Omega

Aviation in a sustainable world

International Conference on Alternative Aviation Fuels

Main thematic Area: Technology

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Royal Aeronautical Society, London
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About Omega

Omega is a one-stop-shop providing impartial world-class academic expertise on the environmental issues facing aviation to the wider aviation sector, Government, NGO's and society as a whole. Its aim is independent knowledge transfer work and innovative solutions for a greener aviation future. Omega's areas of expertise include climate change, local air quality, noise, aircraft systems, aircraft operations, alternative fuels, demand and mitigation policies.

Omega draws together world-class research from nine major UK universities. It is led by Manchester Metropolitan University with Cambridge and Cranfield. Other partners are Leeds, Loughborough, Oxford, Reading, Sheffield and Southampton. Launched in 2007, Omega is funded by the Higher Education Funding Council for England (HEFCE).
www.omega.mmu.ac.uk

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Contents

1.0 Introduction

The issue of alternative fuels is currently attracting considerable attention. The aviation sector needs to know whether this effort is leading towards a real possibility that alternative fuels could be used in aircraft or whether they will be limited to land based applications. There are a number of potential routes available, for example synthetic kerosene or Fischer-Tropsch fuels from coal or biomass, but there is also the possibility to use bio-fuels such as Fatty Acid Methyl Esters (FAMEs) in aviation and plans to test these are in hand. The debate surrounding use of alternative fuels involves a wide range of stakeholders within the industry since design and operational issues are involved. It also extends beyond aviation as there are issues of overall carbon efficiency related to the production of alternative fuels and effects upon other users, especially in relation to bio-fuels. This is a topic which is receiving attention internationally: the EU has initiated programmes in this area including for aviation, the US PARTNER programme has been undertaking a well-to-wake study and there are ongoing studies and trials within the aviation and petroleum industries. The UK has undertaken work on a range of alternative fuels environmental performance issues through its study.

2.0 Rationale

This major conference provided a forum to bring together participants from a diverse set of backgrounds representing most of the main players in the aviation and petroleum industries. It allowed industry experts and academics to provide fundamental information, share practical results and explore pioneering research. As a result of which, the current state of knowledge and whether (and which) alternative fuels are a realistic possibility for civil aviation was discussed, and therefore it played a part in helping to determine the next steps for alternative aviation fuels and widened the debate to involve the policy community.

3.0 Conference Outline

The conference programme occupied two and a half days from the morning of the 24th of November to Lunch time on Wednesday the 26th of November. 52 delegates registered for the meeting, along with 22 speakers. The presentations were distributed into six session headings with the titles “From Feedstocks to Aviation Fuels”, “Alternative Aviation Fuel Characteristics”, “Alternative Aviation Fuels Programmes in the US”, “An Industry & NGO Perspective”, “Bringing Alternative Fuels to the Market” and “Research Needs and Long Term Opportunity”. Each presentation was allocated 30 minutes, composed of 20 minutes for the speaker to give the presentation followed by 10 minutes for the audience to ask questions to the speaker. After several presentations, ranging from two to five based on the numbers of presentations related to the session topics, a 30 minute “panel discussion” session was organised, which consisted of all the speakers fielding any further questions from the audience along with a general discussion between all the conference participants on issues arising from the speakers presentations. At the end of the conference on Wednesday morning, a final discussion on all aspects of

the preceding day's events and the way forward was held. Details of the precise programme and conference speakers and delegates are given in Appendices 1 to 2. Thirteen of the presentations given are available for public download as pdf files at http://www.omega.mmu.ac.uk/international-conference-on-alternative-fuels.htm.

4.0 Synopsis of Presentations

4.1 Day 1, Introduction

Andreas Schäfer, "*Alternative Fuels for Aviation: Drivers, Opportunities, and Constraints*". He provided an overview of petroleum product uses and the location of oil reserves, highlighting the major contribution from transport, with details and predictions concerning transport use growth of the order of 300 to 400% by 2050 and the consequent opportunity for alternative fuels to make an impact in curbing future greenhouse gas emissions. He detailed the main assessment criteria to be used with respect to alternative fuels and the lifecycle greenhouse gas (GHG) emissions of various fuels. He finished with a list of constraints to alternative fuels consisting of enormous potential land & water use and problems that may arise in the commercialisation of cellulosic feedstocks.

Piers Foster, "*Climate Implications of Alternative Fuels*". He provided details of radiative forcing attributable to aviation, estimated to account for 5% of the total in 2005. A breakdown of the individual elements of the aviation contribution to climate change was given. The uncertainty over the impact of induced cirrus cloud was highlighted and current knowledge suggests that this would exacerbate the warming effect. An analysis of lifetime effects indicates in the short term that other components than CO_2 have a significant role, but on a long term timescale of 100+ years, CO_2 is the dominant factor. He finished with some thoughts on the integrated system effects of biofuels consisting of tropospheric CO_2 production associated with their production, along with emissions of CH_4, N_2O and isoprene, and concluded that there was a trade off to be made between reduced CO_2 emission from aviation against reduced food production and tropospheric pollution.

