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TITLE: Alternative Fuel Sources for Military Aviation

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Executive Summary

Title: Alternative Fuel Sources for Military Aviation

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Thesis: Alternative fuel sources are valuable for military aviation and the United States.

Discussion: The use of alternative fuel in military aviation has to be looked through different lenses to consider it a viable option. Many different groups for many different reasons can lobby the use of alternative fuel in military aviation. Four different types of alternative fuel sources are researched for this paper: synthetic fuel, biofuel, hydrogen fuel cell, and solar. All four have positive and negative attributes for military aviation. In considering the four different alternative fuel sources, they must be looked at for their cost to national security, the environment, and viability.

Conclusion: In conducting research into alternative fuel sources, it is evident that there are many different technologies and opinions on which source of alternative energy would be best for the US. The partnership of the civilian aviation community and the military can lead to an alternative fuel source that will meet the power requirements, reduce the US dependence on foreign oil, and protect the environment.

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THE OPINIONS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE INDIVIDUAL STUDENT AUTHOR AND DO NOT NECESSARILY REPRESENT THE VIEWS OF EITHER THE MARINE CORPS COMMAND AND STAFF COLLEGE OR ANY OTHER GOVERNMENTAL AGENCY. REFERENCES TO THIS STUDY SHOULD INCLUDE THE FOREGOING STATEMENT.

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INTRODUCTION

This paper will analyze the types of alternative fuel sources available and the ramifications of using alternative fuels in military aviation. Are alternative fuel sources important to military aviation and the United States (US)? The answer to this question is yes. First, there is a finite supply of fossil fuel based energy sources. Although not researched in this paper, there are many different views and studies on how much time fossil fuels will continue to provide the world a source of energy. One study reports that if 2005 consumption rates are maintained, the world has approximately 41 years worth of proven oil reserves.¹ When fossil fuels are no longer able to provide a sufficient source of energy, an alternative fuel source must be researched, tested and proven to insure military aviation remains an asset. This paper will examine four types of alternative fuel source and the monetary, environmental, and national security costs of those alternative fuels compared to oil. While there are more than four types of alternative fuel sources available, the four chosen for this paper show the most promising results when applied to military aviation.² Monetary, environmental and national security costs associated with an alternative fuel source will be examined as criteria for comparison to oil and over all impact on military aviation and the United States. In the conclusion of this research project, the author will submit an opinion on which alternative fuels would be beneficial for military aviation in the future.

The Department of Defense (DoD) is the largest, single, energy consumer in the US with the largest portion of fossil fuel used.³ In Fiscal Year 2005, the DoD consumed approximately 125 million bbl⁴ (approximately 340,000 bbl a day) of oil or roughly 1.2% of the nation's total fuel usage. Seventy-four percent of the DoD power requirement is

for operating vehicles (aircraft, ship, tactical vehicles) of which 52 % of those vehicles require aviation fuel.⁵ Aviation fuel is not only used in aircraft but also “non-aircraft” systems, such as tanks and generators, to ease logistic requirements on the battlefield.⁶

Alternative fuel performance in civilian studies was compared to the performance data of Jet-A1 aviation fuel. In military studies, alternative fuel performance was compared to JP-5 or JP-8. The difference between JP-5 and JP-8 is the fuels flash point. The Air Force and Army primarily use JP-8 while the Navy uses JP-5 because the higher flash point is safer to use aboard ships.⁷ The primary differences between the JP fuels and Jet-A1 are military required additives. For example, JP fuels must have three additives that Jet-A1 is not required to contain, a corrosion inhibitor/lubricity enhancer, fuel system icing inhibitor and a static dissipater.⁸

There are several alternative fuel being considered for civilian and military aviation. National Aeronautics and Space Administration (NASA), Boeing, Air New Zealand, the Air Force and many others have conducted initial research. This paper will discuss the following sources: synthetic fuel, biofuel, hydrogen fuel, and solar power because of their potential for usage in military aviation.

Synthetic Fuel

One of the most promising near-term alternative fuel options is synthetic liquid fuel produced from a solid carbon feedstock (i.e., coal, natural gas, oil shale).⁹ There are two options for making synthetic liquid fuel: the first is a direct liquefaction technique, however, this process is complex and expensive.¹⁰ The Fischer-Tropsch (FT) process is the other option. The FT process consists of using a feedstock, such as coal, that is converted into carbon monoxide (CO), Hydrogen (H₂) gases and ash. The ratio of CO

and H₂ are adjusted before the mixture is combined with a catalyst that produces jet fuel.¹¹

There are many positive and negative aspects to FT synthetic fuels. One of the most cited positive qualities of synthetic fuels is that it burns cleaner and produces fewer carbon emissions than petroleum based fuels.¹² Specifically, FT fuels produce approximately 2.4% less carbon dioxide, 50%-90% less particulate matter, and 100% less sulphur than traditional petroleum based fuels.¹³ FT synthetic fuel also has excellent low temperature properties for high altitude flight and superior thermal stability for development of highly fuel-efficient engines.¹⁴

