Policy Exchange

research note
July 2009

Green skies thinking: promoting the development and commercialisation of sustainable bio-jet fuels

Ben Caldecott & Sean Tooze

Executive Summary

The development and commercialisation of sustainable bio-jet fuels should become a priority. Bio-jet fuels currently represent the only viable option for significantly reducing emissions from aviation without cutting the number of flights flown. They can be used in old and new aircraft alike, in stark contrast to most other technologies that can improve aircraft fuel efficiency, such as engine and airframe advances.

Despite their potential, the current policy framework in the UK and EU is unable to deliver their deployment and commercialisation. This is partly because current policies, principally the EU Emissions Trading Scheme (EU ETS) and UK Air Passenger Duty (UK APD), do not support the investors and developers involved and fail to create the demand needed to enable commercialisation. In fact, there are no specific policies within Europe that aim to promote the development and commercialisation of sustainable bio-jet fuels. Given the contribution they could make to reducing emissions from aviation, this should change urgently.

Reducing the demand for flights is important, but for some purposes and on many routes there are no practical low carbon alternatives. Aviation is, amongst other things, a fundamental part of the global economy and facilitates inter-cultural exchange. Moreover, people throughout the world want to travel. As a result, we must promote methods that can reduce emissions from those flights that do take place. Sustainable bio-jet fuels are one critical option that can be delivered over the medium term, in time to make a significant contribution to our 2050 emission reduction targets. For this to work, ambitious policies need to be put in place urgently and with the conviction needed to meet the global challenge we face.

Bio-jet fuels are technically feasible and will be imminently certified as safe and compatible to be used in conjunction with standard kerosene jet fuel. Moreover, the advanced biofuels that could be used in aviation should not be confused with first generation biofuels and the specific debates surrounding their sustainability and practicality. On both fronts we have shown that with the right regulatory framework sustainability and dramatic life-cycle GHG emission reductions can be delivered. The marginal land used to produce sustainable bio-jet fuels is also sufficient, so enough feedstock can be cultivated to meet current and predicted total jet fuel demand. This is in profound contrast to the amount of land needed to cultivate sufficient feedstock to meet road transport fuel demand with biofuels.

In order to fundamentally improve the situation in the UK and EU and successfully promote the development and commercialisation of sustainable bio-jet fuels, we recommend the following measures be adopted:

- **To create demand for sustainable bio-jet fuels an *EU Sustainable Bio-jet Fuel Blending Mandate* should be introduced from 2020.** This Mandate would set out clearly and credibly that a rising proportion of jet fuel must come from or be blended with sustainable bio-jet fuels. The proportion required would rise in line with what was technically and economically viable. The Mandate would allow suppliers to anticipate demand and thus be able to raise finance more readily for investments in the relevant plants, supply chains and delivery mechanisms. *This Mandate on the proportion of jet fuel derived from or blended with sustainable bio-jet fuel would start from 20% in 2020 and rise to 80% in 2050 and would secure respective reductions in GHG emissions from the UK and EU aviation sectors of 15% and 60% relative to current predictions.* It would set achievable, observable and enforceable interim targets for the use of sustainable bio-jet fuel from 2020 onwards. *The cumulative emission reductions of our proposals from 2020 to 2050 are valued in 2009 prices at £37.41 billion in the UK and £305.43 billion across the EU.*

- **In the UK we should increase support for companies conducting R&D into the production of sustainable bio-jet fuels.** We recommend the extension and deepening of the HM Government's current R&D tax credit regime for companies which conduct research into sustainable bio-jet fuels in the UK. *We propose that these companies be allowed to claim an additional 40% of eligible R&D spend against their taxable profits.* This additional support, called Sustainable Bio-jet Fuel Research Relief (SBFRR), is modelled on the Vaccine Research Relief (VRR) scheme that already runs in parallel to the standard R&D tax credits available. To provide an incentive for companies to invest in sustainable bio-jet fuel research in the UK, we propose that the SBFRR or an equivalent run for at least 10 years from 2010/11 to 2020/21. *The introduction of this policy is estimated to cost less than £5 million per annum and would make the UK one of the most supportive tax regimes for sustainable bio-jet fuel R&D in the world.* We also recommend that R&D into sustainable bio-jet fuels be eligible to apply for support from Government research bodies and funds, such as the £150 million Innovation Fund announced in June 2009.

- **We should invest in the methodologies and regulatory bodies needed to ensure that bio-jet fuels are produced sustainably and deliver dramatic life-cycle GHG emission reductions.** Bio-jet fuels must be stringently regulated and analysed. In the UK, the Renewable Fuels Agency (RFA), currently the administrative body for the Renewable Transport Fuel Obligation (RTFO), should be charged with drawing up and enforcing these standards. The Global Bioenergy Partnership was established in 2005 to quantify the life-cycle GHG emissions and sustainability of all biofuel feedstocks. This process should be sped up and resourced, in order that both current and future market participants have confidence in the feedstocks and processes used to produce sustainable bio-jet fuels. Without this, the market will fail to flourish and could do harm, not help the environment.

- **The cost of deploying sustainable bio-jet fuels should be minimised.** If our proposals come to fruition, bio-jet fuel production costs may fall to around US$80 per barrel by 2030, with production costs falling further to around US$70 per barrel by 2050. *This compares well with average jet fuel prices of US$62.29 per barrel from 2000 to 2008 and the jet fuel price peak of July 2008 when it reached US$167.70 per barrel.* Should sustainable bio-jet fuels be significantly more expensive than standard jet fuel there should be some flexibility to reduce the impact on airlines. In the UK, we have seen that the UK APD is an ineffective carbon abatement instrument and is *de facto* a revenue raising measure for HM Government. There might be scope post-2020 for this to be reduced in proportion to any additional costs imposed by the introduction of the Mandate. This should be explored after 2020, when the cost of the Mandate can be observed and its impact on airlines assessed.

Introduction

Aviation currently accounts for a relatively small proportion of total greenhouse gas (GHG) emissions[1]: 6% of UK, 4% of European Union (EU 27) and 2% of global.[2] This is likely to change however. Projections show that global demand for aviation will grow at 5% annually for at least the next 15 years.[3] Growth will occur in both mature markets[4] and across less developed markets – most notably China[5]. Consequently, if growth in aviation emissions is left unchecked, by 2050 emissions from aviation are estimated to account for 15-20% of global GHG emissions.[6]

To avoid this fate we must decouple the growth in emissions from the growth in passenger numbers and number of flights taken. This does not seem likely under the current policy framework. In the UK alone, GHG emissions from aviation are projected to rise from around 19.3 $MtCO_2$[7] in 2005 to 29.7 $MtCO_2$ in 2030, stabilising thereafter.[8] Across the EU, emissions will rise from 135 $MtCO_2$ in 2005 to 274.3 $MtCO_2$ in 2030 and then fall to 231.1 $MtCO_2$ in 2050.[9] This is despite the inclusion of aviation within the EU Emissions Trading Scheme (EU ETS) from 2012, the introduction of UK Air Passenger Duty (UK APD) and the anticipated uptake of new fuel efficient technologies.

This predicted growth will occur amongst the backdrop of vocal opposition to proposed airport expansion in the UK. There are also a large number of people, 61% according to a recent poll, who believe that the aviation sector is insufficiently concerned about its environmental impact.[10] Merely stabilising UK emissions from aviation by 2030 is unlikely to be sufficient to diffuse mounting public and political concern.

On an economic and scientific basis, this does not seem to be an adequate response to climate change either. The Committee on Climate Change has recommended that aviation should meet, like other sectors, a legally binding 80% emission reduction target by 2050 from 1990 levels.[11]

If these more ambitious emission reductions fail to occur and aviation grows as planned, there are consequences for the rest of the economy. In the UK, the non-aviation sectors of the economy will be required to secure GHG emission reductions of 89% by 2050 from 1990 levels in order to meet an economy wide 80% GHG emission reduction target.[12] In this version of the future, aviation would account for 35% of total UK emissions in 2050[13] – everyone else will have to work harder to compensate for this. Given this context, how can we decarbonise aviation faster than currently predicted?

The answer will require a number of significant changes, from the replacement of short-haul flights with high-speed rail services to the improvement of engine and airframe technology. This Research Note focuses on one of the most promising and overlooked technical solutions for the decarbonisation of aviation: sustainable bio-jet fuels.

These can deliver significant life-cycle emission reductions, realistically be produced at scale to meet demand for aviation fuel, be deployed using existing infrastructure and aircraft, and avoid the problems that afflicted some of the first generation biofuels used for road transport. Given these benefits, we have investigated how to better promote the development and commercialisation of bio-jet fuels, especially in the UK and EU.

We have looked at the policy instruments that could be used to facilitate their rapid development and deployment and what could be done to ensure that they are produced sustainably. We have also looked at how to enable the UK to become a leader in this important emerging technology.

Current framework for reducing emissions from aviation

The British government is committed to reducing emissions from aviation. The principle policy instruments chosen to achieve this are UK APD and the forthcoming (from 2012) inclusion of aviation within the EU ETS. Both of these instruments are intended to reduce aviation emissions within the UK and EU respectively.

