Project 52

Comparative assessment of electrification strategies for aviation

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Cost share partners: NuFuels, MIT

Objective:

To evaluate:

(1) the operational and economic feasibility of electrification strategies, and

(2) the life-cycle GHG emissions and their associated impacts, relative to conventional petroleum-powered aircraft.

Today's focus:

Assessment of electricity-powered aviation with near-zero impact on climate and air-quality

Project Benefits:

Provide data and guidance on the most promising electrification approaches for aviation

Energy and fuel demand
Calculate the fuel and energy demand for a market scenario

Fuel production and logistics
Model the production and logistics for aviation fuels

Aircraft & operations
Detailed model of aircraft design and operations

Environmental & Cost Implications
Detailed analysis of financial and environmental implications (including climate costs and air quality costs)

Major Accomplishments (current period):

We analyzed potential designs for a narrowbody short-haul aviation system including:

1. Fuels made from electricity
2. Post combustion emissions control (PCEC)
3. Contrail avoidance

Future Work / Schedule:

- Additional assessment of production potentials for electrofuels
- Infrastructure considerations for battery-electric aircraft

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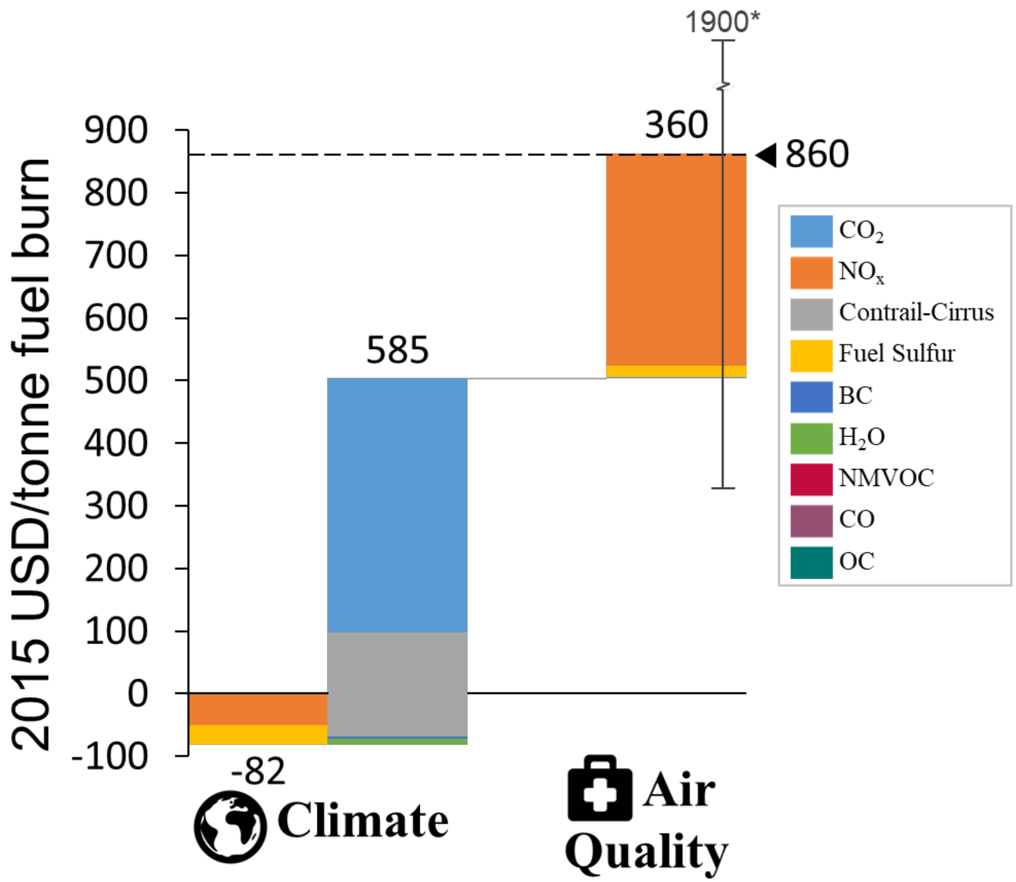
Zero-environmental-impact aviation to account for climate and air quality impacts

Motivation:
Current **external cost of aviation fuel burn**

per tonne of fuel (Jet-A), atmospheric impacts only



Source: Update for Grobler et al. (2019)

Design an aviation system with near-zero environmental impact, considering:

Objectives

- Aviation CO_2 climate impacts
- Aviation non-CO_2 climate impacts
- Air pollution

