Decarbonization in Aviation

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01 Current Sustainability Solutions

AT A GLANCE:

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Biofuels

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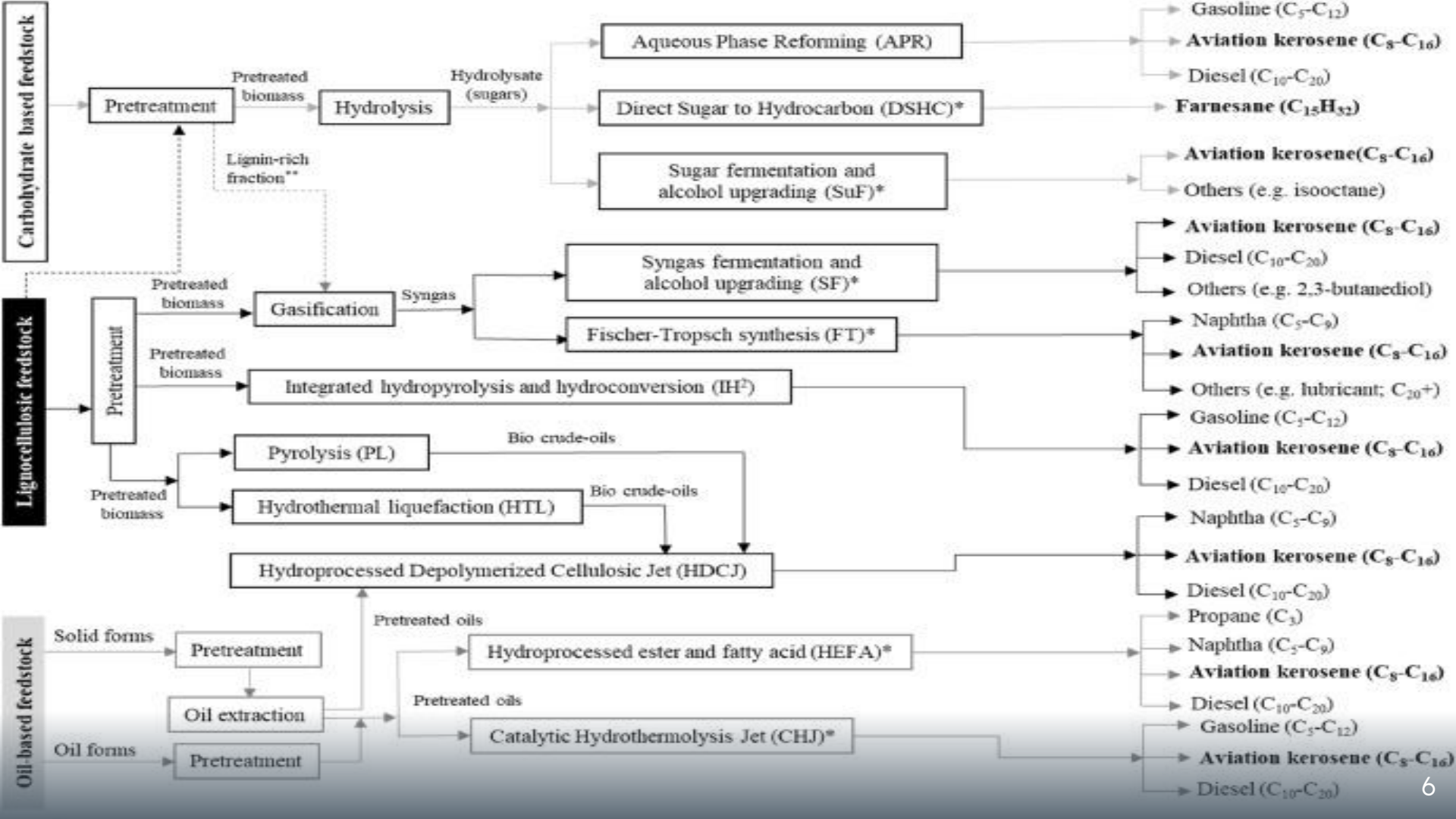
Biofuels

- Fuels produced from renewable biological sources, like plant matter
- Mature and compatible with aviation infrastructure
- 3 feedstock types
- 9 high readiness level pathways


