About dreams and reality: zero-emission aviation

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Norway leads way for aviation biofuels

Norway plans to buy electric planes, mimicking green car success

OSLO (Reuters) - Norway said on Thursday it wants to buy electric passenger planes in the coming years to help slow climate change, building on its success with big tax breaks that have made it the world leader in electric car sales.
Why is an aircraft different?

- The max take-off weight is a hard limit
- The designers are always in search for weight and space
- An aircraft is 10-100 times more energy intense (MJ/seat) as a car.
So you may do this with bus or train
But never ever try it with an aircraft.
Paris versus Aviation emissions

![Graph showing CO₂ emissions (Mton/yr)](image)

- **Reference**
- **Global CO₂ (2.0°C)**
- **Global CO₂ (1.5°C)**
- **CNG**
- **Global CO₂ (2.0°C) GMBM**
- **Global CO₂ (1.5°C) GMBM**
Norwegian ‘Paris’ emissions and aviation

• Assuming:
  – BAU for aviation
  – NDC for all other sectors
  – Excluding electric/biofuels

• In 2080 Norwegian aviation makes long-term NDC goals impossible
OK, we have a problem! But…

- The hydrogen plane?
- The solar plane?
- Or let us make the electric ‘Tesla’ of the skies!
Effects of a range of policy measures

CO2 emissions (Mton/year)

- Reference
- Global CO2 (Pag 2.0°C)
- Global CO2 (Pam 1.5°C)
- SAF market
- SAF 90% subsidised
- Max additional conventional tech

Note: SAF (Sustainable Alternative Fuel) = Biofuel
Fuel efficiency versus growth

![Graph showing fuel efficiency and global aviation emissions over the years.](image-url)
Biofuels use a lot of space

In 2100 we would need over a quarter of the EU to replace all jet fuel in the world:
Demand for bio-based materials

- If it was only aviation demanding bio-mass! We also have:
  - Heavy road freight
  - Shipping
  - The bio-based chemicals and building industries
  - Food production
  - Eco-systems
  - CCS and negative emissions

- It will be a big challenge to provide to all in a sustainable way

- More important: the best biofuels reduce emissions/MJ by 80% (most 40-60%). With ten times the volume of air transport in 2100 we thus still have growth of emissions.
Effects policy measures

- Reference
- Global CO2 (Pag 2.0°C)
- Global CO2 (Pam 1.5°C)
- SAF market
- SAF 90% subsidised
- Max additional conventional tech
- Energy optimum cruise speed
- Scrap age 30 yrs
- $1000/ton CO2 tax
- 200% air ticket tax
- Global slots 10^6 flights
- All measures combined
Distance travelled per mode (pkm, world)

Reference Scenario

Economic Mitigation
Tourist trips per mode (trips, world)

Reference Scenario

Economic Mitigation
Tourism revenues per sector

**Reference Scenario**

- **Acco**
- **Other**
- **Car**
- **Air**

**Economic Mitigation**

- **Acco**
- **Other**
- **Car**
- **Air**
Electric flight revisited

- FT Synfuel
- Jet A
- Liquid Hydrogen
- Liquid Methane
- Methanol
- Ethanol
- Electric Li battery
- Long haul battery
- Short haul battery
- Battery theoretical limit?

Source: https://www.cgabusinessdesk.com/document/5719_Aviation_Addendum._webpdf.pdf
Battery improvements

- For a short haul (range max 1000 km; now 2250 km) Bombardier Dash-8-Q400: almost 7 times current best
- For a long haul A350 this will be 16 times
- Historical improvement: 5-8%/yr
It simply does not fit

- Kerosene tank
- Current battery technology electric plane
E-fuels (Power-to-Liquids); the alternative?

- 3-10 times less land-use per kg
- 0.1-1.0% water use
- Closed carbon cycle
- 95% climate effective
- Almost no conflict nature/food
- Renewable energy availability conflict?

Distance travelled per mode (pkm, world)

Reference Scenario

Economic Mitigation

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Distance travelled per mode (pkm, world)

Reference Scenario

Economic Mitigation PtL
Conclusions

• Aviation’s emissions will spoil the Paris Agreement
• Proposed compensation scheme cannot work
• Sustainable biofuels not very effective
• Electric flight (and all other aircraft redesign technologies) will be too late and/or too little
• Travel growth with steady state economy for aviation would connect aviation to Paris goals
• E-fuels based on Power-to-Liquids helps to keep some aviation growth
Thank you for your kind attention