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Flight path to Sustainable Aviation

Towards establishing a sustainable aviation fuels industry in Australia and New Zealand

Sustainable Aviation Fuel Road Map

May 2011

Acknowledgements

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Flight path to sustainable aviation

Towards establishing a sustainable aviation fuels industry in Australia and New Zealand

Sustainable Aviation Fuel Road Map
May 2011

AIR NEW ZEALAND

QANTAS

Virgin australia

BOEING

AIRBUS
AN EADS COMPANY

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Executive summary

The importance of aviation to the economic prosperity and way of life in Australia and New Zealand has underpinned a significant growth in the region's aviation sector.

While the aviation sector must continue to meet rising demand for air transport services, the industry understands it needs to diversify and conserve its fuel supplies into the future and work towards reducing its environmental impacts, particularly greenhouse gas emissions.

In response to this challenge the global aviation industry has been one of the first industry groups to set ambitious greenhouse gas emission targets, aiming to achieve carbon neutral growth from 2020 and an aspirational goal of 50 per cent reduction from 2005 levels by 2050.

The utilisation of advanced aircraft, fuel conservation and improved airspace management offer the most immediate ways to mitigate aviation's environmental impact. However, against growing demand for air transportation these efforts alone are unlikely to be sufficient to see an overall reduction in emissions in the long term.

The aviation sector needs a substitute for petroleum-based fuel to improve its ability to reduce emissions and also address energy security. This step is more difficult for the aviation sector because, relative to ground transportation, aviation fuel is constrained by a stricter set of safety, technological and regulatory requirements.

The only alternative fuel which can meet all of the environmental, economic and technical challenges is sustainable aviation fuel derived from biomass (non-food parts of crops, plants, trees, algae, waste and other organic matter). Australia and New Zealand are strongly positioned to incorporate sustainable aviation fuel into the aviation fuel mix. The scale of potential biomass production in the region is well matched to the aviation fuel industry's needs, while domestic petroleum supplies are on the decline. However there are currently no significant supplies of sustainable aviation fuel anywhere in the world at this time. Establishing a local commercially viable supply chain is the major challenge needing to be addressed.

This study aimed to determine the feasibility of the Australian and New Zealand aviation sector taking up bio-derived aviation fuels, the benefits of doing so and the challenges that need to be overcome to make it a reality.

Discussion in this report is supported by modelling that was coordinated by CSIRO. A more in-depth technical discussion of the modelling has been published separately in *Sustainable Aviation Fuels Road Map: Data assumptions and modelling* which outlines the assumptions and methodologies used to support the various conclusions and recommendations in this report.

The Sustainable Aviation Fuel Road Map identified several key challenges and opportunities for sustainable aviation fuels. These are listed in the following table.

Key challenges and opportunities for sustainable aviation fuels

Sustainable aviation fuels derived from biomass are a feasible option	Ongoing fuel tests, demonstration flights and proven refining technology have given the aviation industry confidence that bio-derived jet fuel blends can be created to meet the industry's stringent safety and technical fuel standards. One class of bio-derived jet fuel was certified in 2009 and a second covering most other biomass sources is expected to be approved for commercial use in 2011. The critical question that this study examines is whether a sufficient, affordable supply of sustainable bio-derived fuels can be commercially produced for aviation transport. All industries must avoid creating new environmental problems when considering options for addressing current ones. Principles such as maintaining biodiversity and food security need to be upheld if bio-derived fuels are to be deployed as part of the aviation sector's package of greenhouse gas reduction measures. Rules addressing certification of bio-derived fuels as being sustainably produced will be drawn from international institutions together with local refinement to address issues of specific concern to this region.
There is sufficient existing sustainable biomass to support a local bio-derived jet fuel industry	This study has 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 (46 per cent) of the aviation fuel needs of both Australia and New Zealand by 2020 and over 100 per cent of fuel needs by 2050. While some of these resources are currently above the cost of traditional fossil fuel, the quantum of economically viable bio-derived jet fuel production is expected to increase considerably in the future as the cost of new biomass resources and refining technologies decline.
The region is strongly positioned to produce sustainable aviation fuels	Australia and New Zealand are well positioned to establish a sustainable fuels industry given the region's favourable climate, land base, stable geopolitical environments and comparative advantages in skilled labour including construction, research and development and efficient agricultural production. Good governance is also potentially a key advantage for the region, compared to nations with similar climate and land base advantages, because it supports investment as well as the ability to demonstrate sustainability.
There will be challenges in the scale-up of economically viable feedstock production	Lignocellulose (wood and stems from trees and crops) is the most abundant and low cost type of feedstock available at present. However, established refining processes for lignocellulose are high cost. The lowest cost refining systems favour inputs based on biologically derived oils that come from the seeds or other parts of plants or algae. While there are some good prospects, non-food varieties of plant oil have not been produced to a significant scale. Some varieties of plant oil feedstocks remain relatively unstudied, representing a significant potential upside in current resource assessments. Research, development and demonstration will need to focus on both commercial scale development of plant oil resources and reducing the cost of lignocellulosic refining processes to take advantage of the region's full biomass potential.
There will be high demand among industries for biofuels	The aviation industry will have to compete with other industries for biomass feedstocks. Other transport modes, electricity generation and high value product industries such as cosmetics will also be seeking to substitute some biomass for their current fossil fuel inputs. In particular, bio-derived road fuels are generally less expensive to produce than bio-derived jet fuels and receive higher unit revenue making them a more likely target product for sustainable fuel refiners, at least in the short term.

Investment by the refining sector will be impacted by uncertainty	To realise a reasonable return on investment, the high volatility of petroleum oil prices and technological uncertainty mean investors will need expectations of high returns or formalised off-take arrangements to secure project finance. Investment costs can be reduced by integrating a new plant with existing infrastructure but the viability of the existing fuel refining industry in our region is declining in competitiveness because it is relatively old. Further, in a period of capital market volatility, novel mechanisms of risk reduction or risk sharing, such as loan guarantees, may be required.
Aviation fuel distribution infrastructure will not require significant modification, however access arrangements for bio-derived jet fuel suppliers will need to be established	The aviation sector has a relatively streamlined distribution system with much fewer supply points and aircraft compared to the thousands of supply points and millions of vehicles in the road sector. Major airports are typically supplied by one or two fuel pipelines from the refinery and the economics of bio-derived fuels will depend on access to the existing pipeline infrastructure. Use of the existing aviation fuel supply infrastructure will require approval from infrastructure owners and agreement from other airlines using the facilities. The introduction of an approved standard which covers co-mingling for a 50:50 blend of bio-derived aviation fuel batches has been a major step forward in achieving drop-in capability.
A local production industry for sustainable aviation fuels will bring significant economic, social and environmental benefits	If the industry is successful in addressing the challenges, the rewards are significant. This report examines a road map scenario under which the Australian and New Zealand aviation sectors achieve a 5 per cent bio-derived jet fuel share in their fuel use by 2020, expanding that amount to 40 per cent of their total fuel use by 2050. This development further enables the stabilisation of aviation industry emissions from 2020 and assists in reducing emissions from 2030. If this scenario is realised, then by 2030 Australia and New Zealand are expected to save over $2 billion per annum on jet fuel imports and achieve a 17 per cent reduction in aviation greenhouse gas emissions per annum relative to an all petroleum-based jet fuel future. The development of a local sustainable fuel supply for the aviation industry will create direct benefits for employment, and rural and regional development with a potential 12,000 new jobs by 2030. It will also support the continued growth and ongoing contribution to the economy of the $39 billion Australasian tourism industry. Taking a lead in the development of a sustainable aviation fuels industry could also create the opportunity for the region to export high value engineering know-how to the world.

Several actions are recommended to ensure a bio-derived jet fuel industry is established

To ensure the industry commences uptake of sustainable fuels by 2015 and realises the substantial social and economic benefits for the region, this study has identified several recommendations for action that will require the attention of all stakeholders.

These actions are represented in the table below and represented against a timeline in the road map diagram that follows.

Recommendation	Action	Lead Accountability	Timing
Market Structure			
Recommendation 1	Develop a national strategy and action plan for alternative fuels incorporating sustainable aviation fuels.	Federal Government in consultation with State Governments and industry stakeholders	2011 (Planned)
Recommendation 2	Establish appropriate mechanisms for participants in the sustainable aviation fuel supply chain to access government bio-energy industry support focussing on scale-up and commercialisation	Federal Government and State Governments in consultation with industry stakeholders	2011
Recommendation 3	Develop supply chain contracts or other risk sharing mechanisms with sustainable fuel producers to establish a market and manage financial risks	Airlines, fuel supply chain and investors	2012 onwards
Biomass supply			
Recommendation 4	Establish contracts to access supply of existing biomass resources	Sustainable fuel producers	2012
Recommendation 5	Assess the potential of new biomass resources, particularly plant oils that are lesser known	Research institutions, biomass producers	2011
Recommendation 6	Expand local trials of the most promising new biomass varieties	Research institutions, biomass producers	2012
Refining			
Recommendation 7	Assess the most promising locations for sustainable fuel refining capacity	Sustainable fuel producers in consultation with the fuel supply industry and with Government	2011
Recommendation 8	Move to commercialise technology if matching biomass available	Sustainable fuel producers, airlines, in consultation with Federal and relevant State Governments	2013
Recommendation 9	Establish access for sustainable fuel supply to airport pipeline infrastructure	Sustainable fuel suppliers, fuel supply industry, airlines, Government	2013
Recommendation 10	Establish demonstration refining facilities as proof of supply chain where technology is less advanced	Sustainable fuel suppliers, research institutions in consultation with Federal, State Governments	2013
Recommendation 11	Develop lower cost processes for refining lignocellulosic processes	Research institutions, biomass and technology developers	2013
Certification			
Recommendation 12	Establish a harmonised system for sustainability certification of fuel	Government and industry together with global counterparts	2013
Recommendation 13	Finalise approval of the BIO-SPK jet fuel standard which refines plant oils via hydrodeoxygenation.	Aviation Industry	2011
Recommendation 14	Build awareness of sustainable aviation fuels across the value chain	Aviation industry, sustainable fuel suppliers, environmental groups	2011

5% 2020 Establish 2nd commercial scale bio-derived jet fuel refining facility
1% 2015 Establish 1st commercial scale bio-derived jet fuel refining facility
0% 2013 Establish refining demonstration facility
Develop cost-effective lignocellulose refining
Scale up commercial biomass production
Adopt harmonised biomass sustainability criteria
Identify refining locations
2012 Establish supply chain contracts
Assess lesser known biomass resources and establish trials
2011 Establish government support mechanisms
Achieve approval of jet fuel standard for refining plant oil (Bio-SPK)
2009 Jet fuel standard approved for refining lignocellulose (FT-SPK)
2008 Bio-derived jet fuel demonstration flights commence
% = share of bio-derived jet fuel

A new future can be created

Aviation is an essential service

Aviation is fundamental to the Australian and New Zealand way of life. It safely and affordably connects our people and businesses to each other and the world. We rely on air transportation to support key sectors of our economy, particularly international trade and tourism. Aviation is also critical to our rural and regional development and prosperity.

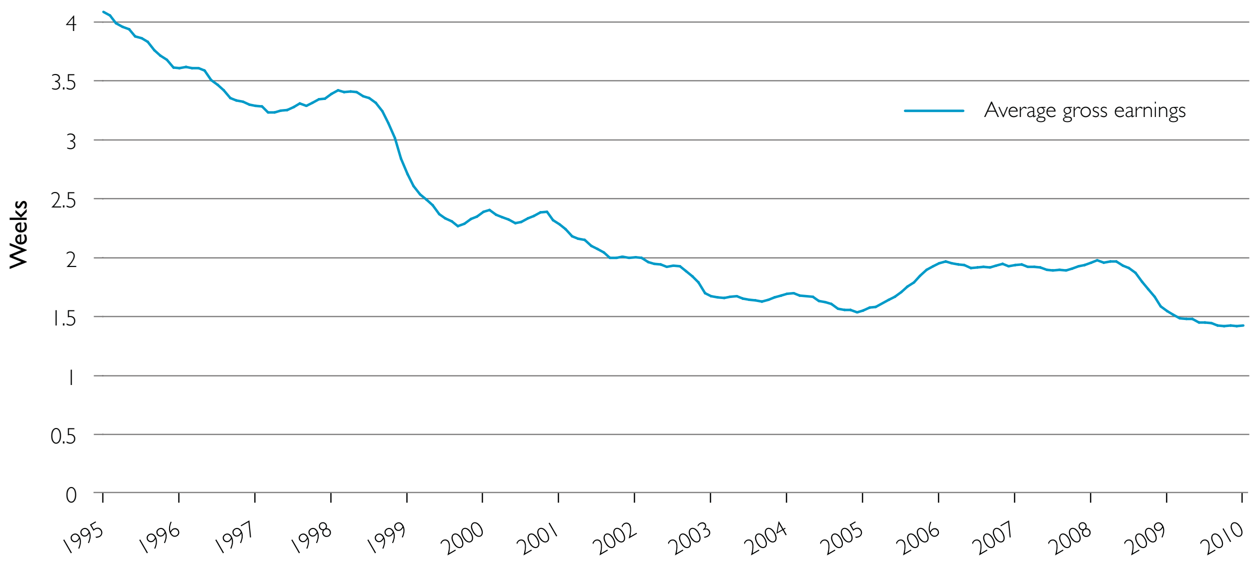
From a global perspective, the aviation industry is crucial to world trade with an estimated one third of the $16 trillion[1] in global trade transported by air. Aviation's global economic impact was estimated at $3.6 trillion in 2007. That is equivalent to 7.5 per cent of world GDP. Aviation employs 5.5 million people world-wide (WTO, 2010; ATAG, 2008).

Australia and New Zealand both have large aviation and tourism related industries that directly employ over 52,000 people in aviation and 580,000 people in tourism (Table 1). Tourism directly contributes $40 billion per annum to the Australian and New Zealand economies.

Besides these economic impacts, aviation plays a pivotal role in connecting our communities. The key advantage of aviation is the speed and convenience at which it enables communities around the world to interact in person. With the declining relative cost of air travel (see Figure 1), the number of people who can afford to fly has increased considerably.

Affordable air travel together with aviation's importance to our economic prosperity has supported strong demand growth. From 2000 to 2009, the number of aviation passengers carried in Australia and New Zealand grew by 60 per cent, with 32 million people carried on international flights and 51 million on domestic flights (Figure 2).

