though product development began several years prior to the formation of this particular company). The majority of companies have sprung up within the last decade though, probably due to the rising concerns about the environment and legislation that might make alternative fuels a great business opportunity in the future.

To continue the analysis of interview questions pertaining to general information about the products, question numbers five, six, and seven will be reserved for the next section. Beginning with question number eight, dealing with the production cost of each product, specific numbers as answers to this question were often a confidential affair and the interviewees were not required to share information they deemed sensitive. There were some companies willing to share, but the identifiable trend with this question is not so much any specific numbers, but the meaning behind the numbers. What this means is that each company must achieve a certain production cost in order to stay relevant in the industry. There is also a myriad of variables that go into the production cost equation. To list a few variables, production cost is completely dependent on the cost of materials, feedstock, workforce, scale of production, and distance that the fuel must be transported to market. The cost of all of these things, and several others, varies greatly with each company and from location to location. Each company does recognize though, that their product will never be competitive unless it can be sold at the very most in parity with petroleum-based fuels already on the market. Whatever the cost of production is for each company, they must do what they can to keep it low enough so that they can continue to operate and sell their product as cheap as or cheaper than traditional fuels.

That leads perfectly into the next question on the list: what is the cost to consumer? Because this was briefly discussed in the paragraph above already, this paragraph will just serve to clarify a few points and provide an example. The trend to sell alternative fuel products just below or at parity with their petroleum-based counterparts holds true for both unleaded avgas and synthetic jet fuel, though some manufacturers think they can pass on a significant savings to their customers. Lars Hjelmberg, of Hjelmco Oil, says that his company can consistently sell their 92/98 octane unleaded avgas at approximately 40 cents cheaper per gallon than 100LL. This savings is directly proportional to their savings in production. In this particular instance, he claims that a major savings point for them is the exclusion of lead from their fuel. He claims that there is a monopoly producing the lead required for 100LL and that the money they save by not needing the monopoly's product has significant downstream effects. Now, companies interviewed in the United States claim they will sell their product at the same price as 100LL, despite their product also having no lead. It is not fair, however, to compare the companies in the U.S. to the companies in Europe because not only are they operating in two different economic climates, but also their products are different. In the U.S., the unleaded avgas octane number is 100, but in Europe the highest octane rating found by this study is 98. There was also one company that produces SPK fuels who claims they can offer a price reduction over traditional jet fuel; Robert Freerks of RenTech, says that when their product enters the market that they should be able to sell it for about 35 cents cheaper per gallon than traditional jet fuel. It is uncertain where the extra expenses come from those that claim price parity and those that expect a cheaper price at the pump, but the trend to sell alternative fuel at a price no higher than traditional fuels is still intact.

The question of where each product is available is another question with an easily identifiable trend. The trend here is for each company to sell their product locally. The definition of locally is often as restricted as within the city of production, or as vast as across a whole country, for some of the foreign producers. By and large in America, most companies are producing and selling their product no further than the boundaries of their own city, if they are in production at all. If they have a small, preproduction pilot plant, they may be selling or donating their fuel to research centers such as at universities or NASA, but as that product is not for sale to the public it is classified as no availability. Even one the most promising companies, Illinois Clean Fuels, with plans for a 30,000-barrel per day facility, plan on selling their product mostly around the Chicago area. The farthest-reaching companies identified were Shell, SASOL, and Hjelmco. Shell has a massive facility under construction that, when finished, should be capable of producing enough fuel to move around. SASOL produces enough fuel to sell all around South Africa, and Hjelmco sells their fuel at scores of airports around Scandinavia with one enthusiastic importer in Japan. Even these last examples are confined when compared to an oil company selling petroleum, though. Even with a few companies beginning to take a foothold, the vast majority of them are still deep in the early stages of their business.

The question of to whom the product is available works well in tandem with the previous analysis. In general, most products are not available to anyone yet. That is, they are not available to paying customers yet. Many products are available to research partners, the government, the military, universities, etc. There are, of course, the exceptions listed above that are into their production stages and selling their fuel. In those cases, the answer to the question is that the fuel is available to anyone and everyone who wants to buy it. These companies are in business to make money like anyone else so if someone has a use for their fuel, they are willing to sell it to them. For those companies not currently in production, the prevailing estimate for when their product will enter commercial production is 2017. When the interviews were performed in December

2012, most companies stated that it would take them about five years to enter commercial production, so a late 2017 estimate is a fair estimate, barring any delays. Steven Johnson of Solena Fuels was the only interviewee from a preproduction company with a sooner estimate; he estimates that Solena Fuels will enter commercial production of their SPK jet fuel by 2015. He also added that his estimate was not counting for any delays, so at least it is safe to say that most preproduction companies are estimating bringing their product to market by 2017.

Product Consequences

With the fifth question in the interviews begins the next category of questions dealing with product consequences. This section aims to find general pros and cons with each product. The most important consequence in most people's mind is the fuel's impact on the environment. However, each fuel also holds various benefits and drawbacks for the pilot, mechanic, and aircraft owner. Questions dealing with less consequential information of interest to these parties can be found in the next category of questions.

Because it is on the forefront of everyone's minds, the discussion about environmental impact comes first. As mentioned earlier, greenhouse gas emissions from piston-powered aircraft represent a negligible percentage of the whole. The real concern with traditional avgas is the highly toxic tetraethyl lead along with other chemicals, such as the scavenger agent, that become airborne toxins when released as exhaust fumes. All 100LL alternatives are completely unleaded, so the main environmental benefit is the lack of these harmful pollutants. With these chemicals removed, the avgas becomes no more harmful than unleaded automobile gasoline to the environment, yet it represents a much smaller piece of the pollution contribution. Perhaps a day will come when CO_2 emissions will become the main concern with avgas, but today is not that day. Today, the battle is against the lead and other toxins.

In contrast, exhaust from the combustion of jet fuel makes up a tangible amount of total greenhouse gas emissions. Fortunately, the trend in alternative jet fuel is to produce SPK fuels, the same as were mentioned in the Army and NASA study in Chapter One. The results from that study and emissions tests for the fuels made by many of the companies interviewed are nearly identical. At taxi speeds, the alternative jet fuel showed up to a 90% reduction in the level of particulate matter and greenhouse gas emissions over traditional jet fuel. At cruise speeds the reduction was still a very significant amount, but reduced emissions at taxi speeds are of particular interest because airplanes taxi at airports on ground level, where humans live and breathe. Ground operations at airports near large cities contribute to air pollution, and a 90% decrease in the harmful emissions could greatly improve breathable air quality over time.

While there is no particular trend in the source of feedstock for these companies, several of the selected sources hold their own environmental benefits. Each company interviewed has a goal of using completely renewable feedstock, if they are not completely sustainable already. Perhaps the most interesting example is that of Illinois Clean Fuels. They have the ambitious goal of building a 30,000-barrel-per-day facility for production use by 2017. Among all the interviews with companies not currently in production, this was the largest production number. They plan to reach their goal by starting out using low-quality coal to supplement their sustainable feedstock. Their research shows that 40% of usable hydrocarbon material is expelled as exhaust from a jet engine. They want to recapture those hydrocarbons and reprocess them into more fuel. They must also reach 40% sustainable feedstock in order to achieve carbon neutrality. All of this will be in vain, however, if their business goes under for financial reasons. Therefore, their initial facility needs to be able to make just enough fuel to be cost effective for both themselves and the consumer. They have calculated that 30,000 barrels per day is the number they need. Because they do not have the capability of producing that amount of fuel using their recapture technique yet, they are using the low-quality fuel, which comes cheap and still produces the same clean product, to supplement their production until they can transition to 100% sustainable feedstock. Additionally, because they are harvesting their feedstock from the gases in the air, their process could not only stop global warming's effects – it could reverse them. Other companies are also selecting feedstock that benefits the environment, such as forestry waste and landfill waste. So while there is no trend as to what feedstock is most popular, there is a trend in that the environment wins when sustainable feedstock is used to make cleaner burning fuel.

