Brussels, 23 June 2021

Summary of key messages delivered at the Technical Workshop "Hydrogen-powered aviation Research and Innovation" (6 May 2021)

In the context of the preparation of the proposed Clean Aviation (CA) and Clean Hydrogen (CH) Partnerships under Horizon Europe, the Clean Sky 2 Joint Undertaking (CS 2 JU) and Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU) jointly held the online technical workshop **"Hydrogen-powered aviation Research and Innovation"** on 6 May.

Experts from leading organisations of the European aeronautic and hydrogen ecosystems were invited to contribute in the workshop (participation was by invitation only) and to provide technical inputs to support:

- the preparation of a **comprehensive European hydrogen-powered aviation research roadmap,** which is currently being developed by the CA Preparatory Group;
- the preparation of forthcoming **Work-Programmes of CA and CH JUs**, including the identification of potential synergy/complementary topic areas for the **calls for proposals scheduled for 2021 and 2022**.

The workshop agenda consisted of a plenary session and four technical sessions, i.e. H2 aircraft requirements, fuel on board and storage, propulsion architecture based on H2 Fuel-Cells, propulsion architecture based on H2-combustion turbines.

Key messages delivered in the plenary session

The European Commission's representative highlighted that with the European Green Deal the European Union has set the ambition to become the first climate-neutral continent by 2050, and has set clear political targets for aviation decarbonisation in both the Smart Sustainable Mobility Strategy (link) and in the Hydrogen Strategy (link).

Hydrogen-powered aircrafts are a promising option in securing a climate-neutral Europe and aviation's maximum contribution to this goal, as suggested by results from key projects (e.g. H2020 project ENABLE-H2, link) and studies (e.g. the European Union's commissioned study "Hydrogen-powered aviation", link).

The high-level objectives for the proposed Clean Aviation partnership include inter alia the specific items stated in the Single Basic Act Art 55 [2]:

> (a) to integrate and demonstrate disruptive aircraft technological innovations able to decrease net emissions of greenhouse gasses by no less than 30% by 2030, compared to 2020 state-of-the-art technology *while paving the ground towards climate-neutral aviation by 2050*;
> (b) to ensure that the technological and the potential industrial readiness of innovations can support *the launch of disruptive new products and services by 2035, with the aim of replacing 75% of the operating fleet by 2050 and developing an innovative, reliable, safe and cost-effective European aviation system that is able to meet the objective of climate neutrality by 2050.*

The Clean Aviation draft Strategic Research and Innovation Agenda (SRIA, link) has defined as one of three key thrusts '*disruptive technologies to enable hydrogen-powered aircraft'.*

Likewise the Hydrogen Europe SRIA (https://www.hydrogeneurope.eu/wp-content/uploads/2021/04/20201027-SRIA-CHE-final-draft-1.pdf) and technology roadmaps under finalisation for the proposed Clean Hydrogen partnership Multi-Annual Work-Plan (MAWP) clearly define key hydrogen-based power/propulsion systems for aviation, and the supporting ground-based solutions as a key area of activity.

As part of Horizon Europe, the European Union's largest research and innovation programme, the proposed **Clean Aviation and Clean Hydrogen Partnerships have a unique opportunity to join forces and resources to accelerate technology development to deliver hydrogen-powered aircraft demonstrators by 2030 for EIS 2035**.

To achieve this goal, the best expertise and resources need to be pulled together from both the hydrogen and aviation eco-systems. At the same time, efficient instruments and approaches are needed to set up an "**innovation architecture**" **that maximizes synergies** between Clean Aviation and Clean Hydrogen JUs, and means and structures need to be in place to ensure vital synergies with relevant European, national and regional programmes.

It was also stressed the importance of **adequate funding resources to be able to take bold steps** from the outset of Horizon Europe and the CA/CH partnerships, in order to succeed in the **European flagship project on hydrogen-powered regional and short-medium-range aircraft** by the decade end.

A representative of the CA preparatory group presented a preliminary version of the **hydrogen-aviation technical roadmap**, where the proposed objective is to prove hydrogen feasibility in aviation.

