Energy Sources and Energy Conversion Processes for Sustainable Aviation

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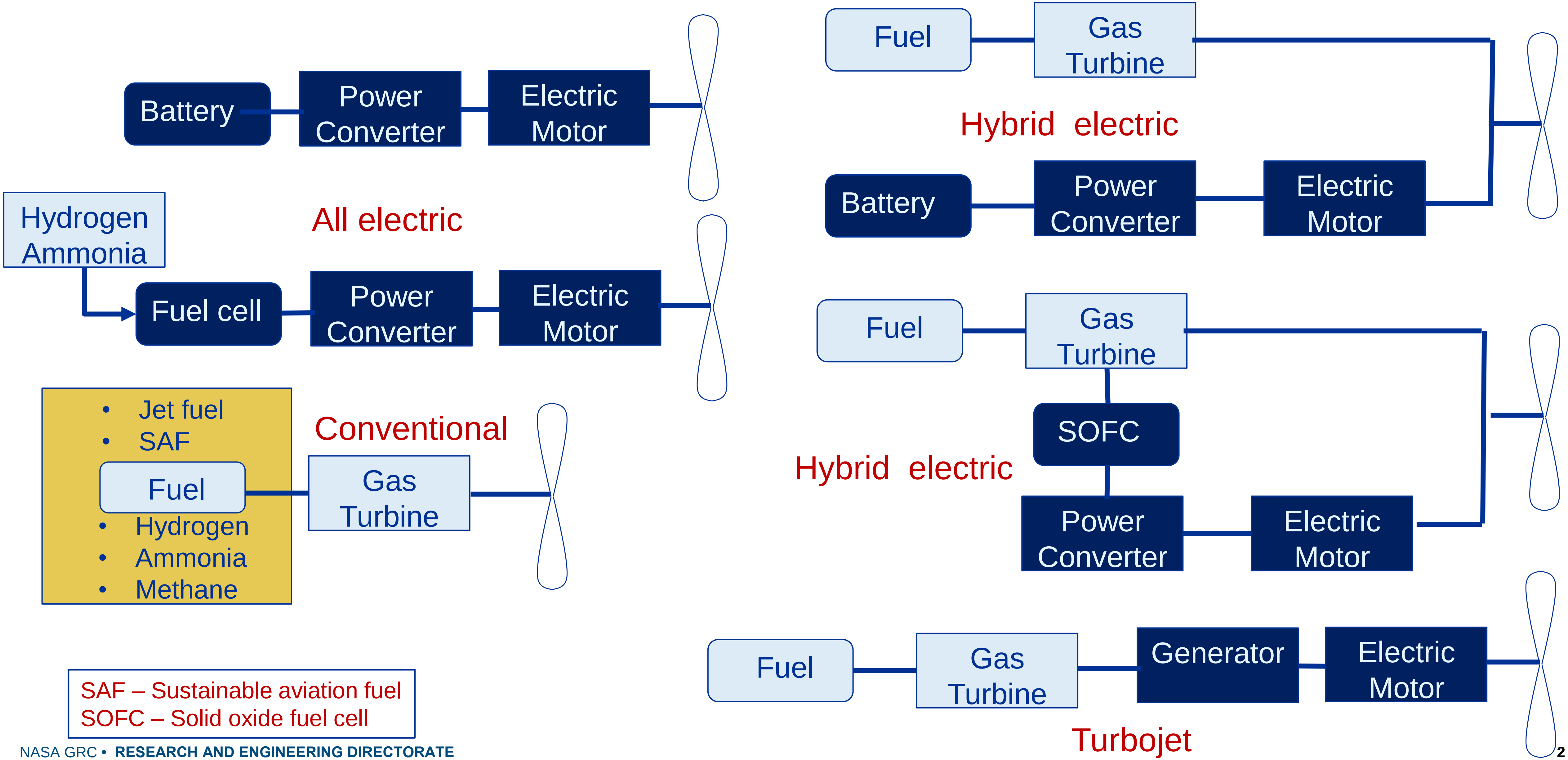
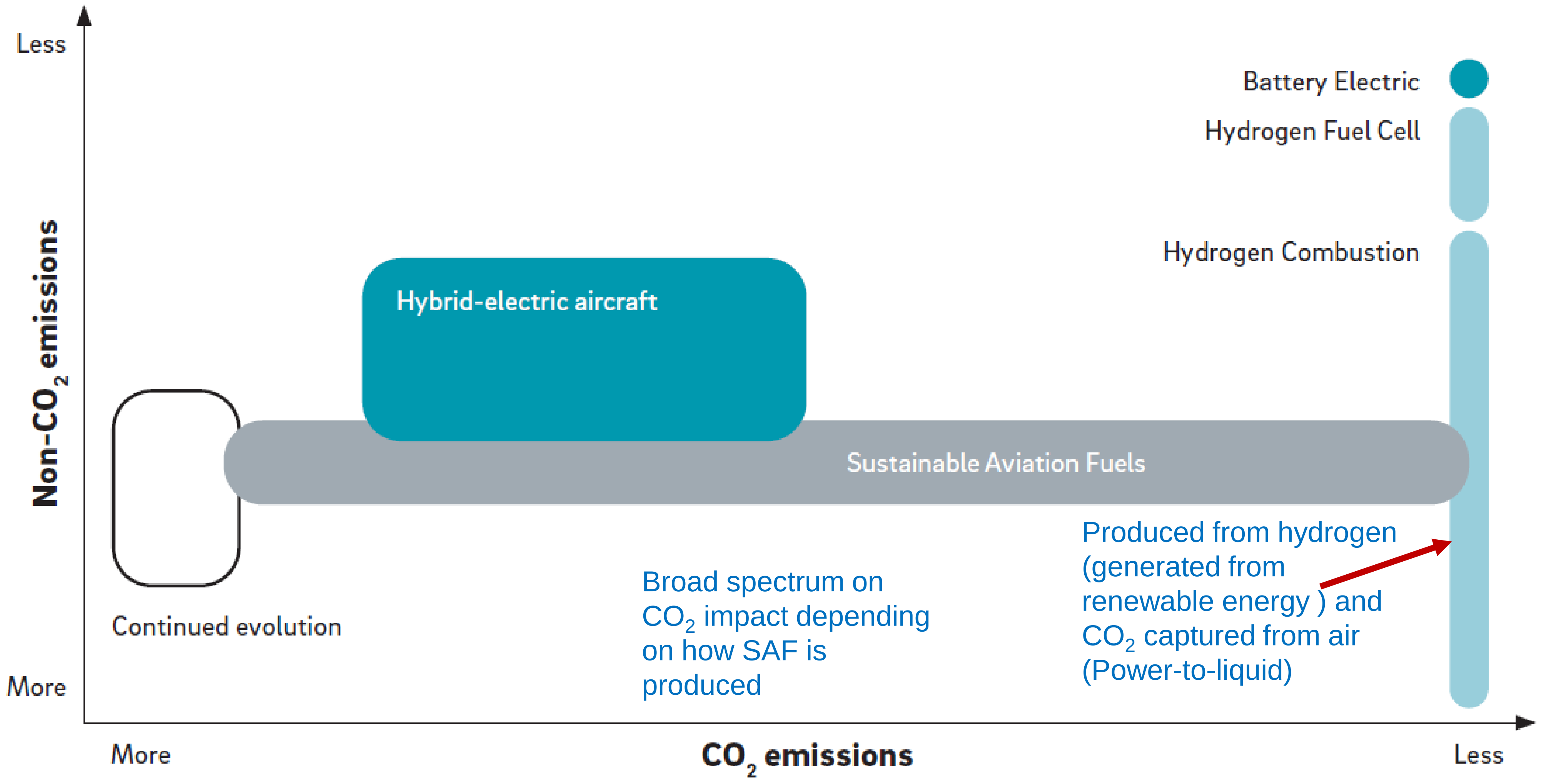
Different Energy Sources and Energy Conversion Processes