Lessening the impact on the environment is something everyone can benefit from, but unleaded avgas and alternative jet fuel hold more benefits than meet the eye at first glance. Both fuels, for instance, are less harmful to their engines than their traditional counterparts. This is because they are lacking in caustic materials that usually accelerate engine wear. In avgas this chemical might generally be lead, and in jet fuel it might be sulfur, just to name a major example. However, since the simplified alternative fuels are much more pure, those chemicals' effects are greatly lessened. Studies conducted by partners of some of the companies interviewed reports that engine life when using unleaded avgas or SPK jet fuel was increased by a factor of 50%. That means that if an engine previously was rated for 2000 hours between major overhauls, it is possible that the same engine, when running on alternative fuels, could run for 3000 hours before needing the costly maintenance. Not only does this represent a major benefit to the pocketbook of the aircraft owner, but also to the safety of the pilot, as there is a 50% less chance of a failure as that overhaul time approaches.

There are also a number of fringe benefits that come along with these new fuels. Pictures and video of oil fields often show pipes coming out of the ground with a large flame at the top. This flame comes from the burning off of natural gas, a byproduct of oil drilling. The problem with this is that the amount of natural gas being burned off represents a vast amount of energy that could have a variety of uses. The reason they burn it is because it is difficult to capture, transport, and process effectively. However, companies that produce SPK jet fuel are willing to use the natural gas as their feedstock. They can handle the transportation and processing, and because those who would otherwise be burning it off have no use for it, the alternative jet fuel companies can buy it cheap.

A benefit specific to unleaded aviation gasoline lies in its transportation from the production facility to the point of sale. Currently, the transportation of 100LL and even 100VLL requires a product specific fleet of transportation vehicles. That means that once a truck has carried 100LL in its tank, it is unable to be used for any other fuel. This raises costs to 100LL companies because they need a specialized fleet for their leaded avgas and a separate fleet for any other products they might produce. By taking the lead out of the avgas, those vehicles can then be used for other fuel types in addition to the unleaded avgas. Ultimately, this saves the company money as well as lessening the environmental impact of fuel transportation. Those benefits can then be passed on to the customer.

Like its positive effects on the environment, one benefit of domestically produced alternative fuels is that they lessen a country's reliance on foreign oil. Specifically, as mentioned in the literature review, the United States has been at the mercy of foreign oil companies for far too long. In recent years, large oil reserves have been discovered under American grounds, but even if the infrastructure to harvest this oil is put in place, the oil itself would present the same environmental problems as all other petroleum-based fuels. What the country needs from a political standpoint is a sustainable fuel source that can be managed on our own terms, and the development and production of SPK jet fuels from sustainable feedstock is a step in the right direction. Robert Freerks of RenTech predicts that SPK jet fuel production in the United States could reduce the reliance of the aviation industry on foreign oil by 50%. Ultimately, the goal would be to reduce the foreign oil dependency to zero percent. The consequences of using domestic oil would be the creation of American jobs, improvements in the economy, and less pressure from foreign agencies – all of which this country desperately needs.

One last benefit, and there may be others depending on who you ask, is that SPK jet fuels weighs less than traditional jet fuel. This is a trend between all the alternative jet fuel companies. This benefit though, is coupled with a drawback. The list of drawbacks with alternative fuels is brief, though it almost unanimously includes the immense buy-in cost to the industry and the difficulty in obtaining large enough quantities of feedstock for competitive production. The other drawback that came up multiple times in the interviews was that the potential energy of the fuel is less than that of traditional jet fuel.

In fact, SPK jet fuels have about 6% to 7% less energy per molecule than the prevailing fuels used today. The benefit and the drawback do counterbalance each other to an extent; though the fuel has less energy per molecule, it also weighs less and therefore uses the energy it does have more efficiently. In most cases, on domestic flights where the tanks would not be filled to capacity anyways, the difference in performance would never be felt. However, on long distance hauls, such as on international flight crossing an ocean, the tanks might be filled all the way up and not be able to carry the 6% to 7% extra fuel it would take to make up the difference between the alternative fuel and the traditional jet fuel. Perhaps this is one reason why the governing agencies are slow to approve the use of anything more than a 50/50 blend at this point in time.

Consumer Points of Interest

One group of people with good reason to be interested in the future of alternative fuels is the customers that buy it. This group could include pilots, aircraft owners, airport managers, or even anyone who lives near an airport. The questions in this section were tailored to find out information that might be helpful in anticipating the transition to alternative fuels, as alternative eventually becomes the norm. The questions probe for information such as what kind of aircraft can use the fuels, what modifications are required to the aircraft, and what legal requirements are there on the consumer's side to legally use these fuels.

Not every aircraft is capable of burning an alternative fuel in their engine, however, the vast majority are. This is not a coincidence. In order for a company producing alternative fuels to be successful, they must make it as easy as possible on the consumer during the transition. This is where the concept of a "drop-in" fuel becomes important. Of all the companies interviewed, every single one of them replied to this question with the same basic answer: if an aircraft can burn 100LL then it can burn a 100UL variety, and if it can burn traditional jet fuels then it can burn SPK jet fuels. The idea is seamless transitions to alternative fuels where the customer can see two fuels for sale, side by side, and choose the one that both saves the environment and might even save them some money. Every company on the list is developing drop-in fuels for their respective aircraft type. One reason why aircraft currently burning 100LL can switch so easily to an unleaded 100 octane avgas is because of the uniform octane level. In the Unites States, 100 octane alternative fuels are the only ones being considered for 100LL replacements. This is because in 2010, an Organization called the Clean 100-Octane Coalition lobbied Washington to get fuels with lower octane ratings off the discussion table (Frequently Asked Questions Regarding G100LL, n.d.). This could present a problem for companies such as Hjelmco Oil who might want to expand into the United States at some point but whose highest fuel octane ratings are only 98. This does not mean that an aircraft that usually runs on 100LL could not use Hjelmco's 98 octane unleaded avgas; there are legal ways to seek the use of any fuel in an aircraft through type certification.

Type certification is a somewhat confusing and legalistic area of aviation that is generally dealt with by manufacturers only. Essentially, in order for an airframe, fuel, engine, or modification to be legally approved for flight, it must receive a type certification from the Federal Aviation Administration. In most cases, an aircraft is certified to run on a particular fuel that is well known and approved itself. If an aircraft owner wants to run their aircraft on automotive gasoline, for instance, they must receive a type certification to do this legally. With the American-based alternative avgas companies in this study, their fuel itself has received certification to be used in aircraft that would otherwise run 100LL. If an aircraft owner wanted to run their airplane on Hjelmco's 98 octane unleaded fuel though, they would need the approval of both the engine and the airframe manufacturer in addition to a type certificate. That seems like an awful lot of work, and it is, which is why there is legislation that can approve a fuel's use in an entire category of aircraft instead of approving it individually. In Europe, Hjelmco's fuel has received its general type certification and legislation has been passed that states that anyone who wished to run their airplane on the alternative fuel need only obtain the approval of the engine manufacturer instead of both the engine and airframe manufacturers. Furthermore, several engine manufacturers, including Lycoming, have given blanket permission for Hjelmco's fuel to be used in their engines. That legislation is only in the European Union though, and there is still plenty of red tape slowing Hjelmco's progress in the United States.