Another cited advantage to FT synthetic fuel is that two of the most common feedstocks are abundant in the US: coal and natural gas (Figure 2). The US has 2% of the world's conventional fossil fuel resources and approximately 30% of the world's unconventional fossil resources, including approximately 1 Tbbl (trillion Barrels of Oil Equivalent = 1000 boe)¹⁵ of shale oil, 800 boe of FT coal, 0.15 boe of petroleum-derived coke, and greater than 32 boe of oil from enhanced oil recovery (EOR).¹⁶ In total, the US has an estimated equivalent of 1.9 Tboe (190,000,000,000,000 bbl).¹⁷ At a consumption rate of 7.5 billion bbl/yr, the conventional and unconventional fossil resources can yield approximately 260 years of energy.

In December 2006, the Air Force successfully completed a test flight of a B-52 that used a 50/50 mix of JP-8 and synthetic fuel made by the FT process.¹⁸ Despite the positive results of the Air Force test, synthetic fuel has drawbacks. First, the FT production process generates twice the carbon emissions as the petroleum fuels production process.¹⁹ However, the development of carbon sequestration technology will

be important to overcome this environmental issue as long as the new sequestration technology does not introduce a new problem set of environmental issues. A second downside to FT synthetic fuel is the lack of lubrication properties because the FT fuel has no sulphur in it, which leads to accelerated wear on the mechanical components of vehicles.²⁰ A third concern is the potential environmental effects. For example, the FT process can use up to eight gallons of water for each gallon of fuel produced.²¹ The water requirement will make construction of FT plants in the western US, where large coal deposits are located, difficult due to lack of water.²² According to the Xinhua News Agency, the Chinese have scaled back major investments in FT plants due to limited water resources.²³ The environmental effects of coal mining in new areas of the US will also have to be considered.

FT plant profitability is another factor for consideration. A demonstration plant was constructed by Syntroleum and produced 100,000 gallons of fuel for the Air Force B-52 tests. Unfortunately, falling revenue and completion of the Air Force tests forced the plant to close. Synthetic fuels have been successfully tested for military aviation use and show potential for reducing foreign oil dependence but synthetic fuel feedstock still comes from a non-renewable source. If the US mandates that military aviation must use renewable energy sources, then another fuel source will need to be found.

Biofuels

One possible renewable energy source is biofuels. Biofuels are combustible liquids that have been manufactured from renewable resources such as plant crops and animal fats.²⁴ Biofuel feedstocks are divided into three-generation categories. Feedstock created from food sources are considered first generation.²⁵ Corn ethanol is a widely

used first generation biofuel feedstock. Ethanol and methanol have poor mass and volumetric heats of combustion that make them unsatisfactory for aviation use.²⁶

However, soybeans, rapeseed (canola), and sunflowers have shown promise as a biofuel feedstock when mixed with petroleum fuels. The following process, using soybeans as an example, illustrates the alternative fuel making procedure. The beans are cleaned, cracked, and compressed into flakes. Then, the flakes are submerged into a solvent that extracts the oil. Once the oil is extracted, it is converted into ester (oil), which can be used directly or modified for another product.²⁷

Second generation biofuels are manufactured from nonfood feedstock, such as jatropha, camelina and switch grass, using advanced technical processes.²⁸ In order to use second-generation biofuel in military aviation, scientists need to overcome a few issues. First, 100% biofuel freezes when tested at normal cruising altitudes. Second, 100% biofuel has a poor, high thermal stability characteristics. Further testing, has shown that using a different separation process, 100%, second-generation biofuel can reach a lower freezing temperature. Further research has also shown, using a 50% Jet-A and 50% biofuel/fuel mix can overcome the problems of freezing and thermal stability.²⁹ A third issue with second generation biofuels is that there is not enough farmland to produce the feedstock needed to supply a large percentage of fuel without decreasing human food production. To use a 15% biofuel, 85% Jet-A blend for US domestic commercial flights would require two billion gallons of biofuel. Thirty-four million acres of land, the size of the state of Florida, would need to be dedicated to the production of feedstock.³⁰

Third generation biofuels or advanced biofuels are also made from nonfood feedstocks; however, the resulting fuel characteristics are indistinguishable from petroleum-based fuels.³¹ In particular, early research indicates algae feedstock meets the requirements of the third generation classification³² and has the potential to overcome many biofuel feedstock issues. Algae is projected to produce anywhere from 10,000 to 20,000 gallons per acre per year of bio-fuel. Thus, a production rate of 10,000 gallons per acre per year would produce 85 billion gallons of bio-fuel in an area the size of Maryland.³³ Algae require CO₂ to grow and ,theoretically, could be used to assist in the CO₂ sequestering during the FT production process.³⁴ Unlike other biofuels, algae based biofuel does not freeze at high altitudes.³⁵