[1]All currency is Australian dollars unless otherwise specified



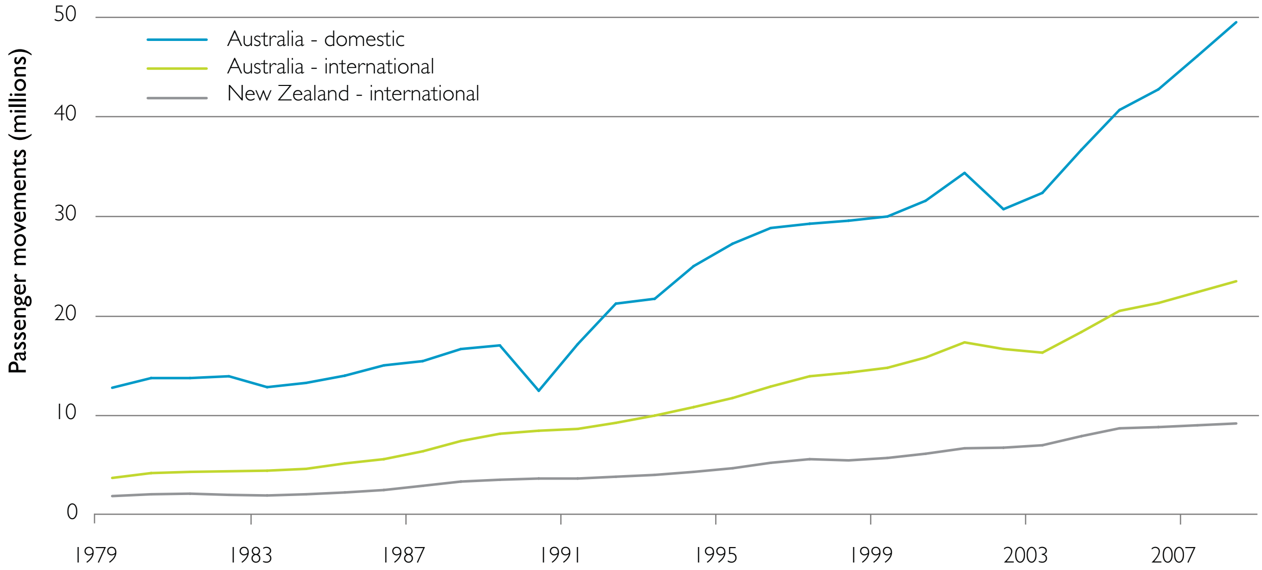
> Figure 1: Weeks of average weekly earnings required to pay for economy London-Sydney airfare. Source: Qantas

> Table 1: Annual contribution of aviation and tourism to the Australian and New Zealand economies

	Australia	New Zealand
Aviation sector direct employment [af]	44,000 persons	8,800 persons
Aviation sector direct GDP contribution [be]	$6.1 billion	$1.4 billion
Tourism sector employment [cf]	486,200 persons	94,600 persons
Tourism sector contribution to GDP [cf]	$32.8 billion	$6.4 billion
Domestic passenger movements [dg]	49.3 million	10.3 million
International passenger movements [d]	23.3 million	9.0 million

a. ABS 2010, Air and space sector, Labour Force, Australia, Detailed, Quarterly, May 2010, Catalogue No. 6291.0.55.003
b. ABS 2010, Australian National Accounts: National Income, Expenditure and Product, Mar 2010, Catalogue No. 5206.0.
c. ABS 2010, Australian National Accounts: Tourism Satellite Account, 2008-09, Catalogue No. 5249.0.
d. Bureau of Infrastructure, Transport and Regional Economics, 2009, Australian transport statistics yearbook 2009, BITRE, Canberra ACT.
e. Statistics New Zealand (2009) National Accounts: Year ended March 2009, includes water transport
f. Statistics New Zealand (2009). Tourism satellite account: 2009. Wellington: Statistics New Zealand
g. Websites of Wellington, Auckland and Christchurch airports

Over the next two decades, global aviation transport demand is expected to continue to grow at between 3 and 5 per cent per annum (Airbus, 2009; Boeing 2009; IEA 2009). In Australia and New Zealand regional growth is expected to be around 4 to 5 per cent per annum reflecting strong trade and personal travel (Airbus 2009; Boeing 2009; BITRE 2010; Graham et al., 2011).



> Figure 2: Aviation passenger movements in Australia and New Zealand to 2008[2]. Source: BITRE (2009) and; Statistics New Zealand (2010a)

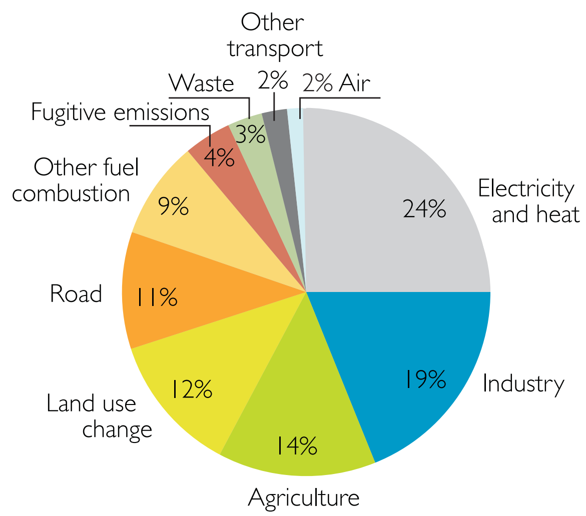
Greenhouse gas emission challenge and aviation industry response

The aviation sector has a strong record of improving greenhouse gas emission performance through fuel efficiency improvements and other innovations. However, growing demand means that it will need to adopt low carbon fuels to maintain and improve its environmental performance.

While the aviation sector contributed 2 per cent to total global emissions in 2005 (Figure 3), it has been strongly focussed on reducing emissions through enhanced fuel economy. Globally, airlines improved the average fuel efficiency and carbon dioxide performance of aircraft by 17 per cent between 2001 and 2009 (IATA, 2010a, IATA 2010b). To ensure that emissions fall even as demand rises, bio-derived jet fuels are another essential part of the industry's greenhouse gas reduction strategy.

Industry targets

Aviation is one of the few sectors with a globally coordinated approach to addressing its environmental footprint. The International Civil Aviation Organisation (ICAO)[3] is targeting 2 per cent fuel efficiency improvements per year until 2020, and aspiring to sustain this rate of improvement out to 2050. The industry will also aim to achieve carbon neutral growth from 2020 (Figure 4). An aspirational target of 50 per cent below 2005 levels by 2050 has been discussed by members of the International Air Transport Association[4] (IATA, 2009).

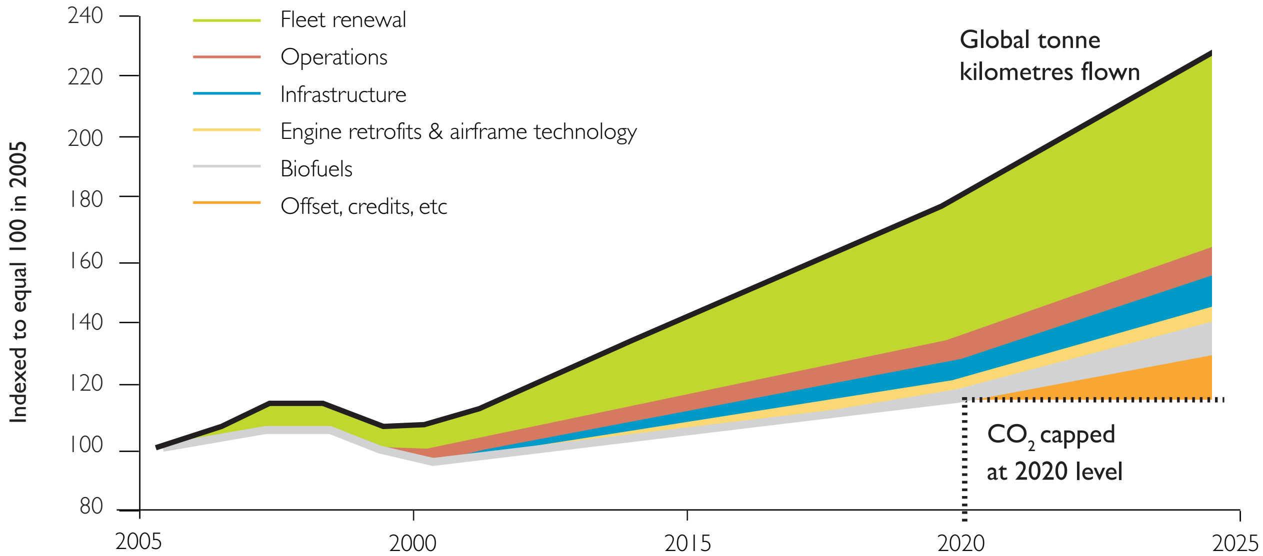


> Figure 3: Industry share of world greenhouse gas emissions in 2005. Note: Total emissions in 2005 were 44.2 billion tonnes carbon dioxide equivalent. Source: Herzog (2009)

[2] A time series for New Zealand domestic passenger movements was not available.

[3] ICAO is the United Nations body tasked with overseeing international civil aviation on behalf of 190 states.

[4] IATA represents 230 airlines across 125 countries accounting for 93 per cent of the world's scheduled aviation traffic.



> Figure 4: The global aviation industry's projected business as usual greenhouse gas emissions, and measures for achieving carbon neutral growth by 2020. Source: Based on IATA (2009)

While a binding global agreement on climate change post 2012 is yet to be reached, New Zealand and the European Union have already introduced emission trading schemes. The introduction of carbon pricing in Australia is likely in the short to medium term.

Given that aviation is a global industry, when a carbon price is introduced it should apply uniformly and equitably to all carriers. Unilateral schemes, on the other hand, may introduce competitive distortions between airlines and across regions.

Abatement options

New, more efficient aircraft together with improved aircraft operations and airspace management offer the most immediate way to reduce aviation's environmental impact and potentially halve global aviation fuel intensity (the fuel required per passenger kilometre) over the long term (Table 2).

If aviation demand grows as expected, consumption of fuel in Australia and New Zealand and associated emissions could still double by 2050 despite fuel efficiency improving by an expected 50 per cent. To avoid this outcome the aviation sector recognises it must explore the feasibility of low carbon fuels.

> Table 2: **Summary of global potential for reducing fuel intensity in aviation**

Type of improvement	Fuel intensity reduction relative to existing fleet
Airframe aerodynamics	20-30%
Airframe light-weighting	20-30%
Engine technologies	15-20%
Air traffic management and operations	7-12%
Total	**40-50%**

Source: IEA (2009)

Note: The total accounts for non-additive effects of combining measures. Local prospects for the listed improvements will differ from the global average due to differing fleet and airport operational conditions.

Bio-derived fuels are the only sustainable alternative for jet fuels

Alternative aviation fuels must meet the same technical standards as conventional fossil-derived jet fuels. Fuels derived from biomass are the only sustainable candidate for substituting current petroleum-derived aviation fuels.

Jet fuels must meet stringent technical and safety standards. Synthetic jet fuels with the same properties as petroleum-based jet fuel can be made from coal, natural gas or biomass. These synthetic jet fuels are referred to as 'drop-in' fuels because they can be used without changes to engine fuel systems and distribution and storage systems.

Carbon intensity of fuel alternatives

Jet fuels produced from coal or gas come with higher greenhouse gas emissions (over 100 per cent higher in the case of coal; (Stratton et al., 2010) and while these may potentially be reduced via carbon dioxide (CO_2) capture and storage (at additional cost), their use would be inconsistent with the aviation sector's goals for levelling and eventually reducing its greenhouse gas emissions and dependence on fossil fuels.

Fuels derived from biomass are currently the only sustainable candidate for substituting current petroleum-derived aviation fuels. The lifecycle greenhouse gas emission reduction (see Box 1) from pure bio-derived aviation fuel varies depending on extraction and processing arrangements but there are several candidates which deliver more than 50 per cent (Stratton et al., 2010). Life cycle emissions of bio-derived fuels are expected to improve with increasing production efficiency and gradual de-carbonising of supply chain processes and inputs.

Bio-derived jet fuel standards

The technical properties of bio-derived jet fuels have been assessed against the jet fuel standards (Table 3). Currently a 50 per cent blend of bio-derived jet fuel (FT-SPK[5]) can be used as a 'drop in' fuel which meets or exceeds the jet fuel standards. The standards have been developed based on specific refining technologies which can be used for many but not all biomass feedstocks. The standard for FT-SPK has been in operation since 2009. A second refining system covering most remaining classes of biomass resources[6] is expected to be approved via ASTM International[7] processes in 2011 for use in up to 50 per cent blends.

> Table 3: Key jet fuel properties and bio-derived jet fuel blends

Criteria	Definition	Current standard (Jet A1)	50% bio-derived jet fuel blend
Freezing point	The point at which the fuel will freeze	Maximum -47°C	✓
Flash point	The temperature of fuel ignition	Minimum 38°C	✓
Heat of combustion	The amount of energy released during combustion	Minimum 42.8 MJ/kg	✓
Density	Amount of fuel by weight within a given volume when measured at 15°C	Between 775 and 840 kg/m^3	✓
Viscosity	The thickness of the fluid or ability to flow when measured at -20°C	Maximum 8 mm^2/s	✓

Source: ATAG (2009); Kinder and Rahmes (2009)

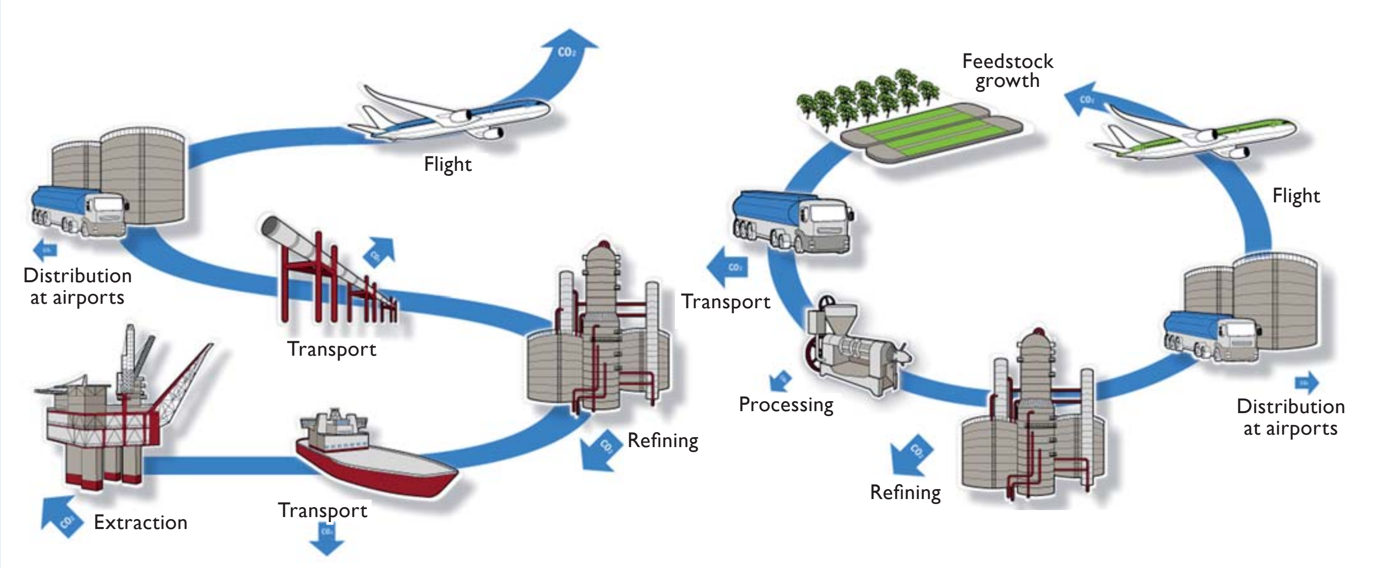
[5] Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK) is produced using the Fischer-Tropsch refining process which is discussed later in this report.

