Preparing aviation's journey towards 2050

ISABE 2017, Manchester

9/6/2017 - Dr. Frank Grauer, Director Engineering Advanced Programs, MTU Aero Engines AG

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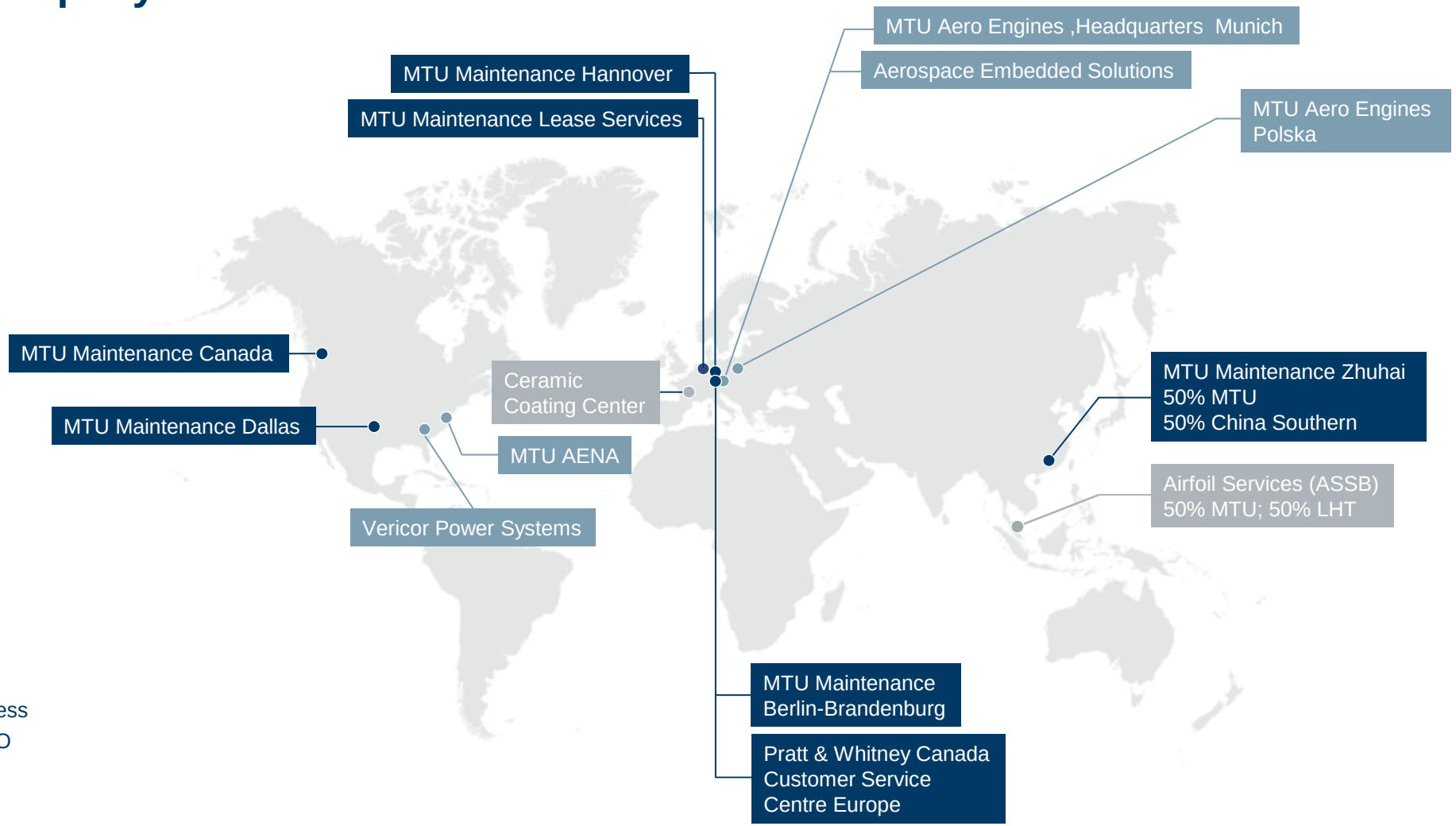
Main company locations worldwide



Global MTU Aero Engines workforce

MTU Aero Engines has a total workforce of around **9,000** employees worldwide – **4,000** of which are employed by MTU Maintenance.

Around **7,300** people work at our locations in Germany:

4,700 in Munich

1,900 in Hannover

700 in Berlin-Brandenburg.

MTU Aero Engines‘ workforce is made up of **48** different nationalities.

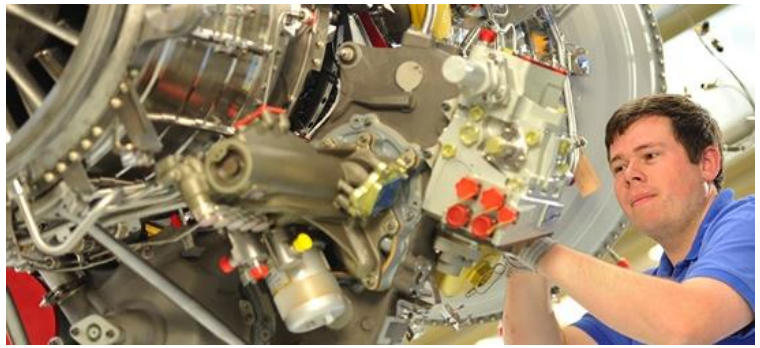
MTU Aero Engines' business model

Commercial engine business

Share in sales: ~ 50%

- Balanced portfolio of products in all thrust categories
- Partnerships with OEMs going back decades

