



LABORATORY OF FLUID MECHANICS AND TURBOMACHINERY
DEPARTMENT OF MECHANICAL ENGINEERING
SCHOOL OF ENGINEERING
ARISTOTLE UNIVERSITY OF THESSALONIKI

Innovative Thermodynamic Cycles for Aero Engines

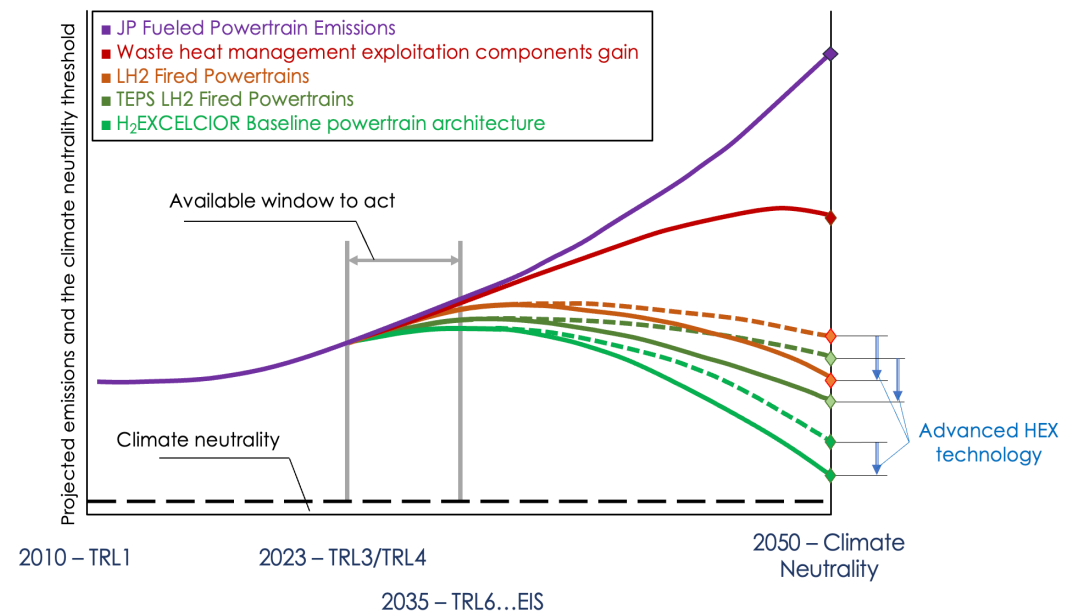
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ERCOFTAC Autumn Festival 2026 - Athens

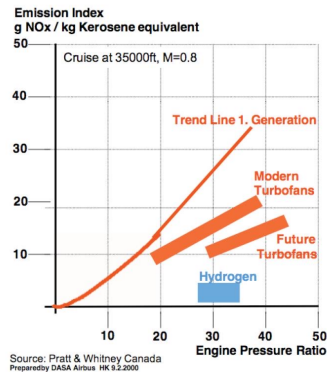
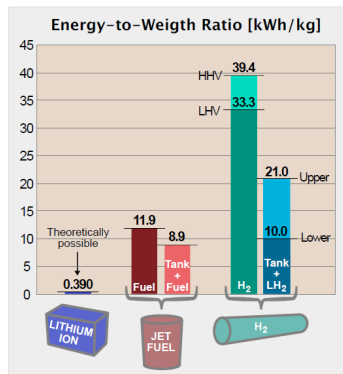


Introduction

- Achieving climate neutral aviation by 2050 requires disruptive propulsion technologies beyond the incremental improvements of conventional aeroengines.
- H₂-powered Turbo-Electric Propulsion Systems (TEPS) are seen as promising candidates, considering both performance and emissions indices.
- The feasibility of hydrogen-powered TEPS remains constrained by challenges associated with components thermal management needs, cryogenic hydrogen utilization and heat dissipation under varying operating conditions.



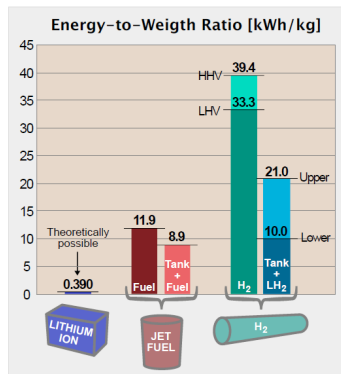
The three main pylons towards climate neutrality



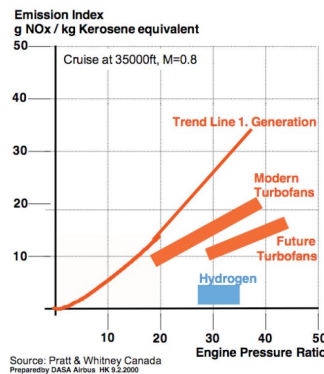
Source: HYDROGEN-ELECTRIC AIRPLANES: A Disruptive Technological Path to Clean Up the Aviation Sector, Jonas Kristiansen Nøland, Member, IEEE

Use of alternative aviation fuels (e.g. LH2)