UK Air Passenger Duty

The APD was introduced on the 1st November 1994[14]. It is an excise duty that is charged on the carriage of passengers flying from a UK airport on an aircraft that has an authorised takeoff weight of more than ten tonnes or more than twenty seats.[15]

Box 1. Air Passenger Duty[16]

In 2007, the rates of the APD were doubled:

Flight Type	Pre 2007 rate	2007 rate
European destinations, economy class	£5.00	£10.00
European destinations, other classes	£10.00	£20.00
Other destinations, economy class	£20.00	£40.00
Other destinations, other classes	£40.00	£80.00
Total revenue raised per annum	£0.9 billion (2005-2006)	£1.9 billion

From November 2009, the APD will be restructured into four distance bands:

Flight Distance Band	November 2009 – October 2010 economy class	November 2009 – October 2010 other classes	November 2010 onwards economy class	November 2010 onwards other classes
Band A (0 – 2000 miles)	£11.00	£22.00	£12.00	£24.00
Band B (2001 – 4000 miles)	£45.00	£90.00	£60.00	£120.00
Band C (4001 – 6000 miles)	£50.00	£100.00	£75.00	£150.00
Band D (over 6000 miles)	£55.00	£110.00	£85.00	£170.00
Total revenue raised per annum	£3.1 billion		£3.6 billion	

The Government will restructure APD from November 2009 into a banded excise duty, with 4 bands based on miles and class travelled.[17] The bands are shown above in Box 1.

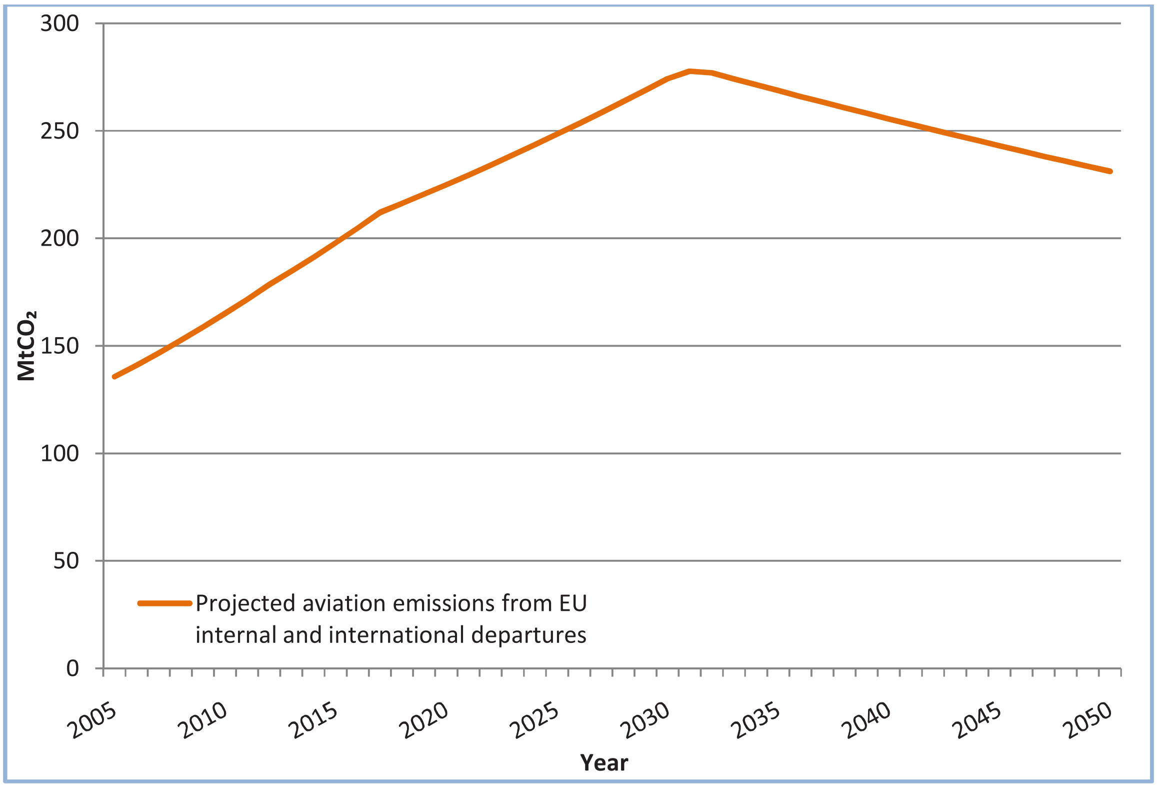
Since 2007, the APD has raised approximately £2 billion in revenue annually[18]. This is forecast to increase to £3.1 billion in 2010-2011, rising to £3.6 billion in 2011-2012.[19] Although the APD has been a successful revenue generator, it has been less effective in reducing UK emissions from aviation. The Treasury has predicted that the APD will save only 0.4 $MtCO_2$ in 2010/11 and 0.6 $MtCO_2$ in 2011/12.[20] In both of these years, this is equivalent to less than 1% of UK emissions from aviation.[21]

Due to the marginal difference the APD has had on reducing UK emissions from aviation the International Air Transport Association (IATA) has said that it "is nothing more than a blunt revenue instrument. It has no credibility as a driver of improved environmental performance."[22]

EU Emissions Trading Scheme

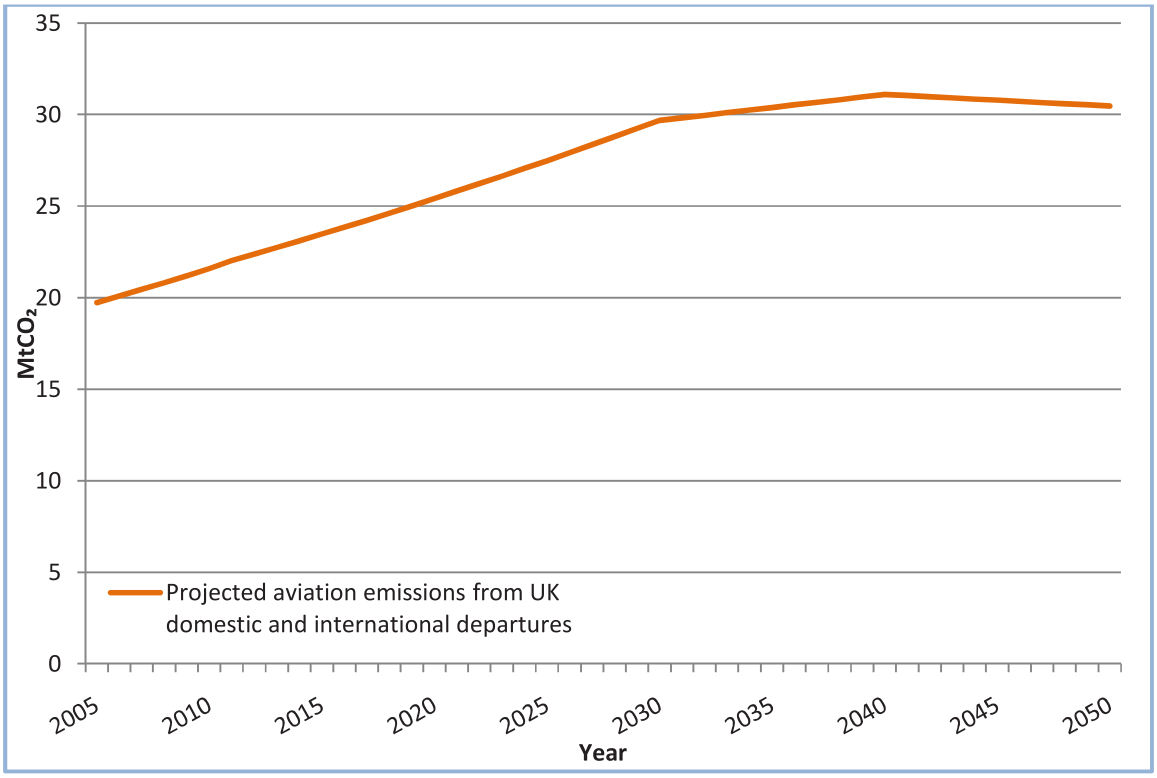
At an EU level, from 1st January 2012 all domestic and international flights arriving at, or departing from EU airports will be included in the 3rd Phase of the EU ETS. During the initial period of inclusion (1st January 2012 – 31st December 2012), the total quantity of permits allocated to aircraft operators will be equivalent to 97% of historic aviation emissions, defined as average emissions from between 2004 and 2006.[23] From 2013 until 2020, the cap will be stabilised at 95% of historic emissions.

Figure 1. Projected aviation emissions from EU internal and international departures[24]



Despite the presence of an EU-wide emissions cap for aviation, emissions are predicted to rise significantly. Even under a near best-case scenario (excluding our proposals), the Tyndall Centre has projected that EU-wide emissions will rise from 2005 to 2030 and only then begin to fall (see Figure 1).

Figure 2. Projected aviation emissions from UK domestic and international departures[25]



As can be seen in Figure 2, a much worse situation will arise in the UK: emissions will rise and then only stabilise between 2030 and 2050. The EU ETS cap and UK APD will fail to secure absolute reductions in UK aviation emissions.

Beyond business as usual

We agree with the Committee for Climate Change that the current policy framework at both a UK and EU level will not deliver emission reductions from aviation commensurate with the challenge we face from climate change.[26] Continuing along this undesirable emissions pathway, as effectively promised by the existing policy framework in the UK and EU, is insufficient. The challenge now is to determine how we can improve this situation and deliver greater emissions reductions more quickly.

The existing paradigm

The aviation sector has maintained a good track record of improving the fuel efficiency of new aircraft, achieving an average annual increase of around 1.5%.[27] The sector itself, as well as government studies, predict that aviation will continue to deliver annual average efficiency improvements of this magnitude for the foreseeable future.[28]

These efficiency improvements and the subsequent emissions savings will be overwhelmed, however, by continued global demand growth for aviation.[29] The result is that regional and global GHG emissions from aviation will continue to rise.