SAF – Sustainable aviation fuel
SOFC – Solid oxide fuel cell

Path for Decarbonization of Aviation



Source: Roland Berger

Evolution of All-Electric Aircraft with Advances in Battery Technology

- Pack specific energy
- Notional specific energy for each class of aircraft

25-50 miles

20 PAX commuter

100 miles

Current, 170-200 Wh/kg

100 miles

20 PAX commuter

200 -250 miles

300 – 350 Wh/kg

50 – 70 PAX

400 Wh/kg

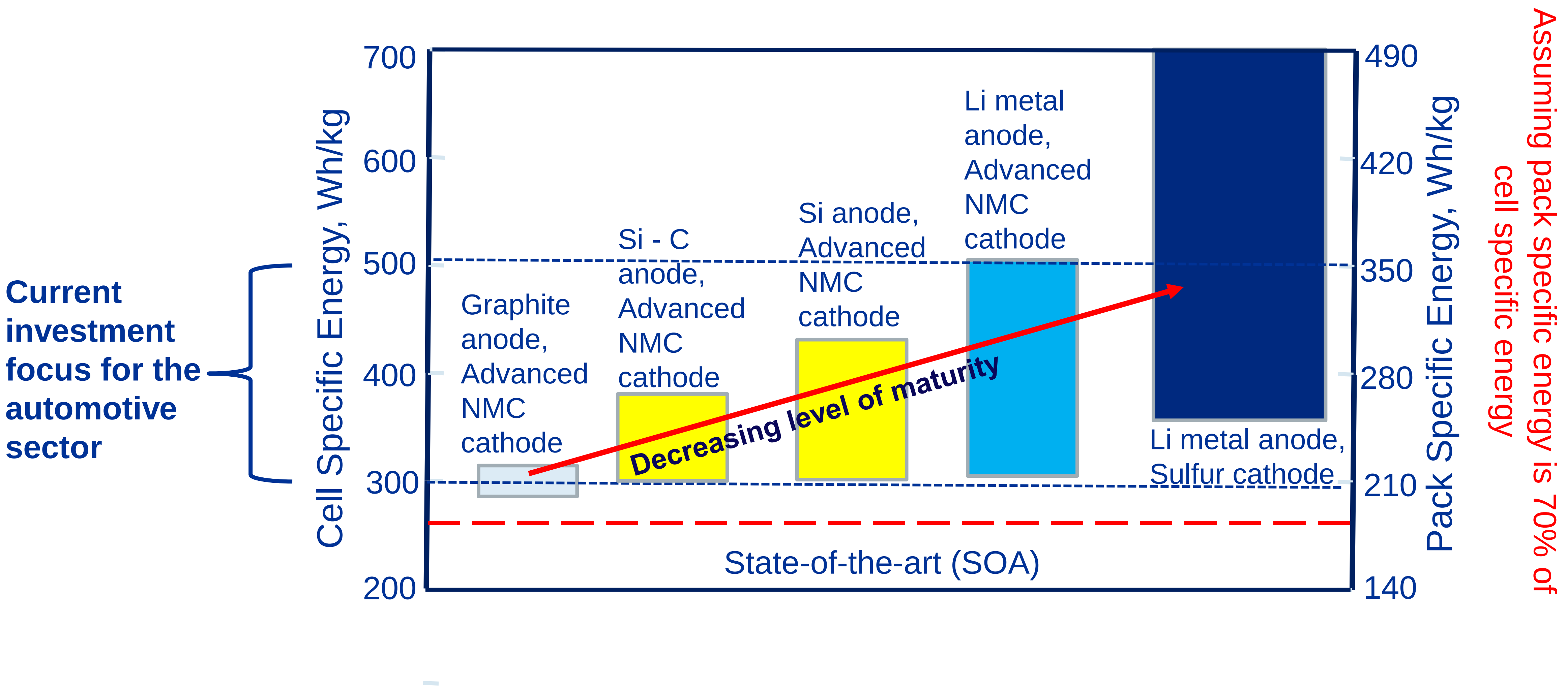
Regional

500 Wh/kg