The three main pylons towards climate neutrality

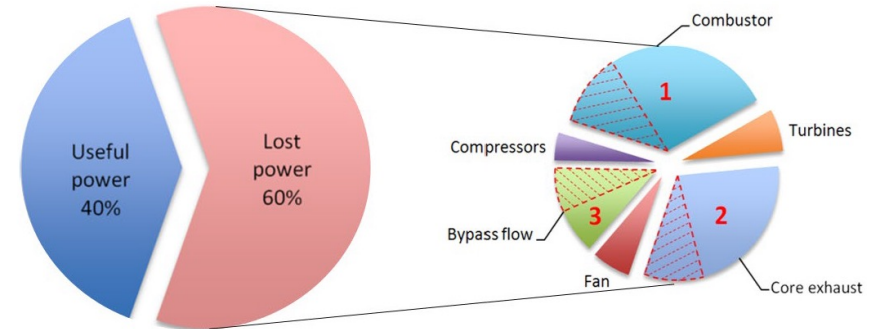


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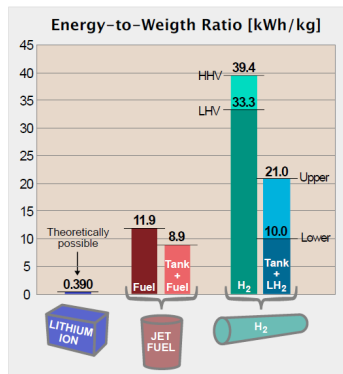
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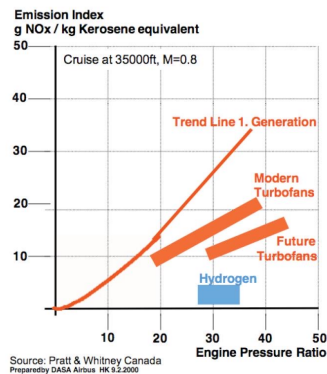
Source: Grönstedt et al. Conceptual design of ultra-efficient cores for mid-century aircraft turbine engines, ISABE-2019-24335

More efficient powertrain and propulsion systems

The three main pylons towards climate neutrality

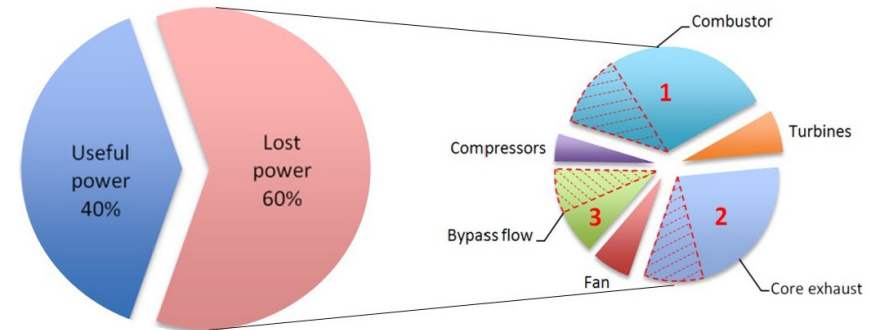


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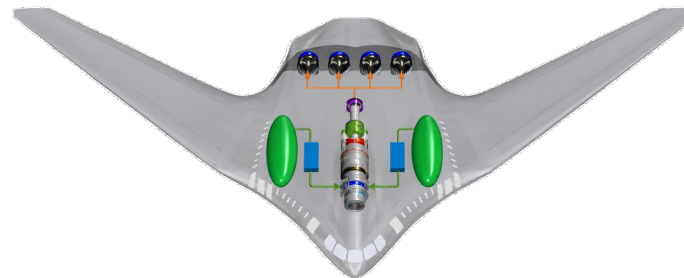
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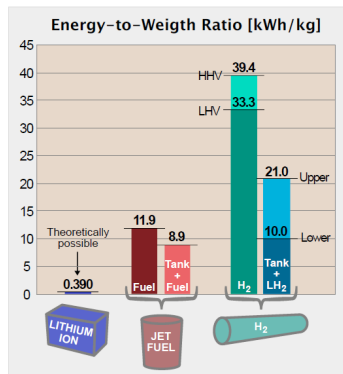
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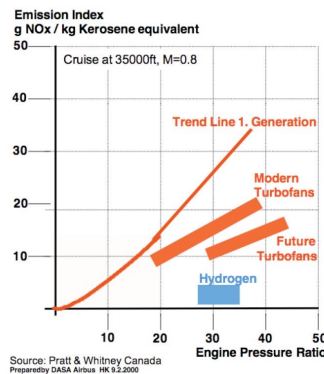


Disruptive aircraft layouts

The three main pylons towards climate neutrality

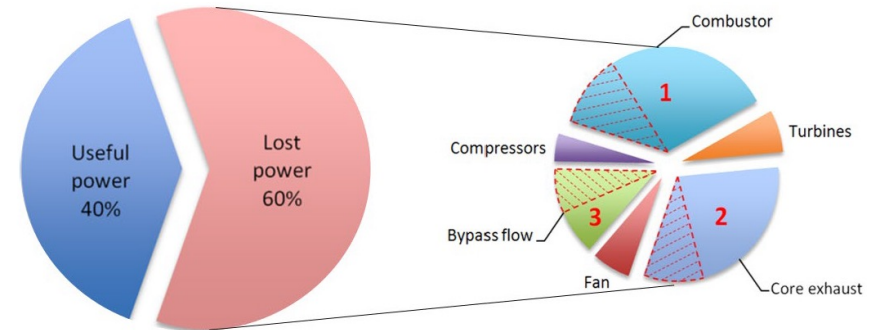


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Alternative fuel system integration in propulsion system architecture



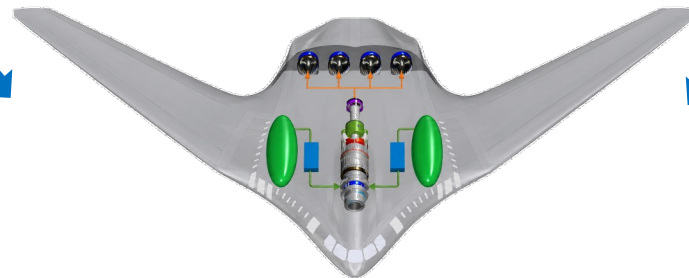
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Use of alternative aviation fuels (e.g. LH2)

More efficient powertrain and propulsion systems

Alternative fuel system integration

Propulsion system integration



Disruptive aircraft layouts

Hydrogen as a fuel to power aircraft

The main idea:

Combination of direct H_2 combustion, superconducting electric motors and distributed propulsion