This technical roadmap focuses on demonstrating fuel cell based propulsion for regional aircraft architectures, and hydrogen direct burn based propulsion for short-medium-range aircraft architectures. Issues such as safety and certification were highlighted and proposed to be at the core of technology development and demonstration.

It was proposed a two-phase approach for the technical roadmap. The first phase (2022-mid 2025) would consist of maturing technology enablers (e.g. MW-scale fuel cells system, H2 storage) and design hydrogen propulsion and aircraft configurations. Following a maturity assessment and concept selection at halfway of the programme (mid 2025), the second phase (mid 2025-2030) would consist of maturing technology enablers, and adapting, integrating and demonstrating in order to achieve 'frozen' hydrogen propulsion and aircraft configurations by end 2029.

The **need to leverage on strong synergies between CH and CA** JUs was mentioned: CH would focus on maturing enabling technologies and components (e.g. MW-scale fuel cells system, H2 storage), whereas CA would focus on aircraft/propulsion system design, as well as integration and demonstration of propulsion architectures.

It was also highlighted that the roadmap should include **a climate assessment of hydrogen combustion** , in order to prove hydrogen adequacy in aviation, and the development of hydrogen **infrastructure** supporting the uptake of H2-powered aviation, such as H2 logistics to/in the airport (including synergies between aircraft usage and ground usage).

Finally, it was mentioned that CH JU is currently preparing topics for Work Programme 2021/2022 and that two topics relevant to the hydrogen aviation roadmap have been already proposed, i.e.:

- development and optimisation of a dedicated Fuel cell for Aviation: from dedicated stack (100'skW) up to full MW-scale system;
- development of specific aviation cryogenic storage tank and associated systems (gauging systems, fuel metering, heat management systems…).

Key messages delivered in the technical session ‘hydrogen aircraft requirements’

The major European airframe manufacturers presented plans concerning the development of hydrogen-powered aircraft and confirmed the **ambition to bring a climate neutral / zero emission aircraft to market with EIS 2035**.

Aircraft concepts for regional (50-100 PAX, <1000nm) and short-medium range (<200 PAX, <2000nm) segments were presented. The regional concept could be powered by hydrogen-hybrid turboprop engines or by several turbo propeller motors powered by distributed hydrogen fuel cells. The short-medium range concept could be powered by hydrogen hybrid turbofan engines.

Regional and single aisle market segments are targeted to be the first one to be investigated, in particular propulsion architecture based on hydrogen fuel cells and hydrogen-combustion turbines.

Airframe manufacturers highlighted the **urgent need to mature enabling technologies, such as light-weight fuel cells system** (>1.5 MW fuel cell stack), cryogen light-weight and flexible **liquid hydrogen storage**, hydrogen distribution system, **thermal management**/cooling system, DC power system and distribution, battery and power management system, and H2 turbines.

Airframers stressed the **need for efficient certification specifications and means of compliance** for H2-technologies, in order to bring into the market safe technologies.

Issues related to industrialisation and H2 operation and maintenance were highlighted, as well as the need for adequate H2 infrastructure (e.g. Airport HUB, H2 liquefier, LH2 Fuel Stations), which will be critical to enable the transition to H2-powered aviation.

Key messages delivered in the technical session ‘fuel on board and storage’

Some of the most important stakeholders on liquid hydrogen storage systems presented their views regarding how to move forward in this field. It was emphasised that there have not been any tests of liquid hydrogen in aircrafts so far. Liquid hydrogen storage systems have been identified as the key technology to enable the use of hydrogen in aeronautic applications.

The first main message that came forward from this session, highlighted by all the participants, is the lack of regulations such as norms, guidelines or standards. This is a critical issue because without them, any development could be later questioned.

The main discussion moved around liquid hydrogen, which was identified as the most relevant technology for the aeronautic applications once a certain size of aircraft is reached. There is a significant **opportunity for technology transfer from space applications** to this sector. The gravimetric index that can be reached (without any technological breakthrough) is 25-27%, though some players also claimed higher values (however there are a lot of parameters that need to be fixed by regulation to qualify these values). The 35% value indicated in the common supported study is considered feasible while the definition of the conditions is critical. Currently the tanks are based on aluminium welding and vacuum insulated tanks. Composite tanks are also being investigated, which might lead to improved gravimetric index.