Box 2. Radiative Forcing[30]

The sum effect of aviation on climate is likely to be significantly greater than the effect of aviation's GHG emissions alone. In addition to CO_2 emissions, aviation releases water vapour, other GHGs and particulates, as well as forming contrails. The release of these additional emissions at altitude acts to increase aviation's climate effects, relative to that of other ground based industries. The effect of the release of these additional emissions, combined with the release of CO_2 emissions, is quantified by a multiplier; the Radiative Forcing Index (RF).

The IPCC estimates that Radiative Forcing of aviation from 1992 to 2050 is 1.9 – 4 times that of its CO_2 emissions alone, while the Radiative Forcing effect of ground based industries is 1.5. However, there is uncertainty associated with the Radiative Forcing metric due to the complexities of extrapolating and quantifying what are often short-lived and localised atmospheric effects. As a result, assigning a Radiative Forcing multiplier to aviation is difficult and uncertain. For the purposes of current policy and climate targets, CO_2 emissions alone are often used as a benchmark to quantifying aviation's climate effect, relative to the activities of other sectors in the economy. This is because CO_2 is long-lived and rapidly diffuses in the atmosphere, allowing accurate comparisons to be drawn.

It should be noted that the adoption of bio-jet fuels for aviation is likely to reduce the Radiative Forcing multiplier. Fuels produced through the thermo-chemical conversion routes used in bio-jet fuel production have already been shown to reduce GHG and particulate emissions.

While the industry predicts that by 2020 new jet aircraft entering service will be 20-25% more efficient relative to those manufactured in 2005 and 50% more efficient relative to those manufactured in 2000,[31] their market share will be low over the long term. Projections suggest that these new aircraft will account for only 1% of aircraft-kilometres flown in 2020, rising to a mere 11% in 2030.[32] So although the sector can deliver efficiency improvements of 1.5% per annum for new aircraft, these rates of improvement cannot be applied to the entire fleet.

In contrast, some improvements can apply to old and new aircraft alike. Enhancing Air Traffic Management (ATM) and operational efficiency can help to reduce emissions from aviation across the entire fleet as it reduces fuel burn through fewer delays at national boundaries and airports. Better operator efficiency also reduces fuel burn through improved flight planning and speed management.[33] Taken together though, improved ATM and operator efficiency only have the potential to realise a 10% reduction in the GHG emissions from all aircraft and flights by 2020[34]. These improvements are already factored into the growth projections shown in Figures 1 and 2.

The fact that improvements to airframe and engine technology are limited to new jet aircraft – with the exception of minor retrofits across the existing fleet – and that the replacement of aircraft is slow, is ultimately down to the characteristics of the industry. Fleet renewal is capital intensive and aircraft have long service lives.

Consequently, to better combat rising emissions from aviation we must reduce emissions from old and new aircraft simultaneously. The challenge is how do achieve this without restricting flights on journeys where other less carbon intensive means of transport are impractical.

Paradigm shift

Like ATM, operational efficiency, flight planning and speed management, sustainable bio-jet fuels can reduce emissions from both old and new aircraft. The emissions savings from bio-jet fuels are, however, potentially much greater than the other enhancements combined. By providing life-cycle GHG emission reductions relative to conventional kerosene jet fuel, bio-jet fuels have the potential to allow the aviation industry to continue to operate and grow whilst reducing the absolute GHG emissions from its activities. Bio-jet fuels that have already been tested emit 16% of the GHG emissions of standard jet fuel.[35] They can also be "dropped in" and used by existing planes, engines and distribution infrastructure.[36]

Box 3. Bio-jet fuel certification[37]

To be used in aircraft all fuels, including bio-jet fuels, must meet a number of challenging specification requirements. This includes a freezing point, thermal stability, energy density, and storage stability criteria. Fuels must also be 'drop-in ready' solutions, i.e. be compatible with existing infrastructure and engine technology. In the case of bio-jet fuel, this means that they must be able to be safely blended directly in commercial volumes with conventional kerosene jet fuel, without requiring any additional duplicative infrastructure or modification to aircraft or aircraft engines.

ASTM certification (the aviation sector's principle standard setting body) will be a major step forward for bio-jet fuels, as it will enable their safe commercial use and guarantee manufacturer, user and regulatory confidence in them. Certification of various key bio-jet fuel processes and feedstocks is likely between 2009 and 2013.

Barring the development of an unexpected technology and given the limits of airframe and engine technology, switching from standard jet fuel to sustainable bio-jet fuel is the only option available to significantly decarbonise the aviation sector. If we are serious about the challenge of decarbonisation, we should aim to harness this opportunity.

Box 4. Producing Bio-jet fuels[38]

Bio-jet fuels can be produced through either biochemical or thermo-chemical conversion routes, although thermo-chemical conversion routes are likely to dominate near and medium term bio-jet fuel production as they utilise more mature technologies.

Thermo-chemical conversion

Thermo-chemical conversion of biomass to produce Biomass-to-Liquid (BTL) bio-jet fuel is achieved through gasification followed by Fischer Tropsch synthesis. Biomass feedstock is gasified at high temperature resulting in a synthesis gas (Syngas), which primarily consists of hydrogen and carbon monoxide gasses, occasionally with small quantities of CO_2. These basic gasses are the building blocks of all liquid hydrocarbon fuels. Syngas produced through gasification of biomass feedstock is then converted into hydrocarbon fuels through Fischer Tropsch synthesis, a catalysed chemical reaction, which produces a number of different hydrocarbon fuels, including bio-jet fuel. Gasification followed by Fischer Tropsch synthesis is also the process used to produce Coal-to-Liquid (CTL) jet fuel, currently produced by Sasol, and Gas-to-Liquid (GTL) jet fuel.

ASTM certification for 50% blends of all synthetic jet fuel is likely by summer 2009, with certification to fly using 100% BTL bio-jet fuel expected as early as 2010.

Alternatively, bio-oils may be hydrotreated to produce hydrotreated bio-jet fuels (HRJ). Bio-oils can be extracted directly from advanced feedstocks with high oil content, such as Jatropha, Camelina or algae, or produced through pyrolysis of biomass feedstocks, whereby biomass feedstocks are decomposed at high temperatures to produce bio-oils. Hydrotreating bio-oils with hydrogen at medium to high temperatures ‘upgrades’ bio-oils to hydrocarbon fuels, such as bio-jet fuel.

Initial work towards ASTM certification of 50% blends of HRJ bio-jet fuel is expected by 2010, with certification to fly using 100% HRJ bio-jet fuel expected as early as 2013.

Bio-chemical conversion

Producing bio-jet fuel through biochemical conversion of sugars and starches derived from biomass feedstocks is also feasible, although currently on a laboratory scale. Sugars may be fermented and dehydrated to form bio-jet fuel. Starches must be biochemically converted via enzyme conversion routes to sugars.

Bio-jet fuels are technically feasible and will be imminently certified as safe and compatible to be used in conjunction with standard kerosene jet fuel (see both Box 3 and Box 4). However, more work is required to develop sustainable commercial quantities of feedstock, the bio-jet processing plants required and the supply chains necessary.

Estimates of the timeframes involved with growing the quantities of sustainable advanced feedstock required to produce commercial volumes of bio-jet fuel vary. Commercial volumes of some sustainable feedstocks are already available, with commercial volumes of other feedstocks expected in 2-4 years, with the most advanced (algal) feedstocks expected to become available within 8-10 years.[39]

In parallel with producing commercial volumes of feedstock suitable for bio-jet fuel, bio-jet fuel processing plants and delivery infrastructure must be developed. The timeframes for developing these plants and delivery systems is broadly similar to that of developing feedstocks, with the first plants capable of processing bio-jet fuel expected within 3-5 years.[40]

Table 1. Bio-jet fuel demonstration flights[41]

Date	Carrier	Aircraft	Partners	Feedstock Type	Blend
23rd February 2008	Virgin Atlantic	Boeing 747-400	Boeing, GE Aviation	Coconut and Babussa (mix of first generation and advanced feedstock)	20% in one engine
30th December 2008	Air New Zealand	Boeing 747-400	Boeing, Rolls Royce, Honeywell UOP	Jatropha (advanced feedstock)	50% in one engine
7th January 2009	Continental Airlines	Boeing 737-400	Boeing, GE Aviation, CFM, Honeywell UOP	Algae and Jatropha (advanced feedstock)	50% in one engine
30th January 2009	Japan Airlines	Boeing 747-400	Boeing, Pratt & Whitney, Honeywell UOP	Camelina, Jatropha and Algae (advanced feedstock)	50% in one engine
October 2009	Qatar Airways	TBA	TBA	TBA	TBA
Spring 2010	JetBlue Airways	Airbus 320	Airbus, IAE, Honeywell UOP	TBA (advanced feedstock)	TBA
2010	Interjet	Airbus 320	CFM, SAFRAN, EADS, Honeywell UOP, CFM International, Airbus	Halophyte (advanced feedstock)	TBA
TBA	British Airways	TBA	Rolls Royce	TBA	TBA

As this is as yet a relatively untapped opportunity, the challenge is to provide the incentives necessary to promote the development and commercialisation of sustainable bio-jet fuels as soon as possible.

Deployment

At present, no specific policies at a UK and EU level aim to promote the development of sustainable bio-jet fuels. Given the contribution they could make to reducing emissions from aviation, this should change.

From our research there are three reforms that could dramatically improve this situation in the UK and EU. Together they would create demand for sustainable bio-jet fuels, ensure sufficient supply is created and enable the UK to become a world leader in the development of this important suite of technologies.

