The Potential and Role of Biofuels in Commercial Air Transport - Biojetfuel

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THE POTENTIAL ROLE OF BIOFUELS IN COMMERCIAL AIR TRANSPORT – BIOJETFUEL

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1. EXECUTIVE SUMMARY

This report provides only an overview and not a detailed analysis of biofuel use in commercial aviation or so called “biojetfuels”. It describes the framing conditions of the aviation industry, discusses future feedstock and cost expectations and estimates the potential effects of biojetfuels on international biomass and biofuel trade in the medium term.

Aviation is a global industry with global problems and challenges that also demands global solutions. The International Air Transport Association (IATA) predicts commercial aviation to grow annually by 5% until 2030, exceeding expected fuel efficiency improvements by approximately 3%; this implies that fuel consumption and emissions will continue to rise. The combination of increasing passenger demand and fuel costs and pressure to reduce anthropogenic emissions for which currently the sector accounts for 2-3% of the total global emissions, has pushed the aviation industry under considerable strain. The IATA is committed to achieve carbon neutral growth by 2020 and 50% reduction by 2050. A major step has also been the introduction of the European Emission Trade System (EU ETS), though this is being contested by various airlines, notably American and Chinese. Hence the key objectives of commercial aviation are to find reliable fuel alternatives to cut costs, and reduce volatility of fuel supply, climate effects, and improve fuel logistics.

The use of biojetfuels in commercial aviation has received considerable attention in recent years, as it is currently seen as one of the best short to medium term option to answer the challenges. Consequently almost all major commercial airlines and also some military sectors (i.e. USA), are heavily involved in testing and developing biojetfuels. Given the nature of the high quality drop-in fuels required in aviation, conversion technologies for the provision of jetfuels from biomass are rather limited, but are not the main obstacle. The most realistic options are Fisher-Tropsch-fuels (FT), and hydrogenated ester and fatty acids (HEFA), which are both closed to market introduction.

The key to the successful implementation of biojetfuel is the availability of feedstock in a large and sustainable scale and in particular it must be available on a significant global scale. Of the various feedstock assessed (at the time of writing), the most economic option is edible oils e.g. palm and soybean oil. However, given the implications with food security, non-edible oils might have a more sustainable potential. So the report focuses on the relevant non-edible oily crops (*algae, jatropha, camelina sativa, salicornia bigelivii*- see Table 4) offering considerable potential for biojetfuel, but only in the long term. Another emerging alternative is the use of lignocellulosic materials and waste, of which various promising examples are examined, though it is too early to say if these options will be economically and technically feasible alternatives. Considerable research advances are still required in order to, develop and successfully demonstrate the viability of conversion technologies associated with non-food biojet fuels,

To be viable in the long term, a fuel needs to be environmentally and economically sustainable. And there is a general consensus in the aviation industry that any biofuel used in the sector should comply with the sustainability criteria developed for road transport, which are available for the US and the EU. Sustainability criteria are a first step towards sustainable biofuel production, but still leave some aspects open and need additional assessment, especially of the indirect environmental effects (e.g. indirect land use change) as well as social aspects. Never the less, they are the best available basis for the development of criteria in the aviation sector. SAFUG (Sustainable Aviation Fuel Users Group), a body formed in 2009 encompassing large stakeholders in the airline business representing 25% of aviation fuel demand, is also collaborating in the harmonization of standards across regions. It is obvious that biomass is expected to play a key role, in meeting the fuel demands of the aviation industry, but this also presents the need to have a unanimous international agreement prescribing feedstock qualities, as a precondition to support the international logistics between countries and for the establishment of efficient biojetfuel.

However, currently the prices of biojetfuels are at least twice the price of conventional kerosene and only small amounts of biojetfuels are available. IATA expects that aviation biofuels could become price competitive by the middle term, due to the combination of two main effects; i) traditional jet fuel price increases (especially when a carbon cost is incorporated) and ii) biojetfuels production costs diminish. This is especially challenging for HEFA, because the production costs of HEFA mainly depend of the feedstock costs. There are of course many factors influencing feedstock costs, but competition for arable land at the beginning of the process chain, as well as competition with alternative energy supply concepts at the end of the process chain, will characterize the future biojetfuel role significantly. Thus one of the main barriers for a much wider use of biojetfuels is the cost of the feedstock which remains prohibitively high.

The evolution in the demand for biojet fuel is driven by many factors but the following are particularly important: i) growth in demand for air travel, ii) overall availability on biojetfuels based on sustainable feedstock and infrastructure adopted for provision; iii) issues relating to environmental, sustainability, social, political, and regulatory; iv) market developmental considerations driven by fossil fuel and feedstock prices, incentives, mandates and other fiscal instruments, and v) technical and sustainability standards for international trade (see Table 6).

Despite all those uncertainties there are limited scenario reports describing the future role of biojetfuels in commercial aviation.: The scenarios consider in different ways the many and varying factors influencing the development of biojetfuels e.g. overall fuel demand, biojetfuel availability, environmental, social, political, legislative, and market development and come to different results (see Figure 12). These scenarios range from an overall demand of 9EJ/yr in 2010 to 16 to 25EJ/yr by 2050 (roughly between 375 to 575 Mt, respectively); demand for additional land also varies from 100 to 500Mha. Given the international nature of the airline industry, most of the biofuel would have to be traded internationally in one way or another. Assuming a blend of 10%, the potential trade of biojetfuel will be between 36.8 and 57.5 Mt by the same year (or 1.6 and 2.5EJ), to be in the conservative side.

There is no silver bullet and it is imperative that policy makers, governments, universities, airlines, farmers, refineries and R&D work together to tackle the fuel problems of the aviation industry. Major advances are also necessary in relation to logistics, regulatory frameworks, quality control management and adoption of appropriate sustainability certifications. In the commercial aviation industry there is only one thing everybody seems to agree, and this is the almost certainty that passenger demand will increase significantly.

2. **INTRODUCTION**

The airline industry is a global and rapidly evolving sector. Commercial aviation is predicted to grow at a rate of 5% annually until 2030, exceeding expected fuel efficiency improvements by approximately 3%; this implies that fuel consumption and emissions will continue to rise. According to the International Air Transport Association (IATA 2011b) the airline industry will progress from carrying 2.4 billion passengers in 2010 to an estimated 16 billion passengers in 2050. The global fleet now numbers 100,000 and there are eight major aircraft manufacturers. This is an industry that requires huge investment, but provides low returns.

The aviation industry needs to take continuous steps to maintain and grow profit margins in an era of increasingly volatile oil prices and uncertainty in supply, as well as reducing its carbon footprint. The use of biofuels in commercial aviation – so called biojetfuels (or rather renewable diesel-like fuels) - are currently politically and environmentally favoured by many airlines, though costs remain a major stumbling block, despite the fact that kerosene is highly expensive and a finite oil-derived fuel.
A large number of studies have been carried out recently, covering many aspects of biofuels and their use in aviation, ranging from interested groups (i.e. IATA), manufacturers (Airbus, or Boeing), to academics and will be discussed in this report., There have been several advancements promoting the use of biojetfuels by the aviation industry achieved in recent years

There is mounting pressure to act from fuel costs, environment or regulatory bodies. A good example is the EU ETS which mandates that all airlines which land in the EU are subjected to the emissions trading scheme. However, this is challenged by many airlines particularly from China and the USA, the consequences of which are still not clear for the industry.

This study has tried to answer two key questions:

> i) What is the potential role of biojetfuels considering increasing demand on agricultural land for a multitude of products and global requirements to reduce GHG emissions in the energy sector?

ii) What are the specific time-frame conditions for the introduction of biojetfuels and what does it mean for international bioenergy trade?

Consequently the key objectives of this study are:

- Assess current the state- of –the-art to kerosene technical alternatives
- Expected production/supply in 2020
- Investigate the technical hurdles and how biofuels fit in the structure of aviation fuels
- Provide detailed information on the two pathways and illustrate the main influencing factors for product quality

The following sections provide: i) a short overview of the current situation for aviation and the role of biofuels (commercial aviation sector, main development of biojetfuels in this industry, environmental issues, policy and legislation, fuels costs, including biojetfuels, emerging technologies); ii) technical options for biojetfuels (current state-of-the art of main processes); iii) feedstock assessment (summary of main feedstock under consideration; feedstock markets, sustainability and certification issues) iv) potential demand for biojetfuels); v) biojet fuels and international trade; and vi) the major conclusions of the study.

3. SHORT OVERVIEW OF CURRENT SITUATION

This section highlights the current state-of-the-art of biofuels utilization within the aviation (commercial sector, main developments, environmental issues, policy and legislation; fuel costs, including biojetfuels, and emerging technologies). More detailed analysis can be found in subsequent sections of this report.

3.1 Commercial Aviation

The period 1990 to 2008 encompassed a growth in the number of flights by 93% (EC, 2011) followed by a slowdown and subsequent rapid rebound. Air traffic growth measured in revenue passenger Km (RPK), is used by the world's two leading aircraft manufacturers, Airbus and Boeing to project growth; they predict a 4.8% and 5.1% increase respectively, from 2010 up to 2030 (Airbus, 2011; Boeing, 2011). See Figure 1.

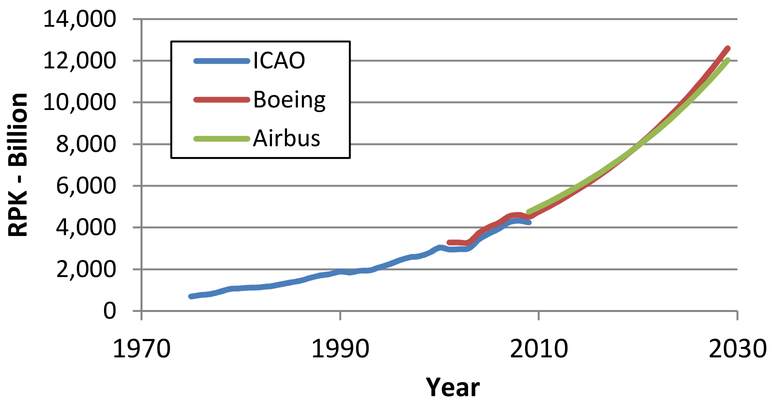

Figure 1. Historic and forecasted growth in the air travel industry measured in RPK. Data from (International Civil Aviation Organization-ICA), 2009, ICAO (2010), Airbus, 2011, Boeing, 2011)

3.2 Main developments of biofuels in commercial aviation

Traditional jet fuel is a hydrocarbon almost exclusively obtained from the kerosene fraction of crude oil ,with a large number of studies providing detailed technical analysis e.g. see Blakey et al., (2011), Bauen et al (2009). Table 1 summarizes the most relevant fuel requirements needed for the introduction of biofuels.

