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**ARE ALTERNATIVE FUELS AN ALTERNATIVE?**

***A REVIEW OF THE OPPORTUNITIES AND CHALLENGES OF  
ALTERNATIVE FUELS FOR AVIATION***

by

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**S Y N O P S I S**

SYNOPSIS .....	119
ABSTRACT .....	120
RÉSUMÉ.....	120
I. INTRODUCTION .....	121
II. AVIATION FUELS.....	122
III. ALTERNATIVE AVIATION FUELS .....	124
A. ALTERNATIVE FUELS DERIVED FROM COAL AND NATURAL GAS .....	125
B. ALTERNATIVE FUELS DERIVED FROM BIOMASS, HYDROTREATED OILS, AND OTHER PATHWAYS.....	128
C. OTHER ALTERNATIVE FUELS .....	132
IV. THE CASE FOR ALTERNATIVE FUELS IN AVIATION .....	135
A. ENERGY SECURITY .....	135
B. ENVIRONMENTAL ASPECTS.....	137
V. CHALLENGES FOR ALTERNATIVE FUELS .....	143
A. CERTIFICATION OF ALTERNATIVE FUELS .....	143
B. ENVIRONMENTAL ASPECTS OF PRODUCTION .....	145
C. COMMERCIAL CHALLENGES AND SCALE-UP OF PRODUCTION .....	148
VI. CONCLUSIONS.....	151

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## ABSTRACT

*The spike in oil price of July 2008 and increased environmental concerns about emission of green-house-gases has sharpened the aviation industry's interest in alternative fuels. The aviation industry, several regulators, and the International Civil Aviation Organization have initiated various programs, conferences, and concepts for the development of alternative fuels. Nevertheless, alternative fuels for aviation are not entirely new: they were first developed during the Second World War. So called synthetic fuels - fuels derived from coal using the Fischer-Tropsch method (FT) - have been successfully used for decades in South Africa. Furthermore, a new standard which allows up to 50 percent blend of certain FT derived alternative fuels with traditional jet fuel was certified in September 2009 for alternative aviation fuels. Given this new trend, however, the question is: are alternative fuels an answer to concerns about fuel security and growing environmental issues faced by the aviation industry? This article reviews the production of traditional aviation fuels and describes the different alternative fuels available for use in aviation. It goes on to describe the growing challenge of fuel security and outlines the impact that certain alternative fuels have on the environment. The article then examines the challenges for alternative fuels, which range from certification, environmental aspects of production, commercial challenges and production scale-up issues. The article concludes that although alternative fuels will undoubtedly play an important role in the future of aviation, the existence of several production and environmental challenges suggest that alternative fuels alone cannot provide the answer. A combination of measures as well as fuel production from various alternative sources will be necessary. In addition, regulators need to develop policies and regulatory frameworks to assure sustainable production of alternative fuels. These challenges notwithstanding, the development and production of alternative fuels for aviation must be fostered and this will require public support.*

## RÉSUMÉ

*La croissance du prix de pétrole en juillet 2008 et les préoccupations environnementales croissantes suscitées par les effets de l'aviation sur l'environnement global ont renforcé l'intérêt que l'industrie aérienne porte aux carburants de remplacement. L'industrie, plusieurs organismes de réglementation, et l'OACI ont initié de nombreux programmes, conférences et concepts pour le développement de tels carburants. Néanmoins, ils ne sont pas si nouveaux qu'on pourrait le croire, ceux-ci ayant été utilisés pendant la deuxième guerre mondiale. Les carburants synthétiques - dérivés du charbon par le procédé Fischer-Tropsch (FT) - sont utilisés avec succès en Afrique du Sud depuis déjà quelques décennies. De plus, en septembre 2009, un nouveau standard mélangeant en parts égales le kérosène et les carburants de remplacement a été approuvé. Vu cette nouvelle tendance, la question se pose de*

*savoir si les carburants de remplacement peuvent répondre aux soucis environnementaux et aux difficultés d'approvisionnement qui entourent le kérosène. Cet article examine la production des carburants traditionnels pour l'aviation et les remplacements potentiels pour le secteur. L'article aborde ensuite le problème émergent de la sécurité du carburant et présente l'impact des carburants de remplacement sur l'environnement. L'auteur examine ensuite les obstacles associés aux carburants de remplacement : la certification, les aspects environnementaux de leur production, les défis commerciaux, et l'échelle de production. L'article conclut que même si les carburants de remplacement vont certainement jouer un rôle important dans le futur de l'aviation, ils ne représentent pas la solution unique aux problèmes affrontés par le secteur aérien. Il faudra plutôt une multiplicité de mesures, y compris la production de carburant issu de sources alternatives. En plus les agences de réglementation doivent développer des politiques et des cadres réglementaires pour assurer la production durable de carburants de remplacement. Malgré tout, le développement et la production de carburants de remplacement pour l'aviation doivent être promus et ceci nécessitera le soutien public.*

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## I. INTRODUCTION

In July of 2008, the price of crude oil reached a peak of US\$ 147 per barrel. In consequence, many air carriers who had not hedged their fuel purchases suffered substantial losses. In addition, this price spike also seems to have triggered the global recession caused by the many defaults in the residential real estate sector, which lead to a near meltdown of financial systems in the Western Hemisphere. Despite the fact that the price of oil has since declined substantially by around 50 per cent, many airlines are concerned about future price spikes that might occur when global demand for crude oil is restored. Increasingly, the industry is worried about energy security, which is the reliable and adequate supply of energy at reasonable prices.

Prior to this unprecedented spike in the price of crude oil, the International Civil Aviation Organization (ICAO) recommended a proactive approach to alternative fuels at the 36<sup>th</sup> Session of its Assembly in 2007 by recognizing "the importance of research and development in fuel efficiency and alternative fuels for aviation that will enable international air transport operations with a lower environmental impact".<sup>1</sup> Two years later, in the summer of 2009, the industry

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<sup>1</sup> International Civil Aviation Organization (ICAO), *Towards a Carbon Neutral and Eventually Carbon Free Industry*, A36WP-85 EX33 (28 August 2007).

announced at the Annual General Meeting the International Air Transport Association (IATA) that the air transport industry would aim for "carbon neutral growth" (CNG) from 2020, with a net reduction in emissions of 50 per cent by 2050 as compared to 2005 emissions. This objective should be reached through steady increases in fuel efficiency, which, in turn, will be achieved with several measures including the application of biofuels in jet engines. Achieving 'CNG 2005' from 2020 through 2030 without biofuels would require fuel efficiency to improve 43 per cent by 2020 from 2005 standards. With biofuels (17 billion liters, 6 per cent of fuel use by 2020), the fuel efficiency required to hit 'CNG 2005' would be substantially less because of lower emissions from fuel burn.

The international airline community has – in light of the need for sustainability – begun to push the research and development of alternative fuels for air transportation. However, while the process of adding up to 50 per cent Fischer-Tropsch synthetic fuel blends from biomass, coal, and gas has recently been approved, the industry has not yet come up with a comprehensive approach as to how to apply and develop alternative fuels for aviation on a large and sustainable scale. Nevertheless, given aviation's dependence on fossil fuel-based jet fuel and the increased international sensitivity towards aviation and climate change, there is little doubt that it is only a question of time for the application of alternative fuels in aviation to be fully introduced. A certification of a 50 per cent blend of hydro-treated renewable synthetic jet fuel is expected by 2012, and a 100 per cent application of the same is expected a few years later. The key question is: are alternative fuels the answer to rising oil prices and can they effectively tackle the challenges of climate change?

## II. AVIATION FUELS

Since its inception one hundred years ago, aviation has depended primarily on fossil fuel-based products to operate aircraft engines. Until well into the 1920's, aircraft engines operated on ordinary straight run motor gasoline.<sup>2</sup> Along with strong growth in aviation activity in the United States during the late 1930's came the development of more adapted aviation gasoline grades, and this resulted in the production of five grades ranging from 80/87 to 110/145.<sup>3</sup> However, the introduction

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<sup>2</sup> George E. Totten, *Fuels and Lubricants Handbook* (West Conshohocken: ASTM International, 2003) at 89.

<sup>3</sup> *Ibid.* Aviation grades generally refer to the amount of lead contained in gasoline, ranging

of the jet engine and the rapidly increasing use of jet fuel resulted in a decline in gasoline consumption in aviation. Subsequently, only two gasoline grades remained: low lead grade 80 and high lead grade 100 gasolines. Finally, the 100 Low Lead grade gasoline (100LL), which was introduced in the 1970's to satisfy the requirements of both low and high octane engines, has become the main aviation fuel for piston engines around the world.<sup>4</sup>

Jet fuel, because of its entirely different combustion requirements, originates from a different point of the refinery process, with a much higher boiling point in the fractional distillation of crude oil. When jet engines were initially developed during the Second World War, the British engines used domestic kerosene, while the German engines operated on a mixture of kerosene and naphtha.<sup>5</sup> For civilian use of jet fuel, the American Society for Testing and Materials (ASTM) issued in 1959 the specification D 1655, which contained three grades. Jet A and A-1 were kerosene-type fuels differing only in freezing point, while Jet B was a blend of kerosene and naphtha that was developed initially for military use. Finally, in an effort to establish one international jet fuel standard, the International Air Transport Association (IATA) issued in 1999 a series of guidelines, which include Jet A, Jet A-1, the Russian TS-1, and Jet B grade.

Jet fuel production takes place during the refinery process of crude oil, which leads to a variety of petroleum products being produced at different boiling points during distillation. The worldwide refinery production output in 2006 was 3,861 million tons (Mt), of which aviation fuels (jet fuel and a much smaller amount of aviation gasoline) represented 6.3 per cent (243 Mt), corresponding to a production of about 5 million barrels per day.<sup>6</sup> While the percentage of jet fuel compared with other refinery products has risen by 50 per cent since 1973, jet fuel production still represents a relatively small fraction of the refinery production output. Well over half of refined petroleum products include the middle distillates (kerosene and diesel), and gasoline products, followed by heavy oils (see table 1 below).

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from 68 octane grade containing no lead to 92 octane with a maximum octane grade of 6 ml tetraethyl lead/gallon. Aviation gasolines are all highly leaded and graded using two numbers, the common grades being 80/87, 100/130, and 115/145 [109,110]. The first number is the Aviation rating (the lean mixture rating), and the second number is the supercharge rating (rich mixture rating).

