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HYDROGEN, A KEY SOLUTION TO DECARBONIZE AVIATION

(Presented by France and the Netherlands)

EXECUTIVE SUMMARY	
The aim of this paper is to inform the Assembly on the merits and potential of hydrogen as a means to achieve aviation decarbonisation, as well as cleaner air transport through reduced air pollution and reduced non-CO_2 effects. The full potential of hydrogen can only be realised through the coordinated and global efforts of all stakeholders, and ICAO needs to play an important role.	
Strategic Objectives:	This information paper relates to Strategic Objective – *Environmental Protection*
Financial implications:	Not applicable.
References:	The Chicago Convention and its Annexes Assembly Resolution A40-18, *Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate change* Annex 16 — *Environmental Protection*

1. HYDROGEN IS NOT A SILVER BULLET, BUT IS A GOLDEN SOLUTION

1.1 Hydrogen (H_2) can be produced anywhere on the planet, from inexhaustible resources, and its use produces no direct CO_2 emissions. When produced from clean electricity, hydrogen has no CO_2 emissions over its life cycle. These properties make hydrogen an excellent option to decarbonise air transport, as raw material to produce Sustainable Aviation Fuels (SAF) (e.g. biomass based fuels or Power-to-Liquids (PtL) fuels), or use directly on-board hydrogen aircraft.

1.2 Furthermore, hydrogen use in fuel cells or hydrogen combustion in gas turbines are expected to be cleaner than the combustion of liquid hydrocarbon fuels. There would be basically no soot emissions and NO_x emissions could be significantly lower, thus bringing health benefits through improved air quality and climate benefits through reduced impact of aviation non-CO_2 effects.

1.3 It is recognised that in the short to medium term, SAF based on biomass offer a ready-to-use solution for all segments of the air transport market. However, many analyses show the potential of hydrogen aircraft: the 2020 study *Hydrogen-powered aviation – A fact-based study of hydrogen technology, economics, and climate impact by 2050,* the 2022 ICCT white paper on hydrogen aircraft, the Destination 2050 roadmap, etc.

1.4 Along with electricity and SAF, H_2 is a key building block towards decarbonisation that will complement the other solutions to cover short-, medium-, and long-range air travel.

2. H_2 AIRCRAFT CAN ADDRESS THE SMALL AND MEDIUM RANGE MARKET

2.1 ICAO's Long-term Aspirational Goal-Task Group (LTAG-TG) under the Committee on Aviation Environmental Protection (CAEP) has assessed means to reduce CO_2 emissions in the areas of aircraft technology, operations, and fuels. The corresponding solutions should be implemented together to maximize results and include aircraft concepts that are at the crossroads of the technology and fuel solutions: rather than conventional fuel or SAF, they will be powered by electricity or pure hydrogen. H_2 can be a power source on-board an aircraft either with fuel cells or by direct combustion in gas turbines. These non-drop-in fuels allow considerable CO_2 reductions when produced from clean energy, in the same order of magnitude as advanced drop-in fuels.

2.2 Fuel cells produce power and would be suitable for propulsion of small regional or business aircraft. Electric aircraft could thus address a share of the short haul market, powered either through batteries or gaseous hydrogen used in fuel cells. Combustion in gas turbines was already studied (Tupolev tested aircraft in the 1980s, Airbus Cryoplane project in the early 2000s) and gained considerable attention recently. With direct combustion, hydrogen aircraft could address both the small and medium range market, starting in the 2030s. With currently expected technologies, long range travel is likely to be decarbonised through drop-in fuels.

2.3 As an example, the ICCT study finds that in 2050, H_2 narrow-body and turboprop aircraft could mitigate 126 to 251 Mt of CO_2e under 20% to 40% adoption rate scenarios. These mitigated emissions represent 6-12% of global (international and domestic) aviation CO_2eq. In these cases, the 2050 clean H_2 demand for narrow-bodies and turboprops would be between 19 to 38 Mt per year while current world H_2 production is estimated at around 70 Mt.