Hydrogen Fuel Cell

Hydrogen Fuel cell research has led to some positive results for the light civil aviation community. On April 3, 2008, Boeing announced that it had flown a manned aircraft powered by hydrogen fuel cells.³⁶ A two-seat, motor-glider was modified by Boeing Research & Technology Europe (BR&TE) and industry partners from around the world with a Proton Exchange Membrane (PEM) fuel cell/lithium battery hybrid system to power an electric motor that was coupled to a conventional propeller.³⁷ The test flights were conducted in February and March at an airfield near Ocana, Spain. Although the aircraft used the combined power from the lithium battery and hydrogen fuel cell to reach test altitude, the results of the test flights were a straight and level cruising speed of 63 miles per hour at an above sea level altitude of 3,300 feet for 20 minutes under the sole power of the hydrogen fuel cells.³⁸ Boeing, along with most of the aviation industry,

does not see hydrogen fuel cell technology becoming the primary power source for large aircraft, but does see the technology as potentially a secondary or auxiliary system.

Along with light civil aviation, there have been positive results in hydrogen fuel cell use in Unmanned Air Vehicles (UAV). November 1, 2007, Horizon Fuel Cell Technologies announced that the *Pterosoar*, a micro-UAV, set a new flight distance record of 78 miles.³⁹ Furthermore, another sole hydrogen powered UAV made its maiden flight on April 2, 2007, in Bern Switzerland. The *Hyfish*, a product of an international consortium, was able to perform a multitude of acrobatic maneuvers and reach speeds of 124 miles per hour (MPH).⁴⁰ This flight was the first high speed flight of an aircraft that used hydrogen fuel cells as its sole power source.

Although the prior examples are positive results in the use of hydrogen fuel cells as aviation power sources, there are major negative issues to overcome. Specifically, for large aircraft, onboard fuel storage and hydrogen fuel cell logistics are an issue. Because of the power requirement, hydrogen fuel must be stored in its liquid cryogenic form which would require a major design change in large aircraft construction.⁴¹ For example, the storage system for liquid hydrogen cannot be placed in the wings of the aircraft because of high insulation and pressure requirements. In addition, the heavier fuel tanks would increase the operating empty weight (OEW) by 13% from the Jet-A fuel system; however, because hydrogen is lightweight, the overall takeoff weight would actually be 5% lighter.⁴²

Aircraft engines are designed to power the aircraft during the heaviest part of the flight, the take-off phase. The reduction in take-off weight makes it possible to downsize the engines to produce 25% less thrust allowing smaller, lighter weight engine to be used,

but would require major engine redesign.⁴³ Aircraft can also be designed with slightly smaller wing because they do not have to hold fuel, but they still need to be large enough to provide the lift to carry the extra weight of the liquid hydrogen fuel tanks.⁴⁴ The weight of the fuel tanks requires the need for 28% more energy for a 500 nautical mile flight compared to the Jet-A fuel tanks; but as the flight distance increases the lightweight properties of the fuel start to overcome the use of the heavier tanks.⁴⁵ Therefore, a 3000 nautical mile trip would only require 2% more energy.

A final issue with the use of hydrogen is the logistics. Access to JP-8 is common on the battlefield and airports, the logistic requirements of liquid hydrogen would require new airfield facilities and new transportation for non-combat and combat use.

Solar Energy

Solar energy is currently used in aviation. The invention of the silicon photovoltaic (PV) cell in 1954, led the way for solar power to become a viable energy source in space and aviation.⁴⁶ *Vanguard I* was the first space satellite to use a solar powered array to power its radio, proving that solar power was a viable option as a power source in space vehicles.⁴⁷ The continued development and success of solar power in space vehicles led to positive results from the research into solar powered aviation.

Since 1974, there have been over 90 manned and unmanned aircraft flights powered by solar energy.⁴⁸ The first solar powered aircraft, *Sunrise I*, completed its first test flight of 20 minutes at an altitude of 100 meters in California.⁴⁹ The first manned flight made by a solar powered aircraft was the *Solar Riser* flown by Larry Mauro on April 29, 1979. The solar panels on the *Solar Riser* did not have sufficient power to drive

the motor directly but were used to charge the nickel-cadmium battery pack.⁵⁰ After a three-hour charge, the batteries were able to provide 10 minutes of power to the engine.⁵¹

Dr. Paul McCready completed the first sole solar energy source aircraft flight on May 18, 1980 in the *Gossamer Penguin*. With the success of the *Gossamer Penguin*, Dr McCready was encouraged by the Dupont Company to build the *Solar Challenger*, which flew 5 hours, 23 minutes from Pontoise-Corneilles France, over the English Channel, to Manston Royal Air Force Base, with solar energy as the sole power source and no onboard energy storage system.⁵²

Since the 1980s, Aero Vironment has designed and built four generations of solar powered UAV's.⁵³ The *Pathfinder*, *Pathfinder Plus*, and *Centurion* all continued to push altitude records for solar powered aircraft as each generation was designed and tested.