<sup>4</sup> *Ibid.*

<sup>5</sup> *Ibid.*

<sup>6</sup> International Energy Agency, *Key World Energy Statistics* (Paris: IEA, 2008), at 20.

## 1973 and 2006 shares of refinery production by product

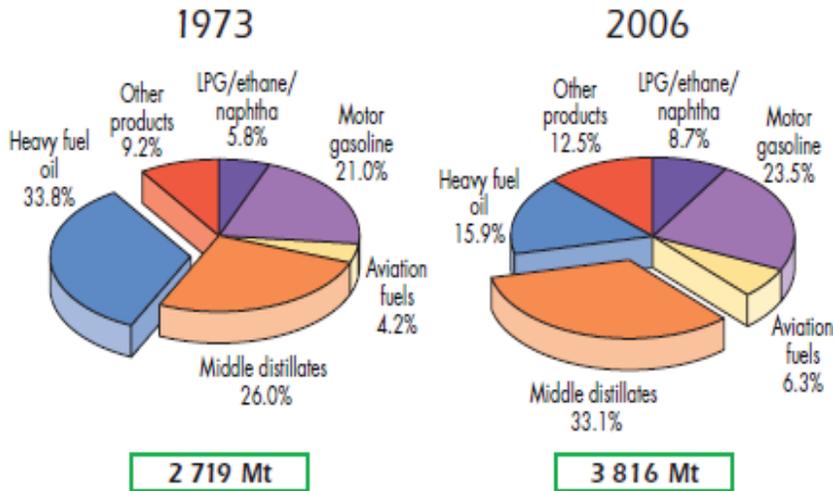


Figure 1 : - World shares of refinery production by product<sup>7</sup>

### III. ALTERNATIVE AVIATION FUELS

The intensified development of alternative fuels for aviation is a relatively recent initiative which resulted from the rising energy cost of crude oil-based products, and increased concern about environmental impacts. However, the idea of producing fuels from alternative sources is not new. During World War II, the Germans successfully developed and produced synthetic fuels from coal using the Fischer-Tropsch process, which converted gasified low-grade coal to 100 octane aviation gasoline as well as to diesel fuel.<sup>8</sup> The method was further enhanced by

<sup>7</sup> *Ibid.*

<sup>8</sup> The Fischer-Tropsch process (or Fischer-Tropsch Synthesis) is a catalyzed chemical reaction in which synthesis gas (syngas), a mixture of carbon monoxide and hydrogen, is converted into various forms of liquid hydrocarbons. The purpose of this process is to produce a synthetic petroleum substitute, typically from coal, natural gas, or biomass, for use as synthetic fuel or synthetic lubrication oil. The original process was invented by the German researchers Franz Fischer and Hans Tropsch, working at the Kaiser Wilhelm Institute in the 1920s. The invention in petroleum-poor but coal-rich Germany in the 1920s was key to producing liquid fuels, and it was used by Germany and Japan during World War II to produce substitute fuels. In more recent history, the South Africa applied an upgraded version of the Fischer-Tropsch method during the apartheid era to produce

South Africa, when it faced difficulties importing sufficient petroleum based products during the economic embargo of the apartheid era. With large coal reserves at its disposal, the South African petrochemical group SASOL continues today to produce diesel and jet fuel from coal by applying the Fischer-Tropsch process.<sup>9</sup>

Generally, alternative fuels need to have a high energy content per unit weight and volume. Ideally, alternative fuels should be able to directly substitute traditional jet fuel by having the same qualities and characteristics. Such alternative fuels, known as "drop-in" replacement fuels, ensure that manufacturers do not have to redesign engines or aircraft, and airports do not have to modify their fuel delivery infrastructure.

#### A. ALTERNATIVE FUELS DERIVED FROM COAL AND NATURAL GAS

Alternative fuels derived from coal, natural gas, or other hydrocarbon feedstocks - synthetic fuels - have existed for several decades. As noted above, the production of jet fuel from coal by applying the Fischer-Tropsch (FT) method has been carried out since World War II, first in Germany and later in South Africa.<sup>10</sup> Below is a description of the production process.

The production of synthetic fuel begins with a feedstock which is a substance rich in carbon that is used as a source material to create synthetic gas. There are three main types of feedstock which can be used for synthetic fuel production: natural gas, coal and biomass. Coal has been used as a feedstock for many years and is currently used in one large-scale synthetic fuel production project by SASOL in South Africa.<sup>11</sup> The resulting products of this process are called coal-to-liquid (CTL) fuels. While several countries with large coal reserves at their disposal see the CTL process as a great opportunity to reduce dependency on crude oil-based products, its biggest drawback is the fact that the CTL

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synthetic oil from coal. Many refinements and improvements have been made, and the term "Fischer-Tropsch" now applies to a wide variety of similar processes. See Kenneth S. Deffeyes, *Beyond Oil: The view from Hubbert's Peak* (New York: Hill and Wang, 2005) at 85 [Deffeyes].

<sup>9</sup> Sasol Ltd. produces about 160,000 barrels of gasoline, diesel fuel, and jet fuel per day, enough to cover 28 per cent of South Africa's needs, without using any crude oil, but by converting coal to these fuels. See generally Stanley Reed & Adam Aston, "What The U.S. Can Learn From Sasol", *Business Week* (27 Feb. 2006).

<sup>10</sup> *Ibid.*

<sup>11</sup> *Ibid.*

process results in very high carbon dioxide (CO<sub>2</sub>) emissions.<sup>12</sup> New carbon capture and storage (CCS) systems are currently insufficiently developed to reduce CO<sub>2</sub> emissions.<sup>13</sup> Nevertheless, the high initial cost of establishing a CTL project, the relatively high energy input required, and the cost of either CO<sub>2</sub> penalties or CCS infrastructure, will most likely continue to pose a hurdle for future wide-scale commercial development of this process.

Another promising feedstock for synthetic fuel production is natural gas. The so called gas-to-liquid (GTL) process is currently applied in Malaysia with natural gas supplies located in areas where it cannot easily or economically be brought to the market. The gas is converted to Ultra Low Sulphur Diesel (ULSD), or Clean Diesel fuel. A similar production process is used at the Oryx GTL plant in Qatar, with a current output of 34,000 barrels per day (b/d).<sup>14</sup> Additional GTL plants are under construction in Qatar and Nigeria. The current worldwide capacity has reached about 50,000 b/d, and upon completion of the two additional plants in Qatar and Nigeria, the capacity for GTL products is expected to reach 200,000 b/d by 2012.<sup>15</sup>

Biomass is the third feedstock for synthetic fuels, and is seen to be promising for the future. The United States Departments of Energy and Agriculture have, for example, estimated that up to 1.3 giga-tons of dry biomass could be sustainably produced for energy production in the U.S., which is theoretically enough to replace 30 per cent of current U.S. petroleum-based fuel consumption.<sup>16</sup> The process of converting biomass to liquid synthetic fuels is called biomass-to-liquid (BTL) process.

The production process of these synthetic fuels involves several

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<sup>12</sup> One barrel of oil produced by CTL results in 0.5 to 0.7 tonnes of CO<sub>2</sub>, which would represent a potential penalty of USD \$ 20 to USD \$30 per barrel. International Energy Agency, *World Energy Outlook 2008* (Paris: IEA. 2008) at 264. [IEA, *WEO 2008*].

<sup>13</sup> Carbon capture and storage is a technical measure to mitigate global warming based on capturing carbon dioxide from large emitting sources and storing it deep underground instead of releasing it into the atmosphere. Despite the fact that CO<sub>2</sub> has been injected into geological formations for enhancing the recovery of traditional crude oil, the long term storage of CO<sub>2</sub> is a relatively untried concept. The first experimental CCS power plant was completed in September 2008 in the German power plant Schwarze Pumpe, and is currently evaluated on its technological feasibility and economic efficiency. International Energy Agency, *Energy Technology Perspectives* (Paris: IEA 2008) at 268.

<sup>14</sup> See generally Shashank Shekhar, "High oil prices can help raise profile of Gas to Liquids" (25 Oct. 2009).

<sup>15</sup> IEA *WEO 2008 supra* note 12 at 263.

<sup>16</sup> See generally Ryan Stockwell, *Transportation Biofuels in the United States*, (St Paul: The Minnesota Project, 2009).

stages. The feedstock is first fed to a gasifier in dry or slurried form. This is followed by a reaction with steam and oxygen at high temperature and pressure in an oxygen starved atmosphere. The resulting product is synthesis gas, which consists primarily of carbon monoxide (CO), hydrogen (about 85 per cent by volume), and smaller quantities of CO<sub>2</sub> and methane.<sup>17</sup> The synthesis gas is then refined in gas treatment facilities which use commercial technologies that are an integral part of the gasification plant, and which remove any remaining impurities. In addition, certain other gases released in the gasification process, such as sulphur and CO<sub>2</sub>, are separated and captured. Thereafter, the purified synthesis feed gas is sent to a liquid fuel synthesis reactor, where hydrogen and carbon monoxide, under heat and pressure and with the aid of cobalt or iron-based catalysts, yield linear hydrocarbons, oxygenated hydrocarbons and reaction water. Finally, the hydrocarbons are cooled successively in a product recovery plant until most components become liquefied. The resulting fuel products burn much more cleanly than petroleum-derived fuels, given the fact that sulphur and other impurities are removed prior to the final production step.<sup>18</sup>

Synthetic fuels for aviation produced by the above-mentioned method have some important physical features which render them not only more environmentally friendly, but also capable of improved operability and efficiency in aircraft engines. Synthetic FT fuels have a higher hydrogen-to-carbon ratio which can result in lower exhaust emissions in certain engines. In addition, these fuels are sulphur free, so exhaust gases do not contain sulphur oxide (SO<sub>x</sub>) emissions. Finally, FT fuels have superior thermal stability as well as excellent low-temperature combustion characteristics. These factors improve efficiency and lower engine temperatures, thus improving engine durability, high-altitude operability and low-temperature engine start-up.<sup>19</sup>

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<sup>17</sup> Inorganic materials in the feedstock, such as ash and metals, are converted into a vitrified material resembling coarse sand, and in certain feedstocks even valuable metals are concentrated and recovered for reuse. Finally, some vitrified material, generally referred to as slag, is recovered for a variety of uses in the construction and building industries. Overall, the process produces very little to no waste, as most products are reused.

<sup>18</sup> James Speight, *Synthetic Fuels Handbook: Properties, Process, and Performance* (New York: McGraw-Hill, 2008) at 22 [Speight].

