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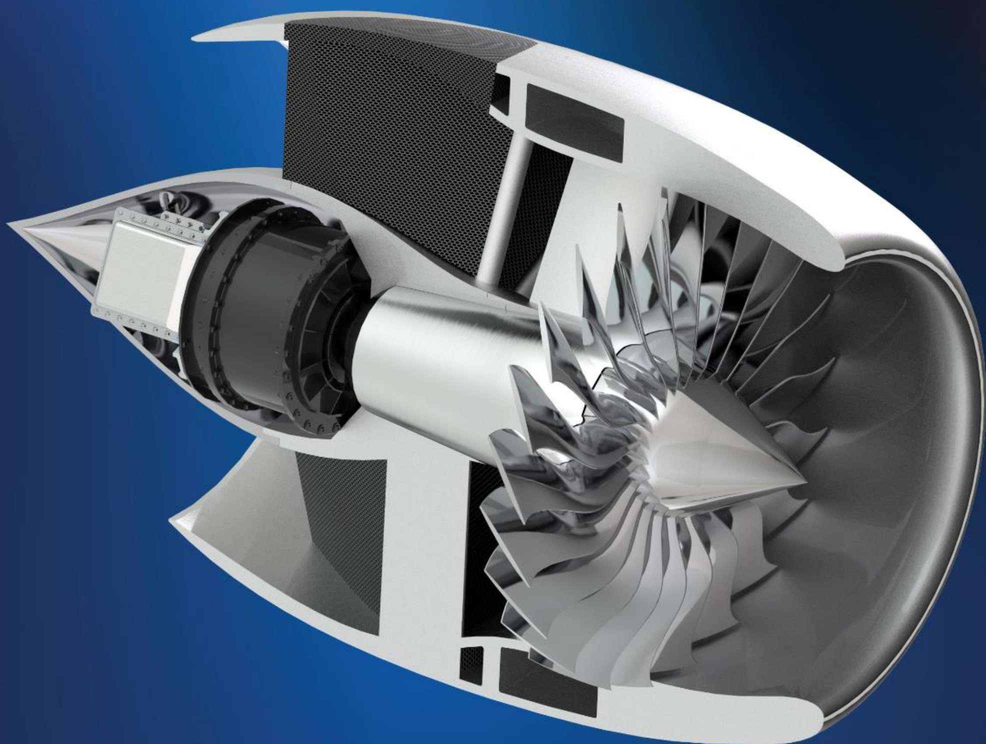
VIENNA AVIATION DAYS 2024



REPORT

HYDROGEN HYBRID-ELECTRIC PROPULSION SYSTEMS AS KEY TO CLIMATE NEUTRAL AVIATION

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Advanced Drivetrain Technologies GmbH
Leonard-Bernstein-Straße 8/2/ EG 1
1220 Vienna
Austria

General CONTACT:

Lorenz Braumann
Advanced Drivetrain Technologies GmbH
Leonard-Bernstein-Straße 8/2/ EG 1
1220 Vienna
Austria

Tel.: +43 676 852 562 100
E-Mail: lorenz.braumann@adt-engineering.at

This report is a summary of the presentations held at the Vienna Aviation Days 2024.

Disclosure:

The report was created by
Advanced Drivetrain Technologies GmbH.

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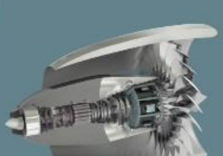
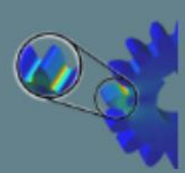
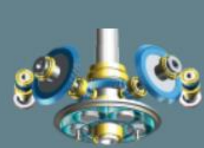


Aviation Drivetrains



Gearbox Design

Thermal Management



KISSsoft Training

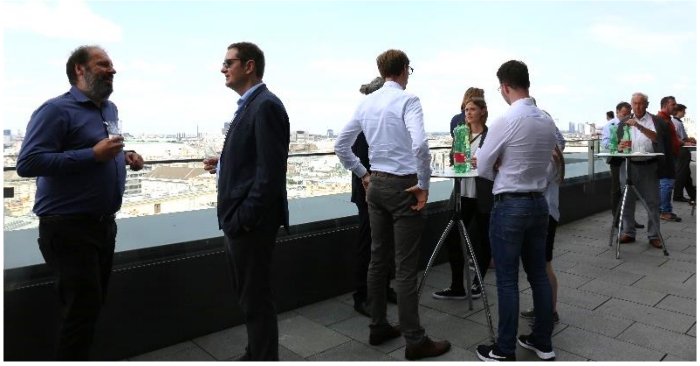
VIENNA AVIATION DAYS 2024

From the 08th to the 09th of July 2024 the Vienna Aviation Days congress had its premiere: more than 100 participants per day and 24 expert speakers came together to share knowledge, results and discuss challenges of hydrogen hybrid electric propulsion. As extreme climate events such as droughts, wildfires, hurricanes and prolonged heat periods become more frequent, the common goal is clear: To enable climate neutral aviation!

This goal however cannot be achieved in individual efforts. For this reason, the Vienna Aviation Days brought together the representatives for aviation research of the Austrian, German and Dutch governments, the European Commission as well as the Clean Aviation Partnership. The panel discussion made clear that the use of synergies is an important tool for collaboration. On transnational level, synergy is only possible as long as both countries benefit from it. For this reason, the German aviation research program *LuFo* and the Austrian counterpart *Take-Off* offer to have joint projects. In order to streamline efforts of different EU member states, there should be a framework that connects national projects to international efforts such as the Clean Aviation Joint Undertaking. Currently, synergies between national and European funding projects are problematic from a legal perspective. It is believed that there is enormous existing potential in unexploited synergies – also when considering non-aviation specific research that may have an application in hydrogen electric aircraft.

(LEFT TO RIGHT) H. AMRI (ADT), J. FERNANDEZ (CLEAN AVIATION), K. WAGNER (BMWK), I. KERNSTOCK (BMK), R. VAN MANEN (LIT) OVERLOOKED BY M. KYRIAKOPOULOS (EC)

However, the challenges are not isolated to policy and collaboration. Carbon neutrality may be achieved through a combination of improved technology, air traffic management, sustainable aviation fuels and economic measures. Starting with technology advancements, the timing is critical: While we had over 60 years to develop the gas turbine, hydrogen systems need to be developed within years so that carbon neutral aviation until 2050 can be reached. For this reason, representatives of Airbus outlined the disruptive development strategy (see FAME) and gave insight into their new testing facilities: the Airbus X-LABS that will allow to prove the function of megawatt-class fuel cell hydrogen propulsion systems. There are also testing facilities that are accessible for academia and



DRINKS AND TALKS DURING THE FIRST BREAK IN FRONT OF THE VIENNA SKYLINE industry: For hydrogen combustion, experimental infrastructure at the TU Graz TTM institute was presented by Patrick Jagerhofer. At the hydrogen test site Lampoldshausen (DLR) The Hydrogen Aviation Lab project aims to demonstrate the feasibility of liquid hydrogen infrastructure in an airplane ground demonstrator.

The development of hydrogen propulsion systems can go in many directions: hydrogen can be either used to be converted into electricity using fuel cells or combusted in a hydrogen gas turbine. For both solutions, the generally liquid hydrogen has to be stored on the aircraft and distributed to the propulsion systems. This process is required to keep the hydrogen liquid as long as possible but also heat it to the required operating temperature at gaseous state – both are main challenges of the project LIQORNE. The thermal management however is just starting at the fuel system: Especially fuel cells place high demands on thermal management: On one hand, large amounts of heat needs to be dissipated from the fuel cell, on the other hand this heat has the potential to be used to increase propulsive efficiency. The project exFan presented their approach of using the ramjet/Meredith-effect within a ducted-fan engine to recuperate and use the rejected heat. The project FlyEco has taken a hybridization route by investigating a very-high temperature SOFC that pre-heats air for more efficient combustion. While not expected on the market in the short term, SOFC have great potential to simplify fuel cell thermal management. Currently, low-temperature fuel cells are used due to their high technology readiness level and power density. Higher operating temperatures would greatly decrease the size of heat exchangers and the thermal management system. For this reason, the project NIMPHEA presented their approach of designing a high-temperature polymer electrolyte fuel cell membrane that may have large impact on future fuel cell electric aircraft.

EXHIBITION OF STORAGE TECHNOLOGIES (ADDITIVELY MANUFACTURED HYDROGEN TANK & STRUCTURAL BATTERY)

While hydrogen electric propulsion was the main topic of the Vienna Aviation Days, technological solutions based on fuel flexible propulsion systems to minimize noise and emissions were discussed within the projects MYTHOS and HOPE.

Hydrogen needs to be stored cryogenically and liquid for most aviation applications, which is a challenge for the storage and fuelling system. On the ground, refuelling and tank swap systems were discussed by the ALRIGH2T project. Especially the safety and design of components that are in contact with liquid hydrogen are critical: TESTFUCHS outlined the challenges in their hydrogen storage systems on both component and subsystem level and the required test equipment. With the HYCENTA exists a knowledge hub within Austria that measures LH2 and develops fast-forward strategies in hydrogen technology such as hydrogen storage. To bring new hydrogen storage systems to life, the AIT presented their own additively manufactured cryogenic hydrogen tank and discussed its benefits. A prototype of the tank was exhibited at the Vienna Aviation Days.

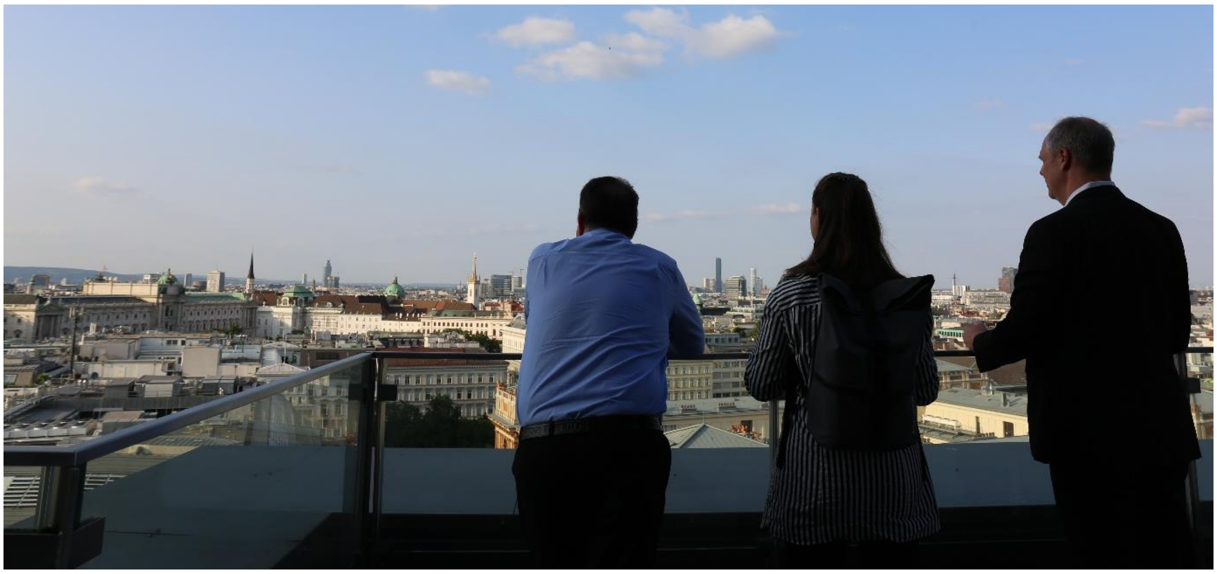
THE SPEAKERS OF THE VIENNA AVIATION DAYS 2024

While batteries may be used as the main source of electric energy for smaller aircraft, they also synergize well with both fuel cell and hydrogen combustion systems as an electric buffer storage that can be used for propulsion and auxiliary needs. The energy density of batteries, however, is currently quite low. The projects MATISSE and SOLIFLY presented their efforts to increase energy density by providing multiple functions within their batteries such as using batteries as structural elements and including sensors within these structural elements.