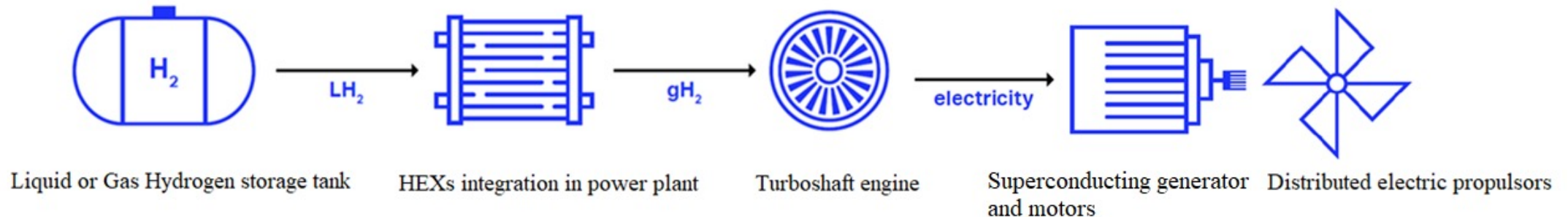


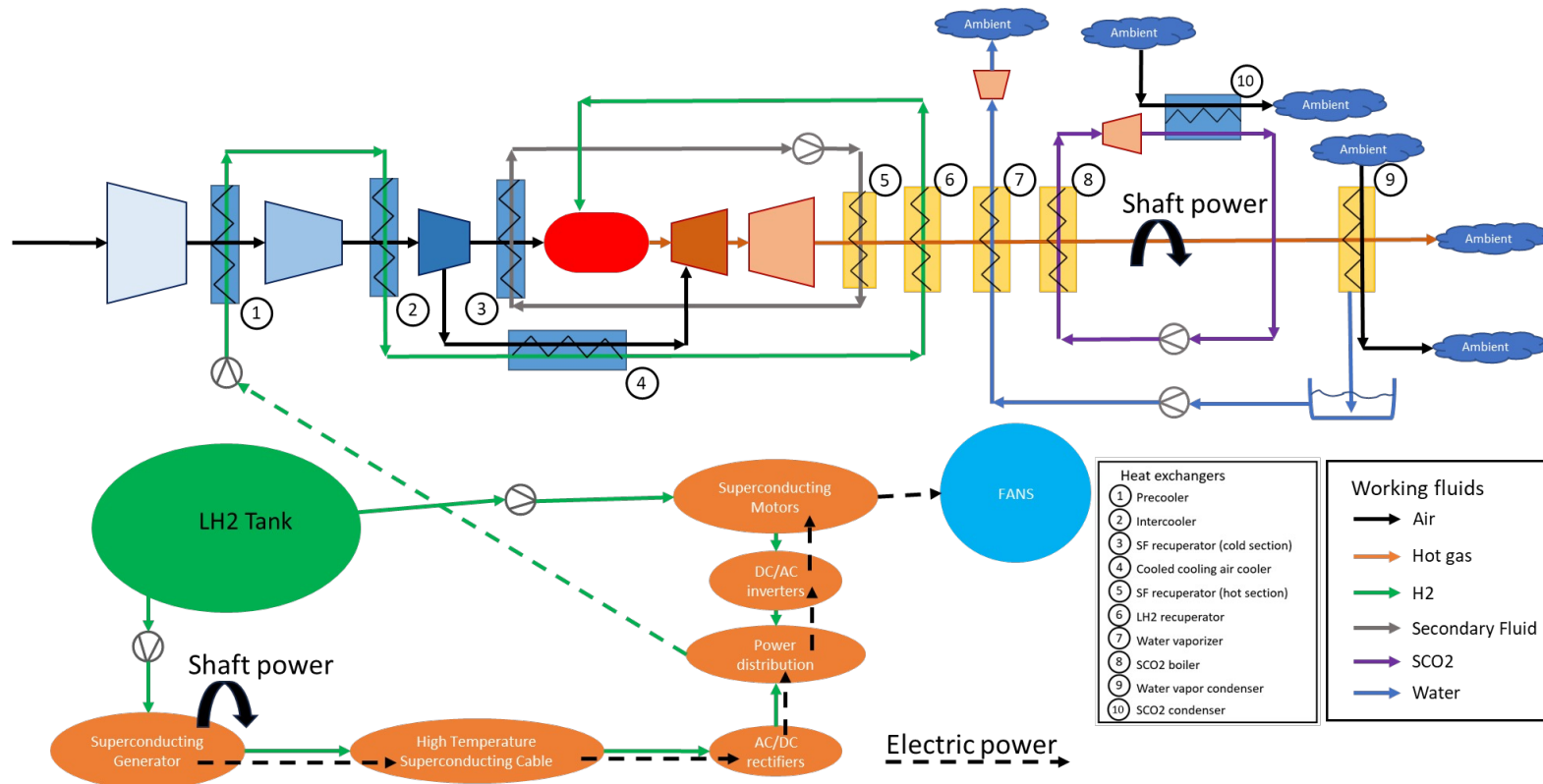
Figure adapted from source: *Hydrogen for aviation, A future decarbonization solution for air travel?* IATA, V2.0- February 2025

Concept description

- Emphasis is given on the preliminary investigation of an H₂-powered TEPS powertrain for a 5 MW class aircraft (e.g. ATR-72).
- Concept implementation is based on integrated heat exchangers and recuperation technologies for efficient H₂ direct combustion.
- Core architecture is kept similar to the one of a turboshaft aero engine, which now, operates as an electric generator.

Concept description

The aero engine concept architecture is compiling an advanced intercooled recuperated turboshaft gas turbine in its core and two bottoming cycles utilizing steam and sCO₂

