Drop-in biofuels for international marine and aviation markets

Summary and conclusions from the IEA Bioenergy ExCo78 workshop

This publication provides the summary and conclusions for the workshop 'Drop-in biofuels for international marine and aviation markets' held in conjunction with the meeting of the Executive Committee of IEA Bioenergy in Rotorua, New Zealand on 9 November 2016.

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IEA Bioenergy: ExCo: 2017:04

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Published by IEA Bioenergy

EXECUTIVE SUMMARY

Luc Pelkmans, Technical Coordinator, IEA Bioenergy

The IEA Bioenergy Technology Cooperation Programme (IEA Bioenergy TCP) held its biannual workshop in Rotorua, New Zealand on 9 November 2016 in conjunction with their Executive Committee meeting (ExCo78). The workshop on '*Drop-in biofuels for international marine and aviation markets*' was prepared in close collaboration with SCION. The workshop consisted of three sessions: (1) setting the scene & organising supply chains, (2) perspectives for marine biofuels, and (3) perspectives for aviation biofuels. The workshop concluded with a panel discussion on policy options and recommendations to support biofuels in international marine and aviation markets.

BIOFUELS IN INTERNATIONAL MARINE MARKETS

Current marine fuels consumption globally is estimated to be around 330 million tonnes of fuel annually, most being heavy fuel oils. As global trade increases, overall fuel demand for marine transport is predicted to double by 2030. The maritime sector is facing stricter emission regulations by the implementation of Emission Control Areas (ECAs) as well as the IMO[1] commitment to reduce fuel sulphur levels. Ships are also subject to local rules in different areas of world, such as the EU or the US. To meet these regulations, ships need to change to more expensive low-sulphur diesel fuels or to install costly scrubber units. It is estimated that 70,000 ships will be affected by this change. Biofuels, which are basically sulphur free, may meet the demand for new fuels in the maritime sector. Marine fuels offer a relatively easy market for lignocellulosic fuels, especially when compared to road or aviation fuels, as the quality constraints are much lower. Pyrolysis oils from lignocellulosic material may form a basis for marine fuel applications.

Some countries have already implemented favourable conditions for marine biofuels, but on the global scale developments are moving very slowly. Both market and product developments are needed to make biofuels a significant part of the future marine fuel mix. While current legislation is focusing on local emissions, a shift to include greenhouse gases is needed. There is consensus that shipping has to do its 'fair share' of emission reduction. Some initiatives have started to introduce liquefied natural gas (LNG) in shipping, which would have clear impacts in terms of air quality; however, natural gas provides limited advantages in GHG emissions so further decarbonisation is needed.

Global regulation is needed with clear GHG reduction targets and mechanisms in the shipping sector, and recognition of biofuels as a pathway to reduce emissions. Shipping companies tend to be risk averse and marine fuel prices are relatively low. Moreover, in the system of chartered vessels it is difficult to make investments and modifications. Nevertheless, cargo owners need to make a real commitment to low-carbon transport. The industry needs to work cohesively, and the sector can learn from the coordinated steps taken in the aviation industry (ICAO[2]).

Next to international industry agreements, country commitments and local incentive schemes can be an important driver and create markets for low-carbon fuels. Typical for marine applications is that fuel distribution is much more centred compared to road fuels. For instance, only 15 ports account for 85% of marine fuel bunkering globally. Ports are making efforts to become 'sustainable ports', while also committing to reduce footprint emissions. There is a need to engage with the shipping lines to better understand the capabilities of and drivers for biofuels.

1 International Maritime Organisation

2 International Civil Aviation Organisation

Road biofuel incentives can be extended to marine fuels, as in the Netherlands, or alternatively CO_2 and other emissions can be included when calculating fairway and port duties (e.g. Clean Shipping Index in Sweden). Tenders for public contracts form an easy mechanism to give CO_2 a substantial value and allow the market to come up with the most cost-efficient carbon reduction solutions.

BIOFUELS IN AVIATION MARKETS

The aviation sector has recognised that biojet fuels are a key component to achieving significant carbon reduction, well after 2050. The recent Carbon Offsetting Scheme (CORSIA) of ICAO to reduce CO_2 emissions creates a commitment to look for low carbon solutions.

Various airlines and ports have engaged in biofuel purchase agreements, direct investments in fuel production facilities and development of alternative fuel feedstock sources. Different airlines have made public commitments to purchase and use biofuels and some are broadly involved in creating sustainable fuel supply chains. Others have announced their engagement in advancing supply chain development. Nevertheless, thus far, development of biojet fuels has been slow and consumption is still limited.

Currently, most biojet fuels are derived through the oleochemical pathway, based on upgrading of oils and fats. This pathway will continue to be the main source of biojet for the next 10 years. In the long-term there may be a shift to lignocellulosic feedstock. The aviation industry will have to compete with other industries for biomass feedstocks. In particular, road biofuels are a more likely target product for sustainable fuel refiners, at least in the short term.

Significant questions remain about the economic viability and the necessary scale-up of the industry. Large scale replacement would require high production ramp up rates, with growth needs significantly exceeding historical global biofuel production growth rates. The development of such an industry would require immediate and sustained investment in alternative aviation fuel production infrastructure, which would only take place if enabled by the right policies.

Alternative aviation fuels will remain more expensive to produce than conventional jet fuel in the short- and medium term and significant cost savings will still need to be realised for many pathways. Including biojet production in a refinery framework (next to higher value chemicals) would also reduce costs. A certain level of higher costs may be justifiable from a societal perspective as long as the environmental benefits (e.g. in terms of CO_2 reduction) compensate for the additional costs.

International agreements are important to get sector commitments; however the offset values in the CORSIA agreement are probably too low to stimulate biojet fuels. Country commitments, national incentives and regional initiatives are needed to launch biofuel markets. Fiscal incentives have the greatest potential to increase investment in carbon reduction in aviation, both for supply chain members and airlines, and could bridge the price parity gap. It is also crucial to de-risk investments as capital investments are very intensive – offtake agreements and long guarantees would aid developments.

There are regions where biojet is promoted as an extension of road transportation policies. Domestic aviation (which falls under the Paris Agreement) also provides more scope for tax incentives for countries with the aim to target emission reductions, so domestic aviation can be a driver for biojet production. Regional multi-stakeholder initiatives, centred around a main airport (the 'BioPort' concept) are emerging, with regional policy incentives; such initiatives can play a key role in the expansion of biojet.

CONCLUSIONS AND RECOMMENDATIONS:

Biofuels are currently mostly associated with road transport, but it is acknowledged that in the longer term the role of biofuels in international transport (aviation, shipping) will increase as these sectors rely on high energy density fuels. While road transport fuels are mostly regulated at national level, aviation or maritime fuels operate in global markets. So the international nature of these sectors requires a different approach to stimulate biofuels in international aviation or shipping.