While hydrogen propulsion systems do not emit CO_2 in operation, the impact of contrail formation and other non-CO_2 emissions needs to be considered to allow for climate optimized trajectories – the research topic of the BECOM project. Pollutant and noise emissions of next-generation aircraft near airports were assessed within the project NEEDED presentation.

DINNER & DRINKS - A PREREQUISITE FOR INNOVATION

After captivating presentations of novel technologies, operational concepts and testing facilities at the Vienna Aviation Days the participants shared the common enthusiasm about aviation until the sun vanished behind the Vienna Skyline invigorated by typical Austrian dinner and drinks.



This was only the first of many iterations of the Vienna Aviation Days. The date for next year's Vienna Aviation Days has already been fixed. We hope to see you there and provide an informative, productive and memorable event!

THE TOPICS

BLOCK 1: POLICY

Climate neutrality is a global challenge, in which all stakeholders need to participate to mitigate the impacts of climate change. For challenges at this scale, individual efforts may not be sufficient. European, German, Dutch and Austrian governments and partnerships focus their efforts in supporting the maturation of technologies and methods that help European aviation in becoming climate neutral, independent, sustainable and competitive.

M. Kyriakopoulos will represent the *European Commission*, Janik Fernandez *Clean Aviation*, Ingrid Kernstock the *Austrian BMK*, Kai Wagner the *German BMWK* and Ron van Manen the Dutch *Luchtvaart in Transitie* to discuss strategies and possible future synergies to accelerate climate neutral aviation.

This block presents challenges and strategies of European policies to support the aviation industry.

European Commission

Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie

Bundesministerium für Wirtschaft und Klimaschutz

CLEAN AVIATION

LUCHTVAART in transitie

European Aviation Research in Horizon Europe

Michael Kyriakopoulos - European Commission

We are all aware that aviation goes beyond transport and is one of the most important economic pillars for Europe. It contributes to our trade balance, like very few other sectors do. We are also mindful that the sustainability challenge is redefining the aviation ecosystem.

The European Union takes a holistic approach aimed at ensuring competitiveness and achieving climate neutrality by 2050. Horizon Europe, the EU's key funding programme for research and innovation with a total budget of €93.5 billion includes a specific allocation for climate, energy, and mobility under Pillar II, out of which the climate, energy and mobility (Cluster 5) is funded with more than €15 billion. Cluster 5 funds aviation research, primarily the three partnerships (Clean Aviation, Clean Hydrogen, and the Single European Sky) as well as fundamental and collaborative research (Destination 5) as well as aviation safety (Destination 6).

The research and development journey of electric aviation in Europe commenced around 22 years ago. Today, there is a fully developed program with multiple demonstrators within Clean Aviation and breakthrough fundamental research within the collaborative program. Hydrogen and fuel cell research for aviation commenced around 25 years ago and FP5-Cryoplane project has been pivotal in exploring this technology.

Overall, at technical level, Europe's aviation research strategy, follows an integrated approach , which doesn't leave behind important areas of research. Apart from advancements in engines, gearboxes, materials, manufacturing- and noise reduction technologies also the infrastructure for small- and large-scale tests of demonstrators is needed for technological progress and digital technologies should be leveraged for aviation advancements. This underlines the necessity to exploit synergies all over Europe to achieve the goal of sustainable aviation.

At policy level, within Horizon Europe, the Commission is working on:

- Connecting even better Horizon Europe Aviation related research (Clean Aviation, SESAR, Clean Hydrogen, Batteries, High Performance Computing partnerships as well as Cluster 4 & 5 collaborative research) with the Alliances (AZEA & RLCF) and other instruments like the EIC, the Innovation Fund – which aim to prepare the deployment of key technologies and entry into service of zero-emission aircraft.
- Connecting even better EU and National programs – especially in a few priority topics such as – non-CO_2 emissions, materials for aviation and SAF.
- Addressing the issue of Research and Technology Infrastructures for aviation.
- Working even closer with European Aviation Safety Agency towards all the necessary regulatory changes and standards.

Janik Fernandez: Clean Aviation Joint Undertaking

The Clean Aviation Joint Undertaking is the European Union's leading research and innovation programme for transforming aviation towards a sustainable and climate neutral future. Clean Aviation advances impact-driven initiatives aimed at achieving reductions of 30% in greenhouse gas (GHG) emissions and addresses the specific technological and regulatory challenges associated with the development of hydrogen-powered and hybrid-electric aircraft.

The program utilises a two-phase approach for technological progress. Initially, various concepts and options for new technologies are developed. This phase involves extensive research and testing to explore the feasibility and potential impact of different solutions. In the second phase the most promising technologies are selected for further maturation and development. This phase aims to refine and prepare these technologies for large-scale implementation by integrated demonstrator tests.Clean Aviation plans to open calls for funding in 2025, with a substantial budget of 900 million euros earmarked for the second phase of technology development. This funding will support projects focused on advancing hydrogen aircraft technologies.

Certain challenges arise in the development of hydrogen-propulsion aircraft. Fuel cell systems need to become lighter, more efficient, and cost-effective. Advancements in powertrains to be capable of efficient hydrogen combustion are needed, as well as innovative storage solutions involving vacuum or foam insulation to safely and efficiently store hydrogen. These technologies need to be integrated into concept aircraft and subjected to testing and certification processes to verify the compliance with aviation regulations. This involves ensuring that new technologies meet stringent safety and performance standards.Clean Aviation actively engages with other European funding projects and industries to leverage synergies. While the focus of CA programme lies on the development and demonstration of new aircraft technologies, other critical technologies such as hydrogen refuelling and hydrogen supply will need to be developed through synergies.

Clean Aviation's structured approach, significant funding opportunities, and emphasis on collaboration highlight the promising advancements being made towards sustainable aviation. The focus on overcoming technical and regulatory hurdles is crucial for the successful deployment of hydrogen-powered and hybrid-electric aircraft, marking a significant step forward in reducing the aviation industry's environmental impact.

SOURCE: [CLEAN AVIATION HIGHLIGHTS 2023]

Aviation Technology in Austria

Ingird Kernstock – Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie

The Austrian Ministry of Climate Action (BMK) has outlined a strategy that focuses on hydrogen as a crucial element for the future of aviation. Austria's aviation research has progressed significantly, largely due to the TakeOff funding program, and the country is aiming to play a leading role in global aviation technology through collaborations within Europe.

SOURCE: FFG- NEW TAKE OFF CALL | FFG

Austria's aviation research has experienced notable success since the early 2000s, particularly through the TakeOff funding program. With 155 million euros invested, this program has helped Austria compete globally and become more visible in the aviation sector. To continue this progress, an extra 10 million euros have been budgeted for the next three years.

Austrian-made aviation components and technologies are well-regarded internationally, and resources like aeronautics.at provide a platform for collaboration within the industry. The BMK plays a vital role in fostering this research environment by connecting various stakeholders and promoting collaborations through agencies such as the Austrian Research Promotion Agency (FFG).

Austria's aviation strategy aims for the country to become a leader in climate-friendly aviation by 2040. Specifically, the goal is to be among the top ten contributors to the development of green aircraft. This requires active participation in European and international projects, as well as a continuous update of research topics to remain at the forefront of innovation.

Collaboration with other countries is fundamental to Austria’s aviation strategy, and regular workshops and networking events support this goal. Austria has previously worked with LuFo and plans to continue these collaborations. Additionally, the TakeOff program, with 12 million euros allocated annually, emphasizes Austria’s dedication to education and skill advancement in aviation, with applications for funding starting in October.

The Austrian Ministry of Climate Action is positioning the country to be a significant player in climate-friendly aviation by 2040, with hydrogen playing a pivotal role. Through strategic funding, collaboration, and innovation, Austria aims to be at the forefront of global aviation technology, driving sustainable advancements in the industry.

Policy & Strategies: Germany

Kai Wagner – Bundesministerium für Wirtschaft und Energie

Germany's aviation sector employs a significant workforce and contributes substantially to the economy, generating 46 billion euros annually. With major investments in research, the sector faces challenges such as supply chain issues, worker shortages, and the environmental impact of aviation, which is responsible for 3% of global CO_2 emissions. To address these challenges, Germany aims for climate-neutral aviation by 2045, with a focus on developing safe, efficient, and climate-friendly aircraft.

The aviation sector in Germany has made climate neutrality a priority, with the goal of achieving this by 2045. The AKKL (working group on climate-neutral aviation) involves multiple ministries and focuses on different aspects, such as ramp-up, technologies for climate-friendly aviation, and creating efficient aircraft. After years of work, the AKKL has put forward actionable recommendations, including scaling up Sustainable Aviation Fuels (SAF), optimizing flight routes to reduce contrail formation, and introducing new landing procedures to cut CO_2 emissions. Additionally, continued research funding is crucial to the strategy's success.

Technological innovations have already been developed, including shark skin technology to reduce drag and fuel cells capable of powering 100-seat aircraft. These advances are aimed at improving aircraft efficiency while minimizing environmental impact.

The LUFO program, which has supported aviation research for 28 years, plays a key role in Germany's aviation strategy. With a budget of 300 million euros this year, LUFO VII focuses on achieving climate neutrality, investing in digitalization, exploring new mobility concepts, and enhancing industry competitiveness. Key performance indicators (KPIs) include goals like a 40% reduction in weight, a 50% reduction in energy consumption, and maintaining current safety levels. To further accelerate development, the UpLiftH2Aviation Project enables both ground and flight tests for promising technologies.

Germany's aviation research is also aligned with several international initiatives such as Clean Aviation, Horizon Europe's AREANA, and collaborations with TakeOff in Austria, emphasizing innovation, sustainability, and collaboration.

Germany is committed to leading the global aviation industry toward climate-neutral flying by 2045. Through collaborative efforts, continued research funding, and technological innovation, the country aims to overcome challenges such as CO_2 emissions and industry inefficiencies. Programs like LUFO and initiatives under the AKKL are critical to ensuring that Germany remains at the forefront of sustainable aviation development.

SOURCE: BMWK- HTTPS://WWW.BMWK.DE

Netherlands' Investment in Aviation Innovation: Leading the Way to Sustainable Flight

Ron van Manen - Stichting Luchtvaart in Transitie

Ron van Manen, Managing Director of Luchtvaart in Transitie, emphasized the Netherlands' commitment to aviation innovation, driven by environmental concerns, economic opportunities, and the need for collaboration to address industry challenges. With substantial government investment, the Netherlands aims to co-lead the development of sustainable aviation technology.

The Netherlands, with its open trade economy, views innovation in aviation as essential for both economic growth and environmental sustainability. To maintain a leading position in the global aviation sector, the country is investing heavily in sustainable technology. The Dutch government has pledged 383 million euros over eight years from the National Growth Fund, although this may be adjusted depending on future government decisions. The total programme funding will be approx. 750 million euros including private in-kind investments.

The largest initiative focuses on sustainable aviation technology, including three flight demonstrators and a startup-friendly environment connected to global OEMs. Hydrogen propulsion is a key area of focus, despite that uncertainties remain about its economic viability, energy sourcing, the structural changes needed in aircraft design and new infrastructure at airports. The Netherlands is currently pursuing three hydrogen aviation projects, ranging from retrofitting existing planes, propulsion systems for new-build aircraft, through to designing, developing and building new hydrogen-powered aircraft.

A key project is HAPSS, which targets regional markets starting with the retrofitting of De Havilland Dash 8 aircraft. HAPSS aims to develop 28-36 passenger aircraft with an 800 km range, addressing the difficulties in retrofitting systems such as space and weight limitations. Future opportunities will include 'forward fitting' on new-build aircraft and supply chain positions on larger commercial aircraft either in the propulsion system or for the on-board energy (i.e. replacing APUs).