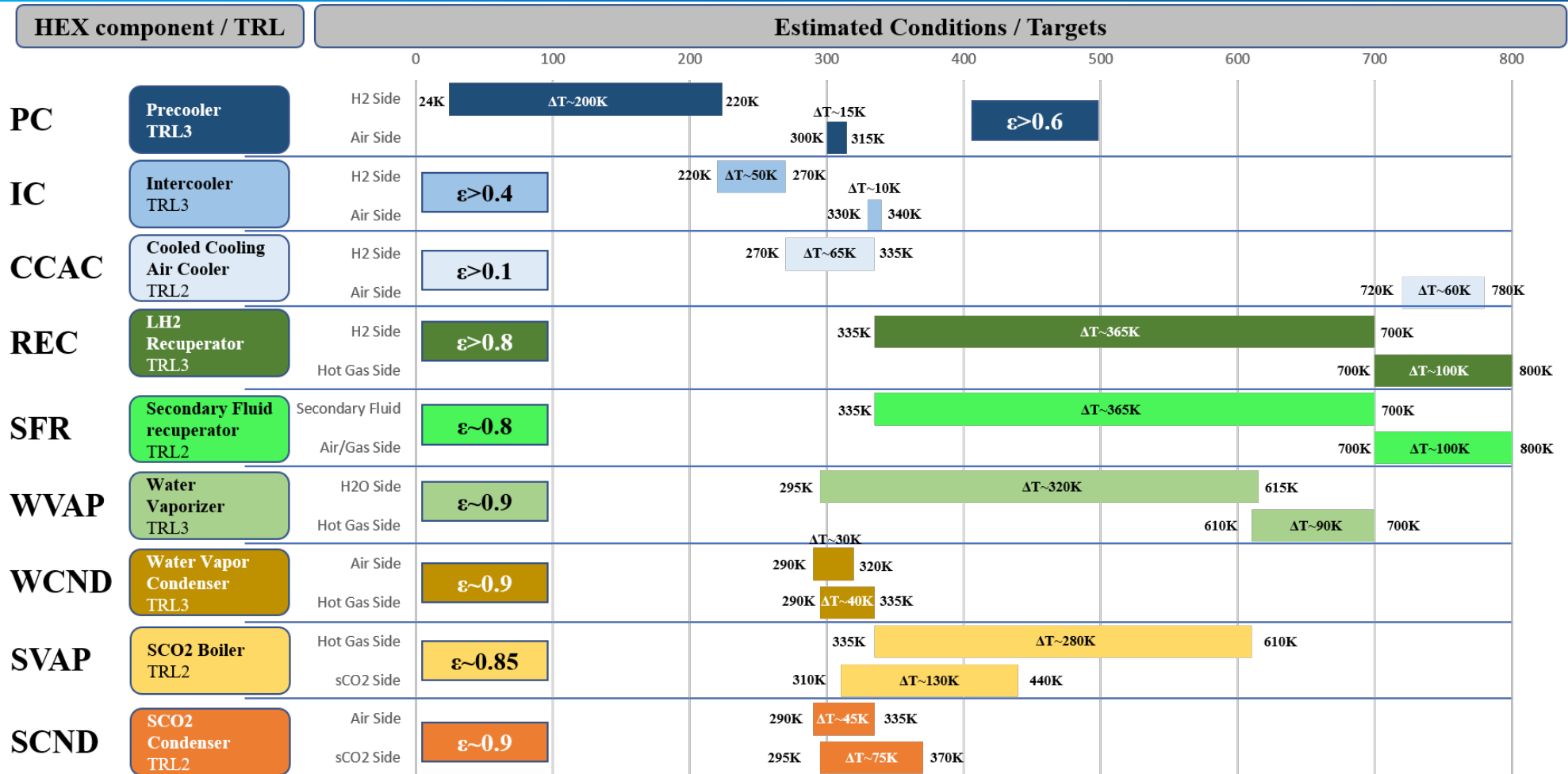


Concept heat exchangers description

Main challenges: pressure losses minimization, thermal effectiveness maximization, installation effects, volume and weight limitations, materials selection, increase thermal gradients

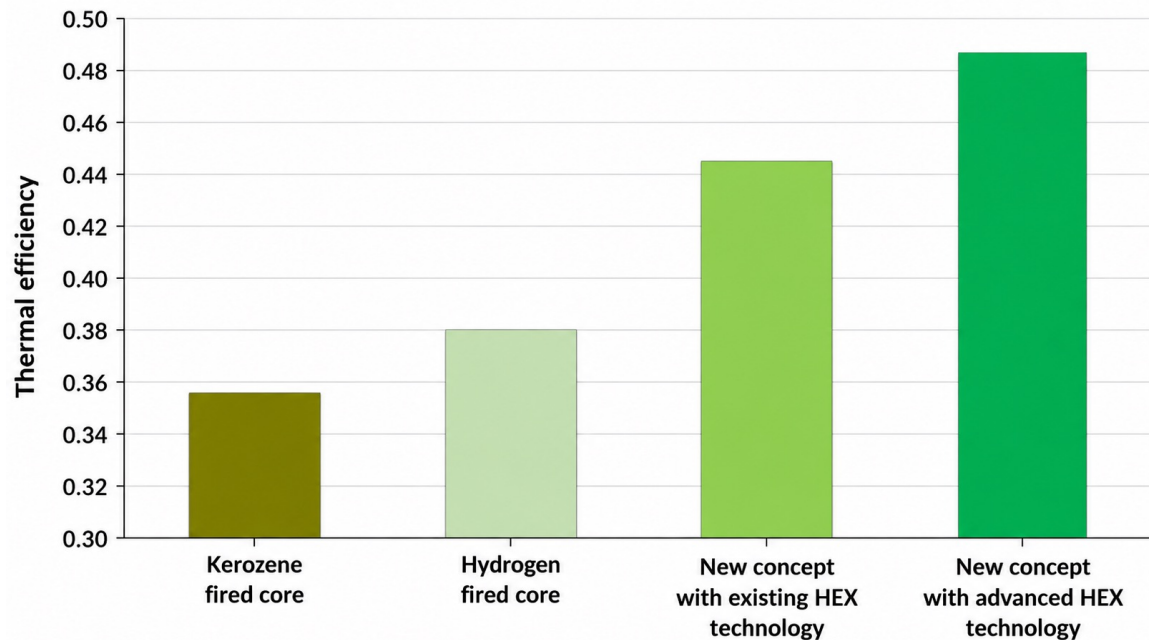
HEX	Operation	HEX	Operation
Precooler	- PC is located between fan and IPC to i) preheat the H2 fuel and ii) cool down air flow to decrease IPC and HPC work. - PC can be used to convert liquid hydrogen to gaseous hydrogen.	Secondary Fluid Recuperator	- Hot turbine exhaust gas is used to preheat the HCP discharge air before combustion with the use of an intermediate secondary heat transfer fluid. - Two interconnected SFRs are installed, one after LPT and one before combustion chamber. - Inside the two SFRs a secondary heat transfer fluid circulates.
Intercooler	- IC is placed between IPC and HPC to i) preheat H2 fuel and ii) cool down air flow to decrease HPC work. - IC can operate with intermediate fluids with the use of secondary fluid (e.g. He).	Water Vaporizer	Uses gas turbine exhaust gas mass flow for the vaporization of the water content due to hydrogen combustion products.
Cooled Cooling Air Cooler	- Use H2 to cool down the HPC-extracted cooling air used for the HPT blades cooling. - Reduces required cooling air mass flow.	Water Vapor Condenser	Uses ambient air flow for the condensation of the water content due to hydrogen combustion products.
LH2 Recuperator	- Hot turbine exhaust gas is used to heat the H2 fuel. - REC has the highest potential for H2 fuel heating before injection into the combustor due to extremely large temperature differences. - REC has the larger available space for installation.	sCO2 Boiler	Uses gas turbine exhaust gas mass flow for the vaporization of the sCO2 in the sCO2 bottoming cycle.
		sCO2 Condenser	Uses ambient air flow for the condensation of the sCO2 in the sCO2 bottoming cycle.

