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Propulsion Technology Options for Climate-Compliant Aircraft Design

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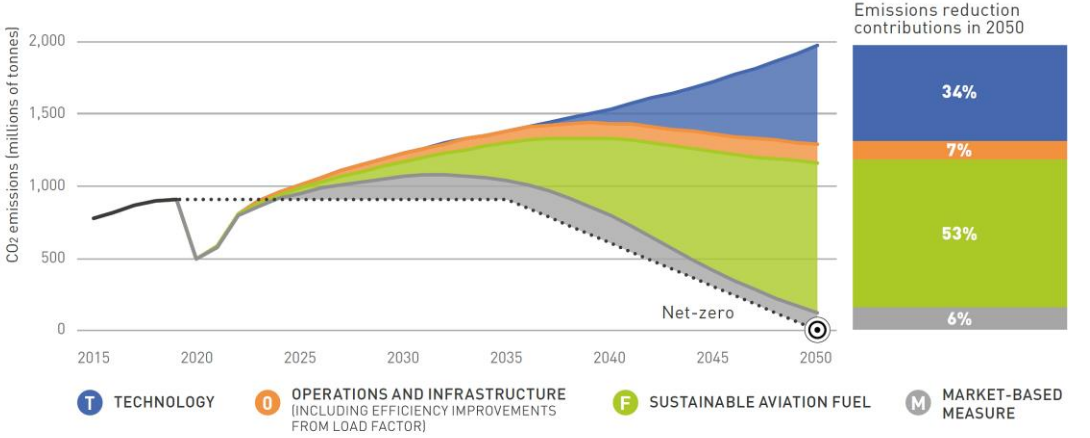
5th Bauhaus Luftfahrt International Symposium
Berlin, 13 March 2024

Climate Targets in Aviation: The Role of Alternative Fuels

ATAG decarbonisation „Scenario 3“

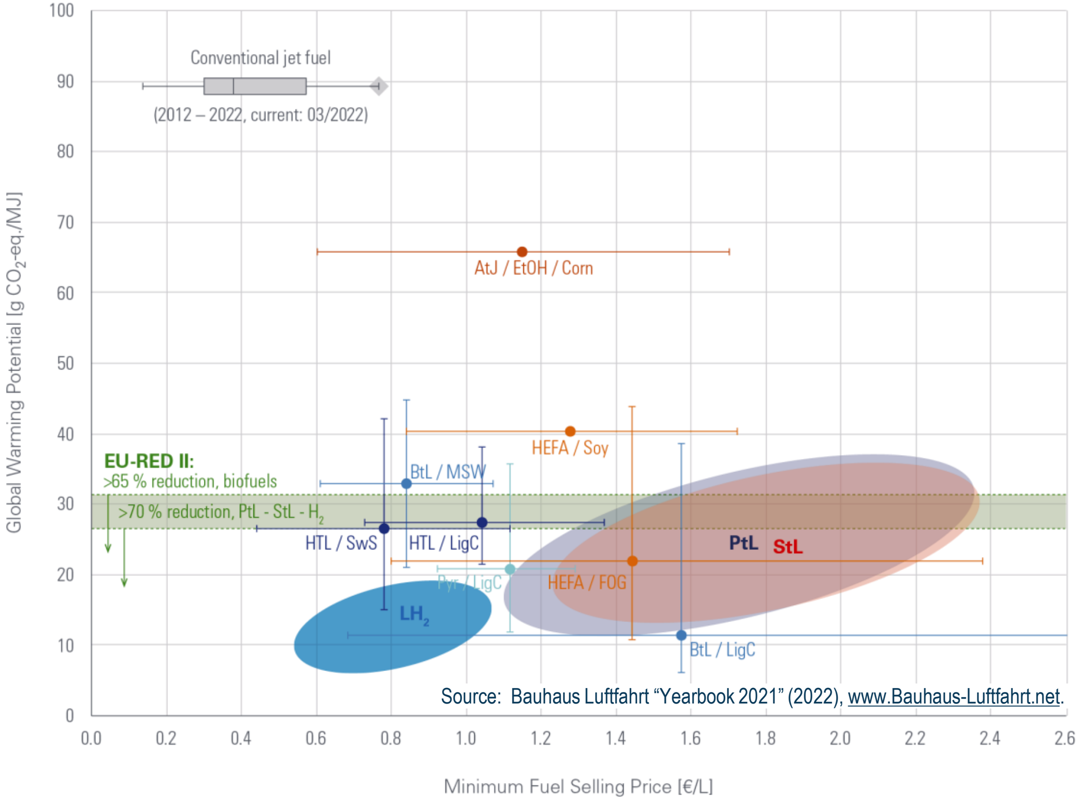
- „Aspirational & aggressive technology perspective“



Sustainable aviation fuel — F_4 — Backcast of what is required (around 1,000 Mt of CO_2) to replace 90% of conventional fuel: 330 Mt (410 billion litres) of SAF with a 100% emissions reduction factor by 2050

Source: Air Transport Action Group, “Waypoint 2050“, Second Edition, September 2021.

Alternative Fuel Options for Aviation



Source: Bauhaus Luftfahrt “Yearbook 2021” (2022), www.Bauhaus-Luftfahrt.net.

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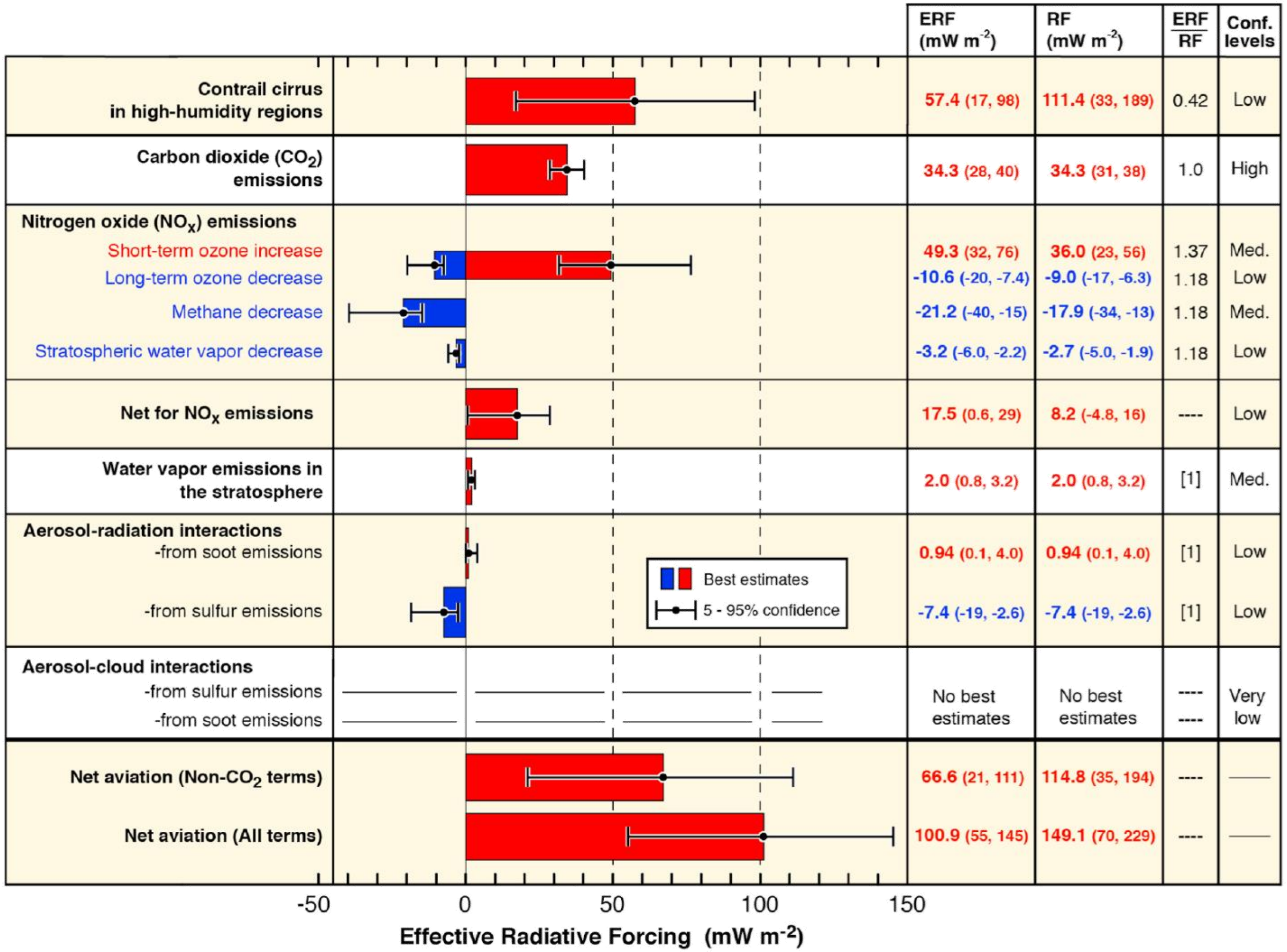
The Full Climate Impact of Aviation



- **Global aviation's radiative forcing terms (1940 – 2018)**

Source:
Lee, D.S. et al. "The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018", Atmospheric Environment, Volume 244, 2021, 117834,ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2020.117834.