In Europe there are a number of testing infrastructures where these systems can be tested and qualified, although there might be **need for more demonstration environments**. There are also additional actions needed to focus on refuelling and the airport LH2 management systems.

The next steps would be to work on the norms and standards, continue the development of improved tanks (composite) and work on ground installations (LH2 electro-pumps).

Key messages delivered in the technical session 'propulsion architecture based on H2 Fuel-Cells'

Propulsion architecture designers/manufacturers participating to the workshop showed that plenty of activities are already underway. There are various concepts being explored: a fuel cell system integrated with a high performance battery in the hull and individual fuel cell engines to replace the turbines. Overall, the current systems have around 600kW power but a scale up to 1.5-3MW is needed (depending on the size of the plane targeted).

For the next actions, **test benches and certification bases were identified as critical**, as well as the scale up of some equipment like electrical motors, LH2 valve or heat management systems.

A particular component that needs to be addressed, which is common to other applications, is the hydrogen compressors.

The fuel cell manufacturers explained that they are bringing their technology from other transport applications, many of them with already established collaborations with aeronautic stakeholders.

The approach proposed by most of the stakeholders is to develop **modular fuel cell systems. The consensus target for overall fuel cell 'stack' power levels required for a successful (initial) penetration of commercial aviation seems to be 1.5 MW**. **Efforts to develop 'aviation grade' fuel cells under the collaborative efforts of CH and CA JU should focus on a roadmap towards reaching this target level**. The first fuel cells are already flying in various demonstration projects.

As for the work ahead, reducing the stack and balance of plant weight seems to be the main objective. Moreover, working at stream temperatures (-45ºC – 50ºC) and withstanding the high shock and vibration specific to this application are other fields to work in.

Key messages delivered in the technical session 'propulsion architecture based on H2-combustion turbines'

Engine manufacturers confirmed their commitment to climate-neutral aviation in line with the CA SRIA. They indicated that key pillars to decarbonise their products are the followings:

- deliver technologies for an ultra-efficient SMR aircraft with at least 30% fuel burn by 2035 (Ultra-efficient next-generation narrow body engine, more-electric aircraft, lightweight equipment and interiors);
- enable massive deployment of sustainable aviation fuels for existing fleets and long range future fleets, and explore hydrogen potential for regional / SMR applications and develop technological bricks;
- deliver hybrid/electric solutions for propulsion at the lower end of the market (large range of products, e.g. generators, motors, power management, wiring and distribution).

They stressed that a H2 engine is not just a basic adaptation of existing engines, as several developments are needed, even if the global functions remain unchanged. The link between the fuel system and the engine will be far more important than in current kerosene-burnt engines, as in H2 propulsion system there will be a strong interaction between the engine and the fuel system in terms of feed management and transitory management. Hence, **the engine/turbine and the fuel system should be developed with an integrated approach**, i.e. in an Hydrogen Integrated Propulsion System (HIPS).

The main challenges for hydrogen-burn propulsion system are related to the fuel system, combustor and operations; in particular:

- minimise contrails impact and NOx emission, and develop accurate methods to measure non-CO_2 effects due to hydrogen;
- maximise HIPS efficiency and minimize HIPS mass and volume;
- maximise power conversion by gas turbine and ensure altitude relight capability;
- ensure performing/safe H2 storage system (e.g. sealing, manage insulation & boil-off, minimise mass and volume, monitor quantity, ensure correct pressure and temperature)
- safety management (e.g. detect leakages, manage fire);
- maximise durability of components and materials;
- develop adequate certification approach;
- set up adequate HIPS test means (e.g. convert aeronautics test benches/instrumentation for use with H2, and convert H2 test benches/instrumentation for aeronautical application);
- design HIPS for airframe integration.

According to engine manufacturers the R&I topics for H2 burn engine should focus on storage system, fuel system development, fuel temperature and vapour pressure control, global management of heat, novel purging & inerting technologies, new sealing solutions (coupled with H2 leak detection systems), material compatibility / hydrogen embrittlement, and engine development (e.g. combustion chamber for H2 burn).