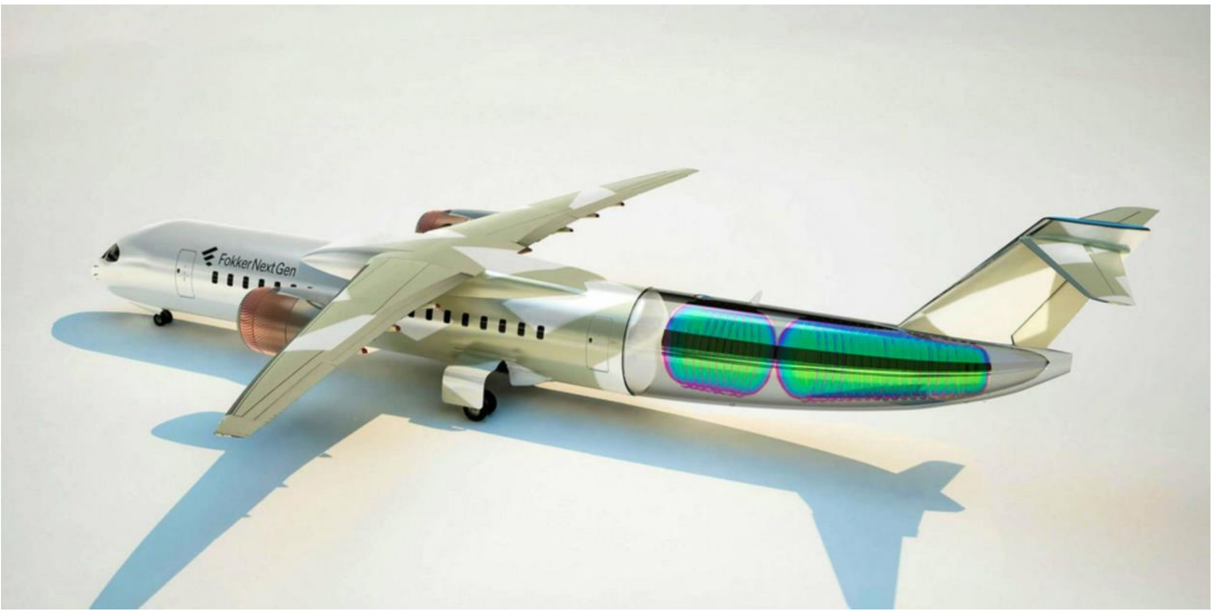
A second project called ICEFlight (currently being evaluated for approval) will explore a 100-seat + fuel cell option, focusing on overcoming challenges like thermal management and waste heat from fuel cells, making use of cryogenics, and allowing larger aircraft to successfully use fuel cells as energy source.

The HOT (Hydrogen Optimisation & Testing) project has completed a concept review for an advanced clean-sheet 120- to 150-seat narrowbody aircraft, proposing a dual-fuel design that combines hydrogen propulsion with a backup system using Sustainable Aviation Fuel (SAF). This design offers flexibility for longer routes, and a transition from current fuels during the upscaling of hydrogen infrastructure, as well as for operational situations (reserves, diversion etc.).

The other sustainable technology projects focus on key areas for the reduction in energy needs of future aircraft: advanced lightweight composite structures, electrical wiring and interconnection systems, and thermal and air management systems. Roughly half of the programme budget allocated to the sustainable technologies is aligned to the hydrogen projects, with the other half supporting the ‘light-weighting’ agenda.

Van Manen stressed the importance of a holistic systems approach, considering the broader impacts of aviation on pricing, policy, and infrastructure. Promoting promising research, integrating startups into the aviation supply chain, and encouraging international collaboration are key to the Netherlands' strategy. Additionally, efforts are being made to develop human capital by attracting new talent to tackle the challenges of sustainable aviation.

The Netherlands is aiming to position itself as a leader in sustainable aviation by investing in hydrogen propulsion and innovative technologies. Through government co-funding, collaborative projects like HAPSS, ICEFlight and HOT, as well as the projects aiming for a reduction in the energy consumption of aircraft (lightweight structures and systems), and a dual focus on both economic and environmental goals, the country is paving the way for a more sustainable aviation industry. Leveraging partnerships and advanced research, the Netherlands aims to address the aviation sector's challenges and drive global progress toward greener aviation.



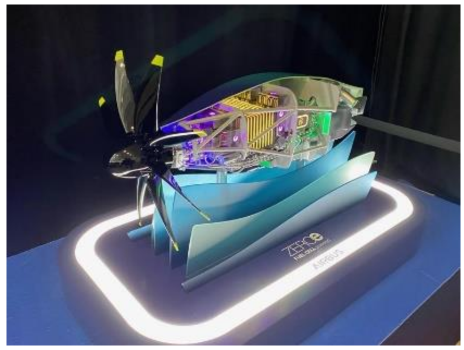
SOURCE: FOKKER NEXT GEN- [NEUE WASSERSTOFF-FOKKER - AEROTELEGRAPH]

BLOCK 2: CHALLENGES & OPPORTUNITIES

The use of hydrogen as a sustainable aviation fuel offers substantial benefits regarding emissions and raw material availability. However, there are several challenges that need to be solved before hydrogen powered aviation may become commercially available: On the technological side, storage, fuelling and the development of a safe hydrogen infrastructure at airports is required. Additionally, there is a need for both the hydrogen propulsion technology and their qualification for a hydrogen aircraft to be permitted to fly.

While hydrogen is generally perceived as climate friendly, the real impact of hydrogen aviation on the environment is still unclear.

This block presents solutions and roadmaps that aim to tackle the general challenges of using hydrogen as an aviation fuel and accurately predicting the climate impact due to non-CO2-emissions.



The ZeroE fuel cell propulsion system & facility for ground tests by Airbus

ZEROe H2OPE BeCoM NEEDED ALRIGH2T LIQORNE

A glimpse towards the future Hydrogen Powered Aviation: LH_2 Ground Infrastructure and Emission Modelling

Michele De Gennaro - AIT Austrian Institute of Technology

Air transport facts and figures, with a pitch on industry drivers and decarbonization path

Air transport is a key element of the European Transport Industry, responsible of ~3% of the anthropogenic CO_2 emissions of the EU-27, 400k jobs, and 130 billion/revenues (~1% of GDP in the EU-27).

The air transport demand is expected to double by 2040, growing at the steady rate of 4-5% per year (RPK). In the reference year 2022, AIRBUS outperformed Boeing by 27% on delivered aircraft units, rolling out 661 aircraft (i.e. 53 A220, 516 A320, 32 A330 and 60 A350) versus the 480 aircraft from its competitor (387 737-MAX and 93 cumulative belonging to the 747s, 767s, 777s and 787s families). Looking at the backlog orders in December 2022, AIRBUS counts 7,239 aircraft versus the 4,576 for Boeing.

Focusing on the foreseeable future, the European aeronautic industry must be prepared to face three main challenges:

1. **Increase competitiveness:** New challenges to the Boeing-Airbus duopoly with the market entry of the Chinese manufacturer COMAC. The C-919, certified by the Civil Aviation Administration of China in September 2022 and first flown commercially by China Eastern Airlines on December 9th, 2022, will likely acquire a non-negligible share of the internal Chinese narrowbody market by 2030. This will limit the ability to expand for AIRBUS and Boeing in the far East.
2. **Reducing airlines' operating costs**: Clearly signalled by the gradual retirement of the 4-engined widebodies (i.e., A340, A380 and Boeing 747), concurrently with the engineering efforts to expand narrowbody economics on transatlantic routes (e.g., see AIRBUS efforts for the developing the A321XLR variant, with expected Entry-into-Service (EiS) in 2024).
3. **Environmental requirements for sustainable aviation:** A significant fuel burn reduction, and inherent technological leaps are needed to achieve air transport carbon neutrality by 2050.

To achieve carbon neutrality, the industry is exploring several strategies:

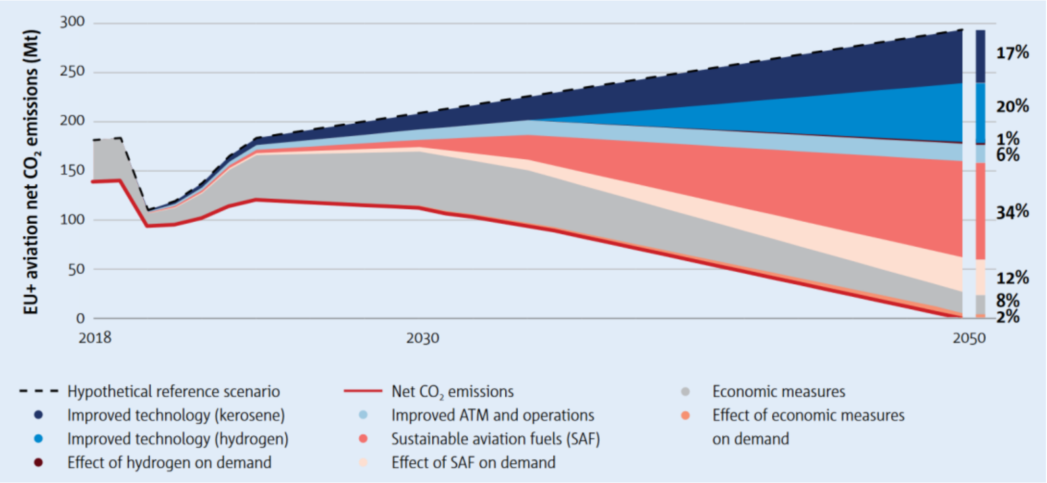
Improved Technology: Development of hybrid and hydrogen (H_2) technologies, contributing 20-30% to the reduction of carbon emissions.

Improved Air Traffic Management (ATM): Enhancing efficiency in flight operations.

Sustainable Aviation Fuels (SAF): Adoption of alternative fuels to reduce carbon footprint.

Economic Measures: Implementing policies and incentives to support sustainable practices.

But there are still some open points. Non-CO2 emissions remain, here data is needed to approximate the influence. (contrails, NOx, SO2, ...). The development of financially sustainable business models for green aviation is needed, acknowledging that initial H_2 planes might incur losses.



SOURCE: EASA AVIATION ENVIRONMENTAL REPORT 2022 (EU27+UK+EFTA)

AIT activities at European level on HPA: LH2 refueling and LTO emissions

ALRIGH2T: Airport-Level DemonstRatIon of Ground refueling of Liquid Hydrogen for AviaTion

ALRIGH2T develops innovative and complementary solutions for LH_2 aircraft refueling, with flow rates and volumes relevant for commercial aviation, as well as meeting safety standards.

The solutions will be demonstrated (TRL6) in two operational European airports: Milan-Malpensa and Paris

Concept 1 - LH2 direct refueling: Involves refueling within a 0.5 km radius at airports during boarding. The aim is to reduce turnaround times (target 30-40 minutes) to minimize ground time.

Concept 2 - LH2 tank swap refueling: This approach allows refueling in remote locations, bringing tanks to the aircraft, thus facilitating H2 refueling at airports without dedicated infrastructure. Demonstrations are planned in Paris.

NEEDED: Next generation data-driven reference European models and methods towards silent and green aircraft operations around airports

The NEEDED project focuses on developing next-generation European reference models to estimate current and future aircraft pollutant and noise emissions, and the number of people affected.

In the Project, aircraft data is used to gain insights into pollutant emissions in the European sky. Experimental measurements are performed at Rotterdam for noise, comparing 30 weeks of operation against current modeling standards. The aim is to achieve TRL4 and ensure compatibility with international models.

