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Alternative jet fuel feasibility

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ABSTRACT

Concerns regarding the environmental and economic sustainability of petroleum based transportation fuels, including jet fuel, are driving interest into alternative fuels. The development of viable alternatives could provide benefits in terms of energy diversity thus reducing dependence on any given nation for our energy needs. This manuscript examines the drivers for alternative fuels in the light of the needs of aviation and it provides criteria wherein potential alternative jet fuels can be compared. A wide range of transportation fuels was qualitatively examined using these criteria. Because of concerns regarding their safe use and the energy efficiency loss that would be inherent in their use, alcohols and biodiesel are better suited for ground transportation. Cryogenic fuels are not feasible in the near term because of the large existing aircraft and airport infrastructure that is incompatible with these fuels. Synthetic fuels offer aviation with a wide range of potential feedstocks that could augment or potentially replace petroleum, but concerns regarding the economic cost of production and the current lack of feedstock availability limits their near term availability to aviation.

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1. Introduction

Since the earliest days of motored transportation when gasoline went from being a byproduct of kerosene production to the driving force in the development of the petroleum industry, the growth and development of oil and transportation have been inseparable. This is because refineries continuously maximize the utility, in the form of economic profit, of a barrel of oil and this utility is tied directly to how the various products from the barrel are used. In 2012, the world demand for petroleum was 89.2 million barrels of oil per day (EIA, 2014a). This annual volume is equivalent to 43,400 gallons per second, or roughly the discharge rate of a moderate sized river such as the Charles or Connecticut Rivers in the Northeast United States. However, only a portion of this oil usage goes to aviation.

Within the United States, 46% of oil by volume that is supplied goes to gasoline while 31% goes to creating middle distillates, consisting of diesel fuel, jet fuel, and fuel oils; jet fuel itself constitutes 8% of this average barrel (EIA, 2014b). In 2010, the U.S. used 27% of the worldwide demand of jet fuel, which is 5.2 million barrels per day (EIA, 2014c). As demand dictates, refineries can direct the petroleum stream that is used to create jet fuel to make diesel fuel instead. This is because jet fuel falls within the distillation range and properties of diesel fuels. The fungiblility of transportation fuels, as well as the resources to make alternative fuels, must be kept in mind when considering alternative fuels.

Unlike previous periods when spikes in the price of petroleum have provoked interest in alternatives to petroleum, the environment represents a potential constraint on the continued growth of all sectors of the economy. Although concerns about global climate change dominate the press, other environmental concerns also need to be addressed. Alternative fuels offer an opportunity not only to reduce aviation's contribution to global climate change, but they could also reduce aviation's impact on air quality as fuel composition could be modified to reduce pollutant formation. However, the development of a biofuel industry could have consequences on land and fresh water usage, as well as other environmental concerns, that cannot be ignored if sustainability is indeed a concern.

This manuscript examines the forces driving the development of alternative jet fuels in terms of economics and environment. It then presents a comparison framework wherein these drivers can be examined. This framework is then applied to a range of fuel options that could be considered by aviation to identify feasible alternative jet fuel options.

2. Motivations driving alternative jet fuel use

As alluded to in the introduction, there are four forces driving the development of alternative transportation fuels: economic sustainability, environmental sustainability, energy supply diversity, and

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competition for energy resources. The relative importance of these drivers varies depending on geographical location.

2.1. Economic sustainability

2.1.1. Cost of energy

As world's energy demand increases, so does the need for production. As shown in Fig. 1, oil prices steadily increased over the past two decades, peaking in 2008 at over $140 per barrel. Even though the world economy subsequently suffered its worst recession since the Great Depression, oil has subsequently stabilized at a price between $90 and $100 per barrel. The peak in 2008 and the recent relatively high prices during a global downturn both indicate a probable end to the era of cheap oil. The increase in fuel prices had a profound impact on airline operation as the recent price spike led to fuel overtaking labor as the dominant contributor to aviation operating costs for the first time.

The escalation of the jet fuel price in the summer of 2008 created a fundamental shift in the economics of air travel in which gains in other areas of the airline industry were negated by increases in fuel costs. As long as jet fuel derived from conventional petroleum remains the dominant fuel, the price of petroleum will define its market price. The difference between the price of jet fuel and petroleum, known as the crack spread, denoted by the dark region in Fig. 1, has averaged 19% of the total price of jet fuel over the last twenty-four years with a standard deviation of 6%. The crack spreads of jet fuel and diesel fuel have historically been similar owing to the similarities in how these fuels are produced.