First, we should mandate that an increasing proportion of sustainable bio-jet fuels are used in flights departing EU airports on internal and international flights. This would send credible long term signals to the developers of sustainable bio-jet fuels, so they can increase production in the timescales required. Second, we should better support R&D into the production of sustainable bio-jet fuels in the UK. Third, we should invest in the methodologies and regulatory bodies needed to ensure that bio-jet fuels are produced sustainably and deliver life-cycle GHG emission reductions. These measures are explored in detail below.

Demand creation

Creating demand for sustainable bio-jet fuels is crucial if we are to enable their production in quantities able to significantly reduce emissions from aviation. Under the current policy framework airlines have little incentive, with the exception of reputational risk, to purchase sustainable bio-jet fuels. According to the representatives of the aviation sector we interviewed, the policy framework proposed post-2012 will not change this situation.

The result of insufficient demand is that oil companies or new start-ups cannot risk building the assets needed to deliver commercial quantities of sustainable bio-jet fuels. This is despite the relevant technologies coming to fruition now (see Box 3 and Table 1). To enable suppliers to make these investments, so that in the next 5-10 years sustainable bio-jet fuels can be produced and bought in commercial quantities, suppliers need to be more certain of future demand for their product.

Table 2. Introduction of an EU Sustainable Bio-jet Fuel Blending Mandate

Years	Sustainable Bio-jet fuel Blending Mandate	Mandated emissions factor of Sustainable Bio-jet fuel[42]	% GHG emissions reduction relative to standard jet fuel (i.e. kerosene)	UK annual average $MtCO_2$ saved relative to projected emissions[43]	EU annual average $MtCO_2$ saved relative to projected emissions[44]
2020 - 2029	20%	0.25	15%	4.09	36.95
2030 – 2039	40%	0.25	30%	9.09	80.80
2040 – 2049	60%	0.25	45%	13.86	109.95
2050	80%	0.25	60%	18.28	138.66

To remove this barrier, we propose the introduction of an EU-wide Sustainable Bio-jet Fuel Blending Mandate (herein referred to as the “Mandate”) that would create predictable demand. This Mandate would set out clearly and credibly that a rising proportion of jet fuel must come from or be blended with sustainable bio-jet fuels. The proportion required would rise in line with what was technically and economically viable. The Mandate would allow suppliers to anticipate demand and thus be able to raise finance more readily for investments in the relevant plants, supply chains and delivery mechanisms.

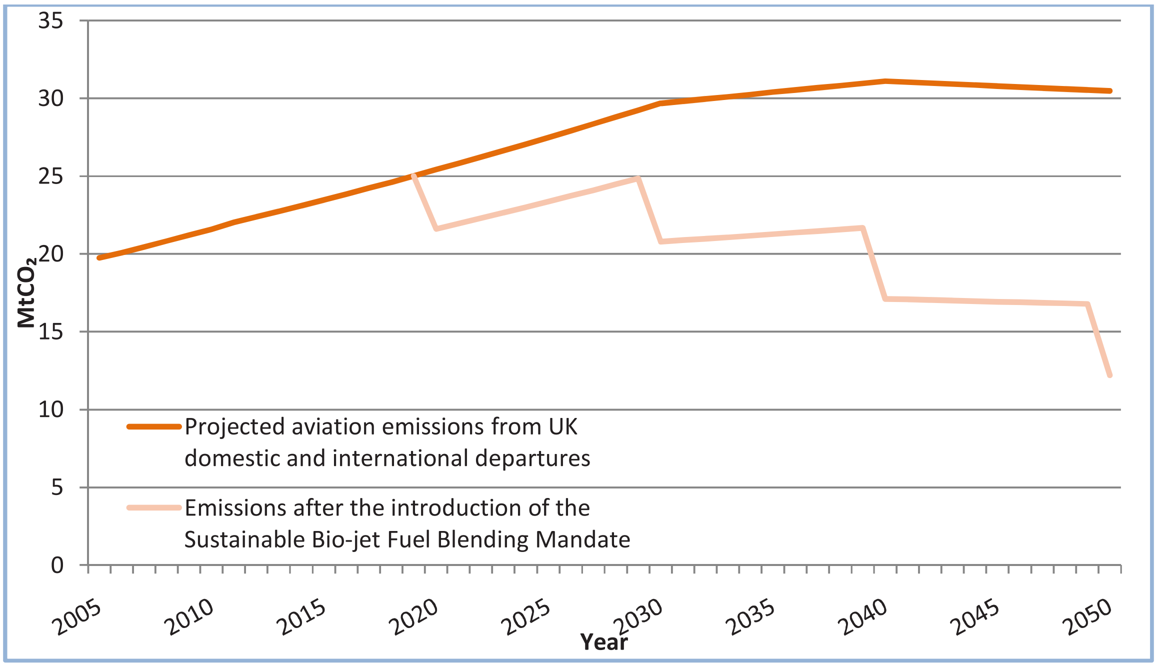
This Mandate on the proportion of jet fuel derived from or blended with sustainable bio-jet fuel would rise from 20% in 2020 to 80% in 2050, and would secure respective reductions in GHG emissions from the UK and EU aviation sectors of 15% and 60% relative to current predictions. It would set achievable, observable and enforceable interim targets for the use of sustainable bio-jet fuel from 2020 onwards.

In Table 2 we have set out the Mandate and shown the proposed blend ratios, when they would come into force for airlines and what minimum level of life-cycle emissions sustainable bio-jet fuels should save relative to standard jet fuels. We have also show the scale of the emission reductions this Mandate would secure in the UK and EU. The impact of the Mandate is illustrated for both UK and EU aviation emissions in Figures 3 and 4 respectively.

The levels proposed in the Mandate were developed after discussions with the companies and sectors involved to ensure they are realistic – in terms of both deployment and likely affordability.[45] The proposed emissions factor of 0.25 was selected after similar consultation. The emissions factor refers to the life-cycle GHG emissions of bio-jet fuel relative to the life-cycle GHG emissions of standard kerosene jet fuel. The proposed emissions factor of 0.25 means that bio-jet fuels under the Mandate would at a maximum emit 25% of the emissions that standard jet fuel would do, i.e. a minimum 75% emission reduction.

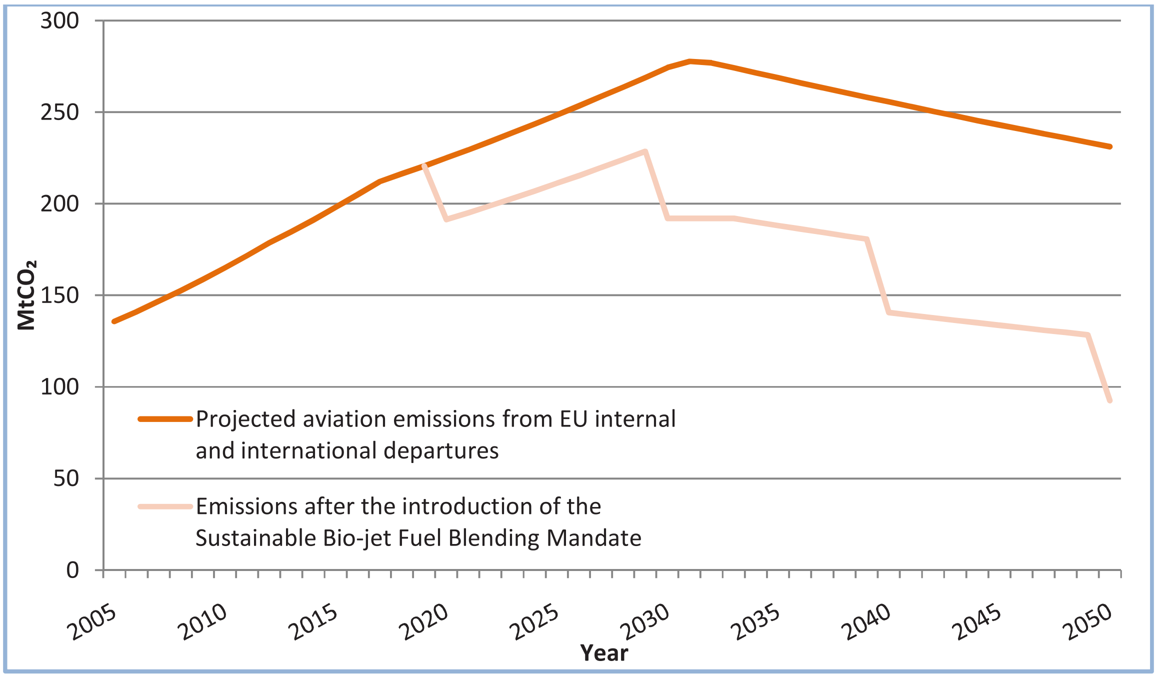
The life-cycle GHG emission of fuels is calculated based on emissions from use, production, processing, transportation and distribution. Life-cycle GHG emissions of bio-jet fuels also takes into account emissions from the cultivation of biomass and changes to land use as a result of their cultivation.

Figure 3. The impact of an EU-wide Sustainable Bio-jet Fuel Blending Mandate on aviation emissions from UK domestic and international departures[46]



Though the new Mandate would increase over time and be raised in phases, from its very beginning (2020) it would apply to all flights and aircraft departing EU airports. We also propose that it shares the exemptions used by the EU ETS when aviation is included post-2012. In summary, this means that the following flights would be excluded: (a) flights performed exclusively for Government transport; (b) military, customs and police flights; (c) flights related to emergency services and humanitarian purposes; (d) flights performed exclusively under visual flight rules as defined in Annex 2 to the Chicago Convention; (e) flights taking off and landing at the same airport and not landing at another destination in between; (f) training flights; (g) flights performed exclusively for research and testing purposes; (h) flights performed by aircraft with a certified maximum take-off mass of less than 5,700 kg; (i) flights on routes where the capacity offered does not exceed 30,000 seats per year; and (j) flights performed by an operator with total annual emissions lower than 10,000 tonnes per year.

