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Sustainable Skies: Technical and Regulatory considerations for the use of Hydrogen as a lifting gas for LTA platforms in the European Union

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1. Abstract

For unmanned initiatives employing lighter-than-air technology (LTA), the use of hydrogen as a lifting gas is highly attractive in view of its low weight, lifting power, renewable nature, low costs, and the possibility to produce it at remote sites. As a lifting gas, its alternative, helium, is more conventionally used, however, helium is very expensive, sometimes hard to obtain and has a heavy CO2 footprint. In addition, it is twice as heavy as hydrogen and has less lifting power. On the other hand, hydrogen has an emotionally charged meaning for LTA platforms, because of the Hindenburg disaster in 1937, now more than 86 years ago, which still somehow has its echo in the development of LTA technology and its use of hydrogen. However, as now the materials now available for envelopes, frames and gas bags are of much better quality, and sensors for monitoring key processes are more easily available, in addition to the capabilities for safe unmanned flight, hydrogen has become a more viable and attractive option to revisit. This paper investigates in more detail the practical experiences of one of the first unmanned LTA hydrogen demonstrators for transport cargo, the FlyWin project in Belgium, as well as the first experiences with two new surveillance carriers, Kelluu and Hylight. With this assessment is explored whether there are currently any impediments for the use of hydrogen as a lifting gas for LTA carriers in the European Union, or what other barriers these developments encountered.

Keywords: Airships, Hydrogen, Regulations.

2. Introduction

Air traffic has seen a massive amount of growth since the beginning of air travel and is likely to continue seeing similar growth as the number of applications increases. With this increase in air traffic, the share of emissions from the aviation sector contributing to global greenhouse gas emissions is also likely to increase. The European Policy on Transport ultimately states that technologies to improve the environmental friendliness of various transport options must be focused on in the coming years. All modes of transport, including aviation, must become more sustainable and have less environmental impacts, with respect to greenhouse gas emissions.[6] LTA technology, airships and balloons could be one such pathway for the reduction of emissions from aviation activities.

An airship or balloon is a type of aerostat or lighter-than-air aircraft that can navigate through the air under its own power.[7] Aerostats gain their lift from a lifting gas that is less dense than the surrounding air.[8] Airships can be of three main types, based on their structure - rigid airships, which use a full rigid supporting structure underneath the envelope to maintain aerodynamic shape; blimps, which have no such structure, but have an over pressurized envelope to maintain aerodynamic shape, and semi-rigid airships; which are between fully rigid airships and blimps, with a supporting structure and a slightly over pressurized envelope to maintain aerodynamic shape.[9]

2.1 Hydrogen vs. Helium for Airships

For initiatives employing lighter-than-air technology (LTA), the use of hydrogen as a lift gas and as a fuel for propulsion through onboard fuel cells, is highly attractive in view of its light weight, the enhanced lifting power, its renewable nature, the low costs compared to helium, and the possibility to produce it at remote sites.

As a lifting gas, its alternative, helium, is more conventionally used, however, it is very expensive, in some countries hard to obtain (also due the priority for its competing use in the medical sector) and has a heavy CO2 footprint. The scarcity of Helium a very real issue for the upscaling of LTA technologies.[10] In addition, Helium is twice as heavy as hydrogen and has less lifting power[11]. The use of helium as a lifting gas also leads to a lower possible payload when compared to using hydrogen.[12]

On the other hand, hydrogen has an emotionally charged meaning for lighter-than-air platforms, because of the Hindenburg accident. This events still has its echo in the development of LTA technology and its use of hydrogen.

However, as the materials now available for envelopes, frames and gas bags are of much better quality, and sensors for monitoring key processes are easily available, in addition to the capabilities for safe unmanned flight, hydrogen has become a more viable and attractive option to revisit. With new materials, coupled with superior, modern technologies, such as purifiers for the lifting gas, the risk of using hydrogen as a lifting gas in airships is significantly