Mitigation of aviation's climate impact- The perspective of BeCoM and HOPE research

Feijia Yin - Technische Universität Delft

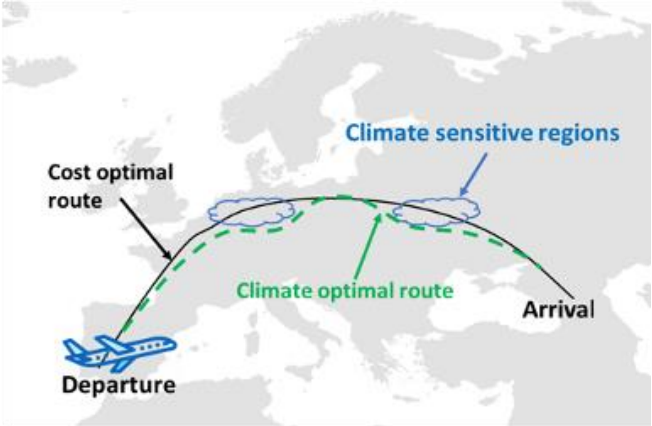
Aviation contributes significantly to global warming, accounting for approximately 3.5% of the total. Notably, non-CO2 emissions, which include contrails and NOx, constitute 66% of aviation's climate impact. Globally non-CO2 effects are about 2.4 times of CO2 effects.

With higher flight ranges, the importance of non-CO2 emissions increases due to cruising at high altitudes where their impact is more pronounced.

BeCoM Project – Better Contrail Mitigation

The BECOM project aims to introduce measures to quantify and mitigate non-CO2 emissions by addressing the uncertainties surrounding contrail formation and their climate impact.

Contrail formation is highly dependent on specific atmospheric conditions. Not all regions of the atmosphere are conducive to contrail formation. Current research focuses on enhancing forecasting technology to identify regions where contrails are likely to form. This would enable operational measures to avoid these regions. By avoiding regions where contrails might form, aircraft trajectories can be optimized to reduce contrail formation.



HOPE Project

The overall goal of HOPE is to design an efficient and fuel-flexible aircraft propulsion system that is compatible with operations for minimum noise and emissions at all stages of aircraft movement.

The HOPE project focuses on developing multi-fuel, low-noise, and low-emission technologies for aircraft. A key innovation in this project is the development of fuel-flexible ultra-high bypass ratio (BPR) engines. These engines can combust multiple fuels, such as hydrogen and kerosene, simultaneously, allowing for an optimized fuel mixture that reduces emissions. Another significant advancement is the design of Auxiliary Power Units (APUs) as fuel cell-based power units. These APUs can manage taxi operations by emitting only water vapor, thus significantly reducing noise and emissions.

Research within the HOPE project also extends to integrated propulsion systems. This includes conducting experimental studies and numerical simulations of multi-fuel combustion to analyze emissions and reduce noise. Aeroacoustic experiments, paired with numerical simulations, aim to develop a comprehensive noise prediction model, which assesses sound exposure metrics to better understand and mitigate noise pollution.

Another aspect of the HOPE project is the climate impact comparison between a baseline B767 aircraft and one equipped with HOPE technology. The analysis reveals that while NOx emissions can potentially worsen climate impact, substantial reductions in NOx (up to 90%) make hydrogen a far superior alternative to traditional fuels. However, the potential impact of contrails remains a concern with hydrogen combustion, highlighting the need for continued research and innovation in this area.

LIQORNE – Combustion Bay One e.U.

Fabrice Guiliani - Technische Universität Graz

An overview about hydrogen combustion engineering was given, where significant progress has been made over the past five years. One notable innovation is the development of recursive sequential combustion technology. This involves a "flying wheel" concept, where trapped burned gases circulate within the system. This technology supports lean combustion, leading to improved performance and efficiency in hydrogen-fueled engines. A demonstration PhD thesis will take place in collaboration with TU Graz starting 2025 in the frame of the FFG-supported MOeBIUS.H project.

LIQORNE: towards a safe, lightweight and fast-responding hydrogen fuel system for aviation

The LIQORNE project, in collaboration with Test-Fuchs and FH JOANNEUM, focuses on the thermal management of hydrogen in aviation.

To convert liquid hydrogen (LH_2) to gaseous hydrogen (GH_2) efficient, low-pressure systems with small, thin pipes to minimize surface area and reduce ice formation risks are used. Furthermore, the heat generated by aircraft engines is utilized to aid in converting LH2 to GH2.

The project uses the Piaggio Avanti P180 aircraft as a base model, equipped with two 750 kW engines. The aircraft consumes 0.03 kg/s of LH2. With a tank 4 times the volume of the current kerosine tank, a maximum range of 4000 km can be achieved. Therefore, transatlantic flights remain unfeasible without the use of Sustainable Aviation Fuel (SAF).

LIQORNE was the pilot project and is now followed by the FFG-supported IRON LIQORNE project, towards experimental demonstration of the solutions discussed below. FH JOANNEUM / Aviation takes leadership on this new project phase.

Challenges and Solutions

Tank Design: The aircraft employs two tanks to enhance balance and redundancy, keeping hydrogen in liquid form as long as possible to facilitate transportation and manage rapid pressure rises.

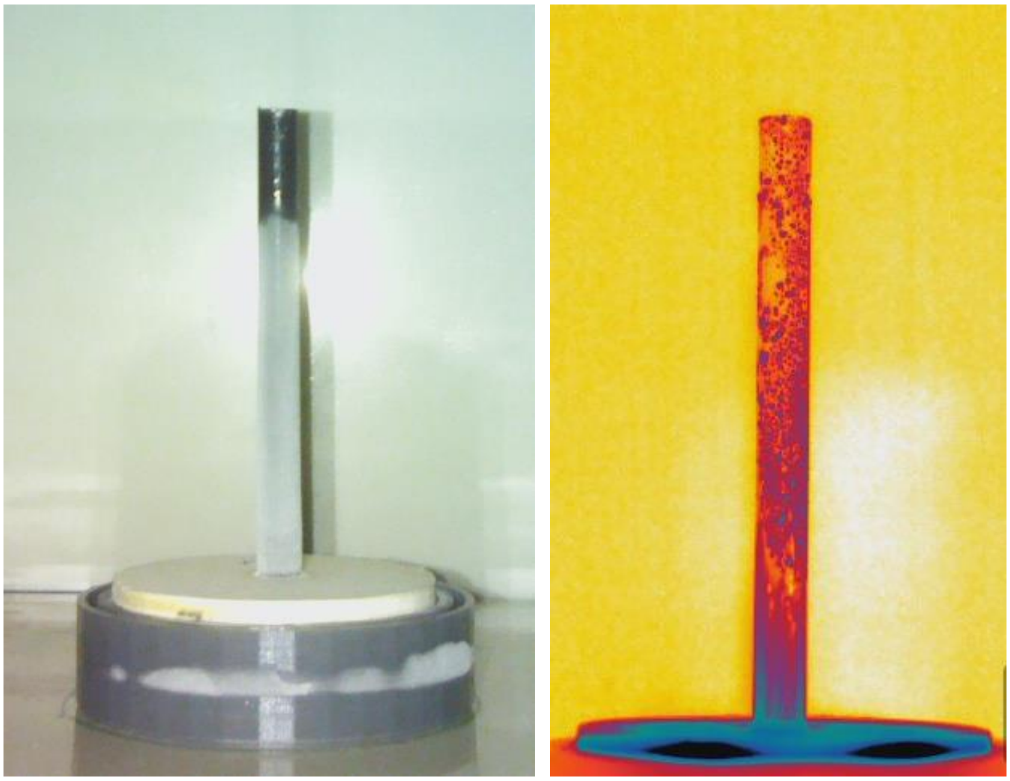
Boil-Off Management: A feasible boil-off management system maintains a maximum overpressure of +0.15 bar, which is relatively uncomplicated.

Hydrogen Pump Issues: A significant challenge is the hydrogen pump, which cannot be lubricated effectively, leading to short operational lifespans.

Alternate pressurizing solution using trapped GH2 vessel: This solution has shown lower pressure gains than expected, and control issues. There is a risk of burnout on the heat exchanger.

Capillarity Effects: Exploring capillarity effects in 3D printed channels, combined with Tesla valves preventing backflows is a very promising solution to promote a well-controlled LH2/GH2 transition.

Icing and Insulation: The possible ice formation on the surfaces of the fuel system exposed to the ambient air is simulated. Dry ice cooling of a stainless-steel pipe, possibly with a layer of isolation, in a climate test cabinet is used to cool the surface, a thermal imaging camera and micro-CT is used to determine the external wall temperatures and the water or ice contents outside and in the pipe. The CAE simulations were performed with Ansys Fluent.



CONDENSATION AND FROST FORMATION AT OUTSIDE WALL OF PIPE (LEFT) AS WELL AS ON THE INSIDE (RIGHT) USING MICRO-CT TOMOGRAPHY.

Experimental Research for Sustainable Aviation

Sustainable Aviation

Airbus has set itself the target of making a crucial contribution to climate action in global aviation: it is the zero-emission target for all Airbus aircraft by the year 2050. One strong lever to meet this objective is the development of zero-emission propulsion systems for future commercial aircraft. Depending on payload-range-requirements, such propulsion systems will be based on battery-electric, hydrogen-hybrid or hydrogen-combustion technologies. One challenge is to replace kerosene as energy source for commercial aircraft, and to store energy either in battery systems (i.e. at low gravimetric energy density) or in hydrogen tanks (i.e. at low volumetric energy density). In either case it is essential to find a compromise between aircraft weight and payload/range capacity.

Experimental Research

One important brick within the scope of development is experimental research on all levels of a propulsion system (equipment level, subsystem level, propulsion system level). On its research and technology site in Taufkirchen, since the year 2019, Airbus is operating a test center for integrated propulsion systems at all relevant power classes of future commercial aircraft. At the Vienna Aviation Days 2024, two examples out of the complete range of experimental research environments, which are in operation in this test center today, were being presented:

- ZEROe Test Bench, to demonstrate the functional integration of a propulsion system based on fuel cell technologies (1.2 MW / 1200 V / 1000 A / OAT).
- ASCEND Test Bench, to explore the basic feasibility of superconducting technologies at cryogenic temperatures (500 kW / 300 V / 3000 A / -200 °C).

While the ZEROe programme, which is currently targeting a turbo-prop aircraft with a payload of ~100 PAX and a range ~1000 nm, is in fact the first step on the path towards the zero-emission target of Airbus, the ASCEND project might be an enabler for the second step from small aircraft to short, medium or even long range aircraft.

Fig.1: Airbus Test Center for integrated propulsion systems

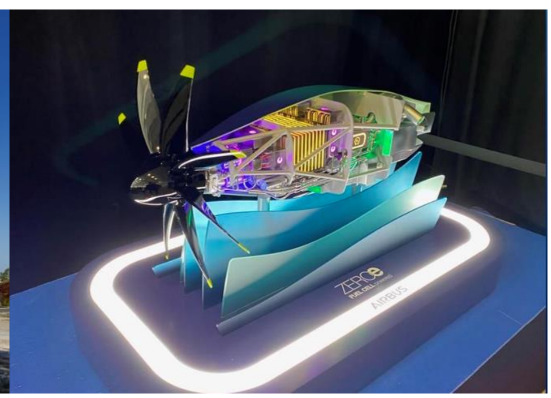


Fig.2: Mock-up of a ZEROe Fuel Cell Engine

Introduction to FAME Project

Johannes Hartmann - Airbus

FAME – "Fuel Cell Aircraft Megawatt Engine" aligns with the European Green Deal's roadmap and aims to significantly reduce the environmental impact of aviation

Currently, there are 26,000 aircraft worldwide. To meet sustainability goals, one focus is on hydrogen (H2) storage and distribution, and fuel cell technologies. Hydrogen presents a solution with no CO2, SO2, soot, or NOx emissions and is expected to have a lower contrail impact compared to conventional fuels. The main focus of the FAME project is the development of fuel cell technology.