(Net) zero climate impact

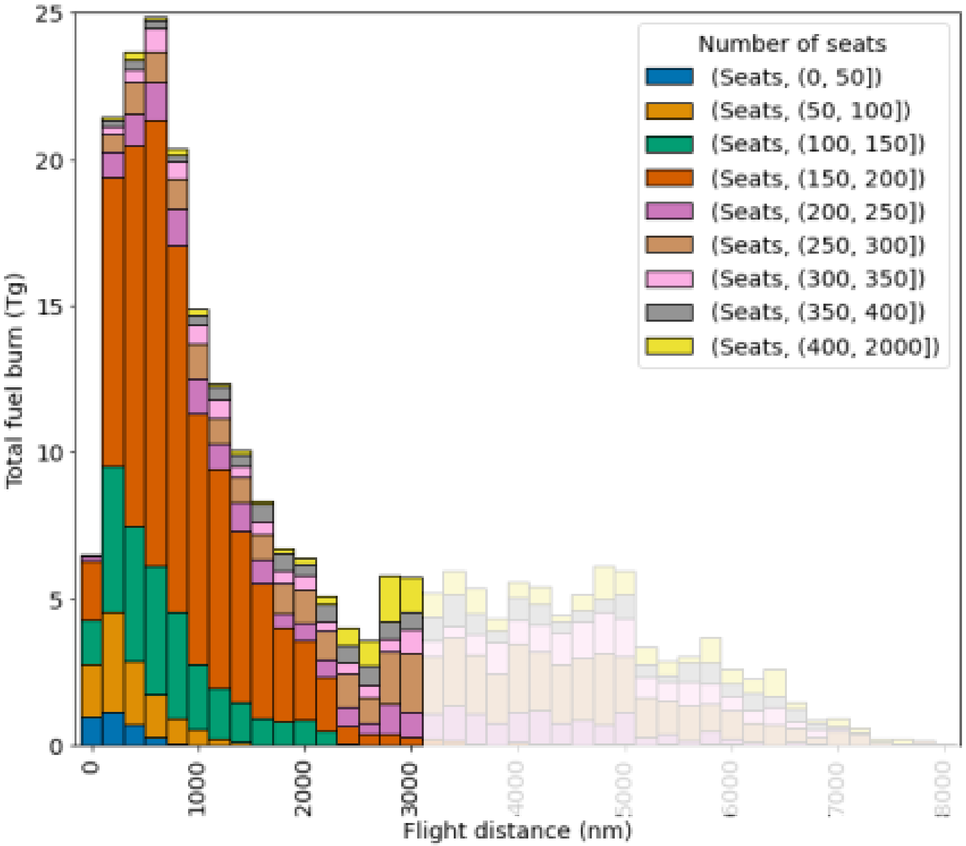
95% re-duction

Costs require detailed analysis!

Initial market study: *short- and medium-range market selected based on global fuel burn distribution*

Distribution of global fuel burn by mission length and aircraft capacity

Scheduled pax aviation only, year 2019



Mission focus for analysis

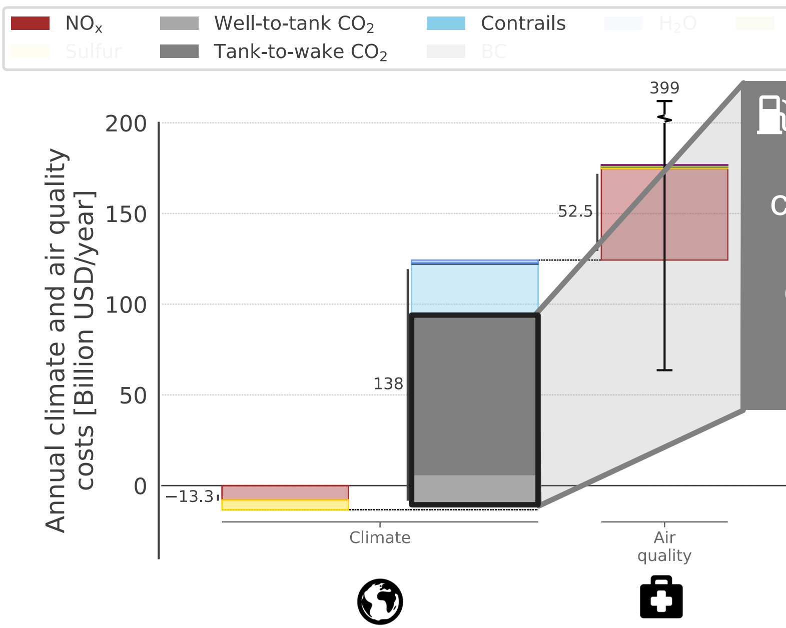
System with similar capabilities as the Boeing 737-9 Max

- *Design range of 3000 nmi*
- *Capacity of 220 passengers*

→ ***System could cover missions which (pre-COVID) caused ~44% of fuel burn***

Preliminary

CO_2 contribution to climate impacts can be addressed via deployment of low-carbon energy carriers



Related to the carbon intensity of onboard energy carrier (fuel) and its production

The **production, transportation** (of feedstock and final fuel) and **combustion** on board aircraft need to be **low-carbon**

Pathways for low-carbon energy for the aviation sector: *Battery-electric aircraft*

Renewable Energy (PV/Wind) → Battery → Battery-electric

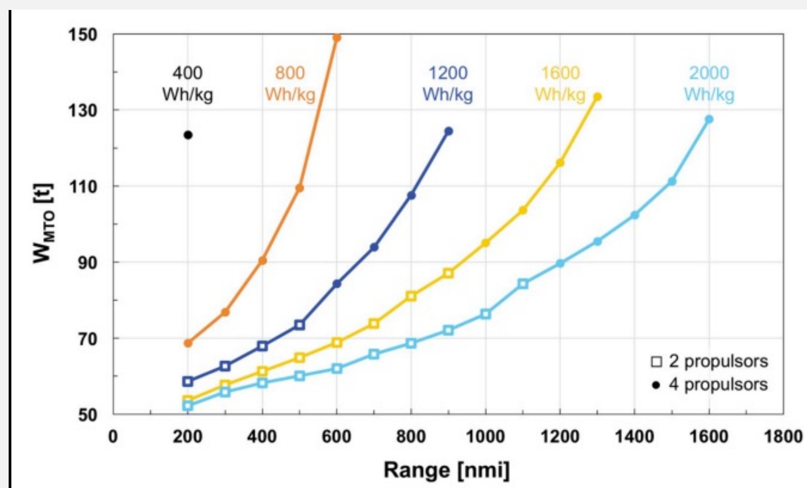
Value proposition:

- No direct (in-flight) emissions
- Lifecycle emissions (close to) zero if electricity produced from renewable sources

Challenge:

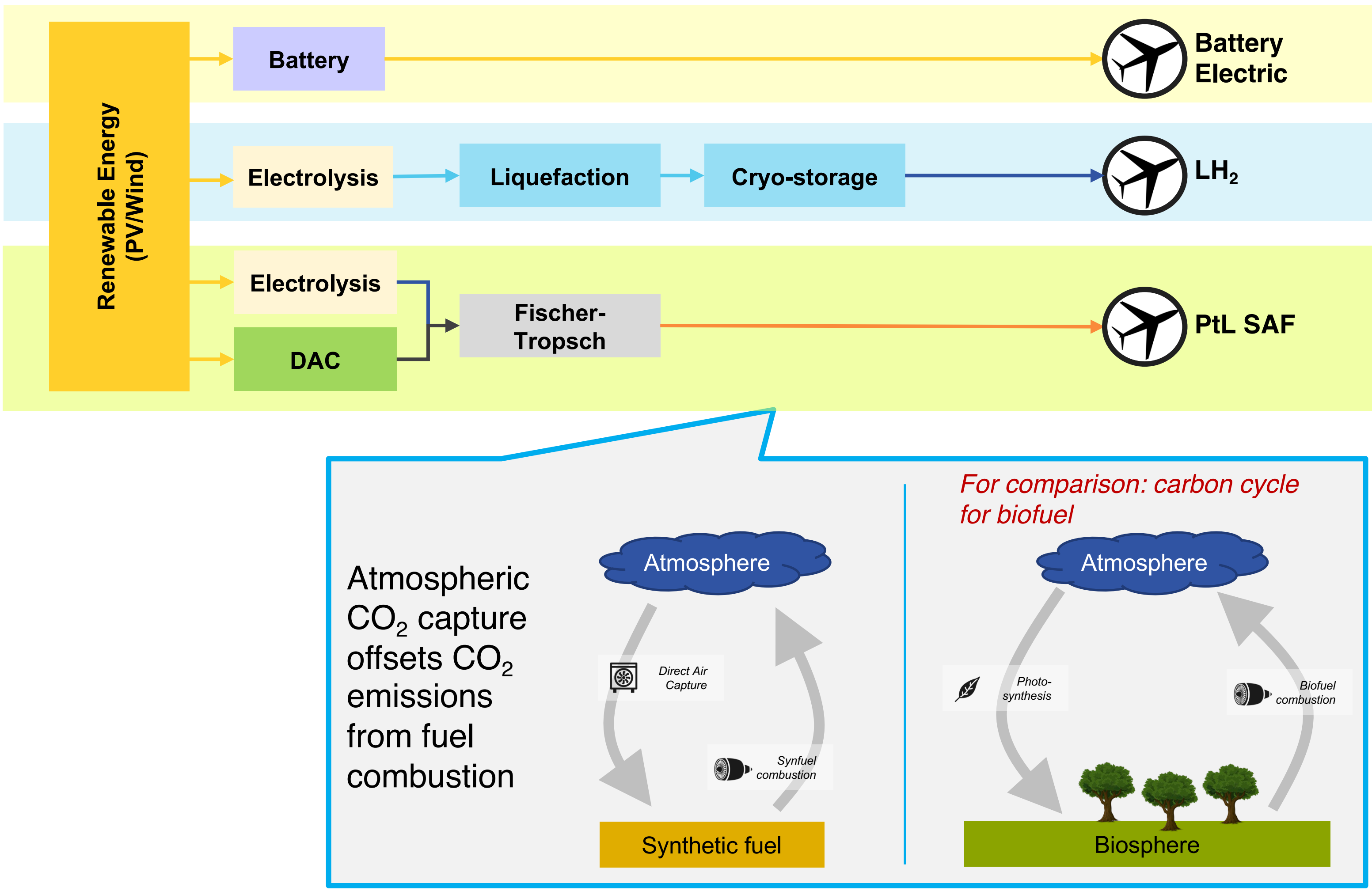
Battery weight fundamentally limits application of battery-electric systems for airliner-sized aircraft

MTOW and maximum range for an Airbus A320-sized aircraft with different battery power densities