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reduced. Pure hydrogen, without leakages from the ambient air, is also non-inflammable. The safety of hydrogen should be revised with the latest information and knowledge that has been gathered during the last century, giving its use in LTA platforms a second chance.
Current regulatory frameworks though, for the use of Hydrogen in aerial vehicles, besides balloons, are not yet tuned to the new developments of innovative airships.
The most difficult it seems to be in the USA where in the FAA guidelines on aviation standards, the following is said about lifting gas for airships in FAA Document "Transport Airship Requirements" (March 2000) under TAR 893 – Lifting gas: "The lifting gas must be non-flammable, non-toxic and non-irritant."[13] A second FAA document, FAA-P-8110-2 "Airship Design Criteria" dated 2/5/95 contains, under 4.48 Lifting Gas: "The lifting gas must be non-flammable."[14] Another earlier document by the FAA (1992) states explicitly that hydrogen is not permitted for use on airships as a lifting gas. [15]
In the European Union, such an impediment to the use of hydrogen in airships does not exist. The cases in this paper show that even in a few Member States of the European Union (Belgium, Finland), permissions were given for innovative airship projects[16] that used hydrogen as a lifting gas throughout the 2015-2023 period.

2.2 Hydrogen for Unmanned Airships

To facilitate the use of hydrogen in LTA technology, also for example for its propulsion, a logical first step would be its use in unmanned cargo or surveillance airship operations. Taking its use in such unmanned application as a first step, hydrogen can be tested rigorously, in order to even perhaps later develop adequate safety for testing in manned. Airships are also particularly suited to surveillance and cargo applications as the speed of travel is not an absolute requirement. Airships can still be faster than ships and stay airborne for much longer than conventional drones.

2.3 Problem definition and formulation

The main purpose in this paper is to further explore the key technical, regulatory and other key issues relating to the use of hydrogen in unmanned lighter-than-air carriers in development the European Union. Hydrogen is of great interest as it is relatively low-coast and can be generated in a renewable, environmentally responsible way, currently also prioritised in the European Hydrogen Strategy[17]. It could truly decarbonise aviation operations. Helium is much more expensive than Hydrogen and its use represents a roadblock to large-scale implementation of LTA technology that is commercially viable.

2.4 Methodology

In this paper, technical, regulatory and other considerations relating to hydrogen are described in detail in the FlyWin project in Belgium that has employ hydrogen as a lifting gas. Furthermore, also described briefly are two other known projects that are using, or aim to use hydrogen as a lifting gas. These descriptions are also made on the basis of participative observation in four workshops and case study presentations within perspective of the European U-LTA Platform co-operation[18]. The key events included a 2019 kick-off meeting at the European Commission DG RTD in Brussels (10/12/2019), two online events during Sustainable Energy Week, one on 1 June 2021 and European Commission`s Greenweek respectively (on 27 October 2022) as well lastly a first discussion with EASA in Cologne on 31 May 2023. Based on this material, possible barriers or impediments, challenges, are described. Based on this identification, follow-up research questions will be presented, as well as tentative recommendations.

2.5 Description of Current Demonstrator Projects Using Hydrogen as a Lift Gas and Their Key Issues.

2.5.1 The FlyWin Airship First Demonstrator

The innovative FlyWin project was founded by Belgian engineer and entrepreneur Laurent Minguet and supported by the Walloon region. The goal of the project is to develop an airship for cargo transport, specifically a universal container (20 tons) that will use hydrogen as a lifting gas, will be unmanned, and will use electric propulsion. The full-scale length of the designed carrier is to be 100m long, rigid structured airship. FlyWin is also involved in another project, named Ballonics: a hydrogen gas balloon program that aims to develop a particular membrane layer for the containment of hydrogen, which is designed to be very light and solid. One demonstrator has achieved 250 cubic meters of volume. FlyWin financed the material and logistics for this program.
Working on FlyWin's demonstrator is the first level of research. The demonstrator's requirements have been defined within the context of operational parameters. The main objective was to achieve a short flight test on the airfield. There was a limitation in terms of wind, rain, speed, etc. The design is defined with the flight's campaign objectives. For

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scaling up, the flight ambitions will certainly increase. FlyWin's final aim is a North Atlantic cruising flight for the serial phase. This new context will define new future technical requirements.

Illustration 1: The first FlyWin Demonstrator at a Floating Test in Beauvechain, Belgium, Flywin, 2019.

Illustration 2: FlyWin, 2019-The Flywin carrier demonstrator, above envisioned the 2nd prototype, left below the first demonstrator, right below back end view of the rigid frame of the first demonstrator, Flywin 2019.

The hydrogen LTA concept suits the Remotely-Piloted-Aircraft-System (RPAS) configuration: having no pilot on board is ultimately safer. Ground staff can operate remotely during all operations: pre-flight checking, take-off, landing, and cruising flights. These aspects ensure satisfactory safety conditions for the ground crew. Otherwise, onboard intelligence and algorithms are better suited to manage cruising flight and ground operations than human management.