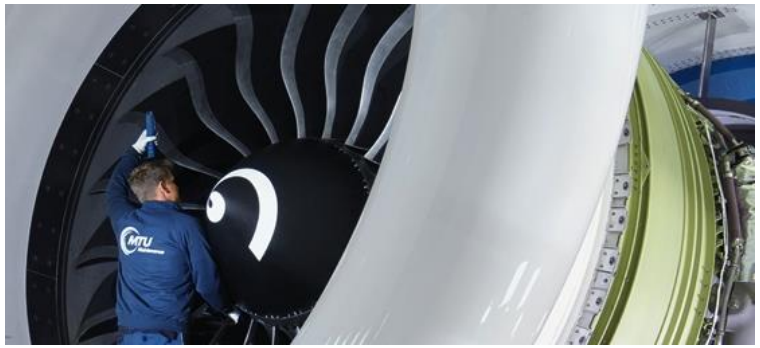
Military engine business



Share in sales: ~ 10%

- European and U.S. engine programs
- Lead industrial partner to the German Armed Forces

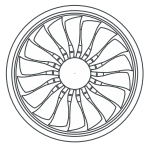
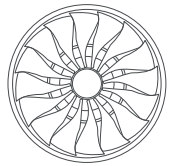
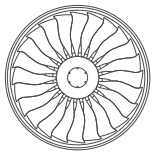
Commercial maintenance



Share in sales: ~ 40%

- Access to high-growth segments
- Provider of services to airlines worldwide

MTU – a key partner to the OEMs

Program	V2500	PW1000G	GEnx	GE9X	GP7000
					
MTU's OEM partners	IAE	Pratt & Whitney A United Technologies Company	GE Aviation	GE Aviation	GE Aviation Pratt & Whitney A United Technologies Company
Program share	16%	15 –18%	6.6%	4%	22.5%

* IAE: International Aero Engines a joint venture of Pratt & Whitney, Japanese Aero Engine Corporation and MTU Aero Engines

MTU is the partner of choice for Pratt & Whitney and GE Aviation in the major engine programs.

Major players in the commercial maintenance market

GE Aviation

Rolls-Royce

MTU Maintenance

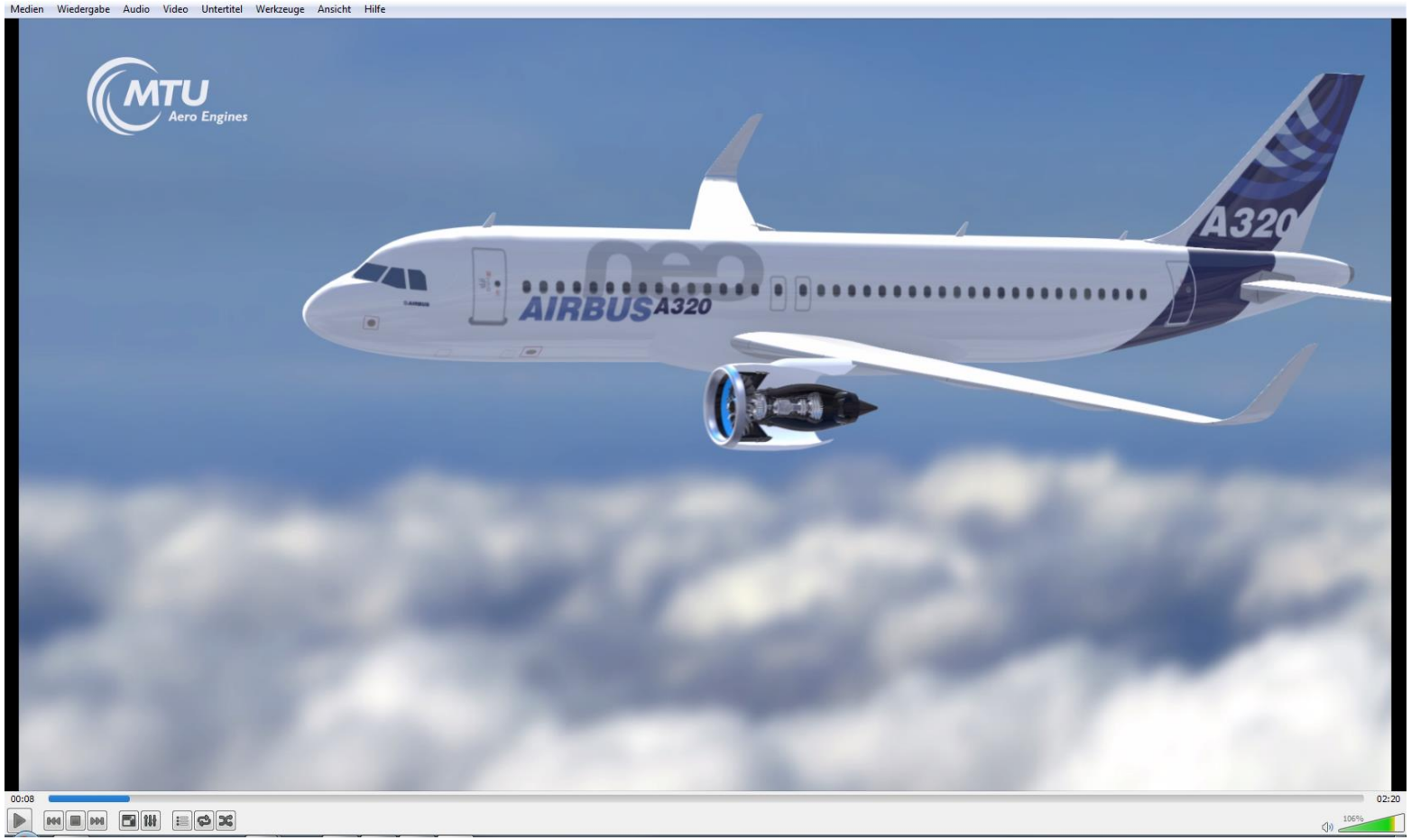
Pratt & Whitney
A United Technologies Company