There is a clear gap between the cost of biofuels and fossil fuels, both for aviation and marine applications. In the first instance, technology evolution will be needed to bring costs down and de-risking investments will be crucial to deploy these technologies; it will also be important to evolve towards biorefinery approaches, delivering a range of outputs. In that sense, marine biofuels and biojet fuels are complementary as they are at different ends of the fuel spectrum (high vs low specifications). Marine fuels are generally of low quality and marine engines can accept different fuel grades, while aviation is much more regulated from a safety management and engine performance perspective, and aviation fuels need to meet high quality standards. Further research and development into the best fit for fuels for the maritime and aviation sector is required.

Negative externalities are not included in current fossil fuel costs, and this distorts the playing field. Including societal cost – e.g. through a carbon tax – can make the case for positive returns for biofuels in a shorter timeframe. To avoid market distortions, a carbon price should be applied across all sectors and then markets would decide.

Reaching a substantial scale of biofuels in aviation and marine applications will require a mix of international and regional initiatives. The recent CORSIA agreement of ICAO creates a commitment in the aviation sector to look for low carbon solutions, although the offset values themselves are probably too low to stimulate biojet fuels. The marine sector so far has focused less on CO_2 emissions, as most regulations are focused on local air quality, particularly to reduce the sulphur content of shipping fuels. This can also create momentum for the sector to consider alternative fuels.

Next to these international industry initiatives and agreements, country commitments, national incentives and regional initiatives are needed to launch biofuel markets. Some countries are opening national road transport biofuel incentives for biojet fuels or marine biofuels. Domestic aviation can also be a way to launch biojet fuels in national markets. In the case of shipping, including CO_2 emissions to calculate fairway and port duties or to award public contracts can encourage the market to come up with cost-efficient carbon reduction solutions.

An interesting evolution is regional multi-stakeholder initiatives, centred around a main airport/harbour (the 'BioPort' concept), with regional policy incentives. Typical for marine and aviation is that fuel distribution is much more centred compared to road fuels. So BioPort concepts can be an important step to launch biofuel markets, both in marine and aviation markets.

The PowerPoint presentations can be downloaded from IEA Bioenergy's website http://www.ieabioenergy.com/publications/ws21-drop-in-biofuels-for-international-marine-and-aviation-markets/

WORKSHOP

WELCOME SPEECHES

Prue Williams of the New Zealand Ministry of Business, Innovation and Employment welcomed the participants to New Zealand and presented the science investments directions of the New Zealand government. The Government's overall strategic direction is to encourage a shift towards renewable energy. Science has a key role in the future of the New Zealand bioenergy story.

Warren Parker, the CEO of SCION, gave a short introduction to the New Zealand forest industry, Scion and bioenergy. 1.7 million hectares in New Zealand are plantation forests. Increased forest planting (up to 1 million additional hectares) is critical to New Zealand meeting its international 2030 carbon commitments. While electricity is already more than 80% renewable, New Zealand will also need to increase bioenergy use in the industrial heating, transport and aviation sectors. Transition to a renewable low carbon bioeconomy is key, with a major role for forest biomass.

Kees Kwant, the Chair of IEA Bioenergy, stated that big changes are going on in the energy sector. Renewable electricity seems to be on the right track, but transport and heating are lagging behind. In the future, biofuels should play a major role in the international marine and aviation sectors where other alternatives such as electric propulsion are much more difficult to implement. This workshop will focus on these markets and the aim is to come to concrete recommendations on what can be done to stimulate furthers steps in these sectors.

Session 1: Setting the scene and organising supply chains

This session was moderated by the IEA Bioenergy Chair Kees Kwant.

ARENA'S INVESTMENT PRIORITIES IN BIOFUELS IN AUSTRALIA

Amy Philbrook, Australian Renewable Energy Agency (ARENA)

ARENA is the Australian Renewable Energy Agency. It was established in July 2012 to improve the competitiveness of renewable energy technologies and to increase the supply of renewable energy in Australia. ARENA has invested 1.1 billion AUD in renewable energy projects with 47 million AUD for bioenergy activities.

The priority areas for biofuel investments are developed through industry consultation, market analysis and outcomes from ARENA funded projects. Specifically in the fuels space, ARENA sees areas of key opportunities to be:

- Pathways that meet demand, i.e. projects that are developed as part of a commercial proposition such as to meet key demand areas, for example, aviation fuel or military fuels;

- Aggregation of feedstocks to facilitate project delivery;
- The downstream end of the biocrude to biofuel sector including refining to produce drop-in usable fuels;
- The role of co-products – it is recognised that high value products tend to form a material component of the commercial proposition of development projects.

PATHWAYS AND COMPANIES INVOLVED IN DROP-IN BIOFUELS FOR MARINE AND AVIATION BIOFUELS

Jack Saddler,
University of British Columbia, Canada,
co-Task Leader of IEA Bioenergy Task 39

IEA Bioenergy Task 39 ("*Commercialising conventional and advanced liquid biofuels from biomass*") has been, and continues to investigate the challenges and potential of technologies for producing drop-in biofuels. A report published in 2014, "The potential and challenges of drop-in biofuels", is currently undergoing an update. There continues to be considerable interest in developing biofuels that can be readily integrated into the existing petroleum fuel infrastructure in a "drop-in" fashion, particularly by sectors such as aviation where there is no alternative, sustainably produced, low carbon emitting fuel source. There are several ways to produce drop-in biofuels, including oleochemical processes (i.e. the hydroprocessing of lipid feedstocks), thermochemical processes, such as gasification, pyrolysis or hydrothermal liquefaction (HTL) followed by catalytically upgrading/hydroprocessing, and biochemical processes, such as the biological conversion of sugars or cellulosic materials to longer chain alcohols and hydrocarbons. In the near-term, biojet fuels will likely be produced via the oleochemical route. However, longer-term biojet production will likely be based on lignocellulosic feedstock using thermochemical platforms. The biochemical route seems much more valuable in rapidly growing chemicals markets.

Canada has vast forest resources and an innovative forestry industry that could potentially support an evolving biojet sector. British Columbia has been at the forefront of increased wood residue utilisation as exemplified by the established pellet sector. A current project, assessing the viability of producing biojet from forest residues based on thermochemical conversion technologies, with involvement of several international partners, including airlines and manufacturers was also presented. The project is focused on producing biojet through upgrading of biocrude from pyrolysis and hydrothermal liquefaction. In addition to a focus on the technical challenges, the project is currently investigating the supporting policy framework that will be essential for development of biojet production in this region (*see presentation by van Dyk below*).