FlyWin envisions sensors everywhere surrounding the airship for their final design - leakage sensors, pressure sensors, wind sensors, humidity sensors, Inertial Measurement Unit (IMU), speed sensors, etc. These sensors give real-time information to onboard computers. The quantity of information that needs to be dealt with will require algorithms for management (more efficiency in terms of capacity and speed execution than human control). H2 gas leakage sensors at different points around the envelope will inform OBC that will react immediately. Writing the control laws is a huge challenge and implementing it is another important challenge.

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To prove the feasibility of the design, the first step was to create a smaller, rigid structured demonstrator of 15m in length. The gas cells used in the demonstrator were designed to be gas-tight, light, electrically conductive to discharge the airship (equipotential), and have high tensile strength and flex resistance. The aluminized layer that was used has a high capacity to contain hydrogen, a molecule so tiny that it can even cross the walls of a steel tanker. All airships and balloons must be equipped with a guide rope to discharge on the ground. To prevent the rupture of the gas bags during altitude control operation, a safety pressure system was designed with a controlled Pressure Relief Valve (PRV), an automatic/controlled Emergency Pressure Relief Valve (EPV), and an overpressure sensor.
Flying tests were undertaken in 2017, and FlyWin has achieved a Hydrogen drone demonstrator (15 m long, 130 cubic meters). This first-scale machine has been deployed several times on a military airfield near Brussels in 2019. FlyWin's test campaign had good results. It demonstrates correct general behaviour, good buoyancy, and balance. It was a tethered flight campaign. It has not been tested with motors on free-flight configuration (i.e., untethered configuration). FlyWin did, however, face some challenges with their demonstrator. First were problems with rips and tears in the aluminized film layer. This membrane had good results in traction but was very fragile during manipulation and cycle of inflating/emptying. The consequence was that gas leakage was observed after, which compromised the lift. The second problem was with the gas physics regarding the mixture of oxygen and hydrogen inside the gas bags. These issues compromised the buoyancy of the aircraft. Finally, a relatively minor problem was vibration inside the carbon fibre structure due to vibrations from the onboard motors for propulsion.

2.5.2 Safety Subsystems and Scaling up.

In perspective of the FlyWin Project detailed hydrogen safety procedures and risk mitigation were described. The crew ground staff were instructed in procedures to guarantee safety during deployment and operations, which include for example the ban on steel tools, mobile phones, etc. near the airship during inflation, and during buoyancy tests. The objective is to avoid sparking or ignition sources. So far, there has been no accident. Technicians and ground staff must respect strict procedures, they must wear full-body fire-retardant suits. The hangar's design must include ventilation systems and gas leakage sensors disseminated in different zone inside the operational area.

Regarding the safety subsystems for fire control on board the airship, FlyWins scientific advisor, the University of Brussels chose a redundancy architecture with 2 segregated pressure relief valves (butterfly type) and remote-control during discussions for H2 gas management. It was a huge challenge for leakage through joints and sewings. Otherwise, obtaining a very light material to respect the mass quote was imperative. All these measures must be improved for scale-up, but the basis is good. Pressure relief valve technology exists for different airships and gas balloons. The design of the airship (rigid, semi-rigid or blimp) does not affect the safety subsystem technology. The relevant parameter is the choice of lifting gas, whether to use Helium or Hydrogen. This choice leads the discussions of the overall airship and subsystem design.
To scale up, one major advantage is the leakage rate, as the leakage rate decreases with greater gas bag size. However, pipe, sizing, time to fully refuel, safety, tankers and other materials will see an increase. To fully fill the gas bags, a supplier of lifting gas (Air Liquide, Linde, others) is first needed. Secondly, deploying any airship requires infrastructure for constant refuelling. For smaller quantities of gas, compressed gas at pressures of 200 bars stored in steel bottles on trucks can be used. For example, FlyWin's demonstrator needed a rack of +/- 18 bottles at 200 bars of pressure. It takes 3 hours to inflate the 3 gas bags completely (130 m^3). For larger quantities, bottles by truck become too expensive. In this case, a pipe industrial network close to core activities would be needed. It will determine the choice of the deployment area and is a strong requirement for follow-up Demonstrators.