Carbohydrate based feedstock
Pretreatment
Pretreated biomass
Hydrolysis
Hydrolysate (sugars)
Lignin-rich fraction**
Aqueous Phase Reforming (APR)
Direct Sugar to Hydrocarbon (DSHC)*
Sugar fermentation and alcohol upgrading (SuF)*
Gasoline (C5-C12)
Aviation kerosene (C8-C16)
Diesel (C10-C20)
Farnesane (C15H32)
Aviation kerosene(C8-C16)
Others (e.g. isooctane)
Lignocellulosic feedstock
Pretreatment
Pretreated biomass
Gasification
Syngas
Syngas fermentation and alcohol upgrading (SF)*
Fischer-Tropsch synthesis (FT)*
Aviation kerosene (C8-C16)
Diesel (C10-C20)
Others (e.g. 2,3-butanediol)
Naphtha (C5-C9)
Aviation kerosene (C8-C16)
Others (e.g. lubricant; C20+)
Integrated hydropyrolysis and hydroconversion (IH2)
Pyrolysis (PL)
Bio crude-oils
Hydrothermal liquefaction (HTL)
Bio crude-oils
Hydroprocessed Depolymerized Cellulosic Jet (HDCJ)
Gasoline (C5-C12)
Aviation kerosene (C8-C16)
Diesel (C10-C20)
Naphtha (C5-C9)
Aviation kerosene (C8-C16)
Diesel (C10-C20)
Oil-based feedstock
Solid forms
Pretreatment
Oil extraction
Oil forms
Pretreatment
Pretreated oils
Hydroprocessed ester and fatty acid (HEFA)*
Pretreated oils
Catalytic Hydrothermolysis Jet (CHJ)*
Propane (C3)
Naphtha (C5-C9)
Aviation kerosene (C8-C16)
Diesel (C10-C20)
Gasoline (C5-C12)
Aviation kerosene (C8-C16)
Diesel (C10-C20)

Electrofuels

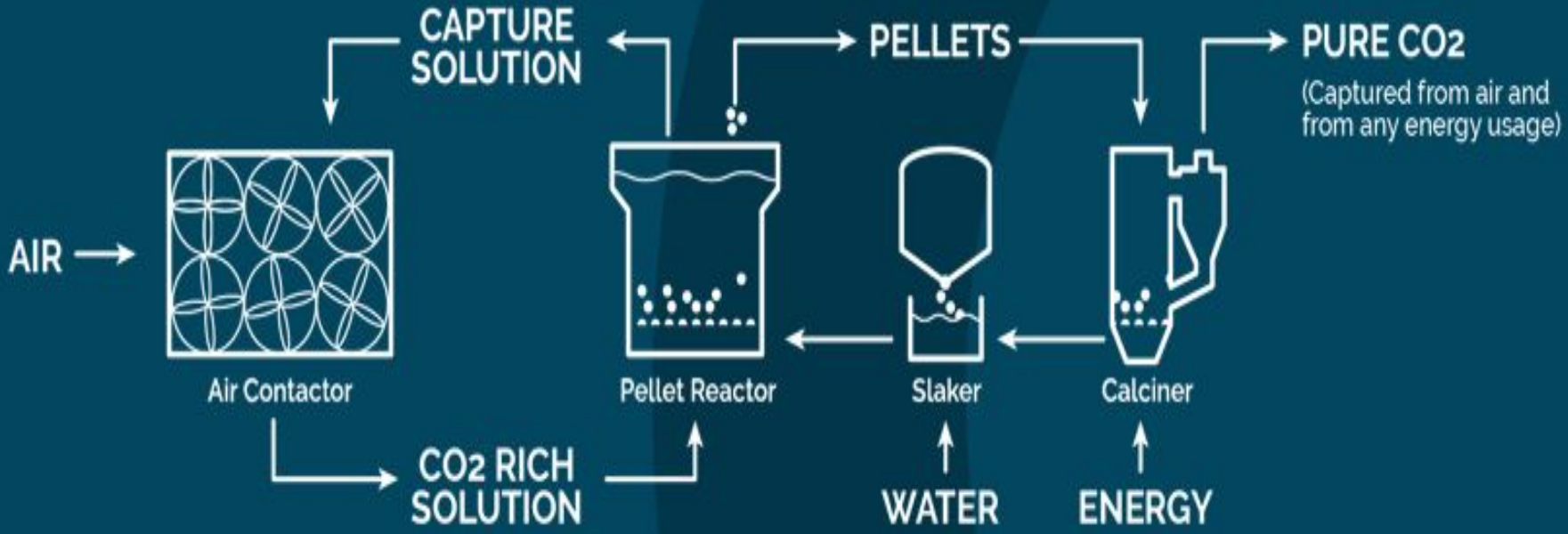
- Capturing CO_2 and CO
- Combine with hydrogen from water electrolysis to obtain useable fuel