While this is highly unfortunate for the European fuel manufacturers, the alternative avgas manufacturers in America have received certification for their fuel to be used, and the permissions from engine and airframe manufactures are close behind. That is a lot of legal footwork to go through just to run a cleaner and better fuel in an airplane, but the ultimate goal is for none of this to affect the consumer. Yes, legally speaking, in order for an airplane to be allowed to run on an alternative fuel, the fuel must receive type certification and approval from the engine and airframe manufacturers. However, this legal work is being taken care of before the fact by many of these companies. By the time their fuels reach market, they will have approval from all necessary parties for use in the vast majority of aircraft. Unless one wants to use a fuel that is not certified for use in their aircraft before it is available to the masses, there is probably no legal action required on the part of the consumer, though it never hurts to ask. Thus, the trend regarding the legal requirements for an aircraft to use an alternative fuel as far as the customer is concerned is that there is no action required. The companies producing the fuel are handling the certifications necessary so that the customer will not have to.

For jet powered aircraft operators interested in burning SPK jet fuels there is one additional legal requirement at this point in time: SPK jet fuels are currently only approved for use in a 50/50 blend with traditional jet fuels. There are ongoing efforts to obtain certification for the use of 100% SPK jet fuel, but currently the fuel must be blended. The reasons behind this are mainly for safety. This is not to say that 100% alternative jet fuel would be unsafe, but instead serves as a precautionary action since so many lives depend on the proper operation of the jet engines. The studies done in 2011 with the Army and NASA used blended jet fuel and the results were still very promising. Using a blended fuel at this point in time is also a compromise of volumes, allowing jet-powered aircraft can be more environmentally friendly but still have enough fuel for long flights as large quantities of SPK jet fuel are hard to come by at this point in the industry's development.

Analysis of Extra Questions

The last question dealing with data that is pertinent to the study does not fall into any specific category, but serves to investigate what could potentially slow the progress of alternative fuels to market. The question deals with what roadblocks each company has faced in the development and production of their product, and once again there are definite trends in the answers. The number one roadblock that every company has dealt with at some point, and many still struggle with, is money. The alternative fuel industry is one with a very high start up cost and requires a lot of investment capital. Furthermore, if the capital is obtained to build a facility, it has to be the right size the meet the demand of the target market; the larger the target market – the bigger the facility. This is one reason why most companies plan to or currently sell their fuel on a local basis only. To put into perspective just how expensive it is to operate in this industry, RenTech interviewee Robert Freerks shared some industry numbers. He stated that for a company building their business from the ground up, a 2,500-barrel per day facility would cost around $500 million to build and get ready for production. He says that even for the major oil companies with all their expertise, building a facility costs about $150,000 per barrel per day. It becomes easy to see why the companies that have formed in the last ten years have had such a difficult time with money, especially after the economy ran into trouble in 2008.

The second roadblock that almost every company has dealt with, and again most are still dealing with, is a slow adoption of their product. This particular issue is one riddled with political interests from several interested parties. The government wants to support “green initiatives”, but they do not want to spend a penny over what they spend on oil now. The major oil companies have powerful lobbies that seek to slow the progress of the alternative fuel industry simply from a business competition standpoint. Also, there is skepticism on the part of the consumer. Many aviators are concerned for the safety, reliability, and performance of an alternative fuel simply because it is new to them. This fear will almost certainly fade as more examples of alternative fuels in use appear. Of the three issues listed above, the one that has slowed progress most, according to interviewees, is slow action from the government. The problem with legislation is greater for unleaded avgas manufacturers right now than it is for SPK jet fuel producers, but many of the startup SPK jet fuel producers have greater problems with money. Brian Miloski of Solena Fuels said that the order in which most companies will run into trouble is first with the certification of their product, which is important to obtain prior to production, and then with finding the funds to produce their product on a profitable scale.

The government, according to Robert Freerks, can be “a fickle woman to dance with.” Sometimes the government can help the alternative fuel industry through research grants and cost subsidies, but according to participants with many years of experience, government subsidies come and go and are something that can never be counted on in the long run. The government also likes to invest in even smaller products, many of which may sound promising but will never see any useful level of production, instead of investing in companies using established methods of alternative fuel production such as the Fischer-Tropsch method. Several companies interviewed share many people’s opinion that government spending is too much and in the wrong places. It is for reasons such as this that these companies are at the mercy of their financiers; there was a definite trend in the answers to this question that each company had at least one instance of a roadblock imposed by investors.

The final two questions on the interview questions list were more to expand the reach of this study than they were for analyzing each participant. There were several useful answers that came from these questions, though. Solena Fuels has a partnership with British Airways and is working on a project with them in the U.K. Swift Fuels has a partnership with Embry-Riddle Aeronautical University for research purposes, as well as a partnership with Continental Motors and Lycoming that could ultimately lead to the certification of 100SF in their engines. A suggestion from Swift Fuels is also what brought GAMI's G100UL to the attention of this study, as they have an otherwise limited online presence concerning their product, which makes them somewhat difficult to find through a simple web search. The partnerships and competitions that were mentioned in the interviews, and sometimes there were none, also show a desire from the aviation community to work together towards a sustainable future.

CHAPTER IV: DISCUSSION

The primary purpose of this study was to evaluate the current state of the alternative aviation fuel industry. The research questions outlined in Chapter 1 were designed to find out the "who", the "what", and the "when" of the industry and to provide information that would make it possible to make an educated judgment about its status. The first research question simply sought to identify the serious players in the alternative fuel game that one could reasonably expect to see selling fuel at their local airport in the future. The second research question attempted to find out why alternative fuels are not more commonplace today, as the need for them has been apparent for many years now. The third research question was designed to investigate the viability of the popular alternative fuel production methods and, in turn, the fuels that those methods produce. With the answers to these questions, it may be possible to determine where the alternative aviation fuel industry currently stands and how it might affect the flying population in the future.

The thorough answer to the first research question is not as straightforward as it may seem. There are many companies producing or working on producing alternative fuels, but in all likelihood, many of these companies will never have their name on the side of the fuel tanks at their local airport. The political climate in the U.S., where most of these companies are located, has been very nurturing for green initiatives during the past ten years. However, the economic climate has been very unforgiving for about the last five. For these reasons, many alternative fuel companies have formed, but only the companies with strong financial backing and wise business practices will expand as the economy turns around.

During the course of this research, every participating company showed promise for running a successful alternative fuels business, but those with the most money and experience are the ones that will likely persevere to become major manufacturers and distributors. This does not mean that the smaller companies will disappear altogether, but they will likely continue to operate on a strictly local level, as is mostly the case right now. The findings of this research indicate that the companies either already strongly established or with the money to wait out the economic storm are companies such as Hjelmco Oil, Shell Aviation, and SASOL. BP Aviation is another company that stands a good chance of succeeding should they pursue alternative fuels, but they declined participation in this study. Even General Electric is working on an alternative jet fuel, though they are better known for their work with aircraft engines. Of the smaller, start-up alternative jet fuel companies, the one with the most ambitious goals is Illinois Clean Fuels. Their plans for a 30,000 barrel-per-day production facility within the next five years could put them on the map in the northern United States in a major way.