The FAME project follows a V-Development Cycle to ensure comprehensive development and qualification of new technologies. The core aim is to demonstrate a megawatt (MW) engine on the ground. The ultimate goal after the project is to integrate an upscaled version of this engine into a short range aircraft, achieving a range of 1000 nautical miles with 100 passengers and 10 MW of installed power. Currently, the project is working on a 1 MW propulsion system demonstration.

Development and Design Process

The process starts with aircraft specifications to form a viable product. For instance, a 2.5 MW engine is planned. Ground demonstrations are crucial for learning and refining the process. After ground testing, the components will be tested individually with partners, and then the complete system will be tested. Scaling rules will be applied to ensure the system meets the specified requirements.

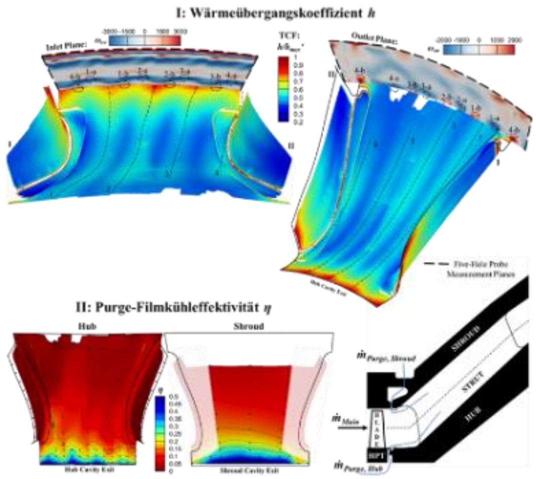
To achieve the ambitious goals, there is a need for rapid development of competitive hydrogen systems. Unlike the 60 years it took to develop gas turbine technology, hydrogen systems need to be developed within years, not decades. This urgency is driven by the necessity reduce aviation climate impact significantly and meet stringent environmental regulations. The FAME project involves 21 partners, each bringing pre-developed components funded by national programs. These components will be assembled into a ground demonstrator through a collaborative effort. The project aims to achieve Technology Readiness Level 4 by 2026 and have the aircraft ready to fly by 2035. This ambitious timeline leverages all available funding frameworks and partnerships across Europe.

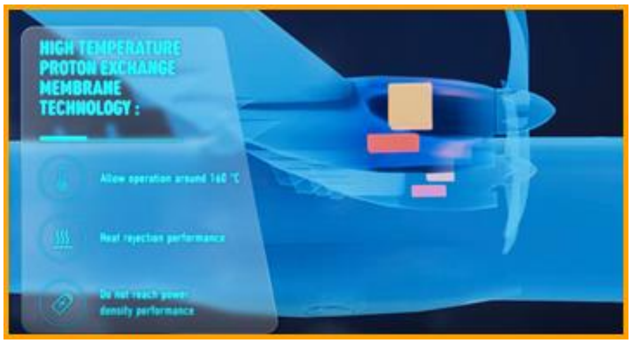
Source: Airbus ZeroE - First zeroe-engine-fuel-cell

BLOCK 3: HYDROGEN COMBUSTION & HYDROGEN-ELECTRIC PROPULSION SYSTEMS

The heart of the zero-emission aircraft is its propulsion system. When using hydrogen as fuel both combustion and fuel cells are possible methods to power the aircraft. For fuel cells in aviation, thermal management is a major challenge as nearly the same amount as electric power must be rejected as heat. Thus, large heat exchangers are necessary and there may be much potential to recuperate energy from the “waste” heat. Combusting hydrogen in an aviation turbine engine is a concept that comes closer to current propulsion technologies. However, hydrogen combustion comes with its own set of challenges: Hydrogen has different combustion properties than kerosene, material choice is critical and while no CO2 is produced, it may lead to NOx emissions.

In this block, solutions to achieve the most efficient and lightweight hydrogen-propulsion systems for future aircraft are presented.





A simulation of heat transfer during hydrogen combustion (TU Graz) & the benefits of a high temperature PEM fuel cell (NIMPHEA)

EXFAN

NIMPHEA

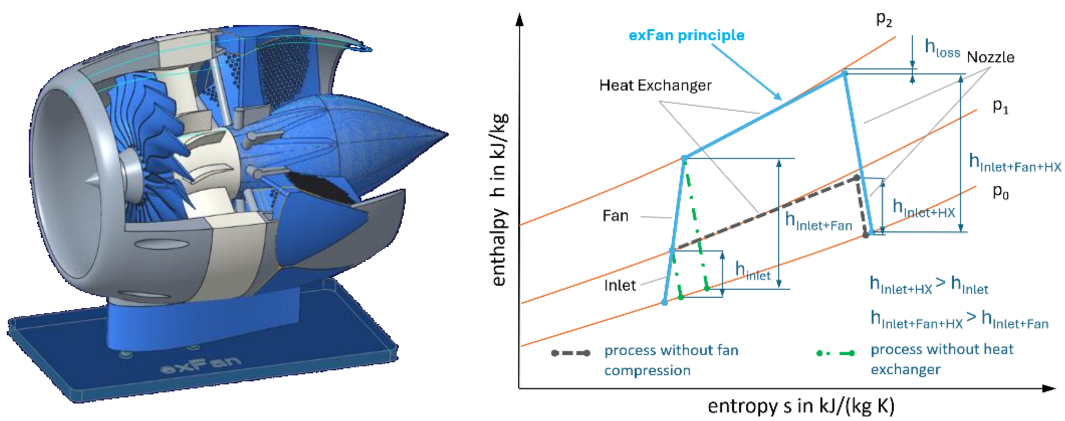
FlyECO

Mythos

exFan - Novel Recuperation system to maximize exergy from anergy for fuel cell powered geared electric aircraft propulsion system

Martin Berens – Technische Universität Wien

In fuel cell propulsion systems large amounts of heat are generated that are usually rejected from the system. Utilization of the produced heat however has the potential to improve efficiency of fuel cell electric propulsion systems – thus reducing the amount of costly hydrogen needed for operation. The research project exFan investigates a strategy to utilize waste heat of fuel cell electric propulsion systems via a Brayton cycle: air enters the inlet and is compressed by the fan and a heat exchanger within the flow path heats up the air flow. This increases the volumetric flow rate which in turn increases the jet velocity producing net thrust. A similar effect has been already applied to aircraft such as the P51-Mustang, however the introduction of additional fan compression increases the efficiency of the Brayton Cycle, producing more thrust.



A parameter study of this mechanism for a twin-engine A320-size aircraft in 0D & 1D gives insight on the potential and challenges associated with the application of the described recuperation system.

Transfer efficiency is best around a flying altitude of 11km in an ISA atmosphere. Above, the heat exchanger size needs to increase leading to reduced transfer efficiency. For a fan pressure ratio (FPR) of 1.2, a flight altitude of 11km and a flight Mach number of 0.8 about 5% of efficiency may be gained even if aerodynamic losses of the flow path including the HX are considered.

While the Brayton cycle efficiency benefits from high pressure ratios, the heat up of the air that enters the heat exchanger makes the heat transfer less effective if the coolant entry temperature is kept constant.

Hot-day take off is the most critical condition: An A320-size aircraft requires only 12.5MW for cruise but about 50MW for take-off. Additionally, ambient temperatures close to the ground may be high which negatively affects heat transfer. The inflow coolant temperature of the heat exchanger has a major impact on the required heat exchanger surface area at take-off and cruise: For a FPR of 1.2, the required heat exchanger surface area needs to be three times as large for an inflow temperature of

80°C compared to 140°C. In cruise condition, this effect is still present but much less pronounced due to the generally greater differences between the temperatures of the air that enters the HX and the coolant.

To assess the performance of the exFan recuperation technology, enhanced models will be created that will give more detail on heat exchanger and fuel cell behaviour, on nacelle drag and system masses as well as aircraft performance. The main challenges are to match the deviating requirements of sea level take-off and cruise as well as to make take-off possible even on a hot day.

Project NIMPHEA

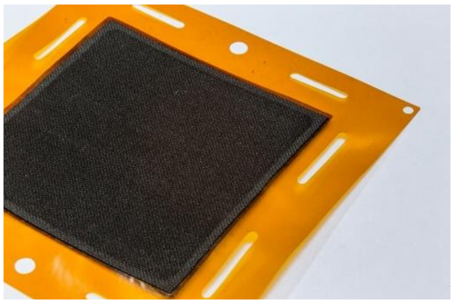
Yan Duranteau –Safran Power Units

The development of high-temperature Proton Exchange Membrane Fuel Cells (HT-PEMFC) for aviation represents a significant leap forward in the quest for sustainable aerospace technologies. Addressing the numerous challenges associated with heat rejection of fuel cells during take-off and during cruise, requires researchers to refine component-level operations to enhance overall performance and reliability – especially on Membrane Electrode Assembly (MEA) level. The NIMPHEA project will develop a new-generation of MEA - the central component of Proton Exchange Membrane Fuel Cells (PEMFC) - compatible with aviation applications.

High-temperature fuel cells can effectively manage heat rejection issues, which are critical during the take-off and cruise phase of flight. Maintaining optimal performance without excessive cooling requirements is a significant benefit. However, when using high temperature fuel cells, the primary challenges revolve around degradation and power density of the membrane assembly, which are crucial for long-term viability and efficiency.

The main challenges that need to be solved in the development of the HT-PEMFC membrane assembly are connected to the manufacturing, the characterization of the electrode/electrolyte interfaces, the integration of new electrode components as well as their performance predictions.The active platinum phase must be deposited by different methods (PVD or Polyol method) and the carbonaceous supports need extremely high corrosion resistance. To validate the performance of HT-PEMFC membrane assembly, aeronautical testing is conducted on several HT-PEMFC test rig. These tests simulate real-world conditions to ensure that the membranes can withstand the aviation use. A Life Cycle Analysis (LCA) on Membrane Assembly level is performed to assess the environmental impact and sustainability of the technology throughout its entire lifecycle to extend the scope of the assessment to the propulsion system level. One of the project's achievements is the development of a catalytic layer with significantly less platinum, nearly reaching the state of the art in performance. Platinum is a critical and expensive component in fuel cells, so reducing its use without sacrificing efficiency is a major milestone. This advancement not only lowers costs but also contributes to the sustainability of the technology.

In conclusion, the development of high-temperature PEMFC membranes for aviation holds great promise for the future of sustainable aviation technology. By addressing key challenges in membrane thickness, manufacturing, predictive modelling, and corrosion resistance, and by leveraging collaborative design and testing, NIMPHEA will make significant contributions to the aerospace industry. The near-state-of-the-art performance achieved with reduced platinum usage further underscores the potential of this technology to revolutionize aviation fuel cells.



SOURCE: NIMPHEA - NIMPHEA.EU

FlyECO

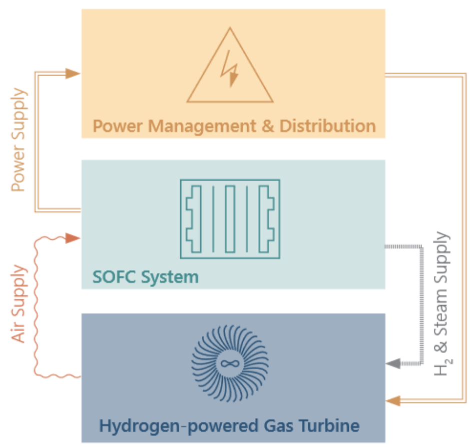
Stefanie de Graaf – DLR

When investigating fuel cells for aviation purposes, LT-PEMFCs with operating temperatures of up to 90° C represent a mature technology with first flying demonstrators and good efficiency. However, they require complex water management and heavy heat exchangers for heat rejection. While other research projects focus on HT-PEMFCs with an acid-based electrolyte and an operating temperature of approx. 180° C, FlyECO investigates the potential future beyond HT-PEMFCs towards solid oxide fuel cells (SOFCs).