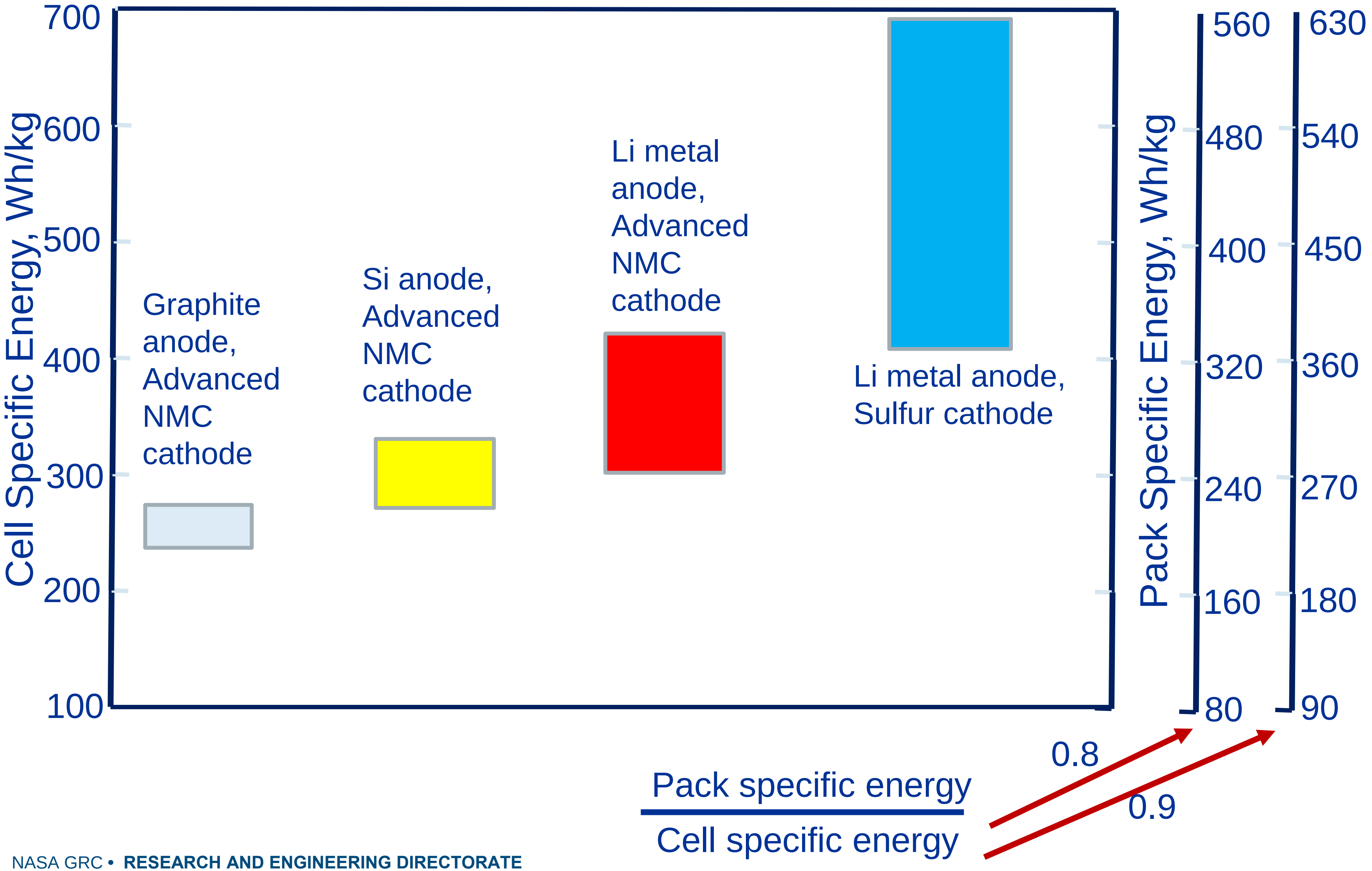
Single-aisle, 737 class

1000 Wh/kg

Progression of Specific Energy of Li Batteries with Liquid Electrolyte



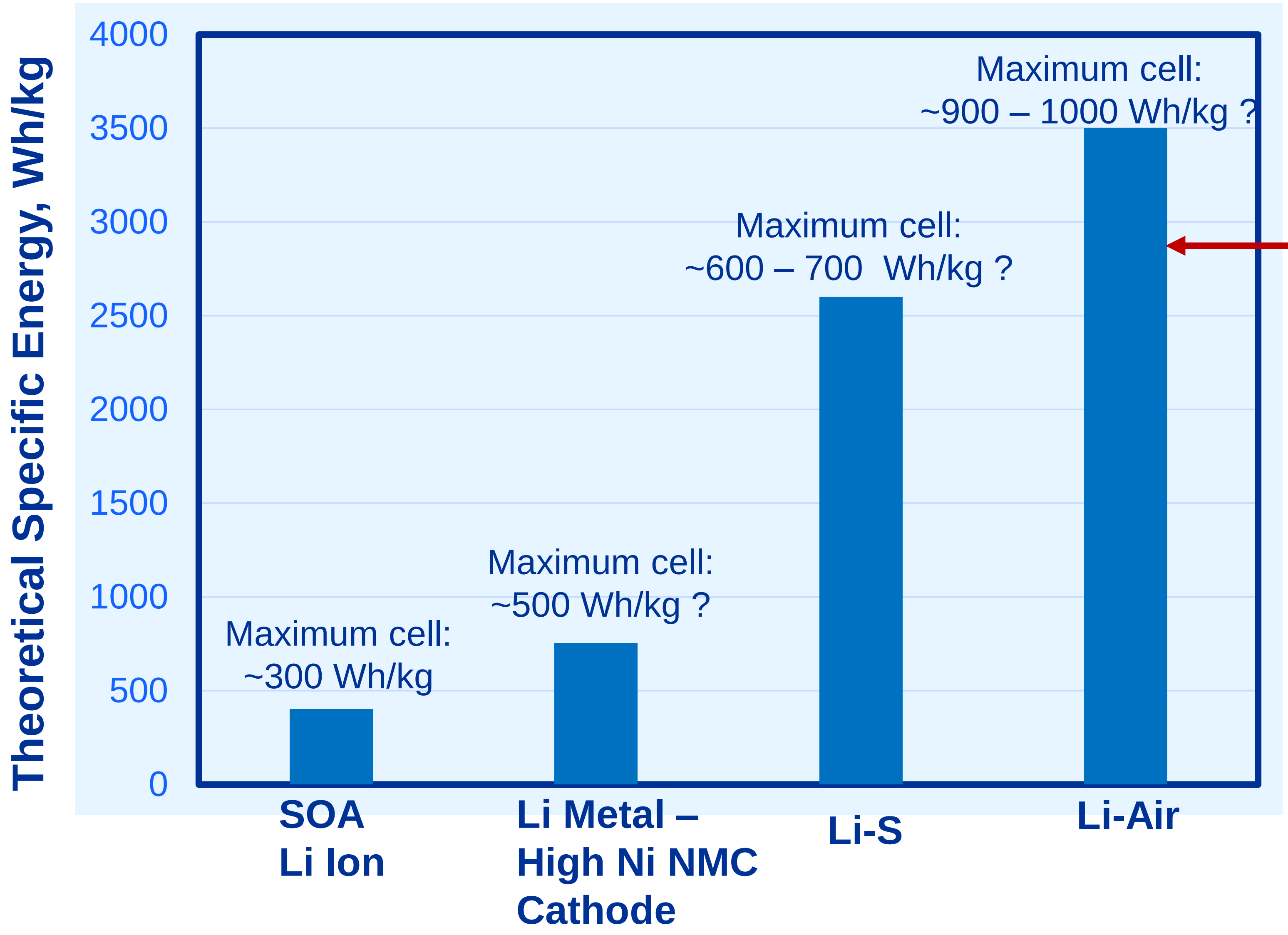
Progression of Specific Energy of All Solid State Li Batteries



Current Status:

- Significant ongoing research – Challenging to achieve 400 Wh/kg at pack level
- Many claims of 300 – 400 Wh/kg specific energy at cell level
- Difficult to predict time horizon – longer-term prospects