<sup>19</sup> D. Daggett, O. Hadaller, et al., *Alternative Fuels and Their Potential Impact on Aviation* (Cleveland: NASA, 2006) at 7. [Daggett et al, *Alternative Fuels*].

## B. ALTERNATIVE FUELS DERIVED FROM BIOMASS, HYDROTREATED OILS, AND OTHER PATHWAYS

Alternative fuels derived from biomass - so called biofuels - can be produced from any renewable biological carbon material. The most common biomass feedstocks include plants that absorb carbon dioxide (CO<sub>2</sub>), grow under sunlight, and are rich in sugars and bio-derived oils. Crops that are rich in sugars (e.g., sugar cane or corn (i.e., corn starch)) are processed in order to release their sugar content. The sugar content is then fermented to produce ethanol. Ethanol, a first-generation biofuel, has become an important alternative fuel for ground transportation. In the United States, ethanol production has been subsidized for many years. However, it was the Energy Policy Act of 2005 which mandated its production on a large scale. The Act launched the Renewable Fuels Mandate under which State governments are required to increase the amount of biofuel (usually ethanol) to be mixed with gasoline sold in the United States to 4 billion gallons by 2006, 6.1 billion gallons by 2009 and 7.5 billion gallons by 2012.<sup>20</sup> In turn, ethanol producers enjoy substantial subsidies amounting to about US\$ 5 billion per year. However, the production of first-generation biofuels, which are typically derived from food crops such as rapeseed, sugar cane and corn, have also created some controversy given the fact that valuable agricultural land is used to produce transportation fuels, resulting in increased food prices.<sup>21</sup> In addition, increased water use and the effects of fertilizers and pesticides may create or worsen environmental challenges in some locations.

For aviation, ethanol is a far less suitable alternative source of energy. The main reason is the fact that the relative energy content is much lower than jet fuel. As a result, ethanol requires 64 per cent more storage volume in order to produce the same amount of energy as a given quantity of traditional jet fuel. On aircraft, this would require wings to be 25 per cent larger and this will increase the overall weight of the aircraft by 20 per cent. In addition, ethanol weighs more than jet fuel. Thus in a situation where ethanol instead of jet fuel is used, this would result in a 35 per cent increase in take-off mass, which in turn would require engines with 50 per cent more thrust. These factors combined

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<sup>20</sup> The *Energy Policy Act of 2005* (Pub.L. 109-58) was a bill passed by the United States Congress on 29 July 2005, and signed into law by President George W. Bush on August 8, 2005, at Sandia National Laboratories in Albuquerque, New Mexico. The Act, described by proponents as an attempt to combat growing energy problems, changed US energy policy by providing tax incentives and loan guarantees for energy production of various types.

<sup>21</sup> Elisabeth Rosenthal, "U.N. Says Biofuel Subsidies Raise Food Bill and Hunger" *The New York Times* 7 Oct. 2008).

would result in 15 per cent more energy usage for a typical 500 nautical mile (NM) trip, and a 26 per cent increase on a 3,000 NM flight.<sup>22</sup> Consequently, an aircraft would need to be entirely redesigned to be operated with ethanol-based biofuels. The increased cost of a modified aircraft, as well as the higher energy input requirement makes ethanol a relatively unattractive alternative fuel when compared to other options. The above mentioned first-generation biofuels such as ethanol and biodiesel do not only fail to meet the high performance and safety requirements of jet fuel, but they also face criticism over the use of agricultural land and its consequent effects on food prices, as well as the impact of irrigation, pesticides and fertilizers on the local environment.

The aviation industry is therefore researching so called second- or next- generation biofuels which are derived from non-food crop sources, and which can be grown in various locations, including on non-arable land and salt waters. The three main requirements for second-generation biofuels include: (i) the use of a sustainable feedstock that is not consuming valuable food, land and water resources; (ii) the ability for mass production in various locations around the world, including deserts and salty water; and, (iii) the potential to be produced in large quantities at stable and sustainable prices.<sup>23</sup>

The most promising second-generation biofuels are based on feedstocks that include *Jatropha*, *Camelina*, *Algae*, or *Halophytes*. *Jatropha* is a plant that can be grown in various soil conditions, including many that are not suitable for traditional agricultural cultivation. It produces seeds which contain 30 to 40 per cent of their mass in inedible lipid oil. This oil can be processed into fuel which contains an excellent energy ratio, comparable or even exceeding jet fuel produced from crude oil. The seeds are toxic for humans and animals, and *Jatropha* has very high yields per unit of surface, thus limiting land use when compared to other crops.<sup>24</sup> Several recent successful flight tests have been carried out using a blend of *Jatropha* and traditional jet fuel.<sup>25</sup>

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<sup>22</sup> D. Daggett et al., *Alternative Fuels*, *supra* note 19 at 6.

<sup>23</sup> See generally James I. Hileman, et al., *The Feasibility and Potential Environmental Benefits of Alternative Fuels for Commercial Aviation*, online: MIT <<http://web.mit.edu/aeroastro/partner/reports/proj17/alt.%20Fuels-icas-2008.pdf>>. Presented at the 26th International Congress of the Aeronautical Sciences (2008).

<sup>24</sup> Compared to traditional soy, which can produce 60 gallons to 100 gallons of oil per hectare (2.5 acres) each year, *Jatropha*'s seeds yield roughly 600 gallons of oil for the same surface area. See generally Greg T. Spielberg, "Alternative Jet Fuel: The *Jatropha* Plant?", *BusinessWeek* (7 Feb. 2009).

<sup>25</sup> As of early 2009, Air New Zealand, Japan Airlines, and Continental Airlines had conducted such test flights. *Ibid.*

Camelina has similar characteristics to Jatropha. Camelina is typically grown in moderate climates such as the Northern plains of the US, and it has its origins in Europe and Central Asia. Camelina was often chosen as a rotational crop with wheat and other cereal crops, during a season when the land would have been unplanted, but it can be grown on even less fertile land. Like Jatropha, Camelina is a crop that produces a high lipid oil content which can be extracted and converted to biofuel for aviation use. In addition, the waste material from oil extraction can be used as poultry feed.<sup>26</sup> Camelina was also flight tested, albeit in a blend with other alternative fuels (see Figure 2 below).

Algae are considered the most promising feedstock for the large-scale production of biofuel for aviation. Algae are microscopic plants that grow suspended in water and undergo a photosynthesis process which converts water, CO<sub>2</sub>, and sunlight into oxygen (O<sub>2</sub>) and biomass. Oil extracted from algae has an excellent energy content which, in most cases, exceeds that of other biofuels. Even more promising is the fact that algae can be grown in polluted or salty water, as well as in inhospitable locations such as deserts. However, another most important fact concerns the speed with which algae can be grown. This results in a production of up to 15 times more oil per given surface than any other biofuel crop.<sup>27</sup>

Halophytes are plants which tolerate or even require sodium chloride concentrations in the soil water they absorb. They typically consist of salt marsh grasses or other saline habitat species, and can be cultivated in salty water or areas that are affected by salty seawater.<sup>28</sup> In the fall of 2008, Boeing launched the Sustainable Aviation Fuel Users Group, which is an airline-led industry working group that aims at accelerating the commercialization and availability of sustainable biofuels. The group recently announced that, in addition to previously concluded research projects on algae and Jatropha Curcus, the group will also launch a sustainability assessment of halophytes.<sup>29</sup>

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<sup>26</sup> See generally Ryan M. Lafferty, et al., *Spring Camelina Production Guide* (Golden: Blue Sun Agriculture Research & Development, 2009).

<sup>27</sup> See generally Toon van Harmelen & Hans Oonk, *Microalgae Biofixation Process* (Appeldoorn: TNO, 2006).

<sup>28</sup> See generally Abdullah Jaradat, "Halophytes for Sustainable Biosaline Farming Systems in the Middle East" in A.A. Alshardan ed., *Desertification for the third millennium* (Rotterdam: A.A. Balkema/Swets & Zeitlinger, 2003).

<sup>29</sup> Boeing, News Release, "Boeing and Leading Airlines Announce New Members Added to Sustainable Aviation Fuel Users Group" (13 Jul. 2009), online: Boeing

Finally, the potential replacement of aviation gasoline (100LL) with biofuel could be achieved by processing Switchgrass into a high-octane fuel by a recently patented proprietary process.<sup>30</sup> The patent describes a process where plant material (cellulosic biomass from e.g., switchgrass) is treated with an acid spray to break down the complex sugar compounds into a mass that bacteria can chew on to ferment into oxygenates. However, one of the major challenges is that the fermentation process produces butanol and acetone. While butanol would be sold separately at market price, acetone would serve as a feedstock to produce isopentane and mesitylene. After the separation of other poorer byproducts, these two ingredients would be combined to form a high-octane aviation fuel. Nevertheless, while the production of 100LL from Switchgrass seems promising, it has not yet been produced in a pilot plant to be tested in aviation piston engines. One major challenge will be to demonstrate that 100LL can be produced at an economic cost below today's wholesale price. Given the relatively high investment cost compared to the relatively small market for 100LL, it will primarily depend on the rising cost of crude oil pushing the price for traditional 100LL higher.<sup>31</sup>

The process of converting biofuels from feedstock to jet fuel consists of extracting the bio-oil from the feedstock, and refining this oil to bio jet fuel. There are basically two methods for processing the biomass feedstock, the biochemical method and the thermochemical method. In the first method, organisms or enzymes convert biomass into the oils and chemicals, and in the second the biomass is heated until it transforms into the final product. Examples of the latter method include direct liquefaction, gasification and the Fischer Tropsch method.<sup>32</sup> The resulting oils, or even animal fats, can be converted into diesel or jet fuel by a process called hydrotreating. During this process, hydrogen is reacted with the oil and it raises the heating value of the fuel through a chemical reaction.<sup>33</sup> Finally, most extracted bio-fuels have to be distilled using a traditional refinery method in order to yield the specified final product.

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<<http://boeing.mediaroom.com/index.php?s=43&item=744>>.

<sup>30</sup> Paul Bertorelli, "Swift AvFuel: Too Good To Be True?", *The Aviation Consumer* (Apr. 2009) 12.

<sup>31</sup> *Ibid.*, at 32.

<sup>32</sup> International Air Transport Association (IATA), *IATA 2007 Report on Alternative Fuels* (Montreal: IATA, 2008) at 54 [*IATA 2007 Report on Alternative Fuels*].