Table 2. Summary of jet fuel requirements from **(Bauen et al., 2009)**

Requirement	Reason	Specification
Energy content	Affects aircraft range	Minimum energy density
Freeze point	Impacts upon ability to pump fuel at low temperature	Maximum allowable freeze point temperature
Thermal stability	Coke and gum deposits can clog or foul fuel system and nozzles	Maximum allowable deposits in standardized heating test
Viscosity	Impacts ability of fuel nozzles to spray fuel and of engine to relight at altitude	Maximum allowable viscosity
Combustion characteristics	Creation of particulates in combustor and in exhaust	Maximum allowable sulphur and aromatics content
Lubricity	Impacts upon ability of fuel to lubricate fuel system and engine controls	Maximum allowable amount of wear in standardized test
Material compatibility	Fuel comes in contact with large range of metals, polymers and elastomers	Maximum acidity, maximum mercaptan concentration, minimum aromatic concentration
Safety	To avoid explosions in fuel handling and tanks	Minimum fuel electrical conductivity and minimum allowable flash point

A big challenge facing the use of biofuels in aviation is the high quality standard requirements, and only very high quality biofuels, such as biodiesel-like fuels, can be used in this industry.

There are basically two type of fuels used in commercial aviation: i) Jet- A (used mainly in the USA) and ii) Jet A-1 used worldwide; the only relevant difference between them is the freezing point (-40℃ for Jet A and -47℃ for Jet A-1). In order to cope with more complex fuel supply arrangements, fuel suppliers developed a checklist (i.e. “Aviation Fuel Quality Requirements for Jointly Operated Systems”, or AFQRJOS[3]) for the Jet A-1 standard based on the most strict requirements of both, ASTM D1655 and UK DEF STAN 91-91 (Shell, 2012).

The early years of the aviation sector were notorious for their fuel inefficiency. However, there has been a constant battle to improve fuel efficiency as illustrated in Figure 2, which shows the evolution of the fuel consumption in relation with the first civil jet aircraft (i.e. de Havilland Comet). Blakey et al., (2011) state that the aircraft fuel burned per seat has been reduced by 82% (using the Comet as reference).

Due to the long life of aircraft products, particularly engines (typically 30-40 years), the speed at which these improvements are incorporated into the total fleet is a slow process. Besides the fuel efficiency of aircrafts, another major area that offers considerable potential for significantly reducing fuel demand is the optimization of air traffic management (ATM) (Blakey et al, 2011).

ATM has the potential to reduce fuel consumption by about a further 15%. However, this is not enough to offset raising costs. Thus it must be a combination of efforts from all arease.g. aircraft design, new materials, ATM, etc.

[3] Agip, BP, ChevronTexaco, ExxonMobil, Kuwait Petroleum, Shell, Statoil and Total recognize this checklist- as the basis of their international supply of virtually all civil aviation fuels outside North America and former Soviet Union (Shell).

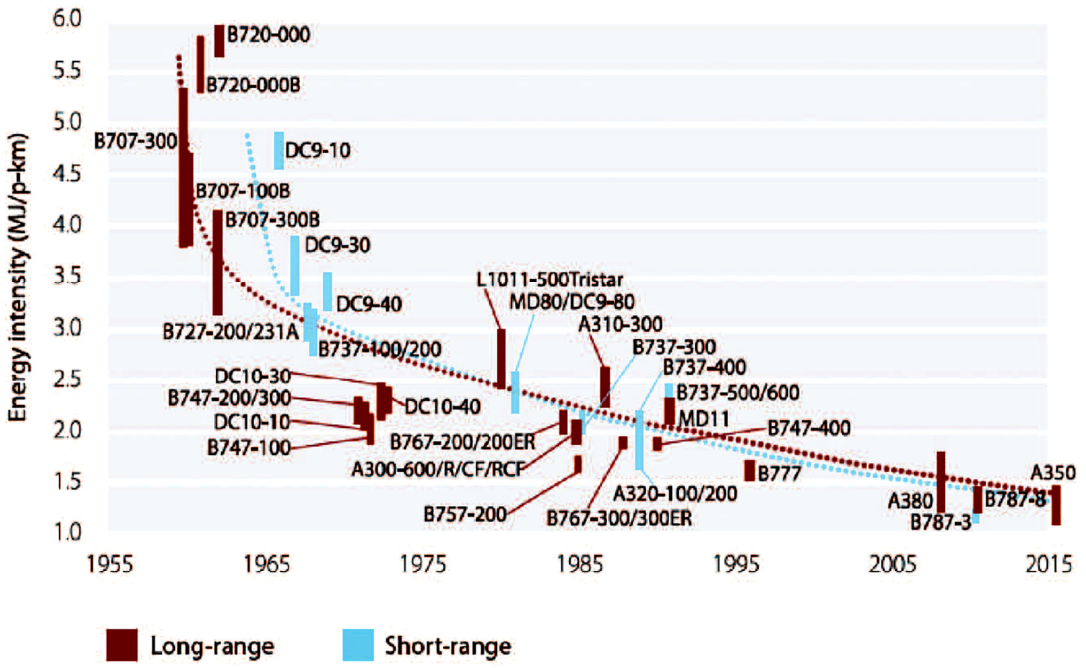

Figure 2: Fuel efficiency of new aircraft, 1955 - 2015

Source: IATA (2011) Vision 2050 (www.iata,org)

3.3 Environmental issues

Aircraft emissions, in conjunction with other anthropogenic sources are impacting Green house Gases (GHG) and hence inducing climate change, though the extent of such impacts are very difficult to predict and are heavily debated. Atmospheric changes from aircraft result from three types of processes: i) direct emission of radioactively active substances (e.g., CO_2 or water vapour); ii) emission of chemical species that produce or destroy radioactively active substances (e.g. NO_x, which modifies O_3 concentration); and iii) emission of substances that trigger the generation of aerosol particles or lead to changes in natural clouds (e.g., contrails). The largest areas of scientific uncertainty aircraft-induced climate effects lie with persistent contrails, with tropospheric ozone increases and consequent changes in methane, with potential particle impacts on "natural" clouds, and with water vapour and ozone perturbations in the lower stratosphere (especially for supersonic transport) (IPCC 1999).

There is no real consensus outlining how much commercial aviation is contributing to total global carbon emissions, but general estimates are between 2-6%. However, there is a consensus that this would increase significantly if current growth trends continue and if no major improvements are made e.g. introduction of renewable sustainable biofuels, technological improvements in aircraft materials, etc.

The public and political pressure on the sector to decrease its GHG emissions is increasing, particularly in Europe. For this reason, the aviation industry has committed itself to achieve carbon-neutral growth by 2020, and a 50% reduction in CO_2 emissions by 2050 compared with 2005 levels (IATA, 2010). Several studies have investigated the development of the aviation related global CO_2 emissions (Figure 3). In the majority of those scenarios the suggested CO_2 reduction cannot be found – so additional efforts have to be taken to change the currently expected trends.

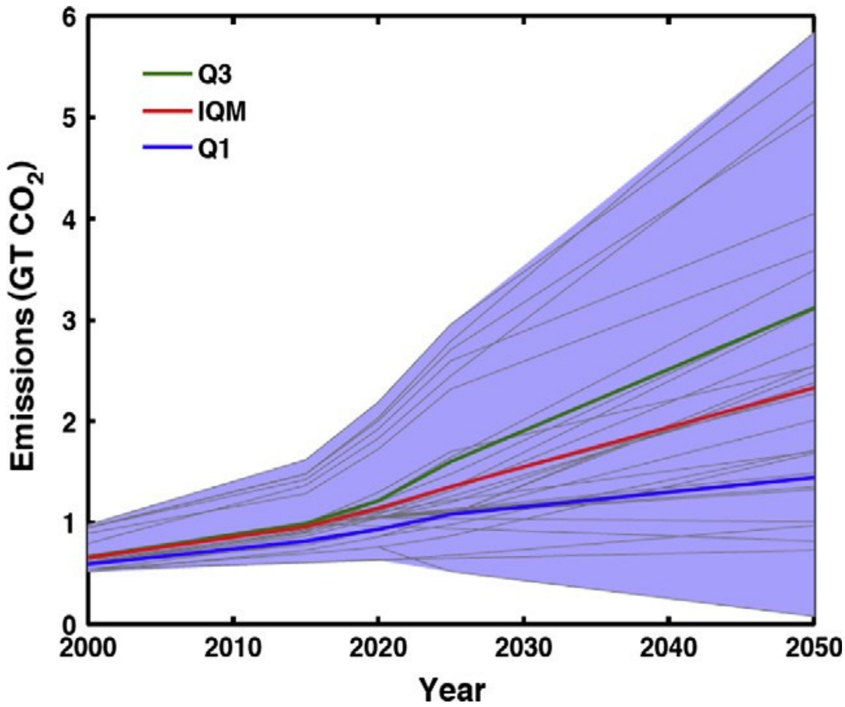

Figure 3. Inter-quartile meta-estimates for global aviation CO_2 emissions. IQM, Q1 and Q3 are the proposed mid, low and high global aviation CO_2 meta estimates adjusted to exclude military aviation. For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article. (Source: Gudmundsson et al, 2012)

3.4 Policy and legislation

Aviation is a global industry with global problems and challenges, the major contentious issue are the associated environmental impacts. For example, emissions of carbon dioxide from aviation were excluded from the binding targets set out by the Kyoto Protocol**.** The European Union has taken the first steps to address this issue through the Renewable Energy Directive. The European Commission also rolled out the "Flightpath 2050, Europe's Vision for Aviation", which outlines research priorities to ensure the growth and competitiveness of the EU, while balancing the concerns of the environment and energy security (EC, 2011)**.**

However, an important controversial issue has arisen regarding the carbon tax under the EU Emission Trading Scheme (EU ETS). In its judgment on December 2011, The European Court of Justice declared it legal and within bounds for the EU to impose this tax on foreign airlines,. However, the United States and China are strong opponents and have taken measures to prevent its implementation. For example, China has taken drastic measures to ban its airlines from paying this duty, supported by the signatures of more than twenty other countries. There has also been threats of retaliatory legal action under the premise that this violates international law and treaty provisions under the Chicago Convention (A4A, 2011). Figure 4 shows estimates of traffic, to and from Europe, from 2001 to 2029.

The EU ETS is a cap and trade system; emission allowances are given or auctioned to aircraft operators. An operator that emits more than its allocated allowances, needs to buy them and operators that did not use all their allowances can sell them[4]. The Directive 2008/101/EC defines the operation of the EU ETS for aviation. Some important operational considerations are:

- In 2012, the total number of allowances allocated for aviation will correspond to 97% of the historical GHG emissions equivalent[5]. This cap will be lowered to 95% from 2013 onwards.

[4] Allowances allocated to the aviation sector cannot be used in other sectors because emissions from international aviation are not integrated into the Kyoto Protocol commitments (EU, 2008).
[5] Based on the mean average of 2004, 2005 and 2006 annual emissions (EU, 2008)

- 15% of the allocations will be auctioned, the rest will be issued free of charge.
- Each aircraft operator is associated to a member state.
- For the allocation and auction processes the reference year will be 24 months before. For example, the allowances allocated to the aircraft operators in 2012 will be based on their air traffic (tonne-kilometers performed) from 2010 (the first reference year).
- 3% of the total allowances will be reserved for fast growing and/or new operators.