Figure 4. The impact of an EU-wide Sustainable Bio-jet Fuel Blending Mandate on aviation emissions from EU internal and international departures[47]



The advantage of flights and aircraft under the EU ETS (with the exception of arrivals into the EU) also being under the Mandate is a reduction in the cost and complexity of monitoring both. It would allow for the same bureaucracy, not a separate one, to monitor and enforce both the EU ETS and new Mandate.

In terms of application, the Mandate would not apply to flights arriving at EU airports which have departed from outside the EU. This is because there are inherent difficulties with monitoring the blend of fuel burnt before arrival. Moreover, monitoring the wide variety of airports throughout the world that have flights departing for EU airports would be difficult and costly. Within the EU, monitoring would be comparatively straightforward as airports generally have centralised fuel storage facilities and these have experience of common-EU wide reporting standards.

Minimising cost

The benefits of reducing emissions from aviation through the introduction of sustainable bio-jet fuels are hard to quantify. If we use, however, the Government's Central Traded Price of Carbon, in 2009 prices our proposals would save emissions worth approximately £37.41 billion in the UK and £305.43 billion in the EU by 2050.[48]

Despite the vast benefits derived from these emission reductions, we should still aim to minimise the costs of the Mandate on the aviation sector. Our objective is to try and significantly decarbonise aviation, not stop all flying or bankrupt airlines operating in the EU.

The cost of introducing the Mandate relative to business as usual is difficult to estimate and depends on a number of variables, not least the price of standard jet fuel. There is a wide body of opinion that predicts a trend of rising oil prices for the foreseeable future, due to both supply and demand pressures.[49] The assumption used for the price of oil and thus standard jet fuel, will determine when sustainable bio-jet fuels become cost competitive.

Table 3. Savings due to the introduction of an EU Sustainable Bio-jet Fuel Blending Mandate

Years	Cumulative UK $MtCO_2$ saved	Cumulative value of UK emission savings (billion £ in 2009 prices based on central traded price of carbon)	Cumulative EU $MtCO_2$ saved	Cumulative value of EU emission savings (billion £ in 2009 prices based on central traded price of carbon)
2020 - 2029	40.94	1.89	369.52	17.09
2030 – 2039	131.90	9.07	1181.28	80.33
2040 – 2049	270.57	22.80	2280.82	180.28
2050	288.86	37.41	2417.48	305.43

Estimating commercial production costs of sustainable bio-jet fuels is subject to significant uncertainty, however best estimates of current minimum production costs are approximately US$100-130 per barrel[50]. However, if commercialisation is followed by rapid, large scale deployment beyond 2020 as proposed here, the estimates show that production costs may fall to around US$80 per barrel by 2030, with production costs falling further to around US$70 per barrel by 2050.[51] This compares well with average jet fuel prices of US$62.29 per barrel from 2000 to 2008[52] and the jet fuel price peak of July 2008 when it reached US$167.70 per barrel.

Should sustainable bio-jet fuels be significantly more expensive than standard jet fuel – this is not at all inevitable given upward pressure on oil prices – there should be some flexibility to reduce the impact on airlines. In the UK, we have seen that the APD is an ineffective carbon abatement instrument and is *de facto* a revenue raising measure for HM Government. There might be scope post-2020 for this to be reduced in proportion to any additional costs imposed by the introduction of the Mandate. This should be explored after 2020, when the cost of the Mandate can be observed and its impact on airlines assessed.

Encouraging R&D

Much has already been done with regards to the research and development of sustainable bio-jet fuels. But, there is more to do if commercial quantities are to be produced in the timescales proposed here.

Feedstock costs currently account for around 85% of estimated bio-jet fuel production costs. In order to improve the cost competitiveness of sustainable bio-jet fuels, more research will be required into developing advanced feedstocks to improve yields and reduce costs. Although the plant processing technologies involved with producing bio-jet fuels are relatively mature[53], reducing the costs in this area will also be important.

To enable further research and development in these areas, we need to reduce the risk for investors. Our proposals, by setting clear signals for the amount of sustainable bio-jet fuels demanded in the EU post-2020 are an important step forward in this direction.

We think, however, that the Government can do more to encourage finance to flow into this area soon. There is a role for Government support as this is a strategic opportunity for the UK to develop a leading role in the development and then commercialisation of this important suite of technologies.

To realise this, we recommend the extension and deepening of HM Government's support for R&D into sustainable bio-jet fuels. R&D into sustainable bio-jet fuels should also be eligible to apply for support from Government research bodies and funds, such as the £150 million Innovation Fund announced in June 2009.[54]

In addition, the tax credit regime for companies which conduct research into sustainable bio-jet fuels in the UK should be enhanced. The current policy framework for supporting R&D from companies in the UK takes the form of tax credits. This benefits companies that 'work to resolve scientific or technological uncertainty aimed at achieving an advance in science or technology'.[55]

R&D tax credits allow companies to set 130% (or 175% for small and medium sized enterprises) of eligible R&D spend against taxable profits up to EUR€7.5 million (capped due to EU state aid rules), thus reducing the corporation tax bill and in effect reducing the overall cost of R&D carried out.[56] Although companies conducting R&D into sustainable bio-jet fuels will already benefit from these tax credits, the level of relief should be increased, especially for research into advanced feedstocks and bio-jet processing technologies.

We propose that companies conducting research into sustainable bio-jet fuels in the UK be allowed to claim an additional 40% of eligible R&D spend against their taxable profits. This additional support, called Sustainable Bio-jet fuel Research Relief (SBFRR), is modelled on the Vaccine Research Relief (VRR) scheme that already runs in parallel to standard R&D tax credits.

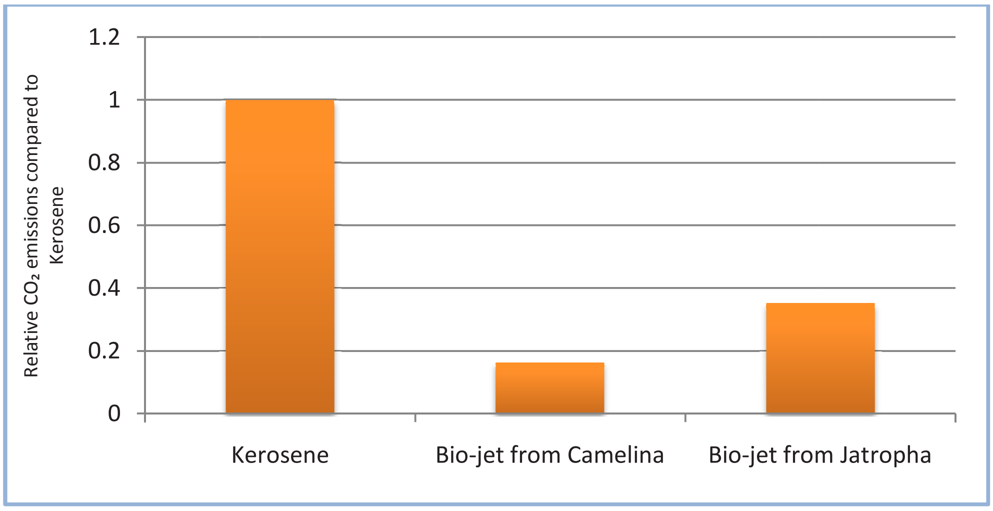
To provide an incentive for companies to invest in sustainable bio-jet fuel research in the UK, we propose that the SBFRR or an equivalent run for at least 10 years from 2010/11 to 2020/21. The introduction of this policy would make the UK one of the most supportive tax regimes for sustainable bio-jet fuel R&D in the world.

In terms of the additional cost of introducing the SBFRR, it is likely to cost a similar amount to the VRR, which cost less than £5 million in 2007/08. This is comparable because both research areas have similar sectoral characteristics.

Ensuring sustainability and life-cycle emission reductions

Policy makers and opinion formers have been cautious of biofuels since 2007/08 when many first generation biofuels were found to emit more GHG emissions than they saved, had negative impacts on food markets and caused undesirable land use change.

Figure 5. Relative emissions of sustainable bio-jet fuels to standard jet fuel (kerosene)[57]



In addition, many of the first generation biofuels that actually secured life-cycle emission reductions had a very high cost per tonne of CO_2e abated due to the scale of the subsidies received through mechanisms such as the Renewable Transport Fuel Obligation (RTFO). The Policy Exchange publication, *The root of the matter: carbon sequestration in forests and peatlands*, highlighted these concerns and proposed how we might avoid similar mistakes in the future. The biofuels that could be used in aviation should not be confused with first generation biofuels and the specific debates surrounding their sustainability.

As can be seen in Figure 5, the advanced feedstocks that will be used in sustainable bio-jet fuels have the potential to offer significant life-cycle GHG emissions reductions relative to many first generation feedstocks and the fossil fuels which they are replacing. GHG emission savings from biofuels are realised during the cultivation of the biomass feedstock as plants sequester atmospheric CO_2 during growth, thereby mitigating the release of GHGs as the biofuel is burnt.

To ensure that sustainable bio-jet fuels deliver significant life-cycle emission reductions and meet crucial sustainability criteria, stringent regulation and analysis of bio-jet fuels must take place. In the UK, the Renewable Fuels Agency (RFA), currently the administrative body for the RTFO, should be charged with drawing up and enforcing these standards.