4.2 Session 1: From Feedstocks to Aviation Fuels

Ian Shield, "*Biomass Resource Availability*". He began with coarse estimates of total land availability (~15 Mha) and crop yields in the UK, converting that to theoretical upper limits to electricity or diesel production (75 and 85% of 2002 requirements). Then he moved on to what actually could be used (~2.5 Mha) without serious disruption to food supply, with some comments on the best sources being ligno-cellulose based and a discussion of their advantages, with further information on the optimal distribution of miscanthus or willow on the available land. Then he illustrated the effects of breeding programmes on improving yields with an indication of the timeframe involved in the case of Willow. He finished with a discussion of some of the economics affecting farm level decisions in terms of gross margins on cereal and energy crops with the conclusion that current market conditions make it very difficult to interest new growers of energy crops.

Maria Vera-Morales, "*Fuel Cycle Perspectives of Aviation Fuels*". She talked about the use of microalgae to produce fuel, beginning with the current status and highlighting some difficulties, such as the lack of any large scale plant, and issues regarding the choice of algae with trade offs between growth rate and lipid content. An analysis was then presented of a 400 ha open algae system coupled to an anaerobic digester and a 300 MW power plant without carbon capture & storage (CCS), in 2 cases assuming 'state of the art' algae growth rate & lipid content as opposed to some 'future' scenario of trebled growth rate & lipid content. In these cases the savings in emissions per kWh are marginal. However, when the power plant capacity is optimised in size to be of the order of 5 to 22 MW, much greater savings of the order of 36 to 61% are predicted. A brief cost analysis was then presented indicating that current 'state of the art' equates to >$600/bbl, whereas the 'future' scenario equates to >$100/bbl. After brief illustrations of potential land use, and a case study with CCS, the conclusions were summarised as the best terrestrial crops currently have higher yields than the best algae, and that major challenges remain across all the disciplines involved in making the commercial use of algae a reality.

Tony Bridgwater, "*Biofuel Production*". He provided details of 1st and 2nd generation biofuels with comments on their yields and the production of bioethanol, biodiesel, and synthetic hydrocarbons. He then presented information concerning the possible routes to produce 2nd generation synthetic hydrocarbons, broadly classified as thermal gasification, Pyrolysis plus upgrading, and Hydro-processing vegetable oil; with details of the challenges and possible costs. He finished with a broad list of challenges for the future involving improvements in crop yields, lignocellulosics pre-treatment, the demonstration of various technologies relating to C5 sugar fermentation, gasification, cleaning and conditioning, hydrocarbon synthesis, fast pyrolysis etc., and the need to robustly compare alternative systems and reduce costs.

4.3 Session 2: Alternative Aviation Fuel Characteristics

Ramya Venkataraman, "*Thermal Stability – Barrier or Opportunity?*" He made some comments on definitions of fuel stability and the JFTOT specification test. The factors influencing fuel degradation were explained and the typical temperatures at which pyrolytic degradation (>400 °C) and Oxidative degradation (100 to 350 °C) occur. The major driver for increased stability is enhanced efficiency achieved by increased engine cycle temperature. Other drivers include the desire to make improvements to injector design and also to move to lower emission systems. Mitigating actions such as air cooling, heat management of complex injectors and improvements in surface technology were discussed and all have drawbacks in terms of cost, weight, complexity and technology immaturity. Other mitigating actions in terms of improved fuel test methodology and chemical modelling capability were mentioned, and Rolls Royce collaboration with Sheffield in developing improved testing facilities was described. The key challenge for alternative fuels are to ensure 'drop-in' characteristics and they must at least equal current stability requirements.

Phillippe Dagaut, "*Alternative Fuel Combustion Technology*". He described the composition of typical kerosene showing the dominance of n-alkanes. Possible bio-fuels were discussed ranging from alcohols, esters, Fischer-Tropsch synthesis and hydrotreatment. The rest of the presentation concentrated on the detailed chemical kinetic modelling of fatty acid methyl esters (FAME) and surrogate kerosene compounds with comparison against experimental jet-stirred reactor data. The conclusions drawn were that the data and model showed that the FAME/kerosene blend had a slightly higher reactivity at low temperature. No significant effect on ignition was predicted although there is no experimental data to confirm this, and that at <20% FAME there is no major impact on the oxidation kinetics of the fuel. The further requirements are for more validation of the proposed kinetic schemes and surrogate model, especially at high pressures which also requires new experimental data that is presently unavailable.

Siân Foster, "*A Change is in the Air: Sustainable Fuels for the Aviation Industry*". She gave the views of Virgin Atlantic on biofuels for aviation. Information on their carbon footprint, and future targets of enhanced fuel efficiency and reduced energy consumption was presented. Details of the background to their demonstration flight of 24th February 2008 were given, the main aim of which was to prove that use of biofuel in civil aviation is possible. The blend had to pass a flash point range (38 to 80 °C), freeze point (<-40 °C), density range (750 to 840 kgm^{-3}) along with further tests on viscosity, energy density, thermal stability and emissions. A FAME derived from babassu and coconut oil was chosen in a 20% blend with kerosene. No performance difference was observed in flight, and post flight checks identified no issues. Issues remain in terms of availability, acceptance, and approval, which require the movement to 2nd or 3rd generation biofuels. But there is a strong business case to pursue these and Virgin anticipates biofuels to contribute 5% of its fuel use by 2015 and >10% by 2020.