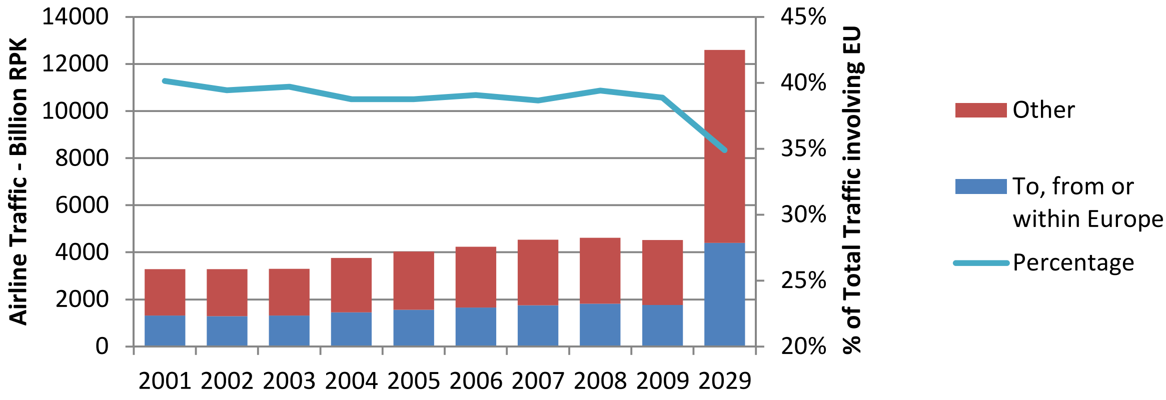

Figure 4. Evolution and projection of global airline traffic and its fraction that arrives to and/or departs from Europe.
Source: (Garnham, 2011).

EU (2009) stipulates an emission factor of 3.15 tCO_2 / t fuel for conventional Jet A-1 or Jet A. Biofuels, on the other hand, have an associated emission factor of 0 under the EU ETS (IATA, 2010).

Anger & Köhler (2010) analysed the impacts of the EU ETS in aviation and concluded that instead of reducing its emissions, the aviation sector is expected to buy allowances from other sectors included in the scheme and credits from other Kyoto mechanisms. It also states that airlines will transfer the cost to their customers and that the demand growth will not be reduced (regardless of the increase in prices) nor the carbon emissions. In their study the potential use of biojetfuels is not considered. These problems could therefore pose serious problems for emission reductions, unless carbon credits become far more expensive than present..

There are also important indirect policy mechanisms that benefit directly the use of biofuels in aviation. These mechanisms try to promote the use of renewable energy (and more specifically, biofuels) through incentives like tax exemptions or subsidies. The two main programs of this type are the US Renewable Fuel Standard (RFS) and the EU Renewable Energy Directive (RED) (IATA, 2010):

- The RFS sets a volume target for US biofuel supply. This target must be met with biofuels that comply with a certain sustainability level and offer a net reduction in GHG emissions (on an LCA basis). If an aviation biofuel qualify under these criteria, each gallon is assigned a Renewable Identification Number (RIN). Airlines can sell these tradable RINs to industries that need to meet a volume target.
- RED mandates a 10% of renewable fuels in transport by 2020 in the EU. In order to qualify as a renewable fuel, it has to fulfil certain sustainability criteria (for example, a certain level of GHG savings on an LCA basis). Each member state, in order to comply with the quota can provide different incentives. Currently the RED is still being transposed into national legislation and therefore there is no definite list of incentives for biofuels.

3.5 Fuel cost trends

Since traditional jet fuel is produced from crude oil, the price is based on crude oil price plus a jet spread or jet crack. Figure 5 presents simplified historical relationship between the crude oil price, conventional jet fuel price and jet spread, from April 1990 to April 2010.

As indicated above, fuel costs account for a growing proportion of airline operational costs e.g. 30% in 2011, in the order of $178 billion, an increase of $37 billion from 2010 (West, 2012). In spite of discrepancies, there is clearly a stark upward trend in prices of oil based products, which in turn reflects in the price of kerosene, which has risen by 68% since2007.

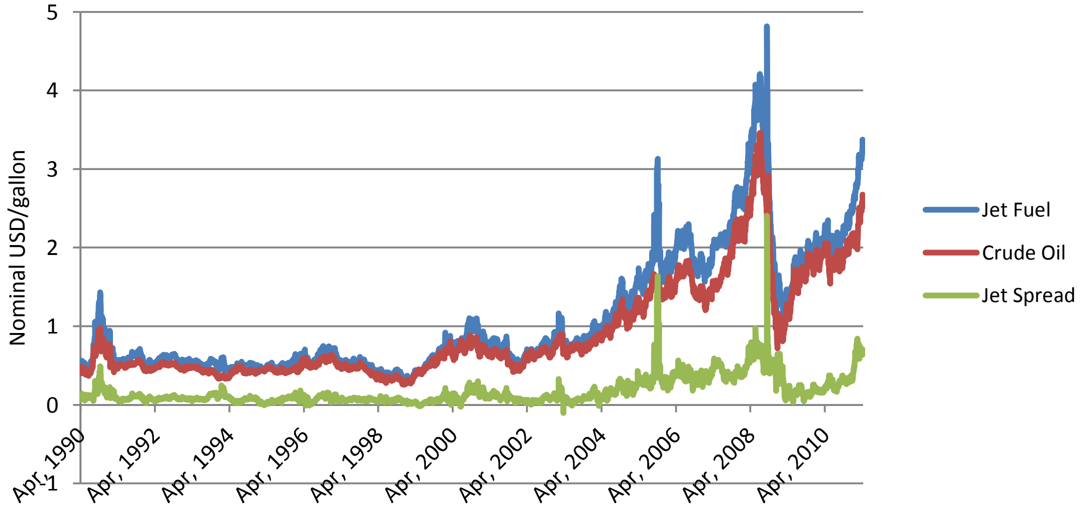

Figure 5. Daily prices for crude oil6, jet fuel7 and jet crack. (Quoted in Garnham, 2011).

Although predicting oil prices is often a futile exercise, given the complexity of the many factors involved, Figure 6 is an attempt to put some numbers, both to conventional jet fuel and ETS carbon credits for the period ranging from 2010 through 2050. It is notoriously difficult to predict oil princes and hence a large margin for uncertainty remains.

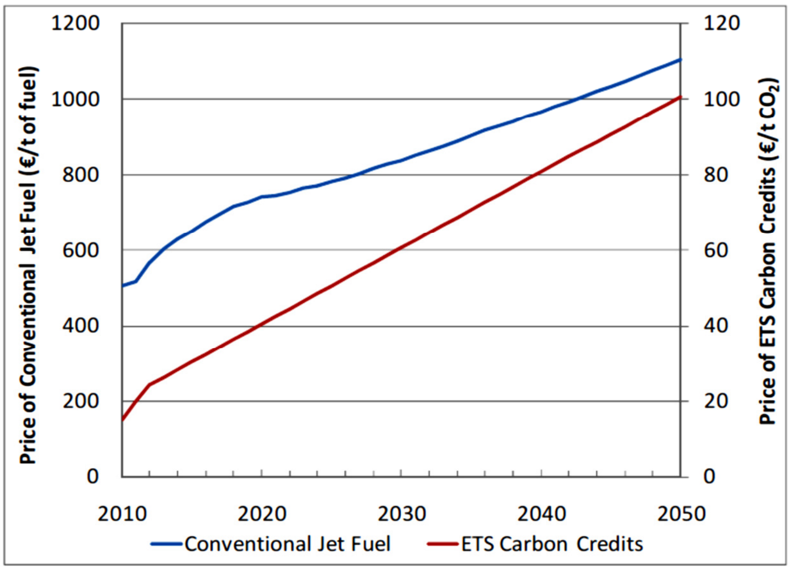

Figure 6. Projections for jet fuel and emissions certificate prices (SWAFE, 2011)

6 Cushing, OK WTI Spot Price FOB
7 U.S. Gulf Coast Kerosene-Type Jet Fuel Spot Price FOB

One way of offsetting potential losses that can be incurred by the volatile oil prices is via hedging[8]. Airlines hedge in order to predict with greater certainty their future cash flows, and make investments and optimal periods of the price cycle, which are practices that investors are highly interested. Figure 7 plot the cost for rapeseed oil, soybean oil and palm oil, from 2010 through February 2012, showing significant fluctuations. In addition, the quantities of biojetfuel required, together with the marginal business models of airlines (0.1% margin average over the last 40 years), makes biofuels at present economically an unviable option

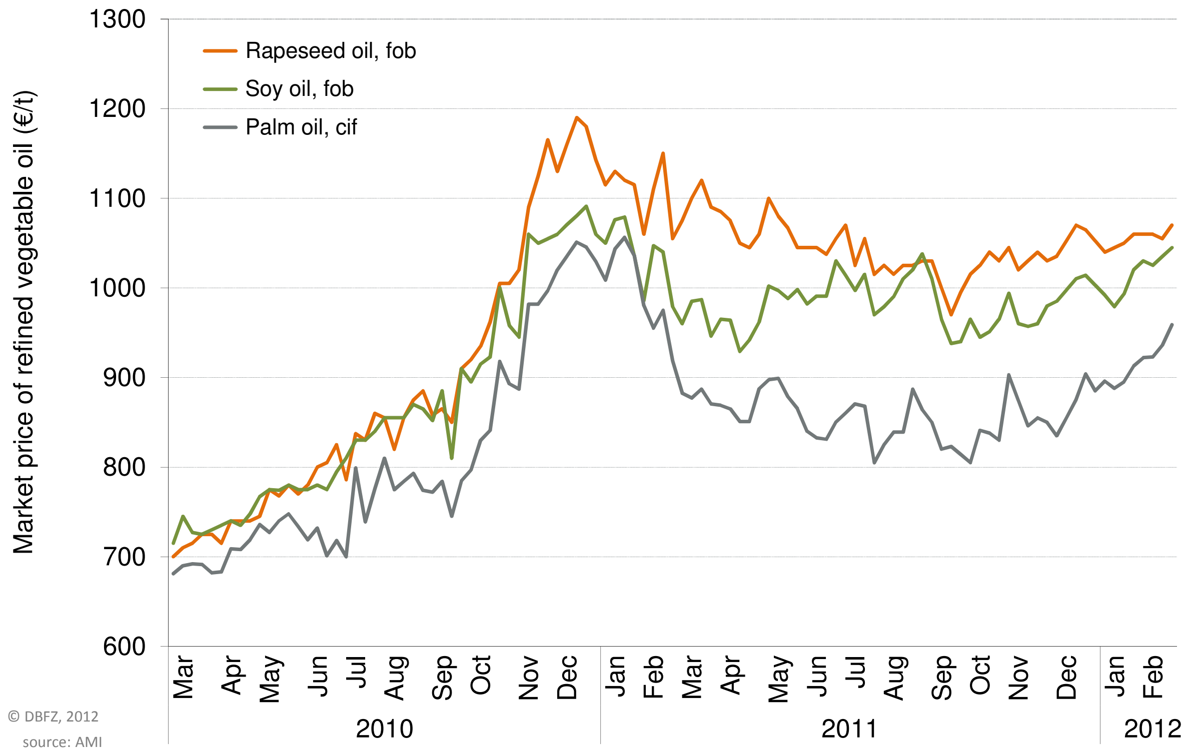

Figure 7: Development of refined vegetable oil prices (AMI)