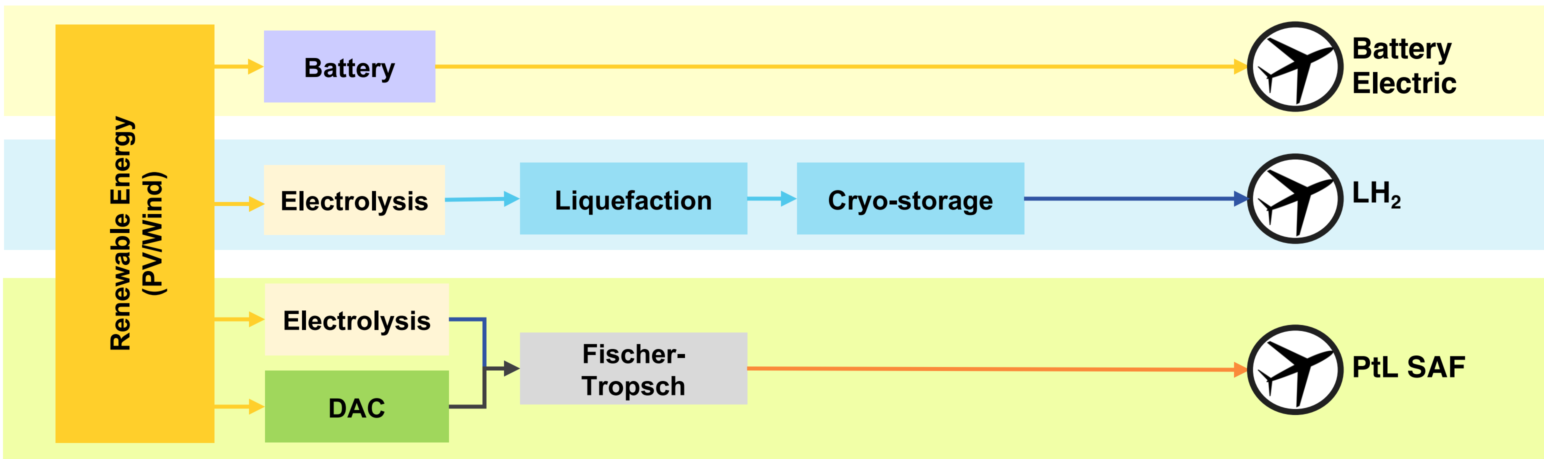


Source: Gnadt et al. (2019)

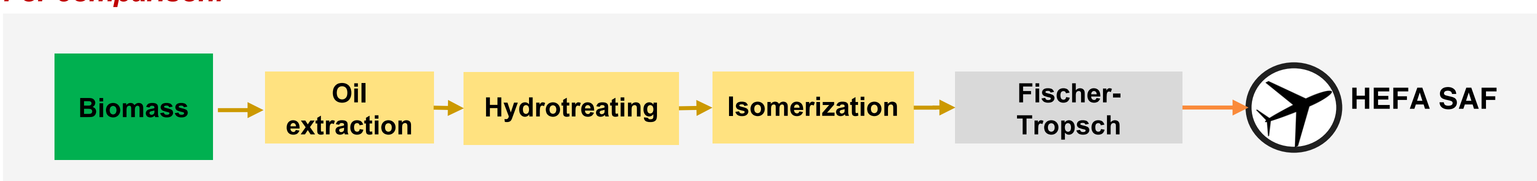
Pathways for low-carbon energy for the aviation sector: *electrofuels*



Pathways for low-carbon energy for the aviation sector: *overview*

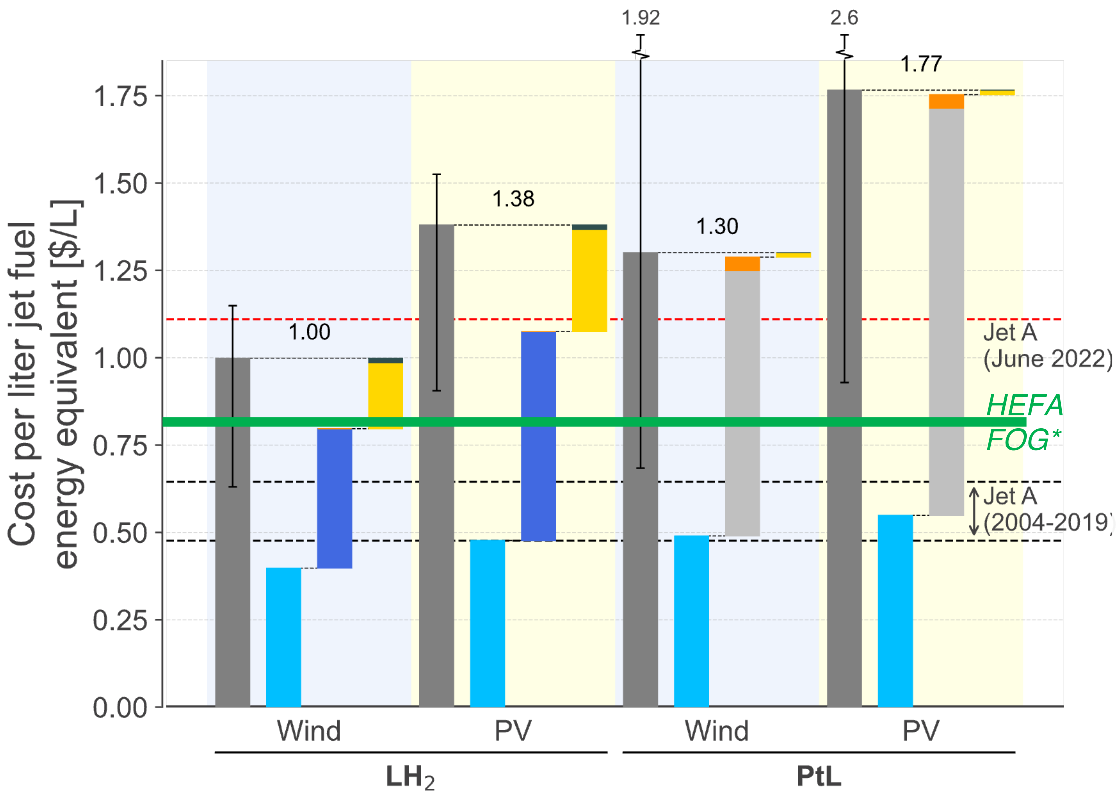


For comparison:



Energy costs likely to increase with electrofuels, but …

Comparison of energy cost under future technologies
LH_2 and PtL for different electricity sources



LCA for energy carriers
LH_2 and PtL for different electr. Sources, future conditions