Lufthansa Technik

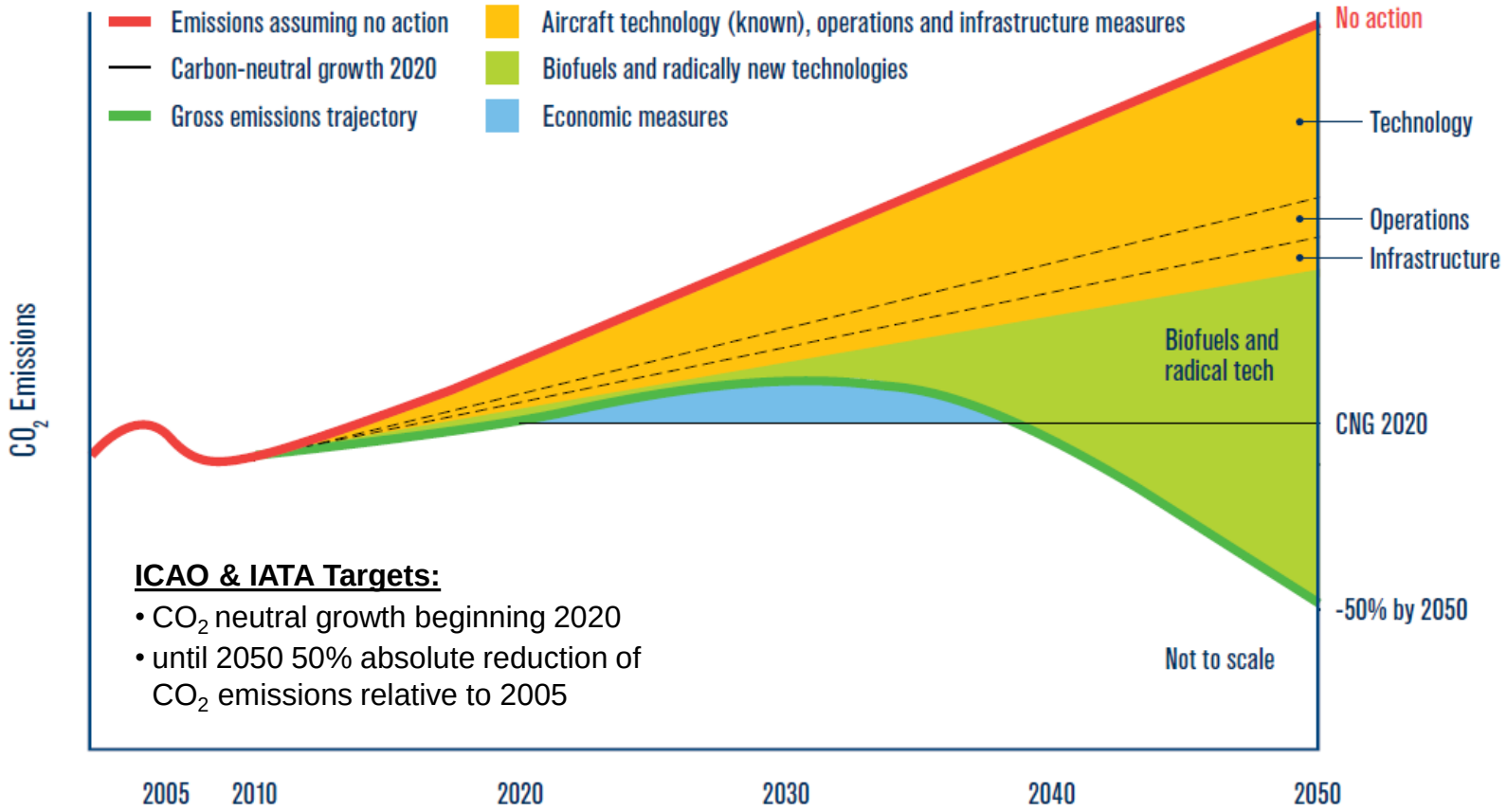
MTU is among the TOP 5 maintenance providers for commercial engines.