3.6 Technical options of biojetfuels

Given the nature of the aviation industry and the high quality of the fuel, the alternatives, even from a technical point of view, are limited. A drop-in biofuel can be understood as a substitute for fossil jet fuel, which can completely be interchanged. Furthermore, this type of fuel is fully compatible with conventional jet fuel and can be

[8] Hedging is the process by which airlines try to secure a fuel price. This shields the industry against losses in times of high fuel prices. Since fuel costs make up 30% of airline's operating costs, which is also the most volatile, hedging creates a level of stability that allows for more accurate projections of profits

used within aircraft respectively engine fuel system or the fuel distribution network without any adaptation. For the application of a fuel within the international civil aviation sector the certification in accordance to the ASTM International standards or the UK Defence Standardization (DStan) are binding. In this context the standard ASTM D 7566 is taken into consideration for the subsequent assessment of relevant biofuel alternatives. From the current point view the following fuel categories are approved by the standard (ASTM, 2011):

- Hydrogenated Esters and Fatty Acids (HEFA)
- Fischer-Tropsch (FT) based on biomass (BtL (biomass to liquid).

Figure 8 shows various options for aviation biofuels

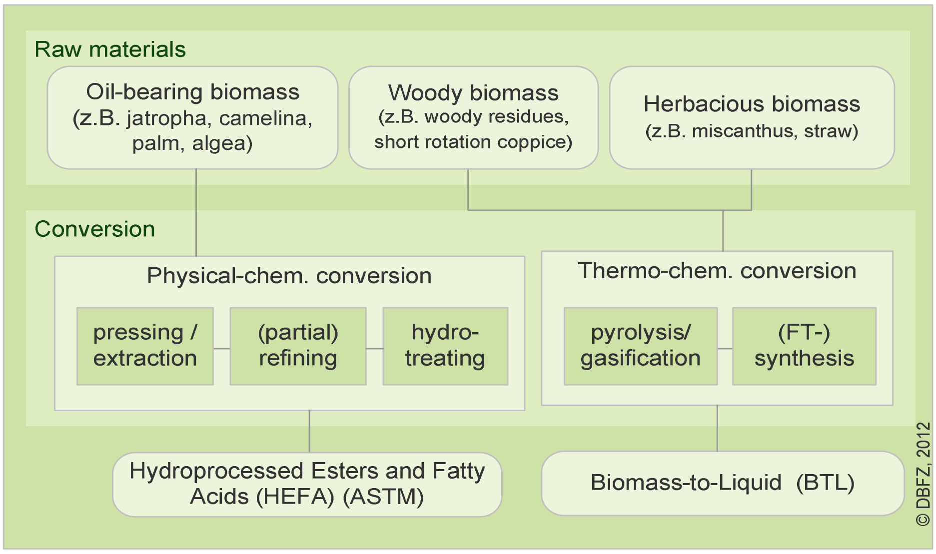

Figure 8. Biofuel options for aviation

HEFA technology is based on the hydro-processing of natural oils and fats (broadly a triglyceride mixture) (Blakey et al., 2011). The products that can be hydrotreated are many e.g. palm oil, soybean oil, coconut oil, rapeseed oil, corn oil, sunflower oil, tallow, used cooking oil (UCO), jatropha oil, babassu oil, etc. Approximately 1.2 t of vegetable oil are required for 1 t of HEFA fuel, which corresponds to 83 % conversion efficiency from vegetable oil to fuel (UOP; 2005), (European Commission, 2003). Taking into consideration oil content of 20 up to 30 % for palm, at least four to five tonnes of palm fruits are required for one ton of HEFA.

One of the main advantages of the HEFA route is that it is possible to integrate this process into an oil refinery, avoiding the need to develop a dedicated production facility (Bauen et al, 2009), but the co-processing with fossil fuels has not been established so far (Seiffert et al. 2011). HEFA as fuel is so far produced from the company Neste Oil Oyj under the name NExBTL. Capacities are so far in a range of

- 380000 t/a (Finland),
- 820000 t/a (Singapore)
- 800000 t/a (Netherlands) (Neste Oil, 2010)

The company UOP Honeywell has certain activities ongoing, especially for the provision of HEFA as aviation fuel; however, no large scale production hasyet been established.

The Fischer-Tropsch synthesis is a catalytic chemical process used to produce a synthetic fuel by processing a synthetic gas obtained from the gasification of a feedstock. Within the FT synthesis the conditioned synthesis gas is converted into liquid and solid hydrocarbons. The resulting products can be distinguished into naphta, diesel or kerosene and waxes as well as combustible gases like propane and butane (Beiermann, 2011; Dinjus et al., 2010; RENEW, 2008). With regard to the conversion efficiency so far an amount of five up to six million tonnes of biomass is needed considered for one million of FT-fuel.

Currently a wide range of concepts with different by-products are in discussion. The conversion process itself is characterized through a complex technology. While the pre-conditioning of the feedstock via mechanical-thermal biomass treatment is mature, approaches with pyrolysis and transport of products (e.g. slurry) are still in a research and development stage. So far the gasification, synthesis and fuel treatment is available for fossil feedstocks and established on a commercial scale. With respect to biomass gasification more or less small and medium scale applications are in operation, whereas proven synthesis and fuel treatment is missing. This demands downsizing of the hydrocracking process and the raw product upgrading in refinery concepts has to be further designed (Seiffert et al., 2011).

It can be assumed that in the medium and long term (i.e. from 2020 up to 2025) FT fuel will be available on a commercial scale (Perimenis et al., 2010). But following the announcement of different industrial consortia for the provision of FT fuel, some plants will be commissioned in the next three years:

- Carbo-V-technology with an annual fuel capacity of 23000 t (solid biomass to fuel)commissioning 2014 (Choren, 2010)
- Solena concept with an annual fuel capacity of 47000 t (waste to fuel) commissioning 2014 (Solena, 2010)
- Rentech concept with an annual capacity of 70000 t (biomass to fuel) commissioning 2015 (Rentech, 2011)

3.7 Biojetfuels- current applications

Almost all major airlines have been involved in some kind of test flights with biofuels; Table 2 summarizes the main contributors up to 2011,the number of tests flights continue to grow and indicating the increasing interest in biojetfuels.

Table 2. Alternative fuel trial flights performed up to 2011

Virgin Atlantic	B747-400	Boeing, GE Aviation	23 Feb 2008	Coconut & Babassu	20% one engine
Air New Zealand	B747-400	Boeing, Rolls-Royce	30 Dec 2008	Jatropha	50% one engine
Continental Airlines	B737-800	Boeing, GE Aviation, CFM, Honeywell UOP	7 Jan 2009	Algae and Jatropha	50% one engine
JAL	B747-300	Boeing, Pratt & Whitney, Honeywell UOP	30 Jan 2009	Camelina, Jatropha, Algae blend	50% one engine
Qatar Airways	A340-600	Airbus, Shell	12 Oct 2009	GtL (not biofuel)	50% four engines
KLM	B747-400	GE, Honeywell UOP	23 Nov 2009	Camelina	50% one engine
United	A319	Rentech	30 Apr 2010	GtL (not biofuel)	40% two engines

TAM Airlines	A320	Airbus, CFM	23 Nov 2010	Jatropha	50%
Interjet	A320-214	CFM, Safran EADS, Airbus, Honeywell	1 Apr 2011	Jatropha	27% one engine
Air China	B747-400	Boeing, Pratt & Whitney, Honeywell UOP, PetroChina	2011	Jatropha	50% one engine
Jet Blue Airways	A320	Airbus, IAE, Honeywell	2011	TBC	TBC

Sources: Garham, 2011; ATAG, 2011

All the trials testing biojetfuels have been performed with only one engine using the alternative (the other using kerosene); generally they last around two hours and are based on a program that includes normal flight phases as well as simulated incidents, with little or no adverse effects reported so far.

The military industry is also heavily involved in testing biojetfuels, particularly the USA Air Force. For example in 2009 the USA military started trials with biojetfuels and has used thousands of litres of HEFA from feedstocks like camelina, jatropha and algae. And in March 18th 2011, the US military has reported a test flight that broke the sound barrier using camelina biofuel in an F-22 Raptor (Business Wire, 2011). More interestingly, the USA Air Force has flown the first aircraft in a mixture of ethanol called Alcohol-to-jet or ATJ[9].

[9] See www.ecoseed.org/renewables/bioenergy/ethanol/15100/)

4. **FEEDSTOCK ASSESSMENT**

The chief aim of this section is to provide an overview of the challenges posed by the feedstocks. Focus will be on the most economically suitable feedstocks that do not compete with food production e.g. algae, jatropha (see Table 3). In the short term it is recognized that the most readily available feedstock are palm oil, soybean oil and rapeseed oil. However, these are major edible oils and should not be considered as a major source for biojet fuel.

4.1 Overview of the most promising feedstocks

From a purely technical perspective there are many biomass feedstocks that can be used to produce jet fuel. Economically, however, the options are limited to a handful of feedstocks. Based on the available and expected technologies oily and lignocellulosic feedstock are most promising. Oily feedstock can be produced on cropland and shows a wide range of area specific yields (figure 9). These are conservative estimates for well established cropland - crop yields vary widely.