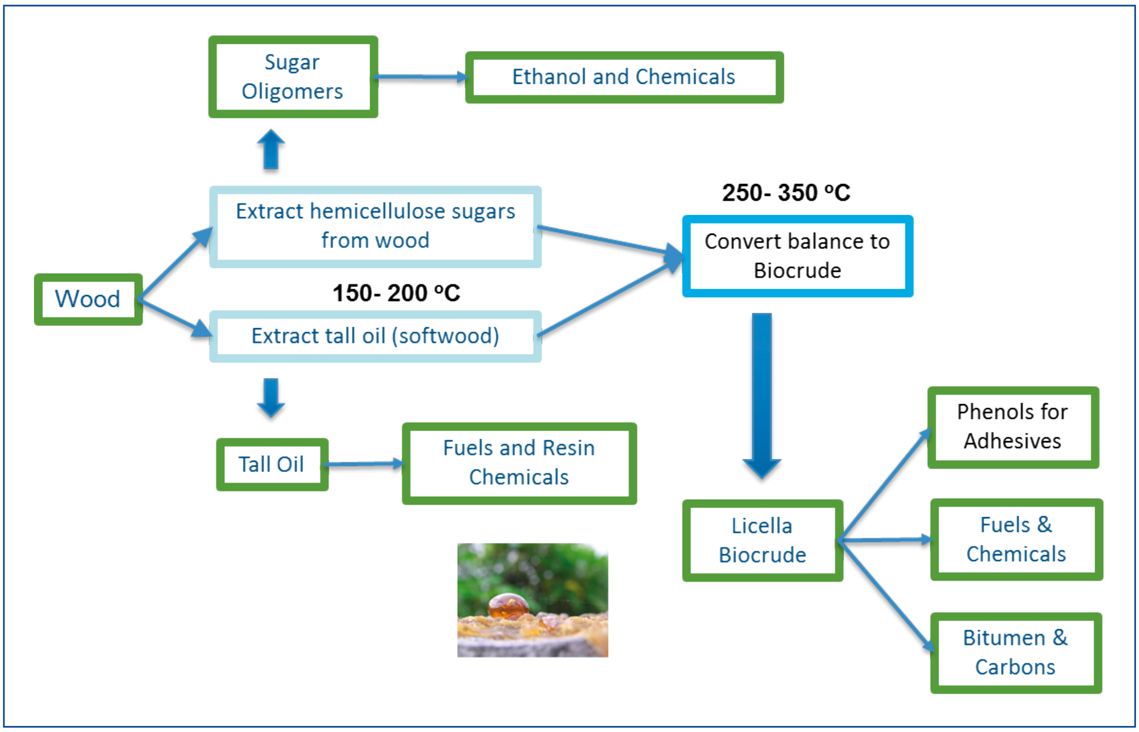
PRODUCTION OF BIO-CRUDE OIL AS A PLATFORM FOR BIO-CHEMICALS, MARINE AND AVIATION FUELS

Steve Rogers, Licella, Australia

Licella is an Australian based company that has pioneered the idea of producing a "bio-crude" oil that can be refined, in the same way as fossil crude, into an array of fuels and chemicals. The technology is able to produce a drop-in fuel, that can be used in existing oil fuel infrastructure.

In the past seven years, Licella has built three pilot plants at its facility at Somersby, Australia, scaling the plant by a factor of ten at each point, and has tested a wide range of lignocellulosic feedstocks as well as micro and macro algae. Today the plant is used to produce bio-crude from potential client's feedstocks for evaluation purposes.

The bio-crude produced can be blended with traditional fossil crude and co-processed using traditional refining infrastructure and catalysts, into a range of finished fuels. A significant portion of the bio-crude can be converted into higher value bio-chemicals that can be used to make products such as resins, thereby assisting with the overall economics of the process.



Products from Licella's Cat-HTR process

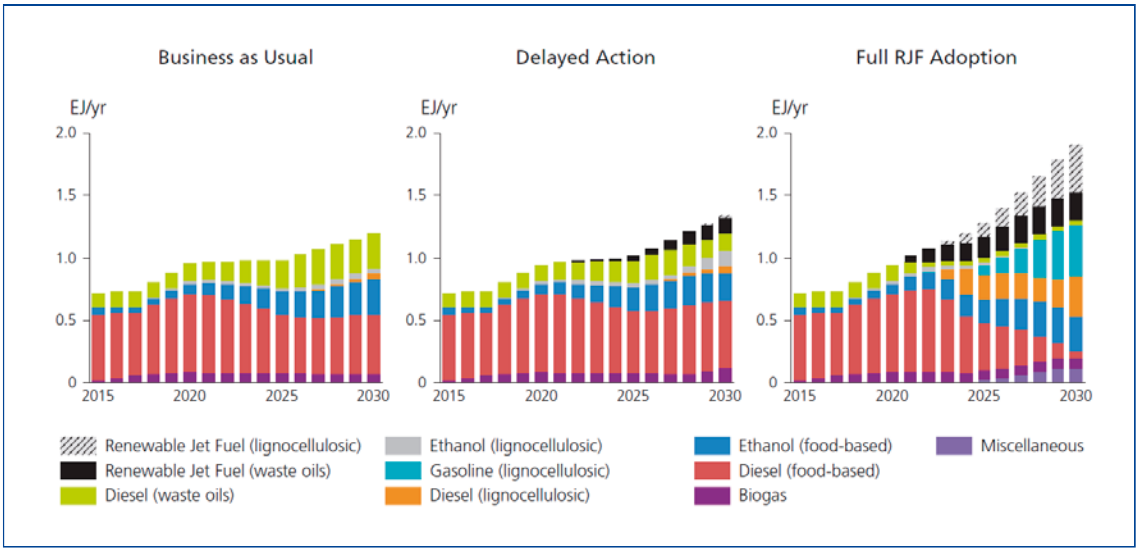
In order to move the technology to the next scale, Licella has recently formed a Joint Venture (JV) with a large Canadian pulp company to integrate the technology in a commercial mill. Given the low current price of fossil crude, Licella believes that selecting a good JV partner where long term objectives are aligned is critical, as well as ensuring the project is eligible for the significant incentives that are available in certain geographies.

The following two presentations were brought forward as they were delivered through videoconference.

A ROADMAP FOR THE ADOPTION OF AVIATION BIOFUELS IN EUROPE

Sierk de Jong, SkyNRG/Utrecht University, the Netherlands

The adoption of biojet fuels in aviation is an important part of the basket of measures to achieve emission reductions in aviation. Significant growth in biojet production volumes is required in the coming decades if the aviation industry is to contribute to a 2°C emission trajectory. In the context of the RENJET project, Utrecht University and partners developed a roadmap for the adoption of aviation biofuels in Europe, which is to be published by the end of 2016. In this roadmap, the feasibility of different biojet deployment scenarios is evaluated and key pre-conditions to achieve these scenarios are identified. Interaction with road biofuels is also indicated.



Feedstock-technology portfolio for all transport biofuels in the EU under different scenarios (RENJET project)

The general findings are that

1. aviation should be addressed in (inter) national decarbonisation strategies,
2. growing a biofuel industry takes multiple decades and hence a long-term vision,
3. significant effort and funding is required and
4. strategic (policy) choices need to be made now to achieve climate targets.