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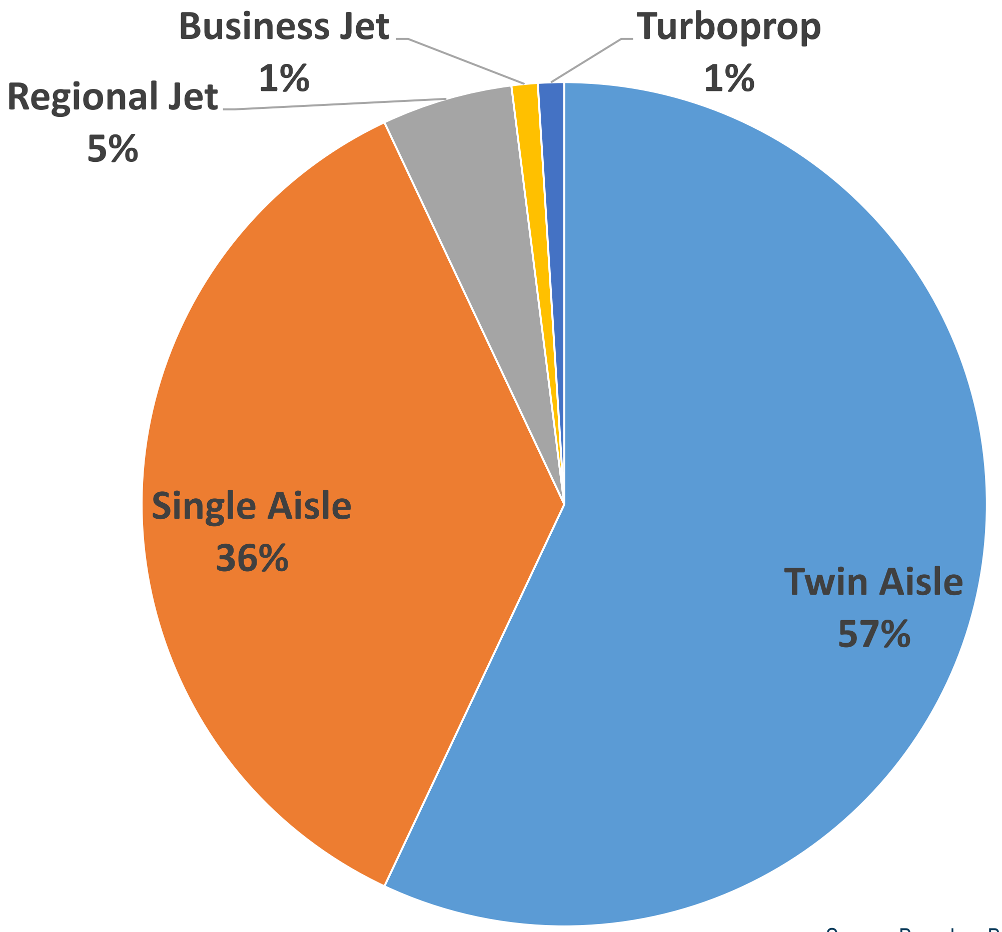
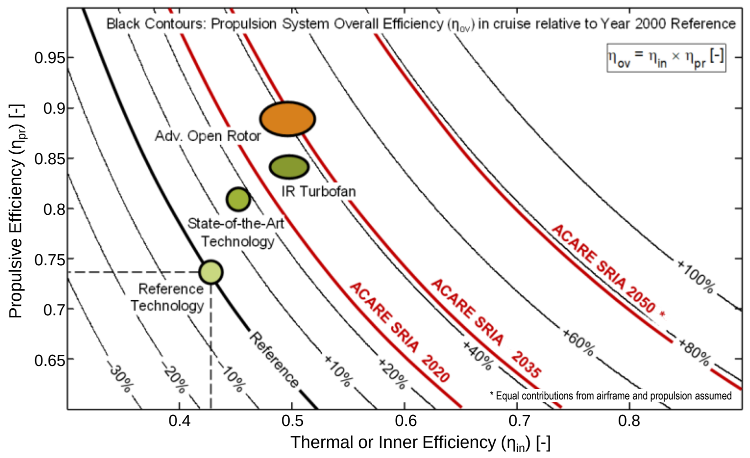
Fuel Consumption of Aviation‘s Global Fleet – A Breakdown

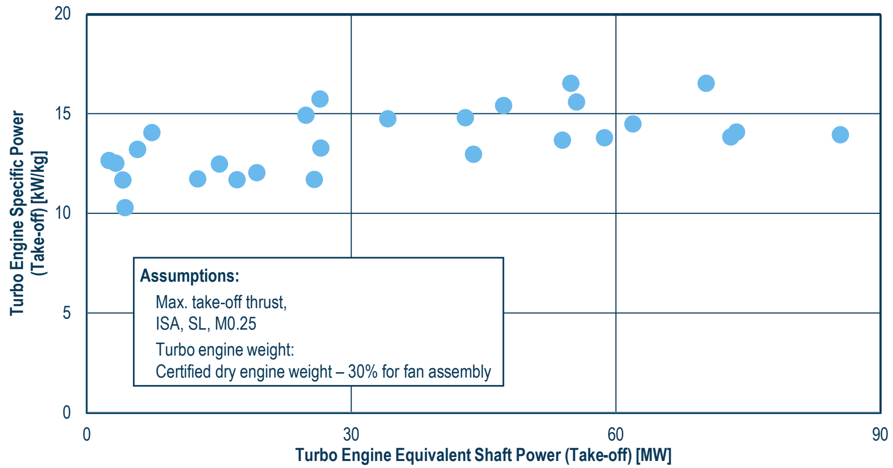


Source: Based on B. Yutko and J. Hansman, Report No. ICAT-2011-05 (2011)

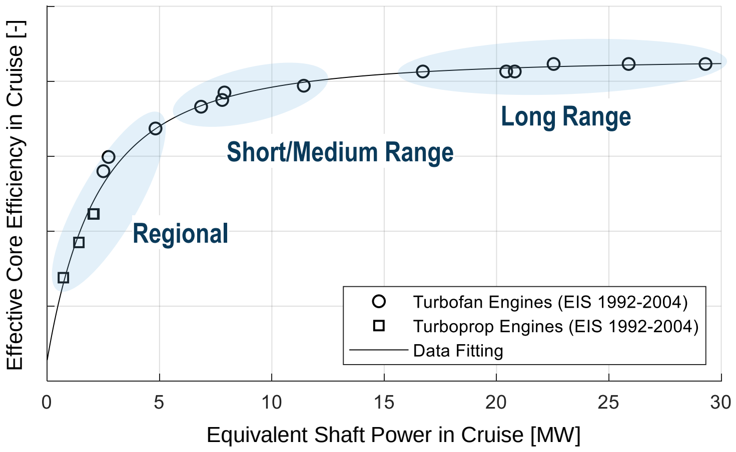
The Gas Turbine: Benchmark for Revolutionary Propulsion

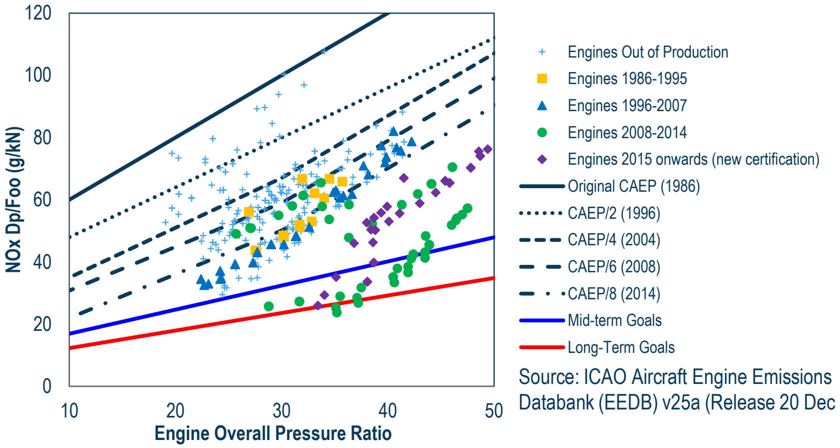
- High efficiency
- High specific power
- Convenient power lapse characteristics
- High reliability