3. HYDROGEN IS A FUNDAMENTAL BRICK OF ANY DECARBONISED AIR TRANSPORT SYSTEM

3.1 In aviation, though H_2 aircraft might be its flagship application, one should note that clean hydrogen will have a role in any decarbonisation roadmap, as illustrated in Appendix A. Firstly, hydrogen is already used in the upstream phase of jet fuel production. Secondly, hydrogen is needed in any alternative fuel scenario. It is a chemical reactant in some SAF production pathways, and being a raw material, crucial in the Power-to-Liquids (PtL) fuels production pathway, that provides a sustainable drop-in fuel from CO_2, H_2 and electricity. PtL fuels are a solution to decarbonise any flights, including long haul. Furthermore, H_2 aircraft are promising, and hydrogen can help decarbonise airports.

3.2 Onboard electricity, advanced biomass-based SAF, hydrogen and PtL fuels are needed and complementary to cover short-, medium- and long-range air travel, making H_2 a key building block towards decarbonisation. Biomass-based SAF, hydrogen and PtL fuels should scale up in parallel over the next decades. They should be deployed together or in a differentiated manner across regions, depending on local specificities of air traffic, energy resources, feedstock availability, and transportation infrastructure. No solution is a silver bullet and is expected to decarbonise air transport on its own, but all these levers have a role to play in order to maximize emissions reduction.

3.3 On-board electricity, hydrogen and PtL fuels have a common feature: they basically translate in a primary electricity need, and they provide CO_2 reduction on a life cycle basis, being as clean as the electricity used in the upstream production process.

3.4 Irrespective of the combination of means to decarbonise air transport, the aviation sector will rely on clean electricity and clean hydrogen production. It should therefore foster clean power capacity and hydrogen ramp-up in the energy sector. To develop and have hydrogen that is both decarbonised and affordable is a fundamental need for the growth of tomorrow's air transport.

4. HYDROGEN RELATED INVESTMENTS ARE MANAGEABLE

4.1 Infrastructure costs are assessed within the LTAG report. Regarding the upstream capital investments to have liquid hydrogen (LH_2) production capacity, the assumption is that LH_2 Unit CapEX decreases from ~50 to 20 billion US$ per incremental MtH_2 of capacity between 2020 and 2050. If not needed in a liquid state for on-board storage, hydrogen production investments can be expected to be lower. Regarding airports, the equipment of a set of 1,000 to 3,000 airports with LH_2 refuelling systems corresponds to an annualized cost of respectively ~1 to 10 million USD per airport, noting that the cost per airport then grows more steeply to equip more airports (see LTAG report, Appendix M1, page 90).

4.2 Ultimately, the cost of H_2 aviation will of course be driven by the cost of H_2, as an upstream raw material to alternative fuels or as on-board fuel directly. Many assumptions on H_2 cost up to 2050 and beyond exist, with a decreasing trajectory as common feature. The average LH_2 trajectory of the LTAG report assumes 7 US$/kg$H_2$ in 2020 (minimum selling price), decreasing towards almost 2 US$/kg$H_2$ in 2050, reaching almost parity with kerosene (at a price of 0.60 US$/L) on an energy content basis (1 kg of hydrogen contains roughly 3.5 times more energy that one litre of kerosene). Again, when not needed in its liquefied form, hydrogen cost is expected to be lower. This would be the case of H_2 as an input material in the production of drop-in fuels. From a cost perspective, the potential of H_2 as a decarbonisation enabler will be all the more fully unlocked as more States transition towards a wider hydrogen economy (economies of scale).

5. HYDROGEN CHALLENGES ARE ALREADY BEING TACKLED BY VARIOUS INITIATIVES

5.1 Challenges related to hydrogen use in aviation are deemed technically manageable and numerous initiatives are paving the way. The main challenges are listed in Appendix B, spanning H_2 as a fuel and for fuel production, H_2 at airports, H_2 aircraft and cross-cutting needs. While technical challenges are obviously being addressed by engineers, an update of airport infrastructure is also needed, as well as dedicated standards regarding hydrogen for aviation and corresponding regulatory frameworks.