Given that the same governing principles of life-cycle GHG emissions reductions and sustainability apply to all biofuel feedstocks and end products, research should aim to develop a global 'harmonized methodological framework'[58] to quantify the life-cycle GHG emissions and sustainability of all biofuel feedstocks.

The Global Bioenergy Partnership was established in 2005 to facilitate this aim, with the UK as a founding partner. It is imperative that such a methodology is produced in a timely manner, to prevent the unintended consequences of policies designed to increase the use of biofuels, such as indirect land use change, and to move towards a system that rewards biofuels that are sustainable and achieve significant life-cycle emissions reductions. As a result, the Global Bioenergy Partnership process should be sped up and resourced, in order that both current and future market participants have confidence in the feedstocks and processes used to produce sustainable bio-jet fuels. Without this, the market will fail to flourish and could do harm, not help the environment.

Box 5. First generation and advanced biofuels

First generation biofuels for road transport refer to bioethanol and biodiesel. These biofuels are produced thorough two conventional conversion routes: bioethanol is produced through fermentation of plant sugars and starches, found in a number of food crops, while biodiesel is produced by transesterification of oils and fats. First generation biofuels can be produced from a number of crops, however many of these crops are already used as food crops or to produce other agricultural products. As a result a number of studies have highlighted a number of drawbacks that apply to some, although not all, first generation biofuels, including:

- Increasing food prices due to direct competition for food crops;
- Limited life-cycle GHG emission reductions;
- Indirect land use change due to competition for biomass used for other agricultural products; and
- Increased water stress and agrichemical use.

Second generation biofuels are generally produced through two major conversion routes: thermo-chemical processing, or biochemical processing, both of which convert lingo-cellulosic material (woody plant material) and plant oils into a range of fuels. These conversion routes are more efficient and effective than first generation biofuel conversion routes, which can only use plant material with high sugar or oil content. Second generation biofuels therefore allow for more of the feedstock to be converted into useable fuel, generating greater yields, in addition to allowing more control over the qualities of the fuel produced.

Third generation biofuels refer to biofuels derived from algal feedstocks, which are processed using the same pathways used for second generation biofuels. As there is significant overlap between the technologies applied to produce second generation and third generation biofuels, they are often grouped together and referred to as advanced biofuels.

Advanced Biofuels address many of the concerns raised about first generation biofuels:

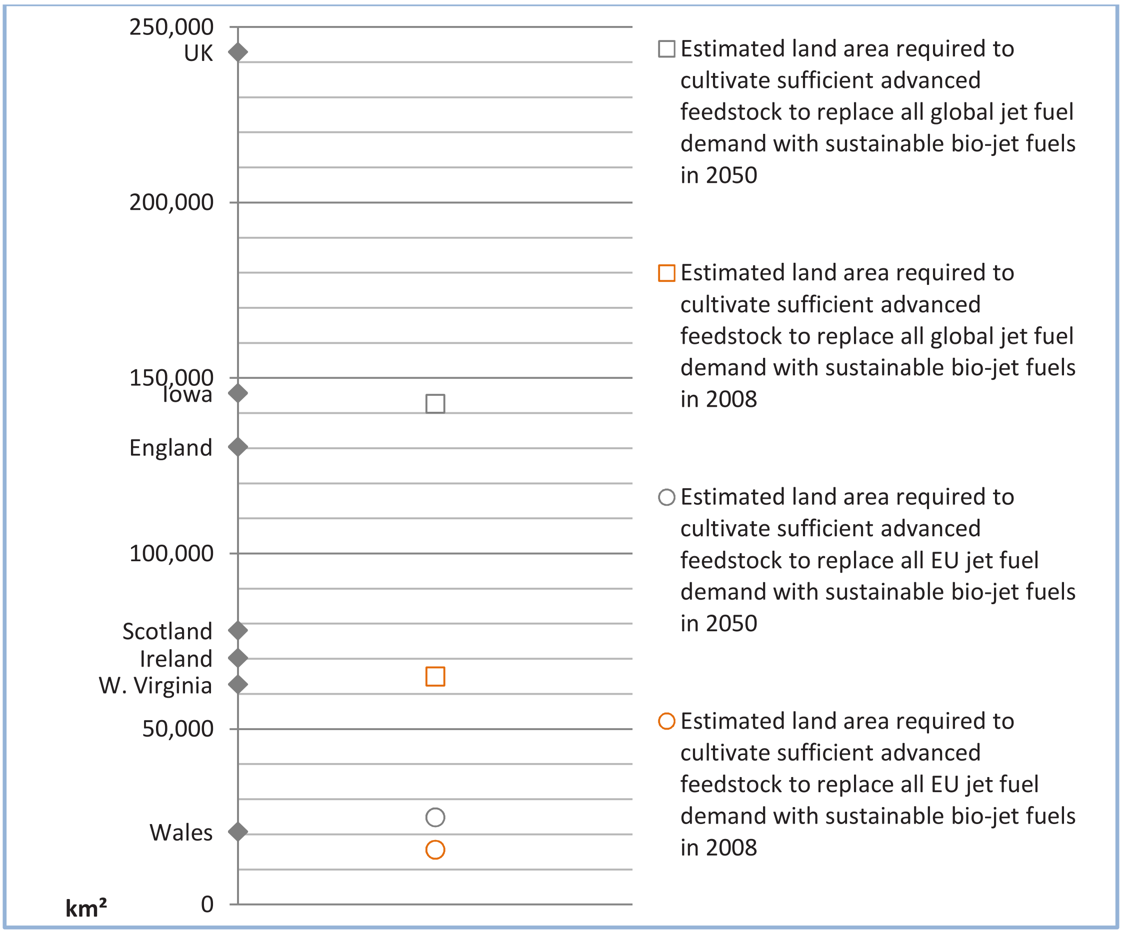
- Feedstocks do not necessarily compete with food crops for arable land as they are specialised energy crops able to grow on marginal land;
- Feedstocks have the potential to generate greater yields, while reducing water and land demands and lower agrichemical dependency;
- Advanced biofuels have greater potential GHG emissions reductions, due to greater yields and more efficient conversion routes; and
- Advanced biofuels offer the potential to co-produce numerous chemical products in addition to biofuel.

Physical limitations

One fundamental determinant of whether sustainable bio-jet fuels can significantly decarbonise aviation are physical limitations – can enough feedstock be produced? This has been a pressing concern, especially for biofuels intended to replace road transport fuels, where the amount of land required far outstrips the land available.

Current global jet fuel consumption is approximately 238 million tons per annum.[59] In 2050 global jet fuel demand from civil aviation is projected to rise to 456.6 million tons per annum under central Intergovernmental Panel on Climate Change (IPCC) estimates.[60] EU jet fuel consumption is currently 50 million tons per annum,[61] projected to grow to around 79.5 million tons per annum in 2050.[62]

Figure 6. Marginal land areas (km²) required to replace EU and global demand for jet fuel with sustainable bio-jet fuels in 2008 and 2050[63]



Meeting current global demand for jet fuel with bio-jet fuels, using the lower yield estimates for advanced feedstocks, would require an area of 65,000km², roughly equivalent to the area of Ireland or West Virginia. Meeting projected global jet fuel demand in 2050 with bio-jet fuels would require an area of around 142,700km², less than the area of England and Wales combined or Iowa.

More relevant for this report, to replace current EU demand for jet fuel with bio-jet fuels, using the lower yield estimates for advanced feedstocks would require an area of around 15,625km^2. This is an area slightly larger than Northern Ireland. To meet projected EU jet fuel demand in 2050 with bio-jet fuels would require an area of around 24,850km^2, an area slightly larger than Wales.

Figure 7. Marginal land areas (km^2) required to meet demand for road transport fuel and replace global demand for jet fuel with sustainable bio-jet fuels in 2008 and 2050

Cultivating the amount of advanced feedstock needed to replace standard jet fuel with bio-jet fuels on marginal land (where advanced feedstocks are designed to be grown) is eminently possible from a phyical persepctive. Satellite studies estimate that total global marginal land availability is currently around 2,900,000km^2.[64] Only 2.25% of this land area would need to be cultivated to produce enough advanced feedstock to replace predicted global jet fuel demand with sustainable bio-jet fuels in 2050.

Conclusion

The development and commercialisation of sustainable bio-jet fuels should become a priority. Bio-jet fuels currently represent the only viable option for significantly reducing emissions from aviation without cutting the number of flights flown. They can be used by old and new aircraft alike, in stark contrast to most other technologies that can improve aircraft efficiency, such as engine and airframe advances.

Despite their potential, the current policy framework in the UK and EU is unable to deliver their deployment and commercialisation. This is partly because current policies, principally the EU ETS and UK APD, do not support the investors and developers involved and fail to create the demand needed to enable commercialisation. In fact, there are no specific policies within Europe that aim to promote the development and commercialisation of sustainable bio-jet fuels. Given the contribution they could make to reducing emissions from aviation, this should change.

From our research there are three reforms that could dramatically improve this situation in the UK and EU. First, we should mandate that an increasing proportion of sustainable bio-jet fuels are used in flights departing EU airports on internal and international flights. This would send credible long term signals to the developers of sustainable bio-jet fuels, so they can increase production in the timescales required. Second, we should better support R&D into the production of sustainable bio-jet fuels in the UK. Third, we should invest in the methodologies and regulatory bodies needed to ensure that bio-jet fuels are produced sustainably and deliver life-cycle GHG emission reductions.

Our proposals would secure reductions in GHG emissions from aviation of 15% by 2020 and 60% by 2050 relative to current predictions. Using the latest HM Government methodology, the cumulative emission reductions of our proposals from 2020 to 2050 are valued in 2009 prices at £37.41 billion in the UK and £305.43 billion across the EU. This demonstrates the potential benefits of tackling emissions from the aviation sector.