Hjelmco Oil, as previously mentioned, is a Sweden-based unleaded avgas company with over 30 years of experience and will likely continue to experience success, even if only in the European Union. Stateside, Swift Fuels is currently the most promising unleaded aviation gasoline manufacturer, though they are currently still in their developmental stages. While there is some talk of unleaded avgas from Shell Aviation, most of their efforts are focused on the higher-demand alternative jet fuel market. Swift Fuels, with a strong research base and myriad partnerships, shows great promise for success as an unleaded avgas manufacturer.

The answers found for research question number two are many, but they boil down into two simple categories: money and politics. As a reminder, the question asked what problems might slow the adoption of alternative fuels in aviation. It is the finding of this study that the acceptance of alternative fuels by consumers will likely face little resistance. This is because the public opinion of the energy industry in general over the last decade has experienced a marked shift towards preferring greener alternatives. If fuel can be made that harms the environment less, or not at all, while still providing equal convenience and performance, most people would readily switch to that fuel. In order for this to happen, manufacturers must provide many examples of the safety and reliability of alternative fuels. Also, aiding in the acceptance of alternative fuels are the new emissions standards mentioned in Chapter 1. The question, however, was what might slow the adoption of alternative fuels.

In the course of a company's journey to bring their fuel to market, they will undoubtedly experience roadblocks of some kind. The research indicated that the first problems a company will face are with the certification of their product. This is more of a problem for unleaded avgas manufacturers than it is for the alternative jet fuel manufacturers because there is no tried and tested unleaded avgas standard. SPK jet fuels are similar enough between companies that those manufacturers generally have a smooth certification process, as the fuel is well known and thoroughly tested. In contrast, each unleaded avgas manufacturer makes a product that is chemically different and new to aviation, so each fuel undergoes a thorough certification process as a brand new fuel. Between the three unleaded avgas companies mentioned in previous chapters, three distinct fuels were associated with them: G100UL, 100SF, and 91/98UL. Each alternative jet fuel manufacturer, on the other hand, could describe their fuel as an SPK jet fuel. In summary, unleaded avgas manufacturers' first problems are with the certification of their fuel, and a streamlining of the certification process will take more standardization of the various fuels.

After a company has been through the certification process, their next step is to work on production. Production requires a facility, and a facility costs copious amounts of money. At best, building a facility and preparing it for fuel production costs around $150,000 per barrel per day. So, depending on how much fuel a company plans on producing each day, the facility could be very expensive. There is also a balance point between how much a company can produce and how much they can sell; therefore, different companies build different size facilities depending on their business outlook. Almost none of the companies currently working on alternative fuels have enough money to build a facility out of pocket, so they require investment capital. This is where the majority of their roadblocks come from; by using other people's money, these potential manufacturers must receive the blessing of their investors for each business decision they make, and the investors do not always know exactly what is best. However, the manufacturers must still please their investors or else there is no money. It is a difficult situation, and for this reason, reaching the point where it is possible to build a facility, produce fuel, and turn a profit to repay their investors is a long and arduous process. The majority of alternative aviation fuel manufacturers are currently in this process.

The other issue that manufactures face is the political roadblocks beyond certification. These roadblocks were mentioned briefly by several manufacturers but never discussed in detail. This is probably because the problem is so deeply engrained that it is difficult to clearly define. Government in general is a massive entity with its hands in many different projects. With the persuasive power of lobbyists advocating either for alternative fuels or against them (and for their petroleum companies), moving swiftly from an established fuel to an alternative fuel is difficult even with all the noted benefits of the alternative fuels. Beyond that, the system of current aviation fuels is so established moving everything toward a new system would take time even without opposing pressures. Essentially, out of the public eye the government is trying to look out for all parties involved, especially itself, and this causes progress to happen very slowly.

The last research question has a much simpler answer. This question asked about the current status of the viable production methods. In a word: mature. The viable and popular methods for producing alternative fuels are quite mature. There is more variation in the production methods of unleaded avgas, but for each company their methods are well developed. For jet fuels, almost all the promising companies use the Fischer-Tropsch process, which has been around for almost a century. The variation in this process now comes from using different feedstock, but the fuel production method is well developed and ready for widespread use. Successful examples of this process in use are seen in companies like SASOL and Shell Aviation. With proper investment and political support, the F-T process could be used to greatly ease reliance on petroleum and reduce the harmful effects on the environment.

Project Significance

The significance of this project has become more apparent as the study progressed, but is a different significance than was originally conceived. Before the study began, the expected significance of this study was simply that aviation businesses might have a better idea when to expect the emergence of alternative aviation fuels. Instead, it was discovered that alternative fuels are knocking at the door of aviation with only a few major difficulties preventing them from becoming widespread. While this study does provide useful information to the flying community about the environmental, political, and economical aspects of alternative fuels and how they perform in existing aircraft, it can also serve as a catalyst for pressure to be put on the lawmakers slowing alternative fuel development. The details of alternative fuels are not common knowledge, and this study is significant in that it may serve as a consolidated source of information for those who will eventually use these fuels, but it should also inspire people to advocate for a quickened adoption of these fuels. When they become widely available, aviators should know that these fuels are beneficial for all people, but in the meantime it might be beneficial to express an interest in alternative fuels to one's state representative.

Limitations

The limitations imposed on this study were inherent to its design. The accuracy of the study was completely dependent on the willingness to share and honesty of the participants. Altruistic mission statements aside, the companies researched in this study are in this business to make money and therefore were not immune to the temptations of exaggeration. Hard figures and performance data were likely true, as they were often proven in independent studies, but predictions about predicted daily production and production dates are mere educated estimations. There were many factors mentioned that could easily push back deadlines, and the dates mentioned in this study are likely best-case-scenario predictions. Many of these companies were competitors and their involvement in this study was a small piece of free advertising, therefore each company was prone to exaggerating the good aspects of their company and diminishing any bad aspects. Specific examples of this were impossible to identify, so the limitation is that study was at the mercy its participants' truthfulness.

A second, related limitation of the study was that some of the questions in the interview touched on possibly sensitive information. This was noted prior to any interviews being performed and no company was asked to divulge any information that they deemed private should they feel uncomfortable doing so. In most cases, potentially sensitive figures such as financial data were not an issue for the interviewees, but there were a couple of instances where information was withheld for this reason. The participants were generally willing to work with the researcher to find an acceptable, less specific answer to those questions and to still comment on the idea behind the question, but specific data for those questions was sometimes unobtainable.

Recommendations

For the general flying public who might be concerned with how they should prepare for the transition to alternative fuels, it is the recommendation of this study that one check with their airframe and engine manufacturers to see if their aircraft is approved for alternative fuel use. For new aircraft purchased in the coming years, this information is likely to be found in the aircraft owner's manual. No alteration should be necessary for the vast majority of aircraft to make the switch to alternative fuels because the fuel manufacturers have designed the fuel to ASTM drop-in standards. ASTM stands for the American Society of Testing and Materials and is the entity responsible for much of the testing and research on newly developed alternative fuels. One should always check with their manufacturers before using an alternative fuel. If the desired fuel is not yet certified, the aircraft operator must obtain a type certificate from the FAA and consider the safety implications of an uncertified fuel before flying.