<sup>33</sup> During hydrotreating the olefinic bonds and carbon-oxygen bonds are reduced, which results in the creation of water. *Ibid.*, at 56.

The airline industry has shown great interest in testing and demonstrating the feasibility of using alternative fuels. As mentioned previously, several flight-tests have recently been conducted with blends of biofuel, all of which have been successful. Some of the biofuels tested even showed higher energy content and thus lower fuel consumption, and cleaner combustion as compared to kerosene (see Figure 2).<sup>34</sup>

Carrier	Aircraft	Engine	Fuel supplier	Date	Biofuel
Virgin Atlantic	B747-400	GE CF6	Imperium Renewables	23 Feb 2008	20% Coconut & Babassu oil (one engine)
Air New Zealand	B747-400	Rolls-Royce RB211	UOP, Terasol	30 Dec 2008	50% Jatropha (one engine)
Continental Airlines	B737-800	GE/Snecma CFM56	UOP, Sapphire	7 Jan 2009	47% Jatropha, 3% Algae (one engine)
Japan Air Lines	B747-300	P&W JT9D	UOP, Sustainable Oils	30 Jan 2009	42% Camelina, 8% Jatropha, 0.5% Algae (one engine)

Figure 2- Recent flight tests with blends of biofuels<sup>35</sup>

### C. OTHER ALTERNATIVE FUELS

Hydrogen fuel (H<sub>2</sub>) is often mentioned in popular discussions and the media as a very clean and environmentally friendly fuel for the transportation sector, given the fact that its combustion emits no carbon dioxide (CO<sub>2</sub>).<sup>36</sup> However, the discussions often omit the fact that production of hydrogen requires a substantial input of energy such as electrical power, and this energy must be generated from nuclear reactors or fossil fuel driven electricity turbines, or any other electricity power source. As such, hydrogen is a means of storage and carriage of energy, but not a source.

For aviation use, hydrogen poses a set of significant challenges. Due to the fact that the volumetric heat of its combustion is poor, airplane design would require substantial modifications and compromises.<sup>37</sup> For example, due to the fact that Hydrogen Fuel (H<sub>2</sub>) or

<sup>34</sup> IATA, *Framework for Implementation of Sustainable Alternative Fuels in Aviation*, Working Paper presented at the ICAO Conference On Aviation And Alternative Fuels, Rio de Janeiro 18-20 November, 2009, CAAF/09 WP018.

<sup>35</sup> *Ibid.*, at 3.

<sup>36</sup> See generally Jeremy Rifkin, *The Hydrogen Economy: The creation of the worldwide energy web and the redistribution of power on earth* (New York: JP Tacher/Putnam, 2003).

<sup>37</sup> Volumetric heat of combustion refers to the heat of combustion per unit volume of fuel.

Methane (LH<sub>2</sub>) can only be used in its liquid cryogenic form, insulation requirements and pressurization issues would require storage of the fuel in the main fuselage and not in the wings as with conventional jet fuel. In addition, the heavy cryogenic fuel tanks increase the basic weight of an aircraft by an estimated 13 per cent above that of kerosene-fueled aircraft.<sup>38</sup> However, the lighter fuel reduces take-off weight substantially. Subsequently, engines and their weight could be downsized, and the wings slightly reduced. Nevertheless, on a typical short mission of 500 NM, a hydrogen aircraft would require 28 per cent more energy, but on long missions (e.g. 3000 NM) the drawbacks of the heavy tanks are almost compensated by the lighter fuel weight.<sup>39</sup> All of these operational factors would entail the development of new aircraft designs, which need to be extensively tested before certification can take place.

A lesser-known alternative fuel that can be used in combustion engines of the transportation sector is Ammonia. Ammonia, a variation of hydrogen fuel, is composed of one atom of nitrogen and three atoms of hydrogen (NH<sub>3</sub>). It has similar characteristics to propane, which is a gas under standard temperatures and pressures, but becomes liquid at higher pressure. The fact that ammonia stores more hydrogen at moderate pressure when in liquid form makes it much more practical means for the storage and transportation of hydrogen. In addition, ammonia can be burned directly in internal combustion engines.<sup>40</sup> Industrial production of ammonia dates back to the First World War, after Fritz Haber and Carl Bosch patented a process to produce ammonia from the nitrogen in the air. Industrial production of ammonia began during the First World War in Germany. It initially served as an ingredient for explosives, and later for a variety of applications including transportation fuel. Despite the fact that ammonia in liquid form was even used as fuel in the rocket airplane X-15, it is not suitable for aviation without major aircraft modifications.<sup>41</sup> The reason is that the caloric value of ammonia is only 22.5 MJ/kg, which is about half that of diesel. Replacing jet fuel with ammonia would therefore result in about twice

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The greater the heat, the higher the energy content of a given fuel. Aircraft, which are weight critical, need to operate with fuels of high volumetric heat of combustion.

<sup>38</sup> Daggett et al, *Alternative Fuels*, supra note 19 at 6.

<sup>39</sup> *Ibid.*

<sup>40</sup> During World War II when diesel fuel was short in many European countries, municipal buses were operated in Belgium using a mixture of coal gas and ammonia. See generally Joe McClintock & John Holbrook, "Alternative Fuels: Taking a Second Look at Ammonia" National Defense Magazine (2008).

<sup>41</sup> Wendell H. Stillwell, X-15 Research Results (Scientific and Technical Information Office National Aeronautics and Space Administration ed., 1964). Online: NASA <<http://history.nasa.gov/SP-60/cover.html>>.

the traditional consumption, thus reducing the range of an aircraft by half.<sup>42</sup>

Other potential alternative fuels or sources of energy for aviation are electric and nuclear power. Electric-powered aircraft run on electric motors rather than internal combustion engines. The electricity is provided from fuel cells, solar cells, ultracapacitors, power beaming, or batteries.<sup>43</sup> However, the main disadvantage of electric aircraft is decreased range due to substantially increased weight of the systems that will generate or store the electricity. The range can be increased by adding solar cells to the aircraft's surface, but the surface area must be large compared to its weight for the cells to have a significant impact on range. Nevertheless, the Boeing Research and Technology Center announced in 2003 that it was developing a demonstrator airplane project aimed at exploring the use of fuel cell technology for future aerospace applications. The objective of the project is to develop and flight-demonstrate an electric-motor-driven airplane powered by fuel cells, in order to evaluate the potential application of fuel cell technology, which is cleaner, quieter and more efficient than current gas turbine technology for future commercial airplane applications.<sup>44</sup>

The concept of nuclear aircraft, where an aircraft uses nuclear energy for propulsion, was researched during the Cold War by the United States and the Soviet Union. The objective was to keep nuclear bombers in the air for extremely long periods of time, which was an important tactic for nuclear deterrence. However neither country created any nuclear aircraft in production numbers. The major challenge that was never adequately solved was the design problem created by the need for heavy shielding to protect the crew from radiation exposure. Nevertheless, Ian Poll, Professor of Aerospace Engineering at Cranfield

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<sup>42</sup> *Ibid.*, note 41

<sup>43</sup> Ultracapacitors present a new way of storing electric energy that are far more efficient than chemical batteries. Instead of storing energy electrochemically, it stores it in an electric field. Ultracapacitors have multiple advantages over conventional batteries, such as a lifetime of over 10 years, resistance to changes in temperature, shock, overcharging, and discharging efficiency. Further, they require less maintenance than conventional batteries and pose less risk to the environment when disposed because they lack toxic chemicals. Raymond A. Sutula & Kenneth L. Heitner, *Ultracapacitors to Find Use in Hybrid Powertrains & Transportation for the 21st Century*, online: United State Department of Energy <[http://www1.eere.energy.gov/vehiclesandfuels/pdfs/success/ultracapacitors\\_5\\_01.pdf](http://www1.eere.energy.gov/vehiclesandfuels/pdfs/success/ultracapacitors_5_01.pdf)>.

<sup>44</sup> Boeing Research and Technology Center, News Release, "Boeing Announces Partners for Fuel Cell Demonstrator Airplane Project" (11 Jul. 2003), online: Boeing <[http://www.boeing.com/news/releases/2003/q3/nr\\_030711p.html](http://www.boeing.com/news/releases/2003/q3/nr_030711p.html)>.

University, and head of technology for the Government-funded Omega project, is proposing a major research program to help the aviation industry convert from fossil fuels to nuclear energy, stating that nuclear-powered aircraft may one day transport passengers.<sup>45</sup>

## IV. THE CASE FOR ALTERNATIVE FUELS IN AVIATION

### A. ENERGY SECURITY

The unprecedented oil price spike of July 2008 - during which the price of crude oil reached US\$ 147 per barrel - had a devastating effect on the global economy at large and on the air transport industry in particular. Fuel costs had been rising for five years, increasing from a traditional 15 per cent of airline operational costs to over 40 per cent for low cost carriers. As many carriers were unable to fully pass on the cost of fuel to passengers, and given the global economic recession that followed, the industry losses for 2008 amounted to well over US\$ 8 billion. Despite the subsequent rapid fall in the price of crude oil, airline losses continued to mount in 2009 and were expected to reach US\$ 11 billion.<sup>46</sup> On the search for the causes of the oil spike, speculation was quickly seen as the major cause, and politicians raised the issue of controlling oil markets. However, several other factors including low inventories, supply disruptions, low refining capacity, and especially rising demand from emerging countries (mainly China and India), were other significant factors that contributed to the spike.<sup>47</sup> In addition to searching for the causes of the spike, the discussion on the long-term availability of crude oil started to regain momentum. Two schools of thought can be identified, which, for the purpose of this article, are referred to as: peak of production and peak of supply.

Peak of supply refers to a potential leveling off in oil production due to the fact that investments in infrastructure for production have been inadequate, and production cannot be increased or even declines in some cases.<sup>48</sup> Some experts predict a so called "oil supply crunch" when demand for oil exceeds current supply of oil produced not due to below-

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<sup>45</sup> Ben Webster, "Nuclear-powered passenger aircraft 'to transport millions' says expert" Times of London (27 Oct. 2008), online: Times of London <[www.timesonline.co.uk/tol/news/environment/article5024190.ece](http://www.timesonline.co.uk/tol/news/environment/article5024190.ece)>.

<sup>46</sup> Kaveri Niththyananthan, *IATA: Sees \$5.6B Net Loss For Airline Industry In '10*, The Wall Street Journal 2009.

<sup>47</sup> Charles E. Schlumberger, "The Oil Price Spike of 2008" (2009) XXIV Ann. Air & Sp. L. 114.