SOFCs offer even higher efficiency up to 65% on cell level. The high operating temperatures of SOFC of approx. 800°C reduce the challenge of heat rejection from the fuel cells, as well as enable opportunities for combined heat and power (CHP) applications. However, SOFCs currently suffer from a low technology readiness level and other challenges for operation in aviation, such as for instance start-up behaviour, low power densities, as well as sealing and durability issues. Furthermore, the cathode air preconditioning requires a large share of the produced power, especially the according compressors.

The European Research project FlyECO investigates the combination of an SOFC and a gas turbine with hydrogen combustion within an integrated power and propulsion system (IPPS) for MW-class aircraft applications with entry into service of 2050. This way, synergies between both systems could be utilized. Bleed air from the gas turbine can be supplied to the cathode of the SOFC, avoiding the necessity for additional compressors within the SOFC system. The water steam produced by the SOFC can be injected in the combustion chamber of the hydrogen-fuelled gas turbine to reduce the combustion temperature and thereby the NOx emissions of hydrogen combustion by at least 50%.

However, to enable such an IPPS, multiple challenges for the system coupling as well as on the side of the gas turbine and the SOFC still need to be solved. The hydrogen powered gas turbine requires a complex conditioning of the fuelled hydrogen and suitable material selection. The impact of the steam injection to reduce NOx emissions must be further investigated and off-design performance as well as transient and dynamic behaviour need to be considered. For the SOFC, the core technical challenges include the power density, the conditioning of air as well as operation, insulation and sealing.



SOURCE: FLYECO - FLYECO-EUROPEAN-PROJECT.EU

The project FlyECO will tackle crucial challenges of such an IPPS by delivering detailed simulations, developing technologies concepts and demonstrating the effect of steam ingestion on NOx emissions and compressor stability.

Project Mythos

Francesca di Mare – Ruhr-University Bochum

The future holds many solutions for aviation fuels that have large potential to reduce the environmental impact of aviation. Drop-In fuels can reduce CO2 by at least 80% compared to conventional jet fuels. Beyond that SAFs also contribute to local air quality below 900m by reducing particulate matter and SOx emissions.

Different blends of SAF and pure hydrogen however currently can not be flexibly used in combustion systems. The research project MYTHOS seeks to develop an innovative design methodology for future civil engines capable of using a multitude of fuels in a holistic approach.

This holistic approach starts at a low-fidelity aerothermal design (0D) that designs the core engine to output specific thrust, fuel consumption, engine efficiency and fan pressure ratios. This stage already considers simplified chemical reactions for initial assessment. Subsequently, compressor, combustor and turbine are preliminarily automatically designed in 3D. Finally, the highfidelity simulations help design every component in more detail. The process is supported by knowledge driven algorithms to generate a virtual-twin on one hand and an exhaustive set of operating scenarios on the other hand, where the usage of high-, medium- or low-fidelity simulation approaches is optimally targeted and calibrated. High-fidelity experiments serve as essential validation basis of component analysis as far as the combustion processes are concerned.

The major challenge to be overcome in is the characterization of different fuels and the design of the injection systems capable to handle different flame speeds and flame dynamics in general. High-accuracy and speed of the multi-fidelity analysis system illustrated above will be of paramount importance to achieve the objectives of the project.

SOURCE: PROJECT MYTHOS - LINKEDIN.COM

Hydrogen related projects at TU Graz

Patrick Jagerhofer – Technische Universität Graz

Hydrogen combustion comes with mutliple challenges and novelties for the aviation industries. In order to investigate the performance and behaviour of hydrogen powered gas turbines in relevant environments, specialized testing equipment is required. The Institute of Thermal Turbomachinery and Machine Dynamics at the Graz University of Technology has testing infrastructure consisting of compressors and blowers in the MW range for Turbomachinery, that allow high-speed wind tunnel and subsonic as well as transonic turbine testing. The research efforts at the TTM start at the combustion chamber, go over the high pressure turbine to the intermediate turbine ducts and the turbine exit casing.

Combustion chamber: In the facilities of the ITTM several research efforts are planned, ongoing and finished: catalytic combustion of hydrogen has already been investigated: A process that uses hydrogen and oxygen to form water with the help of a catalyst. This process occurs at lower temperatures compared to traditional combustion and reduces emissions as well as improving safety and efficiency. In the future recursive sequential combustion of hydrogen will be investigated together with the company Combustion Bay one. In this process, burners are arranged behind each other and in a circle. This allows a considerable part of burnt gases emitted by one burner enter the next for high-efficiency and low-emission combustion.

High pressure turbine: For high pressure turbines, a new large-scale test rig consisting of two-stage high-pressure turbine with cooling and hot streak generator is planned to be set-up. This hot streak generator is able to produce engine relevant hot streaks, that are usually not circular. The hot streak of H2 has a much higher burning velocity than Jet A-1, a higher combustion temperature and is thus more intense. The water vapour additionally leads to a more intense heat transfer bringing additional challenges to the design of the high-pressure turbine and following components.

Intermediate Turbine Ducts: In the TCF the hot streak attaches on the surfaces of the duct and leads to high thermal load. The TCF is currently an uncooled thermal component and the hot streak stresses the limit of materials. The ITTM want to consider the high water vapor content in an H2 fired hot streak and be able to predict the heat transfer and get all experimental data.

Turbine Exit Casing: The heat of the gas flow can be used to preheat cryocooled H2 by integrating a heat exchanger. However, the retroactive effects of heat exchange on this point on the flow need to be investigated to prove the feasibility.

SOURCE: INTEGRATED HYDROGEN INFRASTRUCTURE - TUGRAZ.AT

BLOCK 4: ARCHITECTURE, ON BOARD STORAGE & MODELLING

Liquid Hydrogen with its low temperature of around -250°C creates new challenges in the airplane. Those include tank, on board storage and fuel distribution systems as well as refuelling. Cryogenic technologies are required for long-term liquid storage and the choice of lightweight materials for aviation applications are challenging, especially when safety critical components such as valves are considered. Testing infrastructures for applications of liquid hydrogen are necessary to allow researchers to test technologies early. Battery electric storage often needs to be used in parallel to hydrogen but brings a major challenge due to its low energy density.

This block will outline solutions for onboard energy storage (hydrogen & battery) as well as components necessary for cryogenic hydrogen storage and presents possibilities for testing facilities for researchers & industry.

Liquid hydrogen A320 ground demonstrator (DLR) and a load bearing battery cell (MATISSE) that may be used as a structural element in future more-electric aircraft

Airworthy batteries

Helmut Kühnelt - AIT Austrian Institute of Technology

From Advanced Batteries to MATISSE multifunctional electrical energy storage

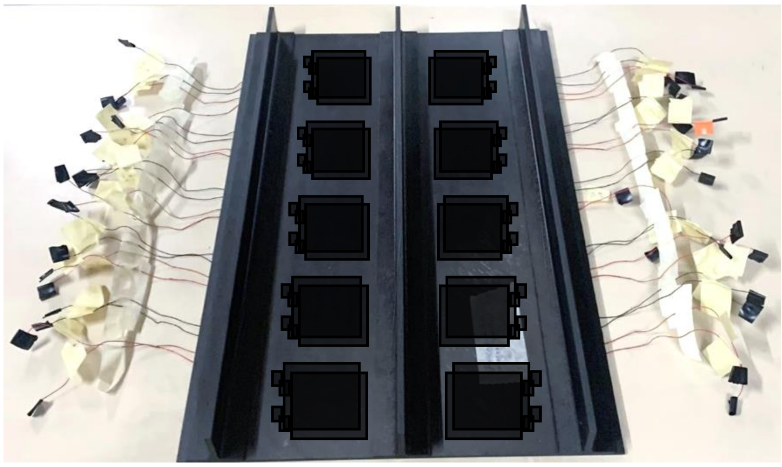
The presentation focused on recent advancements in structural battery technology and emphasized the integration of load bearing battery modules cells as structural components in the aircraft. The combination of energy storage and load bearing capabilities is aiming to enhance the energy density in relation to added weight while providing multifunctionality and addressing safety concerns.

State of the art in Li-ion battery technology

The current state of battery technology has low energy density but exhibits the highest efficiency in energy storage. Efforts in Li-ion solid-state battery technology aim to increase energy densities to 500-600Wh/kg at cell level. This will correspond to 450-500Wh/kg at the pack level, which still represents a substantial weight penalty.

Project SOLIFLY

The transition to structural batteries is driven by the potential to reduce overall aircraft weight through multifunctionality. The feasibility of structural batteries has been demonstrated through the development of a structural battery module in the project SOLIFLY. The structural battery cells achieved an energy density of 50Wh/kg, which corresponds to an energy density of 7-8Wh/kg at module level representing a weight impact of 2.6% in the stiffened panel which can bear 18 tons without impacting global rigidity.

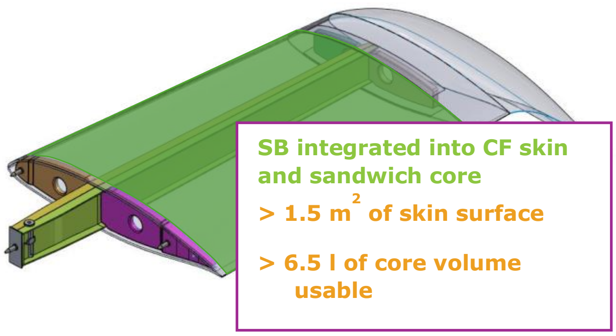


SOLIFLY demonstrator: Hight-strength composite panel with 20 AIT RMS cells in skin © ONERA

Project MATISSE

The MATISSE project, which is an expansion of the SOLIFLY project, aims to improve the structural electrochemistry and integrate sensors for monitoring both battery and structural health into the load bearing battery panels.

The current multifunctional electrochemistry provides an energy density of 92Wh/kg at cell level. The smart cell includes a sensor foil with a microchip monitoring unit to measure the mechanical loads on the cell and structure. During this project a *full-scale detachable wingtip with multifunctional electrical energy storage for the Pipistrel Velis electro* will be developed to TRL4 as a demonstrator.



Potential and Challenges of the technology

Improved structural battery cells could achieve up to 400 Wh/kg at cell level corresponding to over 1 kWh/added kg mass when integrated into solid composite laminates. At integration level, this allows to surpass energy densities of conventional Li-ion-batteries, whilst requiring no cooling due to improved thermal stability of the cells and enhancing safety through additional strain sensors in the structure. For SMR aircrafts 2-3kWh per passenger could be stored through structural parts for non-propulsive electrical loads. Initial integration is being tested in non-safety critical structures.

However, challenges remain, such as the discrepancy in lifetime between structure and battery, which leads to the need for replaceable multifunctional parts with self-test capabilities.

The developments in aircraft design by incorporating high-energy-density, multifunctional structural batteries promise enhanced efficiency, safety, and structural intelligence in future aircraft. Therefore, continuous further development of the structural battery technology should be carried out.

Hydrogen R&D Strategy of Test-Fuchs

Michael Schilling - TEST-FUCHS GmbH

Test-Fuchs research and development strategy on hydrogen is focusing on the expansion of hydrogen (H2) applications beyond the space industry such as hydrogen airports and hydrogen-powered vehicles. The company's initiative, labelled H2-3-4, outlines a significant investment of 3 million euros over four years to tackle emerging topics in hydrogen technology.

Key Areas of Focus

The initiative aims to explore the integration of hydrogen technologies in aircraft & trucks together with the infrastructure which needs to be available to enable the use of hydrogen. A specific emphasis also lies on valve technology for cryogenic applications and on the development of H2 powered ground support equipment. The vision for hydrogen airports in 10-25 years emphasizes the need for infrastructure readiness and shows that adaptation of test equipment to support this future infrastructure is crucial.