Helios was the fourth generation UAV built by Aero Vironment and continued on the progress of the previous three generations. NASA set two major goals for the *Helios* prototype to demonstrate sustained flight at an altitude of 100,000 feet and non-stop flight for at least 24 hours, including at least 14 hours at 50,000 feet.⁵⁴ To meet NASA goals, the *Helios* prototype had two configurations. The HP01 was designed to operate at extremely high altitudes and the HP03 was designed for long-duration flight.⁵⁵ On August 13, 2001, the *Helios* HP01 prototype flew at an altitude of 96,863 feet setting a new record for sustained horizontal flight by a winged aircraft.⁵⁶ Unfortunately on June 26, 2003, HP03 crashed near the PMRF due to the aircraft exceeding its designed airspeed limit causing a failure of wing.⁵⁷ The cause of the designed airspeed being exceeded was contributed to an unexpected persistent high wing dihedral,⁵⁸ which caused the aircraft to have growing pitch oscillations and become unstable.⁵⁹

The British company, QinetiQ, has a solar powered high altitude long endurance (HALE) platform called the *Zephyr*. Although the *Zephyr* is only 66 pounds and has an 18-meter wingspan, on July 28, 2008 it flew for 83 hours and 37 minutes.⁶⁰ The record remains unofficial because the World's Air Sports Federation, which is responsible for measuring and verifying air and space records, was not at the test site for the flight. The success of the *Zephyr* project has brought QinetiQ into collaboration with Boeing to work on the *Vulture* project. The DoD has requested bids on building an UAV that has a 1000 lbs carrying payload and can stay aloft uninterrupted for five years, which the *Vulture* project intends to accomplish.⁶¹

Currently, Bertrand Piccard and Andre Borschberg are working on a manned solar powered aircraft that will be able to fly around the world. The *Solar Impulse* will have a wingspan equal to a 200-ton Boeing 747 jumbo jet but weigh in at just 1.5-ton.⁶² Piccard and Borschberg have flown the *Solar Impulse* in simulation and plan to conduct the around the world flight in 2011.⁶³

Solar powered, manned, and unmanned flight has been proven possible, unfortunately major design issues have to be overcome to make solar powered manned flight feasible for military aviation. One design issue is to maintain a useful payload weight; the aircraft wing design needs to be large but still lightweight. To this point, large lightweight wing designs have been extremely fragile and susceptible to damage from turbulence as in the case of the HP03.⁶⁴ The *Solar Impulse* and *Vulture* project could yield valuable data on how to design a solar powered aircraft that will have a useful load and endurance.

Cost

Up to this point, the paper has focused on the different alternative fuel sources that are available for aviation and environmental considerations. Each source has positive and negative attributes that must be considered. The one attribute common to all sources is cost. When considering cost, the topic can be examined from monetary cost to environmental cost to national security cost. The next section will address monetary and national security cost issues.

In 2008, the United States experienced the biggest inflation-adjusted price per barrel of oil increase since 1979. The nominal peak of \$38 per bbl of oil in December of 1979 was \$106.43 in November 2008 dollars compared to the June 2008 price of \$122.54 per bbl in November 2008 dollars. (fig 1)⁶⁵ Although fuel prices have declined significantly from their one time high, the experience has brought the importance of finding cost effective alternative fuel sources to the nation's attention. Oil meets about 40% of the United States energy needs and about 69% of that oil goes to the production of energy sources (jet fuel, gasoline, and diesel) for transportation.⁶⁶ The civilian and military aviation community is highly susceptible to changes in fuel costs. While civilian aviation can add fuel surcharges to the price of an airline ticket or charge extra for baggage or excess weight, the military does not have that luxury. Military aviation is restricted to the funds that have been allocated in the DoD annual budget. A \$10 increase in the price of a barrel of oil costs the United States (US) military \$1.3 billion and \$600 million just for the Air Force.⁶⁷ The ramification of the increased cost is enormous.

First, an explanation of current DoD fuel procurement practices is needed to fully grasp the implication of changes in the market price on a barrel of fuel. The Office of

Management and Budget (OMB) establishes the price DoD will use to construct fiscal year budget requests. The DoD in turn uses the OMB price to establish the standard price for a barrel of fuel that will be used by DoD fuel customers (military services) for budgeting.⁶⁸ The standard price was created to insulate the military services from the normal ups and downs of the fuel marketplace. It provides the military services and OSD with budget stability despite the commodity market swings, with gains or losses being absorbed by a revolving fund.⁶⁹ The Defense Energy Support Center (DESC), a Defense Logistic Agency (DLA) component, is responsible for procurement of DoD energy sources.⁷⁰ DESC uses the standard price when negotiating contracts with fuel suppliers for DoD usage. The DESC contracts set the per barrel price for one fiscal year (FY) at a time. The contracting process begins with DESC issued solicitations and awarded based on the lowest bid.⁷¹ Along with the standard price per barrel, the DESC bid evaluation model takes into account the product, additives, distribution costs, quantities offered, transportation, storage, terminal throughput constraints, and minimum quantity requirements.⁷² During the fiscal year, DoD pays the actual market rate, which will vary from the budgeted rate.⁷³ The Defense Working Capital Fund (DWCF) picks up the difference between the standard price and the market price.⁷⁴ The DWCF can make or lose money depending on whether the standard price is higher or lower than the market price.⁷⁵

