Chapter 5

ALTERNATIVE FUELS

ICAO
ENVIRONMENTAL
REPORT 2010

Sustainable Alternative Fuels for Aviation

Overview

By ***ICAO Secretariat***

Background

Engineering improvements, technology enhancements, and advanced operations (including efficiency improvements in air traffic management) all have a role to play in reducing aviation fuel consumption and associated carbon emissions. Significant progress has been made in establishing technology goals for reducing aircraft greenhouse gas (GHG) emissions. On a per-flight basis, efficiency is expected to improve continuously through the year 2050 and beyond (see *Climate Change Outlook,* Aviation Outlook of this report).

ICAO is spearheading efforts to promote and harmonize worldwide initiatives for operational practices that result in reducing aviation's contributions to human produced emissions. However, even under the most aggressive technology forecast scenarios, the anticipated gain in efficiency from technological and operational measures does not offset the overall emissions that are forecast to be generated by the expected growth in traffic. To achieve the sustainability of air transport, other strategies will be needed to compensate for the emissions growth not achieved through efficiency improvements.

A promising approach toward closing this GHG emissions mitigation gap is the development and use of sustainable alternative fuels for aviation. Although such fuels already exist, they are not yet available in sufficient quantities to meet the overall fuel demand for commercial aviation.

Drop-in fuels are substitutes for conventional jet fuel that are completely interchangeable and compatible with conventional jet fuel. The reduction in GHG emissions from the use of drop-in fuels developed from renewable, sustainable sources is the result of lower GHG emissions from the extraction, production and combustion of the fuel. Sustainable drop-in alternative fuels produced from biomass or renewable oils offer the potential to reduce life-cycle greenhouse gas emissions and therefore reduce aviation's contribution to global climate change. (see article *Estimating Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels*, Chapter 5 of this report).

Over the short and medium-term horizon, aviation will be heavily dependent on drop-in liquid fuels (see article *Long Term Potential of Hydrogen as Aviation Fuel,* Chapter 5 of this report) and the development and use of sustainable alternative fuels will play an active role in improving the overall security of supply, and will stabilize fuel prices.

The Situation Today

Worldwide interest continues to grow in the development of more sustainable energy sources that could help face the challenge of climate change. For some time now, sustainable alternative fuels for aviation have been the focus of the aviation industry. Today, various consortia for the development of such fuels have been established, as shown in Table 1, and new initiatives are underway. Prospects for the use of sustainable fuels on a commercial scale are now being measured in years, not decades. (see article *Sustainable Aviation Fuel Research*, Chapter 5 of this report).

A broad range of stakeholders from around the world are collaborating to bring new, sustainable, fuels to the market. Of course, safety is paramount, and all aviation fuels must meet the required specifications. (see article *A Global Fuel Readiness Level Protocol*, Chapter 5 of this report).

During the past year, the qualification of some types of fuels was completed, and currently the qualification of others is well advanced. Of particular importance is the ASTM D-7566 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons that was approved on 1 September 2009, since it was the first new jet fuel approval in 20 years! (see article *Proposal to Adopt a Global Fuel Qualification and Certification Protocol*, Chapter 5 of this report).

	Consortia and Research Initiatives
2006	Commercial Aviation Alternative Fuels Initiative (**CAAFI**) formed to promote development of alternative jet fuel options that offer safety, cost, and environmental improvement and energy supply security for aviation
2009	Sustainable Way for Alternative Fuels and Energy for Aviation (**SWAFEA**) is a study for the European Commission's Directorate General for Transport and Energy to investigate feasibility and impact from use of aviation alternative fuels
2010	Sustainable Bioenergy Research Project (**SBRP**) launched to demonstrate the commercial viability of using integrated saltwater agriculture to provide biofuels for aviation
2010	Brazilian Alliance for Aviation Biofuels (Aliança Brasileira para Biocombustíveis de Aviação – **ABRABA**) formed to promote public and private initiatives to develop and certify sustainable biofuels for aviation
2010	Sustainable Aviation Fuels Northwest formed to promote aviation biofuel development in the Pacific Northwest of the United States
	Policies, Methods and Processes
23 April 2009	**EU** requires lifecycle greenhouse gas emission savings from use of biofuels be at least 35% (Renewable Energy Directive 2009/28/EC)
7-9 October 2009	**ICAO** High-Level Meeting on Aviation and Climate Change
14 November 2009	Roundtable on Sustainable Biofuels (**RSB**) published Principles and Criteria for Sustainable Biofuel Production (v.1)
18 November 2009	**CAAF 2009** announces conclusions and recommendations: environmental sustainability/interdependencies, technological feasibility/economic reasonableness, development/use support, and production/infrastructure
18 December 2009	**CAAF 2009** Declaration and Global Framework in conjunction with High-Level Meeting on International Aviation and Climate Change (**HLM-ENV**) outcomes presented as ICAO input to COP15
19 March 2010	US DOD's Defense Energy Support Center (**DESC**) and Air Transport Association of America (**ATA**) sign agreement to combine purchasing power to encourage development/deployment of alternative aviation fuels
	Fuel Certification/Qualification
1 September 2009	**ASTM D-7566 (Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons) approved as first new jet fuel spec in 20 years**
	Tests and Demonstrations
1 February 2008	**Airbus** flew A380 test aircraft with one engine running on 40/60% blend of Gas To Liquid (GTL) synfuel and conventional jet fuel
23 February 2008	**Virgin Atlantic** flew B747-400 with one engine operating on 20/80% blend of babassu oil/coconut oil biofuel with conventional jet fuel
30 December 2008	**Air New Zealand** flew B747-400 with one engine running on 50/50% blend of jatropha derived biofuel and conventional jet fuel
7 January 2009	**Continental Airlines** flew B737-800 with one engine using 50/50% blend of algae and jatropha biofuel mix with conventional jet fuel
30 January 2009	**JAL** flew B747-300 with one engine running 50/50% blend of camelina, jatropha and algae biofuel mix with conventional jet fuel
12 October 2009	**Qatar Airways** flew first revenue flight (London to Doha) on A340-600 with four engines operating on 48.5/51.5% blend of GTL synfuel with conventional jet fuel
23 November 2009	**KLM** flew B747-400 with one engine running on 50/50% blend of camelina biofuel with conventional jet fuel
22 April 2010	**United Airlines** flew A319 with one engine using 40/60% blend of natural gas F-T fuel jet fuel with conventional fuel

See **www.icao.int/AltFuels** for additional accomplishments

Table 1: *Sustainable Alternative Fuels for Aviation Accomplishments.*

It is now an indisputable fact that drop-in alternative fuels are a technically sound solution that will not require changes to the aircraft or fuel delivery infrastructure.

In November 2009, ICAO held a Conference on Aviation and Alternative Fuels (CAAF) to showcase the state-of-the-art in aviation alternative fuels. The Conference also addressed the key issues of sustainability, feasibility, economics, production, and infrastructure. At the Conference, States agreed to develop, deploy and use sustainable alternative fuels to reduce aviation emissions. To facilitate, on a global basis, the promotion and harmonization of initiatives that encourage and support the development of sustainable alternative fuels for aviation, the Conference established an ICAO Global Framework for Aviation Alternative Fuels. It is a web-based living document (www.icao.int/AltFuels). Information about new alternative fuel initiatives and tests to support qualifications appears almost daily.

Current Challenges

Today, sustainable alternative fuels offer the potential to reduce aviation environmental impacts, but are not yet available in quantities sufficient to meet the overall demand by commercial aviation. The cost and availability of sustainable alternative fuels for aviation remain key barriers to their large scale adoption (see article *From Alternative Fuels to Additional Fuels: Overcoming the Challenges to Commercial Deployment*, Chapter 5 of this report).

The testing of new fuels and the establishment of new production facilities require significant capital investment. In addition, since aviation represents less than 5% of the world's liquid fuel consumption, it is possible that fuel producers may initially target larger markets. If the use of alternative fuels is to be part of a comprehensive strategy for minimizing the effects of aviation on the global climate, regulatory and financial frameworks need to be established to ensure that sufficient quantities of alternative fuels are made available to aviation.

As requested by CAAF, ICAO has entered into preliminary discussions with the World Bank and Inter-American Development Bank to facilitate a framework for financing infrastructure development projects dedicated to aviation alternative fuels and incentives to overcome initial market hurdles. Furthermore, the adoption of alternative fuels by aviation might be simpler than for other sectors due to the relatively small number of fuelling locations and vehicles.

The definition of sustainability criteria will determine the types of feedstocks and processes that will be used to produce alternative fuels in the future (see article on *Sustainable Biofuel Raw Material Production for the Aviation Industry*, Chapter 5 of this report). Currently, there is no set of internationally accepted sustainability criteria; however, this issue is not exclusive to aviation.

ICAO's Role in Sustainable Alternative Fuels for Aviation

ICAO has been facilitating, on a global basis, the promotion and harmonization of initiatives that encourage and support the development of sustainable alternative fuels for international aviation. The Organization is actively engaged in the following activities to carry out this facilitation role:

a) Providing fora for education and outreach on sustainable alternative fuels for aviation.

b) Providing fora for facilitating the exchange of information on financing and incentives for sustainable alternative fuels for aviation programmes working with the relevant UN and regional financial entities.

c) Facilitating the establishment of a regulatory framework that assures sufficient quantities of sustainable alternative fuels are made available to aviation.

d) Facilitating development of standardized definitions, methodologies and processes to support the development of sustainable alternative fuels for aviation, taking into consideration the work that has been done so far in this area.

e) Supporting a platform for access to research, roadmaps and programmes.

Conclusions

Sustainable alternative fuels for aviation offer a win-win solution for all stakeholders involved in their development, production, deployment and use. Air carriers will benefit from stabilized fuel prices and supply security. Both developing and developed States will benefit alike from the ability to produce feedstocks and fuels from locations that did not historically produce conventional fuels. Most importantly, the planet will benefit from lower net emissions of greenhouse gasses being released into the atmosphere. ■

Sustainable Aviation Fuel Research

Masdar's Sustainable Bioenergy Research Project

By **Darrin Morgan, Sgouris Sgouridis, Linden Coppell, James Rekoske**

Darrin Morgan *leads strategy development and execution for the Boeing Commercial Airplanes Sustainable Aviation Fuels Program. He is a co-founder of the Sustainable Aviation Fuel Users Group, that accounts for more than 15 % of global jet fuel demand and whose goal is to diversify aviation's fuel supply and reduce lifecycle greenhouse gas emissions.*

Sgouris Sgouridis *is an Assistant Professor in Masdar Institute of Science and Technology. His current research interests focus on sociotechnical systems modeling including sustainable transportation systems and sustainable energy systems management. Dr. Sgouridis is co-PI in on projects related to aviation under carbon-constraints and is co-leading the development of the Sustainable Bioresource Research Project.*

Linden Coppell *joined Etihad Airways in 2009 with responsibility for developing an overall strategy for environmental management. In particular she is ensuring compliance with environmental regulations and developing and implementing programmes for key areas such as carbon and emissions management.*

James Rekoske *is Vice President and General Manager of the Renewable Energy and Chemicals business unit at Honeywell's UOP, a leading developer and licensor of technologies for the production of high-quality green fuels. Prior to this, Jim served as Senior Manager of Catalysis Research and Development for UOP and Technical Director for Petrochemical Catalysts. He was also the Director of Technology for Universal Pharma Technologies, a former UOP joint venture focused on technology and services in pharmaceutical chemistry.*

Introduction

While the benefits of aviation are well known, the aviation industry currently contributes approximately 2-3% of global anthropogenic greenhouse gas emissions. The industry is increasingly aware of the important role it must play in reducing greenhouse emissions and is already taking decisive action. Although, new aircraft technology, fuel conservation and improved airspace management offer the most immediate ways to reduce aviation's environmental impact in the longer term, these advances alone are not sufficient to offset the projected growth in air travel and the associated emissions.