[6] Bio Synthetic Paraffinic Kerosene (Bio-SPK) is produced via hydrodeoxygenation of biologically derived oils. This refining process is described later in the report.

[7] ASTM International, originally known as the American Society for Testing and Materials (ASTM), facilitates a consensus process for developing and agreeing standards in aviation and other industries. The relevant authority within ASTM International in this case is its Aviation Fuel Committee.

> Box 1: Life cycle greenhouse gas emission accounting of aviation fuels

The diagram below illustrates the value chain for the production and life cycle greenhouse gas emissions assessment of fossil and bio-derived jet fuels.



Source: ATAG (2009), *Beginners guide to aviation biofuels*

Relative to using fossil-derived fuels, bio-derived fuels result in a reduction in CO_2 emissions across their lifecycle. CO_2 absorbed by plants during the growth of the biomass is roughly equivalent to the amount of carbon produced when the fuel is burned in a combustion engine – which is simply returning the CO_2 to the atmosphere. These phases of the lifecycle therefore cancel each other out.

However, there are additional emissions produced during the production of bio-derived fuels, such as in equipment needed to grow and harvest the crop, transport the biomass, refine the fuel and so on. When these elements are accounted for, bio-derived fuels are not emission free but are still anticipated to provide an overall emission reduction compared to fossil fuels.

> Table 4: Recent demonstration flights of biomass and natural gas derived jet fuel

Date	Airline	Aircraft	Engine	Partner / fuel supplier	Source of liquid jet fuel blend
Sep 2006	US Air Force	B52 Stratofortress	TF33	Syntroleum	50% natural gas
Dec 2006	US Air Force	C17 Globemaster III	F117-PW-100	Shell	50% natural gas
Feb 2008	Virgin Atlantic	B747-400	GE CF6-80C2	Imperium Renewables, Boeing	20% coconut and babassu
Feb 2008	Airbus	A380	Rolls-Royce Trent 900	Shell International Petroleum, Qatar Fuel	40% natural gas
Dec 2008	Air New Zealand	B747-400	Rolls-Royce RB211-524G	UOP, Terasol, Boeing	50% jatropha
Jan 2009	Continental Airlines	B737-800	CFM International CFM56-7B	UOP, Terasol, Sapphire Energy, Boeing	47.5% jatropha, 2.5% algae
Jan 2009	Japan Airlines	B747-300	Pratt & Whitney JT9D-7R4G2	Nikki Universal/ UOP, Sustainable Oils, Boeing	42% camelina, 7.5% jatropha, 0.5% algae
Oct 2009	Qatar Airways	A340-600	Rolls-Royce Trent	Airbus, Shell	50% natural gas
Nov 2009	KLM	B747-400	GE	GE, Honeywell UOP	50% camelina
Apr 2010	United	A319	-	Rentech	40% natural gas
Mar 2010	US Air Force	A10C Thunderbolt II	TF34-GE-100 Turbofan	UOP, Sustainable Oils	50% camelina blend
Apr 2010	US Navy	F/A-18 'Green Hornet'	F414-GE-400	Sustainable Oils, Honeywell UOP, Boeing	50% camelina blend
Jun 2010	Royal Netherlands Air Force	AH-64D Apache Helicopter	-	UOP, Boeing	Algae and used cooking oil
Aug 2010	US Air Force	C17 Globemaster III	F117-PW-100	UOP, Boeing	25% tallow
Nov 2010	TAM Airlines	A320	CFM International	UOP	50% jatropha

Source: Various online industry articles.

Note: Natural gas demonstration flights are included as they use the same alternative fuel refining technology as one class of bio-derived jet fuels.

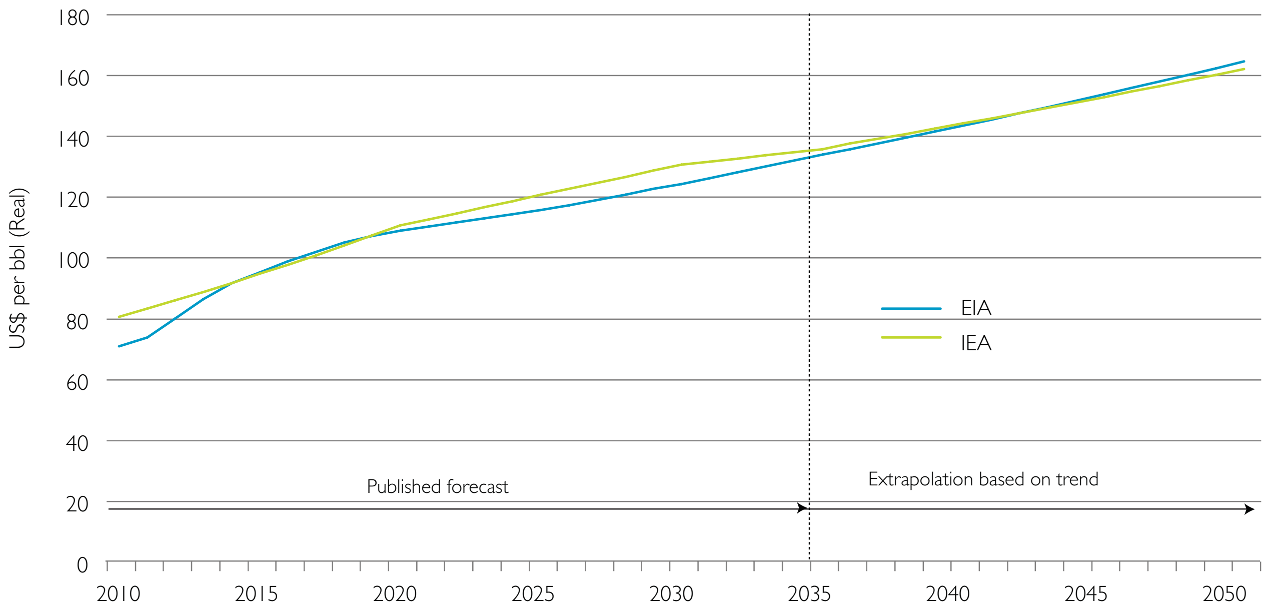
Improving energy security

The adoption of a sizeable share of locally-produced bio-derived jet fuel in the Australasian aviation fuel mix would reduce the total value of our oil imports, which are expected to rise both in volume and unit cost (IEA, 2010; EIA, 2010; Geoscience Australia and ABARE, 2010).

Outlook for oil prices

Forecasts by the International Energy Agency (IEA) and the US Energy Information Administration's (EIA) *Annual Energy Outlook* indicate a rising trend for oil prices with broad consensus on a future real oil price range of US$100 between 2015 and 2020 increasing to US$160 per barrel by 2050 (Figure 5).

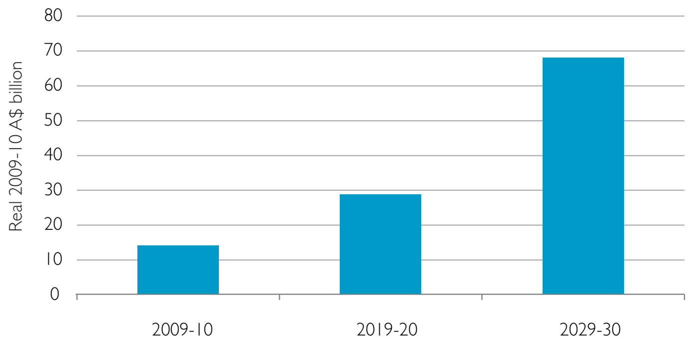
The value of Australian petroleum net imports in 2009-10 was A$14 billion (ABARE-BRS, 2010). Australia's petroleum self sufficiency is currently 59 per cent (based on 2009-10 data) and is expected to decline to 24 per cent by 2030 (ABARE-BRS, 2010; Geoscience Australia and ABARE, 2010). If oil production declines and oil prices increase as expected, by 2029-2030 net oil imports could cost Australia almost A$70 billion per annum in real terms (Figure 6). New Zealand is similarly vulnerable to international oil prices. To avoid these increased costs, and provide a degree of energy security, the region will need to act to reduce its reliance on overseas oil imports.



> **Figure 5:** Oil price scenarios by two leading international forecasters. Source: EIA (2010); IEA (2010).

Domestic refining capacity

The development of a sustainable aviation fuel industry could provide an incentive to increase or renew the region's domestic refining capacity. The long term viability of the domestic petroleum refining industry is unclear, especially as the volume of indigenous crude oil decreases. The uptake of bio-derived fuels could provide an opportunity to invest in refining infrastructure.



> Figure 6: Current and projected annual value of Australian net imports of crude oil and petroleum products. Source: ABARE-BRS (2010); Graham et al., (2011).

Currently the majority of aviation and transport fuels supplied to northern Australia are imported. Small regional bio-refineries could be established in these regions, which include important export industries (e.g. mining) and military bases, providing security of supply (as well as additional economic development).

Australia's aging refineries are currently operating at capacity, producing approximately 5200-5500 ML of jet fuel per annum which is insufficient to meet the region's aviation fuel demand. In general, there has been an underinvestment in local capacity as a result of more competitive refining capability in the near region, particularly Asia. In 2008-09 Australia and New Zealand imported approximately one quarter of its aviation fuel at around A$1.7 billion (ABARE-BRS, 2010; Ministry of Economic Development, 2010; Statistics New Zealand, 2010b).

US approach to energy security

For strategic reasons, military users of aviation fuels in various oil importing countries, particularly the United States, are moving early to address potential energy security issues by offering some of the first major bio-derived jet fuel purchase contracts. US strategic alliances formed in 2010 between the military, civilian aviation and agricultural sectors will also assist in establishing their supply chain (see Box 2).

Through a number of activities the Defence Science and Technology Organisation and Australian Defence Force remain engaged with the US Military and other key allies in the search for viable alternative fuels. Technical data and results from testing and evaluation are exchanged between these countries.

> Box 2: US civilian, military and agricultural strategic alliances for development of a bio-derived jet fuel supply chain

Civilian-military alliance

The Defence Logistics Agency - Energy (DLA-Energy), of the United States Department of Defense which is responsible for military fuel procurement, and the Air Transport Association of America (ATA) which is the principle association of US airlines developed a strategic partnership in 2010 to support the advancement of the development and deployment of commercially viable, environmentally friendly alternative aviation fuels. This goal is to support a cleaner energy economy and promote energy security while safeguarding the environment.

Besides sharing this goal, in practical terms the two organisations will collaborate on three distinct areas:

1. Environment: identifying common methodologies for life cycle assessment of greenhouse gas emissions for alternative aviation fuels.
2. Deployment and logistics: identifying locations or regions suitable for alternative fuels production or deployment, as well as means of distribution to and from those locations.
3. Contracting and finance: jointly publicising supply opportunities, exploring opportunities for complementary fuel supply agreements and developing compatible pricing and finance mechanisms.

(DLA-Energy) has awarded a series of contracts for 600,000 gallons of based bio-derived jet fuel in 2009 and 2010.

Agriculture-aviation industry alliances – 'Farm to Fly'

A five year agreement signed in 2010 between the US Department of Agriculture (USDA) and Federal Aviation Administration (FAA) will promote the development of aviation fuel from forest and crop residues and other feedstocks in order to decrease dependence on foreign oil and stabilise aviation fuel costs. Under the partnership, the agencies will bring together their expertise to assess the availability of different kinds of feedstocks that could be processed by bio-refineries to produce jet fuels.

The partners will develop a tool to evaluate the status of different components of a feedstock supply chain, such as availability of biomass from farms and forests, the potential of that biomass for production of jet fuel, and the length of time it will take to ramp up to full-scale production.

Furthermore, in July 2010, Boeing joined the USDA and the Air Transport Association (ATA) under the 'Farm to Fly' initiative, to develop and advance a comprehensive sustainable bio-derived jet fuel rural development plan. USDA, Boeing and the ATA have established working teams to promote the production of sustainable feedstocks and the development of bio-derived jet fuel production facilities. USDA will work to ensure that biomass sources that may show particular promise for creating sustainable aviation fuel are eligible for relevant USDA bioenergy and biomass programs.

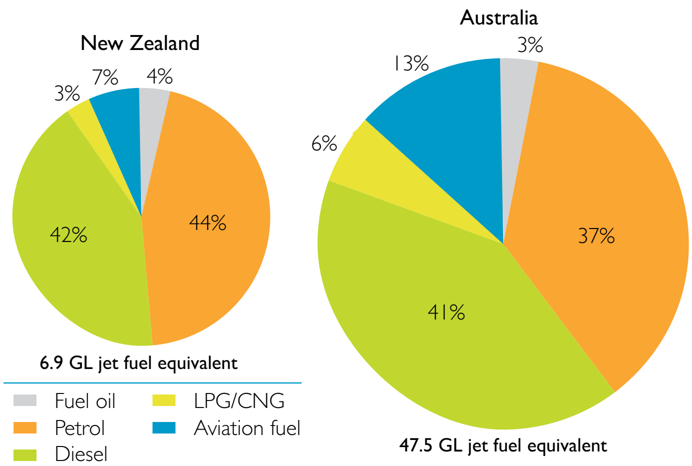
Potential for sustainable aviation fuel production

Resource potential and comparative advantage

Currently there are no significant supplies of bio-derived jet fuel available anywhere in the world. Australia and New Zealand's resource potential is strong. Scaling up a local production industry is the major challenge to be addressed.

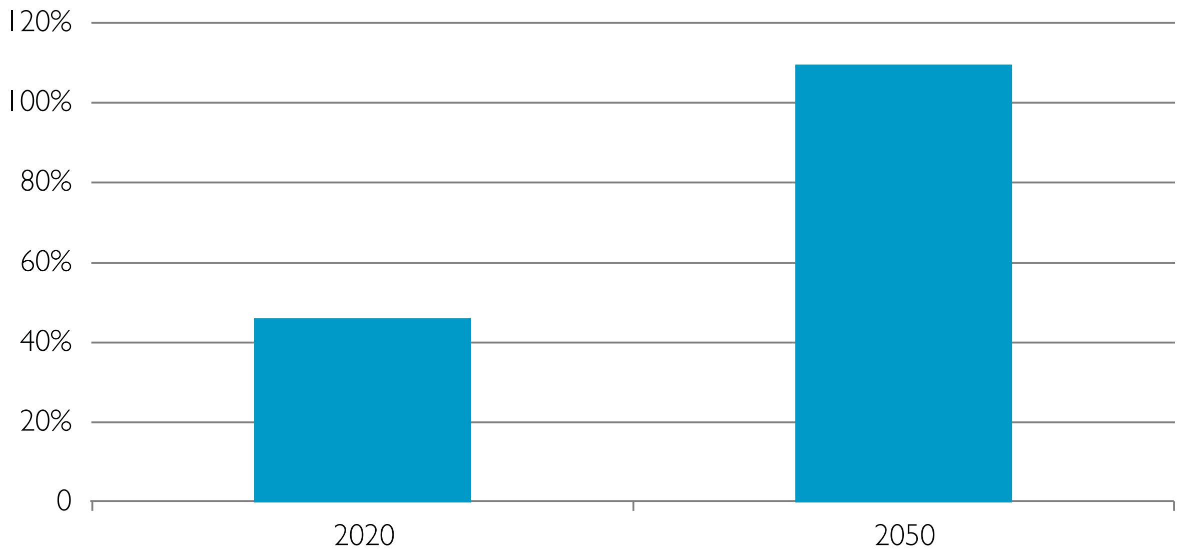
Aviation fuel demand is only a relatively small proportion of total fuel demand, accounting for 7 and 13 per cent of total fuel demand in New Zealand and Australia respectively (Figure 7). Consequently, producing the volume of biomass required to support a significant share of bio-derived fuel in the industry is not as great a challenge as it is for other modes, particularly the road sector.