Concept heat exchangers description



$$\epsilon = \frac{q}{q_{max}}$$

Concept results summary



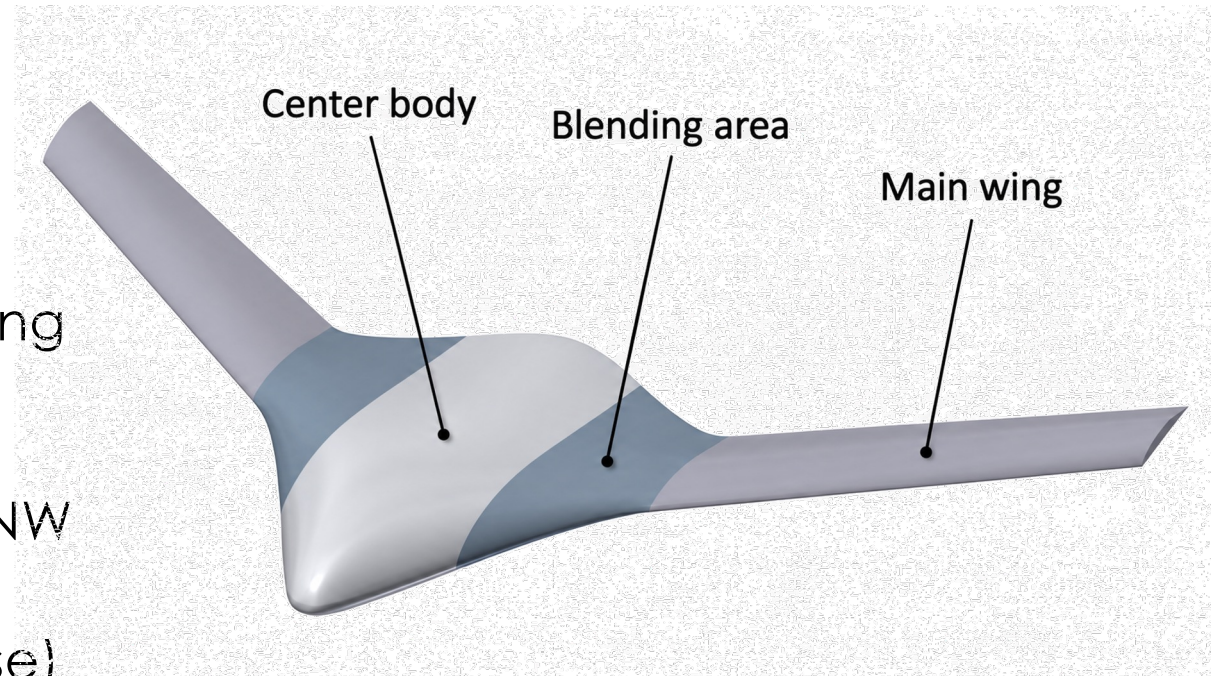
In-house analysis performed in Gas Turb11 software and COCO simulator platform for a state-of-the-art technology level 5MW class powertrain turboshaft gas turbine.

- The investigated concept shows enhanced thermal efficiency in relation to kerosene fired gas turbines.
- The concept thermal efficiency increase is affected by the hydrogen heat exchangers technology level, indicating the need for more advanced hydrogen HEXs designs (higher effectiveness, reduced pressure losses, lightweight HEXs).
- The investigated concept could provide >10% net efficiency improvement in relation to a comparable kerosene fueled gas turbine of same MW class, leading to both performance increase and emissions reduction.

Supporting studies I: integration aspects

The blended-wing-body configuration was selected as a reference platform for this study

- 16-20% increase in peak operating cruise L/D
- 20%-30% reduction in fuel burn compared to tube-and-wing) TNW
- 40% increase in internal volume (volume-to-wetted-area increase)