Source: ACAS December 2014 – Active engines under contract, commercial aircraft excluding turboprops and business jets

MTU Highlights 2016



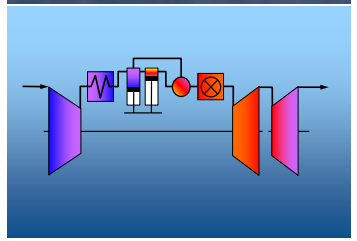
Environmental Challenges | CO_2 Development



ICAO & IATA Targets:

- CO_2 neutral growth beginning 2020
- until 2050 50% absolute reduction of CO_2 emissions relative to 2005

new aircraft concepts



new engine concepts

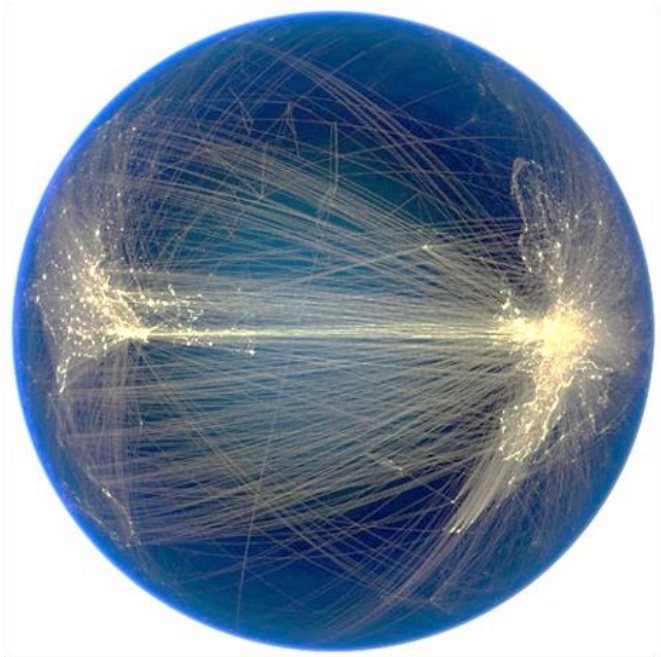
highly improved air traffic management

alternative jet fuels

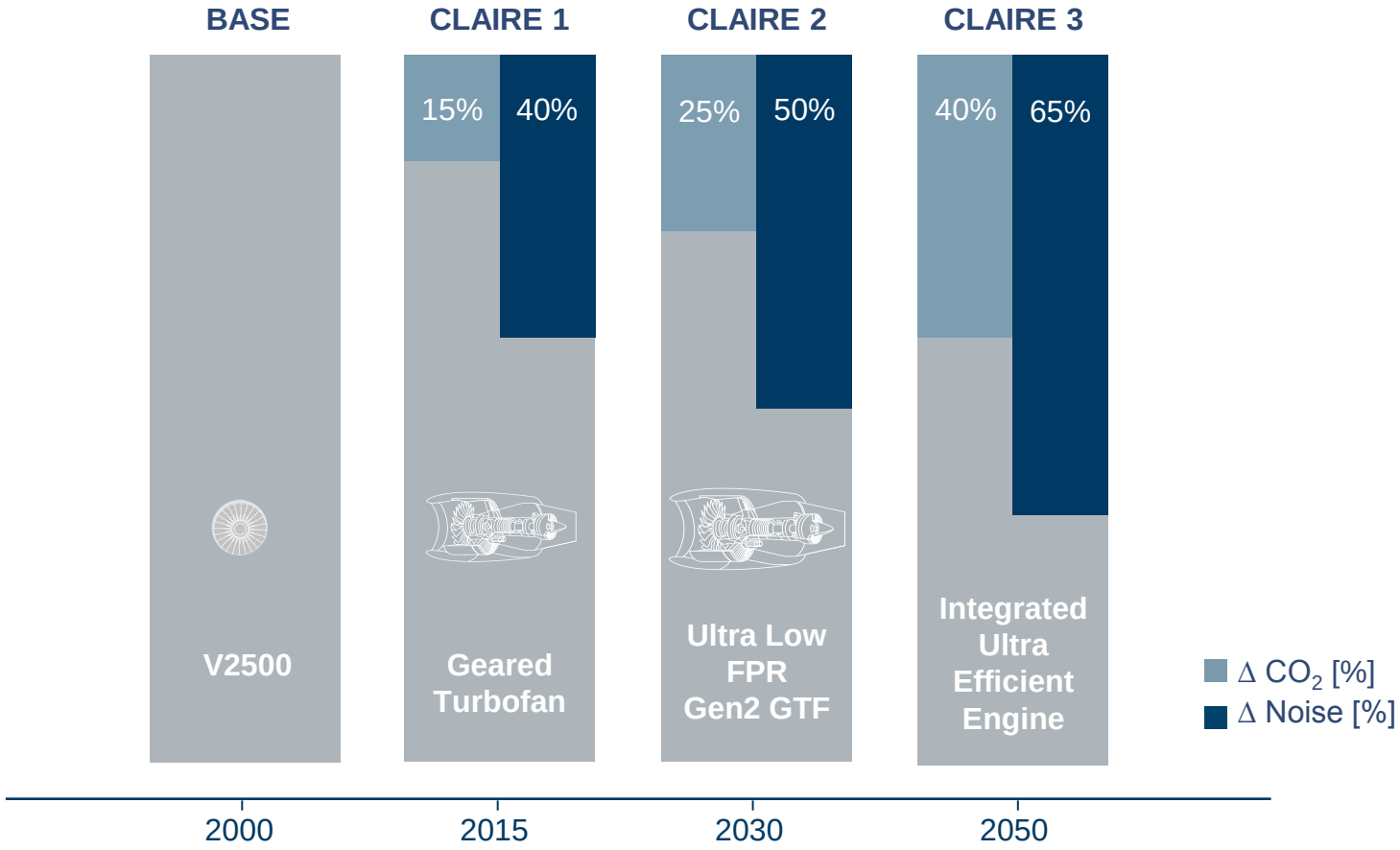
ICAO & IATA setting highly demanding targets for Aviation

MTU's Approach Claire | Clean Air Engine

Supporting the Vision 2020 & Flightpath 2050 Targets



Today's Air Traffic between Europe and the US



Evolutionary development of GTF-engine for 2030+ / revolutionary ideas needed for 2050