Australia and New Zealand are in a strong position with respect to potential bio-derived fuel production. Based on available data it is conservatively estimated that within one decade the region has the potential to supply almost half of the local aviation sector's fuel needs from biomass and supply all its needs over the long term as various novel resources and production systems become more established (Figure 8)[8].



> Figure 7: Fuels consumption by type in Australia and New Zealand in 2008-09. Source: ABARE (2010); Ministry of Economic Development (2010)

[8] Table 5 and Figure 9 provide more detail about which biomass resources are included in this resource assessment.



> **Figure 8:** Scale of potential biomass resources in Australia and New Zealand relative to total aviation fuel requirements in the same region. Source: Graham et al., (2011)

Natural advantages

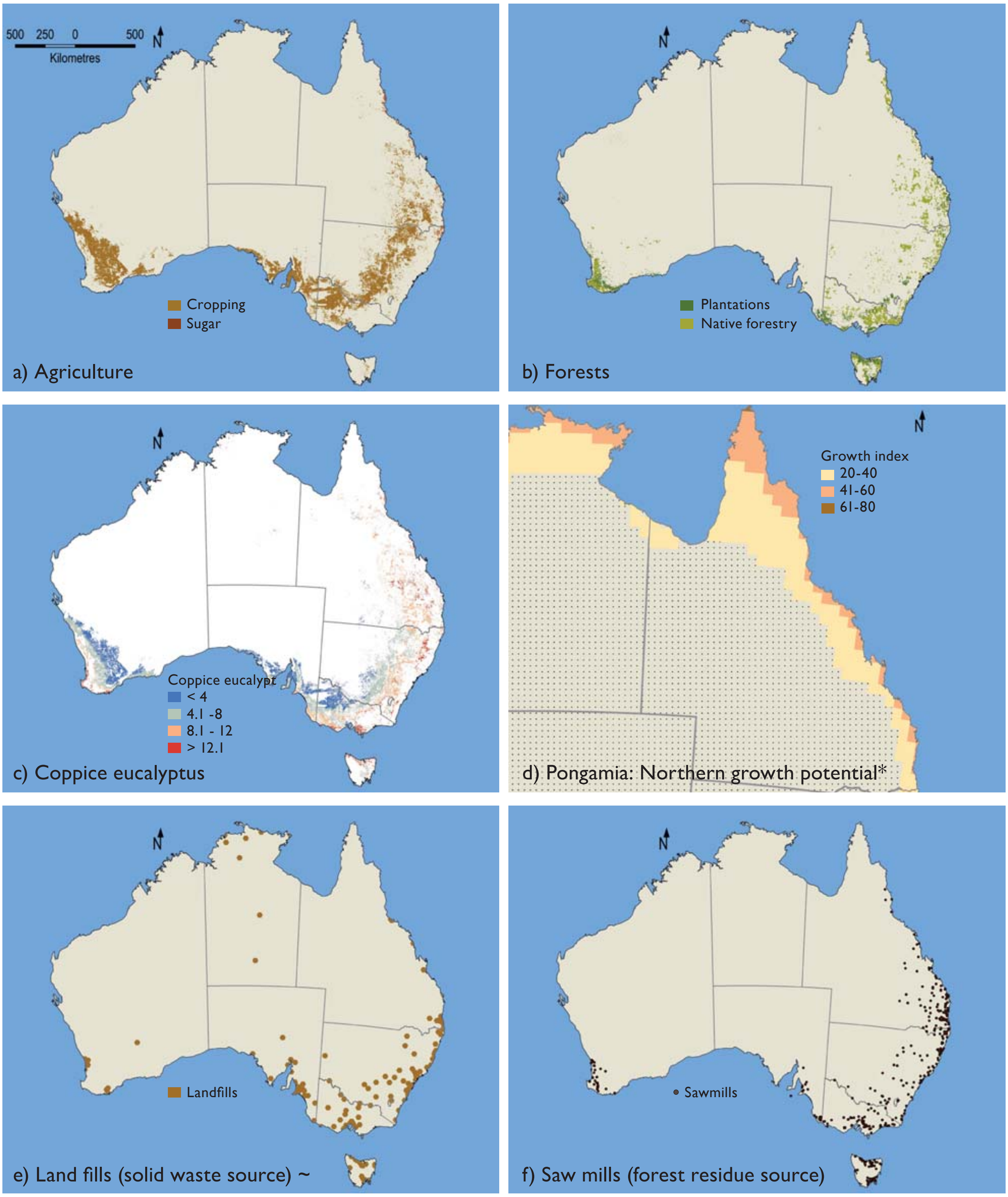
The factors which make the region comparatively well placed for bio-derived jet fuel production include suitable climate zones and considerable land base to produce biomass feedstocks. Potentially the most productive zones in Australia are along the southern and eastern coasts (Figure 9) but this varies by feedstock source. Locations for algae production are less dependent on land fertility, more so on water and industrial sources of carbon dioxide and nutrients. While the potential New Zealand biomass resource is substantial, specific locations have not been assessed.

Algae feedstock production in particular can potentially utilise the vast areas of land with low agricultural potential in Australia. Water and a concentrated source of carbon dioxide or nutrients are also required. The latter can be sourced from power stations and other industrial sites. Australia and New Zealand both enjoy good access to sea water. While fresh water resources are generally poor in most regions of Australia, they are more readily available in New Zealand. Possible changes to local rainfall from climate change will need to be factored into any new biomass production developments and adds financial risks given the uncertain nature of rainfall patterns.

Institutional advantages

Australia and New Zealand have stable geopolitical environments and comparative advantages in skilled labour including construction, research and development and efficient agricultural production. Good governance is also a potential key advantage for the region, compared to nations with similar climate and land base advantages, because it provides a suitable environment for investors as well as supporting the ability to demonstrate sustainability.

Given these advantages, the potential biomass feedstocks that would be suitable for bio-derived jet fuel production in Australia and New Zealand are outlined in Table 5 and include whole or parts of plants, trees and bio-derived product residues.



* Percentage growth index is based only on climate and is relative to maximum growth rate

~ Not included in total resource assessments.

Background: These maps indicate locations of some existing and future potential biomass resources. They are not comprehensive. CSIRO has limited its resource estimates in this road map to only include biomass feedstocks and agricultural systems that do not significantly impact on food production, existing domestic industries or require significant land use change. Sources of biomass where data was insufficiently developed (e.g halophytes, grasses) were also excluded. More details are available in Graham at al. (2011). As a consequence of some exclusions, the total resources available to Australia could be higher once more is known about the potential production of all prospective feedstocks and as the resilience of existing land uses to co-production of biofuels is better understood. New Zealand biomass resource data was sourced from Hall and Jack (2008) and Hall and Gifford (2007). This data was not sufficiently detailed to be located on a map.

> Figure 9: Resource locations and potential land areas for growing feedstocks

> Table 5: Potential sustainable biomass sources and their key characteristics

Feedstock	Description	Yield (dry tonnes/ hectare/year)	Advantages (+) and Key Challenges (-)
Existing sources			
Forests and forest residues*	Bark, sawdust, pulpwood (wood used for processing into paper and related products) and harvest residues.	0.1-3.7	+ Residue, therefore no additional land required + Available year round - Low energy density - Demand from other uses (paper products, electricity generation) - Partially utilised at present
Crop stubble*	The residue remaining after the harvest of grain crops such as wheat, barley and lupins.	1.4-3.3	+ Residue, therefore no additional land required + Available during crop harvest - Low energy density - Potential demand from electricity sector - Minor amounts utilised at present - Concerns with long term soil nutrient balance and erosion potential - More research required on soil carbon impacts
Bagasse*	The stem residue remaining after the crushing to remove sugar-rich juice from sugar cane.	3.8-16.6	+ Residue, therefore no additional land required + Transport to central processing point already carried out for sugar juice extraction - Demand from electricity sector - Nearly all utilised at present but with potential to divert to fuel if more efficient cogeneration facilities developed - Uncertainty around sustainability given high degree of farm inputs and irrigation
Tallow*	Meat and livestock by-product	NA	+ No additional land required - Production already fully utilised at present
Oil seed crops*	Includes canola, juncea and cotton seed. Camelina used overseas	0.6-1.8	+ Produced in between crop rotations to limit impact on food production + Existing harvesting equipment + Extracted oil relatively inexpensive to transport for refining - If used as rotational crops, scale up potential is limited
Urban waste	Municipal solid waste, commercial and industrial waste, palettes, furniture and demolition timber	12-18[1]	+ Concentrated at waste management sites + No additional land required - Contamination with toxic preservatives can restrict use - Potential demand from electricity generation

Potential new sources

Grasses	Various varieties – wild sorghum, kangaroo grass, tall fescue, perennial ryegrass	8-28[2]	+ Could suit degraded land and mitigate soil erosion + Planting may result in increased soil carbon - Little known about local production potential. A variety called switchgrass is under development in the US - Low energy density feedstock - Competition from animal feed and electricity generation - Potentially invasive
Jatropha	Plant that produces seeds containing inedible oil content of 30-40% seed weight	0.5-5.0[3]	+ Extracted oil relatively inexpensive to transport for refining + Requires 1-2 years of cultivation before it can be harvested. - Classified as noxious weed in several Australian states and not permitted for cultivation - No significant scale Australasian trials conducted. Mainly grown in India, Sri Lanka, Africa - Prefers the temperate tropics and tropics. Can grow on marginal land - The seeds are toxic to both humans and animals - Harvesting is by manual means, though branch brushers have been used. Asynchronous ripening of seed represents a limitation to mechanical harvesting. Manual harvesting implies a requirement for markets with low labour costs
Palm oil	Tree that produces high oil content seed	3.7-10.0[4]	+ Extracted oil relatively inexpensive to transport for refining - Usually grown within 5 degrees of the equator mainly in Malaysia and Indonesia, West-Africa. Consequently not suitable for Australasia - Requires high nitrogen fertilisation. - Requires manual harvesting which implies a requirement for low labour costs - Major sustainability issues (food and deforestation), however over the long run these may be addressed through the Roundtable for Sustainable Palm Oil
Pongamia*	Inedible oil yielding legume tree	2.5-8.0[3]	+ Water requirement low but irrigation required in initial years. + Nitrogen input expected to be low based on being capable of nitrogen fixation. + Mechanised harvesting, similar to olives/nuts + Extracted oil relatively inexpensive to transport for refining + Not a bio-security hazard in Australia and non-edible + Currently growing in South East Asia, North Eastern Australia, Pacific, China, East Africa, southern USA, Brazil - Requires 5 to 10 years cultivation before harvesting - Small trials in Australasia, so that suitable areas and likely local oil yields are poorly known - No genetically elite varieties yet

Feedstock	Description	Yield (dry tonnes/ hectare/year)	Advantages (+) and Key Challenges (-)
Potential new sources			
Algae*	Aquatically grown plant species	37-100	+ Does not require arable land and therefore no competition with food + Requires water but can be polluted or salt water + Land use per unit of biomass is relatively low. + Extracted oil relatively inexpensive to transport for refining - Open Pond and photobioreactor requires high concentration carbon dioxide source (e.g. power station, waste management facilities). Heterotrophic fermentation requires large volumes of sugar - Requires various technologies (water separation, oil extraction) not yet proven at commercial scale - Requires nutrients including nitrogen and phosphorous which is predicted to be a limiting constraint in future years - Competition from other industries including neutraceuticals
Halophytes	Salt water and coastal/ desert plant varieties (e.g. salicornia, marsh grasses, mangroves)	10-30	+ Does not compete with food production + Can use salt water + Extracted oil relatively inexpensive to transport for refining - No significant trials in Australasia - Plantation may produce salt by-product or be short-lived
Coppice*	Short rotation tree species (e.g. Eucalyptus, poplar)	3-14	+ Can be grown alongside traditional crops with minimal impact on food production as loss of land offset by reduced soil erosion and salinity mitigation + Well adapted to a wide range of environments, and natural disturbances such as fire + Increases soil carbon - Requires new mechanical harvesting equipment - Low energy density feedstock - Potential demand from electricity generation

*Included in modelling and resource assessments of this study.

[1] This data in megajoules per kilogram of refuse-derived fuel
[2] US switch grass
[3] Indian experience
[4] Malaysian experience

Existing sources

Potential new sourcees

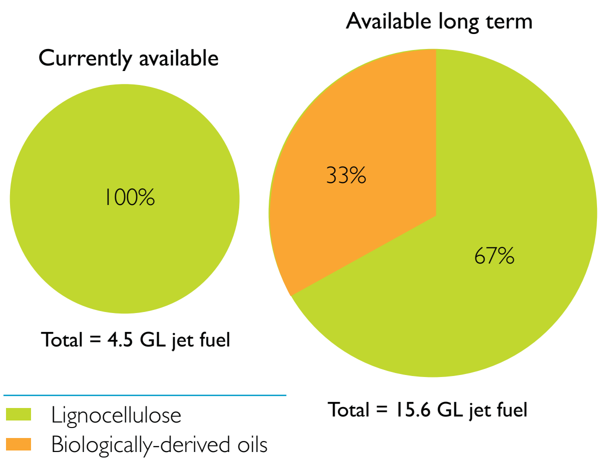
Sustainable aviation fuel refining and distribution

The refining and distribution steps in the aviation fuel supply chain present their own set of challenges that must be overcome if bio-derived jet fuels are to be made available to the aviation industry.

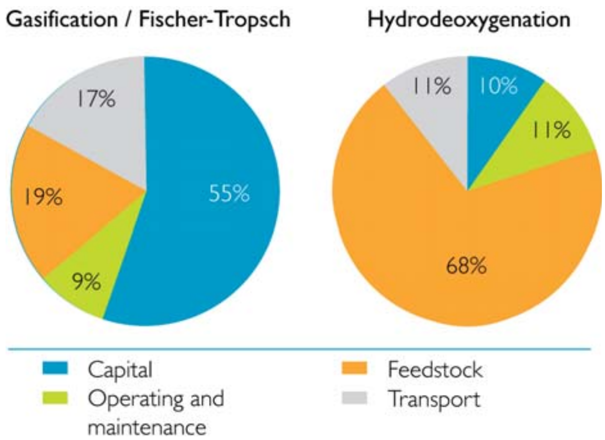
There are several refining pathways that can be used to convert biomass feedstocks into jet fuel (Box 3, Figure 11), depending on whether feedstocks are lignocellulose or biologically derived oils. Lignocellulose is the stems and woody parts of plants or trees. Biologically derived oils come from animals or the seeds or other parts of plants. Urban waste sources can contain either types of biomass.