Path to Achieving 500 Wh/kg or Higher Pack Specific Energy

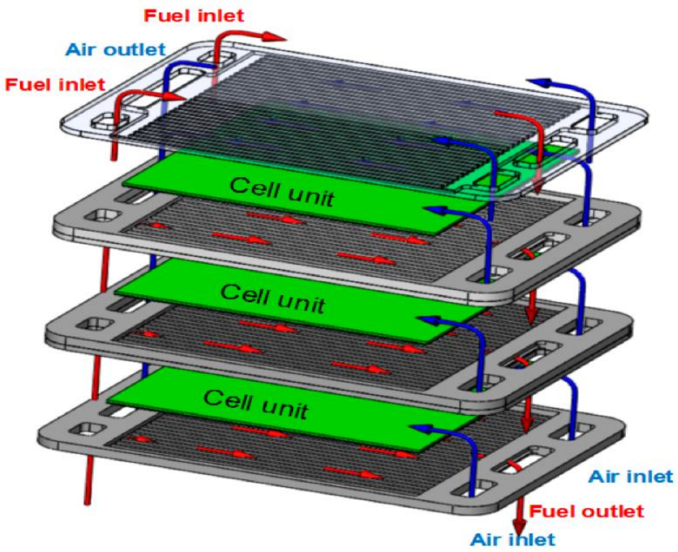


Pore cycle life limits application

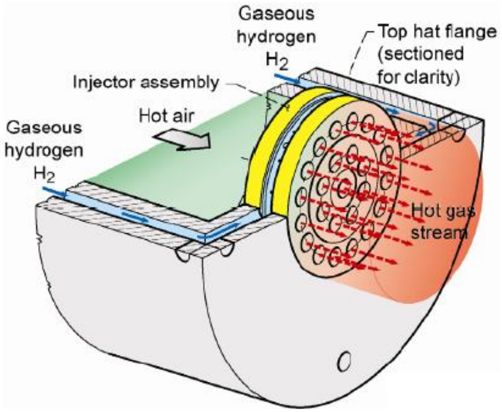
Novel concepts:
Li-CF_6

Challenges for Hydrogen Powered Aircraft

High power density PEM fuel cell system

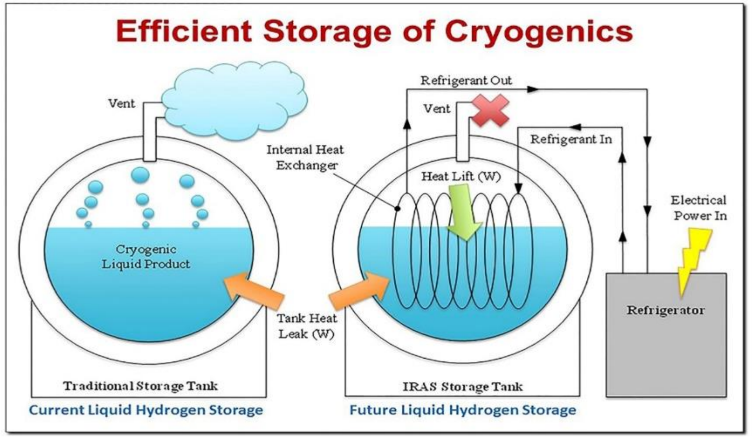


Stable and low NO_x combustor



Hydrogen infrastructure

New aircraft concept

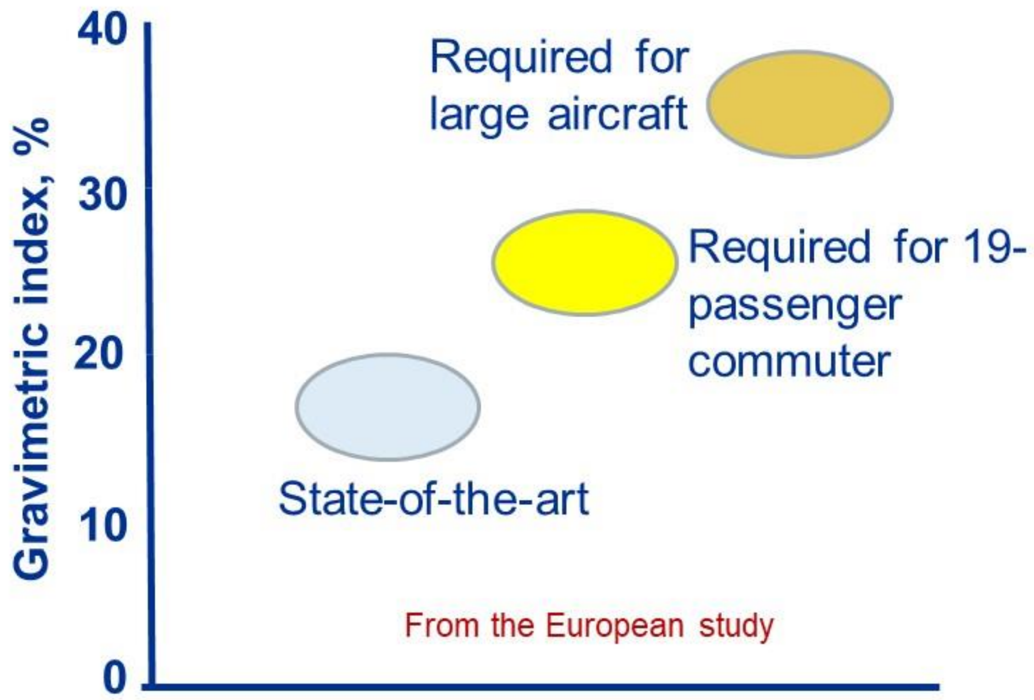


Lightweight and low volume liquid hydrogen storage system