When DWCF funds are needed to pay for the gap between standard price and market price, funds need to be transferred or supplemental spending request have to be submitted to Congress. In 2006, \$374.9 million of previously apportioned fuel supplemental funding (provided in Title IX of P.L. 109-148, the DoD Appropriations Act

of 2006) was redistributed from Defense-Wide Working Capital Fund (DWWCF) to DWCF activities effected by increased fuel cost in FY 2006 (\$262.4 million to the Air Force Working Capital Fund and \$112.5 million to the Navy Working Capital Fund).⁷⁶

The gains or losses in the DWCF can be made up by adjusting future standard prices or by providing DoD customers with a refund. The Office of Secretary of Defense (OSD) Comptroller typically makes the decision to change the price, however the DWCF must remain cash solvent.⁷⁷ During the fiscal year, the DoD can issue a change of standard price memorandum to revise the standard price. The revised price will reflect the revised crude oil assumptions in crude oil by the OMB.⁷⁸ In 2008, there were three standard price change memorandums released due to market price increase in per barrel cost. On June 19, 2008, the Office of the Under Secretary of Defense (OUSD) released a memorandum that raised the standard price from \$127.68 per barrel to \$170.94 per barrel.⁷⁹ On January 21, 2009, OUSD lowered the price to \$69.72 per barrel.⁸⁰ The market price as of January 23, 2009 was \$46.47. All of the price change memorandums were issued to keep the DWCF solvent. Significant changes in market price per barrel have effects on how the DoD spends money.

When considering the use of alternative fuel sources one must look at when an alternative fuel source becomes cost effective compared to crude oil.

FT Process

Using the FT process, industry estimates that building an 80,000-barrel-per day coal-to-liquid refinery would cost between \$7-9 billion, compared to the \$2 billion that it would cost to build a similar capacity petroleum refinery.⁸¹ A FT plant that did not capture carbon dioxide could turn a profit with oil at \$40 per barrel; a carbon dioxide

capturing plant is estimated to be profitable with oil trading at \$50-55 per barrel.⁸²

Another cost consideration is the military contracting process. The military has a five-year limit on how long it can sign contracts for supplies.⁸³ The limited contract time makes the risk of long-term investment by the private sector difficult for the capital needed for FT fuels. Civilian usage of FT fuel could offset the military contract risk if FT produced fuel can be manufactured at a price lower than oil. Long-term profitability was one of the reasons the before mentioned Syntroleum FT demonstration plant closed. Additional monetary cost considerations are environmental ramifications and development of technology to eliminate or reduce the risk to the environment.

Biofuels

On August 15, 2007, Imperium Renewable cut the ribbon on a biodiesel plant that will have the capability to make 100 million gallons of fuel annually.⁸⁴ Imperium spent approximately \$78 million on the plant, with \$45 million going towards holding tanks and distribution cost and \$30 million spent on processing fuel equipment.⁸⁵ One major factors in biofuel production cost is commodity price. Using soybean oil as an example, it takes 7.36 pounds of de-gummed soybean oil to make one gallon of biodiesel.⁸⁶ In August 2007, soybean futures were 37 cents a pound, which put raw material cost at \$2.72 per gallon for biofuel; at this time, wholesale price for refined, regular diesel was \$2.40 per gallon.⁸⁷ Without federal subsidy (50 cents per gallon for used oil and animal fat and \$1.00 a gallon for fresh oil) most biodiesel manufactures would lose money.⁸⁸ The use of food commodities as biofuel feedstock increases the demand for that commodity, which not only affects the price for biofuel production, but also the price of that commodity in food production.

Hydrogen Fuel Cells

The use of hydrogen fuel cells in aviation is still in the early stages of development; however, there has been success with hydrogen-powered flight in UAV and light civilian aircraft. Because of the lack of technical data in manned military aviation or heavy lift aircraft data using hydrogen power, heavy lift land vehicles powered by hydrogen fuel cells will be used as a base when considering cost. In a summary of hydrogen fuel cell powered buses life cycle cost model conducted by the Department of Transportation (DOT) it was determined that fuel cell buses are currently three times higher than the cost of diesel buses.⁸⁹ In addition, the summary stated that capital costs were ten times higher, overhaul costs three times higher, annual maintenance cost two time higher and fuel costs two-three times higher than current diesel bus costs.⁹⁰ Until research is conducted on heavy lift or manned military aircraft, the comparison between hydrogen fuel cell powered buses and diesel powered buses can roughly represent the expected cost difference in aviation. Other major research and development (R&D) investments include production facilities, supply networks, and distribution systems.⁹¹ In addition, redesign of aircraft engines and airframe cost will have to be considered.

Solar Energy

Solar power cost is dependant on continuing improvements in solar collector technology and energy storage devices. Current cost in the US is typically 26 cents to 35 cents per kilowatt-hour, compared to the 3-5 cents per kilowatt-hour from a coal burning electric plant.⁹² Improvements in solar collector efficiency and energy storage devices will allow aircraft designers flexibility to use solar energy as an aircrafts primary power source.