The demand for air transport has increased steadily over the years, with passenger travel, growing by 45% over the last decade, and doubling since the mid 1980s. Sustainable aviation fuels offer the most promising opportunity for reducing aviation greenhouse gas emissions without impinging upon the positive contribution that aviation makes to the global economy. Proven technology has already been developed that converts bio-derived materials into synthetic paraffinic kerosene (SPK). Recent test flights indicate that SPK, when blended with petroleum-based jet fuel in a 50% mixture, meets or exceeds traditional Jet-A1 performance specifications without any modification to the engine or the airframe.

The major challenges now are around agronomy, scale, commercial viability and environmental sustainability. Around the world, emission trading schemes are being developed to reduce greenhouse gas emissions. Under some of these trading schemes, biofuels are 'zero-rated' meaning that they have no carbon liability for the fuel user. While this increases the incentive to develop "drop-in" biofuel solutions that generate lower carbon emissions over the "life cycle", such mechanisms alone are not enough to accelerate the development of a sustainable aviation fuel industry.

This article focuses on the efforts of the Masdar Institute and its partners to develop sustainable aviation fuels through its Sustainable Bioenergy Research Project.

Background

The aviation industry, led by the aircraft manufacturers, airlines and technology companies have proactively sought to undertake initiatives and measures to enable the commercial aviation sector to reduce its carbon footprint.

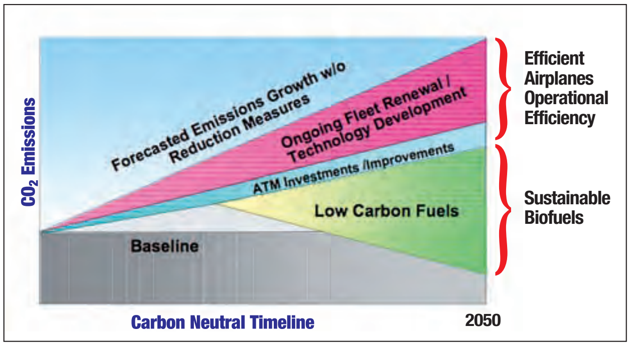

Figure 1: *Aviation industry timeline for carbon neutrality by the year 2050 (Source: Boeing/ICAO).*

Figure 1 depicts the various measures that the aviation sector will need to deploy to enable carbon neutral and/or negative carbon growth over the next few decades. The key point to note is that transitioning to low carbon sustainable aviation fuels is an imperative over and above more efficient aircraft and increased operational efficiencies.

Masdar Institute

In April 2006, the government of Abu Dhabi announced plans to establish an entirely new economic sector centered around the development of a zero carbon city, Masdar. The Masdar Institute of Science and Technology is the centerpiece of that initiative, dedicated to the development and promotion of alternative and sustainable energy. A key initiative of the Institute will be to develop sustainable aviation fuels and biomass-based electricity, working with various partners.

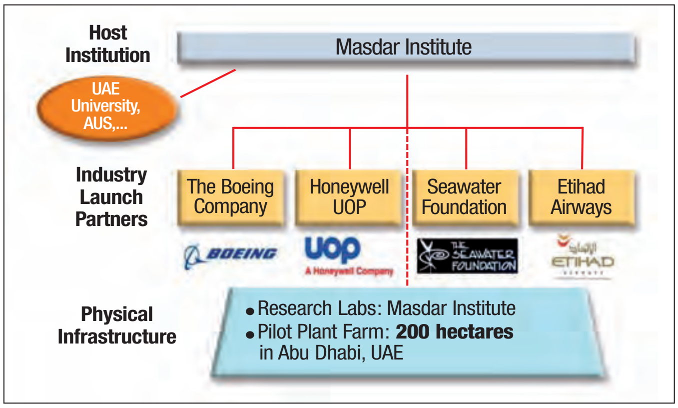

Figure 2: *Masdar Institute, industry partners and infrastructure for Sustainable Bioenergy Research Project.*

The principal activities of the Institute are to:

- Demonstrate and enhance the commercial viability of sustainable biofuel production in arid desert environments using an environmentally sustainable low CO_2 life cycle seawater farming system.
- Dialogue to refine model and attract secondary industry partners over time.
- Conduct research focused on feedstock development and commercial viability.

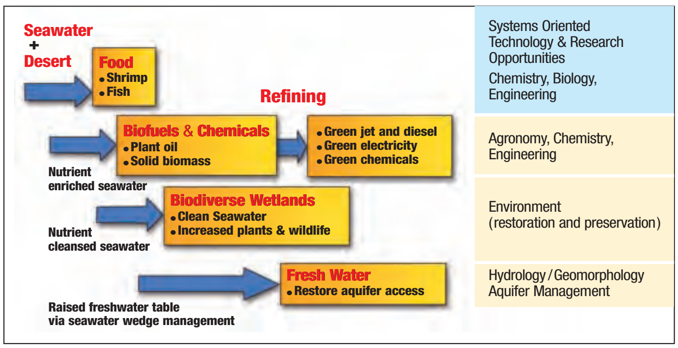

Figure 3: *Sustainable Bioenergy Research Project – conceptual activities model (Source: Boeing).*

Salicornia as Biofuel Source

Salicornia bigelovii, is an annual saltwater tolerant halophyte identified in the 1970's as a potential food and oil producing crop that can thrive on non-arable desert land with only seawater and minimal nutrient inputs. Salicornia's adaptation to salt water irrigation, coupled with crop yields that can equal or exceed freshwater crops such as soybean and rapeseed, make it an ideal crop to reclaim coastal deserts and other degraded coastal land.

Description	Jet A-1 Specs	Jatropha Derived HRJ	Camelina Derived HRJ	Jatropha/ Algae Derived HRJ
Flash Point, °C	Min 38	46.5	42.0	41.0
Freezing Point, °C	Max -47	-57.0	-63.5	-54.5
JFTOT@300°C				
Filter dP, mmHg	Max 25	0.0	0.0	0.2
Tube Deposit Less Than	< 3	1.0	< 1	1.0
Net heat of combustion, MJ/kg	Min 42.8	44.3	44.0	44.2
Viscosity, -20 deg C, mm^2/sec	Max 8.0	3.66	3.33	3.51
Sulfur, ppm	Max 15	< 0.0	< 0.0	< 0.0

Table 1: *Key Properties of Green Jet Fuel* (Source: Honeywell-UOP).

An Integrated Seawater Agriculture System (ISAS) uses aquaculture effluent to provide a majority of the nutrient content to the salicornia fields, with the leftover effluent being treated by a mangrove wetland. Salicornia has the potential to sequester carbon and have a positive land use impact primarily because the desert land it is grown on has minimal stored carbon and organic matter. Such a process shows very strong potential as a sustainable biomass resource without competing with traditional food crops, but instead providing additional food resources in the form of aquaculture products and protein meal to supplement animal fodder.

The Role of Honeywell's UOP

Honeywell's UOP, as a founding and funding member of the Sustainable Bioenergy Research Project, will provide process technology for the conversion of natural oils from the salicornia plants to Honeywell Green Diesel™ and Honeywell Green Jet Fuel,™ as well as process technology for the conversation of waste biomass from these plants to renewable power. UOP will also support the techno-economic analysis of the integrated seawater model and the evaluation of potential co-products along the chemicals value chain.

As an initial step in the project, an assessment, using Roundtable on Sustainable Biofuels Version One principles and criteria to determine sustainability is being sponsored by Boeing and Honeywell with the support of the Michigan Institute of Technology and Yale University.

Honeywell Green Jet Fuel has already been demonstrated using a variety of biological feedstocks including inedible oils such as camelina, jatropha and algae. Activity to date clearly shows that Green Jet Fuel properties meet, and in some cases exceed, specifications for commercial and military aviation fuels.

Green Jet Fuel has already been successfully demonstrated on several commercial airline and US Military test flights. Abu Dhabi's Etihad Airways has publicly announced its intention to be the leader of green aviation in the Middle East.

Etihad Airways and Boeing Roles

As major founding partners of the Masdar Institute, Etihad Airways and The Boeing Company will play the following leadership roles:

- UAE stakeholder engagement leadership.
- Integration of efforts towards global aviation frameworks via Sustainable Aviation Fuel Users Group **(www.safug.org)** and Roundtable on Sustainable Biofuels **(www.rsb.org)**.
- Commercial and strategic expertise on sustainability metrics and market requirements.
- Founding and funding members of the Project.

Summary

The Sustainable Bioenergy Research Project will lay the foundation for arid-land and saltwater based sustainable aviation fuels to reduce emissions cost effectively and mitigate exposure to future regulations and carbon costs. The project will also develop an important source of biomass-based electricity for arid land and saltwater accessible locations and, the participants believe, act as a model for other whole value-chain partnerships in the emerging sustainable aviation fuels industry.

Long Term Potential of Hydrogen As Aviation Fuel

*By **Keiichi Okai***

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He received his B. S. (1996), M.S. (1998) and Dr. (Eng.) (2001) degrees in aeronautics and astronautics from the University of Tokyo. He joined the National Aerospace Laboratory (now JAXA) in April 2001. From October 2006 to September 2007, he was a visiting scientist at the German Aerospace Center (DLR), Cologne Germany.

His research topics are hydrogen and potential alternative aviation fuels, fundamental combustion and aero-engine system concepts. He is an American Institute for Aeronautics and Astronautics (AIAA) technical committee member and participate as expert in ICAO CAEP WG3 activities.

He was awarded the 18th Japan Society for Aeronautical and Space Sciences (JSASS) Award (best paper award) in 2009.

Introduction

To accomplish a significant reduction in CO_2 emissions, drastic efforts to introduce low carbon fuels are necessary. This article highlights hydrogen as a promising alternative fuel based on an assumption of the rapid realization of a hydrogen and fuel cell compatible society, and presents discussion of its technological potential and recommended research activities.

For ground and other transportation industries, R&D activities related to hydrogen and fuel cells are being pursued. Fuel cell technology has been attracting attention in the More Electric Aircraft (MEA) framework. This article examines the potential of hydrogen-fuelled subsonic commercial transport.

Hydrogen as Aviation Fuel

Research into hydrogen-fuelled aircraft has been conducted for many years [1].

In comparison with jet fuels, the merits and drawbacks as well as concerns of hydrogen as aviation fuel are summarized below:

Merits

- Higher energy content per unit weight (3 x)
- Zero (CO_2) emission
- Potential for lower NOx emission
- Easy handling as a combustible gas

Drawbacks

- Lower energy content per volume (1/4 x)
- Difficulty handling in storage and supply (cryogenic fuel)
- Material property (brittleness)

Additional Concerns

- Sustainable supply (with environmental compatibility)
- Infrastructure (airport)
- Impact of water vapor emissions (>2 x) on atmosphere
- Public acceptance of the fuel

As an aviation fuel, hydrogen clearly has strengths and weaknesses. The projected configuration of a hydrogen-fuelled subsonic aircraft is therefore invariably a compromise of the characteristics of hydrogen fuel. For aviation, hydrogen fuel storage during flight should be done in a liquid state due to the fuselage volume constraint.