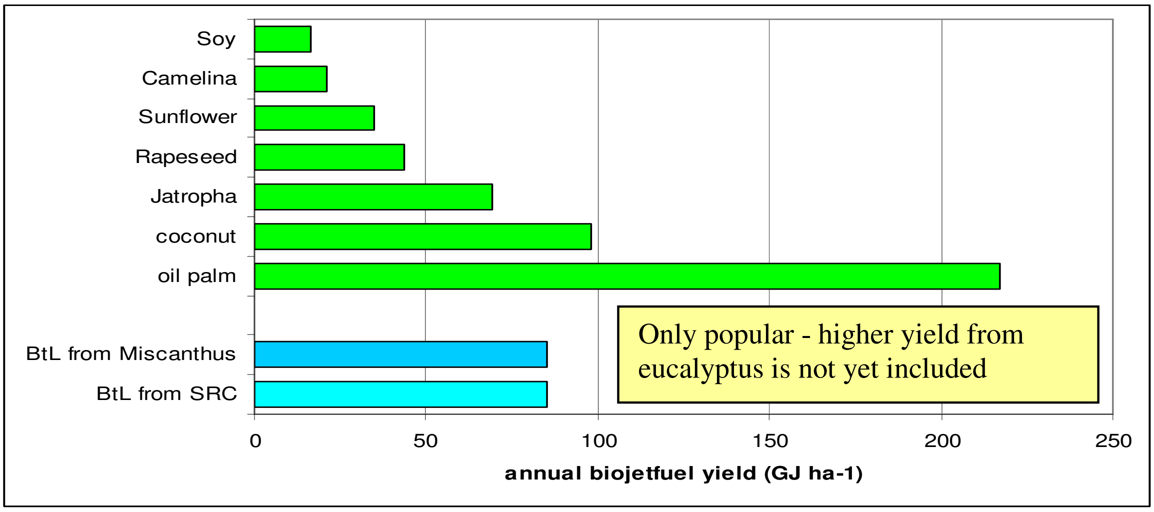

Figure 9. Typical biojetfuel yields from different feedstock (data from Addison 2001)

Productivity in dry seasons and on marginal lands might achieve only a small percentage of these values. The typical annual biojetfuel yield can be taken for a rough estimation of the potential cropland demand of global biojetfuel strategies; for dedicated projects the choice of the crop depends on the particular situation.

Kaltschmitt (2009) calculated conversion rate for BtL at 43%. Lignocellulosic feedstock can also be produced on cropland with more or less comparable biojetfuel yields. Additionally lignocellulosic residues can be taken as feedstock for BtL production. There are different residues connected to land use (forest residues, straw, hay etc.) with typical annual biojetfuel yield of 5 – 20 MJ/yr. The global potential of those residues consists of about 100 EJ/yr (Thrän, 2011). Compared to those residues, biogenic oily waste is produced in comparable small amount (Cullingford, 2009, Agusdinata, 2011).

Feedstock production, either from 1G, 2G or 3G, cannot be separated from the wider context of land use or agriculture. Biofuels need land and land is limited while demand on such land is increasing all the time, not less for food production- its main function, but for many other non-energy uses. Thus the finite availability of land and increasing demand for multiple applications is the key to the success or failure of biofuels. However, this is a very complex issue beyond the scope of this report (e.g. see Rosillo-Calle & Johnson, 2010).

Increasingly, wastes have been gaining popularity, as a viable feedstock alternative, low carbon fuels, especially amongst UK based airlines. Waste evade the issues associated with fuel crops, such as direct and indirect land use change, water requirements, fertilizer requirements, air and water quality, land and labour rights, etc. Most importantly there is potential for huge cost savings e.g. only cost associated with collection, treatment and conversion.

Interest in waste feedstock is well illustrated by the recent deals between Virgin Atlantic Airways and LanzaTech (VAA, 2012) and British Airways and Solena (ATAG, 2011). LanzaTech provides new technology that is a bolt on technology to existing steel mills, chemical production facilities and oil refineries, which captures waste carbon monoxide and converts this to ethanol (LanzaTech, 2010). This is then further converted into jet fuel via Swedish Biofuels technology (VAA, 2012).

Solena is also a waste to energy plant sited in East London, UK, that aims to convert waste normally destined for a landfill into a gas and subsequently use Fischer-Tropsch technology to convert the gas to a synfuel (ATAG, 2011).

Feedstocks receiving the greatest attention at the moment are summarised in Table 3. A major concern is the limitations of feedstock quantity and quality, since only a few feedstocks meet the requirements to produce the strict physical and chemical characteristics of jet fuel. Each crop has benefits and drawbacks in terms of costs, available quantity, yields, etc. Feedstock supply is further compounded by the fact that there are competing uses for biomass e.g. heat, electricity, chemicals, etc.

Table 3: Characteristics of the most promising (non-food) feedstocks for biojet fuel

Feedstock	Brief Description	Pros	Cons
Jatropha curcas	Non-edible, evergreen shrub, produces oily seeds (30-40%), lifetime of 30 years; resistant to drought	Can grow on marginal land and as a hedge	Marginal land means marginal yields, at least unpredictable yields (Herreras, 2010).
Camelina sativa	Edible oil crop, requires little water and fertilizer; short growing season; can be grown in rotation with wheat	By products can be used for animal feed	Depresses growth of nearby plants (PFAF, 2010)
Salicornia bigelovii	Halophyte so grows in salty marshes; seeds are 30% oil;	Can be integrated with fish farming and mangrove (Charlesworth 2010)	Low yields (606 L/ha) versus Japtropha (>1500L/ha) (Garnham, 2011)
Algae	Can be growin in photobioreactors or open raceways (Wenner, 2009) on non-arable land, variety of water sources	Fast growth rates high photosynthetic efficiency, high value co products; can recycle CO2, Algae can be genetically modified to produce specific by-products (lipids) as a result of their metabolic activity.	Economics entail very high degree of uncertainty, high capital costs, require high cost, long term investments; oil extraction can be complex

Source: See Garnham (2011) for further details

Feedstock growth depends on the different climatic conditions, soil types, water availability, etc. As such biofuels have to be treated on a local and regional basis, while the problem that needs to be solved is of a global nature. In 2011, the Air

Transport Action Group (ATAG) published a series of global initiatives being carried out to bring aviation biofuels to commercial status. This shows the diversity of alternatives under consideration with no clear winner, at least for the time being.

4.1.1 Algae

Algae have been heralded as almost a "miracle crop" for biodiesel-like production due to their production potential and many claims have been made which cannot be substantiated. A large number of studies have been carried out to assess the potential of algae as feedstock for biodiesel production e.g. Darzins et al (2010) Bioenergy (2011), Florentinus et al (2008). The latest authors have estimated the global potential of microalgae grown in open oceans at over 6,000EJ/yr plus hundreds more inland. Some studies have stated potential yields as high as 150,000 litres/ha/year of algal oil, however these estimated yields are quite optimistic.

The IEA Bioenergy (2011), quoting various sources, puts the demonstrated productivity at 3,800 litres/ha/yr of algal oil and the future potential at 50,800 litres/ha/yr. Whatever the claims, it is clearly too early yet for any realistic assessment of the potential for algae production and large scale commercial exploitation, it is probably not possible before 2020.

Algae offers benefits as it can be grown on non-arable land and would not, necessarily, compete with food crops, it can also achieve high yields and thrive in brackish and salty water. However, algae grown in open raceways are susceptible to contamination, while photo-bioreactors have been associated with high capital costs. The harvesting and extracting of algae oils can be energy and economically intensive and are not technically fully mature to date. Not surprisingly, there is a consensus among the realm of different stakeholders, from airlines to algae oil producers, that a combination of factors such as, rising oil prices and optimized biofuel yields, as well as governmental subsidies are all required to bring this technology to the commercial level (Gallagher, 2011).

Ultimately algae, as any other feedstock, face various serious stumbling blocks that need to be overcome before becoming a commercial reality:

- High productivity, while at the same time keeping the amount of water and land within reasonable limits
- The ability to be produced sustainably and in large scale Overcome many economic and technological hurdles

4.1.2 Jatropha

Recently jatropha production has been much promoted as an option for biodiesel-like production. Jatropha is a rapidly developing area but detailed knowledge of yields under plantation conditions and best agronomic practices are still largely unknown. Jatropha is a small tree native to Mexico, Central America and some parts of South America but it is now found in many tropical countries/regions such as India, Southeast Asia and Africa. A 2008 report (GEXSi 2008) identified 242 jatropha growing projects covering 936,000 hectares (21,000 in Latin America, 119,000 in Africa and 796,000 in Asia). There is, however, much uncertainty surrounding the precise area under jatropha cultivation as there are substantial data discrepancies (Morgan, 2011).

The choice of location for jatropha plantations does not depend only on the suitability of the climate and land quality, but factors such as government policies (which can include biofuel mandates and subsidies, specific jatropha policies, as in the case in India, for example; and land designation schemes, or more general tax and investment policy), play a significant role.

Jatropha has been proposed as a serious alternative because it offers, potentially, social and economic benefits e.g. it is produced by small landholders, small and large companies and also NGOs, governmental agencies, etc are actively involved. This is because it was generally accepted that it can grow on poor soils and required low rainfall. Reality however, is different as jatropha to be profitable, requires modern agricultural management, reasonably good soil and abundant water, either rainfall or irrigated land which contradicts many of the earlier expectations.

Land and water use are at the core of jatropha production. Portrayed as a crop that does not require good land and little water, however data from current plantations are contradicting these prescribed requirements, as these elements appear to be the key to high productivity of jatropha. An initial review of available sources suggests that far less information is available on the water requirements of jatropha compared to for example maize. This is probably due to the fact that interest in jatropha has been a relatively recent phenomenon. Jatropha is still a predominantly a wild plant and there is limited research projects that have looked at the relationships between farm management practices and yields. This indicates that it may take several years before robust experimental results can be reported (Morgan, 2011).

Many studies have tried to estimate water use, but few have yet to produce reliable results. Table 4 summarises the relationship between water use and productivity of Jatropha Curcas. As can be appreciated, there is a strong relationship between water and productivity.

Table 4 Seed and oil yield results under different irrigation levels

Seasonal Water Applied (mm)	Seeds (kg ha^{-1})	Oil Fraction in Seed	Oil (kg ha^{-1})
55.7	114.75	0.25	28.69
44.6	195.08	0.30	58.39
33.4	103.00	0.29	30.17
22.3	90.42	0.25	22.15

(Source: Quoted from Morgan, 2011; Abou Kheira & Atta, 2009)

There are many publications with data on yields, but there is also an enormous range e.g. from approx. 300 seeds/kg/ha to around 8,000seeds/kg/ha. Jatropha production also varies considerably depending of location, varieties, management practices, etc. The literature also shows that there are significant variations in the methods for extracting oil, for example, Morgan (2011), quoting various sources, indicated an average efficiency of 60% when using a hand power press, 62-80% for mechanical press and between 38-100% when using chemical extraction.

To conclude there is definitely not enough information available currently to quantify with any confidence the water usage associated with jatropha used for biodiesel production. For example, the production of 1 litre of biodiesel could take anywhere between 3,213 litres of water or 778,025 litres of water (huge range!). Considering the fact that water shortages are predicted in many parts of the world, a very serious question that needs to be asked is, if effectively, using jatropha is a realistic alternative.

4.1.3 *Camelina Sativa*

There is ample literature on *Camelina sativa* (e.g. see www.wikipedia.org/camelina), an annual plant which reaches maturity between 80-100 days. Although this plant has been cultivated as an oilseed for its high oil content (c.40%), recently it has caught the attention as a biofuel feedstock given its high potential. The following reasons have been put forward:

- Pproductivity can be increased considerably, even in low-rainfall, non-irrigated areas
- It has been proved to be an excellent jet fuel which also fits into conventional petroleum infrastructure
- *Camelina* has potential to be a large-scale and low-cost, sustainable biofuel feedstock for aviation
- It can be produced on poor land (possibly in underutilized & degraded land)

The USA military has been testing camelina as a jet fuel for many years. A study carried out by the Biomass Advisor Group (http://biomassadvisors.com/blog/thinking/reports) estimated that about one billion gallons (3.785 Billion litres) of biofuels from Camelina could be produced by 2025[10]. According to Moser (2010), Camelina shows excellent promise as a significant source of “drop-in”. It may be that *Camelina Sativa* will become an important biodiesel-crop but this will take years.