National Security

The cost section of this paper has focused on monetary costs in using alternative energy sources for use in military aviation to this point. The final cost consideration for this research project is National Security.

Secretary of State Condoleezza Rice, told the Senate Foreign Relations Committee: "We do have to do something about the energy problem. I can tell you that nothing has really taken me aback more, as Secretary of State, than the way that the politics of energy is . . . 'warping' diplomacy around the world. It has given extraordinary power to some states that are using that power in not very good ways for the international system, states that would otherwise have very little power."⁹³

As of November 2008, the US imported 66.6% of its required oil.⁹⁴ The top 15 countries that export crude oil to the US are (thousand barrels per day); Canada (2,028), Saudi Arabia (1,461), Mexico (1,296), Venezuela (1,071), Nigeria (775), Iraq (452), Angola (438), Algeria (381), Brazil (280), Kuwait (272), Ecuador (214), Colombia (157), Russia (152), United Kingdom (117), and Equatorial Guinea (114).⁹⁵ Approximately 36% of imported oil comes from North American countries, 24% from Middle Eastern countries, 19% from South American countries, 19% from African countries and 3% from Europe.⁹⁶

During the early part of 2009, Israel conducted combat operation in Gaza to eliminate the Hamas rocket threat. The US supported Israel in 2009 as it had in the past when Israel defended her citizens. The Yom Kippur war in 1973, started by Syria and Egypt, led Arab states to declare an oil embargo against nations that supported Israel, one of which was the US. In early 2009, Russia stopped gas exports to the Ukraine due to a

price dispute. Relations between the US and Venezuelan president Hugo Chavez has been strained for many years. The Colombian government continues to have issues keeping crime and violence under control since the 1990s.⁹⁷ The current drug war and economic crisis in Mexico threatens US national security.⁹⁸

International politics and foreign policy conflicts can significantly influence the availability and cost of oil to the US and the world. Countries that export oil to the US can use oil as leverage to influence US foreign policy. A weak foreign government or internal strife within a country the US imports oil from can have a significant impact on US fuel supplies and foreign policy decisions.

Aside from international politics, terrorism can significantly influence the oil market and impact national security. For example, price per barrel of oil jumped \$2.50 after the 29 May 2004 Al-Qaeda attack on the housing compound for oil workers in Khobar, Eastern Province, Saudi Arabia.⁹⁹

Lastly, environmental factors can have a significant affect on the oil market and oil production. For instance, in the summer of 2005, Hurricane Katrina shut down 615 of 819 oil platforms in the Gulf of Mexico and caused an oil production drop of nearly 92%, which led to an initial jump of over \$3.00 in oil prices.¹⁰⁰

Conclusion

The US will have to frame the problem of alternative fuel usage correctly in order to achieve the best return on money and research in alternative fuel. There are many possibilities on how to form a strategy for alternative energy: develop alternative fuels to reduce global warming, develop alternative fuels to reduce US dependence on foreign oil, reduce influence of oil exporting countries on US foreign policy or national security,

support an industry to create jobs, petrol based fuels will eventually run out, are all examples. To use alternative fuel sources in military aviation, the US must decide on what problem or problems alternative fuels will solve and how best to make alternative fuels sources a reality in military aviation. Alternative fuels have to be profitable for companies that make them, either through government subsidies or through R&D into making the manufacturing process cheaper than making fuel from oil. How the US frames the problem will determine the level of difficulty in acquiring support, funding, developing and producing productive alternative fuel programs. By combining national security, foreign oil dependence, the environment, the creation of jobs in a growth industry, and finding an eventual replacement to fossil fuels, will form a strategy for a US alternative fuels program that will have a broad base of support.

DoD is not a large enough customer to drive the alternative fuel market or to be the sole developer of alternative fuels.¹⁰¹ In 2005, DoD only consumed 1.2% of the nations total fuel usage and only 52% was used for aviation fuel.¹⁰² The use of alternative fuel in military aviation will have to be developed by the civilian sector with encouragement, cooperation and funding from the US government. Many companies including Boeing, Airbus, Air New Zealand, NASA, Virgin Atlantic, have already begin the R&D of alternative fuels in aviation with positive results.¹⁰³

Both civilian and military aviation will benefit from advances made in alternative fuels research for the aviation industry. Out of the four alternative fuel sources researched in the paper, biofuels and synthetic fuels exhibit the most potential for military aviation from the research and analysis conducted for this paper.

Solar power and hydrogen fuel cells have successfully been demonstrated as potential alternative fuel sources for UAV and manned light civil aviation. Due to previously mentioned logistic, engineering and design limitations, neither alternative fuel source can be considered a viable option for manned military aviation use.