All of the alternative fuels discussed in this study will be certified by the time they reach mass production. This means very little work, if any, on the part of the pilot. These fuels are also significantly better for the environment, as well as the economy. With so many benefits to unleaded avgas and SPK jet fuels, parties interested in using them should make their opinions known to the politicians who can speed up their certification process. Participants in this study complained about funding being allocated to "silly" projects that will never reach mass production, so a voice advocating for the trusted methods of alternative fuel production discussed in this study could help their development both politically and financially.

Future Project Refinements

To improve on future projects researching this subject, it will be important to increase the number of participants interviewed. To obtain more participants, one could reach out to the same companies listed in Chapter 2, but use additional methods of communications beyond email. About half of the companies that were sent a contact request letter did not reply at all. Perhaps more companies could be reached if telephone communications were utilized to request a contact if the company failed to respond to emails. Also, some companies were willing to conduct an interview, but the scheduling could not be successfully coordinated. To refine the scheduling process when a participant expresses willingness to conduct an interview, initiative could be taken by recommending an interview time instead of requesting that the potential participant suggest one.

One refinement that would help with data organization is to combine similar interview questions into a broader question. It was observed in the study that the companies willing to participate in an interview were not shy when it came to talking about their products. For instance, it was not necessary to ask two separate questions about benefits and drawbacks to a certain question when those two items would be grouped into a single question. The same was true for production cost and cost to consumer. This would allow the interviewee to talk uninterrupted and would help keep the interview to a manageable duration. Additionally, diversifying the methods of recording interviews threefold would help safeguard against any potential data loss. It is the recommendation of this study to use at least one physical means of recording, such as a tape recorder, in addition to at least two digital methods of recording.

Conclusion

The alternative fuel industry is an industry in its adolescence. There are several successful examples of alternative fuel companies providing useful amounts of these fuels around the world, and many hopefuls have cropped up over the last decade. The environmental and political incentives that will eventually come from alternative fuels will ensure their coming, though the aviation community at large will likely not see them until 2017. Designed to work in existing aircraft and provide equal performance, alternative fuels will help provide cleaner, sustainable flight for future generations.

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APPENDICES

APPENDIX A

Interview Consent Form

Middle Tennessee State University Institutional Review Board

Informed Consent Document for Interviews

Principal Investigator: Cody Corbett

Study Title: Emerging Trends in Alternative Aviation Fuels and Aircraft

Institution: Middle Tennessee State University

Name of participant: ______________________________ Age: __________

The following information is provided to inform you about the interview and your participation in it. Please listen carefully and feel free to ask any questions you may have about this interview and the information given below. You will be given an opportunity to ask questions, and your questions will be answered. Upon request, you may be emailed a copy of this consent form. Your participation is voluntary and you are also free to withdraw at any time.

You are being asked to participate in this interview because you work for a company involved in the area of this research and have professional knowledge of the status of the industry. Your responses will be audio recorded.

The data gathered in this study is not confidential with respect to your personal identity unless you specify otherwise. When this material becomes available, it may be read, quoted, or cited from and disseminated for educational and scholarly purposes.

If you should have any questions about this interview please feel free to contact Cody Corbett at (208) 597-5632 or my Faculty Advisor, Wendy Beckman, at (615) 494-8755. For additional information about giving consent or your rights as a participant in this interview, please feel free to contact the Office of Compliance at (615) 494-8918.

STATEMENT BY PERSON AGREEING TO PARTICIPATE IN THIS INTERVIEW
I have been read the informed consent document and the material contained in it has been explained to me verbally. I understand each part of the document, all my questions have been answered, and I freely and voluntarily choose to participate in this interview.

______________________ ______________________________

Date Signature of Interviewee

Consent obtained by:

______________________ ______________________________

Date Signature of Interviewer(s)

____

Printed Name and Title

APPENDIX A (Cont.)

Institutional Review Board Approval

MIDDLE TENNESSEE STATE UNIVERSITY

November 30, 2012

Cody Corbett, Dr. Wendy Beckman
Department of Aerospace
cbc4m@mtmail.mtsu.edu, Wendy.Beckman@mtsu.edu

Protocol Title: "Emerging Trends in Alternative Aviation Fuels and Aircraft"
Protocol Number: 13-137

Dear Investigator(s),

The exemption is pursuant to 45 CFR 46.101(b) (2). This is because the research being conducted involves the use of educational tests, survey procedures, interview procedures or public behavior.

You will need to submit an end-of-project report to the Office of Compliance upon completion of your research. Complete research means that you have finished collecting data and you are ready to submit your thesis and/or publish your findings. Should you not finish your research within the three (3) year period, you must submit a Progress Report and request a continuation prior to the expiration date. Please allow time for review and requested revisions. Your study expires on **November 30, 2015.**

Any change to the protocol must be submitted to the IRB before implementing this change. According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to provide a certificate of training to the Office of Compliance. **If you add researchers to an approved project, please forward an updated list of researchers and their certificates of training to the Office of Compliance before they begin to work on the project.** Once your research is completed, please send us a copy of the final report questionnaire to the Office of Compliance. This form can be located at www.mtsu.edu/irb on the forms page.

Also, all research materials must be retained by the PI or **faculty advisor (if the PI is a student)** for at least three (3) years after study completion. Should you have any questions or need additional information, please do not hesitate to contact me.

Sincerely,

Andrew W. Jones
Graduate Assistant
Compliance Office
615-494-8918
Compliance@mtsu.edu

APPENDIX B

Contact Request Letter

Dear Sir or Ma'am:

My name is Cody Corbett and I am a graduate student at Middle Tennessee State University pursuing a degree in Aerospace Administration. For my thesis, I am doing a study on the state of alternative aviation fuel development and production. I found your company listed on the Commercial Aviation Alternative Fuels Initiative website as a supplier of alternative fuels. If possible, I would love the opportunity to speak with someone in your company knowledgeable about your dealings with alternative aviation fuels via a phone interview to be used in my thesis research. If you could connect me with such a person I would be very grateful. I have no commercial involvement with any company and any information gathered would be used solely for scholarly purposes. I can be reached by phone at [researcher's phone number], or by email at [researcher's email address]. Thank you and I look forward to speaking with you soon.

Sincerely, Cody Corbett

APPENDIX C

Interview Questions List

1. What is your company's product?
2. On what scale is it being produced?
3. What method is used to produce your product?
4. How long has it been in production?
5. What is the environmental impact of your product?
6. What are the benefits of your product?
7. What are the drawbacks of your product?
8. What is the production cost of your product?
9. What is the cost to the consumer for your product?
10. To whom is your product available?
11. Where is your product available?
12. If not currently available, when will your product be available?
13. What kind, type, or models of aircraft can use your product?
14. Is any modification required to existing aircraft to use your product?
15. What legal requirements are there for an aircraft to use your product?
16. What are some of the roadblocks your company has come across in the development and production of your product?
17. Who are your major partners?
18. Who are your major competitors?

APPENDIX D

Swift Fuels Interview Answers

1. What is your company's product?

    We make an unleaded aviation gasoline that we call 100SF, or "Swift Fuel." The ASTM designation is UL102 due to its minimum octane rating of 102, which is higher than the minimum octane rating for 100LL by 3.5.

2. On what scale is it being produced?

    Currently, we have a 10,000 gallons per day pilot facility, most of which is distributed for research.

3. What method is used to produce your product?

    We use the established processes for making hydrocarbon fuels, yet it is much cleaner than the methods used to make leaded aviation gasoline. Our fuel contains none of the harmful and caustic materials that are typically known for harming humans and the environment.