5.2 Many programmes and consortiums are working on these challenges:

a) on the aircraft side, the Clean Aviation Partnership programme, funding the development of disruptive concepts including H_2 propulsion, ENABLEH2 research project, support by various State research programmes to technology development, including French initiatives (Hyperion, BeautHyfuel, Cirrus, Volcan research projects) ranging from light to mid-range aircraft including business jets, Airbus ZeroE aircraft concepts, CFM RISE engine, FlyZero project, Embraer "Energia" family, H2ERA regional aircraft project, ZeroAvia and H2FLY powertrains, Beyond Aerospace project, and counting; and

b) on the airport side, ATI-ACI collaboration about infrastructure build-up at airports, work within the Horizon 2020 project "OLGA", which benefits from a 25 M€ European Union's contribution, various similar projects including one gathering

Aéroports de Paris, Air France-KLM, hydrogen specialist Air Liquide and Airbus and another gathering Incheon International Airport, Korean Air, Air Liquide and Airbus, and counting; important projects of common European interest (IPCEIs) on hydrogen, CertifHy project preparing guarantee of origin schemes.

5.3 The above challenges can be overcome by coordination and engagement of various stakeholders. Government's support and policy measures, such as incentive schemes, as well as appropriate and timely ICAO standards providing stable regulatory framework, are key to foster research and development, early applications, and will sustain momentum across concerned sectors. Overcoming these challenges is the price to unlock major CO_2 reductions.

6. **HYDROGEN MEANS OPPORTUNITIES**

6.1 Airports are excellent candidates to be hydrogen hubs. Beside aircraft fuel supply, they need to provide fuel for their ground captive fleets. Numerous road vehicles transporting passengers and goods could refuel at airports facilities. Some airports, including secondary airports, could have synergies with industrial activities using H_2 located in their surroundings. Airports are therefore beneficiaries and key actors in hydrogen economy development and in mitigation of emissions in and from cities.

6.2 Switching to hydrogen economy is a job creating, value-adding transition. It enables local communities to independently meet their energy needs. More broadly, green power and green fuels supply is a way to develop under-utilized lands and to create jobs in different innovation activities, including hydrogen economy implementation, everywhere on the planet.

7. **CONCLUSION**

7.1 Different parts of the world are paving the way towards a hydrogen economy. Hydrogen is a realistic decarbonisation solution. This is an opportunity for aviation to activate an indispensable decarbonisation lever, while also contributing to hydrogen development and costs drop, by adding its demand to the supply need of other sectors and by providing distribution facilities through airports. H_2 aircraft are a particular application of H_2 solutions, with promising potential. Numerous challenges are ahead but none are insurmountable, provided strong coordination and engagement of stakeholders take place, fostered by appropriate public policies. Various initiatives are currently exploring the technical and industrial feasibility of H_2 use, with some technologies already available and progress expected on others. Stakeholder coordination, technology exploration and the development of demonstrators are needed to overcome the recurring "chicken and egg" problem that affect hydrogen-related solutions in general and to implement progressive early steps. Noting their significant potential for aviation CO_2 emissions reduction, it is desirable to foster the development of hydrogen-related solutions in air transport and to ensure its position in the wider transport energy policy.

7.2 Against this background, France and the Netherlands consider that ICAO has an important role to play, including:

- striving to strengthen its engagement and dialogue with the industry on hydrogen, including through the Industry Consultative Forum (ICF), to identify implications for the organization, particularly in terms of policies and standards;

- striving to work closely with all the stakeholders to prepare in due course the necessary harmonized framework and regulations, and useful guidance documentation, so that no delays are introduced (except if they pertain to technology readiness and financing); and

- considering integrating hydrogen and related topics in ICAO assistance to States, in particular capacity building, including through initiatives such as ACT-SAF.