<sup>48</sup> *Ibid.*, at 132 [Schlumberger, The Oil Price Spike of 2008].

ground resource constraints, but due to inadequate investments by international oil companies (IOCs) and national oil companies (NOCs).<sup>49</sup> Such an oil crunch may result in several years of very high oil prices before capacity meets demand again. The International Energy Agency (IEA) outlined the massive investments needed to maintain and to develop oil production to meet the expected demand in its World Energy Outlook for 2008 (WEO 2008). The IEA estimated that investments required would exceed US\$ 26 trillion (in 2007 dollars) between 2007 and 2030 in the energy sector worldwide, of which 48 per cent will be needed in the oil and gas sector.<sup>50</sup> In its World Energy Outlook for 2009 (WEO 2009), the IEA raised concerns that the upstream oil and gas investment budgets have been reduced in 2009 by about 19 per cent which will have far reaching consequences, potentially leading to a new surge in prices in the coming years.<sup>51</sup>

The second, even more challenging theory is based on the fact that crude oil is fossil fuel-based non-renewable energy, which will eventually reach a point where its extraction is no longer economically feasible. Peak of supply, or so called "Peak Oil", refers to the point in time when the maximum rate of global petroleum extraction is reached. Thereafter, global oil production will flatten out and eventually enter into a stage of terminal decline. Many oil producing countries around the world have already reached this point (United States, Mexico, Indonesia, United Kingdom, Norway, and Yemen), and only a few countries (Saudi Arabia, Iraq, Kuwait, Brazil, and Kazakhstan) are expected to be able to significantly increase oil production in the future.<sup>52</sup> Most experts who subscribe to this theory predict that the peak of conventional oil (easily accessible oil in fields on the surface or in shallow waters) production will occur within the next decade.<sup>53</sup> Critics of the peak oil theory, however, point out that it hinges primarily on the peaking of known resources of primarily conventional oil, while it ignores the huge potential of non-conventional resources. Nevertheless, non-conventional oil production comes at a much higher cost, and it faces, in some cases, operational or environmental limits. Crude oil production from oil sands

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<sup>49</sup> Paul Stevens, *The Coming Oil Supply Crunch* (London: Chatham House, 2008) at 9.

<sup>50</sup> IEA WEO 2008, *supra* note 12 at 39.

<sup>51</sup> International Energy Agency, *World Energy Outlook 2009* (Paris: IEA, 2009) at 43 [IEA, WEO 2009].

<sup>52</sup> Schlumberger, Oil Price Spike of 2008, *supra* note 47 at 122.

<sup>53</sup> Fatih Birol, chief economist for the IEA, recently declared that if no big new discoveries are made and that if oil demand continues to grow, "the output of conventional oil will peak in 2020." The Economist, 2020 vision "The IEA puts a date on peak oil production" Economist (10 Dec. 2009).

provides a good example.<sup>54</sup>

It is generally agreed that a temporary peak in production or a permanent peak of conventional oil production would trigger another spike in oil prices, which would be followed by a sharp decline in global economic activity unless alternative sources of energy are found or developed in sufficient quality and availability. The concept of energy security - in this article referred to as a reliable, adequate and uninterrupted supply of energy at reasonable prices - will increasingly become a dominating argument. This is especially true for the airline industry which is very vulnerable to oil price spikes or supply disruptions. Given the fact that no other sector has so little alternative sources of energy, it must be in the air transportation sector's prime interest to move towards the introduction of alternative fuels.

Nevertheless, the aviation industry still does not seem overly concerned about energy security and its dependence on crude oil based jet fuel. IATA, for example, states that peak oil has not yet been reached, and that current oil reserves are high enough to supply the world for the next 42 years, based on current consumption.<sup>55</sup> In spite of the foregoing, IATA has acknowledged in its recent report on alternative fuels that alternative fuel "is an imminent part of the aviation industry's future", and that peak oil is approaching.<sup>56</sup> A similar conclusion was reached in August 2009 by the European Civil Aviation Conference during its 58<sup>th</sup> Special Meeting of Directors General. The meeting agreed upon a report on the economic and environmental implications for aviation of ensuring continuity of fuel supply, concluding that the world was far from running short of oil, and that there were abundant reserves of crude oil around the globe.<sup>57</sup> However, it did recognize that investment in upstream and refinery infrastructure was low due to the global economic crisis, and this could lead to rising fuel cost.

## B. ENVIRONMENTAL ASPECTS

Aviation has always caused environmental concerns. Initially the focus was on noise.<sup>58</sup> However, in recent years, it is the debate on climate

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<sup>54</sup> Schlumberger, *Oil Price Spike of 2008*, *supra* note 47 at 140.

<sup>55</sup> IATA, *2008 Report on Alternative Fuels*, (Montreal: IATA, 2009) at 5.

<sup>56</sup> *Ibid.* Foreword at 1.

<sup>57</sup> European Civil Aviation Conference (ECAC), *Outline Report on the Fuel Security Task Force* (2009) at 21.

<sup>58</sup> Ruwantissa Abeyratne, *Aviation and the Environment* (Baltimore: Publish America, 2009) at 188.

change and the emission of greenhouse gases (GHG) which has become indissociable from aviation, with the sector being disproportionately targeted when its emissions are compared to those of other modes of surface transportation.<sup>59</sup> The main reason is the fact that air transportation has grown much faster than any other mode of transportation in recent years, and is likely to continue growing rapidly in the future. Certainly, air transportation has become much more fuel efficient, as airlines have had to respond to rapidly increasing fuel cost. Nevertheless, its strong growth rate of 5 per cent over the past 20 years, and its expected further growth of 4 to 5 per cent provide grounds for renewed environmental concerns.<sup>60</sup>

According to the IEA, aviation used 246 Mtoe of energy in 2006, which represents 11 per cent of all transport energy used.<sup>61</sup> Aviation's energy usage is expected to triple to about 750 Mtoe by 2050 according to the IEA's baseline scenario - resulting in aviation accounting for 19 per cent of all energy used. Aviation emissions of GHG included 810 million tons of CO<sub>2</sub> in 2006, which represents 12 per cent of all transport CO<sub>2</sub> emissions. The Organization for Economic Cooperation and Development (OECD) forecasts that CO<sub>2</sub> emission from air transport will grow to 23 per cent of transportation CO<sub>2</sub> emissions by 2050 if no measures are taken.<sup>62</sup> Finally, research suggests that aviation's overall impact on global warming is far greater due to its emissions of other GHGs such as NO<sub>x</sub>, CH<sub>4</sub> and H<sub>2</sub>O, among others, as well as various differential effects of emissions at different altitudes.<sup>63</sup> The statement is based on research that increasingly indicates that the impact on the climate of NO<sub>x</sub> and water vapor is significant, especially at high altitudes of the stratosphere above 10 km of the earth's surface due to its radiative forcing, which is considered to have 2 to 4 times the effect of CO<sub>2</sub> alone.<sup>64</sup>

Given the public concerns about this, which suggests that air transportation may become a highly significant emitter of GHG,

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<sup>59</sup> The Bishop of London declared it sinful for people to contribute to climate change by flying on holiday. Jonathan Leake, "It's a Sin to Fly, says Church" *The Sunday Times* (23 Jul. 2006).

<sup>60</sup> Boeing, *Current Market Outlook 2009 -2028* (Seattle: Boeing, 2009) at 4.

<sup>61</sup> International Energy Agency, *Transport, Energy and CO<sub>2</sub>* (Paris: IEA, 2009) at 313.

<sup>62</sup> Anming Zhang, et al., "Air Transport, Global Warming and the Environment" (2009) 15:1 *Transp. Research Part D* 1, 1.

<sup>63</sup> A Primer, *Aviation & Emissions* (Washington D.C.: FAA Office of Environment and Energy, 2005) at 9.

<sup>64</sup> Radiative forcing is "an externally measured imposed perturbation in the radiative energy budget of the Earth's climate system", which is estimated to have 2 to 4 times the effects of CO<sub>2</sub>.

regulators around the world are under pressure to regulate the sector. Several multilateral and unilateral measures have been announced or are in preparation. The Kyoto Protocol, which was ratified by over 180 countries, only addresses international aviation.<sup>65</sup> The Protocol calls upon the International Civil Aviation Organization (ICAO) to develop mechanisms with its Contracting States to limit and reduce GHG emissions from international flights. ICAO had already worked on various technological and operational measures to reduce emissions, but it did not pursue the development of new global legal and market-based mechanisms to reduce GHG emissions.<sup>66</sup> Instead, in 2004 ICAO developed a template for voluntary agreements between aviation industries and public organizations, and collected and shared information on voluntary actions to reduce aviation GHG emissions by Contracting States and various stakeholders in 2007. At the 36th session of the ICAO Assembly held in September 2007, the Committee on Aviation Environmental Protection presented a report on voluntary emissions trading for aviation. This was adopted by the Assembly only as recommended guidelines.<sup>67</sup> Nevertheless, the 36th Session of the Assembly requested the ICAO Council to form a Group on International Aviation and Climate Change (GIACC) which would be mandated to develop concrete proposals to the United Nations Framework Convention on Climate Change (UNFCCC). The Assembly also requested that ICAO convene a High-level Meeting at which GIACC would present its recommendations for consideration.<sup>68</sup>

The High-level Meeting on International Aviation and Climate Change was held in Montreal, Canada, from 7 to 9 October 2009. GIACC recommended a global goal of 2 per cent annual improvement in fuel efficiency of the international civil aviation in-service fleet, which would

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<sup>65</sup> The Kyoto Protocol is a protocol to the United Nations Framework Convention on Climate Change, an international environmental treaty concluded at the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil, from 3–14 June 1992. The treaty intends to achieve a "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." See *Protocol to the United Nations Framework on Climate Change*, 11 December 1997, 1869 U.N.T.S. 299 (entered into force 16 February 2005) [Kyoto Protocol].

<sup>66</sup> ICAO, *Report by the Council on Market-based Measures regarding Aircraft Engine Emissions*, A35-WP/76, (2004).

<sup>67</sup> The guidelines urge the adoption of voluntary emissions trading schemes that take the form of a Memorandum of Understanding entered into by government and industry. See ICAO Air Transport Bureau *Template and Guidance on Voluntary Measures*, online: ICAO <[http://www.icao.int/icao/en/env/Caep\\_Template.pdf](http://www.icao.int/icao/en/env/Caep_Template.pdf)>.