Carbon Sourcing

- Biomass
- Fossil
- Atmospheric

Hydrogen Supply

- Biomass
- Fossil
- Water-splitting



CE's Direct Air Capture process, showing the major unit operations - air contactor, pellet reactor, slaker, and calciner - which collectively capture, purify, and compress atmospheric CO_2

Electricity/Battery-Based

- Power propulsion
- “More electric” architectures
- Limitations

Hydrogen

- 3x energy-to-weight ratio versus kerosene!
- Storage limitations
- Existing aircraft:

Aircraft Improvements

- Airlines and manufacturers constantly improving fuel efficiency
- More efficient turbojets
- Better aerodynamics
- Weight reduction
- Boeing EcoDemonstrator

02 Challenges of Emerging Energy Source

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Sustainable Aviation Fuels (SAF)

Sustainable aviation fuel (SAF) is a type of aviation fuel that is made from renewable sources. It has a lower carbon footprint than traditional jet fuel, and it can be used in existing aircraft without any modifications.

SAF

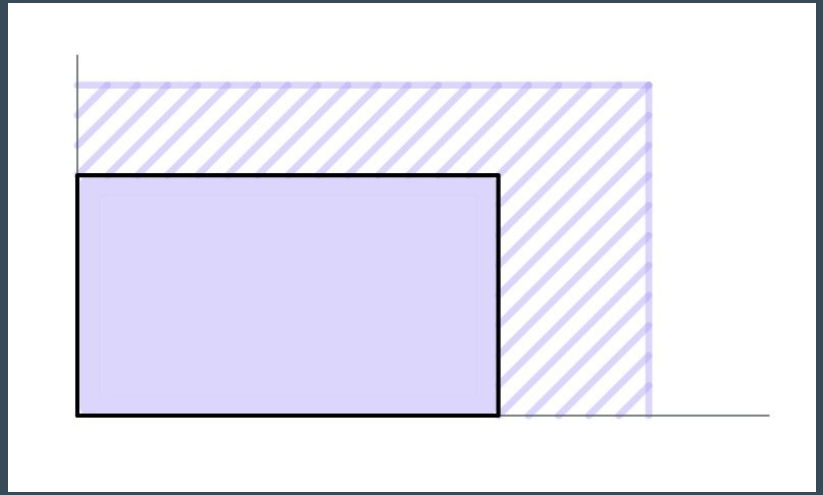
PROS

- Sustainable - renewable material
- No need for airplanes to make modification
- Extra revenue for farmers
- Environmental service
- Improved aircraft service

CONS

- Costs
- Don’t remove the remaining CO2 and toxic emissions
- Collecting renewable sources

Distance vs. Size



Hydrogen Fuel Cells

Hydrogen fuel cells generate electricity from hydrogen and oxygen, producing only water as a byproduct