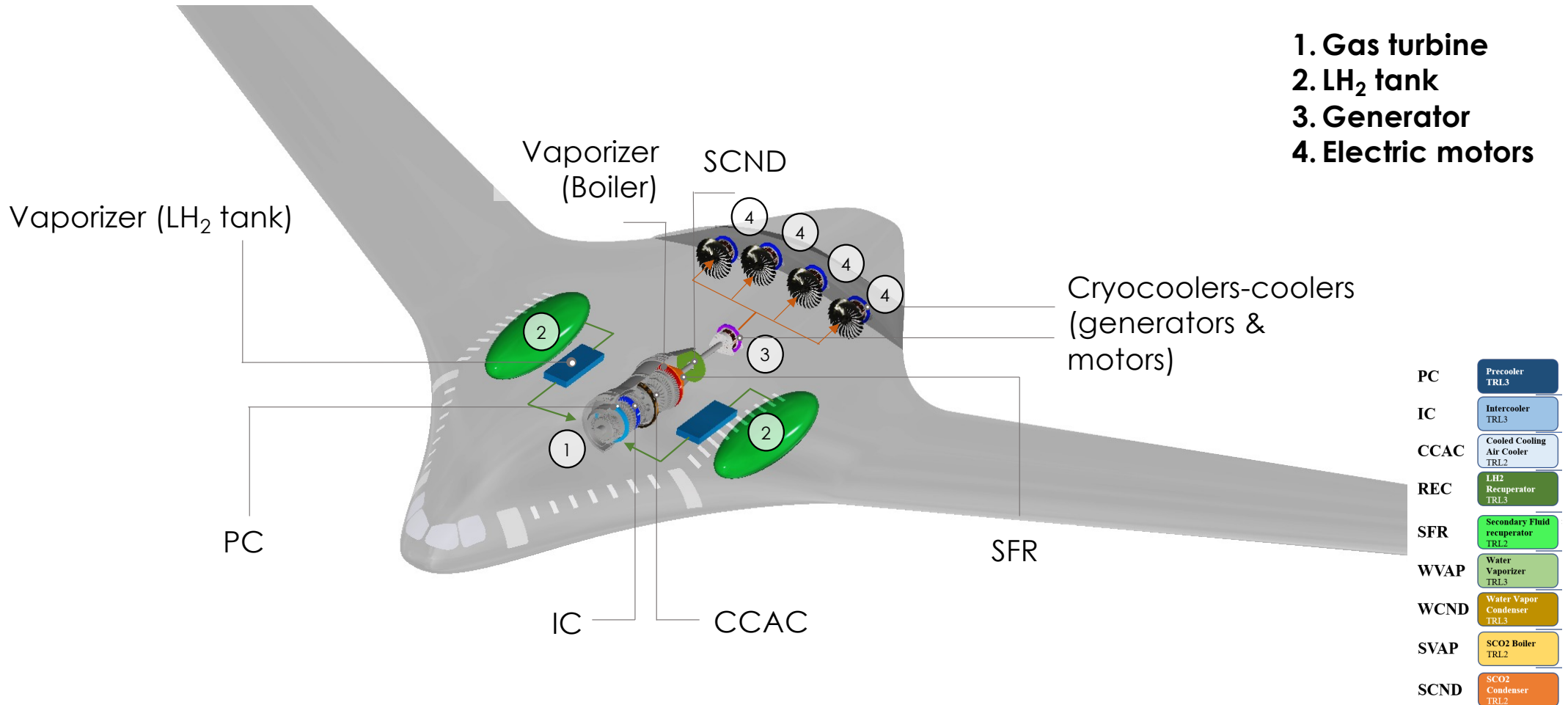


Liebeck., Design of the Blended Wing Body Subsonic Transport, *Journal of Aircraft*, 2004

Ahuja et al., Comparison of blended wing body and tube-and-wing performance characteristics, *The aeronautical journal*, 2025

Panagiotou et al., Conceptual design of a Blended Wing Body MALE UAV, *Aerospace Science and Technology*, 2018

Supporting studies I: integration aspects



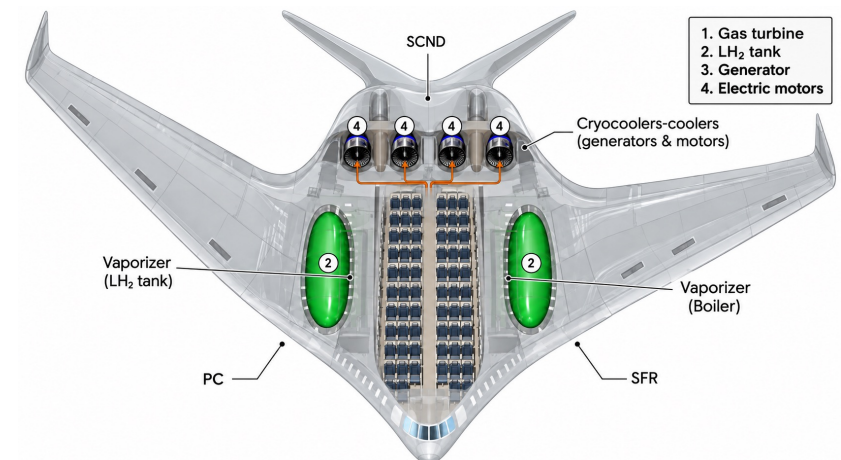
Supporting studies I: integration aspects

- For the integration study an **EIS 2035 TNW** aircraft platform is used as baseline.
- The more conservative gains are considered for the BWB platform, i.e., **20%** reduction in terms of **fuel burn** and **8%** reduction in terms of **empty weight** (Ahuja *et al.* 2025).
- A **5% empty weight penalty** is considered for the **turboelectric** approach (Nøland *et al.* 2021).
- A **30-35% empty weight penalty** is considered for the use of **LH2 powertrains** (Nguyen *et al.* 2022).
- A further **10% empty weight penalty** is calculated for the **advanced HEX systems** using in-house sizing tools and established experience from previous research projects.
- The same in-house tool is used to calculate the weight gains due to fuel burn decrease.

Supporting studies I: integration aspects

- The key metrics of empty weight, fuel weight, GTOW and range are as follows:

EIS2035 Regional A/F	Turboelectric	LH2	H2 TEPS
Empty weight	+5 %	+30 to +35 %	+45 to +50 %
Fuel weight	-10 %	-55 to -65 %	-65 to -70 %
GTOW	~0 %	+ 10 %	+15 %
Range	~0 %	-10 to -20 %	-10 to -20 %



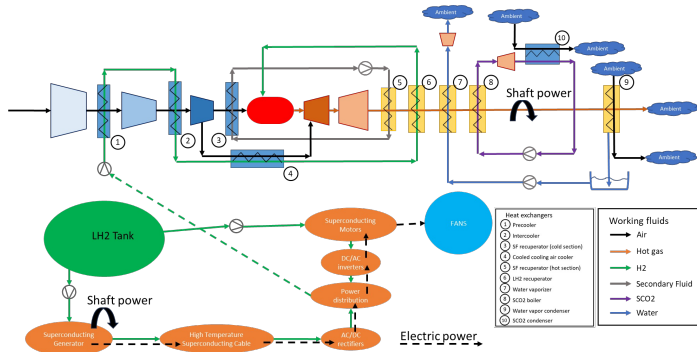
Supporting study II: concept variations

Variations include:

- Integration of $s\text{CO}_2$ sub-cycle between IPC and HPC for simultaneous intercooling and power generation
- Increased Precooling and Intercooling between Compressors using LH_2 as cooling medium using independent component feed
- Use of distributed Precooling and Intercooling in Compressors Stator Vanes Using LH_2 using independent component feed
- Use LH_2 as cooling medium for Water condenser

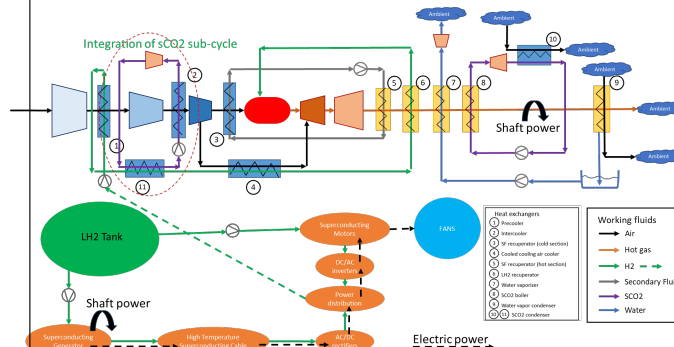
Supporting studies II: concept variations

Initial concept



Reference

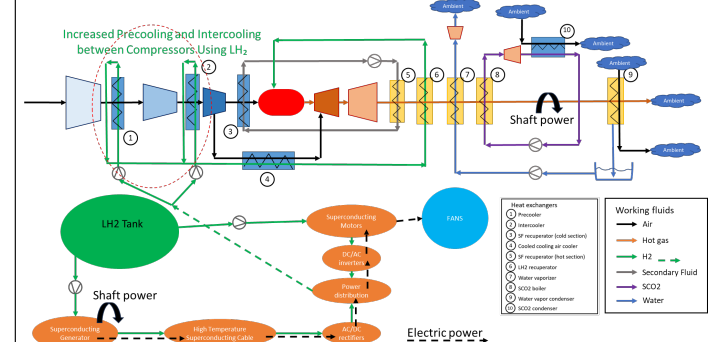
Concept A



Integration of sCO2 sub-cycle

+0.1 %

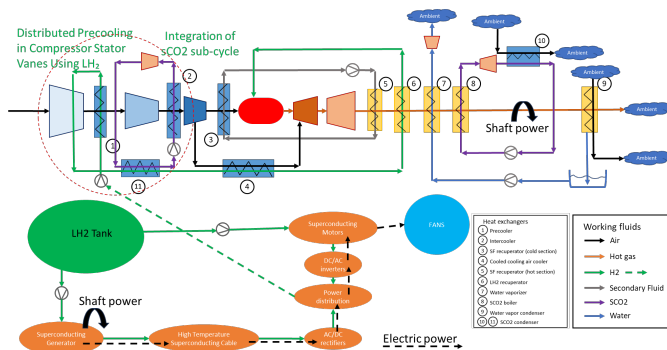
Concept B



Increased Precooling and Intercooling between Compressors Using LH₂

-0.5 %

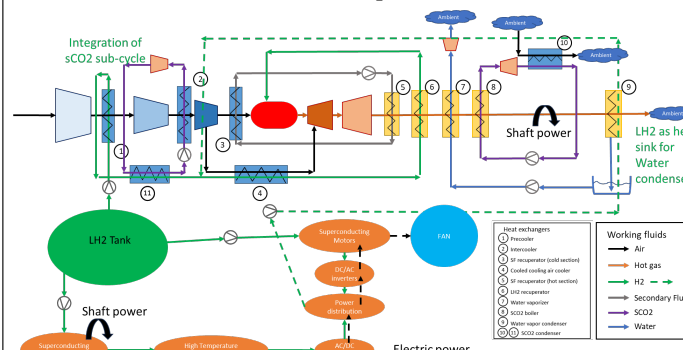
Concept C



Distributed Precooling in Compressor Stator Vanes Using LH₂
Integration of sCO2 sub-cycle