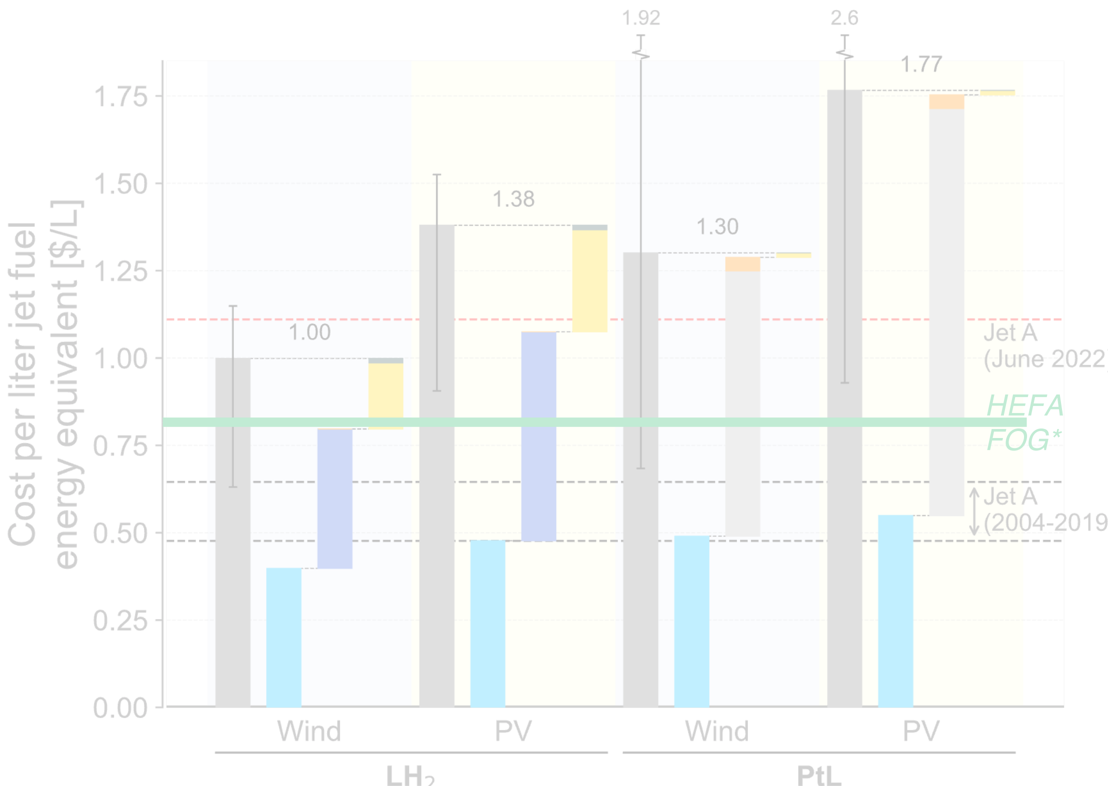
* n-th plant cost following ICAO Rules of Thumb
** CORSIA default LCA value

Preliminary

Energy costs likely to increase with electrofuels, but lifecycle emissions reduced by 85% or more compared to Jet-A

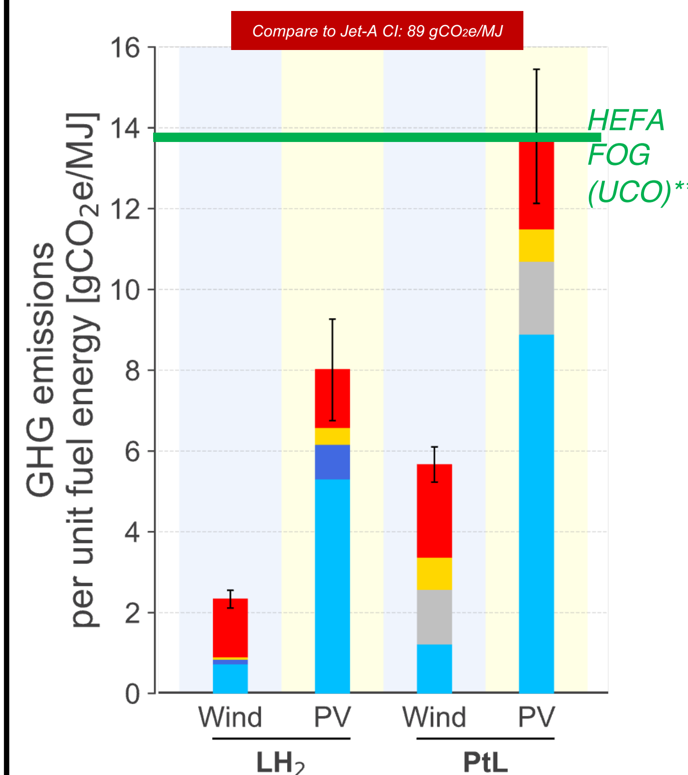
Comparison of energy cost under future technologies