4.1.4 Salicornia bigelovii

Salicornia bigelovii is a species of flowering plant in the amaranth family, also know by the common names dwarf saltwort and dwarf glasswort. This plant is gaining scientific attention for its potential to serve as an oil crop; as it can be grown in desert

[10] Camelina Aviation Biofuels -Market Opportunity and Renewable Energy Strategy Report,"

environments and be maintained with water containing high levels of salts. The plant is up to 33% oil (www.wikipedia.org/wiki/Salicornia_bigelovii)

5. EXPECTED COST AND COMPETITION

5.1 Expected production costs for biojetfuels

Because aviation biofuels are not currently being produced on a commercial scale, there is still a great degree of uncertainty over its production costs. Various studies have tried to estimate such costs for HEFA and FT technologies. Bauen et al., (2009) estimated a cost of approximately 2.8-3.7 USD/gallon (0.74-0.97 $/litre) based on edible oil prices (soy, palm and rapeseed) and the application of the same jet spread that applies to traditional jet fuels. With regard to expected cost development, some significant differences of the cost structure of HEFA and FT have to be considered.

5.1.1 Hydrogenated Esters and Fatty Acids (HEFA)

The biofuel production costs for HEFA include the costs of the raw vegetable oil and the subsequent conversion into the jet fuel including transport from the mill to the refinery. Between the single vegetable oils significant differences occur. Since vegetable oil from established crops like palm, soya or rape result in production costs of 130 up to 390 €/t of oil, especially for vegetable oils like jatropha, production costs occur up to 1000 €/t of oil. The difference between the production costs of the single vegetable oils – especially between the commodities and jatropha – is mainly caused by the cultivation area and the expected yields. Furthermore, the entire raw material provision chain of commodities is fully mechanised, while for jatropha, manual steps (e.g. harvest) still have to be considered.

Thus, the bandwidth of raw materials shows that commodities are characterised by lower supply costs and therewith, from the current economic point of view are beneficial in terms of large scale production of biofuels for aviation. The production costs of HEFA fuels are according to literature in a range of 900 up to 1300 €/t of fuel including the costs for the raw material used. With feedstock costs (vegetable oil) accounting for almost 60to 70% of the total costs.

5.1.2 Fischer-Tropsch-fuels (FT)

Basically, for the production of FT biofuel via gasification of solid biomass the assortments logging residues, short rotation coppice and straw are from the current point of view interesting. Depending on the place of origin as well as the type of conditioning, the production costs of forest residues are in a range of 30 up to 180 €/t dry matter. For wood from short rotation coppice, current production costs range between 60 to 70€/t dry matter. The agricultural residue straw has current production costs of 40 up to 70 /€/t dry matter depending on the type of grain and the location.
The production costs of FT biofuel from solid biomass are in literature varying depending on the conversion concept. While for the *bioliq* concept conversion costs are stated with a volume of approximately 660 €/t fuel within the concept of Choren the costs for biomass conversion are in a range of 1100 €/t fuel. According to the IEA entire production costs of BtL were around 1 €/l fuel in the year 2010, with projection of 10 to 15% cost reduction until 2015 und 20% up to 2030. With respect to the results of SWAFEA production costs of 0.8 up to 0.9 €/l fuel until 2015 and 0.6 up to 0.8 €/l until 2030 can be expected.

5.1.3 Cost reduction potential for biojetfuels till 2020

The comparison between production costs for HEFA and BtL shows that feedstock production costs differ significantly, mainly due to the higher costs for oil crops during the phases of cultivation and harvest, than for lignocellulosic crops.

In terms of the expected cost structure for biofuels an overview of the production costs of HEFA (based on palm oil) and FT biofuel (based on forest wood) is given in Figure 10. It is shown how biofuel conversion costs will develop considering the current discussed cost structures for both fuels and assuming progress ratios from technical learning between the first ant the 10^{th} conversion plant installed. Within this figure for raw material costs the current feedstock prices are considered (palm oil with 750 €/t and woody biomass with 125 €/$t_{dry\ matter}$). The results for FT-fuel show production cost to range from 1500to 1800€/t, for HEFA-fuel it is in the range of 1200 to 1300€/t.

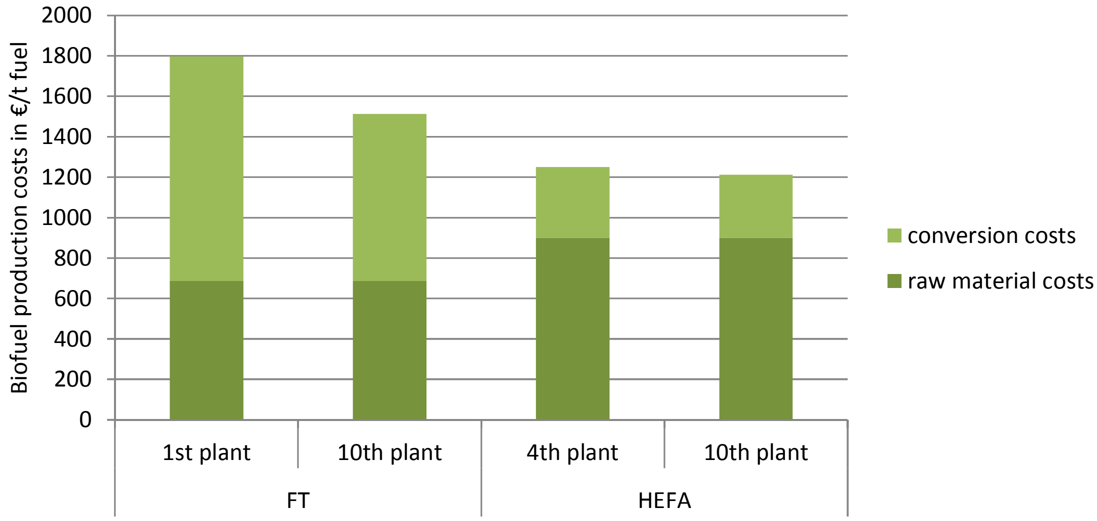

Figure 10. Development of conversion costs for different biojetfuel pathways (DBFZ, 2012), (Lange. 2008), Maniatis, 2011)

With regard to the feedstock costs no cost reduction for the considered raw materials was assumed. The magnitude of cost reductions in the field of biofuel production through scaling and learning effects depends on the development of installed total capacities and utilized plant sizes. In this context the so called progress ratio is of importance. This criterion defines the cost reduction factor for an investment, if the number of conversion plants is doubled. The progress ratio depends on the learning potential of a single technology (Lange, 2007).

Between single technologies the progress ratio varies significantly. The HEFA conversion technology can be considered as a mature technology or as an incremental improvement. Thus, the progress ratio can be assumed in the range of 0.95 (Lange, 2008). This results in an overall investment cost reduction potential of 88 % comparing the first (current plants) and 10th HEFA plant.. For FT conversion technology significant challenges are still given, thus the improvement can be assumed as fundamental. Maniatis assumes a progress ratio for FT fuel of 0.85 (Maniatis, 2011). This results in an overall investment cost reduction potential of 42 % comparing the first and 10th FT plant.

For FT fuel the conversion costs have a major influence on the production ranging between 55 to 62 %. Additionally, the biomass costs show a larger range within the

FT concepts, than the raw material costs for HEFA production. However, the costs for the HEFA feedstock significantly dominate the cost structure with 72 to 74%.
For HEFA the expected cost reduction in terms of technological development is comparably moderate. The current discussed raw material option results in a high bandwidth since for commercial crops significant lower provision cost result than for non-commercial crops. Thus, it can be assumed that only a cost reduction potential might be given for non-commercial crops in future (in comparison to the current status), whereas for agricultural commodities higher market prices can be estimated.

When FT conversion technology will be established in a commercial scale significant reduction for capital expenditures can be expected. But still, there is a wide range of uncertainties in terms of plant reliability and feedstock supply. Similar to the HEFA concept, higher costs for solid biomass as feedstock for FT production is assumed, since the global demand for forest biomass is rising.

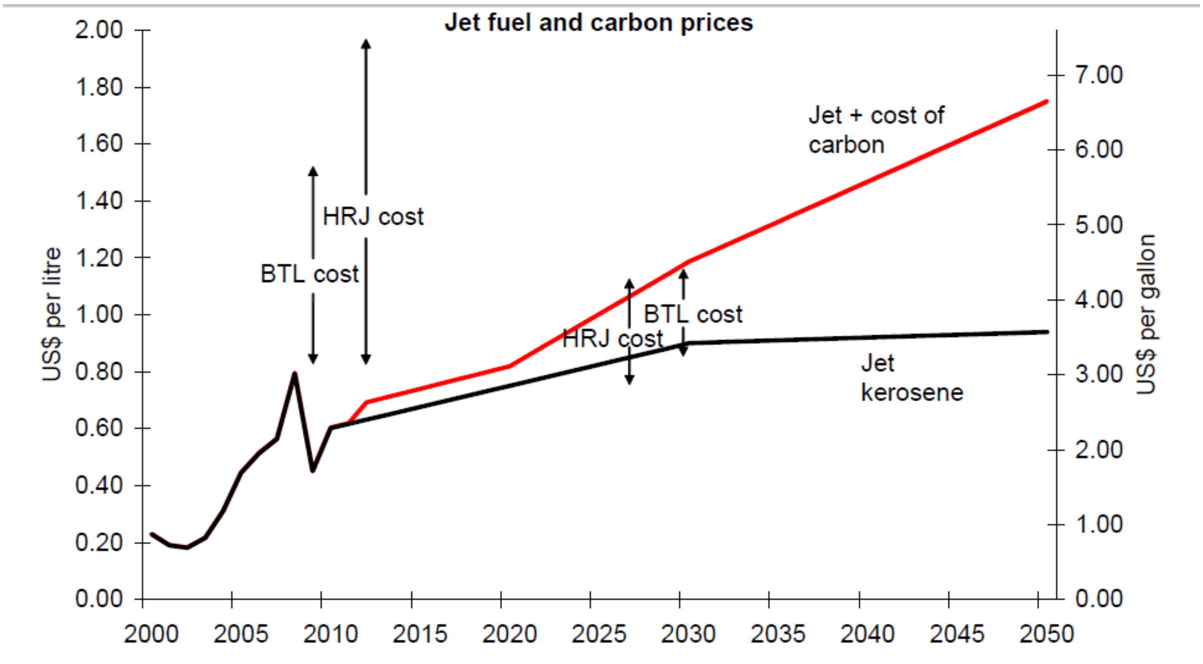

Figure11. Fossil and biomass based jet fuel costs and carbon prices /IATA economics & IEA/

Figure 11 shows the expectation of IATA,deriving how aviation biofuels could become price competitive, due to the combination of two main effects; i) traditional jet fuel price increases (especially when a carbon cost is incorporated) and ii) biofuel production costs diminishing. Considering the cost expectation for the different cost factors described above, the expected costs for the production of biofuels against this background are quite ambitious. In this context major cost reduction for the provision of HEFA can only be achieved with decreasing feedstock costs.