Several recent feasibility studies show that the LH_2 subsonic transport aircraft is realistic, although some uncertainties such as fuel storage and fuel supply systems remain [1,2,3].

In actuality, hydrogen-fuelled flight operation of small aircraft (take off to landing) and of medium size aircraft during the cruising phase have been demonstrated already. Furthermore, small aircraft powered with fuel cells and hydrogen fuel, have already been demonstrated (2008, 2009)[4,5]. These facts attest that hydrogen-fuelled jet propelled aircraft and hydrogen-fuelled fuel cell powered aircraft are currently operable on a small scale. However, the realization of large-scale, long-haul hydrogen-powered aircraft remains a challenge.

From this standpoint, the three major technological challenges for LH_2-fuelled (subsonic) transport are the following:

1. Fuel supply management
2. Tank structure (fuel storage system)
3. Evaluation of effects of water vapor emission on the environment

Depending on the pace of R&D on hydrogen and fuel cells for ground-based transport and related industries, a potential scenario can be drawn up for aircraft as presented in Figure 1. Under this scenario, hydrogen-fuelled aircraft would be developed to meet the requirement to reduce CO_2 emissions and to move away from fossil fuel consumption when the hydrogen fuel management and its storage system technologies are mature enough for aviation purposes.

Current Challenges

Merits of Introduction of Hydrogen to Aviation -Historical and Social Perspective

One concern related to a full hydrogen society is the handling of fuel. In this sense, the aviation industry is ideal to demonstrate the functioning of a hydrogen-fuelled transport society because it has trained experts in restricted areas at airports to supply and manage the fuel.

The aerospace industry has some experience working with hydrogen[1], and valuable experience with hydrogen-related technologies can be gained from the careful development of rocket propulsion over time.

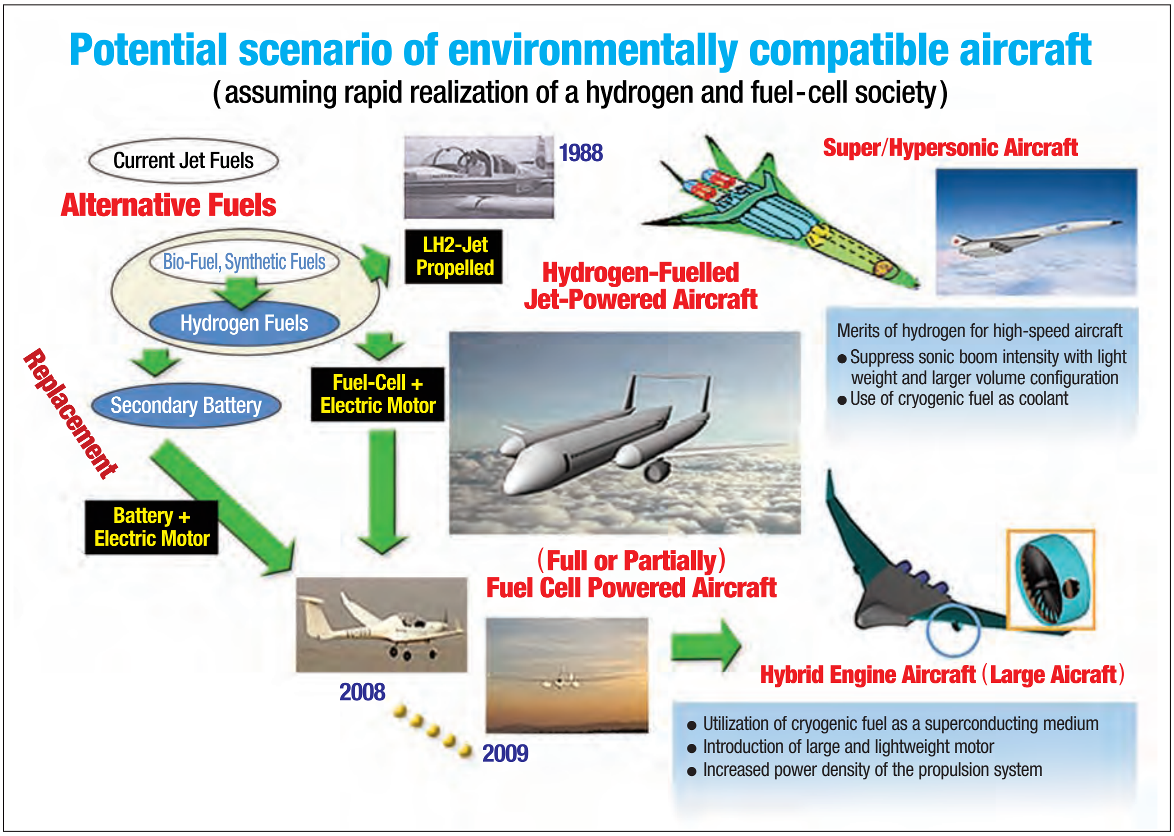

Figure 1: *Potential scenario for environmentally compatible aircraft. Photos from refs.*[1,4,5,6,7,8], courtesy Prof. K. Rinoie (University of Tokyo).

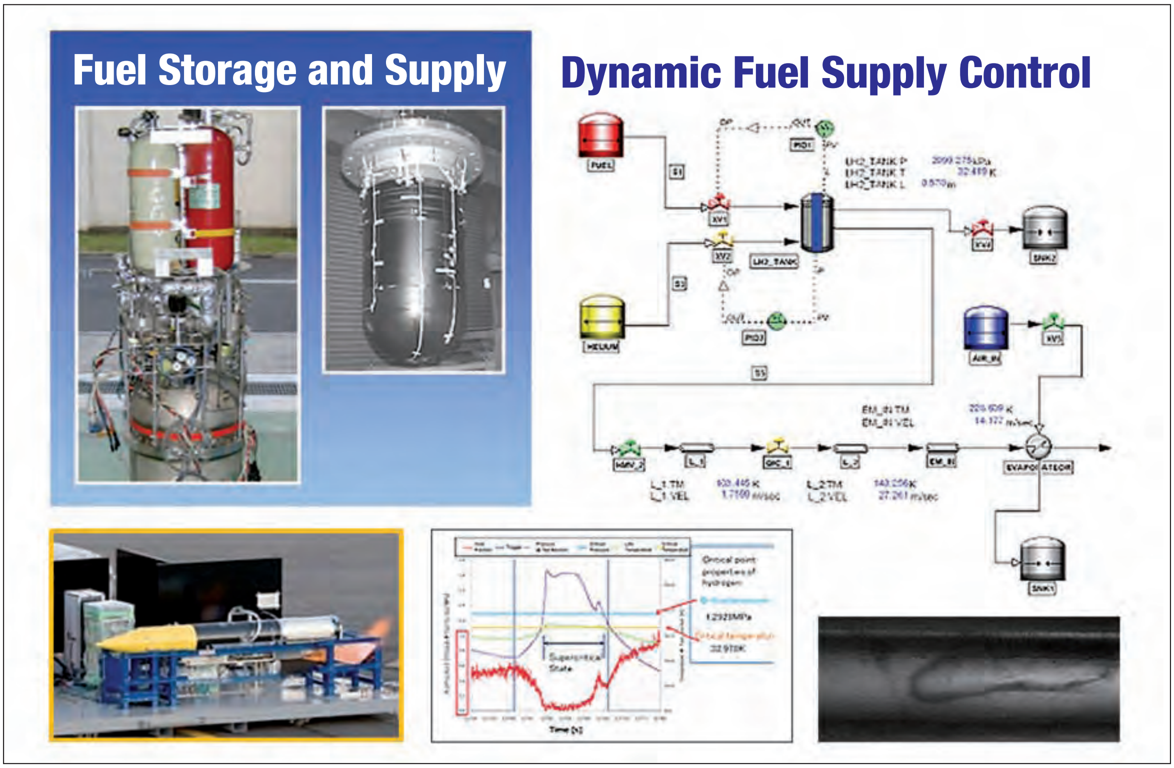

Figure 2: *Hydrogen system management approach* [7,9].

Hydrogen Management Systems Approach

Among the major challenges, fuel supply management and tank storage are two important aspects of handling hydrogen fuel. In order to realize hydrogen fueled commercial aircraft, accumulated experience related to hydrogen fuel management at the systems level is essential. An example of this is presented in Figure 2. A LH_2-fuelled hypersonic turbojet engine scale model was fabricated and an independent unit including the fuel tank, fuel supply, management system, and engine were tested without connection to a ground facility[7]. Through the firing tests, dynamic simulation and operation schemes on multiphase flow were developed[9]. The most recent systems approaches (development of an unmanned long-duration high-altitude aircraft) can be found by consulting reference[11].

Additional Goals to Pursue

Some merits exist to introducing liquid hydrogen as a fuel for hypersonic vehicles. The fuel's high energy density and cooling capabilities are its primary merits. This is a case in which an apparent disadvantage of the fuel can become a merit for a specified purpose.

Furthermore, the inevitable large fuel tank would become beneficial for achieving a low-sonic boom design for large supersonic transport aircraft (SST)[6], which might make supersonic over-land flight feasible.

Another important thing to note is that the introduction of hydrogen fuel would further promote the conversion of power sources from the conventional gas-turbines (or heat engines) to fuel cells. With hydrogen as the fuel, a fuel cell or fuel-cell and gas-turbine combination (hybrid) engine would provide higher efficiency and higher environmental compatibility than a gas-turbine engine. To be used as the sole propulsion power source, however, the power density of the fuel cell needs to be increased by two orders of magnitude.

For use in commercial aircraft, other electrical devices such as electric motors to drive fans should be kept light in weight while being of very large-scale. Present electric motor technology does not meet the requirement, so some innovation is necessary. Several conceptual proposals have been reported for hydrogen-fuelled subsonic transport with electric motors as a propulsion device[8,10].

The rapid increase of electric power demand for modern commercial aircraft make a power demand and supply mismatch quite undesirable. There are several R&D projects currently underway that are related to fuel cells for auxiliary power units (APUs), but most use reform-type fuel cells using current jet fuel. Recent activity includes study of the possible use of hydrogen as the fuel for a fuel cell onboard power supply [12,13].

An R&D project is being conducted on regenerative fuel cells with hydrogen as the fuel to be used to supply onboard electrical power[13]. The regenerative fuel cell is a mutual transformation device (i.e. chargeable fuel cell) between hydrogen energy and electricity. The high energy density capability of fuel cells and this mutual transformation capability present great benefits for the onboard power supply needs. These capabilities can meet the demands of optimized power management.

Combined with the most recent activities of a hydrogen-fuel management approach on the engine system and total airframe system, these near-term R&D efforts would bring us closer to realization of hydrogen-fuelled commercial (or medium/large scale) aircraft.