LH_2 and PtL for different electricity sources



LCA for energy carriers

LH_2 and PtL for different electr. Sources, future conditions



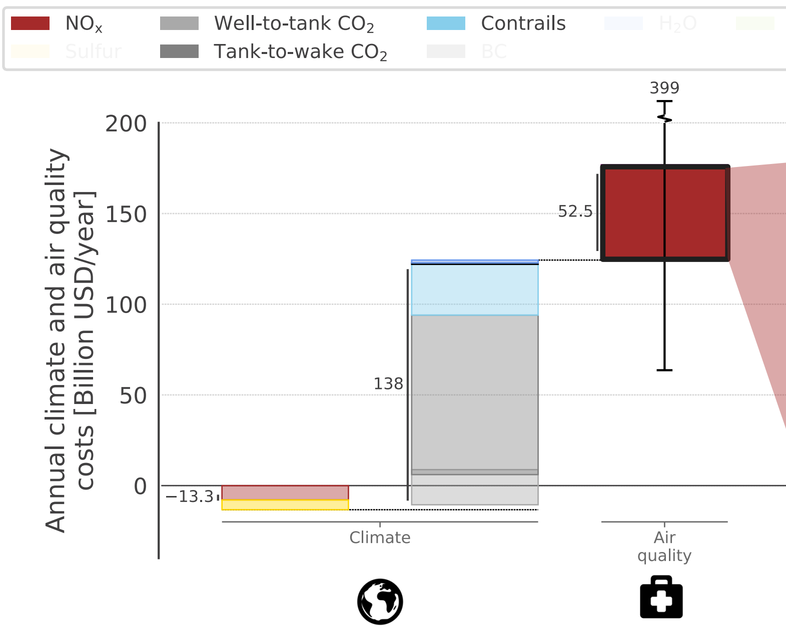
Total	Liquefaction	Conversion	Fueling
H_2 production	CO_2 capture	Transport	Embodied Emissions

* n-th plant cost following ICAO Rules of Thumb

** CORSIA default LCA value

Preliminary

NO_x emissions can be addressed through the design of the aircraft-propulsion system



Function of high temperature combustion

The **aircraft-propulsion system** design needs to **minimize / eliminate emissions of NO_x**

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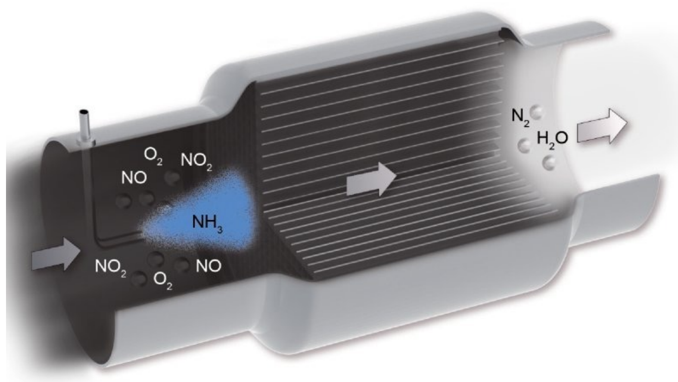
Post-combustion emission control (PCEC) effective for NO_x reduction; possible implementation with small core engines

Solution in other sectors:
Selective Catalytic Reduction (SCR) devices to reduce NO_x emissions



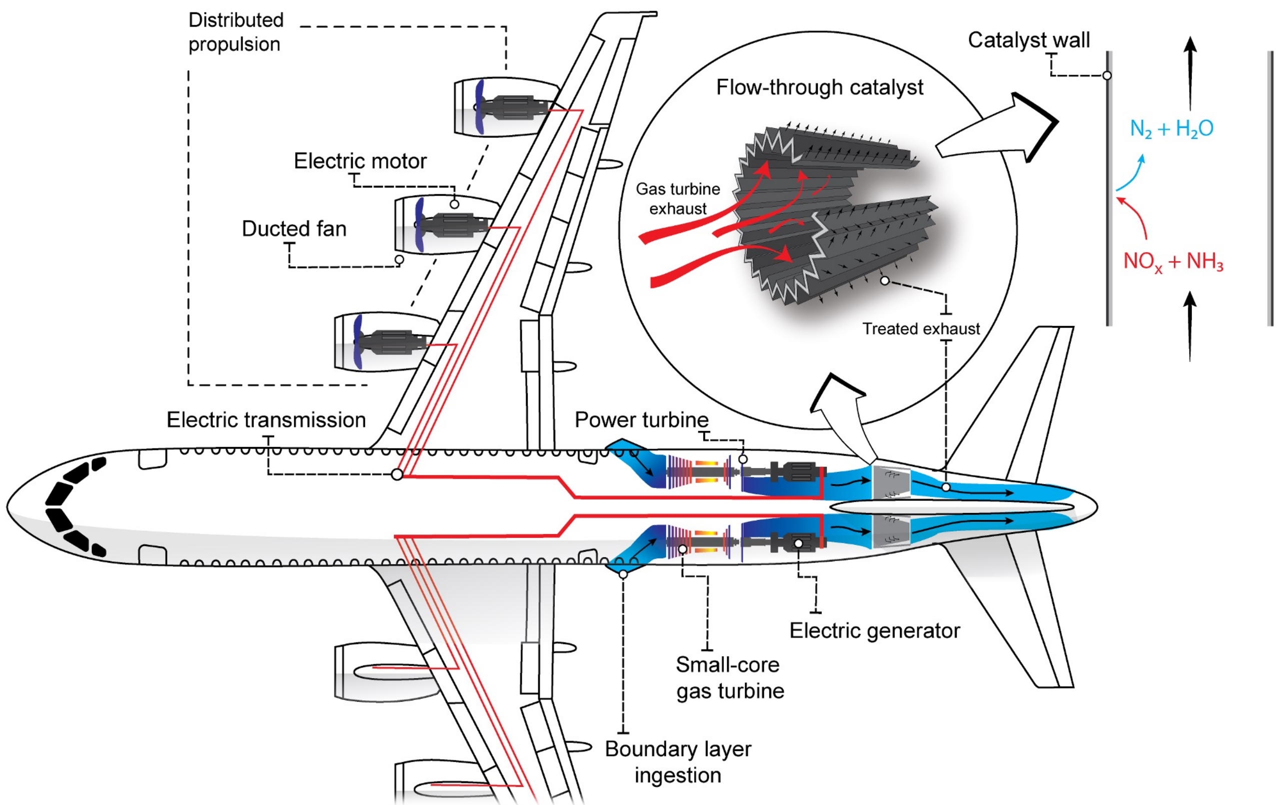
$NO_x + O_2$ → Reducing agent → Catalyst → $N_2 + H_2O$