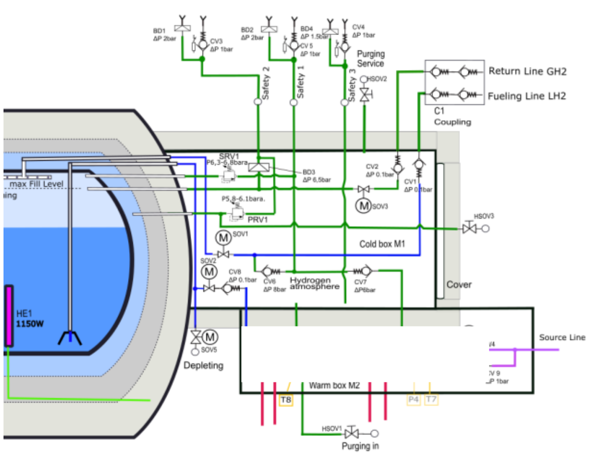
ON – AIR
LH_2 Storage and
$(L)H_2$ management

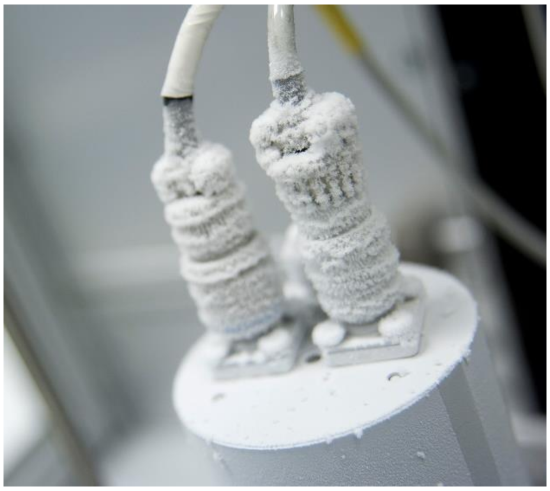
IN-MOTION
LH_2 Valves

TO-TEST
Test equipment for $(L)H_2$ materials, components and systems

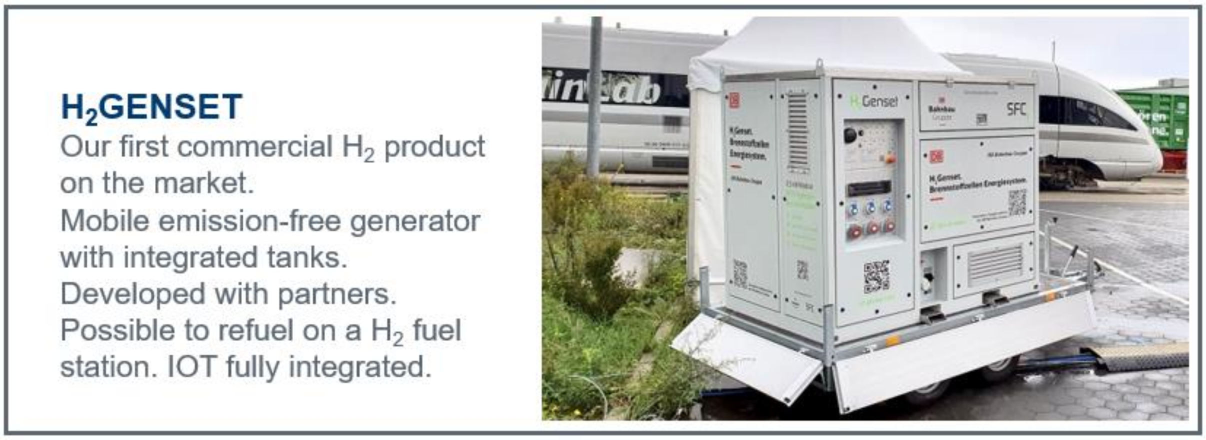
FOR-GSE
Development of H_2 GSEs
H_2 powered GSEs
Mobile emission-free Generator

Historically Test-Fuchs is focused on the component level design, but now due to market demands also addressing subsystems involving valves and piping. The design process relies, apart from testing cryogenic applications, on the creation of digital twins to model core functionality and packaging whilst allowing for continuous monitoring and maintenance towards a data-driven R&D.





Test-Fuchs stands for a collaborative approach within Europe to accelerate hydrogen technology development and wishes for large companies and small & medium sized enterprises to create synergies for mutual benefit. As a partner in the Clean-Aviation network Test-Fuchs contributes to the development of H2 refuelling procedures for liquid hydrogen under real airplane conditions in the Project ALRIGH2T. In terms of decarbonised ground support equipment, a green generator utilising hydrogen has been developed from a demonstrator to a commercial product. In addition to the hydrogen fuel cell the generator also has a battery and its own thermal management system onboard.



Challenges

It is difficult to predict the timeline, when milestones in the projects can be reached and therefore to accomplish the financing of these projects. The distribution of Hydrogen can be challenging, therefore fast demonstrators need to be utilised to identify and address real challenges quickly. Also, a framework for certifying hydrogen-powered aircraft is needed.

Test-Fuchs is strategically broadening its R&D efforts to include a wide range of hydrogen applications, particularly in aviation and ground support equipment. By investing in innovative technologies and fostering collaborations, the company aims to overcome the challenges associated with hydrogen integration, certification, and infrastructure development. This comprehensive approach ensures that Test-Fuchs remains at the forefront of hydrogen technology advancements, paving the way for a sustainable future in aviation and beyond.

Advancing Aviation

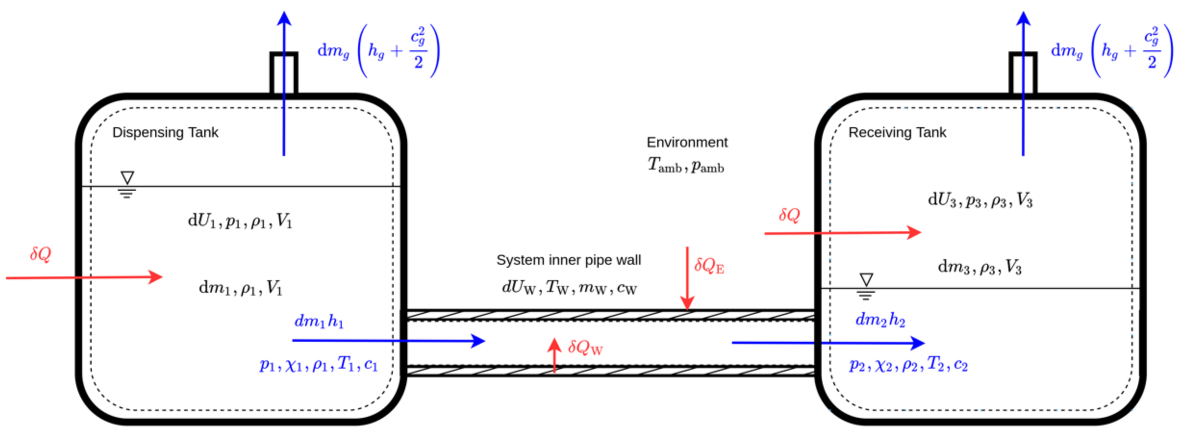
Alexander Trattner - HyCentA Research GmbH

Overcoming Research Challenges in LH2 Storage and Fuel Cell Powertrains

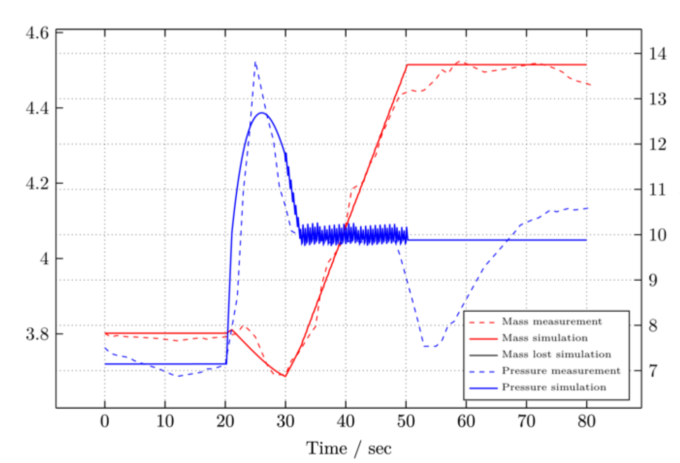
HYCENTA, a subsidiary of TU Graz, consists of an interdisciplinary team of 100 researchers focusing on hydrogen storage, measurement, and testing, particularly in Graz, Austria. The Experience ranges back over a decade with liquid hydrogen (LH2) technology, including collaboration with BMW on the H7 project. HYCENTA has extensive knowledge in measuring LH2 and developing fast-forward strategies in hydrogen technology.

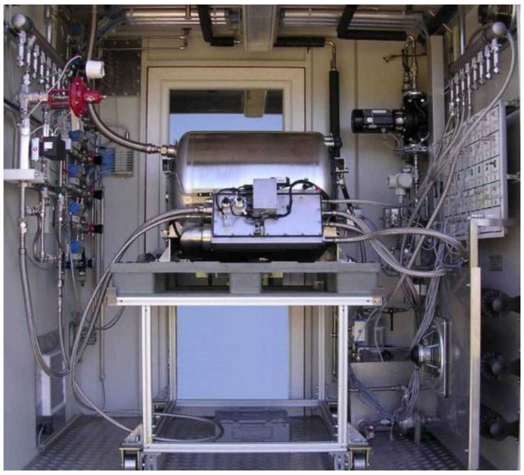
Thermodynamic Analysis and Modelling of Hydrogen refuelling

Regarding thermodynamic analysis a comprehensive model of hydrogen refuelling has been developed and will be available soon. The model includes a cryo-conditioning pump system for efficient refuelling.



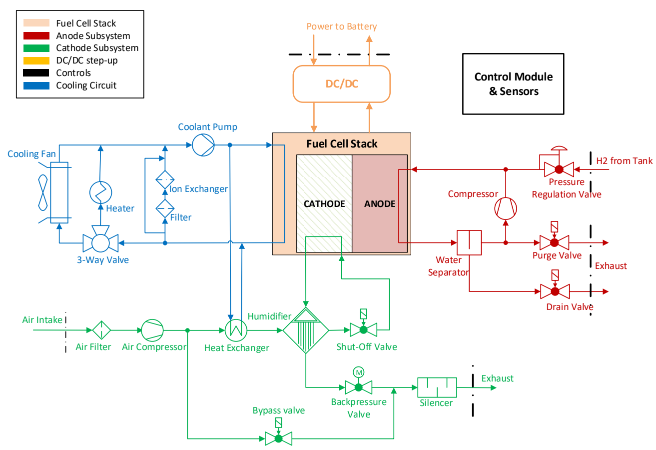
This prediction model is to be validated with data obtained by experiments. The aim is to get a better understanding of the process and to reduce losses originating in refuelling.

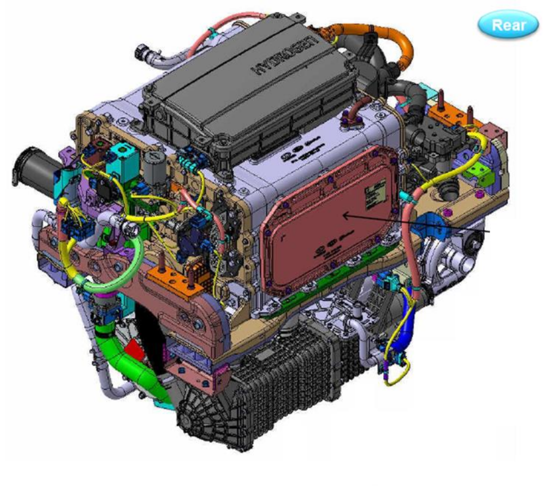




Key steps in advancing fuel cell technology

LT PEM fuel cells need to become lighter and achieve longer lifespans. Degradation is a primary issue, reducing power and efficiency over the fuel cell's lifetime. Eight main degradation mechanisms have been identified, highlighting the need for comprehensive water management and that maintaining saturated water content in membranes is crucial. Humidifiers are impractical due to their size. Thus, new membrane materials are needed. Innovative solutions as jet pumps save space & weight while enhancing efficiency across the full operation range.