<sup>68</sup> ICAO, *Update on the Continuing Progress of ICAO on International Aviation and Climate Change* (Bonn: ICAO, 2009) at 1.

lead to a cumulative improvement of 13 per cent in the short-term (2010 to 2012), 26 per cent in the medium-term (2013 to 2020), and about 60 per cent in the long-term (2021 to 2050), all calculated from a 2005 base level. It also proposed establishing concrete carbon neutral growth objectives for the medium term and carbon emissions reduction goals for the long term, and presented a project to develop a framework for market-based measures in international aviation.<sup>69</sup> However, the meeting did not reach consensus on the proposed measures, but ended with a declaration that went beyond the airline industries' self-proclaimed goal of a 1.5 per cent fuel efficiency gain per annum. It set a goal of achieving an annual average fuel efficiency improvement of 2 per cent until 2020, with the aspiration to do the same in the long term, from 2021 to 2050. In addition, the declaration announced plans to create a market-based mechanism to lower emissions and a comprehensive reporting system to track emissions, which should be reported to the UNFCCC. However, today, the declaration remains in draft form.<sup>70</sup>

Next to fuel efficiency improvements, ICAO further encouraged wider discussions on the development of alternative fuel technologies and promotion of the use of sustainable alternative fuels, including biofuels, in aviation.<sup>71</sup> It also invited States to participate in the Conference on Aviation and Alternative Fuels in Rio de Janeiro in November 2009 (CAAF2009). CAAF2009, which 114 States and International Organizations attended, featured 39 presentations from policy makers, regulatory and certification authorities, international airlines, NGOs, and aerospace and fuel industry representatives. The Conference discussed options, challenges for the development and deployment, as well as initiatives for promotion and international cooperation in alternative aviation fuel development.<sup>72</sup> It also endorsed the use of alternative fuels for aviation, with a special focus on drop-in fuels in the short to medium-term as an important means of reducing aviation emissions. The Conference further declared and affirmed the commitment of States and industry to developing and using sustainable alternative fuels with the objective to reduce aviation's emissions. The Conference finally developed an ICAO Global Framework for Aviation Alternative Fuels (GFAAF) with the objective of facilitating the global promotion and harmonization of initiatives which encourage and

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<sup>69</sup> ICAO, *Market Based Instruments and Climate Change, Proposals for strategies and measures to achieve emissions reductions* HLM-ENV/09-WP/8, (2009).

<sup>70</sup> ICAO, *Elements for a ICAO Position at COP15*, HLM-ENV/09-WP/12, (2009), online: ICAO, <[http://www.icao.int/Highlevel2009/Docs/HLMENV\\_WP012-Rev\\_2\\_en.pdf](http://www.icao.int/Highlevel2009/Docs/HLMENV_WP012-Rev_2_en.pdf)>.

<sup>71</sup> *Ibid.* at A-2.

<sup>72</sup> Presentations available online: ICAO <<http://www.icao.int/waaf2009/>>.

support the development of sustainable alternative fuels for aviation.<sup>73</sup>

The first concrete multilateral measures to address aviation as an emitter of GHG were prepared by the European Commission, which issued in November 2008 its Directive number 2008/101/EC. Under this directive, all flights that arrive at, or depart from, airports within the European Union (EU) will be subject to market-based measures to reduce or compensate for the emission of GHG. Carriers will be given allowances which will be based on their past levels of emissions. In 2012, the number of allowances will equal 97 per cent of historical CO<sub>2</sub>-emissions, and in 2013, the number of allowances will be reduced to 95 per cent of historical emissions. Further reductions will be decided for each subsequent period. Starting from 2013, 15 per cent of total allowances will be auctioned to carriers, three per cent will be reserved for new entrant airlines, while incumbents will receive 82% of permits gratuitously, based on historical operations. The percentage of permits auctioned may be increased as part of the general review of this Directive.<sup>74</sup>

Given these realities, IATA announced at its Annual General Meeting in June 2009 that the industry is committed to significantly reducing CO<sub>2</sub> emissions.<sup>75</sup> IATA, which has over 230 member airlines, represents 93 per cent of scheduled international air traffic and includes all of the world's leading passenger and cargo carriers, declared that it will implement a three-step approach: (i) a 1.5 per cent average annual improvement in fuel efficiency from 2009 to 2020; (ii) carbon-neutral growth after 2020; and, (iii) a 50 per cent absolute reduction in CO<sub>2</sub> emissions by 2050 compared to 2005 levels.<sup>76</sup> The declared pathway to reach these ambitious goals is based on IATA's Four Pillar Strategy. The first pillar includes technological measures such as weight reduction of aircraft, a global airline fleet renewal program, new aircraft design, and the introduction of alternative fuels. The second pillar aims at improving operations of air traffic management, as well as in-flight planning and system upgrades, all leading to reductions in fuel consumption.<sup>77</sup> The third pillar aims at improving the infrastructure of air traffic services and airports with the same aim of reducing emission by fuel burn. Finally,

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<sup>73</sup> ICAO, *ICAO's Response to Global Challenges* (Montreal: ICAO, 2009) at 10.

<sup>74</sup> EC, *Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the community 2009* O.J. L. 8/3.

<sup>75</sup> IATA *Annual Report 2009* (Montreal: IATA, 2009) at 32.

<sup>76</sup> *Supra* note 34 at 1.

<sup>77</sup> See IEA *WEO 2009*, *supra* note 51 at 278

the forth pillar concerns economic measures which include instruments to provide incentives to improve efficiency and reduce emissions, such as emissions trading and carbon offsets.<sup>78</sup>

As stated in IATA's first pillar, the use of alternative fuels is a measure to reduce energy use and thereby CO<sub>2</sub> emissions. Not all alternative fuels emit less CO<sub>2</sub> than jet fuel. In fact, only biofuels and liquid hydrogen produced from water and nuclear power have lower CO<sub>2</sub> emissions than jet fuel.<sup>79</sup> In addition, research indicates that alternative fuels need to have overall low life-cycle GHG emissions to significantly reduce the effects of climate change.<sup>80</sup> Under this consideration, the most suitable alternative fuels are advanced biofuels with very low life-cycle GHG emissions, such as jet fuel produced from (i) biomass by applying the Fischer-Tropsch (FT) method, (ii) from Jatropha, from soy or palm oil, or (iii) from algae. However, the overall life-cycle reduction effect of CO<sub>2</sub> emissions of hydro-processed renewable jet fuel (HRJ) from palm and soy oil depends primarily on the degree of land use change, which may even result in far higher CO<sub>2</sub> emissions than jet fuel produced from crude oil.<sup>81</sup> The overall expected reduction in emissions that contribute to global climate change is estimated to range from 10 to 50 per cent for a combination of FT and HRJ fuels, if the appropriate renewable feedstock is used. A full 100 per cent life cycle GHG reduction could, however, be achieved with halophyte-based biofuels, although this would require effective methods of soil carbon sequestration.<sup>82</sup>

IATA's objective of achieving carbon-neutral growth after 2020 depends on several measures. The effect of introducing biofuels

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<sup>78</sup> IATA The IATA Technology Roadmap Report (Geneva: IATA, 2009) at 12.

<sup>79</sup> David L. Daggett, et al., *Alternate Fuels for use in Commercial Aircraft* (Seattle: Boeing, 2007) at 4.

<sup>80</sup> The life-cycle analysis of GHG emissions of a given fuel examines, from production to combustion, all of the positive and negative effects on the generation of GHG. The GHG emissions of traditional jet fuel include (i) the extraction of fossil resource from domestic and foreign sources (crude oil), (ii) the initial pipeline, tanker, rail, and truck transport to the refinery, (iii) the refinement to jet fuel, (iv) pipeline transportation, blending with additives, transport to bulk storage, and loading into aircraft fuel tank, and finally (v) the combustion, which currently only considers CO<sub>2</sub>. The life-cycle analysis of biofuels require evaluation of the land use effects, which include farming energy and fertilizers, water utilization, land use changes, and CO<sub>2</sub> extracted from atmosphere to grow the biomass feedstock. See generally Mark A. Delucchi, *Lifecycle Analyses of Biofuels* (Davis: University of California, 2006).

<sup>81</sup> *Infra* note 95.

<sup>82</sup> ICAO, *Comparison of Life Cycle GHG Emissions from Selected Alternative Jet Fuels* CAAF09-IP/6 (presented by the United States to Conference on Aviation and Alternative Fuels) at 6.

contributes to this reduction, but it is seen as far less important than fleet renewal and improved load factors. In fact, IATA estimates the reduction of CO<sub>2</sub> emissions by fleet renewal at 600 million tons by 2030, while biofuels would reduce these emissions by 150 million tons. Other measures, such as operational improvements, more adequate infrastructure, and improved engine and airframe technologies would contribute a reduction of another 70 million tons.<sup>83</sup> In other words, biofuel will be an important element for reducing CO<sub>2</sub> emissions, but other measures have a far greater impact.

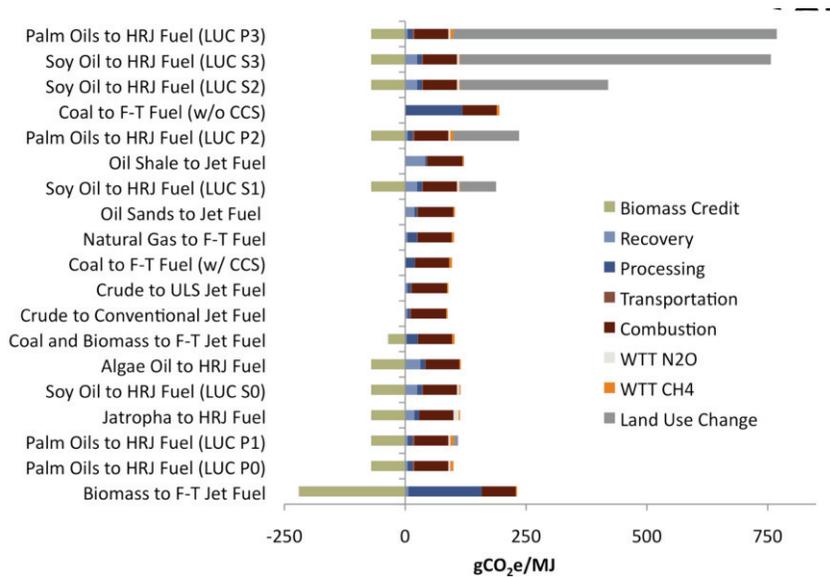


Figure 3 - Life-cycle analysis of GHG of various types of jet fuel production<sup>84</sup>

## V. CHALLENGES FOR ALTERNATIVE FUELS

### A. CERTIFICATION OF ALTERNATIVE FUELS

Aircraft and all of their major modifications are typically certified by a regulatory authority, such as the US Federal Aviation Administration (FAA) or the European Aviation Safety Agency (EASA). Aviation fuels and lubricants are not certified by these institutions.