Handling of liquid hydrogen

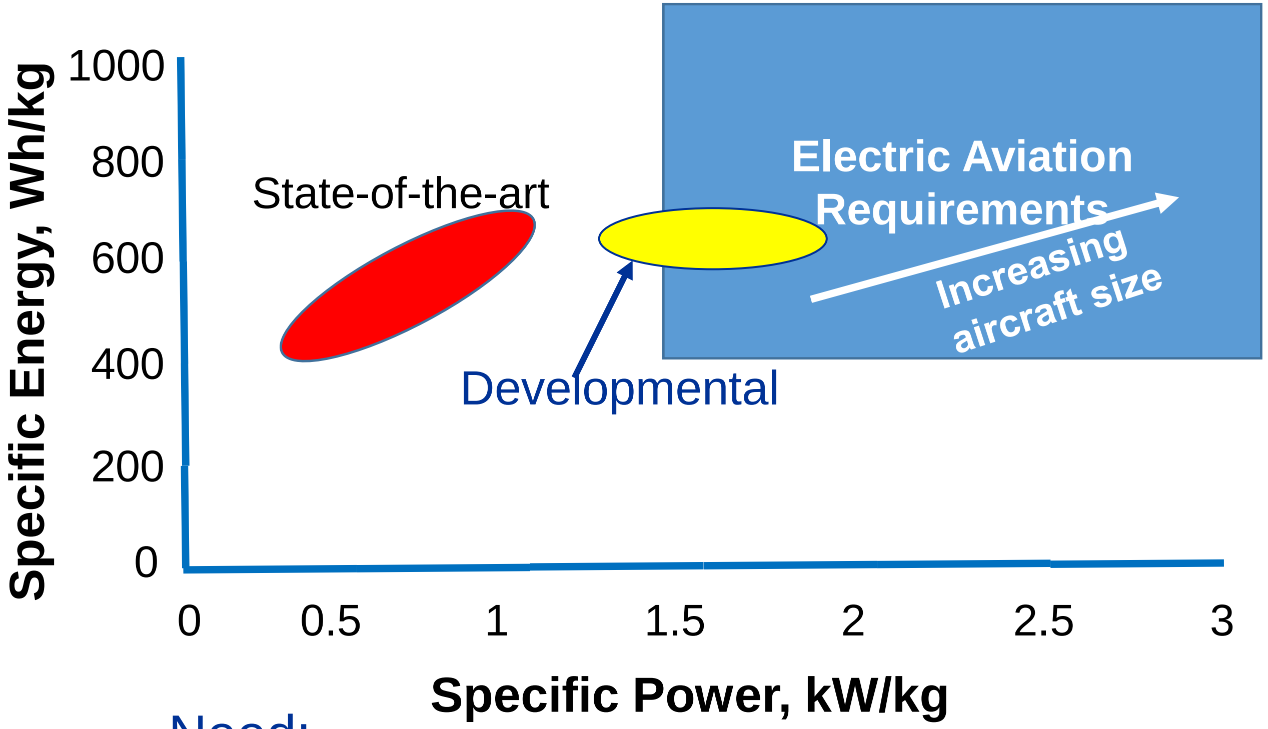
Technology Challenges for Hydrogen Fuel Cell Powered Aircraft

Liquid Hydrogen Storage System



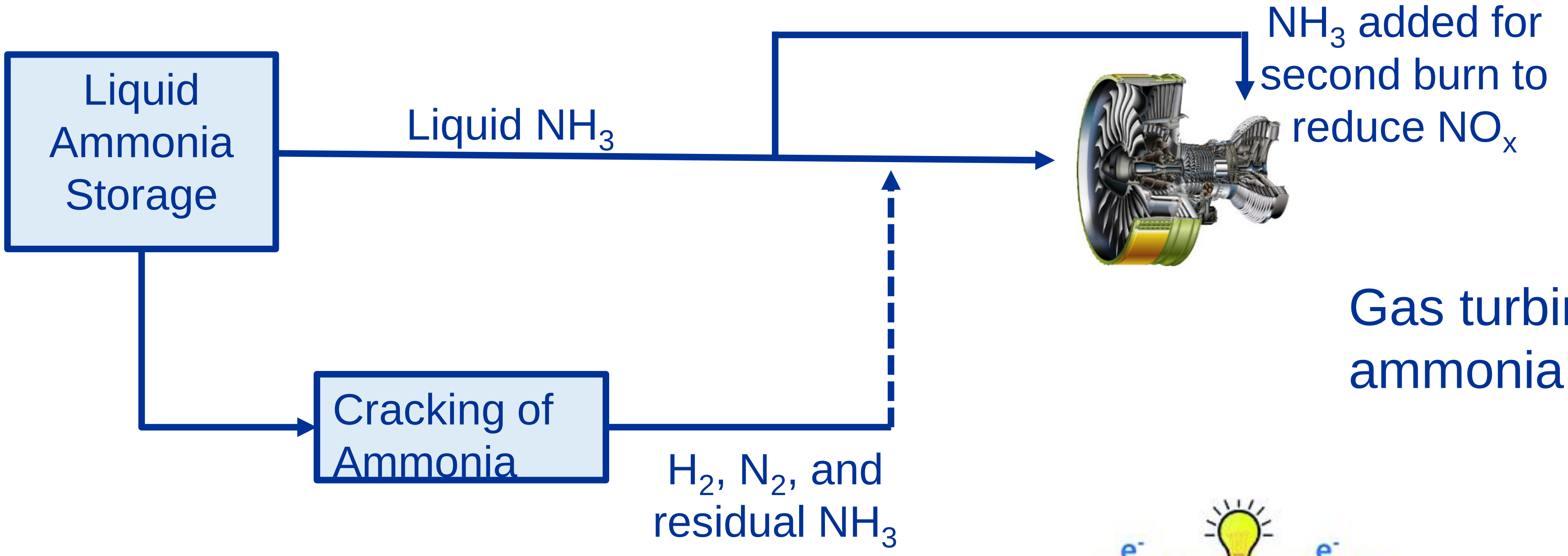
Need:
- Lightweight materials and structural concepts
- Integration with aircraft

Proton Exchange Membrane (PEM) Fuel Cell System



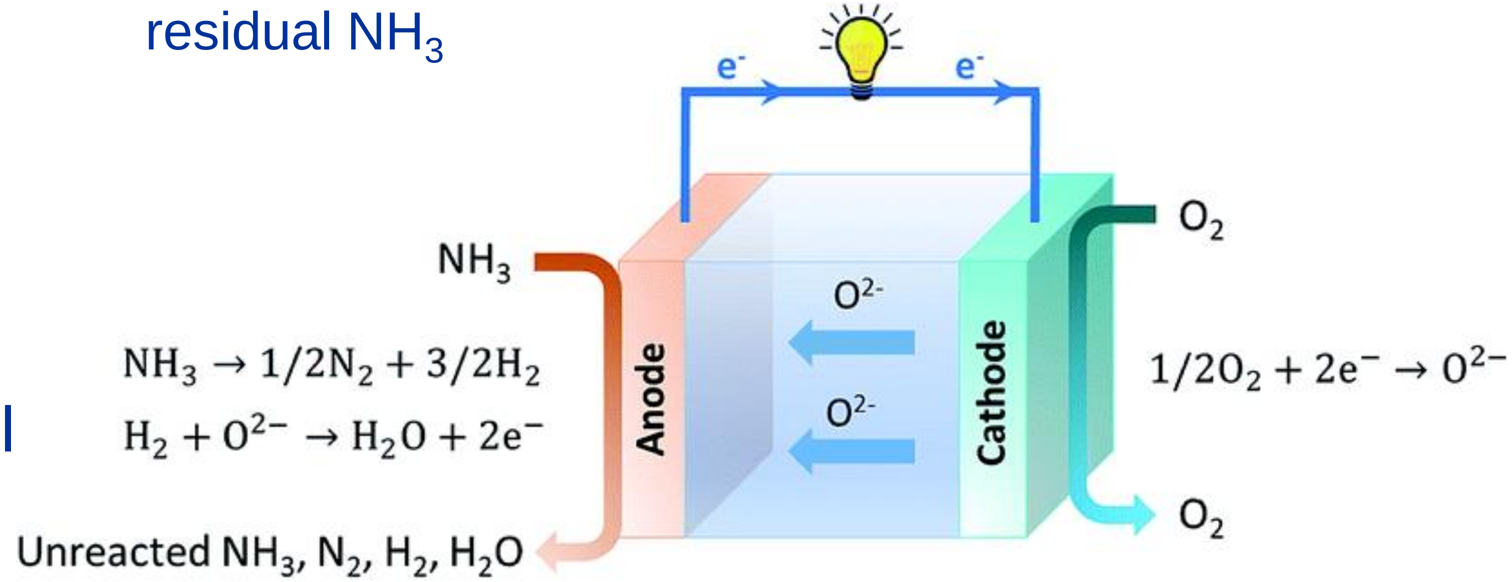
Need:
- PEM fuel cell with higher temperature capability (from SOA 80ºC to 200ºC or higher)
- Integrated, lightweight thermal management system