Moreover, these significant emission savings should not be prohibitively expensive for the aviation sector. If our proposals come to fruition, estimates show that bio-jet fuel production costs may fall to around US$80 per barrel by 2030, with production costs falling further to around US$70 per barrel by 2050. This compares well with average jet fuel prices of US$62.29 per barrel from 2000 to 2008 and the jet fuel price peak of July 2008 when it reached US$167.70 per barrel.

Bio-jet fuels are technically feasible and will be imminently certified as safe and compatible to be used in conjunction with standard kerosene jet fuel. Moreover, the advanced biofuels that could be used in aviation should not be confused with first generation biofuels and the specific debates surrounding their sustainability and practicality. On both fronts we have shown that with the right regulatory framework sustainability and dramatic life-cycle GHG emission reductions can be delivered. The marginal land used to produce sustainable bio-jet fuels is also sufficient, so enough feedstock can be cultivated to meet current and predicted total jet fuel demand. This is in profound contrast to the amount of land needed to cultivate sufficient feedstock to meet road transport fuel demand with biofuels.

Reducing the demand for flights is important, but for some purposes and on many routes there are no practical low carbon alternatives. Aviation is, amongst other things, a fundamental part of the global economy and facilitates inter-cultural exchange. Moreover, people throughout the world want to travel. As a result, we must promote methods that can reduce emissions from those flights that do take place. Sustainable bio-jet fuels are one critical option that can be delivered over the medium term, in time to make a significant contribution to our 2050 emission reduction targets. For this to work, ambitious policies need to be put in place urgently and with the conviction needed to meet the global challenge we face.

References

[1] The six GHGs defined by the IPCC comprise carbon dioxide (CO_2), methane (CHX), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6).
[2] UK Climate Change Sustainable Development Indicator: 2006 Greenhouse Gas Emissions, Final Figures, Defra/NAEI/AEA Energy & Environment, 2008, see http://www.defra.gov.uk/News/2008/080131a.htm; International Transport Forum on Transport and Energy: the Challenge of Climate Change, OECD, 2008, see http://www.internationaltransportforum.org.
[3] IPCC Special Report: Aviation and the Global Atmosphere, IPCC, 1999, see http://www.ipcc.ch/ipccreports/sres/aviation/092.htm.
[4] The Future of Air Transport, DfT, 2003, see http://www.dft.gov.uk/about/strategy/whitepapers/air/.
[5] Current Market Outlook 2008 to 2027, Boeing, 2007, see http://www.boeing.com/commercial/cmo/pdf/Boeing_Current_Market_Outlook_2008_to_2027.pdf.
[6] Building a low-carbon economy - the UK's contribution to tackling climate change, Committee on Climate Change, 2008, see http://www.theccc.org.uk/pdf/TSO-ClimateChange.pdf.
[7] A million tonnes of CO_2, also known as one megatonne.
[8] The UK Air Passenger Demand and CO_2 Forecasts 2009 projections assume that ACARE targets are met. The ACARE target is that new aircraft entering service in 2020 will deliver a 50% GHG reduction over equivalent aircraft which entered service in 2000. The forecasts also take into account the Radiative Forcing effects of aviation, adding a multiplier of 1.9 to CO_2 forecasts. Due to uncertainty of the correct Radiative Forcing multiplier and uncertainty as to the impact of bio-jet fuels on this multiplier (although the adoption of bio-jet fuel is likely to reduce this multiplier) we have chosen to remove the Radiative Forcing multiplier from the forecasts. The forecasts also fail to model the effects of including aviation within the EU ETS. As a result of this, we have included the demand reduction effects of including aviation within the EU ETS as calculated by the DfT in demand sensitivity analysis. UK Air Passenger Demand and GHG Forecasts, DfT, 2009, see http://www.dft.gov.uk/pgr/aviation/atf/co2forecasts09/co2forecasts09.pdf.
[9] CO2 emissions projections taken from Central Violet emissions scenario from: A bottom-up analysis of including aviation within the EU's Emissions Trading Scheme, The Tyndall Centre for Climate Change Research, 2008, see http://www.tyndall.ac.uk/publications/working_papers/twp126.pdf.
[10] http://business.timesonline.co.uk/tol/business/industry_sectors/transport/article6194511.ece.
[11] http://www.theccc.org.uk/topics/global-targets/international-aviation.
[12] Building a low-carbon economy - the UK's contribution to tackling climate change, Committee on Climate Change, 2008, see http://www.theccc.org.uk/pdf/TSO-ClimateChange.pdf.
[13] Delivering on Environmental Goals, Pre-Budget Report, HM Treasury, 2008, see http://www.hm-treasury.gov.uk/d/pbr08_chapter7_159.pdf.
[14] Air passenger duty, Friends of the Earth, see http://www.foe.co.uk/resource/briefings/air_passenger_duty.pdf.
[15] Notice 550 Air Passenger Duty, HM Revenue & Customs, 2009, see http://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageExcise_ShowContent&id=HMCE_CL_000505&propertyType=document.
[16] Air Passenger Duty, 2008 Pre-Budget Report, HM Revenue & Customs, 2008, see http://www.hmrc.gov.uk/pbr2008/pbrn20.pdf.
[17] Delivering on Environmental Goals, Pre-Budget Report, HM Treasury, 2008, see http://www.hm-treasury.gov.uk/d/pbr08_chapter7_159.pdf.
[18] APDR2200 – General: Outline of the regime and contribution to the revenue, HM Revenue & Customs, 2008, see http://www.hmrc.gov.uk/manuals/apdrmanual/apdr2200.htm.
[19] Budget 2008, HM Treasury, 2008, see http://www.hm-treasury.gov.uk/d/bud08_completereport.pdf.
[20] 2008 Pre-Budget Report, HM Treasury, 2008, see http://www.hm-treasury.gov.uk/d/pbr08_chapter7_159.pdf.
[21] See endnote 7; UK Air Passenger Demand and GHG Forecasts, DfT, 2009, see http://www.dft.gov.uk/pgr/aviation/atf/co2forecasts09/co2forecasts09.pdf.

[22] IATA Calls on U.K. Government to Abandon Aviation Duty, IATA Press Release, 2008, see http://www.iata.org/pressroom/pr/2008-04-24-01.htm.
[23] Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community, EU Commission, 2008, see http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008L0101:EN:NOT.
[24] CO_2 emissions projections taken from Central Violet emissions scenario from: A bottom-up analysis of including aviation within the EU's Emissions Trading Scheme, The Tyndall Centre for Climate Change Research, 2008, see http://www.tyndall.ac.uk/publications/working_papers/twp126.pdf. Base 2004 and 2012 figures for CO_2 emissions for all flights departing EU airports from: Giving wings to emission trading, CE Delft, 2005, see http://ec.europa.eu/environment/climat/pdf/aviation_et_study.pdf.
[25] See endnote 7; UK Air Passenger Demand and GHG Forecasts, DfT, 2009, see http://www.dft.gov.uk/pgr/aviation/atf/co2forecasts09/co2forecasts09.pdf.
[26] http://www.theccc.org.uk/topics/global-targets/international-aviation.
[27] IPCC Special Report: Aviation and the Global Atmosphere, IPCC, 1999, see http://www.ipcc.ch/ipccreports/sres/aviation/092.htm.
[28] See endnote 7; UK Air Passenger Demand and GHG Forecasts, DfT, 2009, see http://www.dft.gov.uk/pgr/aviation/atf/co2forecasts09/co2forecasts09.pdf.; Fuel efficiency, IATA, 2009, see http://www.iata.org/whatwedo/environment/fuel_efficiency.htm.
[29] IPCC Special Report: Aviation and the Global Atmosphere, IPCC, 1999, see http://www.ipcc.ch/ipccreports/sres/aviation/092.htm.
[30] Ibid.
[31] Fuel efficiency, IATA, 2009, see http://www.iata.org/whatwedo/environment/fuel_efficiency.htm; EUROPEAN AERONAUTICS: A VISION FOR 2020, ACARE, 2001, see http://www.acare4europe.com/docs/Vision%202020.pdf.
[32] See endnote 7; UK Air Passenger Demand and GHG Forecasts, DfT, 2009, see http://www.dft.gov.uk/pgr/aviation/atf/co2forecasts09/co2forecasts09.pdf.
[33] Sustainable Aviation GHG Roadmap, 2008, Sustainable Aviation, see http://www.sustainableaviation.co.uk/images/stories/key%20documents/sa%20road%20map%20final%20dec%2008.pdf.
[34] IPCC Special Report: Aviation and the Global Atmosphere, IPCC, 1999, see http://www.ipcc.ch/ipccreports/sres/aviation/092.htm.
[35] Life Cycle Analysis of Camelina-based Renewable Jet fuel Shows 84% CO2 Emissions Reduction Compared to Petroleum Fuel, Sustainable Oils, 2009, see http://www.susoils.com/dynamic-content/csArticles/articles/000000/000046.htm.
[36] JAL Flight Brings Aviation One Step Closer to Using Biofuel, Sustainable Oils Press release, Sustainable Oils, 2009, see http://www.susoils.com/dynamic-content/csArticles/articles/000000/000037.htm.
[37] Ministry of Defence Defence Standard 91-91, MOD, 2008, see http://www.dstan.mod.uk/data/91/091/00000600.pdf.
[38] Significant progress made towards adoption of semi-synthetic aviation fuel, CAAFI, 2008; R Altman, The Age of Aviation Alternative Fuels is Now ….Accelerating Progress via the CAAFI Coalition, CAAFI, 2009, see http://airquality.ucdavis.edu/pages/events/2009/revolution/Altman2B.pdf; Dumesic et. al., Catalytic Conversion of Biomass to Monofunctional Hydrocarbons and Targeted Liquid-Fuel Classes, Science, Vol. 332, 2008, pp. 417 – 421.
[39] Progress in Sustainable Biofuels for Aviation, Aviation and Environment Summit, Boeing, 2009, see http://www.envirosummit.aero/images/Downloads/speeches/speeches_downloads/blue_room_morning_billy_glover.pdf.
[40] Ibid.
[41] Flight Testing – The latest developments, Enviro.Aero, 2009, see http://www.enviro.aero/Biofuels.aspx.
[42] The emissions factor of a bio-jet fuel refers to its life-cycle GHG emissions, relative to the life-cycle GHG emissions of standard kerosene jet fuel. The proposed emissions factor for sustainable bio-jet fuel is 0.25,