Hydrogen Fuel Cells

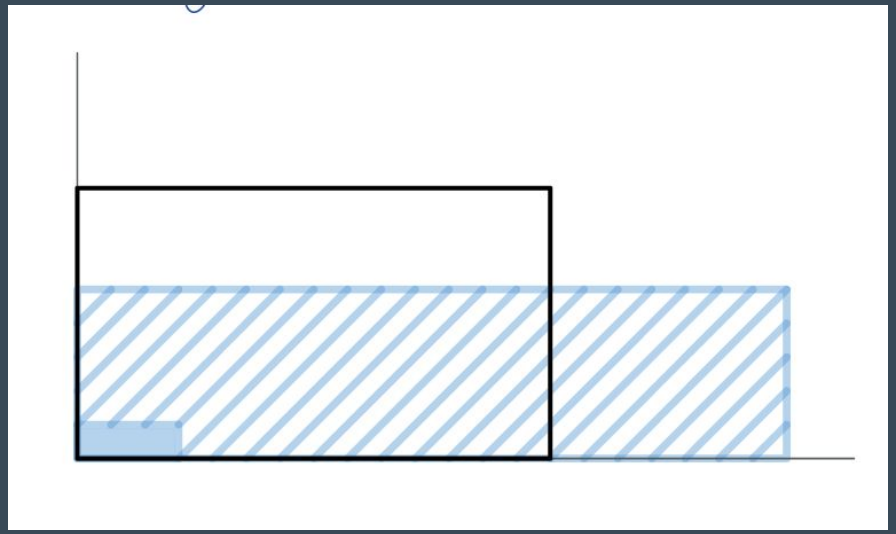
PROS

- Zero emission (only produce water)
- High energy density
- Scalability (can accommodate large aircrafts)

CONS

- Costs
- Infrastructure
- Storage requirement (temperature control)

Distance vs. Size



Electric Aircraft

Electric aircraft are planes powered by electric motors that use electricity stored in batteries or fuel cells.

Electric Aircraft

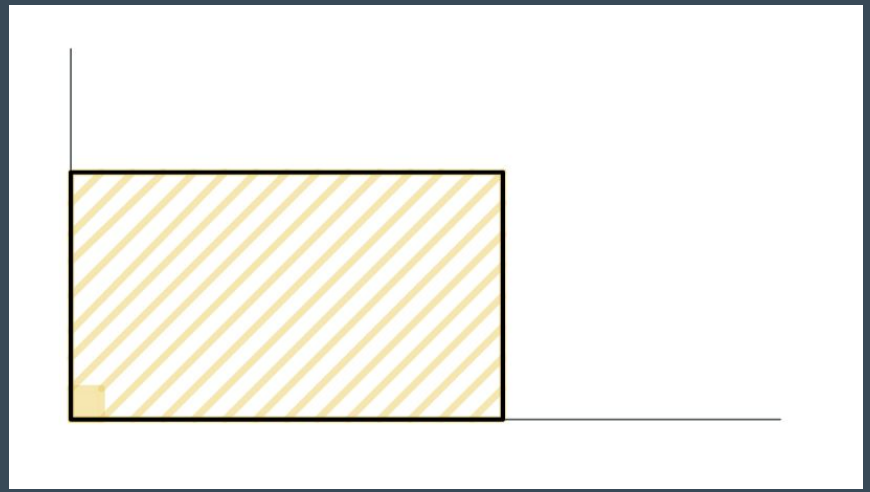
PROS

- Zero emission
- Lower operating cost
- Quieter operation

CONS

- Limited range
- Initial/maintenance Cost
- Weight

Distance vs. Size



Ammonia

Ammonia (NH3) is a compou
that can be used as a fuel in
certain applications. It is a
colorless gas with a pungent
odor and is composed of one
nitrogen atom bonded to thr
hydrogen atoms.

Ammonia

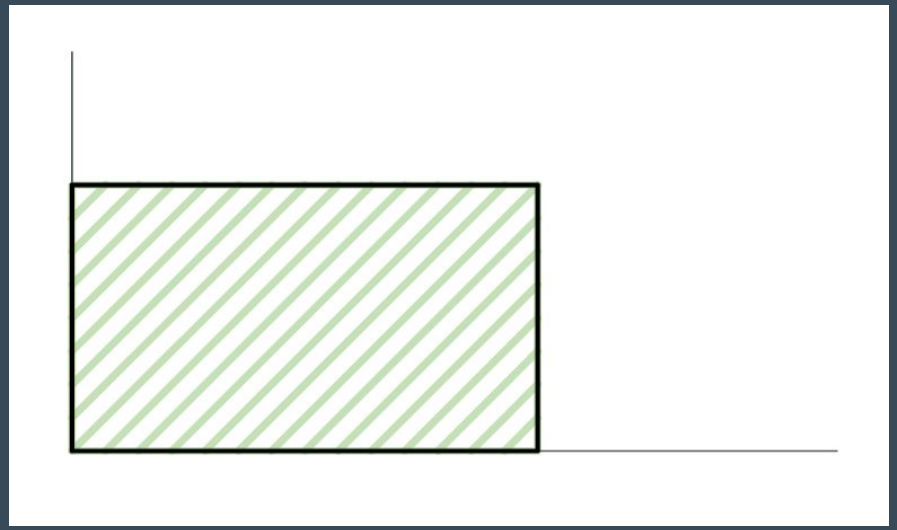
PROS

- Zero emission
- stored and transported easily
- No need for airplanes to make modification