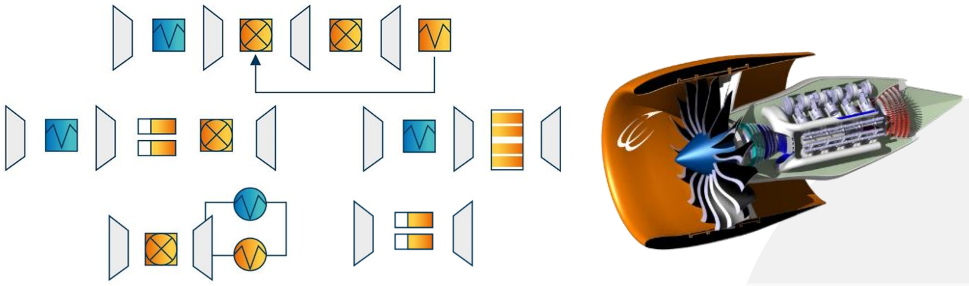
- Strong size effects
- NO_x coupled to cycle efficiency



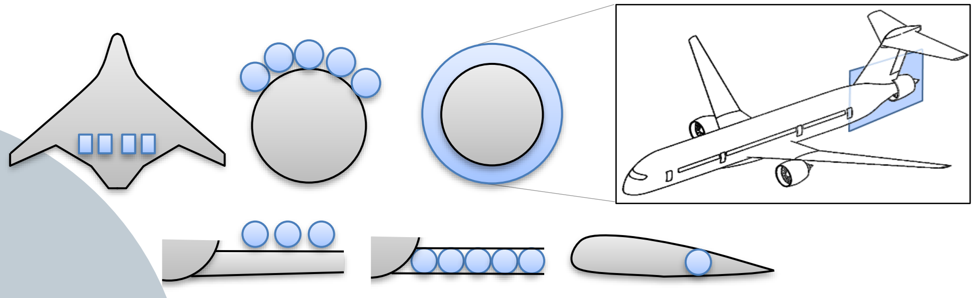


Source: ICAO Aircraft Engine Emissions Databank (EEDB) v25a (Release 20 Dec 2018)

Landscape of Revolutionary Propulsion Technology Options

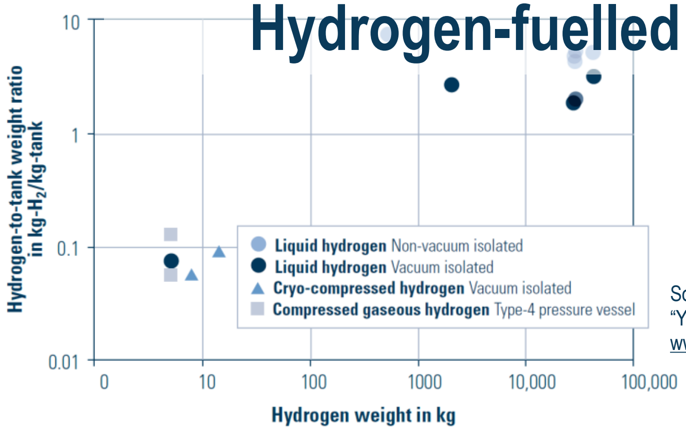


Radical heat engines



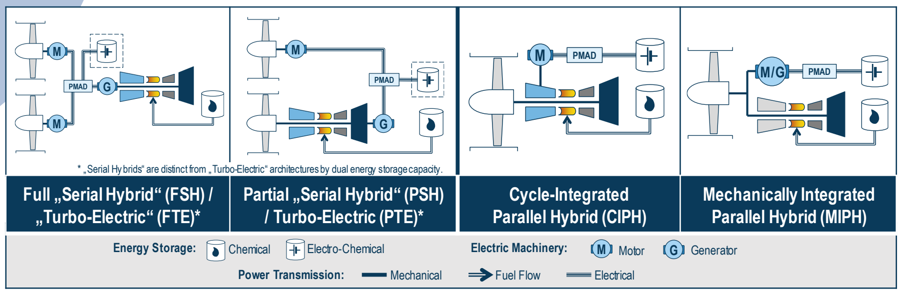
Synergistic propulsion-airframe integration

Hydrogen-fuelled propulsion



Source: Bauhaus Luftfahrt "Yearbook 2019" (2020), www.Bauhaus-Luftfahrt.net.

(Partially) electrified energy & power



Source: Seitz, A. et al., Proc IMechE Part G Vol. 232(14), DOI: 10.1177/0954410018790141, 2018.

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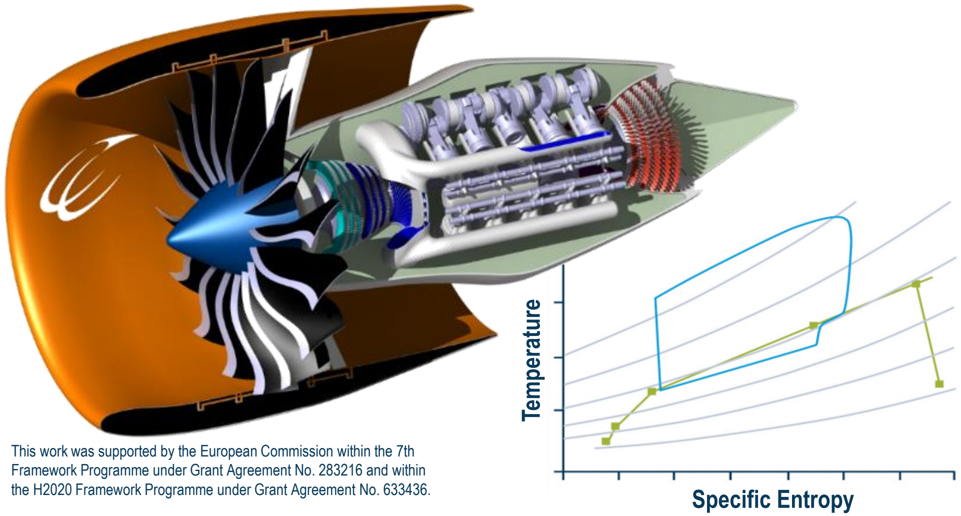
The Composite Cycle Engine (TRL2)



This work was supported by the European Commission within the 7th Framework Programme under Grant Agreement No. 283216 and within the H2020 Framework Programme under Grant Agreement No. 633436.

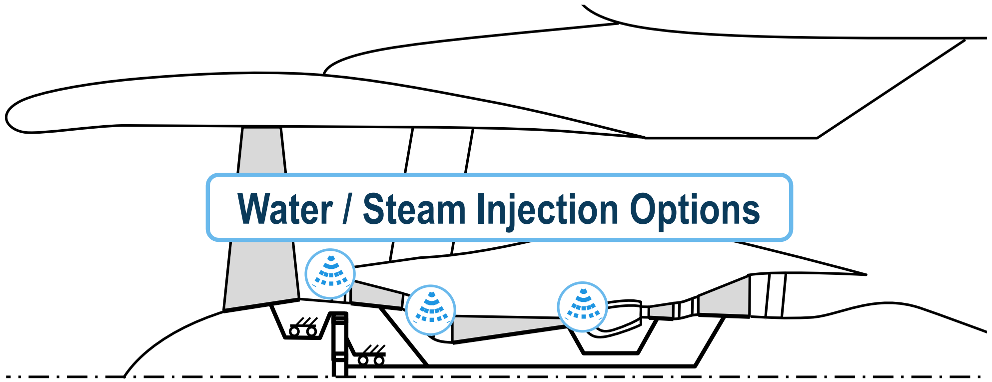
Gas turbine with piston-based gas generator

- Superb thermal efficiency due to pressure ratios >> 100
- BPR >> 20 due to ultra-high specific work output
- ≥ 10 % fuel burn reduction potential over advanced GTF technology
- Critical issue: NO_x emissions

Source: Kaiser, S., Kellermann, H., Nickl, M., Seitz, A., "A Composite Cycle Engine Concept for Year 2050", Paper-ID 0638, ICAS Congress 2018.