Use of Ammonia as a Fuel



Gas turbine using ammonia fuel cell

Direct ammonia fuel cell



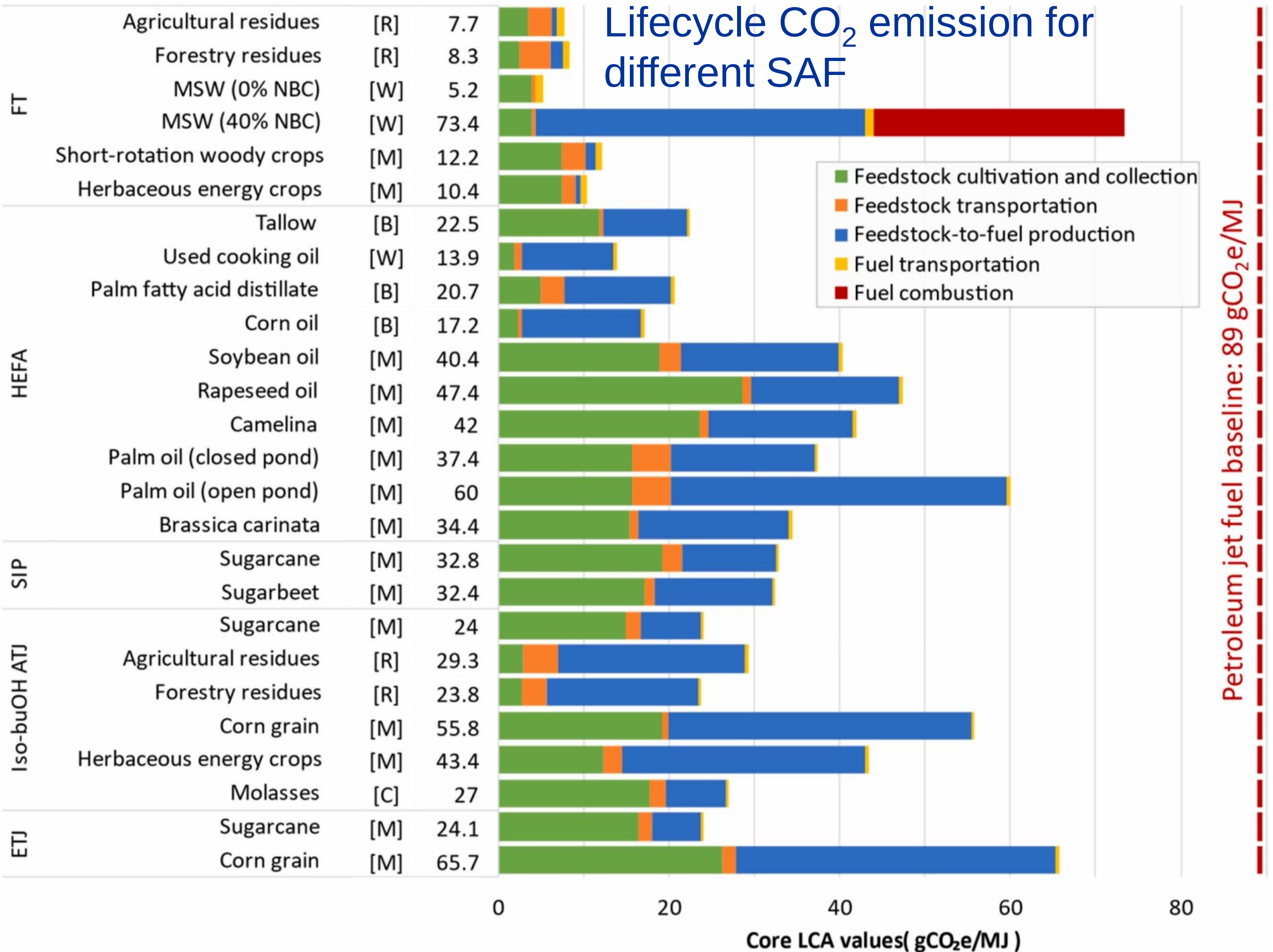
Potential Scenarios for Aviation Decarbonization

Aircraft	2025	2030	2035	2040	2045	2050
9-10 seat commuter	• Battery electric • Hydrogen fuel cell	• Battery electric • Hydrogen fuel cell	• Battery electric • Hydrogen fuel cell	• Battery electric • Hydrogen fuel cell	• Battery electric • Hydrogen fuel cell	• Battery electric • Hydrogen fuel cell
10 – 50 passenger, commuter/regional	SAF	Hydrogen fuel cell	• Battery electric (<30 PAX) • Hydrogen fuel cell	• Battery electric • Hydrogen fuel cell	• Battery electric • Hydrogen fuel cell	• Battery electric • Hydrogen fuel cell
50-100 passenger regional	SAF	SAF	Hydrogen fuel cell	Hydrogen fuel cell	• Battery electric • Hydrogen fuel cell	• Battery electric • Hydrogen fuel cell
100 – 150 passenger	SAF	SAF	Hydrogen combustion turbine	Hydrogen combustion turbine	Hydrogen combustion turbine	• Hydrogen combustion turbine • Hydrogen fuel cell
150 + passenger medium haul	SAF	SAF	SAF	SAF	SAF	Hydrogen combustion turbine
150+ passenger long haul	SAF	SAF	SAF	SAF	SAF	SAF

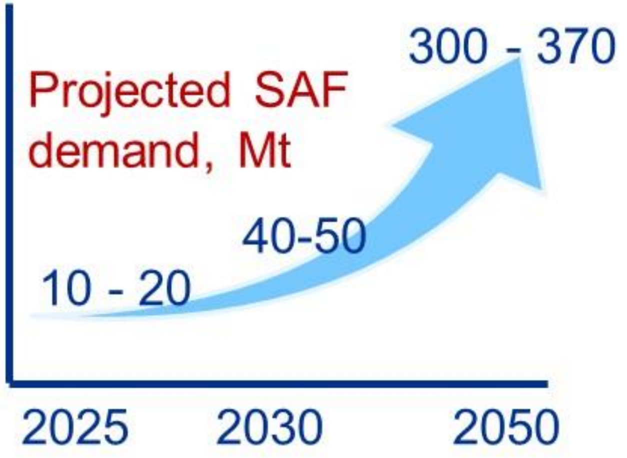
Hydrogen and battery-electric aircraft projected to be up to a third of the aviation energy demand in 2050