CONS

- Cost
- Produce toxic gas

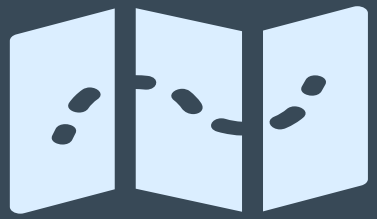
Distance vs. Size



03 Emissions Forecasts

Methodologies of calculations

For individual purposes



Input data:
- Airport locations

External data:
- Fuel burn
- Freight load
- Seating configuration

Methodologies of calculations

Each model gives different insights

AERO
Aviation Emission and Evaluation of Reduction Options

SAGE
System for Assessing Aviation Global Emissions

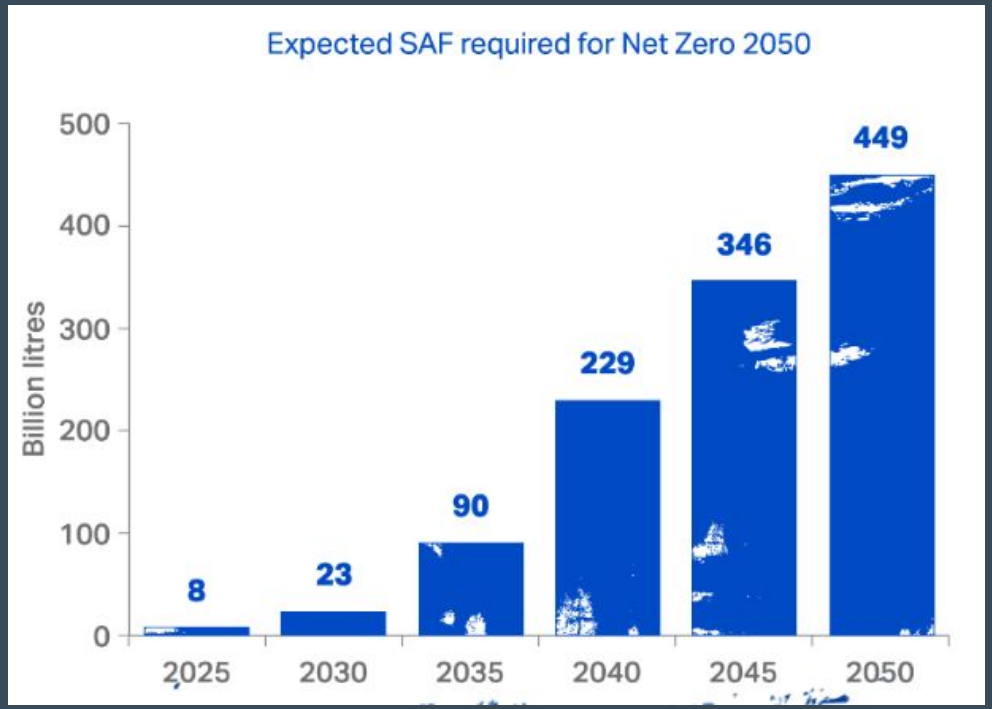
FLEET
Fleet Level Environmental Tool

Forecast results - SAF

In 2016:

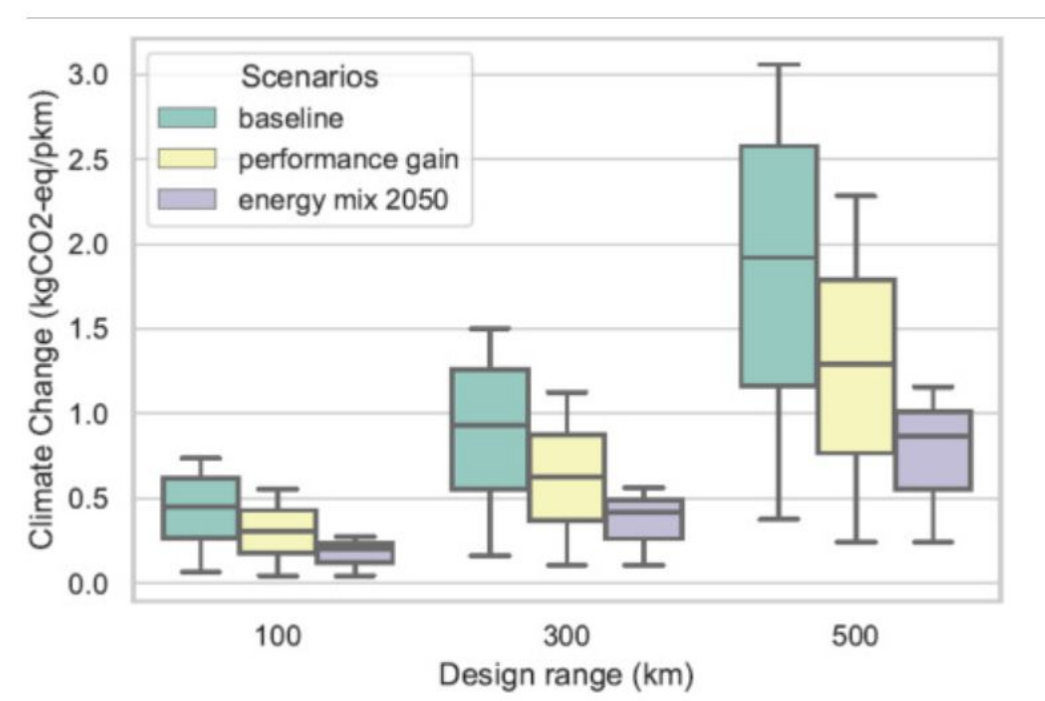
~8 million liters

~500 flights



McCausland, Richard. “Net Zero 2050: Sustainable Aviation Fuels,”

Forecast results - Hydrogen Fuel Cells

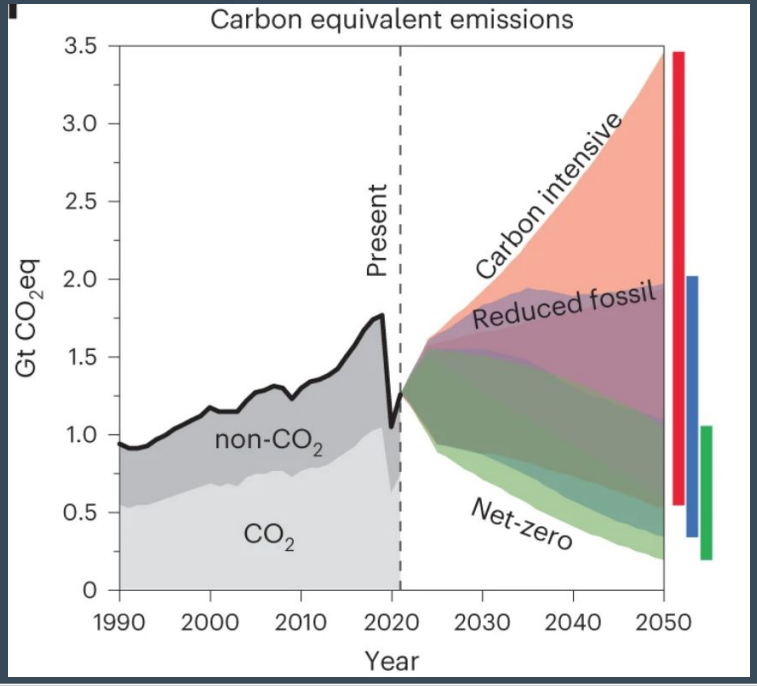


With today's aviation:

~100 g CO_2-eq. per passenger-kilometer

Sofia Pinheiro Melo et al., "Model-Based Assessment of the Environmental Impacts of Fuel Cell Systems Designed for EVTOLs," *International Journal of Hydrogen Energy* 48, no. 8 (January 26, 2023): 3171–87, https://doi.org/10.1016/j.ijhydene.2022.10.083.