Conclusions

Based on the foregoing discussion, the following conclusions can be made about the use of hydrogen as alternative fuel for aviation:

- Hydrogen has long been considered a "new" promising alternative fuel.
- Recent activity towards the development of a hydrogen-based society is a good context for the accelerated development of hydrogen-fuelled aircraft.
  Hydrogen fuelled aircraft would be made possible technologically by the 2030's. However, since their availability on the market depends greatly on hydrogen fuel price, oil market status and the general public's knowledge on low environmental impact, as well as the arrival of the hydrogen-based social systems, the timing of their practical availability remains unpredictable.
- A systems verification approach would be promising because storage and handling of the fuel are important issues.
- Hydrogen-fuelled aviation would provide a good demonstration case for the introduction of a hydrogen society because handling of aviation fuel can be done by trained people and in restricted areas.
- Introduction of hydrogen as an aviation fuel would further encourage the development of fuel-cell powered aircraft. ■

REFERENCES

1 ***Brewer, G. D., Hydrogen Aircraft Technology***
CRC Press, 1991.

2 ***Guynn, M. D. and Olson, E. D., Evaluation of an Aircraft Concept with Over-Wing, Hydrogen-Fuelled Engines for Reduced Noise and Emissions***
NASA/TM-2002-211926, September 2009.

3 ***Westenberger, A., Hydrogen fuelled Aircraft***
AIAA-2003-2880.

4 ***News Release, Boeing Successfully Flies Fuel Cell-Powered Airplane***
The Boeing Company, April 3, 2008.

5 ***DLR portal release, DLR motor glider Antares takes off in Hamburg – powered by a fuel cell July 7, 2009.***

6 ***Horinouchi, S., Future Supersonic Transport with Hydrogen Fuel and BWB Configuration***
JSASS-2010-1067, presented in the 41st JSASS Annual Meeting, 2010.

7 ***Taguchi, H. et al., Firing Test of a Hypersonic Turbojet Engine Installed on a Flight Test Vehicle***
AIAA 2009-7311, 2009.

8 ***Okai, K. et al., Simplified Analysis on Electr magnetic-Driving Fan for Aircraft Propulsion***
AIAA 2008-5729.

9 ***Shirai, Y. et al., Preliminary study on heat transfer characteristics of liquid hydrogen for coolant of HTC Superconductors***
Cryogenic Engineering Conference and International Cryogenic Materials Conference, 2009.

10 ***Collier, F., Subsonic Fixed Wing Project, N+3 (2030–2035) Generation Aircraft Concepts – Setting the Course for the Future***
presented in Aviation and Alternative Fuels Workshop, ICAO, Montreal, February 11, 2009.

11 ***News Release, Boeing 'Phantom Eye' Hydrogen Powered Vehicle Takes Shape***
The Boeing Company, March 8, 2010.

12 ***Emission free power for civil aircraft: Airbus successfully demonstrates fuel cell inflight***
Airbus press release, February 19, 2010.

13 ***IHI press release, ' Corporate research with Boeing on regenerative fuel cells for aviation applications'***
March 3, 2010.

Sustainable Biofuel Raw Material Production for the Aviation Industry

By ***Yuri Herreras, Victor Stern, Anibal Capuano***

Yuri Herreras Yambanis *is an Industrial Engineer from Universidad Politécnica de Madrid, holds a Master in Nuclear Science and Technology from the same university and is currently developing his PhD in Sustainable raw materials for the bioenergy industry. Apart from his academic role, where he has published several articles, he has participated in international congresses and has developed several consulting projects in the renewable energies area.*

From September 2009 he has been managing BIOEca (Bioenergy and Agroenergetic Crops S.L.), a company that specializes in the implementation of integral agroenergetic projects aimed at supplying the biofuel industry with sustainable, competitive, non-food feedstock raw materials.

Victor Stern*, Austrian, born in 1968, is a Chemical with more than 20 years experience in Agriculture technology development and international business management. He has been Executive Vice-president of large agricultural commodity trading companies and entrepreneur. During the last decade he has been developing and implementing state-of-the-art technology applications towards crop yield improvement, soil and water management, with emphasis in biotechnology, nanotechnology, robotics, neural networks and agricultural monitoring networks. He developed overall technology integration in large agriculture deployments to increase agricultural production sustainability, productivity and economical viability. Currently is one of Managing Directors of BIOECA.*

Anibal Capuano*, Argentinean born in 1978, is an Agricultural Engineer specialized in technology applications for agricultural operations. He has been technical and project manager implementing large agricultural projects in Argentina, Brazil, Dominican Republic and Spain for companies in Food and Bio fuel sectors. During the last 4 years he has been full time researching about the issues around implementation of new energy feedstock crops. He is currently Agronomy Director at BIOECA in Spain.*

Raw Materials For the Aviation Industry

Bio-jet fuel Value Chain

Large scale bio-jet fuel production presents a variety of critical challenges that will need to be solved to ensure that the final product is viable, profitable, and sustainable. As shown in Figure 1, throughout the value chain there are important milestones that need to be reached to consolidate bio-jet fuel production in the domains of raw material supply, production technology, and biofuel certification.

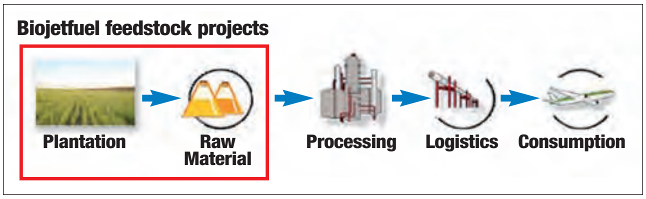

Figure 1: *Bio-jet fuel value chain.*

Aviation Raw Material Requirements

New biofuels for aviation will have to improve their GHG emissions balances throughout the entire life cycle and will have to guarantee that a number of criteria related to indirect effects and basic environmental issues are met. These include such factors as food security, land use, ecosystem interaction, and soil and water uses. Specifically, biofuels made from second generation feedstock crops should comply with the following main characteristics:

- Do not interfere with the food sector.
- Are produced on land not used for food production, or marginal land.
- Do not damage scarce natural ecosystems and are produced so that soil and water will not be contaminated or over-utilized.

- Do not require excessive agricultural inputs.
- Provide a net carbon footprint reduction compared to conventional jet fuel.
- Produce equal or higher energy content than jet fuel.
- Are not threatening to biodiversity.
- Provide socio-economic value to local communities.

Selected Second Generation Feedstocks

Alternative, sustainable aviation fuels can be produced using an ample variety of raw materials. Currently, four main crops are seen to be the primary candidate raw materials to be used, as shown in Table 1.

SHORT-TERM FEEDSTOCKS	LONG-TERM FEEDSTOCKS
CAMELINA	**ALGAE**
Rotational crop	High growth rate
Minimal inputs	Very high production yield
Grown in marginal land	Grown in barren land
Meal approved as animal feedstock	
JATROPHA	**HALOPHYTES**
Perennial high oil yield	Saline habitat
Non food feedstock	Grown in barren land
Grown in marginal land	
Social benefits	

Table 1: *Potential aviation feedstock classification and attributes – short-term and long-term.*

Camelina: Camelina is an annual flowering plant that grows well in low temperate climates. Some varieties of camelina contain 38-40% oil. Camelina can be produced on land not suited for other crops or where other large scale crops are not productive enough, requiring minimal water and fertilizer use. Similar to soy meal, camelina meal contains 35%-47% protein, 10%-11% fiber, and is rich in Omega-3 fatty acids and has been approved as raw material for animal feed. The fact that it is a high-quality animal feed significantly enhances the economics of the crop.

Jatropha: Jatropha is a perennial drought resistant and non-food oilseed crop that grows in tropical and subtropical climates. The plant, adapted to marginal land, does not grow in cold regions. Although very promising, jatropha projects are characterized by the manual harvest requirement, variable yields, and the meal has no clear economic value like camelina sativa.

Algae: Algae are cellular organisms with the ability to perform photosynthesis, thriving off carbon dioxide. They are characterized by their rapid growth rate and high oil production yields, and they can be grown on barren land. Land requirements to quantities of oil produced ratios are significantly lower than for short-term feedstocks. Although algae is potentially the most promising feedstock for the production of large quantities of sustainable aviation biofuel harvesting, processing and infrastructure issues have to be solved before reaching commercial viability for algae in the short term.

Halophytes: These are salt marsh grasses and other saline habitat species that can grow either in salt water or in areas affected by sea spray. To date, there is limited experience with halophytes plantations, although this may be a promising option for arid regions.[1,2]

Large Scale Raw Material Production - Short Term

Sustainability Issues

There are several issues to be tackled in order to ensure the sustainability of the bio-jet fuel project, including: economic viability, environmental respect, and social commitment, as summarized in Figure 2.

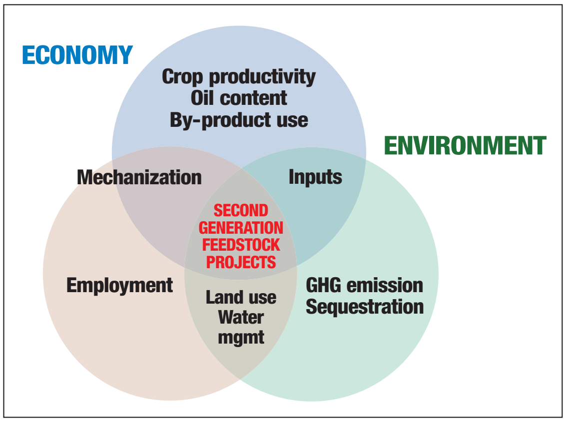

Figure 2: *Bio-jet fuel feedstock projects - main sustainability issues.*

Some of the issues being considered have more repercussions on the economic viability and sustainability of the project. These are: utilization and added value of the by-products (especially meal) from a purely economic point of view; integral crop mechanization (social perspective); and quantity and quality of the agricultural inputs being used (environmental perspective).

Response and Solutions

Guaranteeing the sustainability of large scale bio-jet fuel feedstock projects depends mainly on four primary issues, each of which must be considered and resolved:

A. Feedstock crop;
B. Production areas;
C. Agricultural inputs;
D. Plantation management.

A. Feedstock Crop

The raw materials produced from agroenergetic crops for aviation biofuels must be non food-feedstock items in order to guarantee that they do not compete with the food production industry.

The main technical criteria required for developing viable second generation crops in the short term for the production of bio-jet fuel feedstock are shown in Table 2.

TECHNICAL CRITERIA	REQUIREMENT
HARDINESS	Low agricultural inputs
TERM	Annual crop
CYCLE	Short
RISK	Extensive crop know-how
TECHNOLOGY	Mechanized crop
INVESTMENT	Low implantation investment
LAND	Rotational crops
EMISSIONS	Significant GHG emission reduction

Table 2: *Technical criteria for developing viable crops in the short-term.*

B. Production Areas

Using robust, annual, short-cycle crops, there are mainly three different types of production areas that can be used for bio-jet fuel feedstock production:

Marginal land: Robust crops can be grown, with minimal water requirements, and adapted to harsh climate conditions, on land where food crops are not viable.

Rotational/Fallow land: Can be planted with annual second generation crops, increasing the productivity of following crops and preventing soil erosion.

Double crop land: Areas where robust, annual and short-cycle crops can be grown within the same growing season using a double cropping scheme, thus preventing soil erosion.