Sustainable Aviation Fuel

Lifecycle CO_2 emission for different SAF



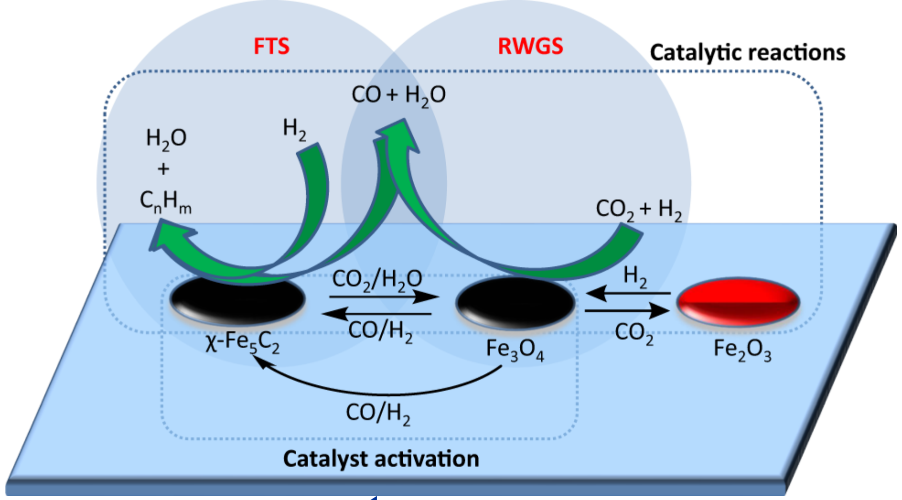
FT – Fischer – Tropsch
HEFA – Hydrotreated esters and fatty acids
SIP – Synthesized iso-paraffins
ATJ – Alcohol-to-jet
ETJ – Ethanol-to-jet
MSW-Municipal solid waste
NBC – No biogenic carbon content



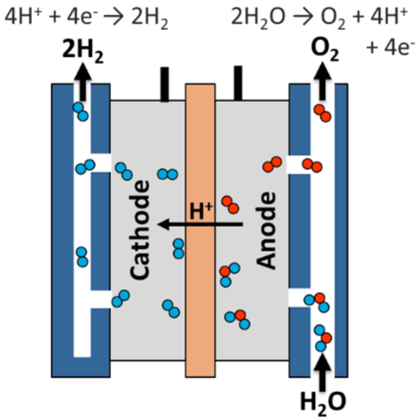
Renewable and Sustainable Energy Reviews Volume 150, October 2021, 111398
CORSIA: The first internationally adopted approach to calculate life-cycle GHG emissions for aviation fuels