5.2 Feedstock market competition

Competition for biomass resources is bound to increase significantly given the range of end-uses in addition to food, e.g. energy, chemicals and many natural products. A considerable challenge is to increase the availability of biomass, without negatively compromising food security. For biofuels there are five main competing factors:

- Competition with other land use requirements for food, fodder and other bioenergy applications
- Competition with other renewable energy carriers at the end use e.g. wind power
- Competition with other non-energy applications other than food e.g. chemicals and natural products
- The competition for environmental use of land (i.e. biodiversity, carbon stocks in soil, sustainability standards (see Sect. 5.3)
- Completion with fossil fuels in all these applications

An in the specific case of biojetfuels, there is an additional competing factor:

- Competition with other bioenergy pathways (i.e. electricity, biofuels for transport (road, marine, etc)).

This competition depends on demanded fuel qualities, catchment areas for the feedstock, conversion and infrastructure. Regional bioenergy supply chains for specific biomass (i.e. biogas, combustion technologies) do not necessarily compete with large scale biofuel provision; this is because the facilities have access to dedicated distribution channels only. Additionally, this depends heavily on the options for alternative fossil fuels and renewable supply systems, which could be used in periods of high oil prices. With regard to alternatives from other renewable energy carriers e.g. heat and power, different options are being considered today and in times of rising fossil oil and biomass prices, those options are preferable from an economic standpoint. Thus, the main competition could be expected to come from biofuels use in road transport, especially heavy-duty transport like trucks, where their use is more widely established. However, it needs to be noted that different markets have to be expected: while biojetfuels have to fulfill a worldwide coherent standard of fuel quality and sustainability and needs to be delivered to very few, but very big selling points (airports), liquid biofuels for road transport can also be provided in a wider range of qualities and central productions systems and not necessarily need to be traded internationally.

5.3 Sustainability and certification issues

Sustainability presents a big challenge and also an opportunity but there must be a fair playing field for all energy sources. To be viable in the long term a fuel needs to be environmentally and economically sustainable. There is a general consensus in the aviation industry that any biofuel used in the sector should comply with the sustainability criteria developed for road transport. IATA (2010) identifies the most relevant standards for biofuels as; the Roundtable on Sustainable Biofuels (RSB), the US Renewable Fuel Standard (RFS) and the EU Renewable Energy Directive (RED). The first one is a voluntary multi-stakeholder scheme, and the other two are regulatory initiatives of the US and Europe.

IATA (2010) identifies the main sustainability criteria for biofuels and provides a comparison of the sustainability issues covered by each standard (see **Error! Reference source not found.**5**)**. SAFUG (Sustainable Aviation Fuel Users Group), a body formed in 2009 encompassing large stakeholders in the airline business and representing 25% of aviation fuel demand, is also collaborating in the harmonization of standards across different regions (SAFUG, 2010).

Currently, there are only two certified pathways for jet fuel production from biomass. These are the high temperature gasification of biomass and waste, followed by a Fischer-Tropsch reaction of the syngas, to form synthetic paraffinic kerosene or Bio-

SPK (EC, 2012) and via the hydro-treatment of vegetable oils and fatty acids (HEFA) and the conversion of hydrogenated pyrolysis oils (HPO) (Bloomberg, 2012).

Issue	RFS	RED	RSB
1. Regulation (R) or Voluntary (V)	R	R	V
2. Applied to Aviation Biofuels	√	X	X
3. Biofuel GHG LCA Saving Threshold	• 20% renewable fuel • 50% biomass based biodiesel	• 35% – all biofuels • 50% – all biofuels (from Jan 2017)	50%
4. Indirect Land-use Change Included in LCA	√	x	X
5. Unauthorized Land Categories	Limited	• High carbon stock • High biodiversity	• Based on land-use impact assessment
6. Local environmental issues: water, air and soil	X	√	√
7. Fertilizer and Pesticide Management	X	x	√
8. Waste Management	X	x	√
9. Invasive Species Controls	X	x	√
10. Genetic Engineering Controls	X	x	√
11. Land Rights	X	√	√
12. Social: Labor Rights and Welfare	X	√	√
13. Health and Safety	X	x	√
14. Gender Aspects	X	x	√
15. Economic viability	X	x	√
16. Independent Certification	√	√	√
17. Origin and Sustainability Characteristics Traceability	√	√	√

Source: IATA, (2010); Garham (2011)

The challenges of sustainability standards for biojetfuels are their worldwide acceptance. This includes the concrete capability of standards for example between the United States of America and the European Union but also the different expectations of different customers, for example with regard to social standards.

6 POTENTIAL DEMAND ON BIOJETFUELS

An important objective of this section is to present some realistic scenarios for market introduction e.g. amount of land needed for biojetfuels, feedstock supply and costs, amount of biojetfuels under different scenarios, in the short, middle and long term (2020, 2030 and 2050), based on expected demand and conversion technologies. An overview on the many influencing factors is given in Table 6.

Table 6. Drivers with potentially the greatest impacts on the development of biojetfuels use in the mid term

Driver	Factor	Explanation /example
Overall jetfuel demand	Growth of the aviation sector	Strong increases are projected: revenue passenger kilometre: the trend of a 5% increase per year is expected till 2030
	Specific jetfuel demand	50% reduction is projected for 2000 – 2050 with contribution from engine design (20%), airframe design (20%) and air traffic management and operations (10%)[11]
Overall biojetfuel availability	Availability of advanced biojetfuel production technologies	One technical concept is introduced (Hydrogenated Esters and Fatty Acids (HEFA) using oily biomass), second one is still in demonstration stage (Fischer-Tropsch (FT) - synthetic fuels from lignocellulosic biomass), but essential for the market availability of larger amounts of biojetfuels
	Infrastructure and logistics for large scale production	Dedicated infrastructure for (i) biomass provision to the conversion plant, (ii) dedicated refineries, and (iii) biojetfuel distribution from the conversion unit to the airports and airlines
	Progress in plant breeding	Improvement of the yield of oily and lignocellulosic biomass from marginal lands and under physiologic stress (i.e.dry seasons) is demanded
Environ-mental effects	Carbon burden of jetfuels	Increased specific GHG emission from new oil sources (oil sand etc.) lead to higher GHG savings of biojetfuels
	Carbon burden of biojetfuels	GHG emissions from land use related biomass provision are not yet fully understood and might increase the concern of energy crop production (i.e. effects on soil-carbon-cycles)
	Effects of additional green house effects	Aviation currently contributes 2 - 3% of total annual anthropogenic carbon dioxide emissions but possibly as much as 5% of radiative forcing in 2005, including cirrus cloud effects. Those effects are not fully understood and might increase the concern of non-carbon emissions from aviation (Lee, 2009)

[11] source: http://www.worldenergy.org/documents/transportation_study_final_online.pdf

Market develop-ment	Development of the oil price	High oil prices increase the demand for alternative fuels – dedicated biojetfuel pathways can become feasible
	Development of biojetfuel prices	Production costs of FT fuels are still characterised by high uncertainties; production costs of HEFA strongly depends on the feedstock prices for oily biomass
	Development of CO_2 prices and/or further regulations	ETS or alternative economic/normative measures support (or prevent) the market demand for biojetfuels. If specific targets for biojetfuels are set (i.e. quota), the demand will increase, even if the CO_2 reduction costs are high
	Further regulations for other emissions forcing the green house effect	Additional regulation of non-carbon green house effects could force alternative transport systems for /or instead of aviation. Biojetfuels than might play the minor role in fighting climate change
Inter-national trade	Standards for biojetfuel quality	Biojetfuels are delivered to few but very international selling points. Their use demands common technical standards for production, handling and use
	Sustainability certification for biojetfuels	Sustainability certification consists of dedicated criteria and can exclude certain feedstock or pathways. Additionally worldwide comparable systems are necessary to prevent impediments of market development

The market introduction of biojetfuels strongly depends on their technical and environmental performance, as well as the provision of coherent and stable, long term trust worthy market conditions. International agreements are a precondition to deliver the biojetfuels to the big international airports and sell them to international airlines. In all the available scenarios, it is estimated that these hurdles will be overtaken successfully.

Several scenarios for the development of the aviation sector are available. They result in a wide range of expected overall demand for jet fuels, between 16 and 25 EJ/a in 2050 compared to 9 EJ/a in 2010 (IEA 2010, Grimme 2011, SWAFEA 2010). Most of the scenarios expect a strong increase if air traffic, with reduced effects on the overall jet fuel demand because of efficiency improvements.

Based on economic and sustainability assumptions, various studies have projected the potential of biofuels in the aviation but with substantial variations, as illustrated in

Figure12[12]. It is clear from the scenarios of biojetfuel, that demand varies considerably, although all scenarios forecast an increase of biofuels in aviation.

The land demanded for feedstock production does not only depend on the biojetfuel portion but also on the productivity of the land, where the crops are grown. For example, to cover the whole biojetfuel demand of 16-25 EJ/a in 2050 with energy crops, a cropland demand of 150 - 500 Mha would be needed (assuming average yields of 50-100 GJ/ha); while for marginal lands due to lower yield, this increases by a factor of 2 or 3 to more than 1 billion ha of land. However, these assumptions could not be met realistically and be sustainable. The International Energy Agency expects, in 2050, a demand of 100Mha to realise a 27% share of biojetfuels consisting of 6.5 EJ/a, to meet its Blue Map demand.