Status Claire 1 | EIS 2015

15% CO_2 and 40% Noise Reduction

Claire 1

Narrowbody aircraft leaving Munich airport

Year 2015
GTF powered A320neo

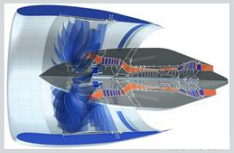
First generation GTF-family is flying successfully achieving more than 16% fuel burn reduction and meeting all noise targets

Challenge Claire 3 | EIS 2050

Additional 15% CO_2 and Noise Reduction relative to Claire 2

Propulsive Efficiency

- increased Bypass Ratio / decreased Fan Pressure Ratio

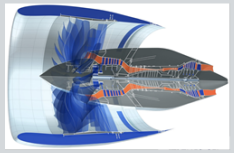


- Open Rotor / Propeller

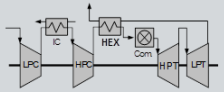
- distributed highly integrated engine

Thermal Efficiency

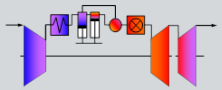
- increased Overall Pressure Ratio



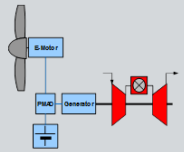
- improved engine cycle

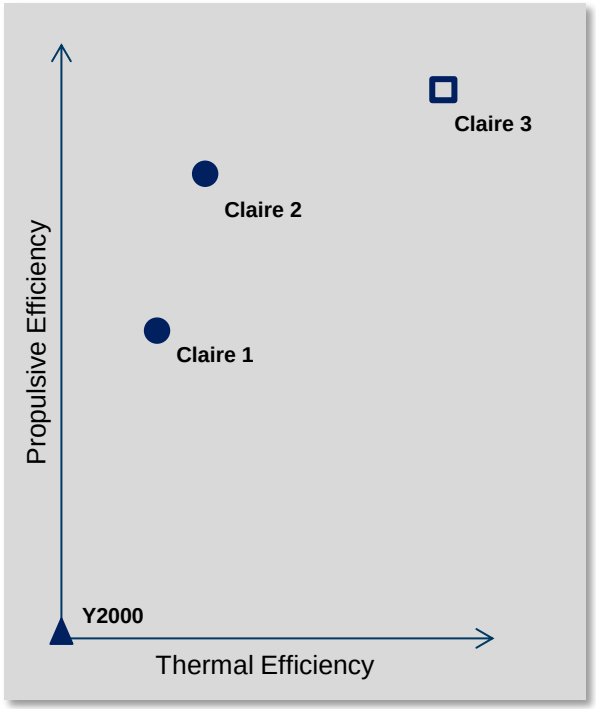


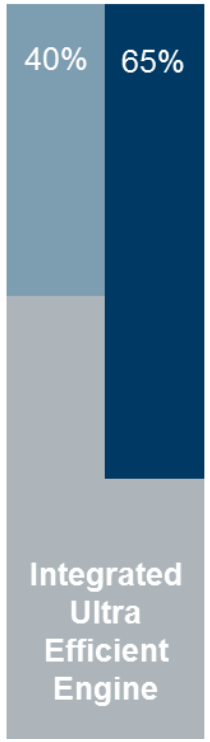
- new engine cycle



- new engine concepts
  - turbo-electric hybrid



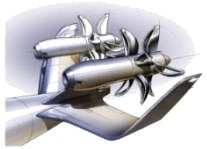




Propulsive and thermal efficiency improvements remain the key on engine level

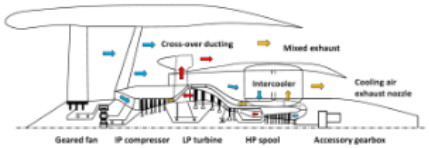
Candidate Engine Concepts

Nutating Disc

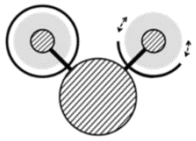


Boxprop

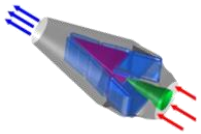
CENTRELINE
turbo electric



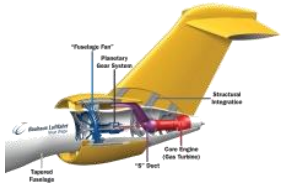
Reverse-Flow Core



Retractable
Nacelle

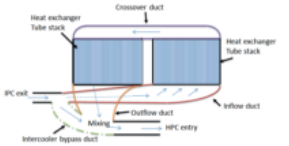


Recuperation

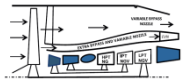


Fuselage Fan

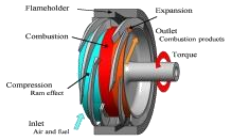
Bauhaus Luftfahrt
Neue Wege



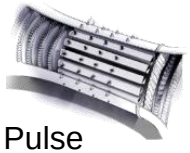
Intercooler



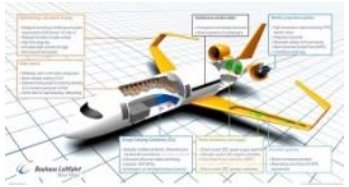
Variable Core



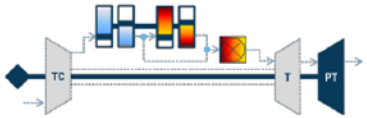
Wave Rotor



Pulse
Detonation



CE-Liner
all electric



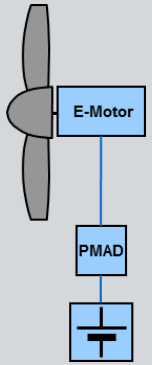
Composite Engine

A wide variety of different concepts under investigation within Universities, Research Institutes and Industry

Electric Propulsion – a Long Term Perspective for Aviation ?