Key options for CCE NO_x abatement

- Compression intercooling
- Advanced piston combustion technology
- Hydrogen fuel combustion
- Water / steam injection



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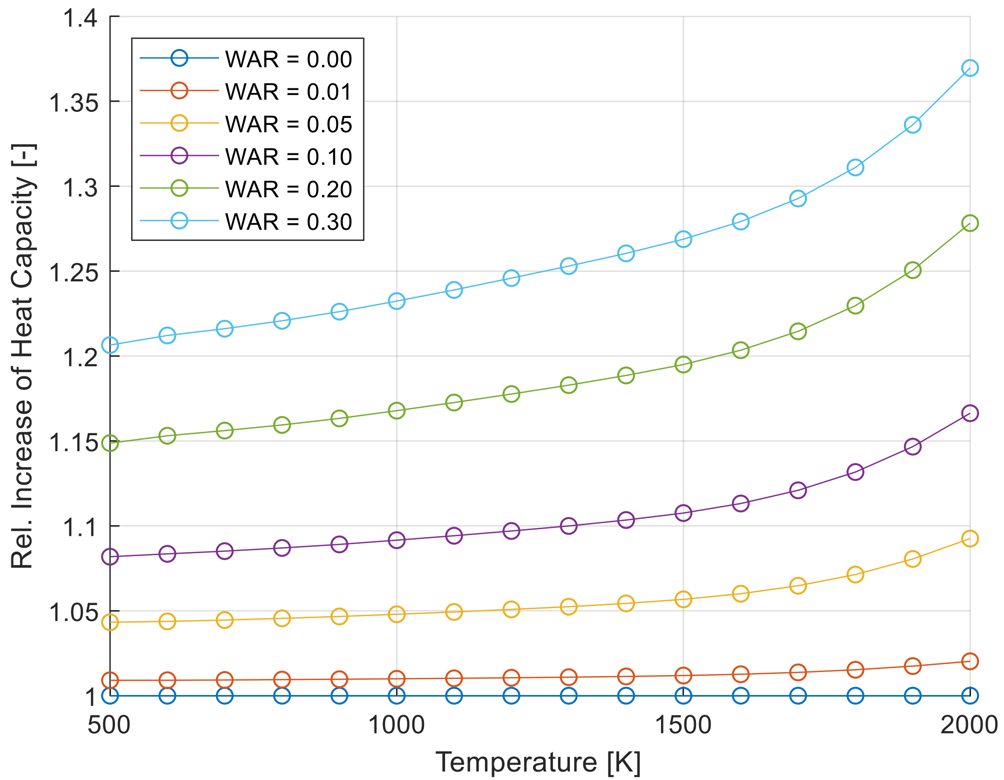
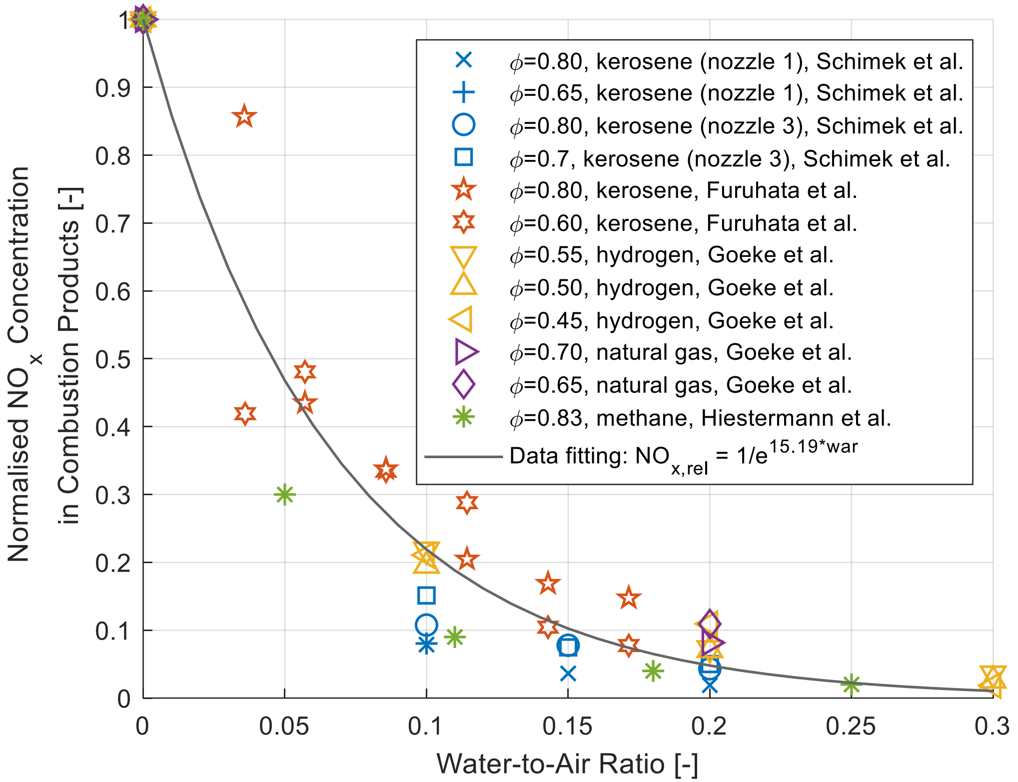
Steam Injection in Gas Turbine Combustion Chamber

Specific heat of turbine working fluid



Source: Seitz, A.; Nickl, M.; Troeltsch, F.; Ebner, K. "Initial Assessment of a Fuel Cell—Gas Turbine Hybrid Propulsion Concept", Aerospace 2022, 9, 68. https://doi.org/10.3390/aerospace9020068

NO_x emissions

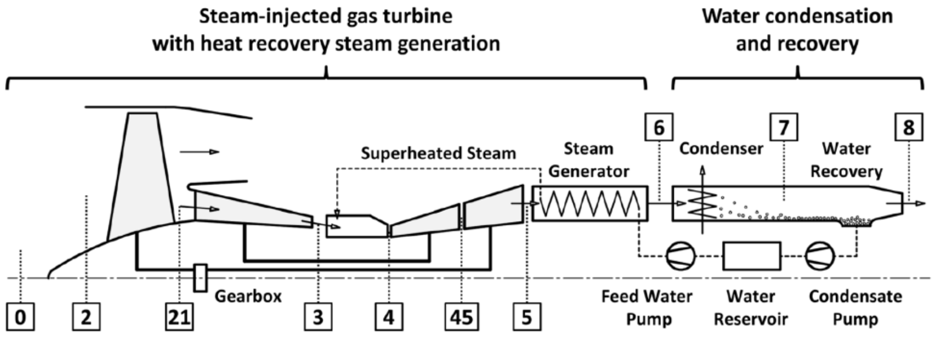


Source: Adapted from Kaiser, S. et al.; „The Water-Enhanced Turbofan as Enabler for Climate-Neutral Aviation"; Appl.Sci. 2022, 12, 12431; https://doi.org/10.3390/app122312431

In-flight Water Supply for Gas Turbine Injection?

Water source options

- Onboard water storage
- Combustion product water recovery from engine exhaust → WET concept by MTU:



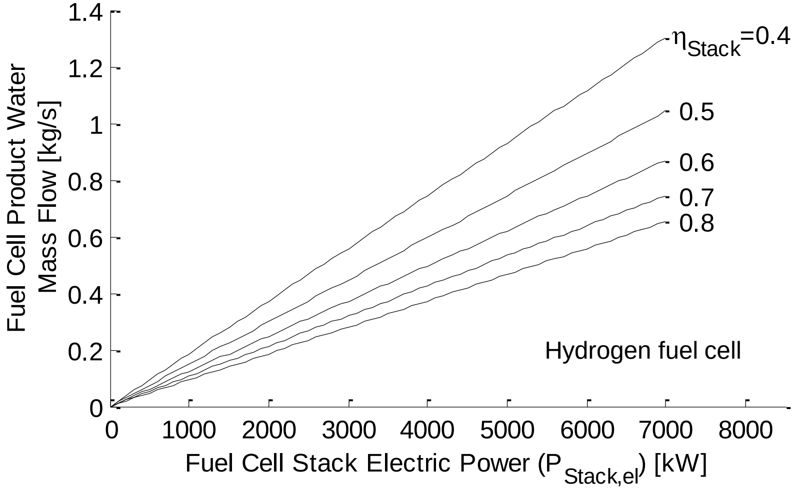
Source: Schmitz, O., et al. "Aero Engine Concepts Beyond 2030: Part 3 - Experimental Demonstration of Technological Feasibility", Journal of Engineering for Gas Turbines and Power, Vol. 143 / 021003-1, February 2021.