4.4 Day 2, Session 3: Alternative Aviation Fuels Programmes in the US

Carl Burleson, "*Commercial Aviation Alternative Fuel Initiative (CAAFI): An Overview*". He began with outlining the challenges consisting of increasing transport reliance, price volatility, climate issues and energy security. He then gave some details of US strategy to reduce carbon intensity and how this includes use of alternative fuels. Then he proceeded to discuss the structure of CAAFI and the parts played by the individual components in R&D, fuel certification, environmental impacts, and the economics. Regarding Alternative fuels in aviation, he concluded there are various reasons for optimism in terms of the existence of fuel options, the effort to certificate these at an accelerated pace, and the commitment of fuel users. However reasons for caution also exist headed by the technical difficulty, safety, and competition from ground users.

Philip Whitefield, "*Inter Comparisons of PM and HAP Emissions from a CFM56 Engine Burning Bio, FT and Conventional Fuels*". He gave details of various fuels and fuel blends tested (Jet A, Jet-A1, 20% ester in Jet-A1, 40% ester

in Jet-A1, 50% Fischer-Tropsch (FT) in Jet-A1, 100% FT). Gaseous emissions were shown largely to be independent of the fuel, the main exception being a distinctive hydrocarbon speciation for alternative fuels. Particulate emissions showed a reduction for all fuel blends, the greatest reduction being for the 100% FT fuel. He finished with details of a future measurement campaign to be performed in 2009.

James Hileman, "*PARTNER's Life-Cycle Analyses of Alternative Jet Fuels*". He began with the motivation for life-cycle analysis in terms of emissions and climate change, air quality and the cost of Jet fuel. He described the lifecycle modelling tools PARTNER used with the aim being to quantify the impacts on air quality and climate change. Initially some "tank to wake" and then "well to wake" results were described. Alcohols were discounted as not viable for aviation use. Coal-to-liquid via FT with CCS have comparable lifecycle greenhouse gas emissions to conventional fuels, and without CCS, lifecycle GHG emission at least doubles. Alternative fuels exist that could both reduce lifecycle CO_2 and improve air quality (e.g., biojet and biomass-to-liquids via FT process), but at present the ability to produce these fuels is limited.

David Paisley, "*Boeing Alternative Fuels Initiatives*". The presentation gave details of Boeing's goal to focus on sustainable biofuels that have low life-cycle CO_2 emissions. This is defined as being from plant sources that are sustainable in terms of not competing for food production, and promoting local and regional solutions and economies. Boeing require a high productivity, economically viable product ($70 to $90/barrel) that meets a series of technical requirements to be compatible with existing systems. The main options Boeing are focussed on are cellulose based fuels produced via enzymatic/microbial conversion, or plant oil based that are hydrotreated, or a combination of low temperature hydrocracking and hydrotreatment. These have an advantage in Fuel quality over biodiesel fuels, and a reduced process energy requirement with respect to FT based fuels.

4.5 Session 4: An Industry and NGO Perspective

Alisdair Clark, "*General Aviation – Alternative Fuels and Future Trends*". The presentation examined the option fuels and issues related to 'light' piston engine aircraft in the niche area of General Aviation. To be viable, alternative fuels must meet key requirements especially in terms of temperature and pressure performance (-50 to 40 °C, 1 to 0.3 atm) as well as having reasonable energy density, and handling and storage properties. Various possibilities were discussed in the presentation. In summary, Aviation Gasoline (AVGAS) alternative fuel options are focusing on an unleaded fuel with some bio-component proposals. Whereas Jet alternative fuel options are following Commercial aviation initiatives, a significant challenge at present for GA is to match the performance, viability and the proven record of existing fuel.

Rob Midgley, "*Alternative Aviation Fuels – Current Options and Challenges*". He gave some background on the "Anything to liquids" (XTL) process that converts any carbon and energy feedstock via the FT process and looked at the

CO_2 impact. Their analysis suggested that without CCS and/or the use of a biomass feedstock, no CO_2 saving could be made. A more detailed discussion of coal and coal/biomass to liquid conversion followed before moving on to Gas-to-liquid and Biomass-to-liquid. The final part of the presentation dealt with the use of natural oils, and the need to hydrotreat them to produce a kerosene type fuel, with the main short to mid term constraint being available feedstock volumes and economics. Bio oils derived from the thermo-chemical treatment of biomass were discussed; the main drawback being the heavy refining required to make transport fuels. In summary, the main challenges seen relate to the capital costs of FT plant, and the challenge of feedstock costs for hydrogenation routes, with a final comment that Aviation has fewer fuel options which are technically more challenging than other sectors.