4. How long has it been in production?

    Our fuel has been in development since 2005, and the pilot facility opened in 2012.

5. What is the environmental impact of your product?

    The biggest impact of our fuel is that it contains no TEL, or tetraethyl lead. Also, it produces 50% less other harmful emissions such as those that contribute to global warming.

6. What are the benefits of your product?

    Our fuel provides increased performance, price parity with traditional avgas, longer engine life, and less harm done to the environment, just to name a few.

7. What are the drawbacks of your product?

    There are some: 100SF is slightly heavier than 100LL, however this drawback is balanced out by the fact that performance is increased. IN the end the fuel performs at least as good as 100LL. Also, perhaps the biggest drawback right now is that it is not yet certified. This is an ongoing process.

8. What is the production cost of your product?

    We plan to sell our fuel at the same price or less than 100LL. This is made possible. This is the only way an alternative fuel can be competitive.

9. What is the cost to the consumer for your product?

    When we begin selling the fuel to the public, it will be at least in parity with the cost of 100LL.

10. To whom is your product available?

    Currently to universities and test facilities mostly. Also, homebuilt aircraft may use our fuel and any aircraft with a STC allowing its use.

11. Where is your product available?

    Presently, our product is available in the USA and Germany. It is also in a few other places around Europe, but mainly in Germany.

12. If not currently available, when will your product be available?

    If everything going according to plan, our fuel should be available for purchase within a year.

13. What kind, type, or models of aircraft can use your product?

    The fuel is a drop-in fuel, so it can be used by anyone currently using 100LL.

14. Is any modification required to existing aircraft to use your product?

    No modification is required as it is a drop-in fuel.

15. What are some of the roadblocks your company has come across in the development and production of your product?

    The product has been in development for several years now, and the main roadblock we have faced is the changing standards over the last few years. Currently though, 100SF will meet or exceed all the required standards for aviation gasoline as leaded fuels are phased out.

16. What legal requirements are there for an aircraft to use your product?

    Currently one would need a Supplemental Type Certificate, but once the fuel is certified and for sale to the public, no legal action will be required for the use of 100SF.

17. Who are your major partners?

    All of our partners are listed on our website. A few examples include Continental Motors, Lycoming, Baere Aerospace Consulting, Purdue University, the FAA, and Cirrus Aircraft.

18. Who are your major competitors?

    There is one domestic competitor that makes a similar product to ours. They are called GAMI, which stands for General Aviation Modifications Incorporated, though we do not really consider them a threat.

APPENDIX D (Cont.)

Hjelmco Interview Answers

1. What is your company's product?

   We have two unleaded products: unleaded avgas 91/96 and unleaded avgas 91/98. Basically, they are the same product, however, the 91/98 is ASTM 910 unleaded fuel meeting D-910 for 9198. Originally, many engines were certified for military grade 91/96, so that's why we also carry 91/96. However, they are two products, with two names, though basically identical.

2. On what scale is it being produced?

   It is in regular production on a very large scale - enough to support between 70 to 80 airports in Sweden. There are also a few airports tat sell our fuel in Japan. There are between 700 and 900 aircraft that have been flying on this fuel for more than 30 years with several million hours of flight time.

3. What method is used to produce your product?

   As it meets the current D-910 standards, we are restricted to using established methods and components. Therefore our process is the same as is used in traditional avgas. What we have done is refined the components to make them cleaner, more pure, and have less environmental impact. We use none of the fancy components used by some of the startup companies in the United States, just the trusted methods.

4. How long has it been in production?

   91/98 has been produced for 21 years. Our company began in 1981 producing an unleaded avgas 80/87 and that fuel already had nationwide distribution in 1981. 80/87 was in production until 1992. The current avgas 91/98 started production in 1991 and is still in production today

5. What is the environmental impact of your product?

Of course, there is no lead. We contribute nothing to the lead poisoning of the air. There are other less harmful properties of our fuel's exhaust such as a decreased amount of soot particles and smaller soot particle size. As for benzene amounts, those are less as well, and benzene is known to cause blood cancer. It is virtually free of benzene, in fact. Exhaust emissions all around are dramatically lower. Many people think that the most dangerous chemical in avgas exhaust is the lead – it is not. The most dangerous chemical is the "scavenger" – it is a chemical agent that removes the lead from the engine after it has done its job. Scavenger chemicals are so toxic that you need special permits from the government and regulating agencies just to handle them. Of course, if you don't have any lead then you don't need any scavenger. Aside from being toxic, it is also an ozone depleting substance, and since there is none in our fuel, our fuel does not contribute to ozone depletion.

6. What are the benefits of your product?

The benefit is that you don't introduce a metal into the engine, such as lead. Metal particles in fuel can attach to engine components and speed up wear on the engine. For instance, a standard Lycoming engine certified for 2000 hours Time Between Overhauls [TBO] typically runs about 3000 hours TBO when using unleaded fuel. That represents a huge financial advantage. That also increases safety because the engine becomes more reliable. So the benefits are mechanical, financial, and also in safety. Another financial benefit is that unleaded fuel is cheaper to produce than leaded fuel because a monopoly company produces the lead and lead cost about $39,000 per ton. For the end user that raises the cost per gallon by about 40 cents, and our fuel can avoid that extra cost.

Also, one problem with the production of leaded avgas is that is that it requires a specialized transportation network for distribution. Any unleaded fuel, whether it be for airplanes or cars or anything, is not allowed to be transported in a tank that has been used to transport leaded fuel. With our unleaded avgas, there is no need for specialized logistics for each fuel, and that saves money as well.

7. What are the drawbacks of your product?

As the market has two types of engines – types that are approved for unleaded fuel, which is about 90% of the world's general aviation fleet, and those that are not, which represents the other 10%. For the 10% that cannot use unleaded fuel, we need to have two supply systems and two fuel tanks, as I mentioned before. If you are the unfortunate owner of an airplane that must have 100LL, your mobility is limited to airports that sell that fuel, which is a dwindling number in Scandinavia. In the United States the percentages are lower – but still about 75% of the US piston-powered fleet could immediately fly on Hjelmco's unleaded aviation gasoline. And I do mean immediately, as it is a drop-in fuel and requires no modification to the engine.

A regulatory drawback is that, when flying, one must use a fuel that is approved by both the engine manufacturer and the airframe manufacturer. It takes approval from both agencies for flying on any fuel to be legal. These approvals are published in the owner's handbook, and in the United States the manufacturers have not been allured to update their handbooks. Despite our company being around for over three decades, manufactures in the USA consider Sweden to be a small and exotic country and have not taken the time to their handbooks just for these efforts going on in Sweden. In Sweden, we have gotten a waiver to use the fuel, and EASA has recently approved it for use in any aircraft where the engine manufacturer has approved the fuel regardless of the consent of airframe manufacturer. This only applies to the European Union though, and the FAA has not done their homework on our product, hence our restricted presence in America.

8. What is the production cost of your product?

Typically, we can produce our fuel for 35 to 40 cents cheaper per gallon than traditional avgas due to its lack of lead and comparable production methods.

9. What is the cost to the consumer for your product?

Typically, we sell our unleaded gasoline about 35 to 40 cents cheaper to the customer for the reasons mentioned before. It has been received very well in Sweden, so much so that there it is actually a problem sometimes to find an airport that sells 100LL still.

10. To whom is your product available?

It is available to anyone with an airplane that on which it is certified to run.