In the short term, with an effort to move away from the dependences of foreign oil, the FT process for making synthetic fuels is the most beneficial choice. The FT process produces a fuel that is 'drop in ready'¹⁰⁴ with current aircraft technology. Using coal and natural gas as the feedstock will allow the US to use its own natural resources and not have to compromise national security or foreign policy to import oil. Continued research is required to solve the environmental issues that the FT process presents, but FT manufactured fuel has been proven to meet the requirements for use in military aviation as seen with the previously mentioned Air Force B-52 test flight.

Long term, biofuel research for aviation usage shows the most promise. Biofuels are renewable, 'drop in ready', and compatible with current aircraft technology. A mixture of fossil fuel and biofuel has met aviation requirements. In January of 2009, Continental Airlines flew a 737 from Houston's George Bush International airport with one of two engine operating on a B50 blend of Jet-A, jatropha, and algae.¹⁰⁵ The tests met all aviation requirements for fuel. Although not a 100% biofuel, a 50% mixture of biofuel and petroleum based fuel can reduce the amount of petroleum based fuel required by the US for aviation usage by 50%. One hundred percent first and second-generation biofuels did not produce the energy needed for aviation usage but research and technology advances have led to third generation biofuels meeting aviation requirements. Algae is a front-runner for a feedstock that could produce a 100% biofuel that meets all

aviation requirements. Continued R&D is needed to determine the highest oil producing strains of algae, the most efficient production process and making production costs profitable but initial test results indicate that these issues can be solved as indicated in the results from research conducted at the University of Malaya.¹⁰⁶

In conducting research into alternative fuel sources it is evident that there are many different technologies and opinions on which source of alternative energy would be best for the US. Unfortunately, one alternative fuel source cannot provide the answer for all sectors. This is best demonstrated with the failure of first generation biofuels to meet the power requirements need for aviation usage. The partnership of the civilian aviation community and the military can lead to an alternative fuel source that will meet the power requirements for military aviation while reducing US dependence on foreign oil, protecting the environment and reducing the risk to national security.

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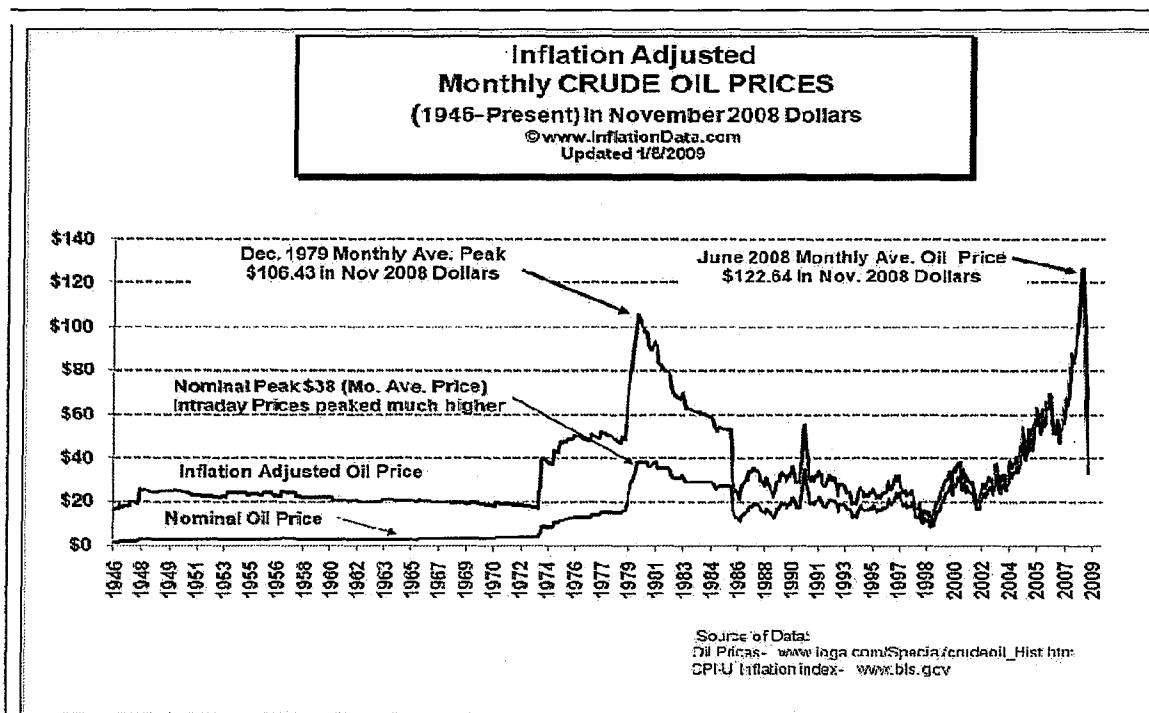
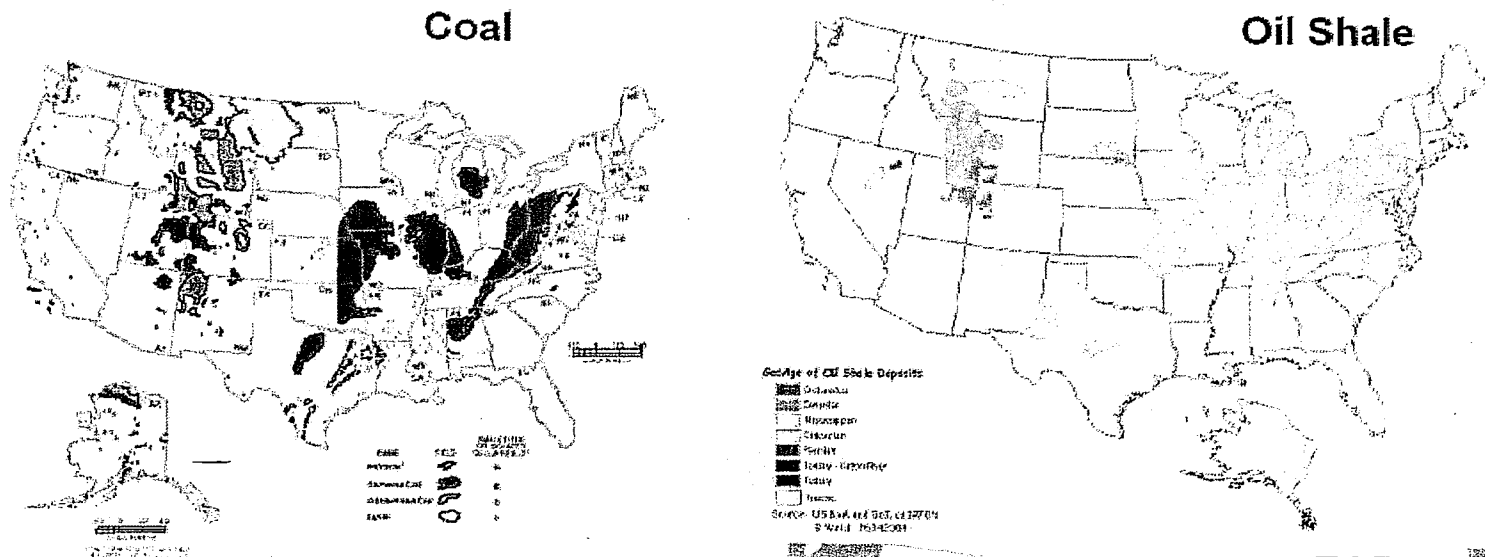