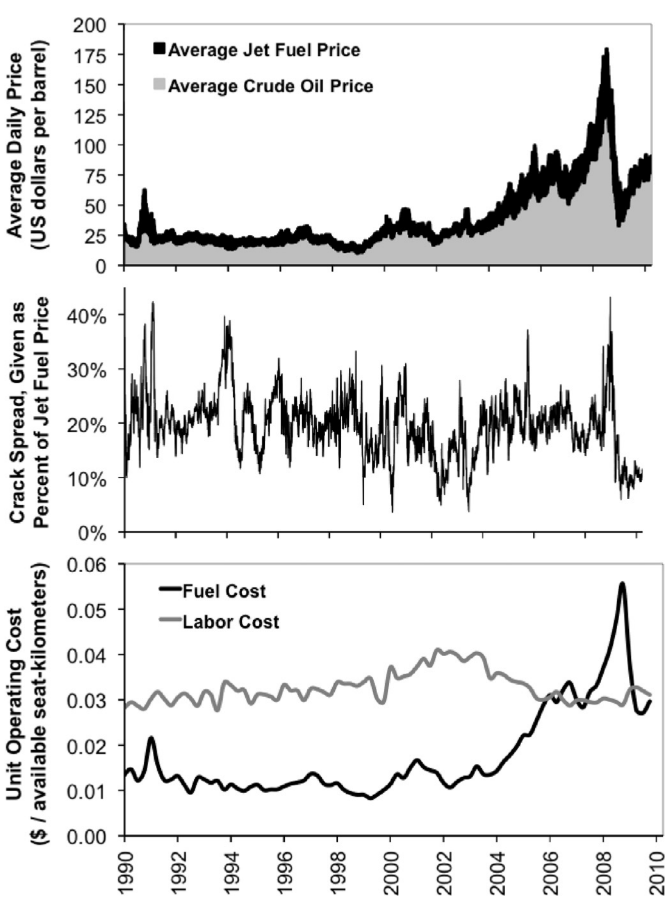

Fig. 1. Crude and jet price history, and the crack spread between these prices, for the United States (EIA, 2010c) and U.S. airline average unit operating costs for fuel and labor (ATA, 2010). Crude and jet prices are based on the average spot prices as reported by the EIA and prices are in 2010 U.S. dollars.

As oil prices increased, previously inaccessible petroleum resources become economically viable thus increasing petroleum reserves. This is evidenced by the extraction of conventional petroleum, (a.k.a., crude oil), from locations farther offshore in the ocean, the development of unconventional petroleum resources such as Canadian oil sands and Venezuelan very heavy oils, and the increase in hydraulic fracturing (a.k.a., fracking) to access petroleum below rock, deep in the earth's surface. On top of the development of conventional and unconventional petroleum, energy companies have responded to increased oil prices with increased investment in facilities, such as those to create synthetic liquid fuels from natural gas using Fischer–Tropsch (F–T) synthesis, expanded ethanol production, and the production of diesel replacement fuels from vegetable oils.

The rise in petroleum prices in 2008 was not the first as there have been periodic shocks in the price of oil. Each shock brings renewed interest in expanded exploration for new petroleum reserves and production of alternatives to petroleum. The oil shocks of the 1970s led to considerable worldwide interest in alternatives with one success being the formation of the Brazilian ethanol industry which today is self-sufficient.

2.1.2. Cost of changing infrastructure

The long life of commercial aircraft and the size of the current aircraft fleet both point toward the need for "drop-in" alternative fuels. Drop-in fuel options are defined as being compatible with today's aircraft technology and infrastructure with little or no modification. In 2012, the worldwide fleet was comprised of 20,310 commercial aircraft (Boeing, 2013), each of which is designed to operate using conventional jet fuel. This is a substantial investment of capital as a new single aisle aircraft from Boeing costs roughly 50 million dollars while a new jumbo jet costs roughly 300 million dollars (Boeing, undated). If the average aircraft replacement cost were 50 million dollars, then a trillion dollars would be required to replace the existing fleet with new aircraft. Of course, this is an oversimplification but it does point to the large current investment in commercial aircraft. Furthermore, at the 2008 rate of aircraft deliveries by Boeing (375), Airbus (483), Embraer (204), and Bombardier (353) of 1415 aircraft per year, it would take roughly 14 years to replace the fleet. Since the number of aircraft in the worldwide fleet is increasing to meet growing aviation demand, the turnover time would actually be longer.

It has been speculated that an alternative fuel suitable for aviation use would benefit from the tightly controlled fuel-distribution infrastructure that supports commercial aviation. However, if the finished fuel satisfies international standards and is compatible with current engine technology, the structure of the distribution system should have little or no effect on the overall prospects of the fuel. This is especially the case with synthetic diesel and jet fuels, which are suitable for distribution from the plant gate.

2.2. Environmental sustainability

2.2.1. Greenhouse gases

In 2012 aviation contributed 2 percent of the world's CO_2 emissions (ATAG, 2012). Aircraft also produce non-CO_2 emissions that contribute to global climate change, as will be discussed in Section 3.2. Within the US, Section 526 of the Energy Independence and Security Act of 2007 (Public Law 110-140) has placed restrictions on the life cycle greenhouse gas emissions of alternative fuels that can be used by federal agencies.

Biofuels offer an opportunity to reduce the life cycle carbon dioxide (CO_2) emissions from transportation fuels. This is not because their use results in a change in combustion emissions of