C. Agricultural Inputs

A key issue related to the implementation of a sustainable feedstock project is minimizing the agricultural inputs required – mainly chemical fertilizers and pesticides - which directly affect the crop yield and quality. The main factors that affect crop yield and product quality are shown in Figure 3.

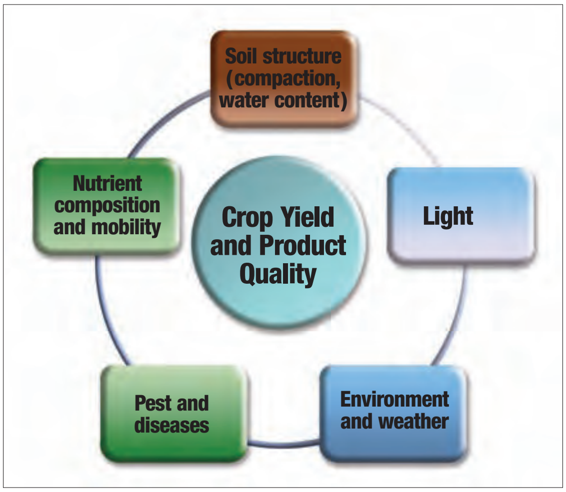

Figure 3: *Biofuel feedstock projects - main factors affecting crop yield and product quality.*

A key sustainable issue is to use technologies to close the biomass loop and nutrients cycles, allowing the improvement of soil - instead of its degradation - as well as increasing efficiency of plant metabolism. All of these technologies are proven and available while the key is to put them together as a single technology package for agricultural implementation.

The cost implementation structure of a biofuel crop is mainly driven by the amount of fertilizer used for its growth. In this sense, reducing the amount and cost of the fertilization program directly implies a lower seed production cost, and thus a cheaper vegetable oil.

One of the main factors related to GHG emissions during the crop's life cycle is nitrogen oxide (N_2O) emissions. Simulations conducted using rapeseed in Europe[3] show that CO_2

and N_2O emissions level reductions - including direct and indirect N_2O emissions due to leaching and volatilization - are of the same magnitude. Thus, any emission reductions achieved through chemical fertilization will have a significant positive impact On the global GHG emissions reduction balance of the crop.

Another key factor is the phosphorous cycle and the future crisis of phosphorous depletion in agriculture[4]. This potential problem for such large projects can be solved by biotechnology, since phosphorous can be recovered from organic waste without depleting scarce mineral reserves further. This is not a problem that cannot be solved, but it does require awareness and technology integration.

D. **Plantation Management**

Another requirement, that complements the application of bio-fertilization protocols and nutrient cycle and soil management, involves the implementation of plantation management systems and agricultural monitoring networks to ensure efficient use of agricultural inputs. Managing the plantations in a highly efficient manner implies integrating different production technologies and advanced management systems that minimize agricultural inputs, secure production goals, and maximize crop productivity.

Conclusions

In light of the foregoing, the following conclusions are made with respect to the implementation of bio-feedstock projects as an alternative source for aviation fuel:

- The aviation sector needs to use newly developed low carbon biofuels to achieve real GHG emission reductions. To achieve the aviation industry goals for 2020, it is necessary to develop a new industry for the production of sustainable bio-jet fuel in the short term.
- Success of this new industry will depend on the achievement and development of certain milestones along its value chain, chiefly among them: processing or conversion technology, new bio-jet fuel certification, and procurement of stable supply of feedstock for bio-jet fuel production.
- Currently, there are proven technologies for bio-jet fuel production. The challenge for the new bio-jet fuel industry is to find ways to develop a sustainable supply of bio-jet fuel feedstocks in regular quantities, at stable prices.
- To achieve such an objective, it is necessary to implement large scale raw material production projects in the short term. Analysis of the main critical factors that would guarantee the viability and sustainability of such projects indicates that, currently, both the appropriate crops and the agricultural technology exist to begin large-scale production of renewable and sustainable raw materials as aviation fuel feedstocks.
- Raw material biofuel production projects for the aviation industry should be initiated with second generation crops – such as camelina – where sufficient agricultural know-how exists and there is proven profitability.
- An important success factor for this initiative is that it allows for the recovery of fallow land, recycling it into prime agricultural land for later use by food-crops production since when third generation feedstocks like algae or halophytes become commercially viable the land area to produce equivalent amounts of fuels will be substantially reduced.

REFERENCES

1 ***Jaradat, A.A., Halophytes for sustainable biosaline farming systems in the middle east***
Alsharhan, A.S., et al. Editors. A. Balkemas/Swets & Zeitlinger, Rotterdam, The Netherlands. Desertification in the third millennium. 2003. P. 187-203.

2 ***Chiaramonti, D., et al. Energy crops and bioenergy for rescuing deserting coastal area by desalination: feasibility study***
Bioresource Technology; Volume 72, Issue 2, April 2000, Pages 131-146.

3 ***Leip, A., European Commission – Joint Research Centre Institute for Environment and Sustainability Climate Change Unit, Integrating an economic model for European agriculture with a mechanistic model to estimate nitrogen and carbon losses from arable soils in Europe – net climate impact of rapeseed cultivation for biofuels***
TFIAM/COST729/NinE Workshop on integrated modelling of nitrogen, Laxenburg, Austria, 28-30 November 2007.

4 ***Cordell, D. (2010). The Story of Phosphorus: Sustainability implications of global phosphorus scarcity for food security***
PhD thesis. Collaborative PhD between the Institute for Sustainable Futures, University of Technology, Sydney (UTS) and Department of Thematic Studies - Water and Environmental Studies, Linköping University, Sweden. Linköping Studies in Arts & Sciences No.509, Linköping University Press, ISBN 978-91-7393-440-4, Linköping.

A Global Fuel Readiness Level Protocol

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The quest for sustainable alternative fuels for aviation involves the consideration of multiple production processes and many different feedstocks using those processes. Synthetic Paraffinic Kerosenes (SPK) from a wide range of feedstocks have now been certified. Fuels from processes such as pyrolysis, fermentation and catalysis are in their infancy for aviation use. This article summarizes the latest developments in this area in terms of risk management considerations and fuel readiness levels for use in aviation.

Background

Aviation and aerospace projects are characterized by the use of risk management tools to govern the creation of high technology products that embody uncompromising levels of safety and efficiency and also create an acceptable environmental footprint. Because of the high cost of managing risk in the complex aviation and aerospace technical and production sector, and in accordance with Systems Engineering principles, a gated approach to risk management through the use of Technology Readiness Level (TRL) criteria has evolved.

Risk Management In Aviation Using Technology Readiness Level

The technology readiness scale initially used by the United States Air Force and National Aeronautics and Space Administration in the U.S., and subsequently by the commercial sector, has been in use for decades for the development of new aircraft, engines and space systems. This technology readiness scale is growing in use in Europe by aircraft and engine manufacturers for risk management purposes but is not incorporated into any European standards.

Together, these risk management tools are a proven means of:

- Characterizing conceptual research from the creation phase throughout the development of sub-elements and components to allow researchers to identify what phase a project is in, as well as identifying potential sources of funds for that research.
- Ensuring that manufacturing is scalable to levels needed for production levels that are both economically viable and environmentally acceptable at pilot plant levels, once proven at the subscale and component level.
- Supporting the certification for air worthiness.
- Supporting deployment across the entire industry in a manner that provides a sustainable business model.

Transition From Technology Readiness Levels To Fuel Readiness Levels

In the case of alternative jet fuels, in contrast to equipment production, the risk resides in separate arenas of both the chemistry of the fuel itself and its compatibility with the aircraft product and fuelling infrastructure. For this reason, use of the existing TRL process was not deemed adequate or appropriate to address this new challenge facing the industry. This led to discussions by various groups and agencies about the feasibility of developing a new readiness level standard that would apply separately to aviation fuel.

In January of 2009 at a meeting of the Commercial Aviation Alternative Fuel Initiative (CAAFI), a research and development initiative involving participants from Europe and the U.S., it was agreed that the U.S. Air Force efforts and an Airbus proposal could be brought together as a single Fuel Readiness Level (FRL). **Figure 1** presents the proposed FRL scale that was put forward for adoption:

FRL	Description	Toll Gate	Fuel Quantity+
1	**Basic Principles Observed and Reported**	Feedstock /process *principles* identified.	
2	**Technology Concept Formulated**	Feedstock / *complete* process identified.	
3	**Proof of Concept**	Lab scale fuel sample produced from realistic production feedstock. Energy balance analysis executed for initial environmental assessment. Basic fuel properties validated.	**0.13 US gallons (500 ml)**
4.1 4.2	**Preliminary Technical Evaluation**	System performance and integration studies entry criteria/specification properties evaluated (MSDS/D1655/MIL 83133)	**10 US gallons (37.8 litres)**
5	**Process Validation**	Sequential scaling from laboratory to pilot plant	**80 US gallons (302.8 litres)** to **225,000 US gallons (851,718 litres)**
6	**Full-Scale Technical Evaluation**	Fitness, fuel properties, rig testing, and engine testing	**80 US gallons (302.8 litres)** to **225,000 US gallons (851,718 litres)**
7	**Fuel Approval**	Fuel class/type listed in international fuel standards	
8	**Commercialization Validated**	Business model validated for production airline/military purchase agreements – Facility specific GHG assessment conducted to internationally accepted independent methodology	
9	**Production Capability Established**	Full scale plant operational	

Figure 1: *Proposed Fuel Readiness Level scale.*

Potential Uses of Fuel Readiness Level Scale

In addition to its use as a risk management tool, FRL has other potential uses such as:

a) A communications tool to help policy makers establish if and when the use of fuels currently in the R&D phase can be envisioned as true production options.

b) A mechanism by which government agencies, laboratories, or universities can determine if and how they can participate, given their organizations' role in R&D.

c) A tool for private and public investment sources to identify whether and where they should invest in deployment among all available options.

Conclusions

The above Fuel Readiness Level scale was developed by CAAFI sponsors and modified in consultation with a key energy supplier, an Original Equipment Manufacturer (OEM) stakeholder, and a fuel process technology developer. It provides a gated process to govern communication of technology maturity leading to qualification, production and, deployment readiness. The FRL was recognized by the ICAO Conference on Aviation Alternative Fuels in November 2009 as a best practice. The FRL continues to be updated and improved by CAAFI with the development and inclusion of detailed Pass/Fail criteria for each of the FRL level "Toll Gates" in order to improve its usability.

The FRL is appropriate for:

- Managing and communicating research status and development needs for R&D Investors.
- Managing and communicating the readiness level to airworthiness authorities and determining the appropriate timing for complementary and required environmental assessments.
- Managing and communicating the practicality of deploying fuels for use in production aircraft, engines and aviation infrastructure.
- Used as a process for aviation fuel development and deployment risk mitigation.

Estimating Life Cycle Greenhouse Gas Emissions From Alternative Jet Fuels

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Alternative jet fuels produced from renewable sources have the potential to reduce aviation's impact on global climate change. However, a full accounting of the life cycle greenhouse gas (GHG) emissions, which extends from the well, field, or mine to the wake behind the aircraft, is necessary to determine whether a biofuel, or any other alternative fuel, will cause an overall environmental benefit or detriment. This article presents background information on the use of life cycle analysis for estimating GHG emissions.