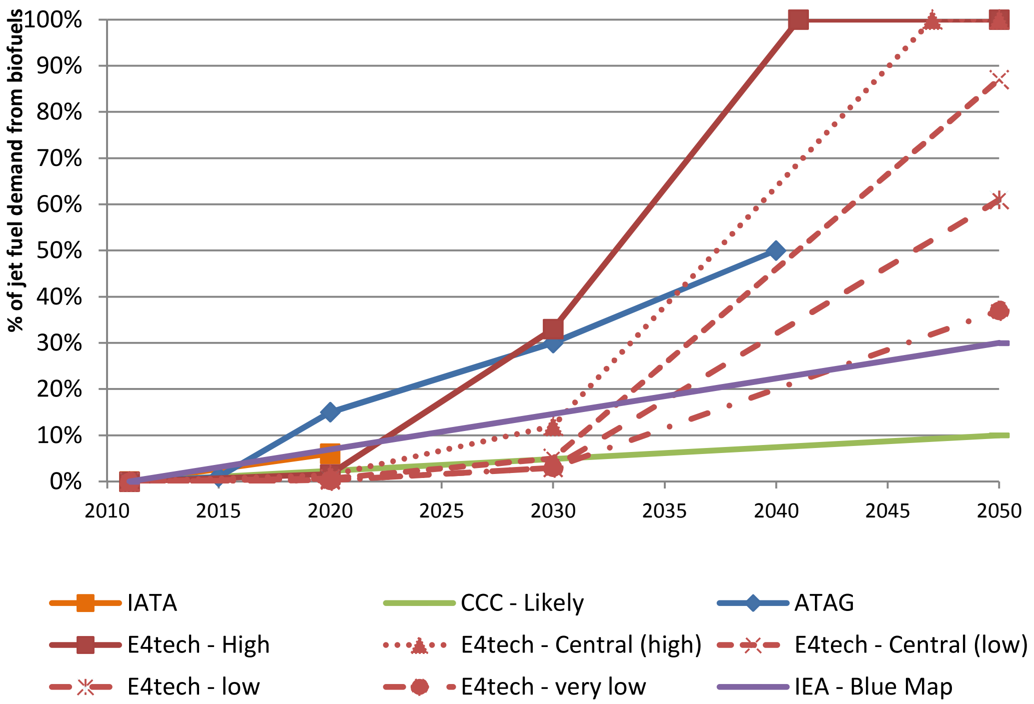

Figure 12. Portion of jet fuel demand supplied by biofuels as projected by different studies.
Sources: (Bauen et al, (2009), IATA, (2010), CCC(2009), Air Transport Action Group (2009); Garnham (2011)

[12] Figure shows data points obtained from different sources. Linear interpolation is shown between data points of same scenarios. This is not necessarily valid in the original forecasts.

7. IMPACTS OF BIOJETFUELS ON INTERNATIONAL BIOENERGY TRADE

The use of biofuels in commercial aviation is technically feasible as shown in this report. However, a remaining stumbling block is the high costs of the feedstocks and their availability in large sustainable scale, as well as biofuel logistics. There is a large financial hurdle involved in bringing the cost of biofuels to such a level, that they become more practical for airlines to purchase in sufficient quantities. There is consensus among academics, consultancies, scientists and airlines that governments must get involved in the form of policy support, R&D and fiscal incentives.

There must also be an internationally agreed standard of addressing aviation emissions. It is crucial that the International Civil Aviation Organization (ICAO) establishes this scheme to address international bunker fuel emissions, under Article 2.2 of the Kyoto Protocol (UNFCCC, 2012), and also to consider the wider implications of the EU ETS and the controversy surrounding it at the moment.

BNEF (2012) indicates that this increase in costs to avoid emissions under the EU ETS is minor compared with the alternative of present day cost of purchasing high quality biofuel blends. As a result, this must work in alignment with other policies that specifically address the R&D of biofuels, in order to accelerate the learning curve bringing biofuels to commercial scale and cost competitive prices. Without this balance, airlines would be left with little option and would be forced to pay the EU ETS fees.

A major concern is with the limitations of feedstock quantity and quality, since only a limited number of feedstocks meet the requirements to produce the strict physical and chemical characteristics of jet fuel, as discussed previously. Each crop has benefits and drawbacks in terms of costs, availability, yields, etc. Increasingly wastes have been considered a viable feedstock option as stated above. Feedstock supply is further compounded by the fact that there are competing uses for biomass e.g. heat, electricity, chemicals, etc, as discussed in Sect. 6.2. Given the large uncertainty in the future demand for aviation fuel it makes it difficult to estimate if biomass can displace enough fossil fuel to meet the carbon reduction targets exists.

Logistics also remain a concern, as the quantities of biofuels available at the main aviation hubs, remain a challenge and so does the transport from the producer to the airport. Adjusted frame condition for international trade is demanded for the majority of the biojetfuels. About 50% of the current cargo and passenger transport is organised in less than 50 airports worldwide. Figure 13 shows the world’s busiest airport hubs which are located in USA, Western Europe, China and Japan. Biojetfuels could be available in major international “hubs” from which they could be distributed to airlines from a major supplier. However, most big airlines have their own “hubs” (i.e. BA uses Heathrow as its main distribution centre) and therefore, this will require strong cooperation between airlines and biofuel providers.

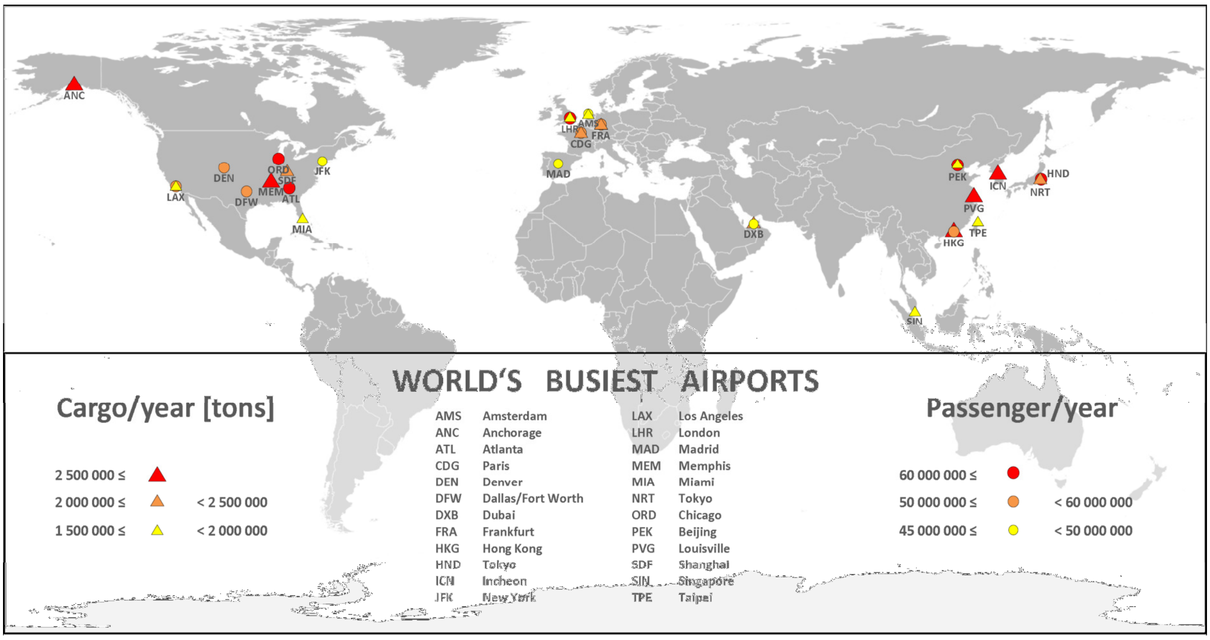

Figure 13: Map of the world‘s busiest airports with data from THE PORT AUTHORITY OF NY & NJ.

Under the different kind of uncertainties (table 6) it is extremely difficult to provide any reliable forecast as to the potential international trade of biojetfuels. As shown in Figure 12 demand for such fuels vary considerably e.g. from about 9EJ in 2010 and between 16 to 25EJ in 2050 (roughly between 375 to 575 Mt). Given the nature of the airline industry, most of the biofuel would have to be traded internationally in one way or another. If we take a consumption of 368 to 575 Mt of aviation fuel by 2050, ata blend of 10% biojetfuel, the potential trade of biojetfuel will be between 36.8 and

57.5 Mt by the same year (or 1.6 and 2.5EJ), to be in the conservative side. 2.5EJ biofuels is the amount of road transport biofuel used in 2010 worldwide, and which was mainly bioethanol and biodiesel produced from rape seed, palm oil, soy oil, sugar cane, corn and wheat. Also those biofuels are traded internationally (Junginger et al 2008).

The commercial aviation has witnessed important technical changes in recent years brought by growing competition. This acceleration has also reduced the life cycle and production run of each new model of aircraft. These developments, in turn, have forced the major manufacturers to drive efficiencies in the production processes, fuel efficiency, etc, (IATA 2011b). Such developments will facilitate the introduction of alternative fuels.

However, at present in the aviation industry there is only one thing agreed upon for certain, this is the expansion of the industry.

8. MAIN CONCLUSIONS

This report has assessed the main determining factors shaping the use of biofuels in commercial air transport. As stated, aviation is a global industry with global problems and challenges that also demands global attempts and solutions. There are many challenges and uncertainties to solve before biojet fuels can be used in aviation in any significant scale. Major advances are necessary in the feedstock production and supply as well as conversion. The main conclusions of this report are:

- Demand for aviation fuel is expected to increase by approximately 1.5 to 3% per year. The environmental impact of the aviation industry is also projected to increase, but remain uncertain.
- The International Air Transport Association is committed to achieve carbon neutral growth by 2020 and 50% reduction by 2050. A major step has also been the introduction of the European Emission Trade System (EU ETS).
- The aviation industry is very keen to develop alternatives to kerosene. Concerns regarding security of supply, environmental issues and policy are key drivers. Biojetfuels are seen, currently, as one of the best short to medium term alternatives.
- Total demand for commercial aviation fuels vary considerably e.g. from approx.9EJ in 2010 and between 16 to 25EJ in 2050 (roughly between 375 to 575 Mt).
- Projections on the use of biofuel in the aviation industry, vary significantly, from 100% of the aviation fuel could be supplied in 2050 to 10%
- Uncertainties on the achievable environmental effects by biojetfuel substitution are reported, concerning the no-carbon greenhouse effect of the air traffic and the greenhouse gas emissions of land use change cause by biojetfuel feedstock provision. Therefore, even in an advanced biojetfuel scenario the aviation sector will continue to cause an increasing portion of greenhouse effects until 2050.
- In the short term, HEFA appears to be the most promising alternative to supply significant amounts of biofuel for aviation
- In the medium term, the most promising alternatives for aviation biofuels is FT-fuel a drop-in fuel alternative. FT is still in the phase of development and is expected to be commercially available in the years 2020 up to 2025

- Most non-food promising feedstocks to be considered are short rotation coppice, woody residues, jatropha, camelina; for the longer term biojetfuels could include algae, and halophytes, for example.
- Aviation biofuels tests have been technically and safely successful.
- The certification process is being adapted to incorporate the use of biojetfuels and is not expected to be an obstacle for its deployment in the medium term, though this will add additional costs.
- Production costs remain the main stumbling block, but are expected to fall when more capacity is installed. Some studies project that they may become price competitive with a carbon taxed jet fuel by 2020-2030.
- The potential for international trade in biojetfuels appears to be high but it is difficult to provide reliable figures. But using some rough estimates, as indicated above, taking a consumption of 368 to 575 Mt of aviation fuel by 2050, at a blend of 10%, the potential trade of biojetfuel will be between 36.8 and 57.5 Mt by the same year (or 1.6 and 2.5EJ).

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