All electric

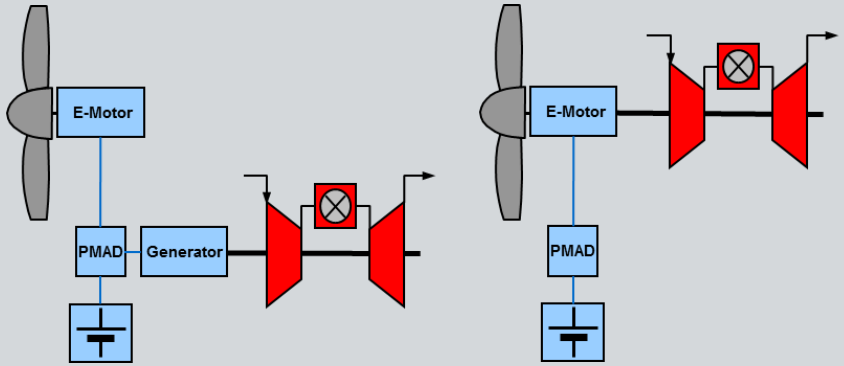
- Electric Motor driving a Fan
- Battery or Fuel cell as power supply



PMAD: **P**ower **M**anagement **A**nd **D**istribution

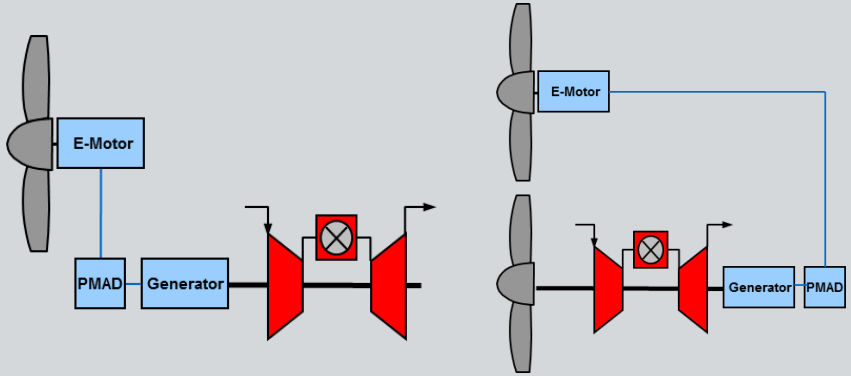
Hybrid electric

- Gas turbine driving Generator
- Battery as additional power supply
- Fan driven by E-Motor (serial hybrid) or
- Fan driven by E-Motor and Gas turbine (parallel hybrid)



Turbo electric

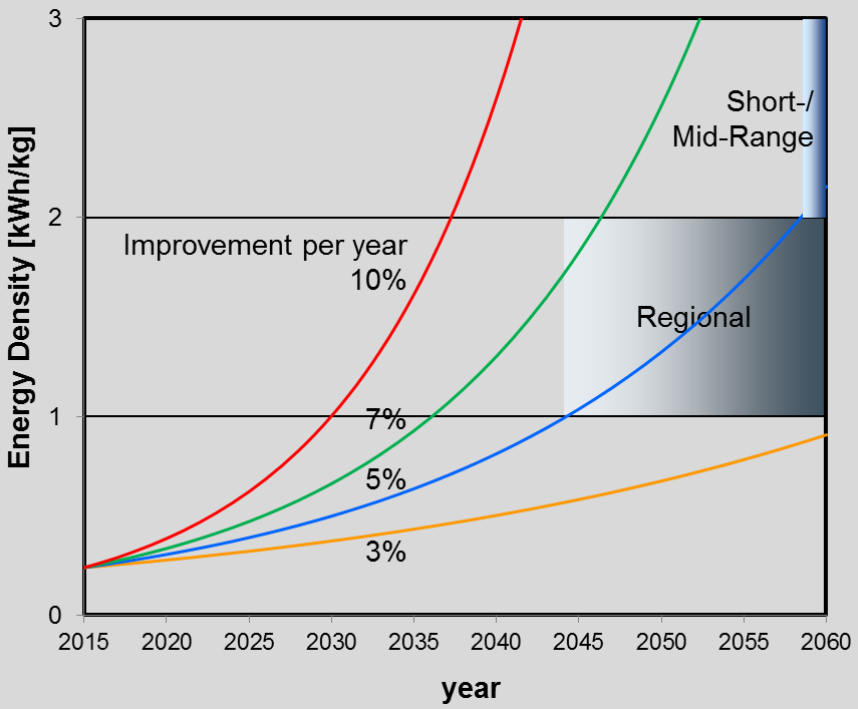
- Gas turbine driving Generator
- Fan(s) driven by E-Motor or
- Fan(s) driven by E-Motor and Gas turbine