Feedstock mobilisation and technology development should be stimulated, in the short term through financial mechanisms, to de-risk investments and cover the price premium (at a local level); in the longer term the price premium should be incorporated into the service (at a global/EU level). The aviation industry should actively support the development of renewable jet fuels and use offsets to buy time; it is also recommended to develop consumer programmes at an airline (e.g. Fly Green Fund) or airport level (e.g. Airport Initiative) to cover the price premium and gain experience with renewable jet fuels.

INTRODUCING SUSTAINABLE MARINE BIOFUELS

Sjors Geraedts, GoodFuels Marine, the Netherlands

So far there has been a lot of attention given to aviation biofuels and very little to the marine sector. Nevertheless, biofuels are the only realistic low-carbon option for the marine sector. However, legislation promoting the use of biofuels in this sector is lacking, as is the awareness of the shipping sector concerning the potential of biofuels. Current legislation is focusing on local emissions; a shift to include greenhouse gases (GHG) is needed. There is consensus that shipping has to do its 'fair share' of emission reduction, but the International Maritime Organisation (IMO) has just postponed its definite GHG strategy to 2023.

Marine fuels offer a relatively easy market for lignocellulosic fuels, especially when compared to road or aviation fuels, as the quality constraints are much lower, so that the lower quality products in biorefineries can be directed to these markets.

Some countries have already implemented favourable conditions for marine biofuels, but at the global scale developments are moving very slowly. Both market and product developments are needed to make biofuels a significant part of the future marine fuel mix.

Global regulation is needed with clear GHG reduction targets and mechanisms in the shipping sector, as well as recognition of biofuels as a pathway to reduce emissions.

Cargo owners need to make a real commitment to low-carbon transport. The industry needs to work cohesively, and the sector can learn from the coordinated steps taken in the aviation industry (ICAO).

Local incentive schemes can be an important driver and create local markets for low-carbon fuels. This can happen through extending road biofuel incentives to the marine sector, as in the Netherlands, or through including CO_2 emissions in incentive schemes (see Clean Shipping Index to calculate fairway and port duties in Sweden). Tenders for public contracts are an easy mechanism to give CO_2 a substantial value and allow the market to come up with the most cost-efficient carbon reduction solutions.

Session 2: Perspectives for marine biofuels

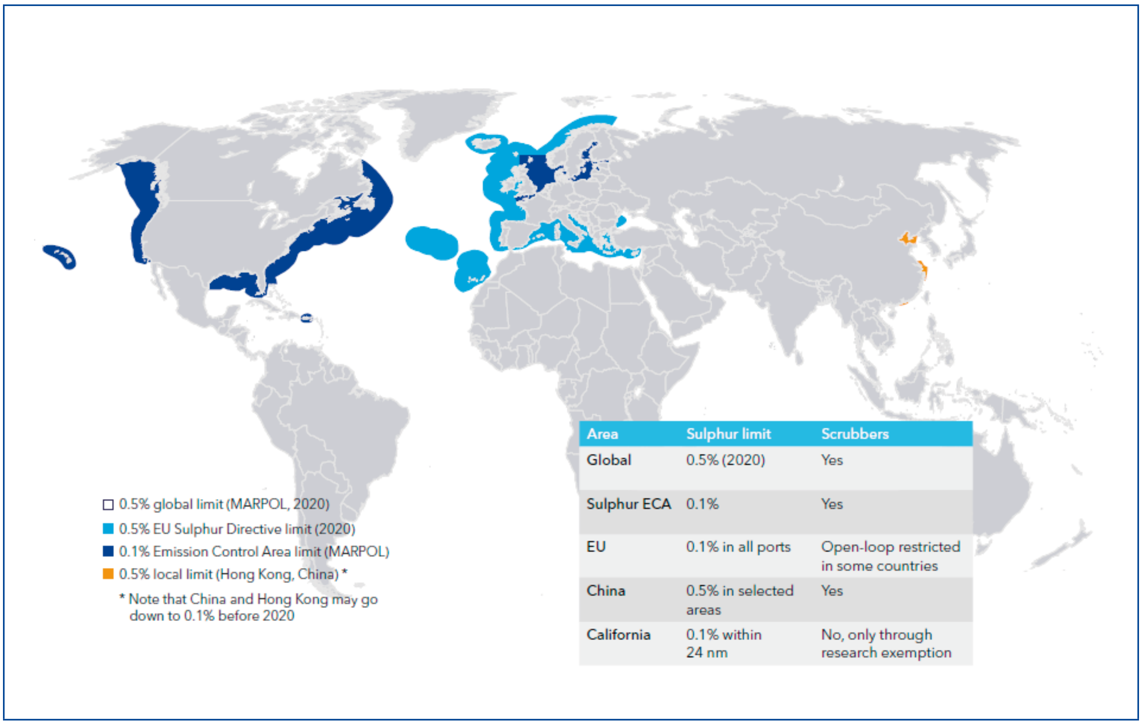
This session was moderated by Corinne Drennan, PNNL.

BIOFUEL SUPPLY TO THE NEW ZEALAND INTERISLANDER

Peter Wells, Interislander, New Zealand

Current marine fuels' consumption globally is estimated to be around 330 million tonnes annually. 80 to 85% is estimated to be residual fuel oils and the balance is mainly distillate fuels.

As global trade increases, overall fuel demand for marine transport is predicted to double by 2030. Globally the biggest impact on marine fuel types used will be regulation of sulphur content of those fuels. The International Maritime Organisation (IMO) is the principle forum for rule generation. MARPOL is the International Convention for the Prevention of Pollution from Ships. Its Annex VI specifically addresses air pollution effects from Sulphur Oxides (SOx) and Nitrogen Oxides (NOx). Sulphur limits in Emission Control Areas (ECAs) are restricted to 0.1% from January 2015. The ruling introduces limitations on sulphur content of fuels progressively, from 3.5% currently, reducing to 0.5% from January 2020. It is estimated that 70,000 ships will be affected by this change. Ships are also subject to local rules in different areas of the world, such as the EU or the USA. As a result of the upcoming sulphur restrictions, the industry is looking at what fuel options there are, including biofuels.



Area	Sulphur limit	Scrubbers
Global	0.5% (2020)	Yes
Sulphur ECA	0.1%	Yes
EU	0.1% in all ports	Open-loop restricted in some countries
China	0.5% in selected areas	Yes
California	0.1% within 24 nm	No, only through research exemption

Marine fuel sulphur regulations

The main challenges are that:

- shipping companies tend to be risk averse;
- marine fuel prices are relatively low;
- in the system of chartered vessels it is difficult to make investments and modifications.

On the other hand, the opportunities are that

- marine fuel standards are relatively easy to meet;
- marine diesel engines are very tolerant of low quality and unusual fuels;
- they are large consumers, with single points of supply;
- multi engine plants in ships have high levels of redundancy facilitating trials;
- skilled engineering staff are on board to monitor and supervise.