Synthetic Paraffinic Kerosene (SPK) are a class of drop-in fuels, which can be created via Fischer-Tropsch (F-T) synthesis or the hydroprocessing of renewable oils to a Hydroprocessed Renewable Jet (HRJ), and have similar molecular composition to conventional jet fuel. The combustion of SPK fuels can results in somewhat lower CO_2 emissions (per unit mass of fuel) as compared to conventional jet fuel due primarily to higher hydrogen to carbon ratios.

Depending on the feedstock that is used in the fuel production and the details of extraction and production, the life cycle GHG emissions from an SPK fuel can vary by two orders of magnitude. If waste products are exclusively used to create the fuel and to power the fuel production process, then the emissions could be as little as a tenth of those from conventional jet fuel; however, if the extraction and production of the fuel results in the conversion of lands with high carbon stocks, then the emissions could be eight times higher than conventional jet fuel.

This article summarizes the key issues regarding the use of life cycle analysis for estimating GHG emissions from alternative jet fuels while highlighting ongoing research being conducted in the United States and Europe to estimate the life cycle GHG emissions from alternative jet fuels.

Estimating GHG Emissions From Alternative Jet Fuels – The Process

A Life Cycle Assessment (LCA) estimate is a compilation and evaluation of inputs, outputs and potential environmental impacts of a production system throughout its life cycle. A LCA of alternative jet fuels involves an evaluation of the environmental impacts of resource extraction, fuel production and fuel combustion on air and water quality as well as global climate change; the focus here is on the creation of an inventory of "well-to-wake" life cycle GHG emissions.

Life cycle GHG emissions include those created from the extraction of raw materials through the combustion of the processed fuel by the aircraft. This can be described with a set of five life cycle stages:

1) *Raw Material Acquisition,*
2) *Raw Material Transport,*
3) *Fuel Production from Raw Materials,*
4) *Fuel Transport and Aircraft Fueling,* and
5) *Aircraft Operation.*

The emissions inventory is generally given in terms of the emissions, or the impact of the emissions, relative to some unit of productivity delivered by the fuel. To allow for an equitable comparison of SPK and conventional jet fuels, which have different energy content on both a unit mass and a unit volume basis, the emissions are given on the basis of a unit of energy delivered to the aircraft tank. To allow for an equitable comparison of carbon dioxide with other GHG emissions such as N_2O and CH_4 that may result from fuel production, Global Warming Potentials (GWP) are generally used to sum emissions into units of carbon dioxide equivalent, CO_2e. As such, life cycle GHG emissions are often given in terms of grams carbon dioxide equivalent per megajoule (gCO_2e/MJ).

Metrics using GWP have major limitations in terms of examining the impact of non-CO_2 combustion emissions from aviation. As such, while non-CO_2 combustion emissions should be estimated as part of a life cycle GHG emissions inventory, an appropriate means of combining these emissions with those from life cycle stages 1 through 4 (from well-to-tank) and the CO_2 emissions from life cycle stage 5 (tank-to-wake) has not yet been defined.

Three areas meriting special consideration in regards to estimating a life cycle GHG emissions inventory, (1) *System Boundary Definition,* (2) *Emissions Allocation among Co-Products,* and (3) *Data Quality and Uncertainty,* are discussed further in the following sections.

System Boundary Definition

Based on the International Organization for Standardization (ISO) guidelines, a life cycle GHG emissions inventory should include a full accounting of the GHG emissions that result from the creation of all materials, energy, and activities that are related to the fuel production; not only those within the processes of the primary production chains, but also those supporting necessary input to the primary production chain. The system boundary therefore needs to be defined such that it captures all of the processes used in jet fuel creation.

If sufficient quantities of agricultural products were redirected from the production of food to the production of biofuels, then indirect land use changes would need to be accounted for in the LCA. For example, complete domestic use of an existing agricultural product as a fuel feedstock would reduce exports of that crop, resulting in compensatory land use change elsewhere. The resulting land use change could lead to considerable GHG emissions, especially if the converted land is from high carbon sequestration systems such as rainforest or peat lands. However, efforts to develop sustainable fuels for aviation are seeking to avoid these sorts of impacts. For example, use of fallow domestic agricultural land or excess production of existing crops would incur no such GHG emissions.

The accurate estimation of GHG emissions from indirect land use change requires the use of sophisticated economic models that capture the agriculture and energy sectors of the global economy. An estimation of the life cycle GHG from soy-based HRJ, which extended the results from such an economic analysis, indicates that the indirect land use change emissions from a large-scale diversion of soy oil to biofuel production could lead to a doubling of GHG emissions relative to conventional jet fuel. This is comparable to the emissions from coal-to-liquids from F-T synthesis if no carbon capture and sequestration were being used.

Emissions Allocation Among Co-Products

Some processes within a fuel production pathway result in multiple outputs. For example, a refinery outputs gasoline and diesel fuel in addition to jet fuel. Another example, exhibited by many biofuels, is the creation of meal in addition to the renewable oil that is then processed to HRJ. The emissions that are created upstream of such processes must be divided, or allocated, among the products.

ISO recommends that emissions be allocated to co-products using the following methods in the following order:

1) *process disaggregation* in which the unit process is divided into two or more sub-processes,
2) *system expansion* wherein the system boundaries are expanded to include the additional functions related to the co-products, and
3) *allocation* by physical properties (e.g., mass, volume, energy content) or market value.

In the case of biofuel production, the life cycle estimate may need to include emissions from biomass creation based on the relative mass, energy content, or market value of the oil and the meal that remains after oil extraction. This is because the system cannot be disaggregated further and system expansion may require a model for the entire agriculture industry. The selection of allocation strategy can significantly affect the GHG emissions from a fuel, including the potential for unrealistic emissions, which indicates the importance of this parameter.

Data Quality and Uncertainty

Data quality and uncertainty depend on time-frame and scale. For example, it is easier to obtain high quality data for an existing product, (e.g., conventional jet fuel from crude oil), than from an emerging or non-existent industry, (e.g., algal HRJ). High quality data are required to develop life cycle GHG inventories that can be used to inform decisions regarding alternative aviation fuels.

Scenario dependent analyses have also been used to bracket emissions from fuel pathways, providing a means of evaluating uncertainty. The underlying data and assumptions were varied to provide three scenarios that provide a mean and an anticipated range of low to high values.

Ongoing Life Cycle Analysis Efforts

Multiple research efforts are ongoing in the U.S. and Europe to estimate the life cycle GHG emissions from conventional and alternative jet fuels. These are in addition to the considerable, similar efforts to estimate the life cycle GHG emissions from ground transportation fuels.

In the U.S., the National Energy Technology Laboratory examined the GHG emissions from U.S. transportation fuels, including jet fuel, derived from conventional petroleum while Partnership for Air Transportation Noise and Emissions Research (PARTNER) researchers have examined a wide range of alternative jet fuel pathways and have recently released a report (available at http://web.mit.edu/aeroastro/partner/reports/proj28/partner-proj28-2010-001.pdf). Boeing is sponsoring research on jatropha based jet fuels at Yale University and algae based jet fuels at University of Washington and Washington State University.

In Europe, Cambridge University in the U.K. examined algal jet fuels as part of the OMEGA consortium while ONERA in France are currently leading an evaluation of a wide range of fuel options as part of SWAFEA (Sustainable Way for Alternative Fuel and Energy in Aviation).

Conclusions

Based on the work done to date estimating life cycle greenhouse gas emissions from alternative jet fuels, the points in the following paragraphs can be concluded.

The ability to compare the life cycle GHG emissions from alternative aviation fuels is an essential element of a global assessment of GHG emissions from international aviation and any other sector that is considering the use of a new fuel. It is the appropriate means for comparing the relative GHG emissions from alternative jet fuels with conventional jet fuel.

The assessment of the life cycle requires a careful definition of the system boundary among other key factors. This definition will allow the analysis to determine if GHG emissions associated with both direct and indirect land-use change will result from the production of the alternative jet fuel.

There are multiple research efforts are underway in the U.S., Europe and other States to estimate the life cycle GHG emissions from conventional and alternative jet fuels, as well as from ground transportation fuels.

Life cycle analysis is the appropriate means for comparing the relative GHG emissions from alternative jet fuels with conventional jet fuel. This recommendation was adopted by the ICAO CAAF in Rio de Janeiro, Brazil in late 2009.

Proposal To Adopt
A Global Fuel Qualification and Certification Protocol

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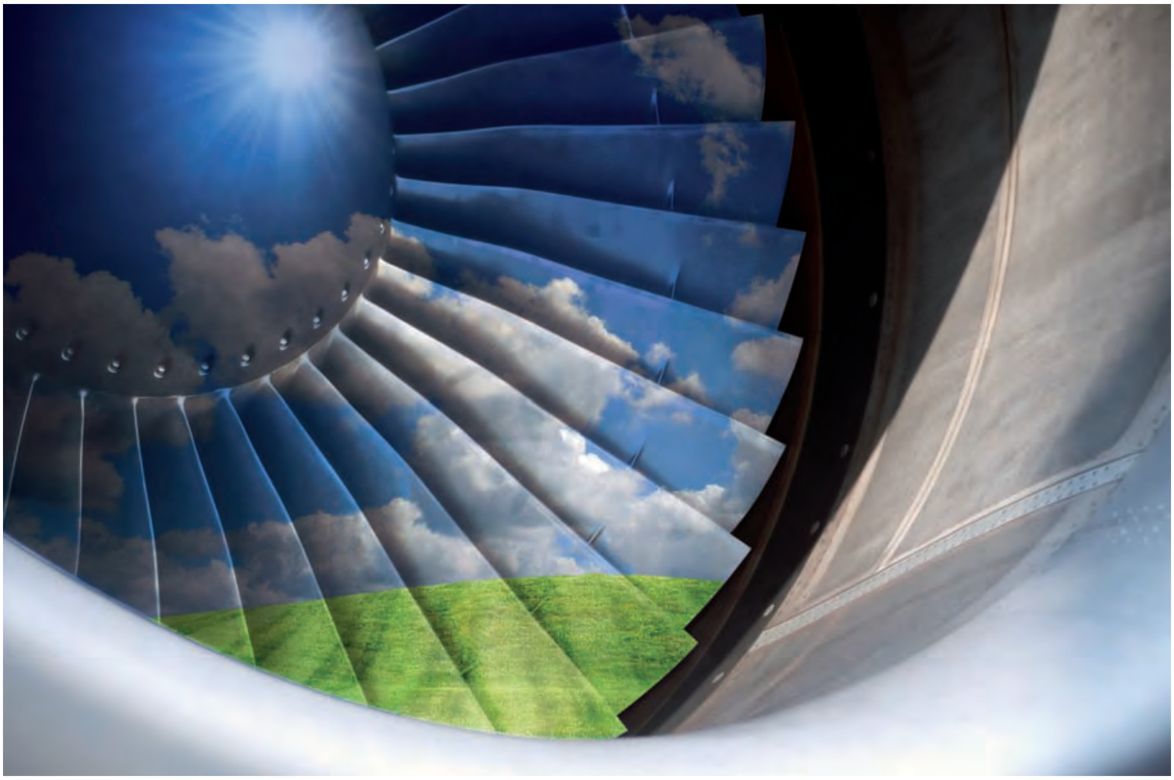
Industry fuel specifications such as D1655 and DEF STAN 91-91 are used by the aviation fuel industry stakeholders to standardize and control the properties and quality of aviation fuel as it travels through the distribution system. Civil airworthiness authorities (CAAs) also rely on fuel specifications to ensure the safety of aircraft operations. The aviation fuel community has developed qualification and certification concepts and procedures to approve an alternative fuel for operation on the existing fleet. This article summarizes the process being developed by the aviation industry in the United States to qualify and certify new classes of aviation fuels.