Refining pathways for lignocellulose

Lignocellulosic sources of biomass feedstocks are generally lower cost (Graham et al., 2011) but also lower energy density[9] than other biomass resources. The majority of available sources of biomass in Australasia are in this form (Figure 10). Lignocellulose can be converted to bio-derived fuels via several processes and most of these processes can produce both road and jet fuels. At present saccharification has received the most research, development and deployment effort. This pathway will produce alcohols such as ethanol for road transport although lignocellulosic ethanol is a higher cost process than the more traditional biochemical fermentation of sugar or grain crops. Additional processes have been developed to produce jet fuels via the lignocellulose saccharification pathway but these are recent developments and there is insufficient public data to assess their potential.



> Figure 10: Scale and type of biomass resources available in Australasia now and long term. Source: Graham et al., (2011)



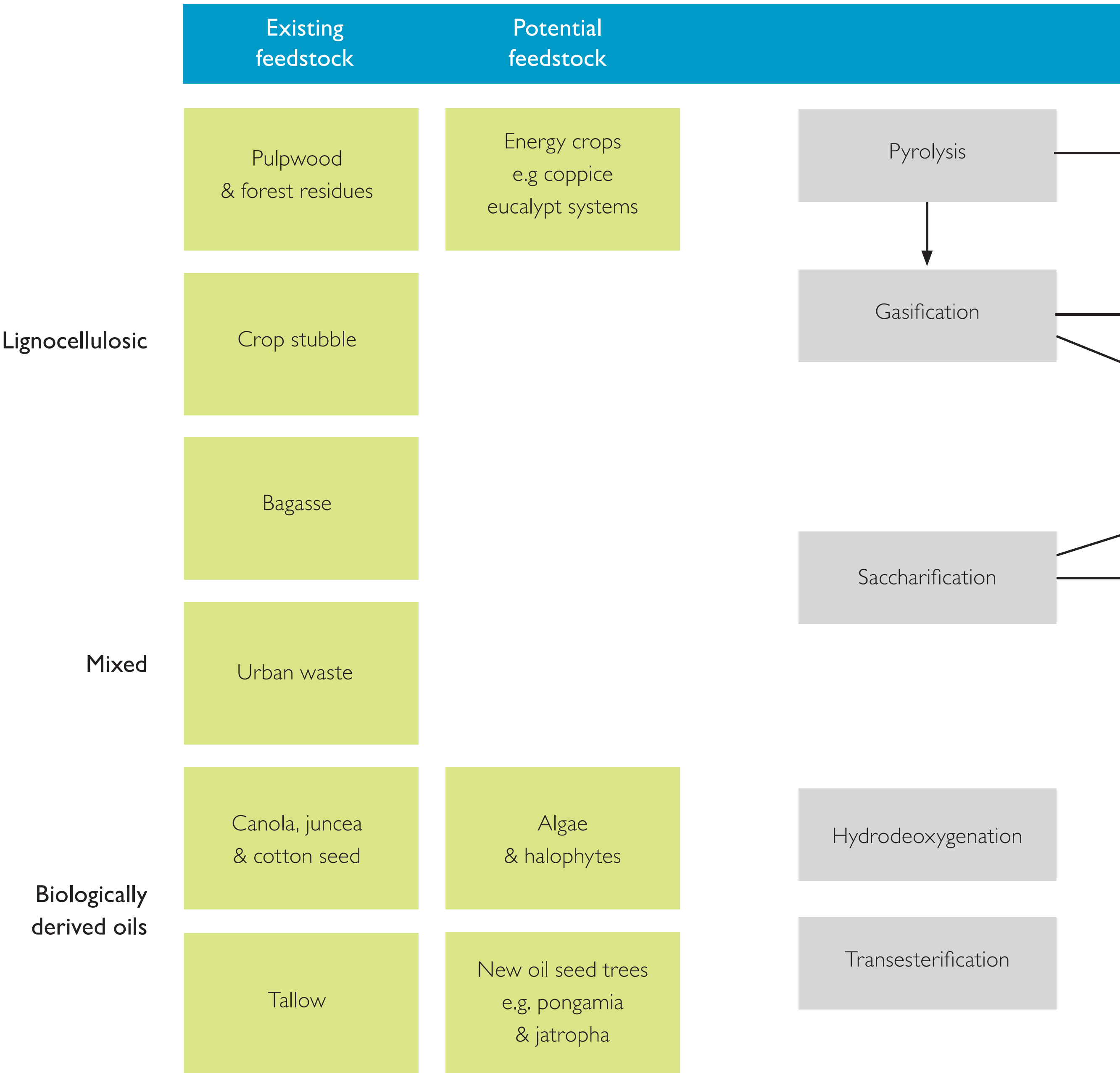
> Figure 11: Contribution of each component to delivered fuel costs for two refining processes. Source: Graham et al., (2011)

Another process for lignocellulose conversion is via pyrolysis and catalytic upgrading. The process is still in the early stages of development. Its major advantage is that it may be able to produce products at small refining scale that match well with the scale and logistics of available feedstock supplies.

The gasification-Fisher-Tropsch lignocellulose refining pathway is well understood conceptually, but has only been demonstrated at commercial scale using fossil fuels such as coal and gas. A major disadvantage of such plants is their high capital intensity. The cost of the refining plant is the greatest contributor to delivered jet fuel costs by this pathway (Figure 12). A key reason for the high capital costs is the difficulty of matching feedstock availability to efficient plant scale. Due to the density of lignocellulosic feedstocks within a reasonable transport distance, gasification-Fisher-Tropsch plants may only achieve around a quarter of their most efficient scale. As a consequence there is significant research and development being undertaken to reduce gasification-Fisher-Tropsch plant costs and demonstrate the more speculative but less capital intensive alternative pathways using lignocellulose feedstocks.

[9] Energy per volume of material.

> **Figure 12:** Possible biomass to liquid fuel refining process pathways



Refining process	Products
Catalytic upgrading	Aviation fuel
Fischer-Tropsch synthesis	Land and sea transport fuel
Catalysis or fermentation	Heat and power
Fermentation & catalytic reforming	Chemical feedstocks

> Box 3: Biomass to jet fuel refining processes

Pyrolysis

Pyrolysis is the thermal decomposition of organic matter in the absence of oxygen. As input to the pyrolysis process, almost any dried and granulated biomass feedstock is acceptable. The products of this process are a bio-char and a thick tar-like liquid called pyrolysis-oil, which is generally unstable and needs to be further refined quickly before it polymerizes to a solid sludge. Gasification is usually the next step in fuel production. However, fast pyrolysis techniques using additional catalytic upgrading are being developed that, if successful, may deliver a more direct and lower cost route to jet fuels.

Fast pyrolysis occurs in a time of a few seconds or less in which the optimum conditions must be created to minimise formation of char. Around 12 per cent of outputs will be char which may have some uses in agriculture.

Gasification-Fischer-Tropsch

Gasification is a thermochemical conversion process that forms synthesis gas or syngas (a mixture of H_2 and CO) by reacting biomass with air or steam under extreme pressures and temperature.

Once the gasification process has been completed, syngas can be further processed into hydrocarbon chains of varying length, through the Fischer-Tropsch synthesis process. The Fischer-Tropsch process for refining syngas consists of feeding pure syngas at controlled pressure and temperature, over a catalyst that assists in the formation of the desired hydrocarbon molecules. The catalysts, typically composed of iron, cobalt, nickel, or ruthenium, are selected based on the desired product fuel molecule.

The hydrocarbon molecules produced require further processing to produce a jet-fuel range product. Depending on Fischer-Tropsch conditions oligerimisation may be required. Alternately, hydrocracking and distillation will be needed, which is a set of downstream processes shared with the hydrodeoxygenation approach, outlined below.

The aviation fuel produced from such a process is known as Fischer-Tropsch Synthetic Paraffinic Kerosene, or FT-SPK, and is already approved for commercial use by ASTM International when blended at levels up to 50 per cent with petroleum derived jet fuel. Although coal and gas based fuels have been produced at commercial scale, biomass refining using the Fischer-Tropsch process is still under development, with no significant fuel volumes produced

The overall energy efficiency of the Fischer-Tropsch bio-derived jet fuel production process is around 45 per cent.

Hydrodeoxygenation process

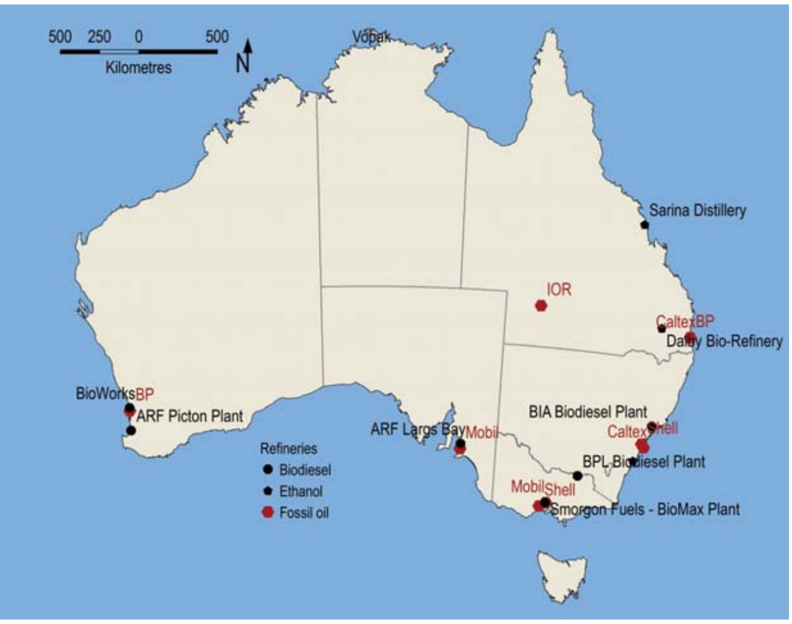
Plant or pyrolysis oils (bio-oils) can be hydrodeoxygenated to produce fuel molecules. Hydrodeoxygenated oil (HDO) has had the oxygen in the compounds chemically removed with catalytic reactions at temperature and pressure. The oxygen in bio-oils can be removed in many forms, including as carbon dioxide, carbon monoxide and water. The composition of the resulting upgraded product is dependent on the input oil – plant oils produce linear alkanes, whereas pyrolysis oils generally produce aromatic compounds. Linear alkanes will require further hydroisomerization to produce the branched molecules needed to give the fuel its required performance properties. Distillation will then be used to isolate the jet fuel fraction. Aromatic products may be used directly as blend components. Hydrogen consumption is a key part of operating costs.

The HDO process uses only liquid bio-oils as input, and is therefore better suited for tree and plant oil feedstocks. However, at present the most abundant non-food feedstocks in the Australian and New Zealand region are lignocellulose.

The energy efficiency of the hydrodeoxygenation process is higher than Fischer-Tropsch at 65 per cent.

Biochemical conversion including saccharification

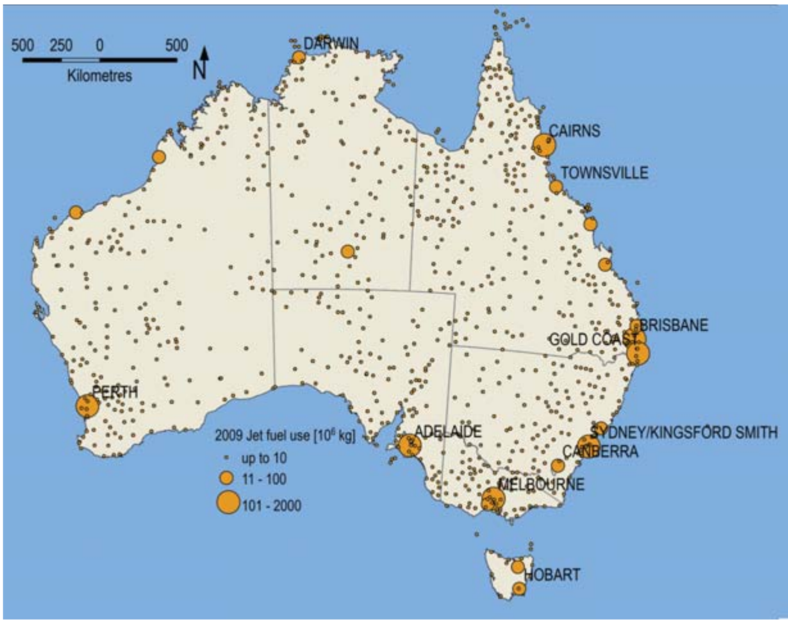
Another promising route for conversion of biomass into liquid fuels involves the fermentation of plant sugars into fuel using yeast or other microorganisms (typically genetically modified). Production of fuels from simple plant sugars, such as corn syrup or sugar cane juice, is relatively straightforward, less so when the feedstock is lignocellulosic biomass, which is refractory to being broken down to its sugar constituents. Biodiesel and jet-fuels can be produced using proprietary biochemical technologies. These third generation technologies involve the use of unique or patented microorganisms and enzymes to control and enhance conversion of biomass-derived sugars into liquid fuels. Additionally, bio-derived alcohols such as bioethanol or biobutanol can be thermochemically upgraded to jet fuel products.



> Figure 13: Map of existing Australian refineries by type

Source: Biofuels Association of Australia;
Geoscience Australia and ABARE (2010)

Note: The existing New Zealand oil refinery is located at Marsden Point, Whangarei



> Figure 14: Indicative map of Australian jet fuel consumption (estimated based on airport flight data*)

* Note: Actual fuel consumption by airport will differ because not all flights refuel at the destination.
Source: Department of Infrastructure and Transport

Distribution

The aviation sector has a relatively streamlined distribution system with fewer supply points and aircraft compared to the thousands of supply points and millions of vehicles in the road sector. While there are many airports in Australia, the majority of aviation fuel is consumed at the major capital city airports (Figure 14). In most cases aviation fuel is delivered at these sites via one or two direct pipelines.

Use of the existing aviation fuel supply infrastructure, including on-airport hydrant facilities, for the delivery of bio-derived jet fuel will require negotiated access from infrastructure owners and agreement from other airlines using the facilities. If this access or approval is not achieved then this could present a barrier to the bio-derived aviation fuel market or require duplicate infrastructure to be set-up. Truck based fuel delivery to the airport and to the aircraft, which allows segregation, may be appropriate at times. At major airports truck based delivery would present significant operational challenges for both airlines and airports, but could be used in the early stages for pilot scale testing.

The existing aviation fuel distribution systems rely on co-mingling of fuel deliveries. The introduction of an approved standard which covers co-mingling for a 50:50 blend of bio-derived aviation fuel batches has been a major step forward in achieving drop-in capability.

The requirement for drop-in capability and thus co-mingling will require the industry to rely on purchase records for the purposes of carbon reporting or making representations about the quantity of certified sustainable bio-derived jet fuel which has been used. There are different methods being contemplated in other regions and it is important that Australia and New Zealand ensure that the most straightforward approach is adopted in this region otherwise it will impact the take-up of bio-derived jet fuel.