Figure 1

Figure 2

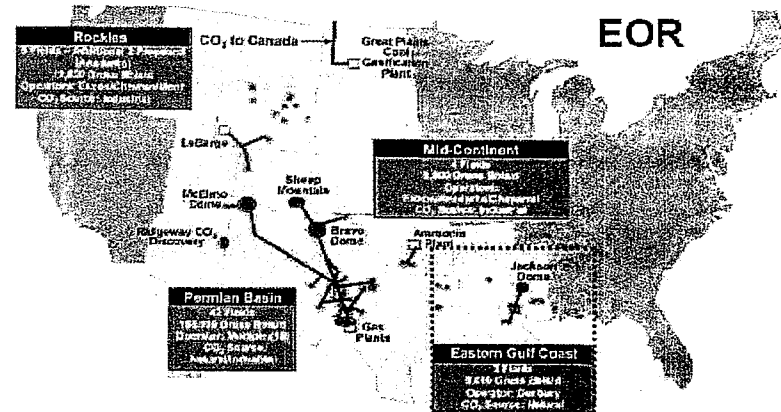
U.S. fossil energy resources



Source: United States Geological Survey, Coal Fields of the United States, 1962-1963; Texas Bureau of Economic Geology, Oil Shale Resources in Texas, 1960; Colorado Geological Survey, Near Surface Oil Shale in Colorado, 1971; Colorado Geological Survey, Coal Reserves and Development, 1971; and Montana Bureau of Geology, 1973.

Domestic Resources

- 1 trillion barrels (shale)
- 800 billion barrels of FT (coal)
- 0.15 billion barrels (pet coke)
- 22.7 billion barrels oil reserves
- 32+ billion barrels of oil (EOR)
- Total of 1.9 trillion barrels



Graphic from T.K. Barna et al. [OSD] presentation

GLOSSARY

bbl	blue barrel of oil
boe.....	barrel of oil equivalent
BR&TE	Boeing Research & Technology Europe
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
DESC	Defense Energy Support Center
DLA	Defense Logistic Agency
DoD	Department of Defense
DoT	Department of Transportation
DWCF	Defense Working Capital Fund
DWWCF	Defense-Wide Working Capital Fund
EOR.....	enhanced oil recovery
FT	Fischer Tropsch
FY	Fiscal Year
HALE	high altitude long endurance
MPH.....	Miles per Hour
NASA.....	National Aeronautics and Space Administration
OEW	operating empty weight
OMB	Office of Management and Budget
OSD.....	Office of Secretary of Defense
OUSD.....	Office of the Under Secretary of Defense
PEM	Proton Exchange Membrane
PMRF.....	Pacific Missile Range Facility
PV	photovoltaic
R&D	Research and Development
US	United States
UAV.....	Unmanned Air Vehicle

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