- Product water of hydrogen fuel cell

Fuel cell product water mass flow

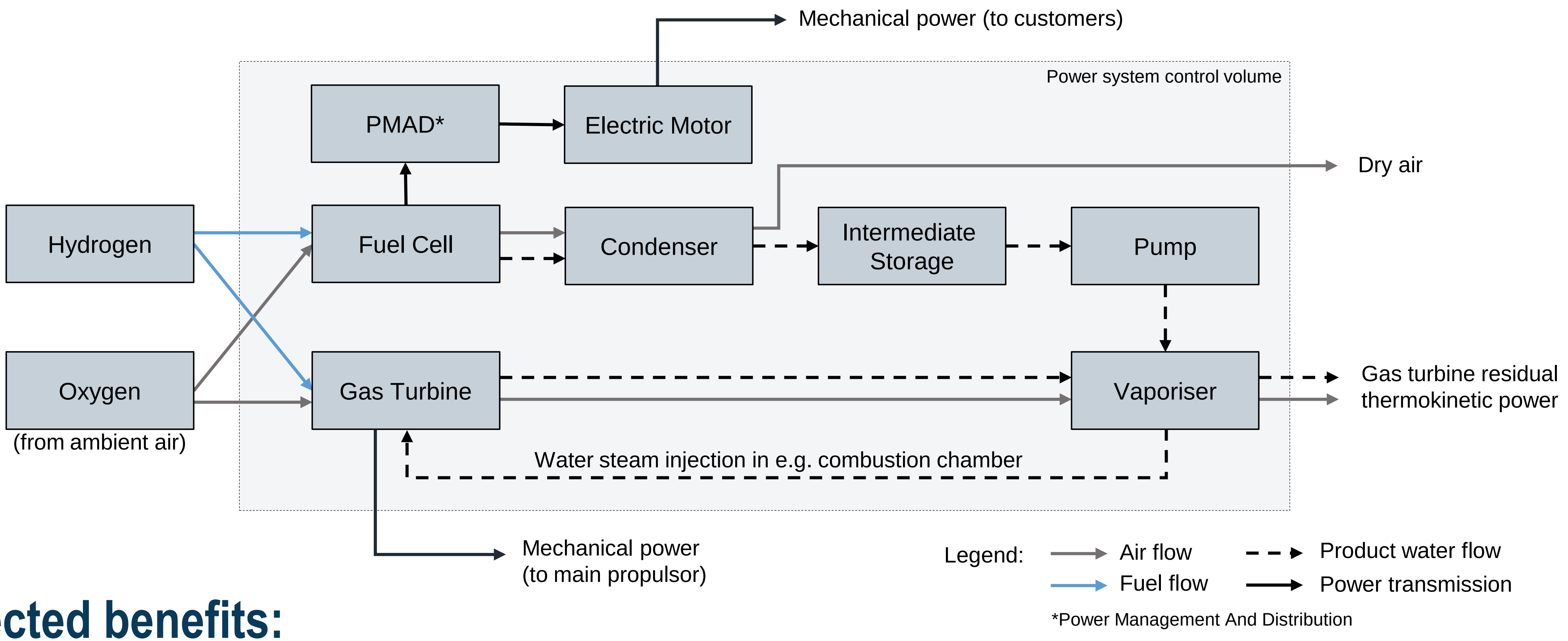
$$\dot{m}_{Stack,H2O} = \frac{P_{Stack,el} \cdot M_{H2O}}{\eta_{Stack} \cdot FHV_{mol}}$$

Product water mass flow; Stack electric power output; Molar mass of water; Stack efficiency; Fuel heating value



Source: Seitz, A.; Nickl, M.; Troeltsch, F.; Ebner, K. "Initial Assessment of a Fuel Cell—Gas Turbine Hybrid Propulsion Concept", Aerospace 2022, 9, 68. https://doi.org/10.3390/aerospace9020068

Combining H_2 Electrochemical Conversion with Combustion



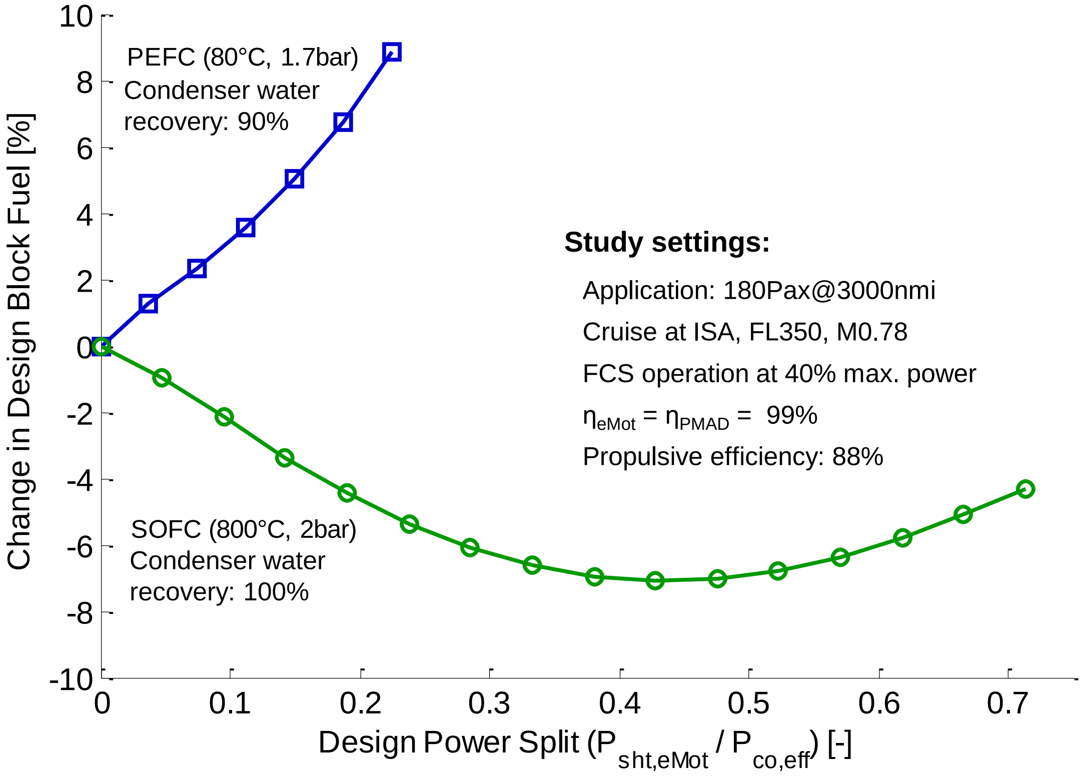
Expected benefits:

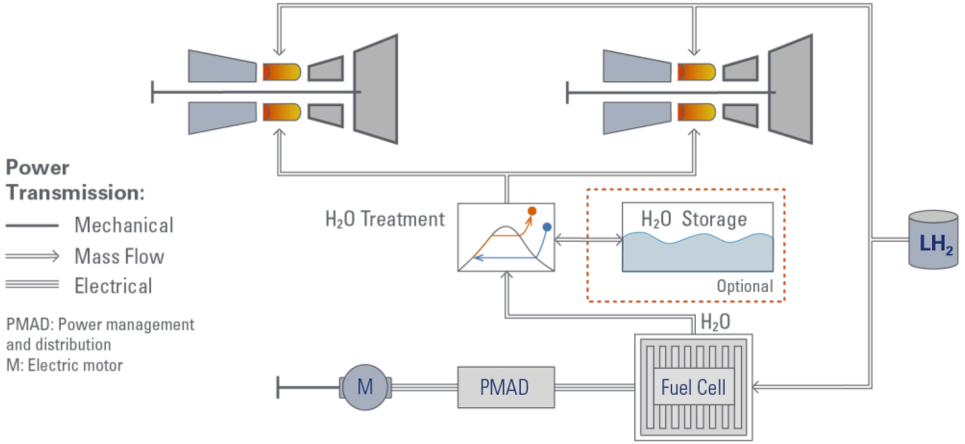
- Use fuel cell product water for performance improvement of gas turbine
- Flexible use fuel cell electric power output e.g. for advanced propulsion integration