+0.2 %

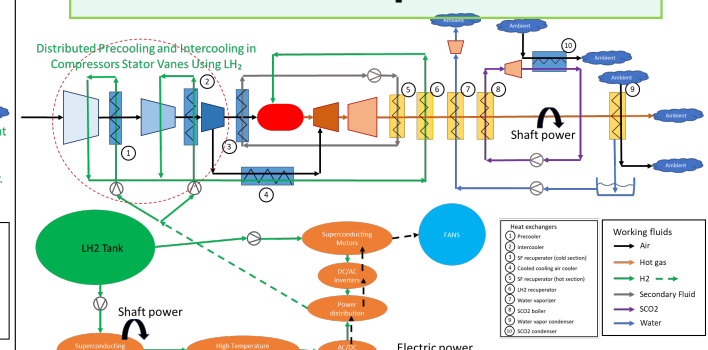
Concept D



LH2 as heat sink for Water condenser
Integration of sCO2 sub-cycle

-3.0 %

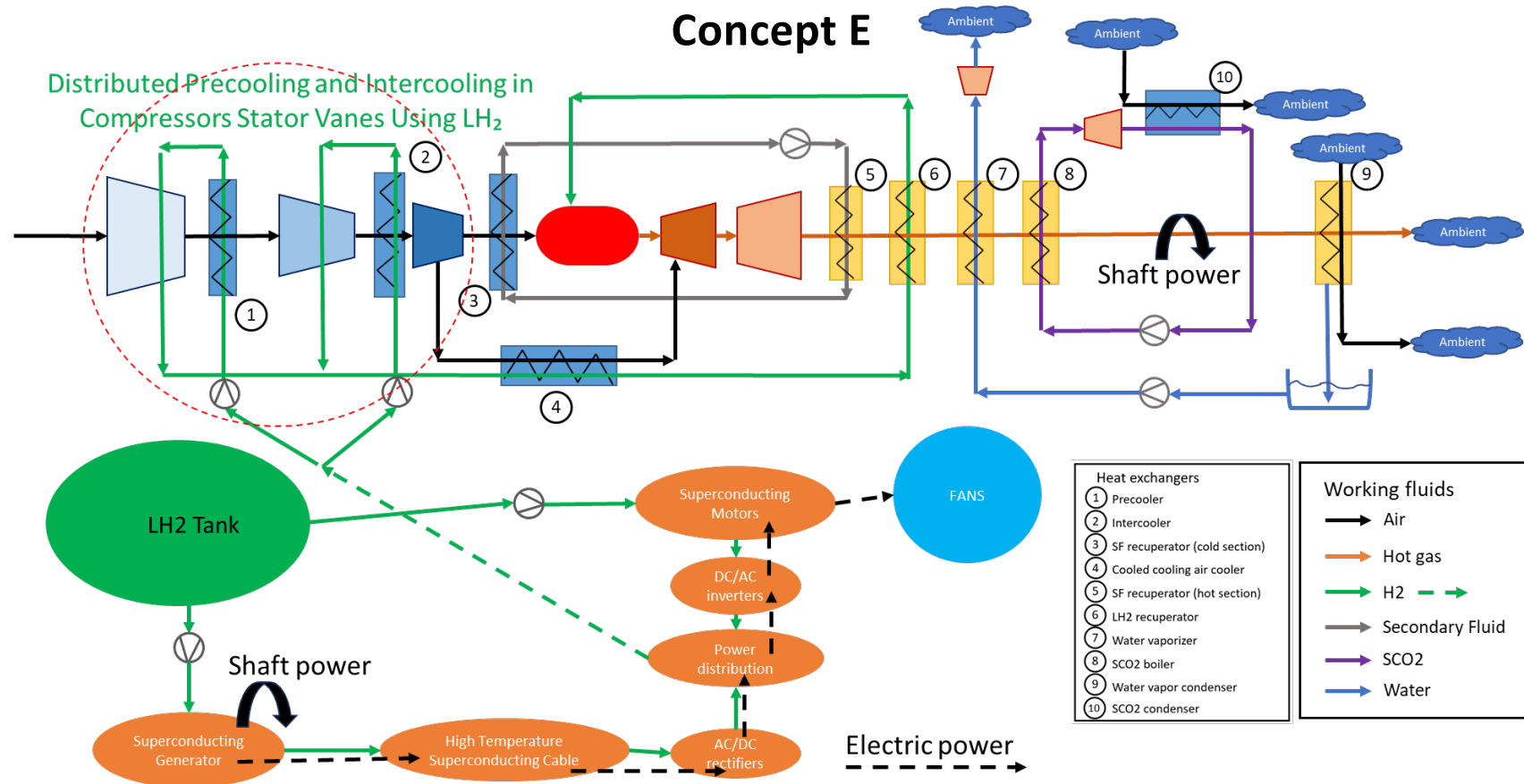
Concept E



Distributed Precooling and Intercooling in Compressor Stator Vanes Using LH₂

+1.0 %

Supporting studies II: concept variations



Trade study additions:

- Distributed Precooling and Intercooling in Compressors Stator Vanes Using LH₂

Result in thermal efficiency:
+1.0%

Supporting studies II: concept variations

Concept E

1. Gas turbine core (air and hot gas path)

Low-pressure compressor -> **Precooler (1)**, which cools the air with LH_2 -> **Intermediate-pressure compressor** ->

Intercooler (2), also cooled by LH_2 -> **High-pressure compressor** -> **Recuperator, cold section (3)**, where the compressed air is heated by a secondary fluid -> **Combustor** (red), burning hydrogen -> **High-pressure turbine** and **power/low-pressure turbine**

Two compressor stages are cooled in sequence, so the compression work is much lower than for an uncooled compressor.

2. Recuperation via a secondary fluid

The design uses a closed **secondary-fluid loop**. It picks up heat in the **hot section (5)** from the turbine exhaust and releases it in the **cold section (3)**, preheating the air before the combustor.

3. Hydrogen path

LH_2 from the tank -> **precooler (1)** and **intercooler (2)** -> It is then heated further in the **LH_2 recuperator (6)** by the exhaust gas. It enters the combustor as warm gaseous H_2 . **Cooling air for the turbine (4)**, the "cooled cooling air" cooler, so less cooling air is needed. Another branch feeds the **superconducting motors** and **generator**, keeping them at cryogenic temperature.

4. Bottoming cycles (exhaust heat recovery)

Steam cycle: Water is pumped to the **vaporizer (7)** and raised to steam. The steam expands in a turbine and exits to ambient.

Downstream, the **water vapor condenser (9)** recovers the water produced by hydrogen combustion into a tank, which supplies the cycle. **sCO₂ cycle:** A closed Brayton cycle. A pump compresses the CO_2 , the **boiler (8)** heats it with exhaust gas, it expands in a turbine, and the **condenser (10)** rejects heat to ambient air before returning to the pump. Both bottoming turbines appear to contribute to the power.

5. Electrical and propulsion system

Shaft power drives a **superconducting generator**. The power then flows through: a **high-temperature superconducting cable**. **AC/DC rectifiers** a **power distribution** unit, which also supplies the pumps. **DC/AC inverters**. **Superconducting motors** driving the **fans**

This is distributed electric propulsion, which fits well with BWB airframes, since fans can be spread across or embedded in the body.

Conclusions

- Further thermal efficiency increase can be achieved through increased intercooling
- Use of precooling and intercooling in compressors stator vanes using LH_2 and independent component feed provides additional optimization potential
- Integration of additional sCO_2 sub-cycle between IPC and HPC for simultaneous intercooling and power generation provides limited benefit
- Use of LH_2 as cooling medium for water condenser is not sufficient
- Integrating these novel concepts provide reduced fuel burn at a considerable weight and range penalty
- Concept variant can provide an additional 1% benefit in relation to initial concept

Partnerships



Thank you for your attention