Jeff Gazzard, "*Alternative Aviation Fuels – Spin or Substance*". He began with some statistics on climate change in the Northern hemisphere, followed by current and predicted emissions from aviation showing a potential doubling of CO_2 emissions by 2015. UK targets of a 60% reduction (now 80%) in CO_2 emissions by 2050 were contrasted with projected aviation emission increases on this timescale. Discounting enhanced radiative forcing, half of the 2050 target emissions were estimated to be from aviation. With enhanced radiative forcing taken into account there are estimated to be more emissions from aviation than the total UK target. Some discussion of the proposed EU ETS followed, with the observation that it would have a minor impact. Discussion of alternative fuels took place along with observations on the land use requirements. His final conclusions were that environmentally FT was not feasible without CCS, but that no industrial scale CCS is currently planned with the costs being in his words "astronomical". Regarding biomass from plants, they have problems in their production, distribution, and viability, and similarly for algae.

4.6 Session 5: Bringing Alternative Fuels to the Market

Jerry Tucker, "*Approving Alternative Jet Fuels*". The presentation commenced with a frame-setting aim of the fuels community and certification authorities to broaden the scope of jet fuel specifications to allow new sources and processes in order to diversify the supply sources. There was specific interest in synthetic fuels, and also an interest in fuels from renewables to mitigate CO_2 emissions. A description of the Sasol alternative fuels already produced followed, along with discussions of the Jet fuel certification process. A proposed way forward is to build on the Sasol experience to produce a generic approval for up to 50% FT kerosenes in "Def Stan 91-91". There is a commitment to look at other fuel sources and processes as they mature from the laboratory and pilot scale, and if necessary, make further specific approvals. However, the goal is to modify the specification in future to allow generic approval. Therefore currently, the proposed changes will only allow synthetic paraffinic kerosenes via the FT process, subject to constraints of a minimal final aromatic content amongst other conditions.

Aaron Berry, "*Early Experience in Operating the RTFO*". He gave a brief introduction to the background to the Renewable Transport Fuel Obligation (RTFO) and discussed "well to wheel" GHG savings for a variety of ethanol and biodiesel sources. He then moved onto "carbon and sustainability reporting" of data on targets up to 2011 with the aim of a 50% GHG saving by then in the renewable fuel component. A breakdown of current feedstocks was presented (Soy>Oilseed rape>Sugar Cane, accounting for 68% between them) with 9% of the total being UK sourced, and only 20% meeting the qualifying environmental standard against a current target of 30% which increases to 80% by 2011. Statistics on individual company performance was then presented, 2 currently meet all targets, 4 meet no targets. The talk moved onto future developments describing the Europe-wide "Renewable Energy Directive" due in April 2010 requiring 20% of energy use across Europe to be renewable energy by 2020, 10% of which must be in road transport, and concluded with the observations that the sustainability of biofuels is a major challenge and that technological advances are likely to be critical.

4.7 Day 3, Session 6: Basic Research Needs and Long Term Opportunity

Chris Wilson, "*Alternative Fuels in Gas Turbines*". He discussed the objectives of the Omega Sustainable fuels for aviation study to evaluate the relative environmental and economic impacts of potential sustainable alternative aviation fuels. He discussed the merits of alternative fuels in terms of what practically could be used, in essence a "drop in fuel" identical or "close enough" to kerosene to allow the hardware to be unchanged. The impact of various alternative fuels on flight range capability was illustrated with associated issues mentioned such as aircraft/engine design, emissions and noise. FAME manufacture was discussed along with some typical trace component levels for various elements and metals of the order of 2 to 3 orders of magnitude higher than standard diesel, along with a note that the kerosene specification requires no metals. GTL fuel composition measurements were shown, and compared to typical Jet A-1. Combustion performance in terms of spray and ignition performance of kerosene and 25% biodeiesel blends was described, and the impacts tabulated of biodiesel for various fuel properties relevant to the aircraft and engine performance. Materials compatibility testing primarily in terms of elastomer properties was described, and also a hot-end engine test facility to simulate the turbine environment in order to investigate fuel and additive effects on hot-end materials; with ongoing issues related to engine component life, and fuel handling and storage.

Alison Smith, "*Biofuels from Plants and Algae*". She began with some background into the estimated potential of various renewable energy resources and the observation that solar energy is 4 orders of magnitude greater than any other (geothermal wind etc.). At 1% photosynthetic efficiency, 5% of the available land could in theory supply half the predicted 2050 world energy requirement. She then briefly discussed some of the issues with 1st and 2nd generation biofuels. The presentation then moved on to discuss the potential advantages of algal biomass, these principally being they are not in competition with food production, potentially

the rate of growth is much higher than land plants, and some strains may produce high quantities of fuel molecules. Constraints for commercialisation were then discussed, for instance the choice of algal strain and the trade off between growth and optimum lipid yield, or the choice between photobioreactors, open ponds or other options. The major problem at present is one of scale and being able to produce enough biomass. No definitive solution was offered, the observation being made that for large scale implementation, integration of biology and engineering will be vital.