Source: Seitz, A.; Nickl, M.; Troeltsch, F.; Ebner, K. "Initial Assessment of a Fuel Cell—Gas Turbine Hybrid Propulsion Concept", Aerospace 2022, 9, 68. https://doi.org/10.3390/aerospace9020068

Fuel Cell – Gas Turbine Hybrid: Initial Assessment (TRL1)

Design fuel study for typical SMR aircraft





Applying lab-scale fuel cell technology

- 7 % less fuel burn with SOFC design
- 43 % of power provided by fuel cell
- 6 % water-to-air ratio in gas turbine
- 60 % less NO_x emissions during cruise

Source: Seitz, A.; Nickl, M.; Troeltsch, F.; Ebner, K. "Initial Assessment of a Fuel Cell—Gas Turbine Hybrid Propulsion Concept", Aerospace 2022, 9, 68. https://doi.org/10.3390/aerospace9020068

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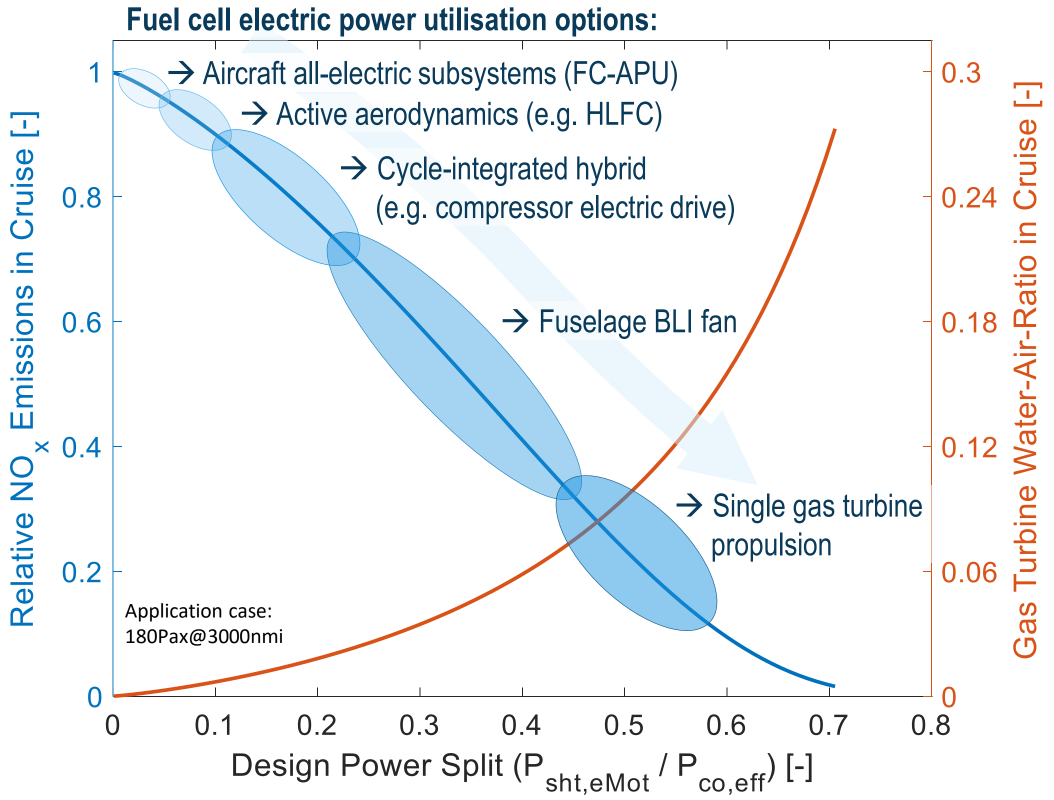
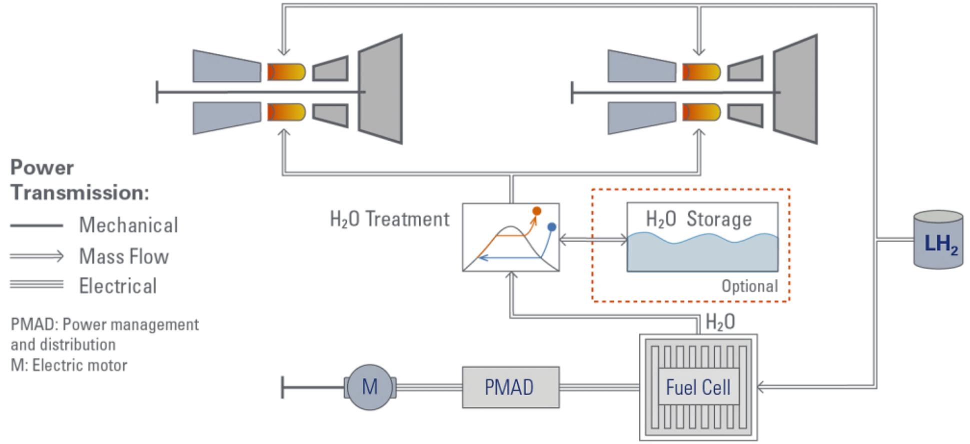
Fuel Cell – Gas Turbine Hybrid Propulsion

NO_x reduction potentials





Fuel cell power utilisation options:

- Aircraft all-electric subsystems (FC-APU)
- Active aerodynamics (e.g. HLFC)
- Cycle-integrated hybrid (compressor electric drive)
- Fuselage boundary layer ingesting (BLI) fan
- Single gas turbine propulsion

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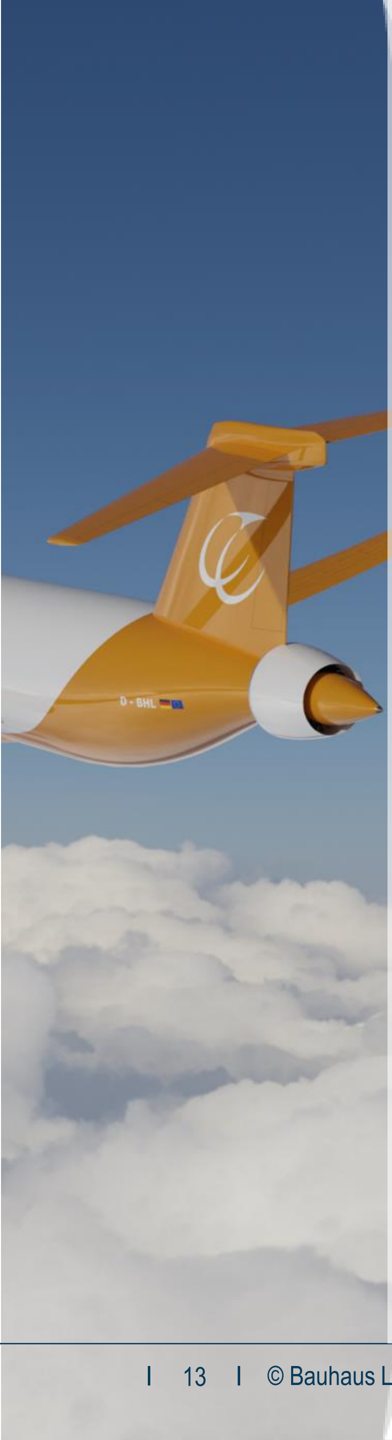
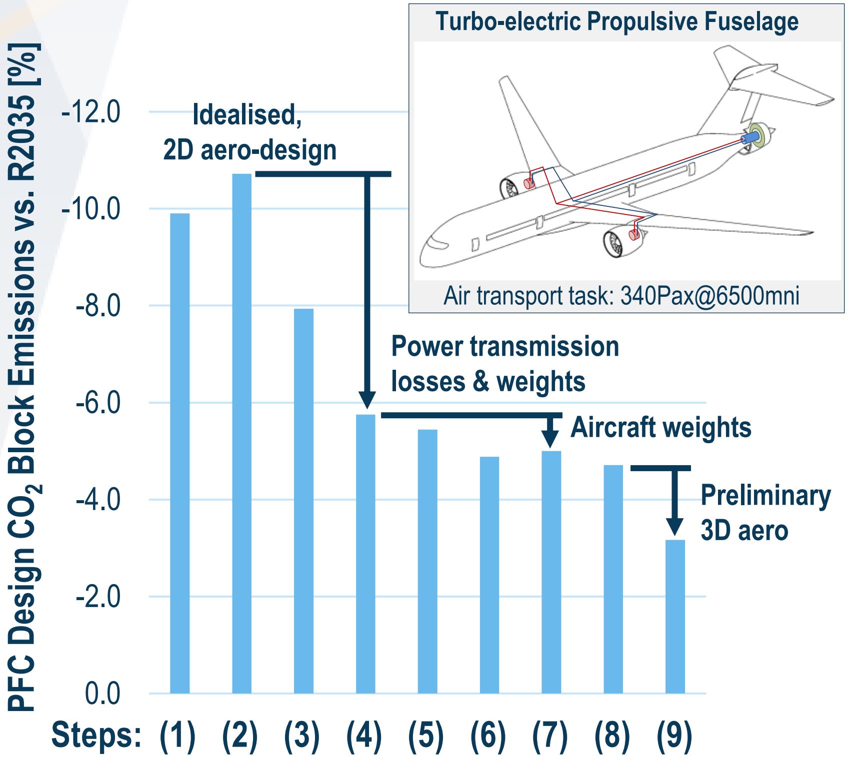


