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Low-carbon fuels for aviation

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Headlines

The aviation industry is responsible for 2.1% of global CO_2 emissions and represents 12% of CO_2 emissions from all transport sources.

Aviation is a particularly difficult sector to decarbonise because alternative fuels are relatively expensive, produce highly distributed greenhouse gas emissions in their production and combustion, and should preferably be compatible with existing aviation infrastructure.

Emissions from aviation also include nitrogen oxides (NO_X), water vapour, particulates, carbon monoxide, unburned hydrocarbons, and sulfur oxides (SO_X). These have a 2–3 times greater climate change impact than CO_2 alone. The non-CO_2 emissions of alternative low-carbon aviation fuels can differ significantly from those of kerosene and have not been fully evaluated.

Biofuels

- Bio-jet fuels are currently the most technologically mature option for low-carbon aviation fuels because some of these feedstocks and processes are already deployed at scale for other uses.

- Bio-jet fuels must be blended with kerosene to achieve certification and can then be used with existing aviation infrastructure. This blending proportionally decreases any potential CO_2 emission saving.

- Bio-jet fuels can be made from a range of feedstocks, which are restricted in the UK to waste materials. UK biofuel feedstock availability is sufficient for only a small proportion of UK aviation fuel demand (<20%). With blending, their contribution to CO_2 emissions saving is much less (<10%).

- Life cycle assessment scenarios show very variable impacts on CO_2 emissions for biofuel processes: only some deliver emissions savings compared to fossil fuel kerosene. Calculations for forest residues appear to show consistent savings in CO_2 emissions compared to jet fuel, but these do not take account of the difference in timescale between emission and re-absorption, leading to a major underestimation of emissions. The diversion of agricultural and forestry waste to bio-jet fuel production will have detrimental effects, for example on soil quality.

Power-to-Liquid fuels

- PtL fuels must be blended with kerosene to achieve certification and can then be used with existing aviation infrastructure. This blending proportionally decreases any potential CO_2 emission saving.

- PtL fuels are currently not produced at scale. Significant technological development is required to reduce production costs and increase production scale.

- Use of PtL fuels in aviation would require a very significant increase of UK low-carbon electricity generation and storage capacity to power production of green hydrogen and CO_2 from direct air capture.

- Life cycle assessment scenarios show that PtL fuels could have 3–10 times lower emissions impact than fossil fuel kerosene if renewable electricity and CO_2 from direct air capture are used to produce the fuel.

Hydrogen

- Hydrogen cannot be used as a drop-in fuel for aircraft, and its use will require significant redesign of aviation infrastructure.
- The greenhouse gas emissions impact of hydrogen depends on its mode of production. Currently, global hydrogen production is mostly from fossil fuel sources, with much less than 1% generated from low-carbon sources.
- Increasing low-carbon hydrogen production via electrolysis (green hydrogen) will require the building of additional low-carbon electricity generation capacity.
- Low-carbon hydrogen production via methane reforming with carbon capture and storage (CCS, blue hydrogen) should use natural gas obtained from producers with low emissions intensity.

The goal of policy will be to promote whichever technologies achieve the desired sustainability targets.

Policy recommendations

A molecular science and engineering approach combines an understanding of molecular behaviour with a problem-solving mindset derived from engineering. This approach is crucial to the development and eventual deployment of the fuel technologies discussed in this paper. The use of hydrogen, PtL fuels and bio-jet fuels in aircraft requires new development or adaption of manufacturing technologies, catalysts, storage facilities, transport facilities, engines, aircraft, and airports. This requires a considerable research effort.