Overall it can be stated that changing regulations will require changes to existing fuel supply arrangements. Some biofuels can be used with minimal changes to ships equipment. It is critical to have consistent quality and volume. Solutions also need to address storage and supply infrastructure needs. Pricing is likely to be a considerable challenge.

A PORT'S PERSPECTIVE ON MARINE FUEL QUALITY

Rosie Mercer, Ports of Auckland, New Zealand

Air quality is an important issue for city ports. They have a social license to operate and community expectations often exceed the requirements of rules and regulations. Ships come close to city centres, in particular cruise ships, which keep facilities running when they are at the berth. Particularly emissions of nitrogen dioxide, sulphur dioxide and particulate matter are to be considered, SO_2 being the biggest concern. Shipping represents around 40% of SO_2 emissions in the region of Auckland.

Port of Auckland

Next to international action on fuel quality (e.g. IMO/MARPOL and Emission Control Areas), different ports are taking local initiatives. The Port of Auckland wants to be a leading sustainable port and has made a commitment to reduce footprint emissions. It seeks opportunities to partner with shipping lines to drive change, and also considers options to incentivise the use of alternative fuels, including biofuels. There is a need to engage with the shipping lines to better understand the capabilities and drivers of biofuels. With the IMO commitments towards 2020 and shipping lines looking for solutions to fulfil these requirements, it is a good time for biofuels to gain leverage.

POTENTIAL AND CHALLENGES OF DROP-IN MARINE BIOFUELS

Claus Felby, University of Copenhagen, Denmark

Merchant shipping is responsible for 90% of international trade. Small and medium sized vessels make up the largest percentage of the fleet by number, but large vessels consume 70% of the marine fuel used. In fact only 15 ports account for 85% of marine fuel bunkering globally. So the sector is operating on a global scale, as opposed to the local/regional scale for road transport. Fuel cost accounts for 50% of operating costs.

A major part of the fuels are heavy fuel oils used in 2-stroke diesel engines. The maritime sector is facing stricter regulations on particle emissions by the implementation of Emission Control Areas as well as a general reduction in fuel sulphur levels. To meet these regulations, ships need to change to more expensive low-sulphur diesel fuels or to install costly scrubber units. 80% of current fuels / engines need to be modified by 2020.

Biofuels, which are basically sulphur free, may meet the demand for new fuels in the maritime sector. From a technical point of view, diesel fuels for large 2-stroke engines have a wider range of fuel specifications as compared to e.g. jet fuels, so new biofuels and feedstocks can be relevant for the maritime sector. In fact, jet fuels are not much higher priced than marine diesel oil.

Scaling is an issue, as any test in shipping engines requires major fuel volumes. Commercial scale production plants / refineries are needed to start the process. A basic process for large-scale cracking of biomass components is needed, most likely a thermal process. Lignin, which has high energy density, is cheap and available at large quantities, and could be a good starting base.

The following recommendations were given:

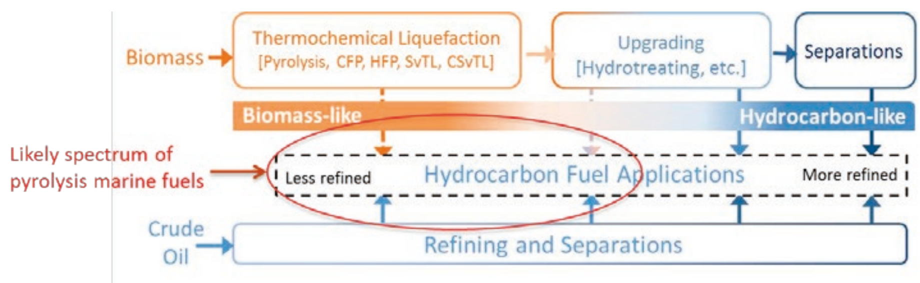
- Commercial (large scale) marine biofuel supply is needed within the next 10 years, preferably based on lignocellulosic feedstocks.
- Full-scale tests should be performed on ocean going vessels.
- Work with IMO on regulations to facilitate biofuel infrastructure
- Long term policies and/or mandatory targets are a must!

PROSPECTS OF PYROLYSIS OF LIGNOCELLULOSIC BIOMASS TO PRODUCE MARINE BIOFUELS

Alan Zacher, Pacific Northwest National Laboratory, United States, Task Leader of IEA Bioenergy Task 34 (Direct Thermochemical Liquefaction)

Zacher presented a review of the suitability of pyrolysis oils for marine fuel applications and the approaches that may be required to upgrade pyrolysis oils for such use. Pyrolysis oil is considered an energy carrier that may have various insertion points into the hydrocarbon economy. However, it has a number of significant differences compared to petroleum derived energy carriers. These differences include: water content, energy density, presence of particles (carbon, alkali metals), viscosity, storage stability, miscibility, low pH and engine combustion (performance, longevity and emissions). The quality requirements of bio-oil must be defined in the context of an end-use and this is also reflected in the upgrading technologies that can be used. The proposed methods for upgrading bio-oils are solvation, physical modifications such as separation or chemical treatment, catalytic upgrading at various levels of severity, or modifications in the bio-oil production process. Modifications to the end use are also likely, e.g. changes to engines, storage and handling. Of course, all approaches add cost.

The upgrading requirements of bio-oil for marine fuel are currently being researched, as well as combustion impacts.



Session 3: Perspectives for aviation biofuels

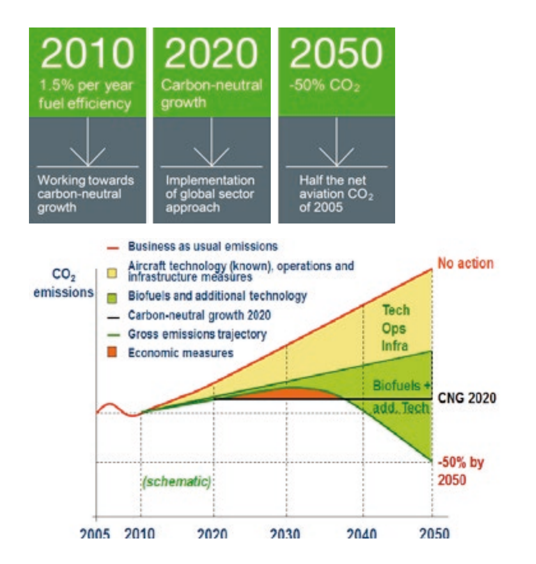
This session was moderated by Jack Saddler, University British Columbia

THE ROLE OF BIOFUELS IN REDUCING EMISSIONS IN AVIATION

Michael Lakeman, Boeing, United States

Aviation is a vital part of modern life. 3.4% of the global economy is supported by aviation, with a 5.4% average yearly growth of passenger air traffic since 1990; 2% of global CO_2 emissions are attributable to aviation. Aviation is under growing social and political pressure to reduce its environmental footprint. The aviation industry recognises its contribution to greenhouse gases and has committed itself to ambitious targets to reduce its carbon emissions. It is important to note that these targets apply at the global level and do not mean slowing down the growth of aviation. They are intended to give the industry a license to grow.