i.e. at a minimum it would emit 25% of the emissions that standard jet fuel would (i.e. a 75% emissions reduction). The life-cycle GHG emission profile of all fuels is calculated to take into account emissions from production, processing, transporting and distributing the fuel, while life-cycle GHG emission profiles of biomass derived fuels must also take into account emissions from the cultivation of biomass and changes to land use as a result of that cultivation. An emissions factor of 0.25 should be achievable, given that life-cycle GHG emissions profiling of bio-jet fuel derived from Camelina demonstrated an 84% reduction in life-cycle GHG emissions relative to standard kerosene jet fuel; Life Cycle Analysis of Camelina-based Renewable Jet fuel Shows 84% CO2 Emissions Reduction Compared to Petroleum Fuel, Sustainable Oils, 2009, see http://www.susoils.com/dynamic-content/csArticles/articles/000000/000046.htm.

[43] See endnote 7; UK Air Passenger Demand and GHG Forecasts, DfT, 2009, see http://www.dft.gov.uk/pgr/aviation/atf/co2forecasts09/co2forecasts09.pdf.

[44] A bottom-up analysis of including aviation within the EU's Emissions Trading Scheme, The Tyndall Centre for Climate Change Research, 2008, see http://www.tyndall.ac.uk/publications/working_papers/twp126.pdf.

[45]Sustainable Aviation GHG Roadmap, 2008, Sustainable Aviation, see http://www.sustainableaviation.co.uk/images/stories/key%20documents/sa%20road%20map%20final%20dec%2008.pdf; From 1st to 2nd Generation Biofuel Technologies, IEA Bioenergy, 2008, see http://www.iea.org/textbase/papers/2008/2nd_Biofuel_Gen.pdf; Fact Sheet: Alternative Fuels, International Association of Air Transport, 2009, see http://www.iata.org/pressroom/facts_figures/fact_sheets/alt_fuels.htm.

[46]See endnote 7; UK Air Passenger Demand and GHG Forecasts, DfT, 2009, see http://www.dft.gov.uk/pgr/aviation/atf/co2forecasts09/co2forecasts09.pdf.

[47] CO_2 emissions projections taken from Central Violet emissions scenario from: A bottom-up analysis of including aviation within the EU's Emissions Trading Scheme, The Tyndall Centre for Climate Change Research, 2008, see http://www.tyndall.ac.uk/publications/working_papers/twp126.pdf. Base 2004 and 2012 figures for CO_2 emissions for all flights departing EU airports from: Giving wings to emission trading, CE Delft, 2005, see http://ec.europa.eu/environment/climat/pdf/aviation_et_study.pdf.

[48] We have applied the UK Central Traded Price of Carbon to the rest of the EU. An EU-wide Central Traded Price of Carbon will differ from the UK calculated one, but this is unavailable.

[49] World Energy Outlook 2008, IEA, 2008, see http://www.worldenergyoutlook.org/2008.asp.

[50] From 1st to 2nd Generation Biofuels, IEA, 2008, see http://www.iea.org/textbase/papers/2008/2nd_Biofuel_Gen.pdf; Biofuels for the US military, DARPA Fact Sheet, 2009, see http://www.darpa.mil/Docs/biofuels_Apr09_200904081556342.pdf.

[51] From 1st to 2nd Generation Biofuels, IEA, 2008, see http://www.iea.org/textbase/papers/2008/2nd_Biofuel_Gen.pdf.

[52] Based on monthly spot prices from 2000 – 2008: U.S. Kerosene-Type Jet fuel Retail Sales by Refiners (Cents per Gallon), Petroleum Navigator, Energy Information Office, 2009, see http://tonto.eia.doe.gov/dnav/pet/hist/a503600002m.htm.

[53] From 1st to 2nd Generation Biofuels, IEA, 2008, see http://www.iea.org/textbase/papers/2008/2nd_Biofuel_Gen.pdf.

[54] Building Britain's future, HM Government, 2009, see: http://www.hmg.gov.uk/media/27749/full_document.pdf

[55] Research and development tax credits, HMRC, 2009, see http://www.hmrc.gov.uk/randd/#2.

[56] CIRD81900 - R&D tax relief: conditions to be satisfied: DTI guidelines (2004), DTI, 2004, see http://www.decc.gov.uk/en/content/cms/consultations/aviation_euets/aviation_euets.aspx.

[57] Life Cycle Analysis of Camelina-based Renewable Jet Fuel Shows 84% CO2 Emissions Reduction Compared to Petroleum Fuel, Sustainable Oils, 2009, see http://www.susoils.com/dynamic-content/csArticles/articles/000000/000046.htm; Renewable Jet Process, UOP, 2008, see http://www.uop.com/objects/Renewable_Jet_Process.pdf.

[58] The Global Bioenergy Partnership Information note, Global Bioenergy Partnership, 2008, see http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/GBEP_standard_material/Background_note_GBEP_update22Dec2008.pdf.
[59] Green Jet fuel for the airline industry, New Scientist, 2008, see http://www.newscientist.com/article/mg19926691.700-green-fuel-for-the-airline-industry.html?full=true.
[60] Chapter 9.4 Long-Term Emissions Scenarios, Aviation and the Global Atmosphere, IPPC, 1999, see http://www.ipcc.ch/ipccreports/sres/aviation/138.htm.
[61] Energy, transport and environment indicators, Eurostat, 2007, see http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-DK-07-001/EN/KS-DK-07-001-EN.PDF.
[62] Using data taken from the Emerald Growth Scenario from: A bottom-up analysis of including aviation within the EU's Emissions Trading Scheme, The Tyndall Centre for Climate Change Research, 2008, see #http://www.tyndall.ac.uk/publications/working_papers/twp126.pdf.
[63] EU jet fuel demand projections extrapolated from the Emerald Growth Scenario from: A bottom-up analysis of including aviation within the EU's Emissions Trading Scheme, Tyndall Centre for Climate Change Research, 2008, see http://www.tyndall.ac.uk/publications/working_papers/twp126.pdf. Global jet fuel demand projections from: Chapter 9.4 Long-Term Emissions Scenarios, Aviation and the Global Atmosphere, IPPC, 1999, see http://www.ipcc.ch/ipccreports/sres/aviation/138.htm. Assumed yields are 32.0 t/ha/year, for algal (advanced) feedstock. Conservative estimates for algal feedstock yields have been used reflecting uncertainty of practical algal feedstock yields, however theoretical algal yields may be as much as 95 t/ha/year to 795 t/ha/year, from A Look Back at the U.S. Department of Energy's Aquatic Species Program - Biodiesel from Algae, National Renewable Energy Laboratory, 1998, see http://www1.eere.energy.gov/biomass/pdfs/biodiesel_from_algae.pdf. Furthermore, the recent development of marine algal biomass feedstocks may ultimately result in marine algal feedstock production, see http://www.wipo.int/pctdb/en/wo.jsp?WO=2008105618.
[64] Nilsson S., The Three Fs: Food, Fiber, and Fuel, International Institute for Applied Systems Analysis, 2007, see http://www.iiasa.ac.at/Admin/INF/conf35/docs/speakers/speech/ppts/nilsson.pdf.

research note

Policy Exchange

About the Authors

Ben Caldecott
Ben Caldecott is Head of the Environment & Energy Unit at Policy Exchange. He was previously Director of the East Asia Section at The Henry Jackson Society. Ben has worked in Parliament and for a number of different HM Government departments and international organisations, including the United Nations Environment Programme (UNEP) and Foreign & Commonwealth Office (FCO). Ben read economics and specialised in China at Cambridge, Peking and London universities.

Sean Tooze
Sean Tooze is a Researcher in the Environment & Energy Unit at Policy Exchange. He was previously a Parliamentary Researcher for Gregory Barker MP, Shadow Climate Change Minister. Sean read biology at Bristol University.

Policy Exchange's Environment & Energy Unit

The threat from climate change requires immediate action to transition the global economy to a low carbon one. Policy Exchange's Environment & Energy Unit conducts innovative and independent policy research into the options available to realise this. We produce a range of publications and bring together stakeholders through events and other means, to disseminate our findings and promote our ideas.

For further information on the work of the Environment & Energy Unit, please contact Ben Caldecott, on ben.caldecott@policyexchange.org.uk

About Policy Exchange

Policy Exchange, an independent educational charity, is Britain's largest centre-right think tank. Our mission is to develop and promote new policy ideas which will foster a free society based on strong communities, limited government, national self confidence and an enterprise culture. In contrast to many other think tanks Policy Exchange is committed to an evidence-based approach to policy development. Our impact speaks for itself: from housing to policing reform, education to the NHS, our proposals have been taken on board by the main political parties. Registered charity number 1096300.

Trustees