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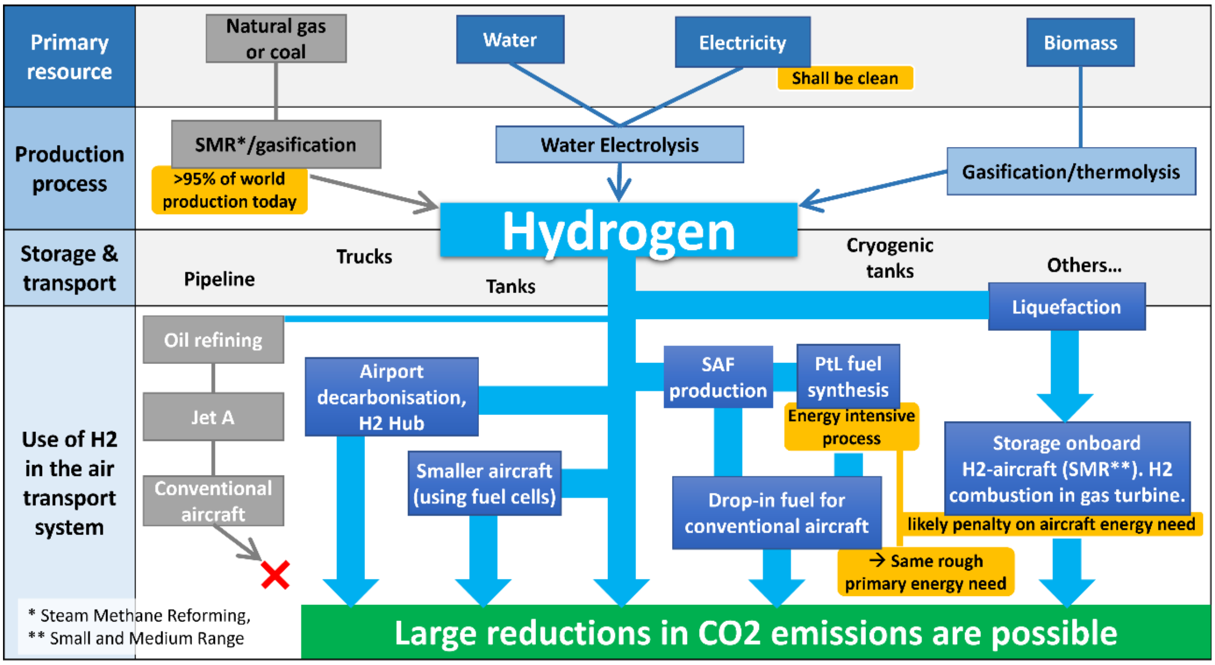
APPENDIX A

ILLUSTRATION OF THE POSSIBLE USES OF HYDROGEN TO SUPPORT THE DECARBONISATION OF AVIATION



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APPENDIX B

PATH TOWARDS CLEAN HYDROGEN DEVELOPMENT IN SUPPORT OF AIR TRANSPORT DECARBONISATION – MAIN CHALLENGES

Hydrogen as a fuel and for fuel production:

- Need of massive clean power capacity to produce clean hydrogen. The huge electricity demand generated by alternative fuels production will require corresponding resources. The associated challenges are to be managed by relevant stakeholders, including governments (ramp-up of low carbon power facilities, land use, competition with other sectors demand, water resources management…);
- H_2 production technologies: some have to be scaled up, some have to reach industrial maturity; and
- Hydrogen logistics, including production, transport and liquefaction capacities, potentially directly within the airport perimeter.

Hydrogen at airports:

- Deployment of refuelling infrastructure: either a light one, by trucks, or significant changes with on-site storage and dedicated H_2 facilities. Need to manage the coexistence of liquid hydrocarbon fuels infrastructures and H_2 infrastructures;
- Infrastructure update (e.g. at gate) to accommodate new aircraft concepts (longer fuselage);
- Safety framework to be developed (leakage, firefighting, safe handling of cryogenic $H_{2\ldots}$); and
- Adaptation of regulations in the airport management system (safety, operations…).

Hydrogen aircraft:

- Aircraft design storing important H_2 volumes while minimising performance penalty;
- Master liquid H_2 tanks technology with high enough ratio of H_2 mass over system mass;
- H_2 high pressure tanks with increased ratio could allow earlier deployment of smaller aircraft;
- Optimised propulsion: high efficiency, low weight fuel cells, efficient and safe H_2 turbines;
- Safe and reliable fuel distribution and components, including sanitizing the system; and
- Economics of the aircraft, including potential H_2 impact on turnaround time.

In all cases, it is necessary to develop suitable regulatory frameworks, and to manage H_2 losses over the whole supply chain, for safety and economic reasons, and because such losses might induce a climate forcing.

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