11. Where is your product available?

We sell our fuel in Scandinavia. We are a Scandinavian producer and sell mostly in Sweden, Denmark, Norway, and Finland. We also have an enthusiast in Japan that has been importing our fuel for more than five years. In Japan they use it for helicopters who want to operate inside large cities where leaded fuel has been banned, so with unleaded fuel there are no restrictions.

12. If not currently available, when will your product be available?

    It is already available in Scandinavia and Japan. When we will bring our fuel to America is up to the FAA and that possibility is presently being researched.

13. What kind, type, or models of aircraft can use your product?

    Any piston-powered aircraft certified to use unleaded fuel by the engine manufacturer in the EU and by both the engine and airframe manufacturers in the USA. Lycoming is an example of an engine manufacturer that has approved the use of our fuels in their engines.

    Additionally, engines of high horsepower are more likely to be required to use 100LL, but the vast majority of general aviation, being small single engine airplanes for the private pilot types, care covered by our fuel.

14. Is any modification required to existing aircraft to use your product?

    No modification is required. Our fuel is a transparent drop-in fuel covered by ASTM D-910, which is the same standard that covers 100LL. However, you must make sure to use the right type of engine oil. You must make sure to use a high quality one, such as Shell 15W-50 which is the most used engine oil in the world. This means that most aircraft would truly require no modification before dropping in our fuel, and worst-case scenario they would just have to change their oil. There are regulations on the oil and fuel however; as an operator, you much use one of the oils approved by Hjelmco as the manufacturer. Fortunately, Shell 15W-50 is approved oil. Aside from that, it is fully transparent.

15. What legal requirements are there for an aircraft to use your product?

    That depends on location. In the USA, the engine and airframe manufacturers must approve the fuel use and in the EU it only requires the approval of the engine manufacturer. This is due to legislation from the European Aviation Safety Agency to help expedite the adoption of unleaded fuels.

16. What are some of the roadblocks your company has come across in the development and production of your product?

    Opposition from the major oil companies, mainly. Everyone in the market has been fed a corporate lie that an unleaded aviation fuel is unachievable. Therefore there has been a fair amount of incompetence and a slow acceptance of our product. A good example of this is the FAA, who has yet to recognize our product for the United States.

17. Who are your major partners?

    None, actually. We were the first company to develop this fuel and we built the company from the ground up by ourselves. We produce, store, distribute, and sell; every part of the supply chain is handled by us. We are a family owned company.

18. Who are your major competitors?

    We really have no competitors in Scandinavia. Swift Fuels in America is working on a similar product.

APPENDIX D (Cont.)

Illinois Clean Fuels Interview Answers

1. What is your company's product?

   Our company produces a Fischer-Tropsch synthetic jet fuel. It is an SPK, which stands for Synthetic Paraffinic Kerosene. The fuel is made using the Fischer-Tropsch process.

2. On what scale is it being produced?

   It is currently in the developmental stage. We are taking existing methods of producing used overseas by companies such as SASOL and using them domestically. When complete, our facility will be a 30,000-barrel per day plant.

3. What method is used to produce your product?

   The process is called Gasification and Fischer-Tropsch conversion. Essentially, solid coal and biomass is converted to hydrocarbon and reassembled over a catalyst using a process called FT conversion to manufacture a synthetic paraffinic kerosene fuel.

4. How long has it been in production?

   Our company has been developing this fuel since 2006.

5. What is the environmental impact of your product?

   It is the cleanest liquid transportation fuel one can manufacture. There is no sulfur, aromatics, or other bad stuff down to parts per billion level. There is nothing in the fuel other than just pure hydrogen and carbon (in and out). And the biomass is environmentally friendly too. There is biomass blending and sequestration on the front end as well. The fuel enables a massive reduction in lifecycle greenhouse gasses. There are a lot of variables in determining a carbon footprint depending on location, feedstock, etc. However, there is a 7% reduction in life cycle greenhouse gas for just carbon capture and sequestration. Blending biomass in the front end can be sourced from the air. When 40% of biomass is sourced from the air, you reach carbon neutrality. The ultimate plan is to *reverse* global warming; a negative carbon footprint is the goal. We are starting at 10% biomass moving towards 100% ultimately. There is a 20% reduction in greenhouse gas initially, moving towards full carbon neutrality in about 5 years. One of the biggest problems is the size of the plant. 30,000 barrels per day a the minimum production scale in order to be competitive. Using coal and biomass in the same facility helps with the initial generation and funding of the infrastructure.

6. What are the benefits of your product?

Because there are less caustic contaminants in the fuel, engine lifecycle is increased. Boeing and some independent airlines have carried out tests that show an improvement in engine life and even improved fuel efficiency. All in all the molecules contain less energy but more of the molecule is used in combustion, so performance is nearly identical to traditional jet fuel.

7. What are the drawbacks of your product?

It costs 4 billion dollars to build a plant and there are none in the USA yet. However, the facilities will come eventually and the fuel helps save the polar bears. It is also completely sustainable and will be produced domestically. So, other than startup costs there are no real drawbacks. It will also be a transparent transition for the downstream user.

8. What is the production cost of your product?

    Production cost is a function of economy of scale, which is brutal in this industry and in all areas of alternative fuel. The cost of manufacturing is directly proportional to the production scale. Small scale will save on capital cost, but it will be harder to make money later. Larger scale is better. Illinois Clean Fuels can make it for about $1.50 per gallon and sell it at price parity with traditional fuels. It's also difficult to predict where the market will be in five years.

9. What is the cost to the consumer for your product?

    The plan is to sell it at price parity with traditional fuels. This is actually a necessity in order for it to be competitive at all.

10. To whom is your product available?

    Well, it is used for jets only. Currently we have sold some to the Department of Defense, FEDEX, and to a few ambitious private owners.

11. Where is your product available?

    It is available primarily to airports in the Chicago and Indianapolis areas. This is due to the cost of transportation. The price of the fuel goes up if you have to transport it and it is much more efficient for all parties involved to just sell it locally.

12. If not currently available, when will your product be available?

    The plan is for the plant to be finished and the fuel to be available by 2017, barring any permitting delays and no global economy catastrophes or other unforeseen delays. An example of an unforeseen delay could be the discovery of an endangered species on the land where we harvest our feedstock.

13. What kind, type, or models of aircraft can use your product?

    Any aircraft currently using traditional jet fuel can easily switch to our SPK fuel.

14. Is any modification required to existing aircraft to use your product?

    No. It is an ASTM certified drop-in replacement for all jet aircraft in a 50/50 blend.

15. What legal requirements are there for an aircraft to use your product?

    None because the fuel itself is certified, but its only certified for use in a 50/50 blend. There are ongoing efforts for the certification of 100% FT fuel. Once it is past ASTM, CAAFI, and FAA processes then it is good to go for commercial use.

16. What are some of the roadblocks your company has come across in the development and production of your product?

    We ran into some issues with out investors at one point. Investment capital is difficult to get. The financial infrastructure in America is currently not conducive to running a start-up company.

17. Who are your major partners?

    N/A

18. Who are your major competitors?

    N/A

APPENDIX D (Cont.)

RenTech Interview Answers

1. What is your company's product?

   We make what would be termed "Synthetic Paraffinic Kerosene," and it confirms to ASTM D7566 Annex A. It is not a legal jet fuel until it is blended and tested though. Many other companies call their product a jet fuel, but this is incorrect until it has been blended and tested. Our fuel is certified at a 50/50 blend ratio with traditional jet fuel.