Assuring sustainability

There are significant positive environmental and social benefits that would result from an expanded bio-derived jet fuel production industry. However, stakeholders will need to be assured that bio-derived jet fuels are produced sustainably.

This new industry will create direct benefits for employment and regional development, and indirect benefit for communities by supporting improved environmental outcomes such as increased biodiversity and improved water quality[10]. Social acceptance will be influenced by these factors and how they are included in assessments of the overall sustainability of the supply chain.

Rural and regional communities

It will be important that new bioenergy projects seek community support during their development and that communities are informed about likely impacts from new developments, including any social impacts. For example, community concerns may arise about the displacement of traditional farming, particularly if the new farming system is large scale (potentially millions of hectares) yet does not support the same level of community infrastructure. Bioenergy based farming practices may also impact local and landscape-scale water use. Clearly project developers would benefit from frameworks which assist them in identifying possible impacts (positive or negative) on the community.

Aviation customers

Aviation's customers will also play a key role. Consumers will need to be assured that the bio-derived jet fuels that the aviation industry adopts are produced sustainably and are safe to use. Safety is addressed through international fuel standard processes which have been long established. A new process for sustainability assessment of feedstock production together with a system for tracking feedstocks will be required to achieve certification of feedstocks as 'sustainably-produced'.

Sustainability certification

Options for achieving confidence in sustainability of the fuels include adoption of an existing scheme such as the Roundtable on Sustainable Biofuels (RSB) already identified by SAFUG (see Box 4), or the development of a single-product scheme (i.e. a certification system as has been established for palm oil – the Roundtable on Sustainable Palm Oil). The scheme must be consistent with and mutually recognised by those developed internationally. Aviation is a global industry, therefore global harmonisation of sustainability credentials is important. For airlines to claim credit on international flights for using 'sustainable' fuels, a consistent set of criteria needs to be used. Some local adaptation of these international schemes might be needed in order to address local sustainability issues, while maintaining cross-region applicability.

The implementation of a global and local sustainability framework and assessment system will be a significant task – but there is good opportunity to build on existing processes and institutions. A rigorous, globally harmonised system for ensuring sustainability of bio-derived jet fuels will bring the advantages of consumer acceptance, confirmed environmental benefits and a consistent basis for regulatory/legislative support for these new fuels.

[10] Woody biomass production can be used to lower the water table and help mitigate salinity. This type of biomass production could also assist in connecting remnant vegetation.

> Box 4: International institutions for the development of a sustainable bio-derived fuels industry

The Sustainable Aviation Fuel Users Group (SAFUG)

SAFUG was formed in September 2008 with support and advice from the world's leading environmental organisations including the Natural Resources Defence Council and the Roundtable for Sustainable Biofuels (RSB). The group is focused on accelerating the development and commercialisation of sustainable aviation fuels. Group members agree to contribute to the robust sustainability and certification regimes via the RSB global multi-stakeholder process.

All members subscribe to a sustainability pledge stipulating that any sustainable bio-derived fuel must perform as well as, or better than, kerosene-based fuel, but have lower carbon emission across their lifecycle. The user's group pledges to consider only renewable fuel sources that:

- Minimise biodiversity impacts
- Require minimum land, water, and energy to produce
- Don't compete with food or fresh water resources.

In addition, cultivation and harvest of plant stock should provide socioeconomic value to local communities.

Roundtable on Sustainable Biofuels (RSB)

The mission of RSB is to ensure that bio-derived fuels deliver on their promises of climate change mitigation, economic development and energy security without causing environmental or social damage, such as that resulting from deforestation and food insecurity. The Standard developed by the RSB consists of a set of normative documents and guidelines. It covers the entire bio-derived fuel value chain from 'farm to tank' and addresses the negative impacts potentially caused by bio-derived fuel production.

The RSB has developed a third-party certification system for bio-derived fuels sustainability standards, encompassing environmental, social and economic principles and criteria through an open, transparent, and multi-stakeholder process. Participation in the RSB is open to any organisation working in a field relevant to bio-derived fuels sustainability.

Roundtable on Sustainable Palm Oil (RSPO)

In response to the urgent and pressing global call for sustainably produced palm oil, the RSPO was formed in 2004 with the objective of promoting the growth and use of sustainable palm oil products through credible global standards and engagement of stakeholders.

RSPO is a not-for-profit association that unites stakeholders from seven sectors of the palm oil industry – producers, processors or traders, consumer goods manufacturers, retailers, banks and investors, environmental or nature conservation NGOs and social or developmental NGOs – to develop and implement global standards for sustainable palm oil.

Commercial Aviation Alternative Fuels Initiative (CAAFI)

CAAFI is a coalition of airlines, aircraft and engine manufacturers, energy producers, researchers, international participants and United States government agencies. Together these stakeholders are leading the development and deployment of alternative jet fuels for commercial aviation in the United States. CAAFI's goal is to promote the development of alternative jet fuel options that offer equivalent levels of safety and compare favourably on cost with petroleum based jet fuel, while also offering environmental improvement and security of energy supply for aviation.

Environmental considerations

A number of practices will need to be followed, which will differ depending on the feedstock and location, in order to ensure that bio-derived jet fuel production is environmentally sustainable. The main environmental considerations are soil, water and biodiversity impacts.

Soil

Soil quality issues include changes to the propensity for erosion, nutrients, fertility levels, soil carbon and moisture retention. Impacts will depend on climate, soil type and management practices, particularly the amount of biomass residues removed from the site. However, soil issues will not be applicable to algae production which occurs in water.

Water

Water impacts for land based feedstocks depend on the amount of irrigation required, fertiliser use and depth of root systems. Algae production will require significant volumes of water but it can use saline or non-potable sources. Nutrients are required and in some cases are available from waste streams that also contain water (e.g. sewerage). The fuel refining stage may also consume significant amounts of water but need not be co-located with biomass production.

Biodiversity

Biodiversity impacts can be positive or negative depending on the initial state of the land used for biomass production. Replacement of diverse forest environments with single species biomass production would be detrimental to biodiversity. However, introduction of biomass co-production to agricultural land increases biodiversity.

Land

There is limited potential to expand the land on which traditional bio-derived fuel feedstocks such as tallow, canola, wheat and sugar co-products are produced. The scope for increasing yields per hectare from existing crop land in Australia is also limited because of water limitations to plant growth in most areas and mature agronomy and plant breeding technologies for well-established food crops. The water availability in New Zealand is less limited but nonetheless this nation faces similar constraints to its mature agricultural sector. The outcome of these constraints is that next generation biomass must find a niche within existing available land.

Next generation biomass

A range of non-traditional or second generation biomass sources (Table 5) may overcome these challenges to sustainable production. As discussed, algae does not require agricultural land, and can be grown in saline water. However it does have an additional requirement for a concentrated carbon dioxide source (for example, from power stations). Nutrients such as phosphorus and nitrogen are also important and there are concerns these may become scarce in the medium to long term.

Agriculture and forest residues can be sustainably harvested from existing production areas by retaining sufficient amounts to protect soil fertility. Various new tree based biomass systems producing lignocellulose can be integrated into existing crop and grazing land with only a small penalty for short term food production balanced against some longer terms benefits to the sustainability of land use.

Soil quality and biodiversity impacts will still need careful attention due to the large land base required for biomass production and the likely use of intensive harvesting regimes.

Careful consideration of location will also be important. Most cleared land is already used for some form of agriculture (cropping or grazing), and further clearing of native vegetation is highly regulated in most states. Even where possible, land clearing will need to be considered carefully against relevant bio-derived fuel sustainability principles (particularly in relation to maintenance of biodiversity and improvements in greenhouse gas balance). The precise impacts of a given land use change are often location-specific, scale-dependent and differ with feedstock type. These issues can be studied further and addressed in project-scale and landscape-scale impact assessment processes.

Economic viability

Market pressures

Over time a growing proportion of bio-derived jet fuels will be priced competitively compared to traditional petroleum-based jet fuel. Crude oil market volatility and competition for feedstocks from alternative uses will be key challenges to overcome.

Fuel represents a large share of costs for airlines. The commercial environment means airlines will not be in a position to adopt higher cost sustainable bio-derived jet fuels and keep their airfares competitive.

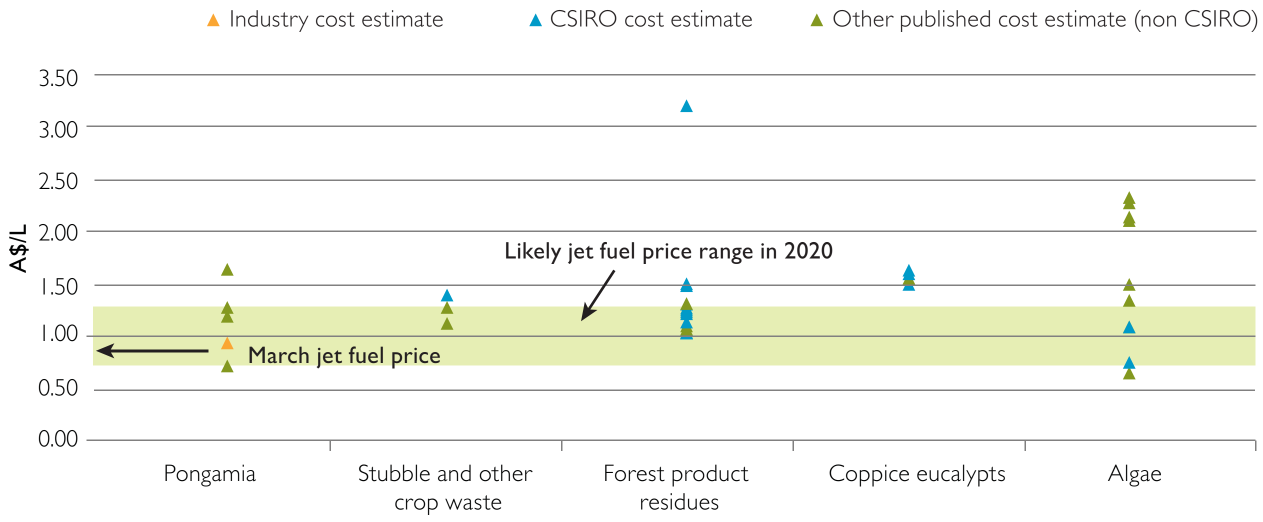
Market prices

The average jet fuel price in March 2010 was around 85 cents per litre after distribution to major centres (more for regions). The price is mainly set by the global oil price. Local demand and supply conditions in south-east Asia have only a minor impact. Bio-derived jet fuel blends can directly substitute for petroleum jet fuel so they will have to compete against this price to be taken up by airlines.

An economic assessment and survey of available biomass carried out for this road map study indicates that there will be a subset of bio-derived jet fuel supplies available to compete with the fossil based jet fuel price (Figure 15), providing commercial developers are able to realise their projected biomass yields and costs. New production systems such as algae, pongamia and coppice eucalypts are the most uncertain.

Future markets

The scale of economically viable production is expected to expand considerably in the future as the cost of novel biomass resources and refining technologies decline and due to the expected rising trend in fossil-based jet fuel prices over time.



> **Figure 15:** Estimates of bio-derived jet fuel costs from different feedstock sources by 2020. Source: Graham et al., (2011)

Increased jet fuel prices make bio-derived jet fuels more economically viable but also mean that aviation is more expensive for all users. Even as the expected costs of bio-derived jet fuel fall due to more efficient production methods, these savings will be difficult for fuel end-users to capture. Unless they enter into fixed price long term supply agreements, bio-derived jet fuel producers will look to the prevailing oil product-equivalent price, plus any available premiums for providing a low carbon product, to set their price.

Real oil prices are projected to continue increasing beyond US$100/bbl (Figure 5) as global economic growth returns to average this decade, with a steady upward trend continuing throughout the projection period (IEA 2010; EIA 2010).

Even if the oil price remained constant, the cost of converting oil into aviation fuel is likely to increase. This is because oils produced at the remaining oil fields are expected to be 'heavier' on average and it is more costly to refine these heavier oils into jet fuel (Woods, 2007).

Another factor that increases the price users would be willing to pay for bio-derived jet fuels is the potential introduction of carbon pricing. Globally harmonised carbon prices modelled by Commonwealth of Australia (2008) ranged between A$20 to A$43 per tonne of carbon dioxide equivalent (CO_2e)[11] on commencement, rising at around 4 per cent per year to achieve targets for atmospheric concentrations of greenhouse gas emissions at 550-450 parts per million[12]. At present, prices of carbon permits (referred to as EU Allowances) in the existing European carbon emission trading system were reported in the range of A$17 to A$21[13] per tonne of CO_2e in the first three quarters of 2010 (European Climate Exchange 2010).

If the price of jet fuel plus the cost of purchasing carbon emission permits is higher than the price of bio-derived jet fuel, then it will be economically viable for airlines to use bio-derived jet fuels as a way of meeting their obligations. Each A$50 per tonne of CO_2e emission permit costs adds 12 cents per litre to oil based jet fuel costs[14].

Reducing costs

Like any new industry there is significant potential to reduce the cost of bio-derived fuels over time. As production scales up we can expect improved biomass to jet fuel conversion efficiencies and reduced feedstock costs as supply-chains become more efficient and specialised. These new technologies will mature and new technologies may arise, with the potential for step-changes in per unit production costs.

For example, capital equipment and processes for efficiently harvesting biomass feedstocks will draw on those already

[11] The term CO_2e is used to describe the quantity of CO_2 plus other greenhouse gases released during combustion at the same time notably nitrogen oxides and water vapour.

[12] These carbon price scenarios were modelled by Commonwealth of Australia (2008) on the basis of two government designed global emission trading scheme scenarios with the scheme commencing in 2010 and two emission trading scenarios developed by the Garnaut review, in those cases commencing in 2013. There is currently no national or global commitment to implement any of the modelled schemes. Hence these are only a guide to possible future carbon prices were such schemes to be agreed and implemented some time in the future.

[13] Reported as €12 to €15 and converted at an A$/€Eu exchange rate of 0.71.

[14] Assuming the carbon permit costs for combustion of the fuel (based on carbon content) are acquitted at the sale of the fuel and permit costs are one hundred per cent passed through to the fuel purchaser.

available for large scale food or forestry production. However, over time that equipment will be adapted to the particular needs of extraction for bioenergy. Integrated processing of biomass could also result in some high value co-products that can offset bio-derived fuel harvesting costs.

A significant risk factor potentially increasing the cost of bio-derived fuel production in the future is climate change.

The impacts of climate change may positively or negatively affect local feedstock yields over time. In general, projections show Australia is expected to become dryer in the Southern regions, and wetter in some locations in the North (CSIRO, 2011), although not all proposed biomass sources are agricultural.

The impact of uncertainty

While the trend is positive, technological and fuel market uncertainty could lead to delays in investment in key biomass production and refining infrastructure.