Challenges and Opportunities of Liquid H2

LH2 currently occupies a niche market, representing only 2% of hydrogen usage. Rapid advancements are expected in heavy-duty mobility, with potential applications in aviation. Significant opportunities may arise for small and medium-range (SMR) aircraft to eliminate NOx and CO2 emissions by utilising fuel cells, whilst also reducing contrails by 60-80%.

The issues arising from the usage of Liquid H2 are a 20-30% loss of heat value during liquefication and potentially further losses during refuelling due to the cooling down process. The daily boil-off rates which can reach up to 3% present a significant challenge in storage technology.

With a focus on overcoming challenges related to storage, refuelling, and fuel cell degradation, HYCENTA aims to advance hydrogen technology for heavy-duty mobility and aviation. As Verification and validation are critical for advancing fuel cell and H2 refuelling technology the establishment of a new research facility funded with 10 million euros by TU Graz underscores the commitment to innovation and the development of efficient, sustainable hydrogen solutions.

Benefits of using wire-based additive directed energy deposition for manufacturing on an aluminium tank concept for mobile liquid hydrogen tanks

Stephan Ucsnik - AIT Austrian Institute of Technology

At the LKR, a subsidiary of the AIT Austrian Institute of Technology, the potential of aluminium tanks for liquid hydrogen storage in aviation and heavy-duty trucks and the specifics of additive manufacturing for large tank components are researched.

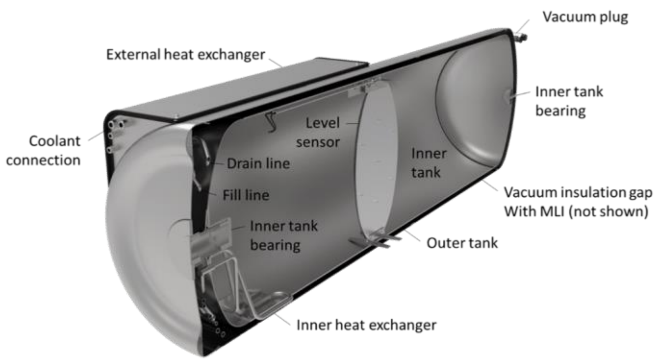
Wire-Based Additive Manufacturing

The benefit of wire-based directed energy deposition (W-DED) lies in the design freedom as complex geometries and features can be directly implemented into the structure. Parts of up to 3m diameter can be built and the manufacturing costs are relatively low, as the process is fully automated (can theoretically run 24/7).

The challenges in the process arise from the weld seams being "weak spots" in the material and the very rough surface after the W-DED process, which requires milling. It is of high importance to provide the correct wall thickness accounting for material shrinking in the W-DED process to be able to achieve the desired geometry later after milling.

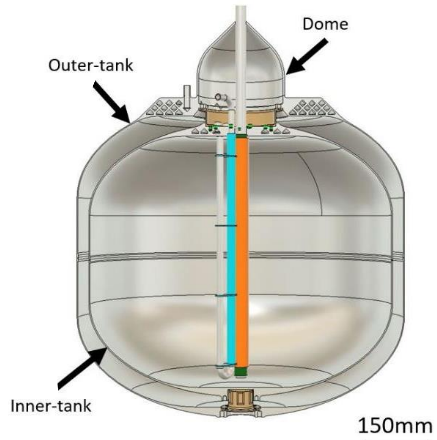
Cryogenic Tank Design

State of the art tanks for liquid hydrogen are made of steel double walls with a vacuum supported isolating layer and a low gravimetric index. This allows them to be used in heavy duty road transport but these can not reach the energy vs. weight requirements for aviation applications.



Aluminium is lighter than steel and has good mechanical properties relative to its density, with minimal embrittlement effects from hydrogen. Liquid hydrogen tanks made from Aluminium are approaching the energy density target from Clean Sky 2 of 12 kWh/kg, with current demonstrators achieving around 7.76 kWh/kg, significantly better than steel. The possibility of integrating complex piping into the tank structure with W-DED helps to mitigate boil-off-effects due to reduced surface area for heat exchange.

A 10kg proof-of-concept demonstrator tank with a 150-liter capacity has been developed while addressing the challenges of low material strength in the weld seams, the outer tank being bulge loaded and achieving high thermal decoupling of the outer and inner tank for minimal boil-off-losses.



The concept tank is developed in a consortium together with PEAK, Ryll-Lab and Test-Fuchs. Fluid pipes are integrated into the dome sections and integration of further function like sensors into the structure is possible. The function will be demonstrated using liquid nitrogen soon.

There are promising advancements in wire-based additive manufacturing and the use of aluminium for cryogenic hydrogen storage tanks. A new laboratory for research and development will be operational at LKR within two years, which will allow to enhance the investigation into wire-based additive manufacturing. However, challenges such as weld seam stability, thermal isolation, and boil-off reduction must be further addressed to achieve reliable and efficient liquid H2 storage solutions for both aviation and heavy-duty applications.

Hydrogen Site Lampoldshausen

Jan Haemisch - Deutsches Zentrum für Luft- und Raumfahrt

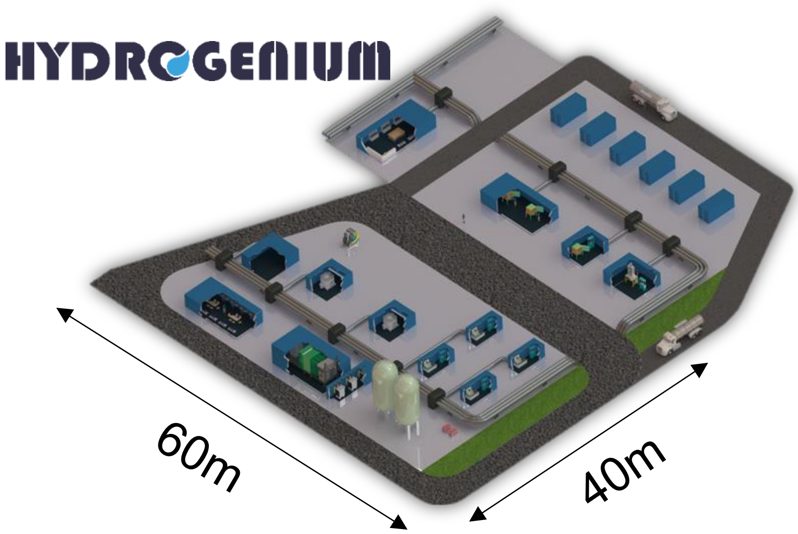
Testing for aerospace and beyond

The insititute of Space Propulsion in Lampoldshausen is one of the biggest hydrogen consumers (~380 tons mainly liquid hydrogen per year) of the world, functioning as a European test centre for space propulsion systems. An overview of the testing capabilities, recent advancements, and the challenges associated with hydrogen testing and integration into aerospace applications is provided.

Infrastructure and testing capabilities

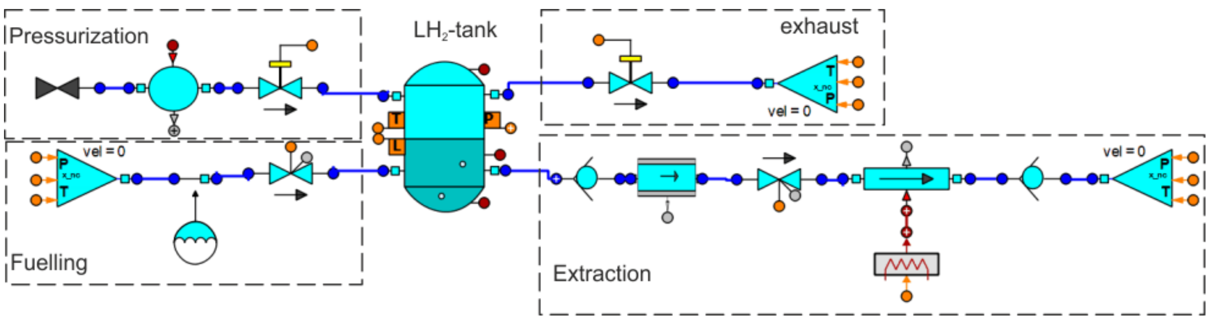
At the Institute of Space Propulsion in Lampoldshausen technologies with all TRLs ranging from fundamental research (1-3) up to engine and stage tests (7,8) can be investigated. Also, the Ariane 5 and 6 main engines have been tested on site, where approximately 40 tons of liquid hydrogen were burned in ~ 10 minutes during the tests.

A technology open hydrogen test field, the H2 Container Test centre, is established and will be operating by Q3 of this year. This will allow customers to bring their own test equipment to perform the testing in a safe area on four separate test positions which can be operated 24/7. On the test field there is access to green hydrogen (liquid and gaseous), gaseous nitrogen and helium. A second test field dedicated to tests with large quantities of liquid hydrogen is the Hydrogenium, which is currently in the design phase and will start operation in 2026 and will allow for larger facilities to be tested.



Integration of liquid hydrogen into an airplane

The hydrogen aviation lab project aims to demonstrate the feasibility of liquid hydrogen infrastructure in an airplane ground demonstrator. The fuel cell is solely to supply sufficient power for the coffee makers and the oven. The whole supply chain shall be demonstrated: from fuelling to maintenance phases on ground.



Challenges in hydrogen testing

The challenges in handling liquid hydrogen lie in temperature management, the inherent handling complexity and the availability. The extremely low temperatures of liquid hydrogen, where everything except helium is in a solid state are problematic. Preventing damage from liquefied air condensing on lines and mitigating the risk of fire due to liquid oxygen to be considered. Also, there is a limited availability of liquid hydrogen, with only four production sites in Europe and currently also no possibility for the Space Propulsion Test Centre in Lampoldshausen to liquefy H2 on site. If today's airplanes used liquid hydrogen as fuel the German airline industry alone would require 9000 tons per day, which represents to 25 times the current world production.

The Space Propulsion Institute's extensive facilities and expertise support a wide range of testing capabilities, from fundamental research to near-operational stages. The availability of accessible test infrastructure in the H2 container test centre and Hydrogenium represents a significant step towards integrating hydrogen into aviation, allowing to tackle the challenges of hydrogen in the field. The critical issues of temperature management, complexity, and hydrogen availability underscore the need for continued innovation and collaboration in hydrogen technology for aerospace applications.

EXFAN

exFan is an EU funded collaborative research project set out to devise a novel heat dissipation and recovery system within a high-powered electric fan propulsion system driven by fuel cell technology. Central to this objective is the incorporation of a ducted heat exchanger (HX) within the propulsion system's nacelle. It will use the "Meredith effect" (ME) incorporating the ram jet effect to generate thrust from waste heat. The breakthrough innovations proposed in exFan will: allow aircraft manufacturers to offer savings in operation costs, enable European aeronautics industry to maintain global competitiveness and leadership, create significant contribution in the path towards CO and NOX emission free aircraft, investigate how heat propulsor can be integrated within a hydrogen-electric propulsion system, advancing it to Technology Readiness Level 3 (TRL 3)

Project Coordinator

Technical Coordinator

Research Coordinator

Project Partners

ADT
engineering
Advanced Drivetrain Technologies

Let us design the link you need between thrust and sustainable aviation

Advanced Drivetrain Technologies GmbH
Leonard-Bernstein Straße 8/2/1
1220 Vienna

+43 676 852 562 900
office@adt-engineering.at
https://www.adt-engineering.at/

INGENIEURBÜRO
STAATLICH GEPRÜFT