Fuselage Boundary Layer Ingesting Propulsion (TRL3)

CENTRELINE — AIRBUS, ARTTIC, Bauhaus Luftfahrt Neue Wege., CHALMERS, MTU Aero Engines, Politechnika Warszawska, Rolls Royce, SIEMENS Ingenuity for life, TU Delft, UNIVERSITY OF CAMBRIDGE

Stepwise analysis of fuel efficiency



Turning the fuselage wake flow into propulsive force

- 11 % less fuel burn (idealised design)
- 3 – 5 % less fuel burn (turbo-electric)

Excellent compatibility with

- Efficient wing & engine technology
- LH_2 fuel storage in fuselage
- Advanced power trains based on fuel cells and / or HTS electric technology

Source: Seitz, A., Habermann, A.L., Peter, F., Troeltsch, F., Castillo Pardo, A., Della Corte, B., van Sluis, M., Goraj, Z., Kowalski, M., Zhao, X., Grönstedt, T., Bijewitz, J., and Wortmann, G., "Proof of Concept Study for Fuselage Boundary Layer Ingesting Propulsion". Aerospace 2021, 8, 16. https://doi.org/10.3390/aerospace8010016. This work was supported by the European Commission within the 7th Framework Programme under Grant Agreement No. 323013 and within the Horizon 2020 Research and Innovation Programme under Grant Agreement No. 723242.

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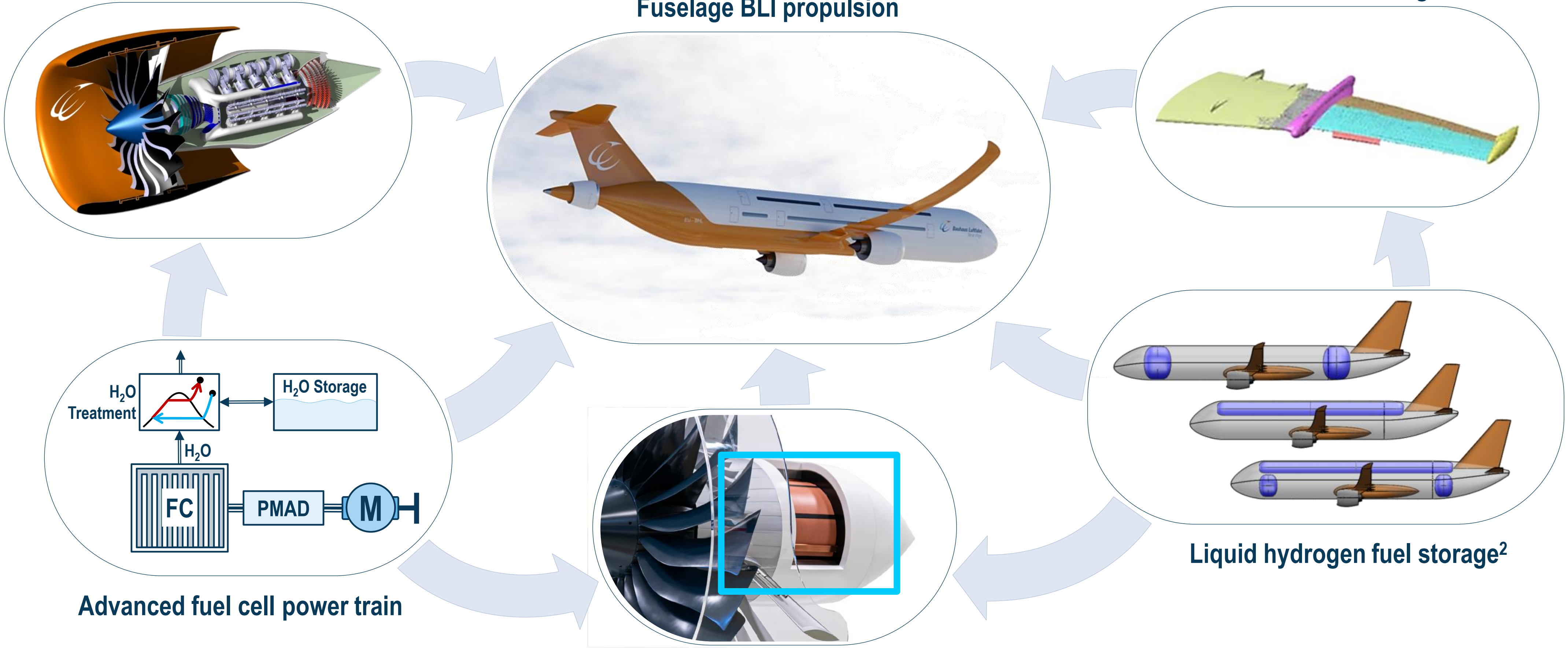
Propulsion Technology Integration for the Long Range