Power – to - Liquid (PtL) Fuel

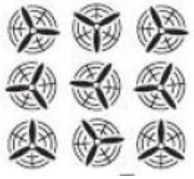

Renewable energy



Water ⇨ Electrolyzer ⇨ Green hydrogen ⇨ Reactor ⇨ Fuel

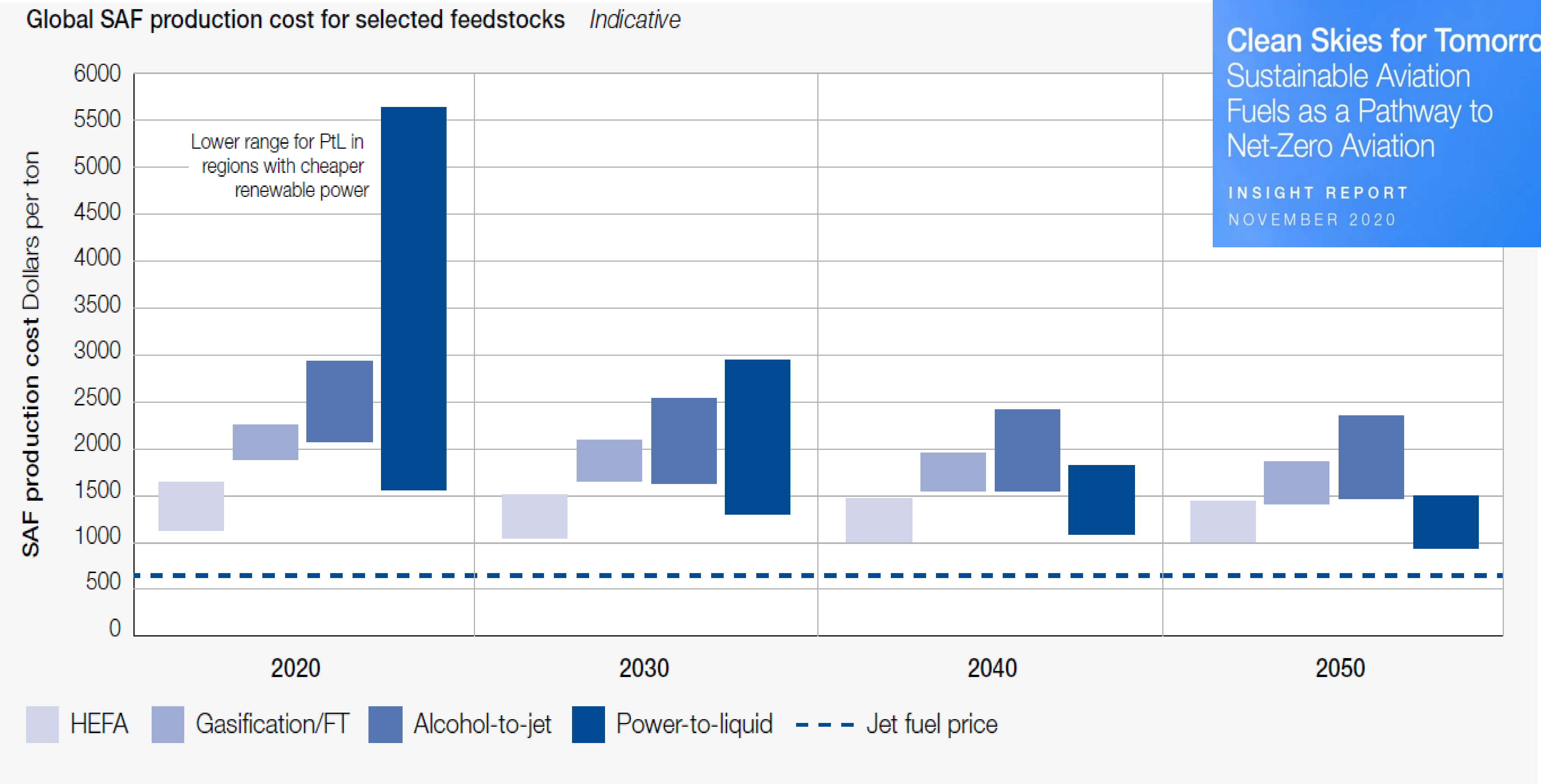


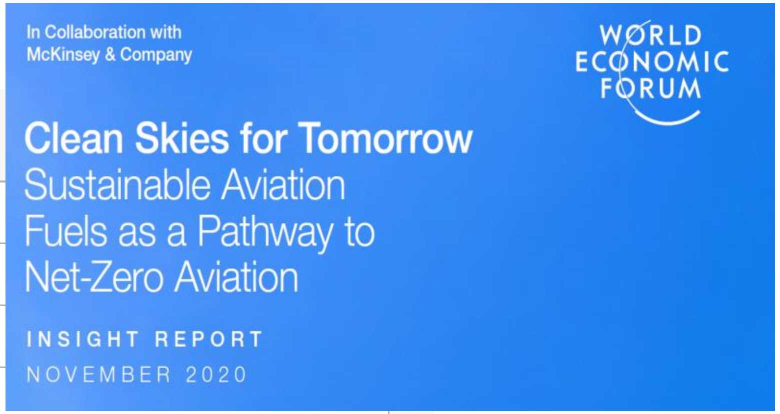
CO_2 from direct carbon capture and industrial exhaust



90 – 100 % CO_2 reduction

Power-to-Liquid Fuel Projected to be Cost Competitive Beyond 2040





Impact of Net-Zero Aviation on Energy Usage

Electricity consumption at a typical intercontinental hub, GWh/year

Today

Terminal
280

Future with battery and hydrogen-powered aircraft

280	Terminal
450-500	Aircraft charging
20-70	Pumping and cooling
500 - 1600	Liquefaction
Total	**1250 - 2450**

Projected energy need for net-zero aviation

By 2050, net-zero aviation could require an additional 5850 terawatt-hr (TWh) of renewable electricity (5% of the expected global demand), 95 million tons of hydrogen (0 – 20% of the expected global demand, and 12 exajoules of sustainable biomass (10-25% of the global expected global sustainable biomass availability)

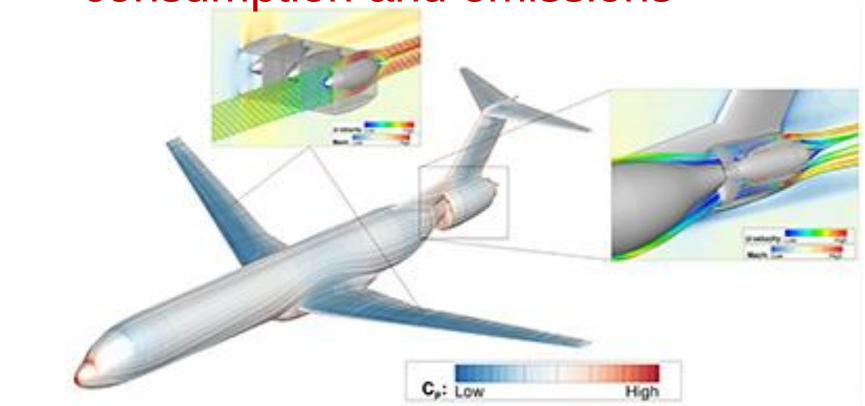
Source: McKinsey & Co

Efforts to Increase Energy Conversion Efficiency and Reduce Energy Consumption for Propulsion Systems

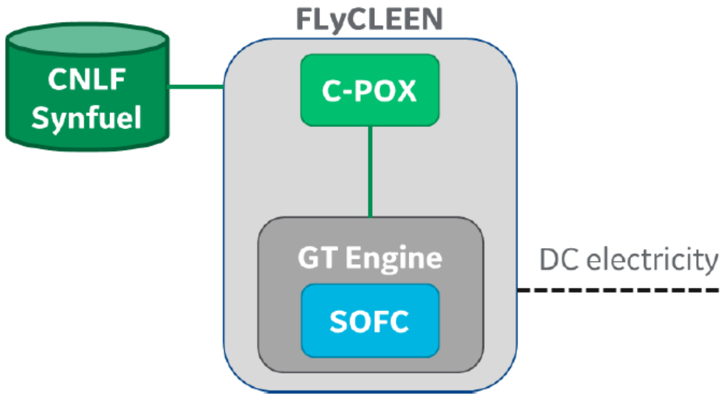
Single-Aisle Turboelectric Aircraft with Aft Boundary Layer Propulsion (STARC-ABL)

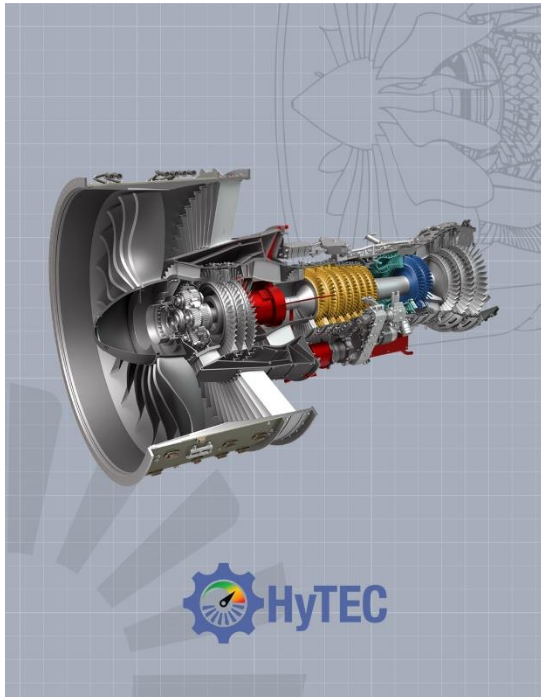
Hybrid electric propulsion

SUbsonic Single Aft eNgine (SUSAN) Electrofan, which shows great potential to reduce aviation energy consumption and emissions



Gas turbine – solid oxide fuel cell (SOFC) hybrid system





Increasing energy conversion efficiency of gas turbine engines

Summary

- Multiple pathways, with no single clear alternative, for decarbonization leading to net-zero aviation in 2050
  - Battery-electric, hydrogen-powered, sustainable aviation fuel including power-to-liquid
  - Significant technology advances needed for using alternate energy sources for large aircraft

- Significant energy requirement for realizing net-zero aviation

- Infrastructure challenges remain for realizing net-zero aviation

- Gas turbine engine improvements and hybrid electric propulsion systems will be important for reducing CO_2 emissions in the near and mid-term