Robert Whitfield, "*Some Emerging Sustainable Feedstocks*". He began with a "sustainability overview" and some principles for example with respect to food security and land use with strategies to address these by the use of drought tolerant plants, algae, and salt-water plants. A brief summary of the recent Algal Biomass Summit in Seattle followed, in terms of species, companies, technology and costs, a key conclusion being that all projects implicitly acknowledge the need for sales of co-products in order to make algae oil profitable. The remainder of the presentation dealt with "Integrated Seawater Agriculture", a combination of fish/seafood farming, halophyte cultivation and salt production, and its many potential benefits. In terms of biofuel production, the main plant species is "Salicornia bigelovii Torr.", a halophyte capable of growing in the high salinity of sea water. Some details of this were given along with the properties and composition of the oil it produces. The benefits of Integrated Seawater Agriculture were summarised as follows: There is about 40,000 km of desert coastline which provides a huge potential for exploitation that is not in conflict with food production or fresh water use, the combination of uses allows costs to be shared thus making biofuel production financially viable, and the pumping of seawater from sea to land could in principle reduce current rates of sea level rise.

Kevin Hughes, "*Alternative Fuels Database*". He gave some details of the current state of the Alternative Fuels Database, its aims being to provide a single source of relevant data for individual fuel components sourced from the available literature. In constructing the database, the principle methods of accessing the available literature were stated as being either the Chemical abstracts Service online, or the NIST Chemistry WebBook. Illustrations were then given of the use of these 2 data sources. The final part of the presentation gave some details of the database itself, constructed with Microsoft Access 2007, with illustrations of the current database structure and some questions regarding its future.

5.0 Summary of Discussion

As a result of the presentations, questions, and panel discussions, the following points regarding various aspects of the subject were made.

5.1 Feedstocks for Alternative Aviation Fuels

It is clear that biomass resource availability is a major constraint, brought about by a combination of land and water requirements with many speakers on all 3 days

commenting on these points. First generation biofuels based on foodstuffs (for example sugar, wheat, corn, vegetable oils) have been important in introducing biofuels and increasing awareness, but in the future, higher potential yields and the absence of competition with food, give second generation biofuels, based on for example the processing of lignocellulosics, a clear advantage. Several speakers commented on the potential of algae, with its advantages of potentially a higher growth rate, reduced land use and higher lipid content, however it was pointed out that this is not currently feasible on a commercial scale and much work remains to be done to rectify this and also make it economically viable. The use of halophytes was noted as potentially having a big contribution to make in the future. These were claimed to be economically viable due to various synergies with associated fish/seafood farming and other co-products. Additionally halophyte production has the advantage of being sustainable as it can exploit large areas of currently unproductive desert land thus providing a biofuel source free of competition with fresh water usage and food production.

5.2 Engineering Issues

These were not considered to be a major problem, and a number of trial flights have been made or scheduled under limited conditions (Virgin Atlantic, New Zealand Airways, and Continental). Thermal stability has not proved to be a problem so far, but there was considerable discussion about the need to remove metals in the context of engine component lifetimes, to the effect that FAME's with their high contaminant levels are not considered a feasible long term aviation fuel, and that synthetic kerosenes produced for example via the FT process represent a much more viable alternative. A number of speakers gave information on the US alternative aviation programmes, these included FAA, MIT and Boeing as well as contributions from the UK (Shell, BP). The weight penalty or reduction in flight range capability caused by the use of alternative fuels containing oxygen was discussed, which could favour the use of synthetic kerosene type fuels over FAME's.

5.3 Approval/certification of fuels

This is a complicated process involving many aspects of the fuel performance as well as combustion properties. These are a variety of things such as cold flow properties, the level of allowable contaminants such as metals, thermal stability, and compatibility with existing engine components and fuel system seals. The current status is that a generic approval exists for up to a 50% synthetic FT based kerosene blend with a commitment to look at other fuel sources as they mature from the laboratory scale and make specific approvals as required, with the aim of allowing generic approvals later.

5.4 Scientific Issues/Climate Effects

There is a reasonable understanding of alternative fuel combustion chemistry, both the FAME type and synthetic kerosenes, and several studies have been made on the fundamental combustion characteristics indicating no particular problems in using alternative fuels, although more experimental studies are desired related to high

pressure combustion along with chemical model validation at these conditions. There was considerable discussion concerning the climate effects, including emission of CO_2, black smoke, and NOx. Concentrating on CO_2 as the main concern, forecasts of future aviation contributions to 2050 CO_2 emissions targets were made, with potentially ~50% of allowed emissions originating from aviation in some scenarios where reliance was solely upon fossil-based aviation fuel. Various lifecycle analyses were presented. While synthetic FT kerosenes may be the best option from an engineering perspective in terms of a "drop in" alternative fuel, if these are produced from coal the lifecycle greenhouse gas emissions at least double. Even the use of CCS in such circumstances only brings the lifecycle greenhouse gas emission back to the level of conventional fuels, and to make any CO_2 emission reductions requires the use of biomass feedstocks.