Increasing focus on Turbo electric propulsion concepts

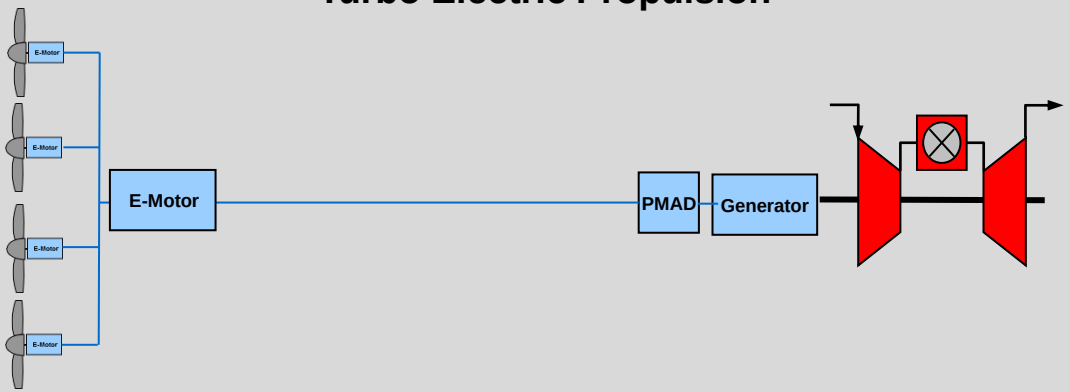
Electric Propulsion – a Long Term Perspective for Aviation ?

All Electric Propulsion



Scenarios regarding the evolution of battery energy density

Turbo Electric Propulsion



Does the expected benefit justify the additional weight and complexity of the system ?

Electric Propulsion – a Long Term Perspective for Aviation ?

	General Aviation	Regional	Narrowbody	Widebody
All electric	✓ 	? [1] 	✗ 	✗ 
Turboelectric	? [2]	? [2]	? [3]	? [3]

1: Conceivable for short range, low PAX, in case of Battery energy density reaches 1-2 kWh/kg
2: Conceivable with conventional Generator/Motor-Technology, sufficient system-level benefit to be proven
3: Conceivable with superconducting devices only. System-level benefit to be proven

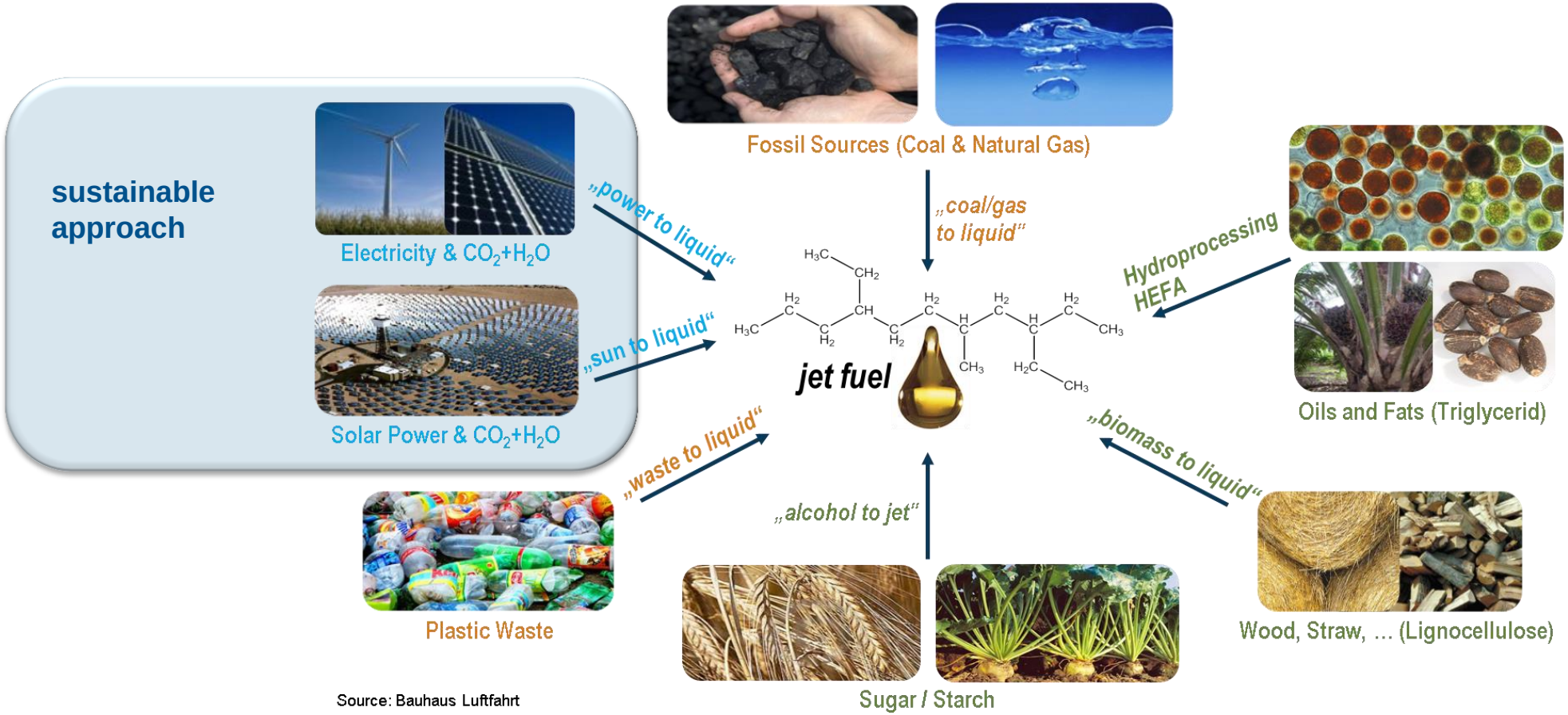
Basic conceptual work still to be completed to confirm benefits and opportunities of electric propulsion systems