<sup>83</sup> IATA, *The Economics of Carbon Neutral Growth* (Montreal; Geneva: IATA, 2009) at 1.

<sup>84</sup> Hsin Min Wong James Hileman, Pearl Donohoo, Russell Stratton, Malcolm Weiss, & Ian Waitz, *Lifecycle Analysis - Background and Current Progress* (Cambridge: Massachusetts Institute of Technology, 2006) at 21.

Instead, their production specifications are defined and described by industry associations, such as the American Society for Testing and Materials (ASTM) or, in the case of military use, by the Defense Ministry of a given country such as the United Kingdom's Defence Standard (Def Stan). In order for aircraft systems such as engines or the fuel management system to be certified by a respective authority, these systems need to operate within their declared performance criteria using the specified fuel and lubricants. Alternative fuels need to undergo an extensive testing process, and pass the Original Engine Manufacturers (OEM) approval review, before they can be used in a specific engine type. Nevertheless, the respective regulatory authorities (for ASTM the FFA, and for Def Stan the EASA) do oversee the testing and OEM approval process, and they can request additional information or further testing.<sup>85</sup>

Specifications for fuels and lubricants have remained consistent during the past several decades and this has allowed engine and aircraft manufacturers continuity in the design of systems. An alternative fuel which meets the same specifications as the existing fuel type is considered a "drop-in fuel" and is in compliance with already established and certified operating limitations for existing aircraft and engine systems. Given the existing large fleet of aircraft around the world, and the massive cost of developing and certifying new aircraft or engines, alternative fuels must be developed to fully meet existing specifications. The certification process need therefore only examine alternative fuel's compliance with these specifications.

In 2006, the Commercial Aviation Alternative Fuels Initiative (CAAFI) was created following growing concerns about energy security and aviation's environmental impact. Its objective of exploring the potential of alternative jet fuels for aviation has developed into four major areas: (i) fuel certification and qualification; (ii) research and development; (iii) the environment; and, (iv) aspects of business and economics.<sup>86</sup> In order to achieve a first certification of alternative fuel, CAAFI initially focused on providing support for the creation of a new jet fuel approval process by ASTM International, which was subsequently issued as standard D4054.<sup>87</sup> This allowed ASTM to focus

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<sup>85</sup> IATA 2007 *Report on Alternative Fuels* (Montreal: IATA, 2008) at 43.

<sup>86</sup> CAAFI was founded by the Federal Aviation Administration, the Air Transport Association of America, the Aerospace Industries Association and the Airports Council International-North America. CAAFI now includes several U.S. and international aerospace manufacturers, researchers, energy companies, and government agencies.

<sup>87</sup> American Society for Testing and Materials (ASTM) International, *International Standard*

on the first certification, which consisted of a 50 per cent FT synthetic jet fuel blend from biomass, coal, and gas. The certification process was supported by the fact that the UK Fuel Standards Organization had already approved in 1999 a 50/50 blend of semi-synthetic jet fuel derived from coal using a Fischer-Tropsch process for use in all commercial and military engines.<sup>88</sup>

In September 2009 the ASTM published the "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons" under its designation D 7566.<sup>89</sup> Under this standard, alternative fuels generated from a variety of feedstocks, including biomass to liquid, natural gas to liquid, coal to liquid and combinations thereof, can be used in existing aircraft and engines if they are produced by the FT method and consist of a 50 per cent blend with conventional Jet A. A fuel standard which was used in South Africa for ten years has now become a global standard. However, the industry is aiming at full certification of the use of all alternative drop-in fuels. It anticipates the certification in 2010 of a blend of 50 per cent hydro-treated renewable synthetic jet fuels blends (e.g. algae), and the 100 per cent usage of FT synthetic jet fuel from coal, biomass, and natural gas. Finally, by 2013 the certification of 100 per cent hydro-treated renewable synthetic jet fuel should take place and this would allow all specified drop-in alternative fuels to be used in commercial aviation.<sup>90</sup>

## B. ENVIRONMENTAL ASPECTS OF PRODUCTION

The production processes of alternative fuels derived from coal, natural gas, or other hydrocarbon feedstock are well developed as many have existed for several decades. However, from an environmental standpoint, the production of synthetic fuel from coal is controversial. The production of fuel from coal is done by the CTL process, which applies direct liquefaction, where coal is hydrogenated, carbonized, or

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*Practice D4054, "Guideline for the Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives"* (2009).

<sup>88</sup> Since approval in 1999 of semi-synthetic jet fuel derived from coal using a FT process and manufactured by Sasol, all aircraft flying out of OR Tambo (Johannesburg) International Airport during the past decade have operated on Sasol semi-synthetic blend with no reported problems. Given this experience, the DEF STAN 91-91 standard was issued in December 2007, which approved the use of 100 per cent Sasol full-synthetic fuel. See IATA 2008 *Report on Alternative Fuels* (Montreal: IATA, 2008) at 39.

<sup>89</sup> See generally American Society for Testing and Materials (ASTM) *International, Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons* (2009).

<sup>90</sup> ICAO, *The ICAO Workshop on Aviation and Alternative Fuels - A Summary of Research and Perspective* (Montreal: ICAO, 2009) at 9.

converted into a gas first, and then into a liquid using the Fischer-Tropsch process. The CTL process depends on the abundance of coal of stable quality, and requires relatively high amounts of energy. The CTL production method is seen by many as an opportunity for countries with large reserves of coal, such as China or the United States, to reduce their dependence on crude oil. However, the biggest drawback is the fact that the CTL process results in very high CO<sub>2</sub> emissions.<sup>91</sup> New carbon capture and storage (CCS) techniques are currently being developed to address this issue.<sup>92</sup> Nevertheless, the high initial cost of establishing a CTL project, the relatively high energy input required, and the cost of either CO<sub>2</sub> penalties or CCS infrastructure, will continue to present a major hurdle for a wide-scale development of this source of coal-based fuel products.

The production of biofuels has not escaped environmental attention either. One of the main issues is the change in land use for expanded agricultural production, which may result in increased GHG emissions, and a loss of biodiversity.<sup>93</sup> In 2007, global fuel crop production for transport biofuels covered about 26.6 million hectares (Mha) or 1.7 per cent of global cropland.<sup>94</sup> This represents an increase of 93 per cent in only three years, when the area cultivated was a measly 13.8 Mha. The cropland for transportation biofuels is primarily located in the US and Canada (17.5 Mha), in the European Union (8.3 Mha), and in Latin America (6.4 Mha). While the current production of transportation biofuels consists primarily of first-generation-type biofuels (primarily corn and sugarcane based), it is raising serious environmental concerns. One of the prime issues is the fact, that land use change can lead to significant CO<sub>2</sub> emissions, especially when forests, savannah, grassland

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<sup>91</sup> One barrel of oil produced by CTL results in 0.5 to 0.7 tonnes of CO<sub>2</sub>, which would represent a potential penalty of US\$ 20 to US\$ 30 per barrel. International Energy Agency, *World Energy Outlook 2008* (Paris: IEA, 2008) at 40.

<sup>92</sup> Carbon capture and storage is a technical measure to mitigating global warming based on capturing carbon dioxide from large emitting sources and storing it deep underground instead of releasing it into the atmosphere. Despite the fact that CO<sub>2</sub> has been injected into geological formations for enhancing the recovery of traditional crude oil, the long term storage of CO<sub>2</sub> is a relatively untried concept. The first experimental CCS power plant was completed in September 2008 in the German power plant Schwarze Pumpe, and is currently evaluated on its technological feasibility and economic efficiency. International Energy Agency, *Energy Technology Perspectives 2008* (Paris: IEA, 2008).at 268.

<sup>93</sup> United Nations Environment Panel, *Towards sustainable production and use of resources: Assessing Biofuels* (Paris: UNEP, 2008) at 63.

<sup>94</sup> N.H. Ravindranath, et al., *GHG Implications of Land Use and Land Conversion to Biofuel Crops*, online: Global Bioenergy Partnership <[http://www.globalbioenergy.org/uploads/media/0810\\_Ravindranath\\_et\\_al\\_-\\_GHG\\_implications\\_of\\_land\\_use\\_and\\_land\\_conversion\\_to\\_biofuel\\_crops.pdf](http://www.globalbioenergy.org/uploads/media/0810_Ravindranath_et_al_-_GHG_implications_of_land_use_and_land_conversion_to_biofuel_crops.pdf)>.

and abandoned land are converted to biofuel cropland.<sup>95</sup> This has become an issue in tropical countries, where the rapid expansion of biofuel production is fueled by the fact that sufficient rainfall is maximizing productivity per given surface.

Another challenge for the large-scale production of biofuels is the requirement of water. Recent research on the water footprint of energy from biomass revealed that the production of biofuels requires 70 to 400 times more water than energy derived from other sources, such as fossil fuels, wind, and solar.<sup>96</sup> Increased diversion of water for human purposes to crop irrigation may eventually lead to major challenges or even conflicts in many parts of the world which already suffer from seasonal or permanent water shortages. Furthermore, a decrease of water quality is an environmental aspect of the production of biofuels. The main problem is one of eutrophication, a process whereby water receives excess nutrients that stimulate excessive plant growth, thereby reducing dissolved oxygen and causing other organisms to die. The result is decreased biodiversity, changes in species composition and dominance, as well as toxicity effects that can affect large areas. This process has been observed in the Northern Gulf of Mexico and in some Atlantic coastal waters.<sup>97</sup>

Finally, the most controversial issue concerning the widespread production of biofuel is land use for food production. From 1965 until 1995, the increase in cereal yields exceeded the human population growth rate, but since the middle of the 1990s, population growth has increased at about the same rate as average global yields.<sup>98</sup> The UN estimates that the world population will continue to grow from 6.1 billion in 2000 to about 8.3 billion in 2030, an increase of 36 per cent. The increase of the world food supply necessary to feed the growing population depends on continued increase of yields from available cropland. While this is uncertain, the additional demand for biomass production will in most cases be at the expense of cropland currently producing food supply.