5.5 Economic Issues

Various analyses of costs were presented. The profitability of biomass production from a UK farming point of view in relation to conventional food crops was assessed. Current market conditions make it difficult to attract new growers of energy crops, implying no large scale increase in UK land based biofuel sources in the foreseeable future. To be viable at current market conditions, the goal is to produce an alternative fuel at the order of $70 to $90 per barrel. Lifecycle analyses of costs in relation to algae production indicated a current "state of the art" figure of ~$600 per barrel with ambitious future process improvements reducing this to ~$100 per barrel, including the contribution from valuable algal co-products. Therefore, accepting that these potential improvements in algae derived biofuel are achievable, it may be possible that in the future commercial algal sources of biofuels are viable. An alternative are halophyte biofuel sources, claimed to be economically viable and environmentally sustainable from the one presentation concerning them.

6.0 Concluding Remarks; Basic Research Needs, Long term opportunities

As a result of these individual presentations and various discussions, the following issues were clearly identified:

1) The major issue is the large scale economic supply of a sustainable fuel. For example in terms of the UK RTFO, currently supplying 2.61% of UK road transport needs, ~80% is sourced from first generation feedstocks such as Soy, Oilseed rape, Sugar cane and Palm oil. By 2020 EU regulations envisage 10% of all European transport requirements being met by alternative fuels, therefore requiring a quadrupling in supply from the current level. It is clear that even this proposal which still leaves 90% of transport needs dependent on conventional fossil fuels will cause major problems without significant progress in the commercialisation of alternative feedstocks that do not compete with food production, based on the processing of lignocellulosics, algae, and halophytes. These alternatives were demonstrated as having potential, but significant technological and economic hurdles remain to be overcome before they will be ready for large scale use in transportation.

2) From the Engineering and Certification perspective, demonstration flights have occurred with no issues raised in terms of the engine performance of alternative fuels as blends with kerosene. Concerns were raised over the metal contaminant levels of FAMEs that preclude their commercial use in aviation because of adverse lifetime effects on hot engine components. The favoured alternative fuel for aviation is a “drop in” fuel allowing current hardware to be used without modification. The main candidate therefore is synthetic kerosene produced via the FT process converting coal or a biomass feedstock. Coal may satisfy the requirement of a secure supply, but even with CCS it will not lead to any reduction in GHG emissions, and therefore a conversion of biomass via FT with CCS is the desired solution. Alternatives such as enzymatic/microbial conversion, or plant oil based that are hydrotreated, or a combination of low temperature hydrocracking and hydrotreatment, as discussed by the Boeing representative may be more energy efficient than the FT synthesis, but these remain to be demonstrated on a commercial scale. Total replacement of kerosene does not seem feasible at this time, as current fuel certification demands a minimum aromatic component in terms of the properties of the fuel with respect to elastomer seal performance.

3) Regarding the Scientific perspective, fundamental chemical kinetic modelling and validation against experiment, along with experimental tests of the spray combustion of alternative fuels indicate that the combustion performance of alternative fuels is reasonably well understood, and is similar to conventional kerosene combustion, although a need remains to validate the high pressure performance and chemical models of FAME based fuels.

4) In terms of GHG emissions, if nothing is done then aviation is projected in some scenarios to account for 50% or more of a 60% (now 80%) UK target for CO_2 emissions reduction by 2050. Use of the favoured option of synthetic kerosene as an alternative aviation fuel will require the use of CCS to make any significant progress in reducing aviation GHG emissions. This target pressure is also serving to accelerate work addressing the potential of biofuels.

Finally, it was recognised that there was a need for a future updating conference on the same topic bringing together UK stakeholders and academia. This could concentrate on the economics of the first, second, and third generation routes to alternative fuels and the effect of the possibility of carbon taxes.

7.0 Glossary

1st generation biofuels

Biofuels produced from sources directly in competition with food production, typically from sources such as starch, sugar, animal fats and vegetable oil.

2nd generation biofuels

Biofuels produced from non food crops, consisting either of waste biomass from food production, or specific energy crops such as willow or miscanthus.

3rd generation biofuels

Algae based biofuels, with the potential to be much more efficient than traditional land based crops.

Biodiesel

A biofuel produced from vegetable oils or animal fats by a transesterifaction chemical process.

Cellulosic / lignocellulosic feedstocks

Feedstocks derived from the cell walls of either the non edible components of food crops, or specific energy crops, including wood based.

Chemical kinetic modelling

The prediction of the time evolution of the individual chemical species concentrations and temperature in a reacting mixture of chemicals.

Fatty Acid Methyl Esters

The generic name for the chemical species produced by the transesterification process in the production of biodiesel.

Fischer-Tropsch

The name for the process by which a mixture of carbon monoxide and hydrogen is converted with the aid of a catalyst into a liquid hydrocarbon.

Gasification

The process by which a solid or liquid biomass is converted into carbon monoxide and hydrogen by the reaction at high temperature with a controlled amount of oxygen and/or steam.