Aircraft – Engine Integration | Visionary Concepts

Highly integrated engines, smart structures, drag reduced wing & body, minimized control surfaces

Alternative Sustainable “Drop-in” Jet Fuels

Enabling a CO_2-neutral utilization of existing engines



Source: Bauhaus Luftfahrt

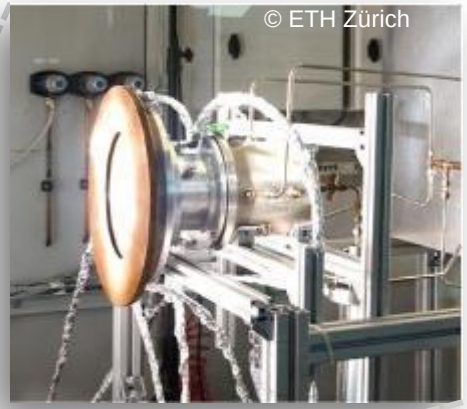
Alternative sustainable and CO_2 neutral synthetic fuels will significantly contribute to achieve FP2050 targets

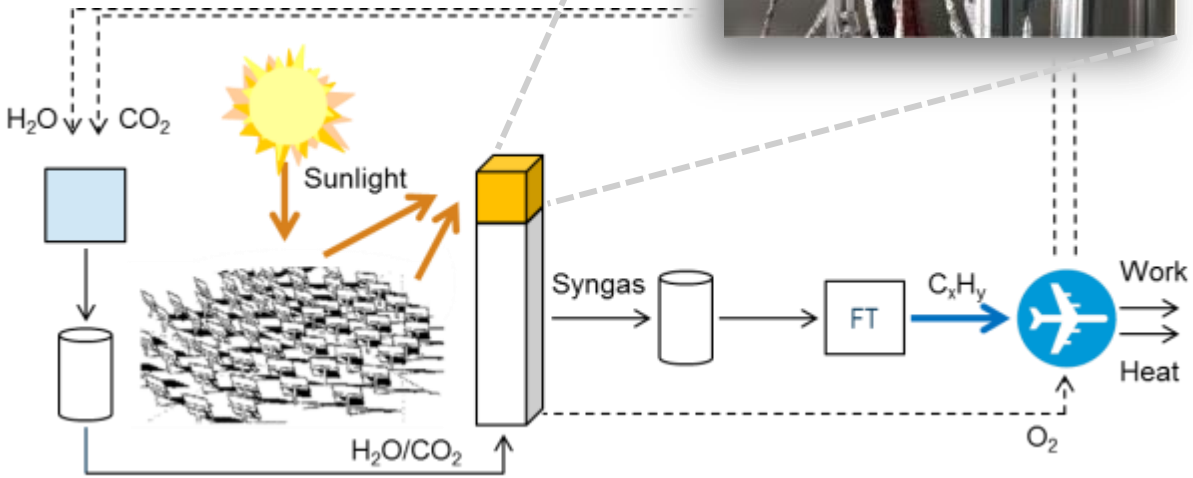
Solar Thermal Jet Fuel | SolarJet

Sustainable drop-in Jet Fuel with Small Land Requirements

Production Process

- CO_2
- H_2O
- solar power





Sun to Liquid Field Demonstrator (Successor of Solar Jet), IMDEA Energía at Móstoles Technology Park, Madrid, Source: Bauhaus Luftfahrt

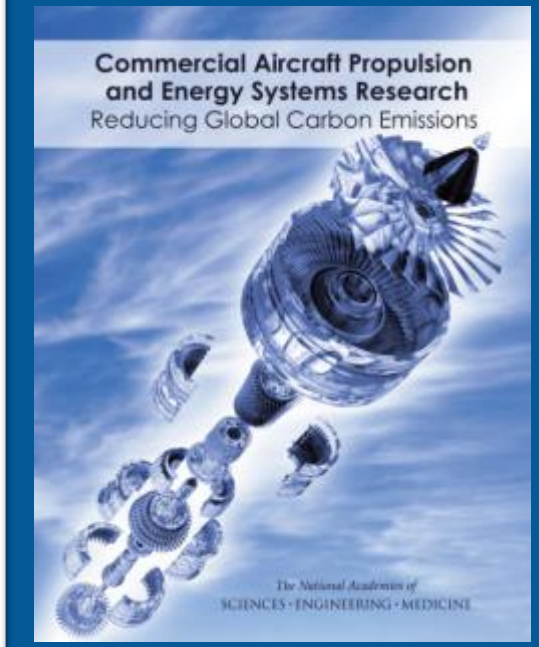
SolarJet technology approach not conflicting with any land used for food production – currently at low TRL

Achieving the Overall Targets | Flight Path 2050

Key technologies to invest in

- **highly integrated** aircraft-engine concepts and design
- improved engine **propulsion** and **thermal efficiency**
- development of **„drop-in“ sustainable alternative** jet fuels
- assessment of **turbo-electric engine concepts**

NASA initiated study:



- Aircraft-Propulsion Integration
- Gas Turbine Engine Research
- Sustainable Alternative Jet Fuels
- Turboelectric Propulsion Research

MTU view is well in line with NASA-Study

Preparing Aviation's journey towards 2050 is a huge task …

… full of engineering challenges

… requiring a sound view on all different approaches

... with no unique solution visible right now

… needing integrated A/C & engine solutions

… offering amazing opportunities for researchers worldwide