2. On what scale is it being produced?

   Presently, we have a10 barrel a day pilot plant for Fischer-Tropsch fuel from biomass. There is the potential for a couple thousand barrels per day if the fuel is made from animal fats. The pilot plant is a mostly just a commercial demonstration used to develop engineering data for a large-scale plant. Compare that to 250,000 barrels a day for traditional jet fuel.

3. What method is used to produce your product?

   We use the Fischer-Tropsch process that takes the biomass and runs it through a gasification process that takes whichever form the carbon is in and converts it into carbon monoxide and oxygen. CO and H_2 are called synthesis gasses because you can synthesize many fuels from them. Then, we run them over a catalyst that produces hydrocarbons and water in roughly equal amounts. Carbon goes to CH_2, and O_2 goes to water. The result is a linear hydrocarbon fuel that requires further processing into jet fuel. The raw FT products are then converted into the finished jet fuel and chemical byproducts.

4. How long has it been in production?

The process has actually been around since the 1920's. It was used in World War 2 and then in South Africa, where it is still in use to this day. Our company has been work on this product for six years in biomass and 30 years in coal and gas conversion.

5. What is the environmental impact of your product?

It's a very benign fuel. If you take all the bad stuff out of a traditional fuel you essentially are left with paraffinic hydrocarbons. Our fuel reduces particulate matter up to 96% and 10 to 50% for other emissions.

6. What are the benefits of your product?

The first thing is alternative energy sources. For instance, our fuel can be made from natural gas that would otherwise be burned off with no purpose. Eventually we could reduce oil imports by 50%. We can even use coal, which is otherwise thought to be very dirty, but we can convert it into a clean fuel. It is the cleanest use of coal possible.

7. What are the drawbacks of your product?

There are very few drawbacks. One perhaps might be that it has 6% to 7% less molecular energy. However, this really could only hinder long-range flights that need fill their entire tanks. On shorter flights, it is actually more efficient because the fuel weighs less than traditional jet fuel. Therefore the drawback is balanced out by a benefit.

Another drawback is that, for biomass, we are only about 45% energy efficient. Also, feedstock takes up a lot of land.

8. What is the production cost of your product?

    Natural gas to liquids is the cheapest way to make our fuel from a large-scale resource. This makes it cost competitive to traditional fuels. The cost would be about 80 to 90 dollars per barrel raw and 130 dollars per barrel processed.

9. What is the cost to the consumer for your product?

    In the current market, estimates are that they could make fuel at about $2.75 per gallon as opposed to $3.10 per gallon for traditional fuel.

10. To whom is your product available?

    Currently, some has been given to a few airports, a United Airlines project, and to NASA. All recipients have been domestic except for one Canadian airport. Its been given away for research and tests mostly. There is just not enough production to sell it commercially at this time.

11. Where is your product available?

    Our product is available mostly in the US. As mentioned before, there is also one airport in Canada that has our fuel.

12. If not currently available, when will your product be available?

    The current plan is for production and availability by 2017

13. What kind, type, or models of aircraft can use your product?

    Any jet aircraft currently using traditional jet fuels. It is a drop-in fuel.

14. Is any modification required to existing aircraft to use your product?

    No modification is required as it is a straight drop in ASTM fuel. However, the product we produce must be blended with traditional jet fuel in a 50/50 mixture to be used legally.

15. What legal requirements are there for an aircraft to use your product?

    There are no legal requirements on the user's end. Because the fuel itself is certified and meets the ASTM requirements and the FAA requirements, it is safe legal, and already approved for use in jet aircraft.

16. What are some of the roadblocks your company has come across in the development and production of your product?

    Money. A 2,500-barrel-a-day plant would cost between 500 and 750 million dollars. Depending on the production details the price may vary but none of these projects are for the faint of heart. Even the major oil companies' plants cost about $150,000 per barrel per day. You can't depend on the government for subsidies either despite them helping from time to time. The government likes to throw their money at silly projects that will never see daylight.

17. Who are your major partners?

    N/A

18. Who are your major competitors?

    N/A

APPENDIX D (Cont.)

Solena Fuels Interview Answers

1. What is your company's product?

   We make an SPK jet fuel - a sustainable biofuel from a renewable feedstock.

2. On what scale is it being produced?

   There is no production currently. Our product is still in its developmental stages. The technology is in place, but building this type of company takes time and we just are not to the production phase yet. Also slowing the progress is the acceptance of new technology, the new technology in this case being the production of fuel using waste as the feedstock. The cost of capital is also extremely high; in fact, it is the worst it has been since 1932.

3. What method is used to produce your product?

   It is a slightly tweaked Fischer-Tropsch process. The FT process is a trusted and proven industry standard. We use a high temperature thermo-conversion process on the front end to break down the hydrocarbons.

4. How long has it been in production?

   We have only been making the fuel developmentally for just a couple of years. However, the patented process that we use has been in development by our founder for ten years. Legally we were formed in 2012, but the company has been in development since 2009.

5. What is the environmental impact of your product?

    In a full-lifecycle study for a project with British Airways, Solena's fuels surpassed all alternative fuel environmental standards, both American and European, by a landslide. Also, by using waste as the feedstock, we keep garbage out of landfills. Subsequently, the carbon savings are multiplied because you are using hydrocarbons that would have otherwise been waste and have already been through one lifecycle. Also, not using fossil fuels to produce the fuel represents another set of benefits.

6. What are the benefits of your product?

    First of all, it is a well-known fuel in the industry with lots of research and acceptance. Using waste as a feedstock is a benefit also because it does not use an edible crop that should otherwise feed a hungry mouth. That also helps with location and price. Waste is located close to cities and airports usually, unlike woodchips and forestry refuse. The price benefit is that we actually get paid to take our feedstock off the hands of waste management companies.

7. What are the drawbacks of your product?

    There are no drawbacks that I can think of.

8. What is the production cost of your product?

    Specific numbers are confidential, but production costs for alternative fuels are comparable to those of traditional fuels. There are many variables that go into determining production cost though.

9. What is the cost to the consumer for your product?

    We will sell the fuel at price parity with traditional jet fuel otherwise no one will buy it despite a desire to use jet fuels.

10. To whom is your product available?

    The product is not available to customers right now but we have shared it with our partners at British Airways for research purposes. Hopefully it will be commercially available by 2015.

11. Where is your product available?

    Again it is not in commercial production yet so it is really not available anywhere, but eventually it has the potential to be available anywhere there is feedstock. We are currently developing eleven locations, and it is certified worldwide. London, morocco, New Jersey, and California are a few examples.

12. If not currently available, when will your product be available?

    2013 will mark the beginning of plant construction, and production should begin by 2015.

13. What kind, type, or models of aircraft can use your product?

    Jets. It is an alternative drop-in jet fuel and should work in any aircraft that currently is using traditional jet fuel.

14. Is any modification required to existing aircraft to use your product?

    No modification is required as it is a drop-in fuel.

15. What legal requirements are there for an aircraft to use your product?

    None. The fuel is already certified so by the time it is for sale there should be no legal effort required on the part of the customer.

16. What are some of the roadblocks your company has come across in the development and production of your product?

    Our main roadblocks all concern money. Issues with financing are the number one problem we have run into and are the number one problems for other companies in this industry.

17. Who are your major partners?

    British Airways is a partner of ours, but they probably won't be able to provide much more information than I have shared.

18. Who are your major competitors?

    Our main competitors are the big oil companies still working with petroleum.