2016 has been an important year for aviation in terms of carbon emissions. In February 2016, an ICAO Airplane CO_2 emissions standard was agreed, which impacts OEMs[3]. In October the ICAO Carbon Offsetting Scheme (CORSIA) was adopted. CORSIA is a carbon offset programme for international commercial flights, covering CO_2 emissions. It is aligned with carbon neutral growth. The CORSIA has a phase-in process: The first part of the scheme from 2021 until 2026 is voluntary for States to participate in (but, it should be emphasised that once a State is in the scheme, all airlines based there are part of it too, for all their routes to other States taking part in the scheme). So far, 66 States have volunteered to join. The second phase of the scheme from 2027 is mandatory, with some exemptions for small aviation markets. In total, it is currently expected that over 80% of the growth in aviation CO_2 from 2020 will be offset, but other States are also encouraged to volunteer to join the scheme, which will boost the coverage.



CO_2 emission reduction targets of the international aviation industry (IATA)

ICAO's Committee on Aviation Environment Protection (CAEP) developed a set of scenarios, which looked at the potential cost of the global offsetting scheme to the industry. Looking at different projections of price and industry CO_2 growth, the CAEP forecasts that the cost of the scheme may be equivalent to 0.2 to 0.7% of industry revenue in 2025, increasing to 0.4 to 1.8% in 2035. Fuel costs represent around a third of operating costs, and carbon offsets could increase those by 3 to 8%.

Aviation needs 'drop-in' biofuels, meeting (or exceeding) the performance of petroleum derived fuels, which can be blended directly with conventional jet fuel, and require no change to airplanes, engines or fuelling infrastructure. Four pathways have been approved since 2011: HEFA (hydro-processed esters and fatty acids), Fischer-Tropsch synthetic fuels, Alcohol-to-Jet and

3 Original Equipment Manufacturer

synthesised iso-paraffins (SIP) from sugars. The commercial projection of biojet fuels is rising with the first dedicated commercial aviation biofuel refinery in California (AltAir). Off-take agreements between biofuel producers and airlines are growing and have moved beyond demonstration, with many of the major airlines involved.

'Green diesel' is a game changer for aviation biofuel, as HEFA jet fuel and Green Diesel are produced from the same process.

PROSPECTS AND EVOLUTIONS OF SUSTAINABLE AVIATION FUELS IN AUSTRALIA

David White, Whitejet, Australia

Since 2006 the airline industry in Australia has had a strong interest in utilising low carbon alternative fuels in their aircraft fleet. With a strong need for guidance on how best to support the development of a local industry, Virgin Blue (now Virgin Australia) took the lead in establishing the Australian Sustainable Aviation Fuel Users Group (SAFUG), the core membership also including Air New Zealand and Qantas. The main output from this Group was a roadmap study, released in June 2011, which identified the potential of a renewable jet fuel industry in Australia.

The roadmap study calculated that by using a variety of existing and new non-food biomass resources and sustainable practices for growing them, there will be sufficient biomass to support almost half of the aviation fuel needs of both Australia and New Zealand by 2020 and over 100% of fuel needs by 2050. Lignocellulose is the most abundant and low cost type of feedstock. However, it has lower energy density than other biomass resources and established refining processes for lignocellulose are high cost. The lowest cost refining systems favour inputs based on plant or algae oils, which are by themselves more expensive to produce.

The aviation industry will have to compete with other industries for biomass feedstocks. Other transport modes, electricity generation and high value product industries will also be seeking to substitute some biomass for their current fossil fuel inputs. In particular, road biofuels are a more likely target product for sustainable fuel refiners, at least in the short term.

With high market volatility and technological uncertainty, investors will need expectations of high returns or formalised off-take arrangements to secure project finance. Further, novel mechanisms of risk reduction or risk sharing, such as loan guarantees, may be required.

Significant work has been undertaken on specific aspects especially feedstock and conversion (biorefinery). A focus is required on downstream elements and supply chain integration. A nice example is the Brisbane BioPort initiative, with partners SkyNRG, Virgin Australia and the Brisbane Airport Corporation. The aim is to determine the most promising supply chain combination with the ultimate goal of producing an investable business case and advancing to the construction phase. No pre-commitment is made to a specific feedstock, logistics or technology combination upfront.

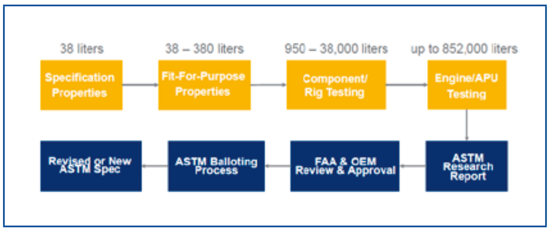
The key financial issue is to unlock capital – both debt and equity. To be economically viable renewable jet fuel must be priced at a level the market will find acceptable. With current prices of fossil jet fuel and renewable jet fuel, the biofuel option would be much more costly at existing CO_2 offset costs (rated at 10$/tonne CO_2). The question is how to bridge this gap, bearing in mind the volatility of fossil fuel prices (jet fuel price levels in September 2016 were only half the level in mid-2014). Oil import regions like Australia and New Zealand can be very vulnerable to international oil prices.

Government support for renewable transport fuels should provide incentives to produce renewable fuels over fossil fuels. They should not skew production towards one particular renewable fuel over another. While producer grants are structured to provide excise relief, their impact from a whole market perspective must be considered.

AVIATION BIOFUELS: ENHANCING TECHNICAL AND ECONOMIC COMPETITIVENESS

Corinne Drennan, Pacific Northwest National Laboratory, United States

Aviation fuels contain different hydrocarbon families: cyclo-paraffins, n-paraffins, iso-paraffins and aromatics. Iso-paraffins have high energy content and high combustion quality even at low temperatures. Aromatics have rather poor combustion quality, but around 7% aromatics are needed to ensure seal swell. So biofuels should comprise the right molecules and meet specific performance and storability criteria. The ASTM process can be quite lengthy, and throughout the process, increasingly larger amounts of fuel are required, involving substantial capital and operating costs for pilot fuel production. Component, rig and engine testing also represent a significant cost to the producer.



ASTM process for jet fuel approval

The main cost drivers for biofuels are feedstock and capital investment. The solutions can be to aim at waste and low cost feedstocks, reduce hydrogen demand and pressure, and to leverage existing infrastructure (refinery integration). Refinery operations germane to biofuels include hydrotreating, alkylation and hydrocracking. From a refiner's perspective, safety, reliability, predictability and profitability are crucial. Risks and challenges are low when starting from well-defined and consistent quality single molecules (like ethanol, butanol, farnesene); risks increase when using intermediates requiring minor treating (like triglycerides), and are highest for oils that need composition changes (like pyrolysis oils).