Introduction

Early turbine engines were designed to operate on kerosene fuels due to the wide availability, low cost, and desirable performance properties of those fuels. Over the decades since the introduction of the first turbine engines, demands for improved performance and safety resulted in aviation fuel specifications defining tightly controlled versions of kerosene. These specifications established tighter controls on the fuel properties necessary to accommodate technical advances in turbine engine design. Two aviation turbine fuel specifications used in many areas of the world are ASTM International Standard D1655 and Defence Standard 91-91 issued by the United Kingdom's Ministry of Defence.

Aviation fuel is transported in bulk and frequently changes ownership as it moves from its origination at the refinery to its final destination at the airplane. Industry fuel specifications such as D1655 and DEF STAN 91-91 are used by the aviation fuel industry stakeholders to standardize and control the properties and quality of aviation fuel as it travels



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through the distribution system. The producers must formulate the fuel to meet the specification properties, fuel handlers in the distribution system such as pipeline companies must certify that the fuel meets the specification when delivering fuel, aircraft engine designers must design their engines to operate over the range of fuel properties in the specification, and aircraft operators such as airlines must ensure that the fuel loaded on to their airplanes meets the criteria of the specification.

Civil airworthiness authorities (CAAs) also rely on fuel specifications to ensure the safety of aircraft operations. Airworthiness regulations issued for aircraft and engines require that operating limitations be established for each certificated design. These operating limitations typically specify the industry, military or company aviation fuel specifications that the aviation fuel must meet for use on the specified aircraft and engine.

The existing fleet of turbine-engine-powered aircraft has been designed to operate on conventional aviation turbine fuel (jet fuel) that meets the major industry specifications described above. However, due to recent environmental, supply stability, and cost issues related to conventional petroleum-derived jet fuel, approvals have been requested to use new, alternative fuels derived from nonconventional feedstocks on the existing fleet of turbine engine powered aircraft. In response to these requests, the aviation fuel community has developed qualification and certification concepts and procedures to approve an alternative fuel for operation on the existing fleet.

This article describes the process being developed by the aviation fuels industry and the Federal Aviation Administration (FAA) to qualify and certify new classes of aviation fuels. It is believed that the concepts presented here should be applicable to other CAAs and fuel specification-writing organizations.

Aviation Fuel Qualification and Certification

As mentioned above, fuel specifications are an integral element of the aviation fuel infrastructure. Consequently, a new specification needs to be developed, or an existing specification needs to be revised, to enable the use of any new alternative aviation fuel in this infrastructure. Qualification processes are used by specification-writing organizations, such as ASTM International, to develop new fuel specifications, or to revise existing specifications, in order to add a new alternative fuel. These qualification processes include a technical evaluation of the fuel, followed by development of the specification requirements and criteria. A description of the ASTM aviation fuel qualification process is described later in this article.

If the alternative fuel is found to have essentially the same performance properties as conventional jet fuel, then it is considered a drop-in fuel. Conversely, if substantive differences exist between the performance properties of the new alternative aviation fuel and conventional jet fuel, then the fuel is considered a non-drop-in fuel.

Drop-in fuels may be incorporated into the existing jet fuel specifications, and will therefore meet the established operating limitations for the existing fleet of turbine engine powered aircraft. For these, amended airworthiness certification of the existing aircraft and engines is not required.

Non-drop-in fuels will require a new specification, and therefore will not meet the established operating limitations for the existing fleet of turbine engine powered aircraft. In these cases, amended airworthiness certification of the existing aircraft and engines is required to incorporate new operating limitations.

Industry Aviation Fuel Qualification Process

The process that ASTM International uses to approve a new fuel consists of a test phase to evaluate the fuel or additive, followed by an approval phase that includes ASTM International balloting on the new specification, or revision to an existing specification, for the fuel.

Test Phase

In general, the fuel must undergo sufficient testing and development to show that, under the conditions in which it will be used in an aircraft, it is compatible with typical engine and aircraft materials. The fuel must comply with the specification properties that are necessary to meet the performance and durability requirements of the airplane, rotorcraft, or engine. The data should address compatibility with other fuels, lubricants, and additives that are approved for engines and aircraft. Fuels must be shown to be capable of being mixed with other approved fuels or additives at all anticipated temperatures. The fuel must be shown to maintain its properties at limiting operating temperatures to prevent blocking of fuel lines and filters.

The test phase includes investigations of the effect of the candidate fuel on fuel specification properties, fit-for-purpose properties, materials compatibility, component rig tests, or engine tests. The extent of the test phase depends on the chemistry of the new fuel or additive, similarity to approved fuels and additives, and engine manufacturer experience. Departure from engine manufacturer experience would require more rigorous testing. The results of the test phase will be documented in a research report prepared by the fuel formulator with oversight by the aircraft equipment manufacturers. The research report provides the data and information necessary for review of the ASTM International members who participate in the balloting process.

Approval Phase

Upon completion of the test phase, the research report is reviewed by engine manufacturer representatives on the ASTM International Aviation Fuels subcommittee. If approved by the engine manufacturers, a draft specification with appropriate language and criteria is developed. This draft specification and the research report are submitted to the entire subcommittee for review and balloting. The specification and research report may go through several revisions before a final version of the specification is approved by the membership. The subcommittee ballot is followed by a committee level ballot before final approval by ASTM International and publication of the specification.

ASTM International is considered a voluntary consensus standards organization. These organizations are characterized by a balanced membership of stakeholders, each with an equal voice that participates in a well-defined process to create industry standards or specifications. Because the specifications produced by these organizations go through a rigorous technical vetting process, they are considered to provide very robust control of quality and performance. Consequently, CAAs such as the FAA utilize these standards and specifications in their regulatory oversight of aviation.

FAA Airworthiness Certification for New Alternative Fuels

The airworthiness certification process of the U.S. Federal Aviation Administration (FAA) relies on the development and oversight of specifications and standards by voluntary consensus standards bodies such as ASTM International.

These specifications are used to define the operating limitations that must be established by the aircraft and engine manufacturers to gain type certification of their product.

For new aircraft and engine designs, no additional fuel-related testing will typically be required beyond that required for the product certification program. This is because the new aircraft or engine is undergoing a complete certification compliance program using either existing jet fuel or the new alternative jet fuel. The certification of a new airplane or engine requires a comprehensive compliance plan that should encompass all of the airworthiness standards applicable to fuels and should cover the complete range of operating conditions to which the fuel is exposed. Additional materials compatibility testing is required only if the new airplane or engine design contains new or unusual materials that the fuel would come in contact with that were not evaluated during the industry qualification process described earlier.

However, for previously certified aircraft and engines, the extent of fuel-related certification testing will be based on whether the fuel is a drop-in fuel or non-drop-in fuel.

Drop-in Fuels

As described above, drop-in fuels must meet the existing operating limitations of certificated aircraft and engines. Typically, the operating limitations will be specified as "Jet A/A-1 Fuel", or "Jet A/A-1 Fuel meeting ASTM D1655". Because the drop-in alternative fuel will be incorporated into the existing jet fuel specifications, there will be no change required to these operating limitations and no associated certification testing. In effect, the alternative fuel seamlessly enters the fuel distribution infrastructure and requires no special treatment or identification, and is co-mingled with conventional jet fuel. From the perspective of the certificated aircraft and engine, conventional fuel and the drop-in alternative fuel provide identical performance and safety.

Non-Drop-in Fuels

The certificated operating limitations for a previously certified aircraft or engine will need to be revised to add the specification reference for the new alternative fuel. In addition, modifications to the design of the aircraft or engine may need to be incorporated to accommodate the new alternative fuel. This will require an amendment of the type certificate or a supplemental type certificate (STC) (if the applicant is not the original equipment designer). In either case, the fuel-related regulatory requirements must be revalidated by testing of aircraft and engine. In most cases, certification approval of an engine to operate with the new alternative fuel will need to be followed by certification approval of the aircraft on which the engine is installed.

Conclusions

The following conclusions can be made with respect to adopting a global fuel qualification and certification protocol:

- The concepts presented here should be applicable to other CAAs and fuel specification-writing organizations.
- There are benefits and advantages to be gained by cooperating with other CAAs and voluntary consensus standards organizations to facilitate the approval of new alternative fuels.
- The current industry qualification and global certification processes are the appropriate means for approving a new alternative jet fuel.

REFERENCES

1 *ASTM International Standard **D1655**, "Standard Specification for Aviation Turbine Fuels."*

2 *ASTM International Standard Practice **D4054**, "Guideline for the Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives."*

3 *ASTM International Standard **D7566**, "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons."*

4 *Defence Standard 91-91: "Turbine Fuel, Aviation Kerosine Type, Jet A-1 NATO Code: F-35 Joint Service Designation: AVTUR."*

From "Alternative" Fuels to "Additional" Fuels: Overcoming the Challenges to Commercial Deployment

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In commenting on the tremendous progress made in the development of alternative aviation fuels, a participant at the May 2010 ICAO Colloquium on Aviation and Climate Change offered a keen observation: we may want to start referring to the fuels as "additional" fuels, rather than as "alternative" fuels. There was resounding agreement in the Colloquium that aviation is striving for that very target, but that challenges remain. In this article we identify the key challenges to deployment of aviation "alternative fuels" at a scale to warrant the fuels being considered "additional." Perhaps more importantly, we note the work that is being undertaken by industry, governments, researchers, would-be feedstock and fuel suppliers, ICAO and others to overcome those challenges.

The Desire for Alternatives

There can be no question that the world's airlines are dedicated to the development and deployment of sustainable alternative aviation fuels. A quick review of the industry's commitments bears this out. In April 2008, the Air Transport Association of America (ATA) issued an alternative aviation fuels commitment stating that its members "are dedicated to the development and deployment of safe, environmentally friendly, reliable and economically feasible alternatives to conventional petroleum-based jet fuel."[1] Members of the Sustainable Aviation Fuel Users Group (SAFUG) later pledged to "advance the development, certification and commercial use of drop-in sustainable aviation fuels."[2] And the International Air Transport Association (IATA) has expressed is continuing commitment to sustainable alternatives to petroleum-based fuel as a critical means to reduce the industry's carbon footprint, break the "tyranny of oil" and "drive economic development in all parts of the world."[3]

The airlines are certainly not alone in their quest. In early 2006, ATA, the U.S. Federal Aviation Administration (FAA), the Aerospace Industries Association (AIA) and the Airports Council International-North America (ACI-NA) banded together to form the Commercial Aviation Alternative Fuels Initiative (CAAFI). As a coalition of airlines, aircraft and engine manufacturers, airports, energy producers, universities, international participants and government agencies, CAAFI aims to promote the development of alternative jet fuel options that offer equivalent levels of safety and compare favourably with petroleum-based fuels on cost and environmental bases. Work of the various stakeholders over the past few years has proven that alternative fuels to power commercial aircraft in flight are real. Indeed, since 2008 there has been a string of successful test flights of commercial aircraft utilizing an array of biofuel and synthetic fuel alternatives,[4] in addition to countless rig tests and analyses.