Hydrocracking (and Hydrotreatment)

The process where complex organic compounds are broken down in the presence of hydrogen to produce saturated hydrocarbons, at the same time removing sulphur and nitrogen by their conversion to hydrogen sulphide and ammonia.

Jet A (and Jet-A1)

Standard jet fuels meeting defined physical and chemical criteria.

Kerosene

A hydrocarbon liquid produced by the fractional distillation of petroleum between 150 and 275 °C containing carbon chain lengths of 12 to 15 carbon atoms.

Lifecycle greenhouse gas

An assessment of the greenhouse gas emission, usually carbon dioxide, made over all the distinct processes of a fuel's life, consisting for example of the production, distribution, and combustion of the fuel in question.

Microalgae

Microscopic algae that are unicellular species existing individually or in chains or groups with sizes in the micrometer to hundreds of micrometer range.

Miscanthus

A type of grass suitable for biofuel production as a result of its high growth rate.

Photobioreactors

A closed vessel system providing light, water and nutrients for the production of Algae.

Pyrolysis

The degradation of complex chemical species into smaller species by the use of heat in the absence of oxygen.

Radiative forcing

A term in Watts per square metre that describes the perturbation of the energy balance between incoming solar radiation and outgoing radiation at the boundary between the troposphere and stratosphere.

Tropospheric

Dealing with the lowest portion of Earth's atmosphere, typically to a height of 7 miles at mid latitudes.

Well-to-wake

The analysis of any quantity associated with the several distinct stages of a fuels life, from the initial fuel extraction or production, it's refinement, distribution, storage, and use.

Appendix 1: Conference Programme

Omega International Conference on Alternative Aviation Fuels Programme
Royal Aeronautical Society, London
Monday 24 – Wednesday 26 November 2008

Monday 24 November 2008
Chair: Alan Williams, University of Leeds

09.00 – 11.00
Introduction

09.00	Registration and Coffee	
09.45	Roger Gardner (Omega)	Introduction / Opening Address
10.00	Andreas Shafer (Institute for Aviation and the Environment, The Martin Centre for Architecture and Urban Studies, Cambridge University).	Alternative Fuels for Aviation: Drivers, Opportunities and Constraints
10.30	Piers Forster (University of Leeds)	Climate Impact Considerations for Alternative Fuels

11.00 Coffee and Tea

11.30 – 14.00
Session 1: From Feedstocks to Aviation Fuels

11.30	Ian Shield (Rothamsted Research)	Biomass Resource Availability
12.00	Maria Vera-Morales (University of Cambridge)	Fuel Cycle Perspectives of Aviation Fuels

12.30 Lunch

13.30	Tony Bridgewater (Aston University)	Bio-fuel Production
14.00	Panel Discussion	

14.30 – 17.00
Session 2: Alternative Aviation Fuel Characteristics

14.30	Ramya Venkataraman (Rolls Royce plc)	Fuel Thermal Stability

15.00 Coffee and Tea

Monday 24 November 2008 cont …

15.30	Phillippe Dagaut (CNRS, Orleans)	Alternative Fuel Combustion Chemistry
16.00	Sian Foster (Virgin Atlantic Airways Ltd)	A Change is in the Air: Sustainable Fuels for the Aviation Industry
16.30	Panel Discussion	
17.00	End of Day One	

17.00 Conference Reception

Tuesday 25 November 2008

Chair: Chris Wilson, University of Sheffield

08.30 Registration and Coffee

09.00 – 12.00

Session 3: Alternative Aviation Fuels Programmes in the US

09.00	Carl Burleson (Federal Aviation Administration, FAA)	CAAFI Alternative Fuels Programme
09.30	Philip Whitefield (Missouri University of Science & Technology)	Inter Comparisons of PM and HAP Emissions from a CFM56 Engine Burning Bio, FT and Conventional Fuels

10.00 Coffee and Tea

10.30	James Hileman (Massachusetts Institute of Technology, MIT)	Partners Life-Cycle Analyses of Alternative Jet Fuels
11.00	David Paisley (Boeing)	Boeing Alternative Fuels Initiatives
11.30	Panel Discussion	

12.00 Lunch

13.00 – 15.00

Session 4: An Industry & NGO Perspective

13.00	Alisdair Clark (BP Product Quality and Aviation Team)	General Aviation – Alternative Fuels and Future Trends
13.30	Rob Midgley (Shell Aviation Limited)	Alternative Aviation Fuels – Current Options and Challenges

14.00 Jeff Gazzard (Aviation Environment Federation) — Alternative Aviation Fuels – Spin or Substance

Tuesday 25 November cont ….