Regulatory pressures and fuel price volatility resulted in vertical integration, i.e. upstream investments of airlines in the supply chain. Typical are fuel purchase agreements, direct airline investments in fuel production facilities and development of alternative fuel feedstock sources. Various airlines have made public commitments to purchase and use biofuels and some are broadly involved in creating sustainable fuel supply chains. Others have announced their engagements in advancing supply chain development.

ECONOMIC AND ENVIRONMENTAL PERFORMANCE PERSPECTIVES OF ALTERNATIVE AVIATION FUELS

Robert Malina, University of Hasselt, Belgium/ Massachusetts Institute of Technology, United States

Alternative jet fuels have received considerable attention from policy-makers as a potential means to mitigate aviation's contribution to global climate change. While current consumption of alternative jet fuel is less than 0.01% of global jet fuel consumption, the aviation industry is aiming for a large-scale replacement of petroleum-derived jet fuel with non-fossil alternatives by 2050.

A wide body of literature shows that alternative jet fuels from different feedstock to conversion pathways can significantly reduce life cycle GHG emissions compared to conventional jet fuel from petroleum, if adverse impacts from land-use change can be avoided. However, the potential magnitude of aviation GHG emissions' reductions from the use of alternative fuels is limited by their specific environmental benefits (which differ by type of biofuel), and the availability of the fuels.

Significant questions remain about the economic viability and the necessary scale-up of the industry. Biojet as a co-product in biochemical production may create commercial opportunities, although, volumes would be limited. Large scale replacement would require high production ramp up rates. Growth needs would significantly exceed historical global biofuel production growth rates when total GHG emission reductions of greater than 20% need to be achieved in 2050, and overall investment needs would be in the order of tens of billions of US dollars. The development of such an industry would require immediate and sustained investment in alternative aviation fuel production infrastructure, which will only take place if enabled by the right policies. The CORSIA CO_2 off-sets (equivalent to around 0.1 US$/gallon) would not be a game changer for aviation biofuels.

Alternative aviation fuels will remain more expensive to produce than conventional jet fuel in the short- and medium term. One must remember that societal perspectives are different from investor's perspectives, and these are also the basis for policy intervention. Higher costs are justifiable from a societal perspective as long as the environmental benefits compensate for the additional costs. In order to achieve this, significant cost savings will still need to be realised for many pathways.

PERSPECTIVES FOR BIOJET SUPPLY TO AIRLINES

Chris Field, Air New Zealand

Fuel is around 25-30% of airlines operating costs and there are no alternatives to energy dense, drop-in fuels for aircraft. Biofuels provide significant benefits as they are renewable, reduce GHG emissions and decouple from commodity based fossil fuels. But they must be competitive and sustainable. The following are challenges before widespread use can be anticipated:

1. Biofuels must be capable of distribution and use without modification to aircraft or existing infrastructure. This requires stringent and time consuming safety certification which is exacerbated by the number of feedstocks and conversion processes being considered.
2. The industry has signed up to a challenging ICAO greenhouse gas reduction target and any biofuel must demonstrate a life cycle carbon reduction from source through to use.
3. Additional sustainability criteria and measures beyond GHG reduction must also be taken into account when sourcing biofuel.
4. The current and short term forecast price of fossil fuel makes a difficult hurdle for investors.

Airlines are looking for ways to encourage this nascent industry by offering potential off-take agreements, but this is only one element in the supply chain risk from an investor or lender perspective. There are many other parties that need to collaborate to support a viable local solution for biofuel production in New Zealand and Australia. Leadership, collaboration and a supportive environment are the keys to success.

THE KEY ROLE OF POLICY IN DEVELOPMENT OF BIOJET FUELS

Susan van Dyk, University British Columbia, Canada

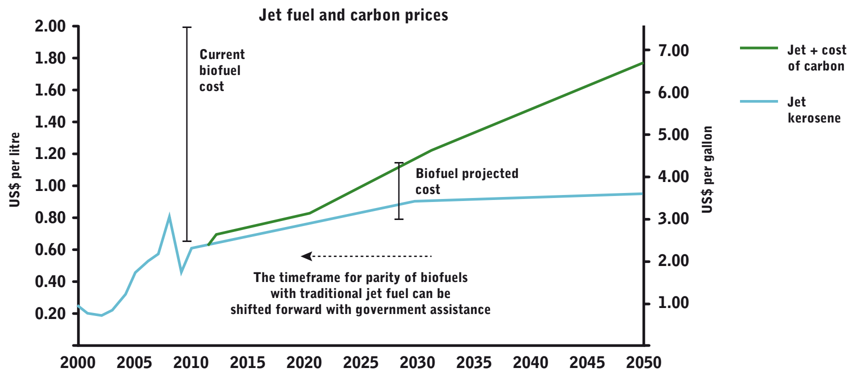
The development of biofuels for road transportation has been driven by strong supporting policies that have created mandates and provided incentives to producers / blenders, in addition to policies supporting feedstock development and construction of facilities. This has resulted in significant production and consumption of biofuels in jurisdictions such as the USA, Brazil and the EU.

The aviation sector has recognised that biojet fuels are a key component to achieve significant carbon reduction, well after 2050. However, development of biojet fuels has been slow and consumption is still limited. Currently, most biojet fuels are derived through the oleochemical pathway, based on upgrading of oils and fats. This pathway will continue to be the main source of biojet for the next 10 years. In the long-term there may be a shift to lignocellulosic feedstock.

Significant expansion of biojet fuel production and consumption will require strong, long-term policies similar to what has driven the development of road transportation fuels. However, aviation has international and national components falling under different regulatory frameworks which require a different approach compared to road transportation.

Mandates have been the driving force of road transportation biofuels development, with emission reduction as a key metric. But this is difficult to apply in aviation as this is challenged by current low production volumes / capacities and international competitiveness. Fiscal incentives have the greatest potential to increase investment in carbon reduction in aviation, both for supply chain members and airlines, and could bridge the price parity gap. There are regions where biojet is promoted as an extension of road transportation policies, e.g. since 2013 biojet can earn RINs and blender credits in the USA, and biojet can receive 'biotickets' in the Netherlands in the frame of the renewable energy targets. While renewable diesel is cheaper to produce than biojet, this may create competition for the same incentive. On the other hand, biojet can be produced as a co-product of renewable diesel, so that there may be synergies in these developments.

Market based mechanisms, like the CORSIA agreement are unlikely to have a significant impact on the development of biojet fuels; further policies at national level have to be explored to find unique solutions for this sector.



Source: Jet kerosene price based on 25% markup over IEA's crude oil forecast in Energy Technology perspectives 2010. Carbon price taken from UK DECC 2010 central case forecast for traded carbon price. All are in constant (inflation adjusted) US dollars. IATA Economics. Schematic, indicative diagram.

Indicative projections of jet fuel and carbon prices (IEA)

Regional multi-stakeholder initiatives, centred around a main airport/harbour (the 'BioPort' concept), with regional policy incentives, can play a key role in the expansion of biojet. Domestic aviation (which falls under the Paris Agreement) also provides more scope for tax incentives for countries with the aim to target emission reductions, so that domestic aviation can be a first driver for biojet production.

