Reviewing the development of alternative aviation fuels and aircraft propulsion systems

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Introduction

- Alternative aviation fuels such as bio-jet fuels, liquid natural gas (LCH_4), hydrogen (H_2), electro-jet fuels and direct electricity use play a vital role in decarbonizing the aviation sector.
- Electro-fuels are produced via electrolysis of water followed by different synthesis processes combining H_2 and captured carbon. [6].
- New aircraft propulsion systems are being studied and developed to operate on alternative aviation fuels [1].
- Electric propulsion systems can reduce both the CO_2 and non-CO_2 emissions from aviation sector [7-9].
- The review maps the development on alternative aviation fuels and related aircraft propulsion systems focusing on cost and technical maturity.

Method

- The review includes 89 different publications published between 2005-2019.
- Minimum jet fuel selling price (MJFSP) of 12 alternative aviation pathways including production cost of electro-jet fuels and H_2 were reviewed.
- MJFSP is the minimum price a costumer must pay for purchasing the jet fuel so that a zero-equity net present value (NPV) is achieved [10, 11].
- The electro-jet fuel production cost was estimated 'well-to-tank' cost from renewable resources [12] and H_2 production cost was estimated from different pathways [13, 14].
- The cost for LH_2 and LCH_4 were market purchasing price and we assumed them as the MJFSPs.
- All obtained cost values were converted to USD/GJ and made equivalent to 2019 cost.

Challenges and opportunities

- Both the bio-jet and electro-jet fuels are currently not economically competitive.
- The volumetric energy of liquid hydrogen and liquified methane is low which requires larger fuel storage tanks.
- Some alternative aviation fuels have low flame stability and combustion efficiencies which obstruct easy work in the existing engines [1, 32].
- Supply of some alternative aviation fuels at airports via existing pipelines is not appropriate [33].
- One challenge of electric aviation is the limited onboard energy storage capacity in batteries [34].
- To improve the high specific energy of the battery is material-intensive [35].
- The sole use of fuel cells cannot provide enough power required for take-off.
- Implement spherical tanks with increased thermal insulation and fix fuel tanks on the top of the fuselage to reduce wing areas [1, 30, 37].
- H_2 and NH_3 can be burnt with oxygen to improve fuel mixing which reduces NO_x emissions [6, 30].

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Technical maturity of different alternative aviation fuels

Table 1: Current status of reviewed alternative aviation fuels [12, 15-21]

Process	Energy efficiency*	Certified level of blending (%)	Technology Readiness Level (TRL)	Fuel Readiness Level (FRL)
Fischer-Tropsch – Synthetic Paraffinic Kerosene/Aromatic (FT-SPK/FT-SPK/A)	0.36	50	6-7	7
Hydroprocessed Esters and Fatty Acids – Synthetic Paraffinic Kerosene (HEFA-SPK)	0.71-0.77	50	9	9
Direct sugar to hydrocarbons (DSHC) or Hydroprocessing of fermented sugars-Synthetic Iso-Paraffinic kerosene (HFS-SIP)	0.50	10	7-9	8
Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK)	0.91	50	6-7	8
Co-processing	N/A	5	7-8	6-7
Catalytic Hydrothermolysis (CH)/Hydrothermal Liquefaction (CH/HTL)	0.58-0.89	50	4-6	6
Hydroprocessed Depolymerized Cellulosic Jet (HDCJ)	0.36	In progress	-	6
Aqueous phase processing/reforming (APP/APR)	0.32	In progress	-	6
Advanced Fermentation/Fermentation	0.31-0.34	No certification	Under demonstration	-
Mixed alcohol synthesis (MAS)	0.40-0.44	No certification	Proposed technology	-
Pyrolysis to Jet	0.6-0.8	No certification	In progress	-
Electro-jet [Power to liquids (PtL)]	0.38-0.63	No certification	5-8	-
Electro-jet [Biomass to liquids (BtL)]	0.38-0.63	No certification	5-9	-

*Energy efficiency: The ratio of energy output (upgraded jet fuel) and the total energy input (process energy input and feedstock energy input) [22] or thermal efficiency of a refinery.

Economic performance

- HEFA fuels are generally less expensive except they are produced from microalgae [27, 28]

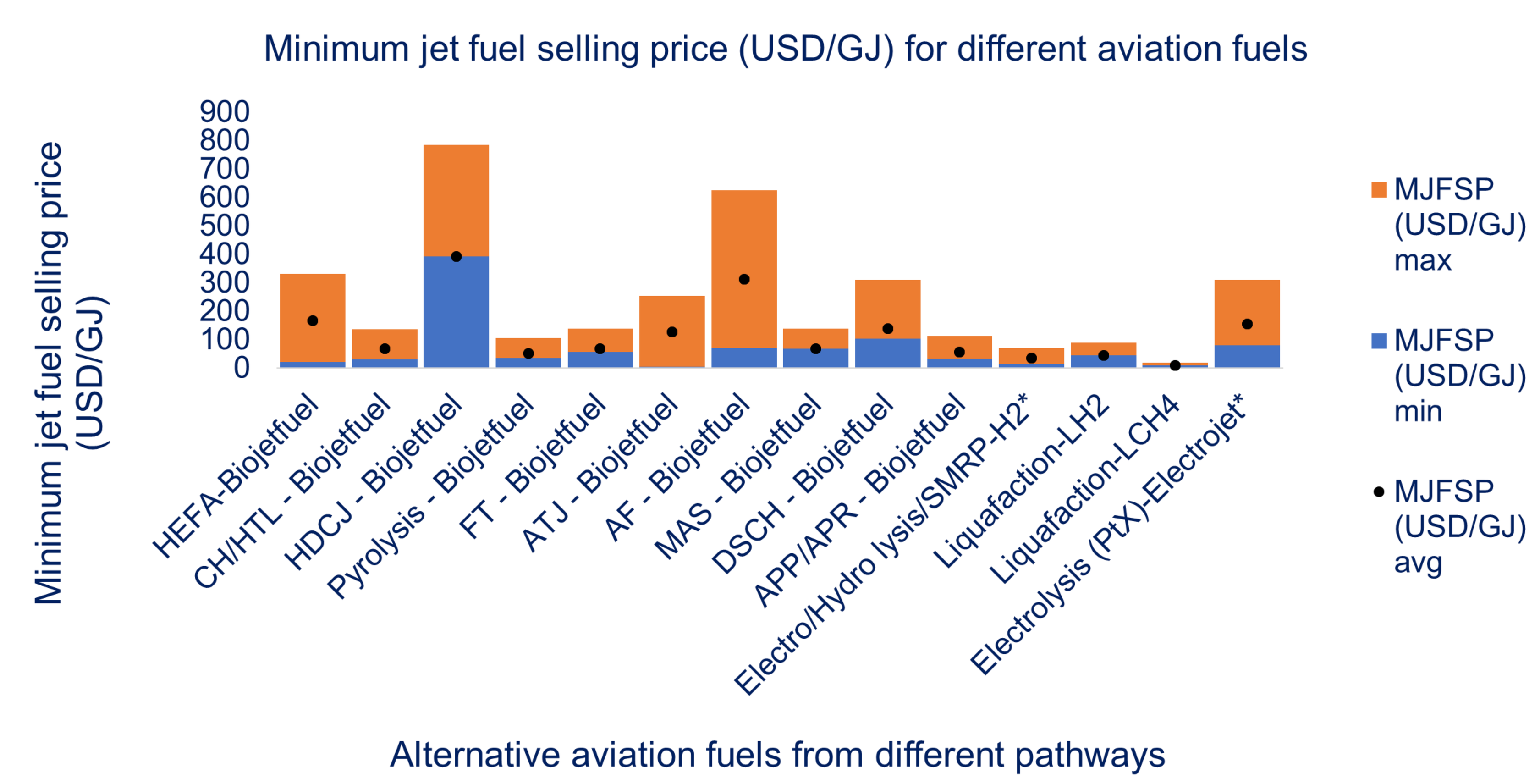
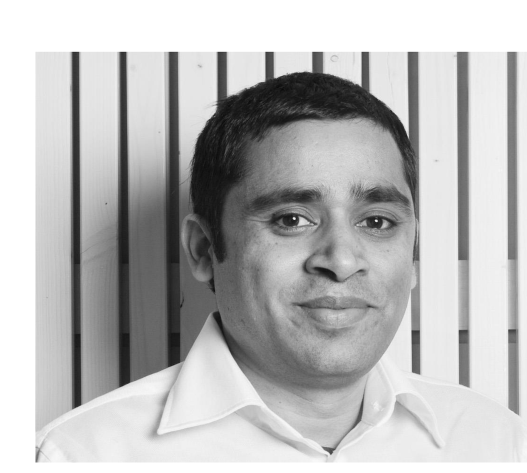


Figure 1: Minimum jet fuel selling price (MJFSP) of different aviation fuel pathways (*production cost)

- Camelina oils (HEFA), Palm Oil (HEFA), Yellow Grease (HEFA), willow (FT), wheat straws (ATJ) and forestry residues (CH/HTL) showed lower MJFSPs than other feedstocks.

Discussion and conclusion

- Feedstock cost, refinery capital cost, co-product revenues, plant capacity, reactor construction, catalyst used and electricity cost impact on MJFSPs.
- The MJFSPs of the most pathways are higher than the purchasing price of fossil jet kerosene.
- HEFA, CH/HTL, ATJ and FT fuels seem more economical than other bio-jet fuel pathways.
- LCH_4 is cheaper than other aviation fuels as the market price of the natural gas is relatively low.
- Production cost for electro-jet fuel is higher than some bio-jet fuels and fossil jet fuel [38].
- Economic incentives, carbon penalties and other governmental policies are required to further expand the utilization of alternative aviation fuels.
- Alternative aviation fuels reduce GHG emissions but modifications to engines, fuel storage tanks and aerodynamic systems are required.



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