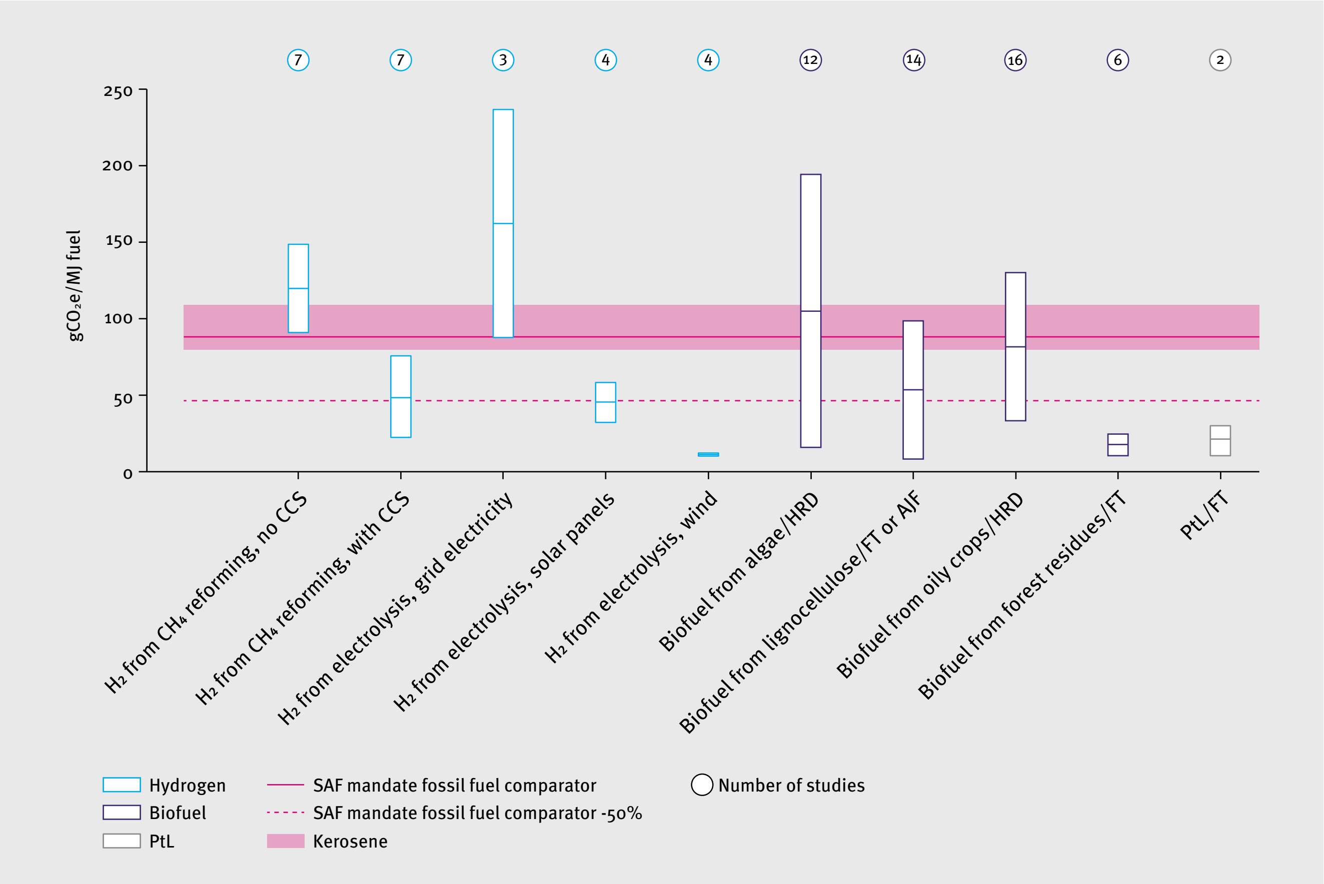
We make the following policy recommendations:

For all low-carbon fuel types:

- Implement policy support only where a low-carbon fuel technology has been demonstrated to achieve the following criteria: i) to provide at least 50% CO_2 emissions saving when deployed at scale *vs* the kerosene baseline, in line with the UK Sustainable Aviation Fuel Mandate[1]; ii) where there is enough feedstock for its production at a meaningful scale; iii) its use will not have a negative environmental impact.
- Support the development of infrastructure (e.g. aircraft, airports, fuel transport, fuel storage, operational practices) for low carbon fuels, when these fulfil the criteria in the previous point.
- Implement more rigorous life cycle analyses for low-carbon fuels, and update standardised methodologies such as CORSIA[2] to:
    - Include evaluation of the secondary impacts of resource use choices (burden-shifting) relative to current fossil fuels.
    - Take into account the CO_2 emissions from fuel production as well as combustion (well-to-wake approach).
    - Include non-CO_2 effects of both production and combustion in assessments of the impact of low-carbon fuels.
- Develop aircraft fuel systems which do not require the presence of aromatics in the fuel.
- Collaborate with commercial entities in the sector, especially those who own infrastructure, to generate momentum for change.
- Build systems to promote information-sharing between commercial entities and the independent research sector to help define research priorities and enable research projects, while protecting IP appropriately.

For bio-jet fuel technologies:

- Standardised life cycle analysis methodologies, such as CORSIA, should address the scalability of the benefits of the co-products and land-use change, and also the time delay between CO_2 emission and photosynthetic reabsorption.
- Improve existing bio-jet fuel production processes to optimise fuel composition and reduce the need for blending.
- Improve existing bio-jet fuel production processes to improve yield of conversion and reduce resource pressure.
- For municipal waste and other heterogeneous sources of feedstock material, develop robust processes that can efficiently convert this to fuel.



Life cycle assessment comparison between fuel pathways

Data for kerosene includes production and combustion (well-to-wake).[3] For other fuels, well-to-tank and well-to-wake are equivalent because combustion values are either zero (for hydrogen) or defined as zero in the carbon accounting model (bio-jet fuels, PtL fuels).[4] Data excludes non-CO_2 emissions. Footnotes: (i) for H_2 from CH_4 reforming, the range includes methane emission factors of 0.5% to 6.5%. (ii) for bio-jet fuels, HRD = hydroprocessed renewable diesel; AJF = alcohol to jet fuel; FT = Fischer-Tropsch process; range includes both with and without CCS and land-use change calculations. (iii) PtL calculations use FT synthesis with CO_2 from direct air capture; range depends on calciner type used for direct air capture.

For Power-to-Liquid fuel technologies:

- Increase UK production of low-carbon electricity and energy storage. Reduce and stabilise the price of low-carbon electricity.
- Scale up production of green hydrogen.
- Assess the scalability of direct air capture using existing technologies.
- Develop novel solid adsorbents and membranes to reduce direct air capture cost.
- Develop mechanisms to reduce the price of PtL fuel relative to fossil fuel kerosene.
- Develop novel affordable catalysts to improve the efficiency of fuel production, preferably in a single step reaction and at low temperature.
- Develop novel fuel production pathways (in addition to Fischer-Tropsch) that meet certification requirements.
- Develop PtL fuels which can be used as a 100% replacement for kerosene.
- Promote and support the commercial development and implementation of improved technologies for all stages of the PtL fuels production chain.

For hydrogen technologies:

- Increase UK production of low-carbon electricity and energy storage. Reduce and stabilise the price of low-carbon electricity.
- Scale up production of green hydrogen.
- Scale up carbon capture and storage (for blue hydrogen production) by developing improved absorbents, adsorbents and membranes in scaled-up industrial CO_2 capture units with lower energy demands.
- Develop advanced materials for cost-effective electrolysers to enhance both performance and durability.
- Develop new pressurising and cooling infrastructure for efficient storage and refuelling of hydrogen.
- Redesign aircraft to locate fuel tanks in the fuselage.

Major technical improvements are required before any of the fuels discussed here can be considered as a viable replacement for jet fuel in terms of sustainability and cost. The Institute for Molecular Science and Engineering will work to identify solutions that will overcome existing limitations by using the expertise available at Imperial College London.

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