Trends indicate that the economic viability of bio-derived jet fuel will gradually improve over time; however this is not sufficient to ensure investment will take place. Particular scenarios may be very positive but if the general level of uncertainty is too high then investment may be delayed or even avoided. Key uncertainties affecting the uptake of bio-derived fuels and hence the risk to investment include the oil price, feedstock production costs and refining costs.

Oil price

Crude oil has a particularly volatile price history on weekly, yearly and decadal scales. Most forecasters agree the oil price will rise over time due to lack of large new oil discoveries but the question is how fast and how much this rise will be.

Feedstock production costs

Feedstock production costs are reasonably well understood for existing resources such as crop stubble, oil seed grown between crop rotations, and forest products and waste. The main uncertainties for these biomass resources, however, are changes in demand for other uses (mainly forest products) and the unknown effect that a sudden increase in demand by a new bioenergy industry may have on price.

Also uncertain are prices of biomass feedstocks that are yet to be developed to any significant scale – including new oil seed plantations, mixed farm forestry and algae. Reliable production yield estimates are the strongest determinant of costs; yet these can only be determined in large scale trials or commercial implementations under local Australian and New Zealand conditions, which are still to be conducted. However, some knowledge of realised production costs has been developed from smaller scale trials and overseas experience (Figure 15).

Even after trials are conducted, in any given year, costs and production yields may vary depending on the climate conditions and biomass source.

Bio-derived fuel refining costs

The cost uncertainty of bio-derived jet fuel refining mostly reflects the lack of experience in building commercial scale plants. However there are two other factors driving this uncertainty.

The first factor is that the oil price impacts on the costs of key refining inputs. For example hydrogen which is a key input, is typically produced from natural gas, the cost of which is not always but often linked to the oil price. Feedstock supply costs are also affected by the oil price via fertiliser, harvesting and transport costs.

The second factor creating uncertainty around refining costs is the logistics of aggregating feedstocks from many small suppliers and transporting these to the plant. Long and thin supply chains might place limits on the scale of refining possible. Alternatively, production may take several years to reach the required scale due to limits on the rate of new biomass plantings. If sufficient quantity of feedstock is not available within an economically viable transport distance, scale or time then the refining plant will not be built to maximum efficient scale. Fuel refined using smaller scale plants can be twice the cost of a plant of ideal size. Plants that are better suited to lower scale and are capable of using a flexible range of feedstocks will be favoured as the industry emerges.

Overcoming uncertainty

Biomass production risks can be reduced if producers are large. Also some non-agricultural based feedstocks are much less affected by climate. Feedstock producers also reduce their investment risk by the mere fact that their product could also be provided to the land transport sector, as will be discussed in the next section.

For the refining and end-use sectors of the aviation fuel supply chain, however, the way forward to prevent the potential investment delays could involve some form of risk sharing via long term off-take arrangements. It should be noted that forward contracts longer than two years do not have much precedence in the current aviation fuel supply chain due to the inflexibility they create in competing within the highly competitive and price sensitive global airline industry.

If the residual uncertainty in the bio-derived fuel supply chain remains high it could represent a market failure. It is likely that other approaches for supporting fledgling industries, such as government funded pilot projects, no-cost margin-dependent producer loans, feedstock establishment subsidies and user equity partnerships for more mature projects, may need to be considered to assist in accelerating the scaling up of the bio-derived jet fuel supply chain over the next decade.

Competition from road and other sectors

There will be great demand for biomass as a number of industries seek to diversify away from fossil fuel inputs. The key competitors are other transport modes, electricity generation and various petrochemical users.

Globally, aviation represents about 11 per cent of current transport fuel demand. In contrast road transport is the largest fuel consumer at 71 per cent and history shows that road users have a high willingness to pay greater fuel prices to maintain personal mobility and access to business freight services.

Compared to aviation, road and rail transport has a greater variety of alternative fuels and energy modes available to it. Natural gas, liquefied petroleum gas and bio-derived fuels are viable options. As oil prices rise, the land transport industry is also likely to electrify a much greater portion of its fleet.

Road fuel market prices

The road sector is a significant competitor for current and future bio-derived fuels in Australia and New Zealand. Partly due to road excise arrangements in both countries, parts of the road sector are able to pay around 15 cents per litre more than the aviation sector for liquid fuels. But even if the aviation and road sector had comparable prices, some types of bio-derived road fuels are cheaper to produce than bio-derived aviation fuels, making the sector a more likely target for bio-derived fuel refiners.

For example, biologically derived oils can be converted to road biodiesel via a process called transesterification for 15-20 cents per litre less than the cost of producing bio-derived jet fuel. However it should be noted that road biodiesel produced through this lower cost path has disadvantages in the form of poor performance in cold weather, water absorption, and capped blend limits in many newer engines. Also if the feedstock is lignocellulose rather than biologically derived oil the cost of producing road and jet fuels are much closer.

Evolution of liquid fuel markets

Whether this competition with the road sector means the aviation industry will fail to secure an economically viable bio-derived fuel supply in the future varies depending on several drivers:

- The size of the available feedstock supply relative to the whole transport sector
- Ongoing excise arrangements for bio-derived fuels in the road sector
- The availability and cost of other alternative fuels, especially electrification of the road sector
- The export demand for road fuels
- Changes in the relative cost of biomass feedstock refining technologies for road and aviation fuels
- The rate of road fleet turnover and the rate of uptake and social acceptance of high blend bio-derived fuel vehicles.

Under prevailing conditions and from a pure market perspective, the land transport sector is likely to be the primary end use market for bio-derived fuels in the short term. However, over the longer term it is expected that most factors will improve in favour of the aviation sector.

Bio-electricity

The electricity sector is another competitor for the use of biomass. In both Australia and New Zealand, small scale biomass electricity plants (supplying waste heat for industrial processes) would be viable under carbon pricing and would most likely compete for lignocellulosic feedstocks. It is possible for these plants to use oilseed or algae feedstocks but they are generally less suited, and these feedstocks would be much more expensive than the equivalent energy in lignocellulose. Bio-electricity power plants are slightly more viable in New Zealand where alternative electricity generation options are more limited and costly.

Other petrochemical users

Other petrochemical uses include cosmetics (foundations, moisturisers and aromatics), pharmaceuticals, preservatives, detergents, pesticides, smoke flavours, plastics and adhesives. Some petrochemical uses are high value relative to fuels.

As a consequence, although relatively minor, some biomass resources are expected to be diverted to this use.

Interestingly, such utilization of biomass resources could actually spur the development of bio-derived fuel feedstock supplies, as high-value 'co-products' which do not parasitize the primary biomass supply can in effect subsidize the cost of biomass production.

End game for biomass users

While the use of biomass in electricity generation and short haul passenger vehicles is economically viable at present a longer term view suggests these are not likely to remain the most natural end users of biomass resources. Competition between generating electricity or producing liquid fuels will likely be resolved by changes in the cost and carbon intensity trajectories of the incremental megawatt hour (MWh) versus the incremental barrel of oil. The incremental MWh is getting less carbon intense (owing to advances in lower cost, low carbon solar, wind and other renewable technologies) while the incremental crude barrel is getting more costly and more carbon intense, as increasingly heavy oil shales and tar sands are exploited. These considerations tend to suggest that the most profitable use of limited biomass resources in the long term will be to provide liquid fuels for transport services.

Within the liquid fuel market the relative competitiveness and lower carbon emission intensity of electricity will likely push rail and urban short haul transport (which is able to store enough electricity for each journey) towards greater electrification leaving long haul transport and aviation as the main users of bio-derived fuels (see, for example, IEA, 2009; Commonwealth of Australia, 2008; Graham et al., 2011). These potential transport and electricity market developments are illustrated in Figure 16.

End use	Fuel source	Timeframe		
		Current	Near term	Long term
Electricity	Fossil	Stable	Declining	Declining
	Biomass	Stable	Growing	Declining
	Electricity	NA	NA	NA
	Other renewables	Emergent	Growing	Stable
Short haul transport	Fossil		Declining	Declining
	Biomass	Growing	Growing	Declining
	Electricity	Emergent	Growing	Growing
	Other renewables	NA	NA	NA
Rail	Fossil	Stable	Stable	Declining
	Biomass	Stable	Emergent	Declining
	Electricity	Stable	Growing	Growing
	Other renewables	NA	NA	NA
Aviation and other	Fossil	Stable	Stable	Declining
	Biomass	Emergent	Growing	Growing
	Electricity	NA	NA	NA
	Other renewables	NA	NA	NA

Legend

NA Technology/fuel not applicable

Emergent Growing Stable Declining

> Figure 16: Possible evolution of transport and electricity markets

Summary of state of play and key challenges

Much has already been achieved in a short period of time in bringing the goal of securing a more sustainable aviation fuel supply closer to reality.

Important recent milestones in the development of this new industry include:

- The successful demonstration of fit-for-purpose performance of bio-derived jet fuels in commercial and military aircraft over the past three years.
- Technical certification of one class of bio-derived aviation jet fuel in 2009 with a second due in 2011.
- Establishment and demonstration of alternative biomass to jet fuel refining processes, although below commercial scale.
- International development and trials of bio-derived fuel sustainability principles and guidelines.

The significant increases in oil prices between 2007 and mid 2008 played a part in focusing industry in assessing the options for addressing fuel conservation and alternative fuels.

The increasing concern of governments and the community regarding climate change are also important contributing factors.

This report has aimed to identify some of the opportunities and challenges that are involved in the commercialisation of sustainable aviation fuel supply industry in the region and the key strategies to address them.

No single stakeholder can implement all of the required steps to overcome these challenges. They require inputs from various parts of the fuel supply industry value chain, government and the community.

The current state of play, key challenges are critical stakeholders are summarised in Table 6.

> **Table 6:** Summary of challenges for establishing sustainable bio-derived jet fuel




	Resource assessment	Biomass	Fuel refining	Technical approval and sustainability certification
Status	• Yield and cost of existing biomass resources reasonably well understood	• Large volume of lignocellulosic feedstocks produced as residue not utilised or utilised for other purposes • Large potential for bio-dervied oil feedstock but negligible amount produced • Commercial scale production based on crop residue	• Several established bio-derived jet fuel refining processes • Other bio-derived jet fuel refining processes at early stages • Commercial scale activities producing road fuel only	• Precedents exist in other sectors and government reporting arrangements • One class of bio-derived jet-fuels approved • Partially coordinated international sustainability principles developed with trial implementations underway
Challenges	• Establishing potential for lesser known biomass resources	• Aggregating and matching production and transport to refining scale • Trialling new biomass varieties with larger potential volumes, improving agronomy and establishing their performance	• Ensuring jet fuel is a priority product for bio-refinery output • Establishing preferred refining technology matched to feedstocks • Proving the viability of early stage refining processes • Gaining access to existing pipeline infrastructure	• Establishing a process for certifying the sustainability credentials of the fuel
Critical stakeholders	• Research community • Government • Early stage investors	• Investors • Government • Agricultural and forestry industry • Local communities	• Investors • Government • Refining industry • Aviation industry	• Government • Other regulators, NGOs and institutions • Agricultural and forestry industry • Aviation industry • Refining industry • Research community

Seizing the opportunity

Benefits to the community

A local production industry for sustainable aviation fuels will bring significant economic, social and environmental benefits. Modelling has been conducted to quantify some of these benefits.

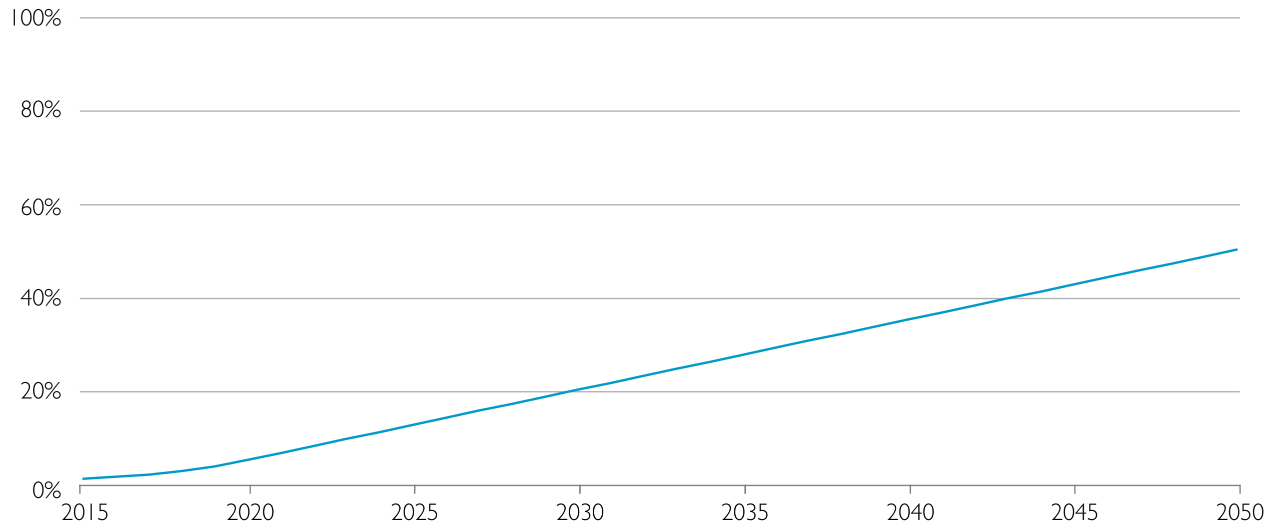
In order to explore the likely benefits to the community of the uptake of bio-derived jet fuels in the aviation sector, a road map scenario was developed and assessed as part of this study. The road map scenario assumes the construction and operation of two commercial scale refineries by 2020, the first in 2015. This allows for likely delays in development, construction and in building up the necessary feedstock volumes. This scale of refinery development would allow the Australian and New Zealand aviation industry to achieve a 5 per cent bio-derived jet fuel share by 2020. Beyond 2020, the share of bio-derived jet fuel consumption was assumed to steadily increase to a 50 per cent share by 2050 (Figure 17).

Based on this road map scenario, modelling was conducted to determine the benefits to the community in terms of greenhouse gas reductions and avoided oil imports.