In light of all of this activity, a question posed by the Chairman, President and Chief Executive Officer of United Airlines, Glenn F. Tilton, comes to mind: "If the airlines need alternative fuels, want alternative fuels, and we've flown aircraft with them, why then, don't we have them?"[5] While noting there is no simple answer to this question, Mr. Tilton observed, in sum, that we need to overcome the obstacles to commercial application of these fuels. Indeed, from an airline point of view, before any alternative fuel can have commercial application in aviation it must be demonstrated to be (1) as safe as petroleum-based fuels for powering aircraft; (2) capable of being produced so as to provide reliable, cost-competitive supply; and (3) more environmentally friendly than today's fuels.[6] We outline each of these challenges below, along with the steps being taken to address them.

Safety

Safety is the airlines, airframe and engine manufacturers' number-one commitment. To ensure safety, commercial jet fuel must meet precise technical and operational specifications, and jet engines are designed to work with jet fuel having these specific characteristics. This is the first and most critical challenge for alternative aviation fuels. Significantly, the aviation community has established processes for meeting this challenge.

Any alternative jet fuel must satisfy the regulatory and standards-making organization specification requirements for jet fuel. In the United States and much of the world, the recognized jet fuel specification is set by ASTM International.[7] Until very recently, ASTM D1655, "Standard Specification for Aviation Turbine Fuels," was the only ASTM jet fuel specification. Based on a process forwarded by CAAFI and other supporters, in August 2009, after completing its rigorous review process, ASTM approved D7566, "Aviation Turbine Fuel Containing Synthesized Hydrocarbons." This specification allows for alternatives that demonstrate that they are safe, effective and otherwise meet the specification and fit-for-purpose requirements to be deployed as jet fuels, on a par with fuels under ASTM D1655.

The initial issue of D7566 enables use of fuels from the Fischer-Tropsch (FT) process in up to a 50 percent blend with conventional jet fuel. FT fuels can be generated from a variety of feedstocks, including biomass (biomass to liquid) and natural gas to liquid, in addition to coal to liquid and combinations thereof. Most critically, however, the ASTM D7566 specification is structured, via annexes, to accommodate different classes of alternative fuels when it is demonstrated that they meet the relevant requirements. An annex is currently under consideration for hydrotreated renewable jet (HRJ) blends (also referred to as bio-derived synthetic paraffinic kerosene, or "Bio-SPK"), which is expected to be approved by 2011, with other alternatives (e.g., hydrolysis/fermentation, lignocellulosic bioconversion, pyrolysis/liquefaction) to follow as data from technical evaluations is obtained.

By meeting the rigorous jet fuel specification and fit-for-purpose requirements, sustainable alternative aviation fuels are demonstrated to be "drop-in" fuels, completely compatible with existing airport fuel storage and distribution methods and airplane fuel systems. Accordingly, they do not carry any added infrastructure costs for airlines, fuel distributors or airport authorities, adding to their commercial viability.

While much of the leading work on alternative aviation fuels is occurring in the United States, the global nature of the aviation industry and its overall regulatory framework allow for international deployment. Despite the existence of jet fuel specifications separate from the ASTM specification, such as the United Kingdom's Defence Standard (Def-Stan) 91-91,[8] collaborative processes are in place to allow for data exchange to harmonize the specifications as data and conditions warrant. Further, ICAO, as the United Nations (UN) body charged with setting standards and recommended practices for international aviation, is providing a forum for further information exchange and international policy development on sustainable aviation alternative fuels.[9]

Supply Reliability and Cost Competitiveness

Fuel costs are a significant portion of an airline's operating costs – in many cases, the greatest portion. Given that airlines typically generate razor-thin profit margins even in good years – and incur substantial losses in bad years – any fuel used by the airlines must be competitively priced and reliably provided.

As noted by Bill Harrison, Technical Advisor for Fuels and Energy at the U.S. Air Force Research Laboratory, scaling up supply and making alternative aviation fuels cost-competitive may well be the most significant challenge to their commercial deployment.[10] Due to the nascent nature of the enterprises, in most instances, feedstock production for alternative fuels – particularly for biofuels – is still in the early stages of development, requiring investments to construct commercial-scale processing facilities. Refinery facilities can require significant upfront capital, which can be challenging to obtain in current market conditions. Also, with feedstocks representing up to 80 percent of the cost of alternative fuel, appropriate incentives are essential to develop the feedstock base. Absent that, even if financing is adequate to construct alternative jet fuel facilities, the resultant fuel may nonetheless be unaffordable to the consumer. Long-term contracts between alternative-fuel suppliers and consumers must be predicated on the fuel being cost-competitive. Further, in the case of bio-feedstocks, it is imperative to develop an appropriately incentivized agricultural base that yields adequate energy content but does not compete with existing food crops.

As United Airlines' CEO has pointed out, airlines generally are not in a position to finance alternative fuel companies in light of the financial challenges the airlines have faced for many years. They are, however, sending the "market signals" that they are prepared to purchase alternative aviation fuels that are safe, reliable, cost-competitive and environmentally beneficial. In addition to general statements in this regard, several pre-purchase agreements announced to date bear this out. Further, aviation is an attractive buyer, with airports representing ready-made nodes in a network of concentrated demand. Indeed, in the United States, four airports – Los Angeles (LAX), New York-Kennedy (JFK), Chicago O'Hare (ORD) and Atlanta (ATL) – each support uplift of more than one billion gallons of jet fuel annually. The 10 largest airports account for approximately half of all U.S. commercial jet fuel uplift, with the 40 largest locations accounting for an estimated 90 percent. And demand for alternative jet fuel increases further when factoring in military requirements, as through the "Strategic Alliance for Alternative Fuels"[11] signed in March 2010 by ATA and the U.S. Defense Energy Support Center (DESC), the procuring arm for the U.S. military.

While concentrated demand prevails, as recognized in ICAO's Declaration of the Conference on Aviation Alternative Fuels, additional funding is needed from governments and the private sector.[12] CAAFI is among the groups working to promote such funding. Governments should be encouraged to do more. As spelled out in its Global Framework for Aviation Alternative Fuels,[13] the ICAO task to provide "fora for facilitating the exchange of information on financing and incentives for sustainable alternative fuels for aviation programmes working with the relevant UN and regional financial entities" should be helpful.

Environmental Benefit

A significant driver for the deployment of alternative aviation fuels is the benefit they may bring in reducing emissions from aviation, whether associated with local air quality or global climate change. In terms of local air quality, for example, alternative fuels tend to have much lower sulphur content than petroleum-based fuel, and hence lower particulate matter emissions. As carbon is fundamental to powering aircraft engines, this and the carbon dioxide generated upon combustion cannot be eliminated from drop-in jet fuels, but they can be reduced, either through increasing the per-unit energy provided in the fuel, reducing carbon somewhere along the "lifecycle" of the fuel, or some combination thereof. Indeed, there can be emissions all along the "life" of the fuel – from growing or extracting the feedstock, transporting that raw material, refining it, transporting the finished fuel product and using it. By examining the emissions generated at each point in the lifecycle, one can ensure that the emissions benefits that are sought are in fact real and do not create emissions "dis-benefits" along the way.

CAAFI, SAFUG, the European Sustainable Ways for Alternative Fuels and Energy in Aviation (SWAFEA) and other groups have made significant progress in confirming the methodologies for lifecycle analysis of alternative aviation fuels[14] and in supporting or performing case studies that use these methodologies.[15] While the emissions aspect of this work is most central, these groups also are focused on ensuring that alternative fuels ultimately are sustainable under all relevant environmental criteria, including land use, water management and the like. However, rational and supportive standards and/or regulations for documenting and crediting the environmental performance of the fuels will need to be put in place.

From a fuel-user perspective, there are at least three elements necessary to the alternative fuels environmental regulatory structure to support commercial viability. First, any demonstrated environmental benefit relative to traditional jet fuel should be credited. Of concern in this regard are regulatory proposals that seek to require alternative fuels to achieve benefits of several orders of magnitude over traditional fuels before any environmental credit is given. Second, the regulatory provisions need to recognize that airlines typically commingle the fuel they purchase in common-carrier multi-product pipelines and airport fuel storage facilities, such that the purchasing airline might not actually fly with the exact fuel it purchases. For commercial viability, part of which requires avoiding duplicative storage and distribution infrastructure, the regulatory structure will need to accord the environmental credit to the airline that purchases the more environmentally beneficial fuel, even if that airline does not fly with it. Finally, aviation is a global business. For airlines to be able to fully employ alternative fuels, the environmental criteria for alternative aviation fuels in international aviation ultimately will need to be made compatible worldwide. ICAO has a unique and most important facilitating role to play in this regard.

Conclusion

The aviation community is dedicated to the development and deployment of environmentally friendly alternative aviation fuels. These fuels are real – we know how to fly them. Now we must make them commercially viable so they are not only "alternative fuels," but "additional fuels." Groups like CAAFI are critical to this desired outcome. So, too, are ICAO and its 190 Member States.

REFERENCES

1 *Commercial Aviation Alternative Fuels: The ATA Commitment*
http://www.airlines.org/Energy/AlternativeFuels/Pages/CommercialAviationAlternativeFuelsTheATACommitment.aspx.

2 *SAFUG was formed in September 2008*
http://www.safug.org/docs/sustainability-pledge.pdf.

3 http://www.iata.org/pressroom/pr/Pages/2010-06-07-02.aspx.

4 *An overview of these test flights was provided by Paul Steele, Executive Director of the Air Transport Action Group*
at ICAO's Colloquium on Aviation and Climate Change.
http://www.icao.int/CLQ10/Docs/7_Steele.pdf.

5 *Keynote address to the Commercial Aviation Alternative Fuels Initiative (CAAFI)*
Annual Meeting (Sept. 30, 2009).

6 *See Young, Key Steps for Airlines in Purchasing and Deploying Alternative Fuels*
(presented at the ICAO Colloquium on Aviation and Climate Change,
http://www.icao.int/CLQ10/Docs/7_Young.pdf).

7 http://www.astm.org/COMMIT/COMMITTEE/D02.htm, Committee D02 on Petroleum Products and Lubricants.

8 http://www.dstan.mod.uk/standards/deftans/91/091/00000600.pdf.

9 *ICAO, Global Framework for Aviation Alternative Fuels*
http://www.icao.int/icao/en/env/AlternativeFuels/Index.html.

10 *Harrison, Alternative Fuels: How Can Aviation Cross the Valley of Death*
(Massachusetts Institute of Technology Master's Thesis, 2008).

11 http://www.airlines.org/News/Releases/Pages/news_3-19-10.aspx.

12 http://www.icao.int/CAAF2009/Docs/CAAF-09_SD003_en.pdf.

13 *See supra note 9.*

14 *Estimating Lifecycle Greenhouse Gas Emissions from Alternative Jet Fuels*
(presented by the United States at the ICAO Conference on Aviation and Alternative Fuels, 16-18 November 2009,
http://www.icao.int/CAAF2009/Docs/CAAF-09_WP004_en.pdf.)

15 *Stratton, Wong and Hileman, Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels*