Is Aviation the next IMO?

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The Bauhaus Luftpahrt Approach

- Founded in November 2005 by Airbus, IABG, Liebherr, and MTU Aero Engines

- A non-profit research institution with long-term time horizon
  - Strengthening the cooperation between industry, science and politics
  - Developing new approaches for the future of aviation with a high level of technical creativity
  - Optimizing through a holistic approach in science, economics, engineering and design

- Going “New Ways“ for the mobility of tomorrow
Outline

- How can the Sulphur and PM emissions be reduced in the aviation industry?
- Is biofuel the certain future?
- What expectations can be made for the future of jet fuel?
Measures and motivation to reduce sulphur/aromatic content

- **Sulphur and aromatic content can be reduced by hydro-desulphurization (HDS) and hydrodearomatization (HDA)**
  - Existing technology, commercial catalysts

- **Local air quality concerns at airports**

- **Non-CO₂ climate effect**
  - Order of magnitude comparable to CO₂ effect
  - Aromatics: Mainly contrails und cirrus
  - Sulphur: Contribution to contrails, but also cooling effects

Source: see e.g. https://www.topsoe.com/processes/hydrotreating/kerosene-hydrotreating; https://report.flughafen-zuerich.ch/2018/ar/de/luftqualitaet/Grewe, Mitigating the Climate Impact from Aviation: Achievements and Results of the DLR WeCare Project, Aerospace 2017, 4, 34;
Pollutant emissions from aviation fuel combustion

Ground based and airborne measurements relate fuel composition to pollutant emissions

- **NOx and CO**: No significantly effected by fuel composition (mainly controlled by combustion process)
- **Particle emissions**: Clear link to sulphur and aromatic content, clean fuels can reduce, but not eliminate particle emissions from current engines
- **SO$_2$** is (obviously) linked to sulphur

Current regulations do not require low sulphur/aromatic content

- Blends with synthesized kerosene: Minimum aromatic content required

<table>
<thead>
<tr>
<th>Maximum sulphur content by mass</th>
<th>Aromatic content</th>
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<tbody>
<tr>
<td><strong>Gasoline (EN228)</strong></td>
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<tr>
<td><strong>Jet Fuel (ASTM 1655)</strong></td>
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<tr>
<td><strong>Synthetic jet fuels (ASTM 7566)</strong></td>
<td>15 ppm</td>
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<tr>
<td><strong>Diesel (EN590)</strong></td>
<td></td>
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<td><strong>Marine sector (IMO 2020)</strong></td>
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<td><strong>Marine sector (ECAS)</strong></td>
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<tr>
<th><strong>Jet fuel (ASTM 1655)</strong></th>
<th>&lt; 25%&lt;sub&gt;vol&lt;/sub&gt;</th>
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<tbody>
<tr>
<td><strong>Jet fuels containing synthesized hydrocarbons (ASTM 7566)</strong></td>
<td>Min. 8%&lt;sub&gt;vol&lt;/sub&gt;</td>
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<tr>
<td><strong>Blend components (ASTM 7566) FT-SPK, HEFA, SIP, AtJ SPK with aromatics</strong></td>
<td>&lt; 0.5%&lt;sub&gt;mass&lt;/sub&gt; (&lt; 20%&lt;sub&gt;vol&lt;/sub&gt;)</td>
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Abbreviation: FT-SPK: Fischer-Tropsch Hydroporocessed Synthezised Paraffinic Kerosene, HEFA: SPK from from hydroprocessed esters and fatty acids, SIP: synthesized iso-paraffins produced from hydroprocessed fermented sugars; AtJ: Alcohol-to-Jet SPK
Typical sulphur and aromatic content in Jet A-1 samples

- Sulphur content: On average significantly below 3000 ppm
- Aromatic content: Distribution around 18%

Reduction of SO$_2$ emissions is effective when regulated

- Policy measures to reduce SOx emissions are effective

- Likely reasons:
  - Profound environmental concerns
  - Technical solutions are available at tolerable cost

Source: Centre on Emission Inventories and Projections / Environment Agency Austria
www.ceip.at/ms/ceip_home1/ceip_home/data_viewers/official_tableau/
Reduction of SO$_2$ emissions is effective when regulated

- Striking effect in road transportation, SO$_2$ emissions from aviation are rising with fuel consumption (from a low baseline)

Source: Centre on Emission Inventories and Projections / Environment Agency Austria
www.ceip.at/ms/ceip_home1/ceip_home/data_viewers/official_tableau/
Outline

- How can the Sulphur and PM emissions be reduced in the aviation industry?
- Is biofuel the certain future?
- What expectations can be made for the future of jet fuel?
Is biofuel the certain future?

- Biofuels are the only near-term alternative for renewable jet fuel (HEFA/ATJ)
- But investment in biofuels are not in line with ambitious scale-up

Power Sector:
Investments redirected towards renewables
Continued policy support

Transport & Fuels:
Persistent fossil dominance
Adaption of policies due to sustainability concerns

Source: IEA World Energy Investment 2019, iea.org/wei2019. All rights reserved.
Are biofuels scalable towards jet fuel demand?

- **Bottom-up estimate of agricultural land availability**
  - Exclusion of land areas (sustainability criteria)
  - Subtraction of land area for food and fodder cultivation

- **Matching crop-specific productivity maps (20 energy crops)**

- **SPK theoretical potential:**
  - > 1000 Mt/yr based on 2005 data sets

- **Similar efforts underway to estimate production potentials from wastes and residues (H2020 HyFlexFuel)**

Source: F. Riegel et al. Global Assessment of Sustainable Land Availability for Bioenergy and Food Production, 27th European Biomass Conference and Exhibition, Lisbon, May 2019

DBFZ/BHL: Public report Regional feedstock potentials and preference regions for HTL projects (to be published), www.hyflexfuel.eu
Cost and GHG performance of biofuels

**Conventional jet fuel**

- **BtL Biomass to Liquid**
- **HTL Hydrothermal Liquefaction**
- **StL Sun to Liquid**

**Graph: Cost vs. GHG emissions**

- **BtL / eucalyptus**
- **HEFA / jatropha**
- **HEFA / MSW**
- **HEFA / yellow grease**
- **HEFA / UCO**
- **HEFA / camelina**
- **BtL / poplar**
- **BtL / forestry residues**

**Metrics:**
- **Specific GHG emissions [gCO2eq/MJ]**
- **MFSP [EUR/L]**

[* per L kerosene-eq]
Upcoming competition from renewable fuels

Upcoming competition from renewable fuels

Outline

- How can the Sulphur and PM emissions be reduced in the aviation industry? What are the alternative options?
- Is biofuel the certain future?
- What expectations can be made for the future of jet fuel?
Aviation fuel demand will likely grow

Fuel demand and revenue person kilometers on continued growth pathway

Industry market forecasts expect growth beyond efficiency improvements

Current market vs. world population: ~ 1160 km per person and year

Source: Data derived from most recent issues of IEA “Key world energy statistics” and IATA “Economic performance of the airline industry” biannual reports; Growth in industry RPK derived from IATA “Air passenger market analysis, November 2019”; https://webstore.iea.org/statistics-data  www.iata.org/publications/economics  www.worldometers.info/world-population
Prospects and limitations of electric flight

- **Electric flight limited by battery mass**
  - Concept Ce-Liner, target: Cover 80% of air traffic (900 nm)
  - Requires battery specific energy density > 1 kWh/kg

- **Hybrid/Turbo-electric concepts**
  - From fuel perspective: No change in primary energy carrier

- **Urban and Intra-Urban air mobility**
  - Viable concepts for short duration flights
  - Substitution of conventional aircraft in niche markets
  - Novel opportunities for more radical designs

Prospects for hydrogen as aviation fuel (long haul)

- **Interdisciplinary Design Project Hy-ShAir**
  - Focus on the long-haul air transport market

- **Supply perspective for electricity derived fuels**
  - Benefits of LH₂ production vs. synthetic fuel production can outweigh penalties of LH₂ logistics

- **HyLiner – Hydrogen powered long haul aircraft**
  - Combustion of LH₂ in gas turbine
  - Comparable energy demand at aircraft level
  - Potential for implementation of annexed technologies

Sources: C. Penke et al. Pathways and environmental assessment for the introduction of renewable hydrogen into the aviation Sector (to be published) ; F. Troeltsch - Concept for a hydrogen-powered long-haul aircraft, Bauhaus Luftfahrt Symposium, 8.5.2019
Key conclusions

- Sulphur and aromatic content linked to air quality and non-CO$_2$ climate effect
  - De-sulphurization and de-aromatization is technically feasible
- Biofuels are the only short term renewable fuel option
  - Scalability of biofuels is questionable
- Synthetic fuels from H$_2$O and CO$_2$ provide a scalable perspective
- Battery electric flight is attractive for short durations and distances
- Liquid hydrogen may provide another alternative to liquid hydrocarbon fuel in the long-term future
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