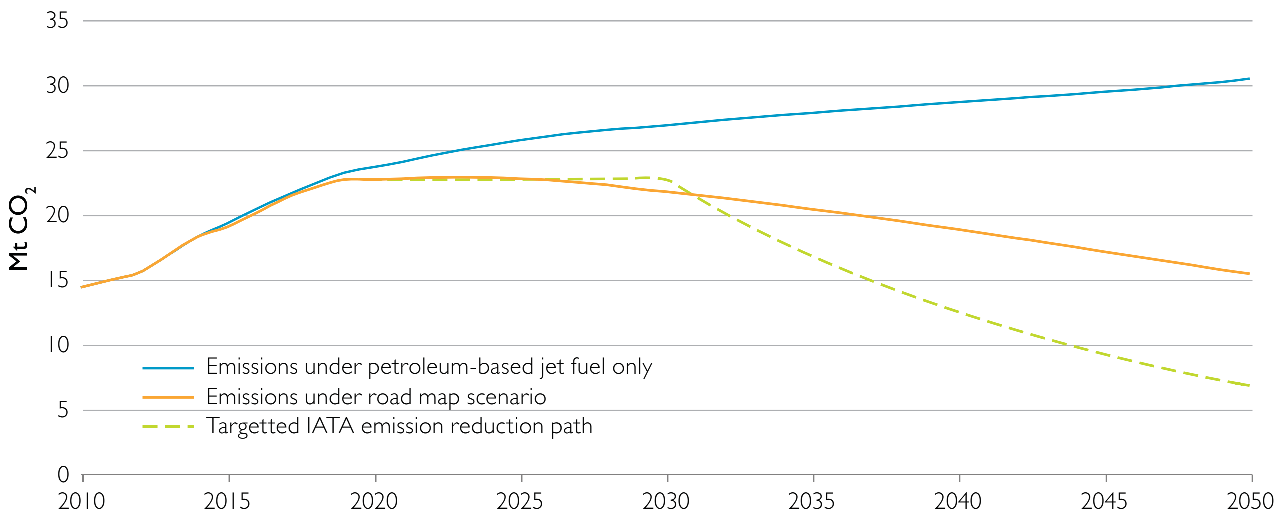
Carbon abatement

Under the road map scenario, the uptake of bio-derived jet fuels causes a significant slowing and then halts the growth of aviation sector emissions in the period between 2020 and 2030. This is broadly consistent with IATA's global industry target. By 2050 total aviation industry emissions are reduced almost to their 2010 levels (Figure 18). While this is not as low as the IATA target of a 50 per cent reduction on 2005 levels, this is still a substantial achievement considering the industry is expected to deliver five times the current passenger and freight services (and associated economic and social benefits) by 2050.

There are sufficient biomass resources in Australasia (Figure 8) to support construction of a more ambitious



> **Figure 17:** Share of bio-derived jet fuel in total aviation fuel consumption in Australasia under the road map scenario

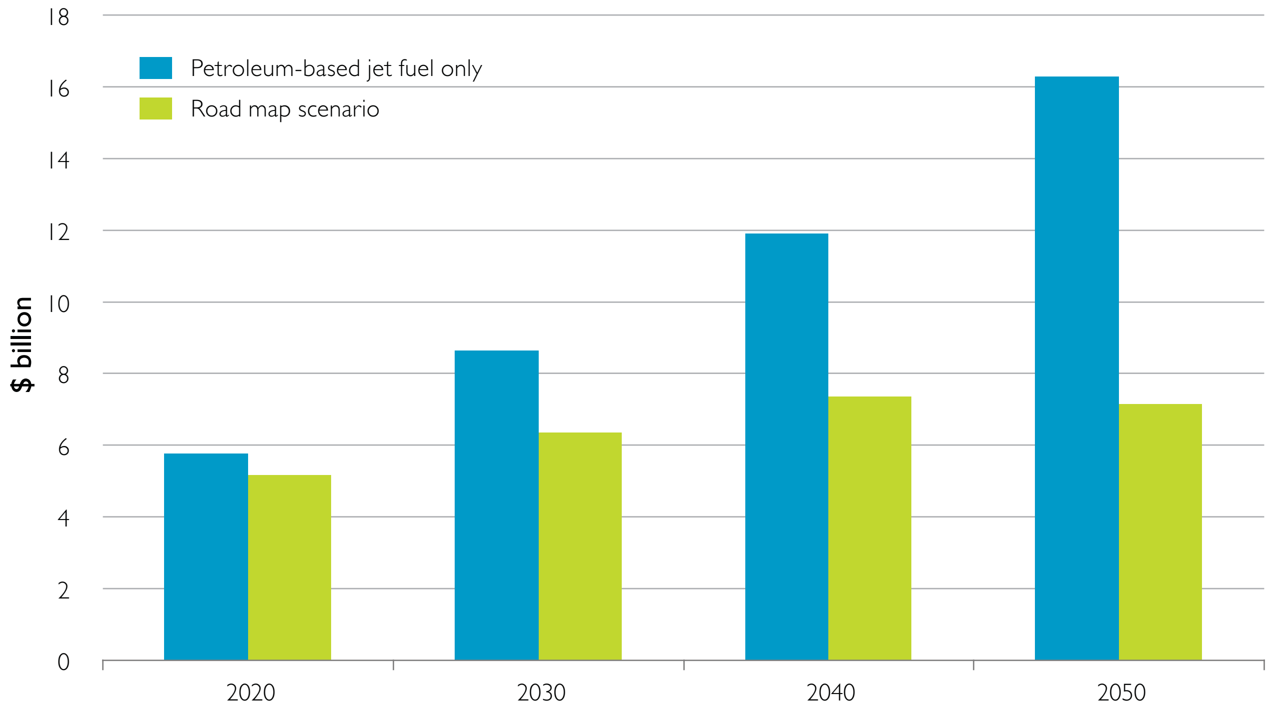


> **Figure 18:** Projected Australasian aviation sector greenhouse gas emissions under the road map scenario compared to petroleum-based jet fuel only and the targeted IATA emission reduction path. Source: Graham et al., (2011)

bio-derived jet fuel uptake scenario that would allow the Australasian industry to reach the IATA 2050 targeted emission reduction path. However, it would require use of higher cost biomass resources from lower yielding areas and greater competition for biomass with other sectors. Given the main concern of this study is establishment of the industry during this decade, this possible scenario was not explored further.

Improved energy security

The projected oil imports under the road map scenario are shown in Figure 19 and are compared to the case where only petroleum-based jet fuel is consumed. The Australasian region has around 5200 to 5500 million litres of jet fuel refining capacity but with aging infrastructure and declining domestic oil production this is not expected to expand and the region



> **Figure 19:** Projected value of jet fuel imports under the road map scenario compared to petroleum-based jet fuel only. Source: Graham et al., (2011)

already imports around A$3 billion of jet fuel. The projections show that with no uptake of bio-derived jet fuel, imports are projected to rise to just under A$6 billion by 2020 and to over A$16 billion by 2050. Alternatively, under the road map scenario, if the region adopts domestic production of bio-derived jet fuels, imports can be reduced by over A$0.5 billion by 2020. By 2050, over A$9 billion of imports can be avoided.

Rural and regional employment

Those avoided import expenditures will instead fund domestic biomass producers and jet fuel refiners who will in turn employ a significant workforce. Furthermore, that workforce will likely be situated in rural areas where additional employment opportunities can greatly assist in building population and income critical mass that can induce further employment.

Precise employment estimates associated with the road map scenario are not available given the industry is in its infancy. The biomass production stage is expected to be the most labour intensive and therefore the highest employment creation activity. Biomass production also includes collection, transport and handling.

Different types of biomass will have different workforce needs. Biomass production systems that are closest to normal crop production will require a relatively large agricultural style workforce for soil preparation, cultivation and harvesting, depending on the degree of mechanisation, which will be significant in developed countries like Australia and New Zealand. Biomass production based around residue collection may be less labour intensive in collections stages but involve more handling and transport.

Based on a relatively mechanised agricultural biomass production system, it is estimated that the first supplies of bio-derived jet fuel in our road map scenario, would employ around 500 rural workers in the biomass production and transport stages in Australasia, growing to 3500 by 2020 and 12,000 by 2030. The World Economic Forum estimated that a global bio-derived fuels industry could create 800,000 jobs by 2020 (GlobeNet, 2010; World Economic Forum, 2010). Whichever country takes the lead in the development of a sustainable aviation fuels industry could create the opportunity for their region to export know how and engineering skills to the world.

Establishing a commercial industry

Key barriers to commercial deployment of sustainable aviation fuels are biomass production, economics and the establishment of a new value chain. Broad cross-sector investment and collaboration will be required to establish this new industry. Strict adherence to sustainability principles will be necessary to ensure the success of the industry.

Industry, research, investment and government sectors all have a role to play in establishing a successful sustainable aviation fuels industry. There are several parallel streams of activity that need to take place. This report has highlighted the need to move out of the laboratory into commercial scale-up where possible, with concurrent research and development continuing on biomass sources and emerging technologies with longer lead times.

A key priority in value chain design is identifying optimal feedstocks, conversion technologies and locations for plantations, refineries and infrastructure. This study has provided a high level view but more work is required by researchers in collaboration with government and investors and industry partners.

The key focus of industry and the investment community will be building a business case for investment, sourcing investment funding and co-ordinating investments along the value chain which will require a very significant level of collaboration. The airline industry can play an important role to support these objectives by establishing off-take agreements with refiners for volumes of bio-derived jet fuel, which in turn will support refiners in developing supply relationships with biomass producers.

In parallel, industry and investors will look to Government to ensure certainty around government support to overcome any potential market failures so that business arrangements deliver price signals and support for initial value chain investment and expansion. An appropriate vehicle for this activity could be the development of a national strategy for alternative fuels.

Industry will look to establish demonstration or early stage commercialisation of facilities where technologies and feedstocks are already available. At the same time, stakeholders will increase efforts to investigate specific biomass resources and refining options that are less mature but present opportunities for reducing costs or exploiting the region's natural advantages that will sustain the industry in the long term.

The most important contribution of the research community is in improving the efficiency of the biomass production stage. The research community will be important in working together with industry and investors in bringing down the costs of biomass production. Modelling conducted as part of this study found that a 20 per cent reduction in sustainable biomass production costs could, holding all other factors constant, bring forward establishment of the industry by around five years (Graham et al., 2011).

The greatest advances in reducing costs and improving biomass production yields are likely to come from applying the best international commercial and science partnerships to resources where we have comparative advantages.

Finally, all stakeholders have an important role to play in meeting public needs for information to ensure comfort on the safety and sustainability of bio-derived aviation fuels. Transparent debate and discussions around certification will be required.

Role of government

While the bio-derived jet fuel industry is expected to be commercially independent over the long term, it faces various technological and market uncertainties which could make initial commercialisation challenging. A review of government support mechanisms to assist the transition of the industry from its fledgling stage will need to be conducted in order to determine what role government could play.

The review of bio-derived jet fuel supply chain economics conducted as part of this road map has indicated that bio-derived jet fuels are expected to be commercially viable in the long term. The challenges faced in the short term include technological and market uncertainties and competition from other users of biomass resources. Some of these challenges are shared by other industries seeking to transition with respect to low carbon technologies.

Globally, many governments support research and commercialisation of low carbon technologies and many have specific programs targeting bio-derived fuel production. The experience of conducting this study has highlighted that almost none of the existing Australian and New Zealand government programs are directly targeted at bio-derived fuels for use in aviation. This is to be expected given the potential for bio-derived jet fuels has only come to light in the last few years. However, given the significant potential that has now been identified it is appropriate to take stock and review the range of government support mechanisms available and their potential application to the bio-derived jet fuel supply chain.

Reviewing the type of government support mechanisms that might be appropriate was beyond the scope of this road map study. It is therefore a priority that industry and government together review how existing government support mechanisms for bio-derived fuels and renewable energy could be accessed by the aviation industry for development of bio-derived jet fuel supply. As part of this review, it will be important to identify mechanisms that build on rather than detract from existing measures targeting bio-energy industry development and to identify any measures which unintentionally hinder development. This is the approach taken in the United States through the 'Farm to Fly' program announced in the 2010. This program is reviewing the existing support mechanisms with a view to extending them to aviation if appropriate.

Mechanisms that directly target early stage commercialisation of the supply chain will be of most value as this is a priority for the sector. Some other priorities are resource assessment including proximity of refining infrastructure, biomass production trials, and refining technology development.

The recommended actions of all stakeholders to achieve commercial scale bio-derived jet fuel production by 2015 are summarised in Table 7.

> Table 7: Recommended actions to achieve a commercial scale bio-derived jet fuel industry

Recommendation	Action	Lead Accountability	Timing
Market Structure			
Recommendation 1	Develop a national strategy and action plan for alternative fuels incorporating sustainable aviation fuels.	Federal Government in consultation with State Governments and industry stakeholders	2011 (Planned)
Recommendation 2	Establish appropriate mechanisms for participants in the sustainable aviation fuel supply chain to access government bio-energy industry support focussing on scale-up and commercialisation	Federal Government and State Governments in consultation with industry stakeholders	2011
Recommendation 3	Develop supply chain contracts or other risk sharing mechanisms with sustainable fuel producers to establish a market and manage financial risks	Airlines, fuel supply chain and investors	2012 onwards
Biomass supply			
Recommendation 4	Establish contracts to access supply of existing biomass resources	Sustainable fuel producers	2012
Recommendation 5	Assess the potential of new biomass resources, particularly plant oils that are lesser known	Research institutions, biomass producers	2011
Recommendation 6	Expand local trials of the most promising new biomass varieties	Research institutions, biomass producers	2012
Refining			
Recommendation 7	Assess the most promising locations for sustainable fuel refining capacity	Sustainable fuel producers in consultation with the fuel supply industry and with Government	2011
Recommendation 8	Move to commercialise technology if matching biomass available	Sustainable fuel producers, airlines, in consultation with Federal and relevant State Governments	2013
Recommendation 9	Establish access for sustainable fuel supply to airport pipeline infrastructure	Sustainable fuel suppliers, fuel supply industry, airlines, Government	2013
Recommendation 10	Establish demonstration refining facilities as proof of supply chain where technology is less advanced	Sustainable fuel suppliers, research institutions in consultation with Federal, State Governments	2013
Recommendation 11	Develop lower cost processes for refining lignocellulosic processes	Research institutions, biomass and technology developers	2013
Certification			
Recommendation 12	Establish a harmonised system for sustainability certification of fuel	Government and industry together with global counterparts	2013
Recommendation 13	Finalise approval of the BIO-SPK jet fuel standard which refines plant oils via hydrodeoxygenation.	Aviation Industry	2011
Recommendation 14	Build awareness of sustainable aviation fuels across the value chain	Aviation industry, sustainable fuel suppliers, environmental groups	2011

Acronyms

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ASAFUG	Australasian Sustainable Aviation Fuel Users Group
ASTM	ASTM International, formerly American Society for Testing and Materials
ATAG	Air Transport Action Group
bbls	barrels (equivalent to 159 litres)
Bio-SPK	synthetic paraffinic kerosene or jet fuel refined via the hydrodeoxygenation process
BRS	Bureau of Rural Sciences
°C	degrees Celsius
CAAFI	Commercial Aviation Alternative Fuels Initiative
CO_2e	Carbon dioxide equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DESC	Defense Energy Support Center
EIA	Energy Information Administration
FAA	Federal Aviation Administration
FT	Fischer-Tropsch (a fuel refining process)
FT-SPK	synthetic paraffinic kerosene or jet fuel refined via the Fischer-Tropsch process
GDP	Gross Domestic Product
HDO	Hydrodeoxygenated Oil
HRJ	Hydroprocessed Renewable Jet fuel
IATA	International Air Transport Association
ICAO	(International Civil Aviation Organisation
IEA	International Energy Agency
Kg	kilograms
L	litres (equivalent to 0.2642 US gallons)
MJ	mega joules (a measure of energy content)
MWh	megawatt hour
NGO	non-government organisation
RSB	Round table on Sustainable Biofuels
RSPO	Round table on Sustainable Palm Oil
SAFUG	Sustainable Aviation Fuel Users Group
USDA	US Department of Agriculture
WTO	World Trade Organisation

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