Small core, high power density engines open opportunities for emissions control

- There is a move towards smaller, power-dense engine cores with lower mass flow rates
- Fraction of thrust produced by core compared to total thrust has reduced
- Implementation of PCEC “under wing” remains difficult due to the size of the device and associated drag; can be combined with turbo-electric architecture

Notional implementation of PCEC on a turbo-electric aircraft

Notional implementation for a narrowbody aircraft



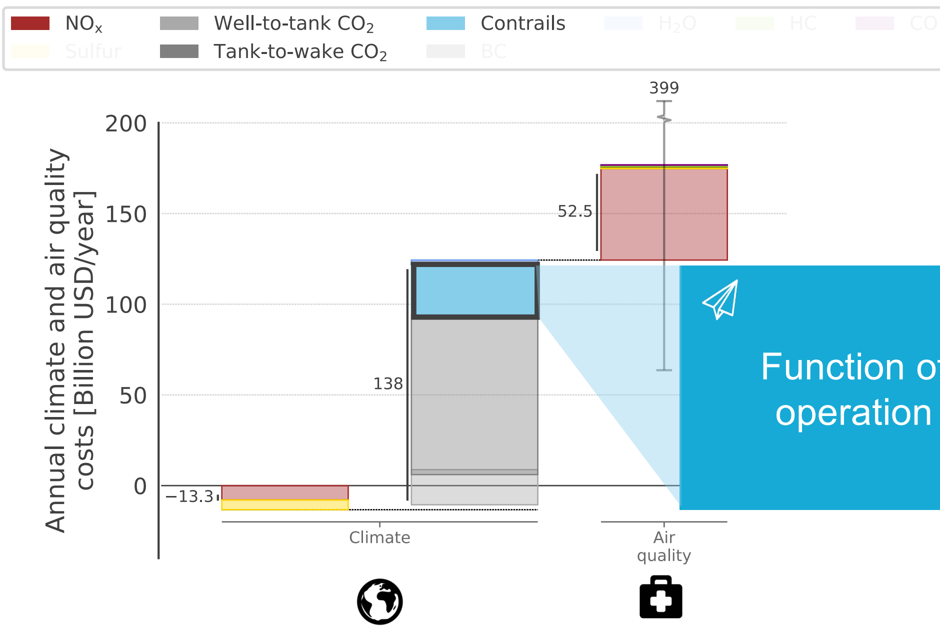
Performance metrics

NO_x reduction (deNO_x)	95%
Increase in mission fuel burn*	0.5%
Catalyst mass (per engine)	91 kg
Reductant mass (1500 km mission)	21 kg
Additional system mass (pumps, storage tanks, etc.)	128 kg

* due to catalyst, reductant and related systems.

Prashanth, P., Speth, R. L., Eastham, S. D., Sabnis, J. S., and Barrett, S. R. H. H. "Post-Combustion Emissions Control in Aero-Gas Turbine Engines." Energy & Environmental Science, Vol. 14, No. 2, 2021, pp. 916–930. https://doi.org/10.1039/d0ee02362k.

Contribution of contrails to climate impacts can be reduced via operational contrail avoidance



Function of operation

Aircraft need **operational capability to avoid** persistent contrail forming regions

Conservative estimate:
Fleet level contrail length reduced by ~70% for ~1% increase in fleet averaged fuel burn based on a fleet level simulation study *

** See ASCENT 78 for more detailed analyses*

Preliminary

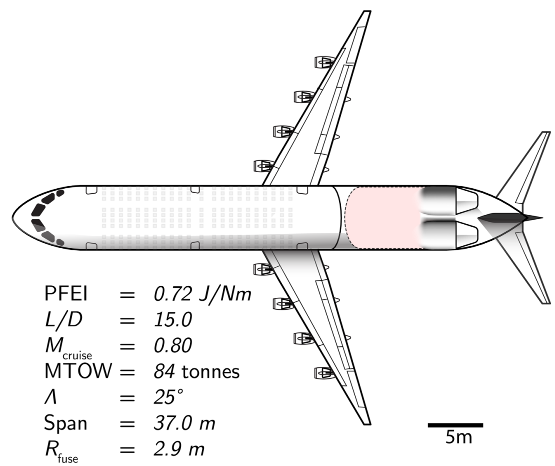
Aircraft assessed using MIT's TASOPT code; short haul (net)-zero impact LH_2 aircraft with ~20% higher energy consumption compared to SAF

Conceptualization of the aircraft system based on TASOPT

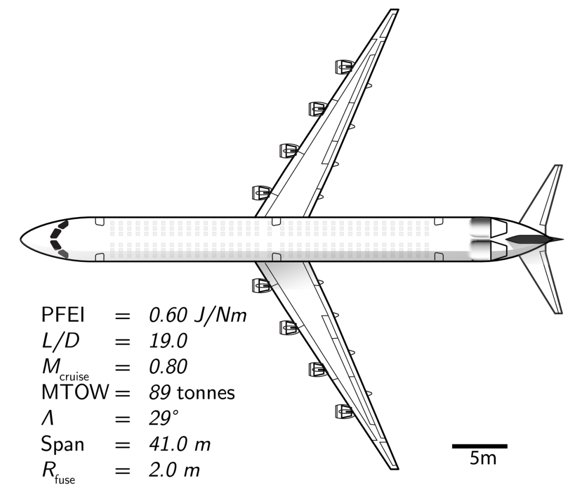
- *Physics-based design tool that combines structural, aerodynamic, and thermodynamic sub-models to produce aircraft performance metrics.*
- *Relies on first-principles approach when possible, rather than extrapolated fits from empirical data.*
- *Includes joint optimization of airframe, propulsion, and operations.*