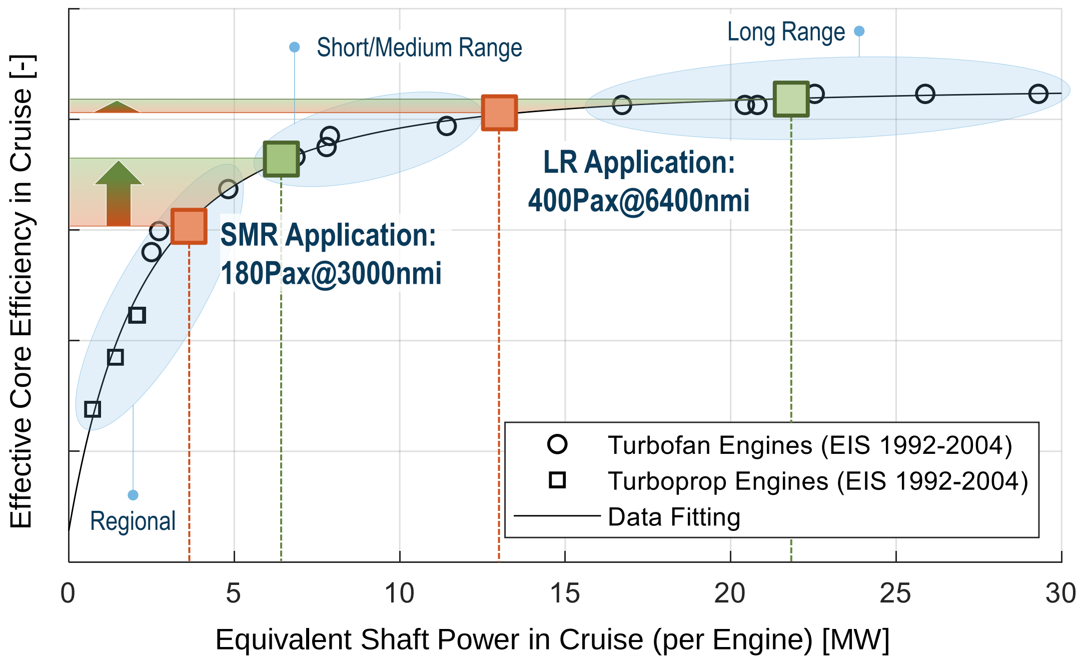


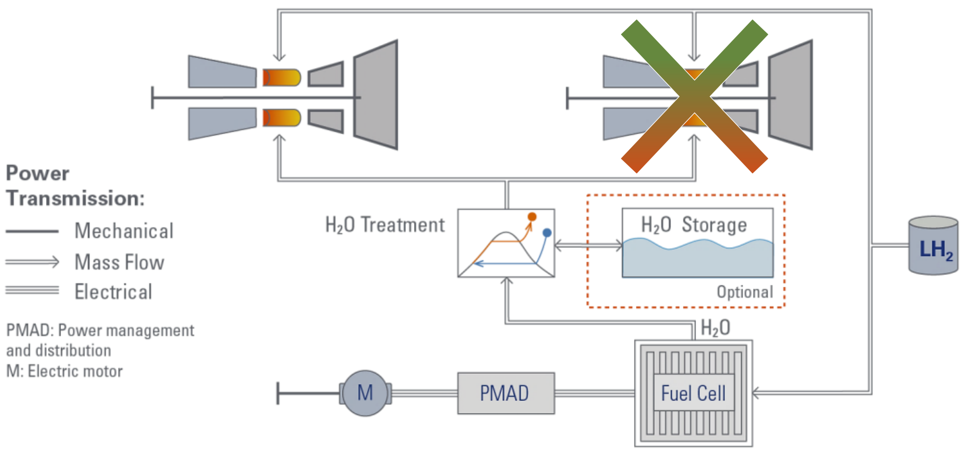
Source: Seitz, A. "Towards Climate-Neutral Aviation: Revolutionary Options for Aircraft Motive Power", Invited Keynote at the 25th Conference of the International Society of Air Breathing Engines (ISABE), Ottawa, Canada, 29 September 2022.

Images: [1] Kierbel, D. "Closing of Clean Sky 1 SFWA-ITD BLADE project", Presented in Brussels, 21-22 March 2017.
[2] Troeltsch, F., et al. "Re-Thinking the Long-Haul Air Transport Segment" Aerospace Europe Conference, Bordeaux, France, 25-28 February 2020.
[3] ASUMED Project, Grilli, F., et al, Journal of Physics: Conference Series 1590 (2020), doi:10.1088/1742-6596/1590/1/012051

Single Gas Turbine Propulsion for the Short/Medium Range

Impact on gas turbine sizing power and thermal efficiency





Fuel cell – gas turbine hybrid as basis

- Twin gas turbine, power split 43%:
- Single gas turbine, power split 50%:

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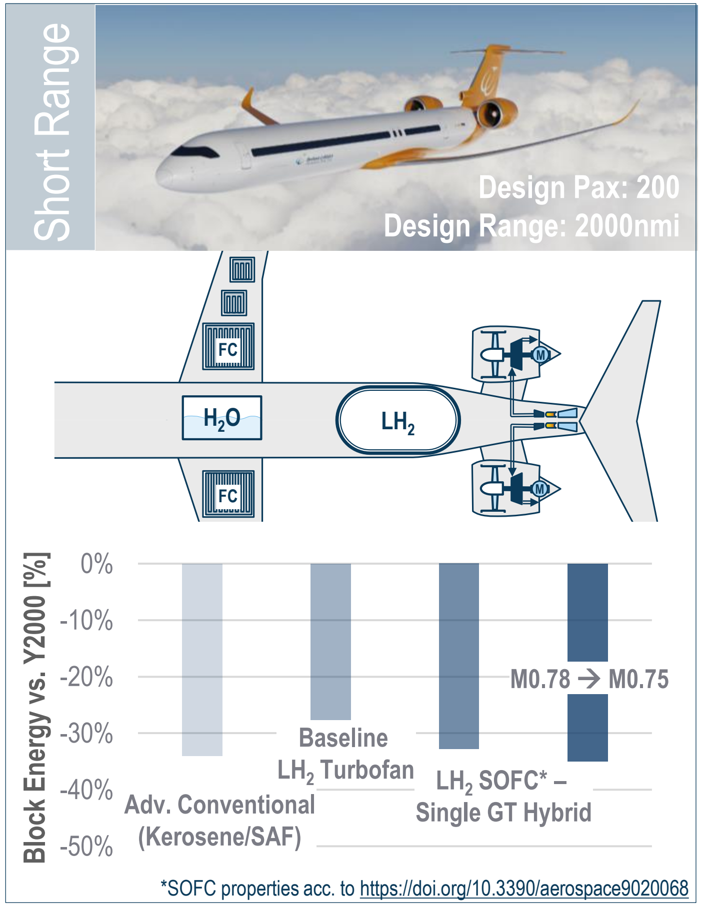
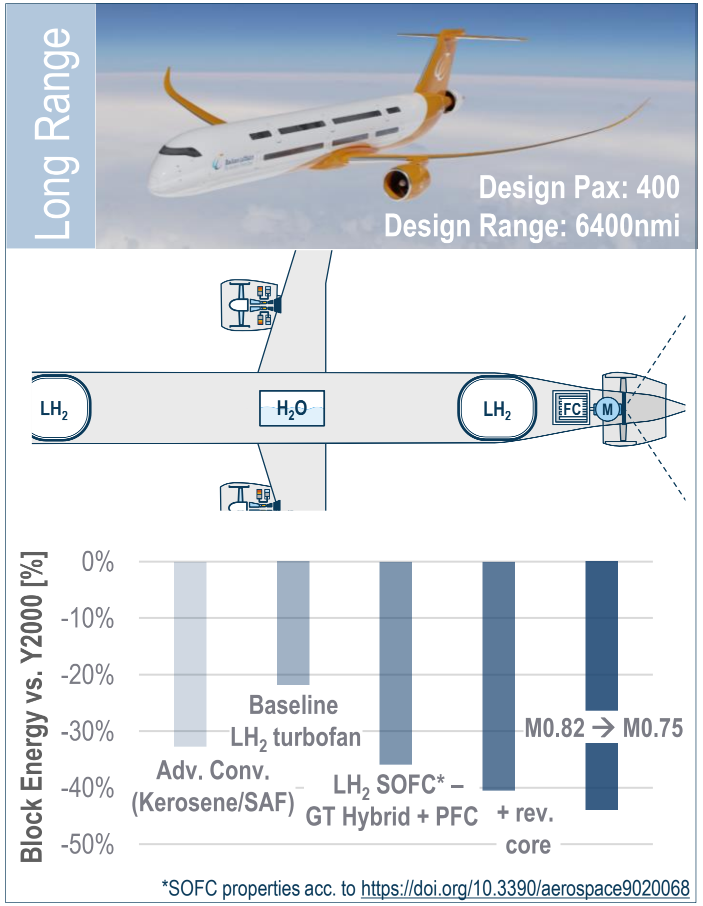
Evaluation of Climate-Compliant Aircraft Concepts (TRL1)

- **LH_2 aircraft concepts**
  - Short range and
  - Long range
  - First presented at ILA Berlin Air Show 2022





Source: Seitz, A. "Rapid Aircraft-Level Evaluation of Revolutionary Propulsion Concepts", 13th EASN International Conference, Salerno, Italy, 5-8 September, 2023.

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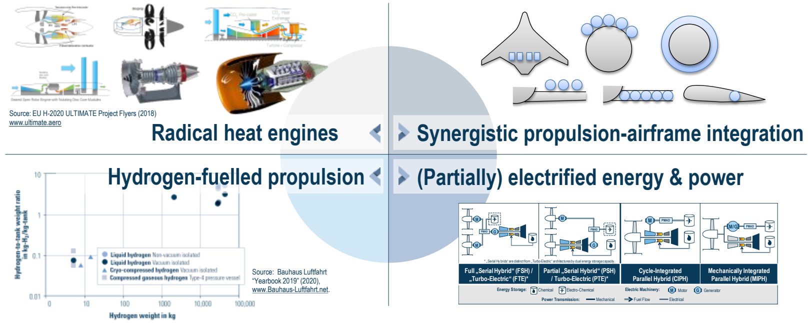
Conclusions



- Key design targets for reduced climate impact:
  Significantly improved energy efficiency + drastic non-CO_2 reduction
- Design & technology need to address the SMR and LR market segments
- Gas turbine technology remains the backbone of advanced propulsion for large aircraft
- Radical heat engines: Superb thermal efficiency of CCE, but great NO_x challenges
- Hydrogen: Significant non-CO_2 reduction potentials via advanced fuel cells
- Fuselage BLI: Effective mitigation of efficiency penalties due to LH_2 fuel storage
- Fuel cell – gas turbine hybrids: Extend fuel cell applicability to higher thrust classes + effective NO_x abatement via product water utilisation + may enable single gas turbine configurations for SMR aircraft

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Thank you!

Contact: **Arne Seitz**, Visionary Aircraft Concepts, https://www.bauhaus-luftfahrt.net