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<sup>95</sup> One reason is that the clearing of natural vegetation mobilizes stored carbon in vegetation and soil, which leads to a carbon debt of that land, which will take decades to be compensated by the CO<sub>2</sub> absorption by growing crops. See *supra* note 93 at 67.

<sup>96</sup> P.W. Gerbens-Leenes, et al., *The Water Footprint of Energy from Biomass: A quantitative assessment and consequences of an increasing share of bio-energy in energy supply* (Enschede: University of Twente, 2008) at 1059.

<sup>97</sup> *Supra* note 93 at 58.

<sup>98</sup> *Ibid.*, at 46.

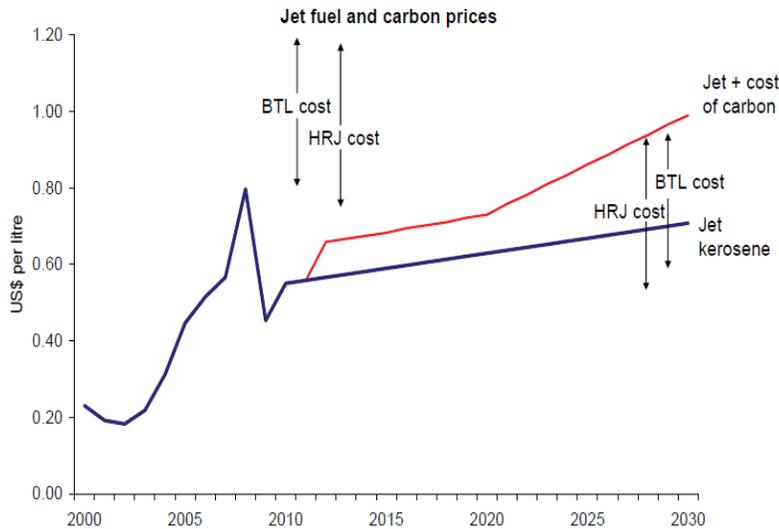
The three most promising types of feedstocks for biofuel for aviation are Jatropha, Camelina and algae. Jatropha and Camelina are both relatively compatible with traditional cropland use, and the case is often made that growing this kind of feedstock would not affect traditional cropland. Jatropha can be cultivated in arid and non-arable land, and Camelina is mostly grown as a rotational crop with wheat and other cereal crops during seasons when land would otherwise be left unplanted. However, the enormous surface of land required to switch from crude oil to biomass based jet fuel alone would certainly create some serious conflicts affecting traditional cropland, especially in an economic environment where crude oil prices remain very high for a protracted period of time. Algae-based biomass offers the most environmentally-friendly production, as it can be grown from any sort of water in the most unsuitable land for crop production such as the desert. Nevertheless, a possible severe increase of crude oil fuel prices would trigger a rush on biofuels. This, in turn, may motivate many traditional crop farmers to switch their production to more lucrative biofuels, even if their land may be more suitable for food production. As such, the advantage of certain biomass feedstocks not competing with food production may vanish quickly when energy becomes a scarce and expensive resource.

### C. COMMERCIAL CHALLENGES AND SCALE-UP OF PRODUCTION

Alternative fuels for aviation have been in production for decades. However, except for the South African production of coal based synthetic jet fuel, there have been few solid outcomes to date. The production of alternative fuels in large quantities poses both a commercial as well as an infrastructural challenge.

The cost of production of alternative jet fuel varies between the different methods. The two most promising methods in terms of cost are HRJ fuels from oil crops (typically from Camelina, Jatropha, or Algae), and biomass to liquids applying the FT conversion. The cost of producing these fuels is currently between US\$ 0.80 and 1.20 per liter, which is 50 to 100 per cent above the cost of jet fuel produced from crude oil (see Figure 4). However, with a future decrease in the production cost for HRJ and BTL fuels, and by taking into account the cost of purchase of carbon emission rights under the EU Emissions Trading Scheme, these alternative fuels could become competitive within the next 10 to 20

years.<sup>99</sup> In addition, should the price of crude oil rise significantly, alternative fuels could become commercially viable sooner. Nevertheless, the past volatility of oil prices also suggests that any medium or long-term financing of alternative fuel production is faced with many uncertainties, and this creates additional costs and difficulties.



Source: Jet and cost of carbon based on UK DECC central case forecasts for oil prices and traded carbon prices. Biofuel costs various sources described below. All are in constant (inflation adjusted) US dollars.

Figure 4 - Aviation biofuel supply costs compared with the cost of using jet kerosene, including the cost of carbon emissions.<sup>100</sup>

Another significant hurdle for commercialization and for scaling-up production of alternative fuels is the surface of land required for production. The aviation industry consumes worldwide between 1.5 and 1.7 billion barrels of Jet A1 annually. The industry estimates that the production of biofuels could become commercially viable when just 1 per cent of jet fuel comes from biofuels.<sup>101</sup> However, one of the major challenges to scaling-up production will be cost of land acquisition, as well as expenditure for necessary infrastructure, such as specialized oil refineries for crop based production, or photo bioreactors for algae-based biofuel production. The land surface required for the production of the feedstock depends on its type. A rough estimate quotes the land

<sup>99</sup> *Infra* note 100, at 45.

<sup>100</sup> IATA, *2009 Report on Alternative Fuels* (Montreal: IATA, 2009) at 45.

<sup>101</sup> This would suggest, for example, that 10 per cent of the world's fleet operate with a blend of 10 per cent biofuel and 90 per cent Jet A1. Air Transport Action Group, *Beginner's Guide to Aviation Biofuels* (Geneva: ATAG, 2009) at 18.

requirements for the entire current crude oil-based production of jet fuel by only one alternative source to be for: (i) Jatropha - 2,700,000 square kilometers (sq km) or the size of Argentina; (ii) Camelina - 2,000,000 sq km or the size of Mexico; and, for (iii) algae, - 68,000 sq km or about the size of Ireland.<sup>102</sup> While there are certainly large areas of non-arable land available, or in the case of algae based feedstock, various water surfaces which include almost all types (seawater, wastewater, ponds and lakes), one must bear in mind that jet fuel production from alternative sources will be competing with all other crude oil derivatives.

Given the cost and large dimensions of required surface, the industry expects that scaling-up production might take several decades before alternative fuels can entirely replace traditional jet fuel. In a recent study, the United Kingdom Committee on Climate developed various scenarios on when biofuels in aviation are expected to develop technology and new crops; address production sustainability constraints, and break even with the cost of traditional jet fuel production. The different scenarios, the best case heavily depending on new synthetic hydrocarbons from yet to be developed processes, and the worst case primarily based on BTL production using the FT methods, range from a full replacement by 2040 to only a 40 per cent replacement by 2050 (see Figure 5). The IEA, which developed a reference scenario to stabilize greenhouse gas emissions at 450 ppm,<sup>103</sup> estimates that with sufficient investment and government support, about 42 million tons of aviation biofuels could be used. This represents a global blend of 15 per cent with traditional jet fuel, and confirms the average estimate in Figure 5.<sup>104</sup>

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<sup>102</sup> *Ibid.*

<sup>103</sup> The 450 ppm scenario analyzes how global energy markets would develop if countries take coordinated action to limit global temperature increase to 2 degree Celsius. See IEA, *WEO 2009*, supra note 51 at 221,

<sup>104</sup> *Ibid.*, at 231.

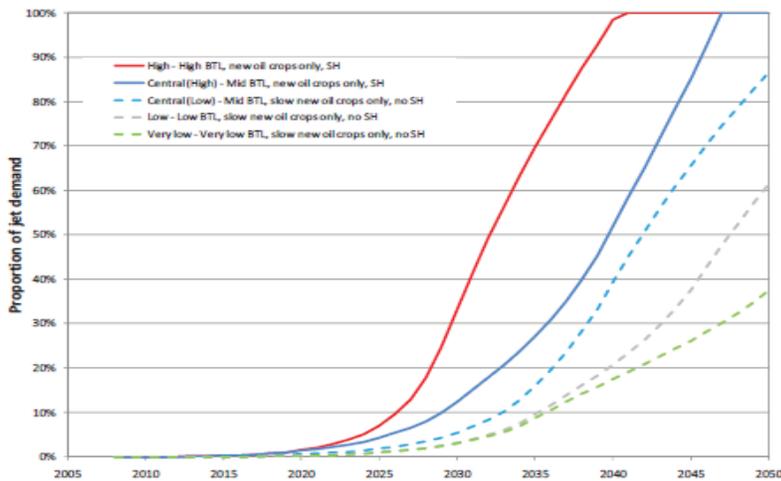


Figure 5 – Timeline scenarios for the replacement of crude oil based jet fuel in global air transport.<sup>105</sup>

## VI. CONCLUSIONS

Alternative fuels are becoming increasingly significant and are seen by many as having the potential to replace conventional jet fuel in the future. However, there are many unresolved challenges concerning the scaling-up and environmental aspects of production which need to be solved. There are alternative fuels in existence today which would both reduce life cycle CO<sub>2</sub> and improve air quality, but at present the production of these fuels is very limited. Furthermore, if unregulated production of these biofuels would entail land use changes; these biofuels could have lifecycle GHG emissions that are many times worse than conventional jet fuel. Achieving carbon neutrality seems to be possible, but large tracts of land surface would be needed and costs may be prohibitive, and aviation would need to compete with other sectors for these limited biomass resources. Therefore, only a multiple-feedstock solution that uses feedstocks with low life-cycle emissions and high yield and which do not require arable land appears to be the feasible solution. However, establishing sustainable large-scale production of these biofuels will take years, maybe decades, before they can replace petroleum-based jet fuel, and produce significant environmental benefits.

<sup>105</sup> *Supra* note 100 at 46.

Should conventional oil production unexpectedly reach a temporary or permanent peak within the next two decades, alternative fuels would only partially be able to replace traditional jet fuel. In addition, because aviation use represents only 6 per cent of crude oil consumption, alternative jet fuel production might quickly become pushed into a niche when other crude oil consumers are forced to switch to alternative fuels (e.g. diesel for road transportation), unless aviation promptly establishes a dedicated production and distribution infrastructure. The positive aspects for the aviation sector include the fact that it is the only sector with a global regulatory and industry approach, which has led to certification and policy statements. However, countries where production will take place must establish a regulatory framework to address environmental challenges of production. In addition, incentives for production of environmentally sustainable alternative fuels by subsidies or minimum purchase price may be necessary in order to address the fluctuation in crude oil price, which currently leaves financing of certain alternative fuels unpredictable.