Forecast results – SAF, Hydrogen and Electricity



Bergero, C., Gosnell, G., Gielen, D. *et al.* Pathways to net-zero emissions from aviation. *Nat Sustain* **6**, 404–414 (2023). https://doi.org/10.1038/s41893-022-01046-9

04
Regulations and Incentives

In the US

EPA

2016: EPA identifies aviation as significant source of GHG and air pollution

2020: EPA announces plans to enact regulation aligning with International Civil Aviation Org. (ICAO) standards

2021: EPA enacts first aviation GHG standard

- Targets new aircraft, not existing
- Modeled after
- Mostly met by existing aircraft, thus no net emissions reductions predicted

2022: US Supreme Court limits EPA's ability to regulate air pollution

SAF Tax Incentive

$1.25

Credit for each gallon of fuel

50%

Minimum reduction of GHG emissions required to qualify

$0.01

Additional credit for every % GHG reduction over 50%

In the World

Carbon Offsetting Reduction Scheme for Int'l Aviation (CORSIA)

107
Nations participating in CORSIA

77%
Int'l aviation represented

90%
Aviation traffic represented post-2027

<u>Carbon Offset Strategies</u>
Reforestation
Direct Air Capture (DAC)
Carbon Capture Utilization and Storage (CCUS)

IATA: Net-Zero by 2050

SAFs

Potential of 80% CO2 reduction, 65% of overall emissions reduction

Offsetting

CORSIA offsetting and carbon capture strategies

Operations and Infrastructure

Improved airport efficiency and logistics

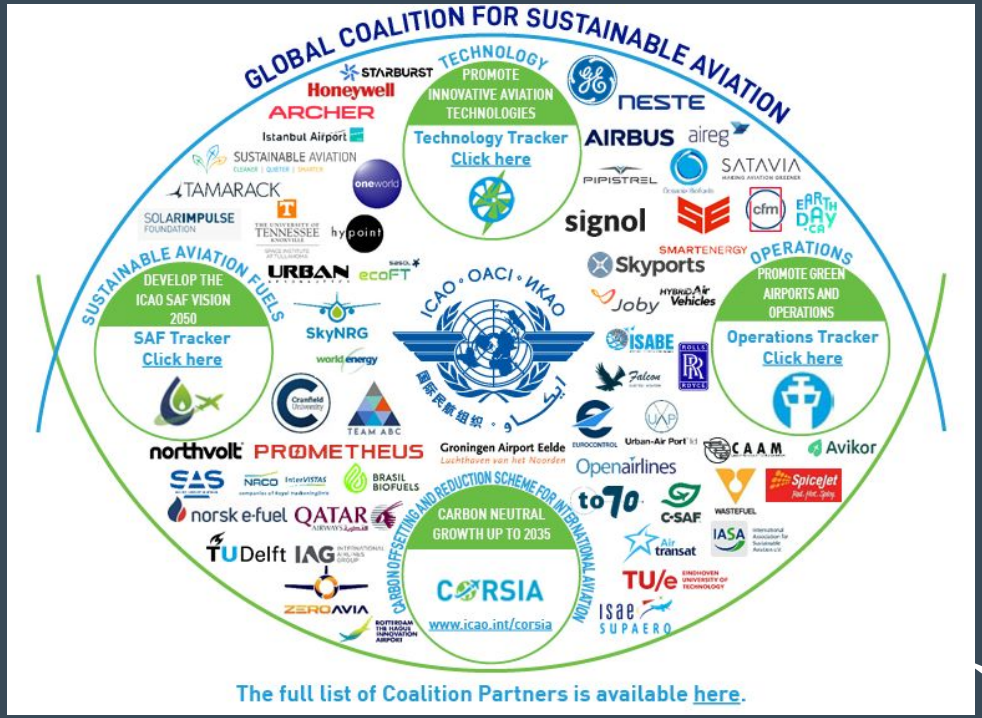
New Aircraft Technologies

More economical engine and airframe designs

ICAO

Coalition of member nations

Sets forth standards and guidelines for sustainability



Conclusion

- Current sustainability solutions are promising, but have a lot of limitations. These are the targets for newest engineering efforts.

- Great variations of emissions depending on technologies and scenarios

- International and local policies are essential for promoting cleaner aviation practices


Thank you!