Outputs for 220pax, 3000nmi range class aircraft

Zero Impact Aircraft powered by LH2



Zero Impact Aircraft powered by SAF

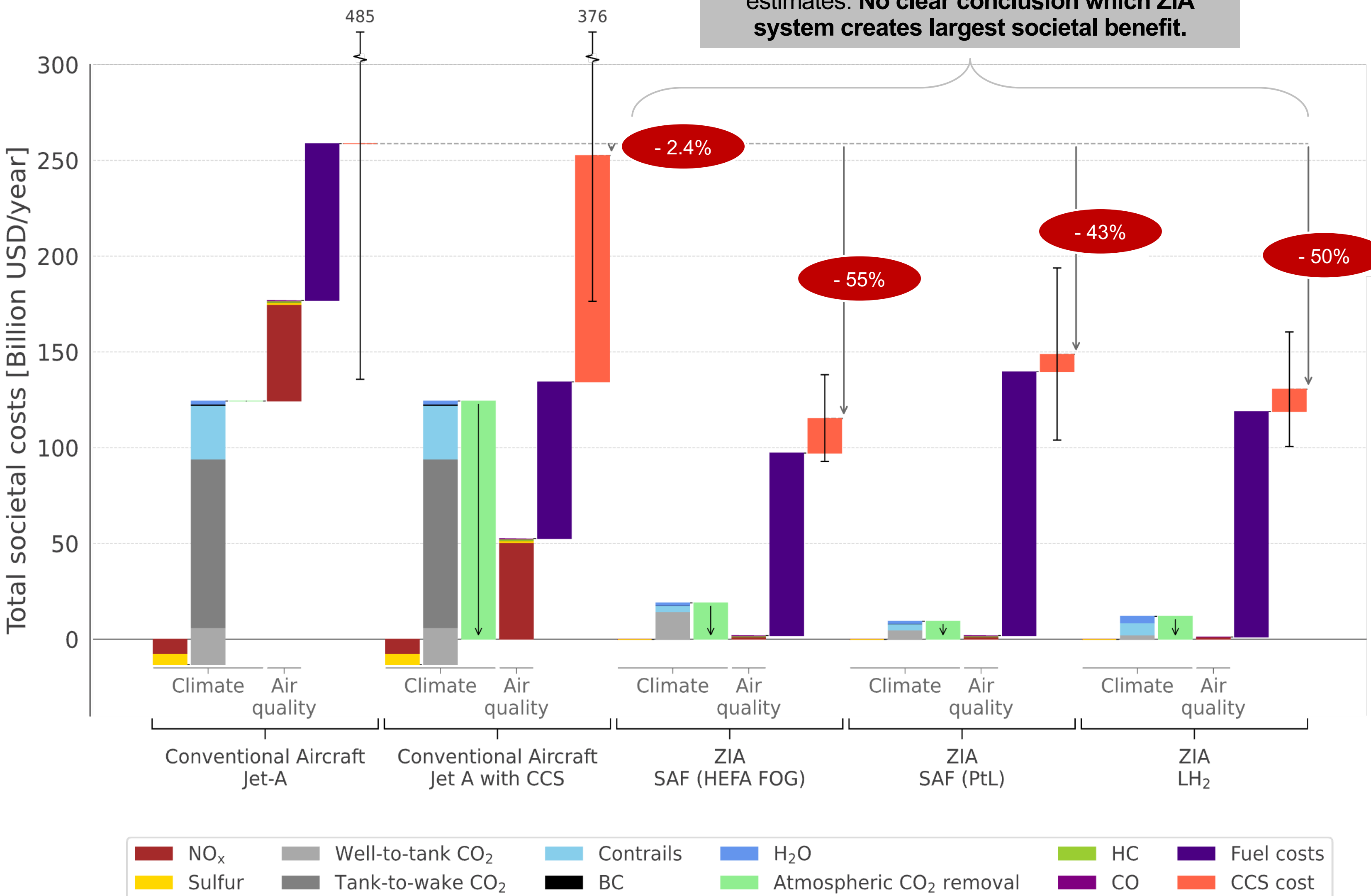


- LH_2 powered aircraft requires **~20% more energy** than a SAF aircraft for the same mission – heavy tanks, increased fuselage drag, reduced wing relief
- Fleet average **reduction in NO_x of ~96%**

Preliminary

Results: ZIA concept reduces net societal cost (fuel (incl. CCS) + environment) of aviation by ~43-55%, while accounting for higher fuel costs

Uncertainty analysis reveals overlapping cost estimates. **No clear conclusion which ZIA system creates largest societal benefit.**



Preliminary

Takeaways

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AVIATION SUSTAINABILITY CENTER

- Consider (at least) **climate and air quality** when discussing a zero-environmental-impact aviation system

- Need a **system-level approach to engineer a viable system** – fuel production, aircraft-propulsion design, and operation

- **Fuels:** A net-zero system does not seem to necessitate switching fuel to (L)H_2; benefits seem achievable with SAF (both PtL and biomass-based); identification of potential additional benefits of LH_2 require further analysis.

- Zero-impact air transportation is **not necessarily prohibitively expensive** (operating cost increase on the order of 5-25%) but **provides societal net benefits**