14.30 Panel Discussion

15.00 Coffee and Tea

15.30 – 17.00

Session 5: Bringing Alternative Fuels to the Market

15.30 Jerry Tucker (Ministry of Defence) — Approving Alternative Jet Fuels.

16.00 Aaron Berry (Renewable Fuels Agency) — Early Experience in Operating the RTFO

16.30 Panel Discussion

17.00 End of Day Two

Wednesday 26 November 2008

Chair: Kevin Hughes, University of Leeds

08.30 Registration and Coffee

09.00 – 12.30

Session 6: Basic Research Needs and Long Term Opportunity

09.00 Chris Wilson (University of Sheffield) — Alternative Fuels in Gas Turbines

09.30 Prof Alison Smith (Algal Bio energy Consortium, University of Cambridge) — Biofuels from Plants and Algae

10.00 Robert Whitfield (Global Seawater Inc) — Some Emerging Sustainable Feedstocks

10.30 Coffee and Tea

11.00 Kevin Hughes (University of Leeds) — Developments on the Leeds Alternative Fuels Database

11.30 Panel Discussions and The Way Forward

12.30 Lunch

13.30 End of Conference

Appendix 2: Speakers and Delegates

Name	Affiliation	Status[1]
Aaron Berry	Dept for Environment,Food & Rural Affairs	Speaker
Tony Bridgwater	Aston University	Speaker
Carl Burleson	Federal Aviation Administration (FAA)	Speaker
Alisdair Clark	BP Product Quality and Aviation Team	Speaker
Phillipe Dagaut	C.N.R.S Orleans	Speaker
Siân Foster	Virgin Atlantic Airways Ltd	Speaker
Roger Gardner	Omega	Speaker
Jeff Gazzard	Aviation Environment Federation	Speaker
James Hileman	Massachusetts Inst of Technology (MIT)	Speaker
Kevin Hughes	University of Leeds	Speaker
David Paisley	Boeing	Speaker
Robert Whitfield	Global Seawater Inc	Speaker
Jerry Tucker	Ministry of Defence	Speaker
Philip Whitefield	Missouri University Science&Technology	Speaker
Ramya Venkataraman	Rolls Royce Plc	Speaker
Ian Shield	Rothamsted Research	Speaker
Rob Midgley	Shell Aviation	Speaker
Andreas Shafer	University of Cambridge	Speaker
Maria Vera-Morales	University of Cambridge	Speaker
Alison Smith	University of Cambridge	Speaker
Piers Forster	University of Leeds	Speaker
Chris Wilson	University of Sheffield	Speaker
Mohamed Pourkashanian	University of Leeds (OrganisingCommittee)	
Alan Williams	University of Leeds (Organising Committee)	
Mr Audrius Bagdanavicius	Cardiff University	
Dr Joanna Bauldreay	Shell Global Solutions	
Mr Paul Bogers	Shell	
Mr Peter Brook	QinetiQ	
Ms Elena Catalanotti	University of Leeds	
Mr Cheng Chong	Univesity of Cambridge	
Dr Andrew Clague	QinetiQ	
Mr Craig Conlon	University of Leeds	
Mr Jonathan Counsell	BA	
Dr Mike Crompton	Department for Transport	
Mr Justin Cunningham	Professional Engineering Magazine	
Mr Richard Deighton	Omega	
Mr Jon Drapkin	Heathrow Hydrant Operating Co Ltd	

Mr Dominic Duggan	Quantitech Ltd
Mr Colin Dunn	Department for Transport
Mr Bernard Fitzsimons	Aviation and The Environment
Dr John Green	Greener by Design
Mr Martin Hagstrom	FOI
Dr Scott Hartman	Shell
Ms Kathryn Howard	The Ecology Foundation
Dr Oliver Inderwildi	University of Oxford
Dr Ralf Kurtenbach	University of Wuppertal
Dr Hu Li	University of Leeds
Mrs Laura MacIver	Innospec Limited
Mr Dhanish Mahmood	University of Leeds
Dr Nadeem Malik	Queen Mary, University of London
Dr Neal Morgan	Cambridge University
Mr Cesar Mota	Newcastle University
Mr Simon Mulqueen	Innospec Limited
Mr Stephan Naundorf	Bauhaus Luftfahrt E.V
Mr Alexandre Neophytou	Cambridge University
Ms Ana Nieto Riaguas	Repsol YPF SA
Prof Francis Palmer	University of Leeds
Dr David Parmenter	Airbus UK Ltd
Mr Andrea Pastore	Cambridge University
Mr Tom Reynolds	University of Cambridge
Dr Andrew Ross	University of Leeds
Mr Paul Sands	Virgin Atlantic / CATE
Miss Ida Shafagh	University of Leeds
Mr Tim Snijders	T U Delft
Mr Thomas Sondey	Cranfield University
Mr Christopher Surgenor	GreenAir Online
Dr Andrew Sutkowski	Infineum UK Ltd
Prof Murray Thomson	University of Toronto
Ms Aimee Turner	Flight International
Mrs Ilona Uryga-Bugajski	University of Leeds
Mr Agustin Valera	Cardiff University
Mr Matt White	JetBird
Mr Ian Wilson	
Mr John Witton	Cranfield University
Mr Stephen Wright	University of Leeds
Ms Paula Zard	Idext

1) Delegate unless otherwise stated