Karlstad BioPort project (SkyNRG)

PANEL DISCUSSION ON POLICY OPTIONS AND RECOMMENDATIONS TO SUPPORT BIOFUELS IN INTERNATIONAL MARINE AND AVIATION MARKETS

The panel session was moderated by Paul Bennett, SCION and Jack Saddler, UBC.

Panel participants were Michael Lakeman (Boeing), Robert Malina (Univ. Hasselt/MIT), Chris Field (Air NZ) and Claus Felby (Univ. Copenhagen).

Cost gap

There is a clear gap to be filled between the cost of biofuels and fossil fuels, both for aviation and marine applications. At the moment biojet fuels are far more expensive than fossil jet fuels, and this can be expected to persist, at least in the short to medium term. From the technology side, it was stressed that biojet production should be in a refinery framework (next to higher value chemicals), and this would reduce costs. In fact, the fossil industry has also evolved in this direction in the past century (with current oil refineries, delivering a range of outputs). In that sense, marine biofuels and biojet fuels are complementary as they are at different ends of the fuel spectrum (high vs low specifications). Such synergies should be further pursued. The key to success is not to focus too narrowly on one product; this makes a business case much more robust.

Negative externalities are not included in current fossil fuel costs, and this distorts the playing field. The difference between societal and investor costs is central to the whole discussion. Including societal cost (e.g. through carbon tax) can make the case for positive returns in a shorter timeframe. The question is how to bridge this difference and convince governments and sectors to play an active role in this.

The discussion also led to the issue of willingness to pay. Airlines are very hesitant to increase ticket prices. There was some discussion about whether consumers are willing to pay a 'green premium'. Some claimed that leaving it to the customer will not work (*e.g. the success of low cost airlines – people look for the cheapest tickets, no matter what the background is of the airline*; others mentioned that flying passengers are open to paying a premium for carbon offsets (not connected to the flight itself), or for flights using biofuel (connected to the actual flight). The impact of offsetting on flight ticket prices is generally very limited.

Solutions

In principle, a carbon price should be applied across all sectors and then markets will decide. There is a tendency for people to start to accept the idea of a carbon tax (as for taxing cigarettes and alcohol), as the problem of carbon emissions is more and more being recognised. However, if carbon prices become common practice, someone will have to pay the cost. The question will be how to handle the transition phase (i.e. when some sectors / players have implemented a carbon price, and others have not, will the latter have a competitive advantage?). Panellists were asked what level the carbon price needs to be to make a real difference, and it was stated that this would probably need to be a three digit number (i.e. over a hundred US$/tonne carbon).

Policies are actually driving evolutions at the moment. The actual value of fuels is very low, and incentives / carbon price mechanisms are decisive for alternative fuels. There are programmes to support market entry, with subsidies for such facilities. What is crucial is to de-risk investments. CAPEX is very intensive, and offtake agreements and long guarantees would aid developments.

International initiatives like ICAO's CORSIA initiative help to get the focus in the same direction, but the current carbon offsets (valued at 0.10 US$/gallon biofuel) are too low to compensate for the additional costs of biofuels. Next to these international industry actions, country commitments and national / regional initiatives are needed. Incentives for road transport biofuels can be extended to include biojet or marine fuels. Biojet fuels in the USA can use blender credits and RIN markets, which are valued at around 1.0 US$/gallon biofuel.

Regional bioport developments are starting to appear in several regions, in fact in both marine and aviation biofuels, supported by regional incentives. These initiatives provide the opportunity for actors to 'walk the talk'. Bioports can be important to launch biofuel markets in aviation and marine applications.

Conclusions

Biofuels are currently mostly associated with road transport, but it is acknowledged that in the longer term the role of biofuels in international transport (aviation, shipping) will increase as these sectors rely on high energy density fuels. While road transport fuels are mostly regulated at national level, aviation or maritime fuels operate under global markets. So the international nature of these sectors requires a different approach to stimulate biofuels in international aviation or shipping.

There is a clear gap between the cost of biofuels and fossil fuels, both for aviation and marine applications. In the first instance, technology evolution will be needed to bring costs down and de-risking investments will be crucial to deploy these technologies; it will also be important to evolve towards biorefinery approaches, delivering a range of outputs. In that sense, marine biofuels and biojet fuels are complementary as they are at different ends of the fuel spectrum (high vs low specifications). Marine fuels are generally of low quality and marine engines can accept different fuel grades, while aviation is much more regulated in the frame of safety management, and aviation fuels need to fulfil high quality standards.

Negative externalities are not included in current fossil fuel costs, and this distorts the playing field. Including societal cost (e.g. through carbon tax) can make the case for positive returns for biofuels in a shorter timeframe. To avoid market distortions, a carbon price should be applied across all sectors and then markets will decide.

Reaching a substantial scale of biofuels in aviation and marine applications will require a mix of international and regional initiatives. The recent Carbon Offsetting Scheme (CORSIA) of the International Civil Aviation Organisation (ICAO) to reduce CO_2 emissions creates an industry commitment to look for low carbon solutions, although the offset values themselves are probably too low to stimulate biojet fuels. The marine sector thus far has focused less on CO_2 emissions; most regulations are focused on local air quality, particularly to reduce the sulphur content of shipping fuels. This can also create momentum for the sector to consider alternative fuels.

Next to these international initiatives and agreements, country commitments, national incentives and regional initiatives are needed to launch biofuel markets. Some countries are opening national road transport biofuel incentives for biojet fuels or marine biofuels. Domestic aviation can also be a way to launch biojet fuels in national markets, at least in larger countries like the US. In the case of (regional) shipping, including CO_2 emissions to calculate fairway and port duties (e.g. Clean Shipping Index in Sweden) or tenders for public contracts giving CO_2 a substantial value can encourage the market to come up with cost-efficient carbon reduction solutions.

An interesting evolution is regional multi-stakeholder initiatives, centred around a main airport / harbour (the 'BioPort' concept), with regional policy incentives. Typical for marine and aviation is that fuel distribution is much more centred compared to road fuels. For instance, in terms of marine fuels, only 15 ports account for 85% of marine fuel bunkering globally. So BioPort concepts can be an important step to launch biofuel markets, both in marine and aviation markets.

Acknowledgements

The workshop sessions were facilitated by Kees Kwant, Corinne Drennan, Jack Saddler and Paul Bennett. The contributions of these and also the invited speakers are gratefully acknowledged. A special thanks goes to the host, in particular Paul Bennett and Gillian Todd of SCION for providing the venue and taking care of all practical issues before and during the workshop.

Luc Pelkmans, the Technical Coordinator of IEA Bioenergy, prepared the draft text with input from the different speakers. Pearse Buckley, the IEA Bioenergy Secretary, facilitated the editorial process and arranged the final design and production.

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Further Information

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