2.5.3 Regulatory Hurdles for FlyWin's Demonstrator?

EASA is the central aviation safety authority in the European Union. But each national authority inside the EU is a stakeholder: DGAC France, SPF Mobility and Transport Belgium, etc. It is important to share information and propose ideas to develop new rules and regulations. As far as the current state of certification for the use of Hydrogen on an Airship, different EASA related to LTA exist: CS 30 EASA Airship, CS 31 EASA gas Balloons, Transport Airship Requirements Europe (TAR), HCC for Transport Hybrid Airships Lockheed Martin, Airship Design Criteria US Navy, etc.
Regarding the use of Hydrogen in manned LTA platforms, EASA published in 2022 a "Special Condition SC GAS Airships" which even mentions "Flammable gas" for lifting gas. Obtaining certification will not be a challenge or a roadblock to upscaling if the engineering knowledge and due diligence are demonstrated to be up to the mark it seems. Authorities and industries could work together to build rules and regulations according to this document.

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To obtain the permits to fly their demonstrator, FlyWin achieved a complete safety case that explains the R&D project, defines the design and details precisely how to deploy the demonstrator on the airfield in safety conditions. This document has been presented to 3 different authorities in Belgium, namely Defense, Mobility Administration and Ministries. Flywin eventually obtained the Permit to Fly for testing and developing an innovative carrier.
Since there is currently no exact legal framework regarding the use of hydrogen on Airships in Wallonia/Belgium, specific allowances were made for the demonstration and research project. FlyWin presented and explained the safety case document to the different authorities to inform them in detail. All the subsystems linked with H2 were explained: 2 Hydrogen pressure relief redundancy valves, the Hydrogen aluminized membrane characteristics, Hydrogen safety procedures, etc.
Besides Hydrogen safety, regulatory hurdles for lighter-than-air aircraft are also due to potential crashes and ground disasters. Dirigibles are lighter than air. For aeronautic authorities, one of the main dangers in a hazard scenario is the loss of link and control with an airship uncontrolled in the airspace. The balloon can potentially travel everywhere in the sky, at every atmospheric level. Ground operations are delicate too for LTA (take-off, landing) due to the requirement for highly trained ground staff, presence of ignition sources on the ground, discharge and equipotential problematics, ground effects, etc.

2.6 KELLUU, unmanned airship for aerial surveillance and monitoring.

In 2018 start-up Kelluu[19] was founded in Finland. The Kelluu airship is designed for aerial monitoring of, amongst others, energy infrastructure. It is an LTA unmanned U-LTA carrier, using hydrogen as a lifting gas and in a fuel cell for its electric propulsion. Since that time, it has successfully developed its practice and has already commercial operations in Finland.

Illustration 3, Demonstration flight, Kelluu, 2022.

Illustration 4. Close-up photo of the Kelluu carrier, Kelluu, 2022.

The Finnish authorities have granted a permit to fly for its operations. It did not seem that Kelluu had met many challenges in obtaining the permit for the development of their carrier. Since 2019 they have already flown their carrier for a number of years in different climatological conditions, both the in Finnish summer as well as in the winter period.

2.7 Hylight Demonstrator

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An even more recent initiative in Europe is the Hylight Aero carrier. This is also an initiative for a surveillance carrier, in the end with the objective as well to develop a carrier for monitoring of energy infrastructure[20]
The company has also developed a first demonstrator that has flewn in Italy and in France. The end objective of this carrier is also to use hydrogen as a lifting gas. See also illustration 5 for a picture of the first demonstrator.

Illustration 5: Hylight Demonstrator on one of the first Demonstration Flights, Hylight 2022.

2.8 Exploration regarding the conditions for unmanned airships by EASA and Hydrogen.
In a workshop on possible conditions for unmanned LTA Carriers at EASA in Cologne on 31 May it was indicated that the use of hydrogen or other lift gases is fully open and the only key criterium is `safe operation` with minimal risks. There is no restriction on lift gases as hydrogen, if meeting proper safety standards. As so far not applications so far have been made for unmanned U-LTA carriers, this technology development is a novelty for EASA that is developing its approach. From the side of EASA however there is no policy to forbid or discourage the use of hydrogen as a lifting gas for LTA carriers.

In the discussion it was noticeable that for small scale unmanned surveillance carriers, using hydrogen as a lifting gas, the `specific`category for certification could apply, while for manned or cargo airships, the more labour intensive `certification category` would apply, due to the relatively unknown risks.
At this moment, no application for LTA unmanned airships have been made as far as known under the EASA drone regulations. See also illustration 6 for an overview of the typology for certifications for unmanned carriers, based on the EASA drone regulation.

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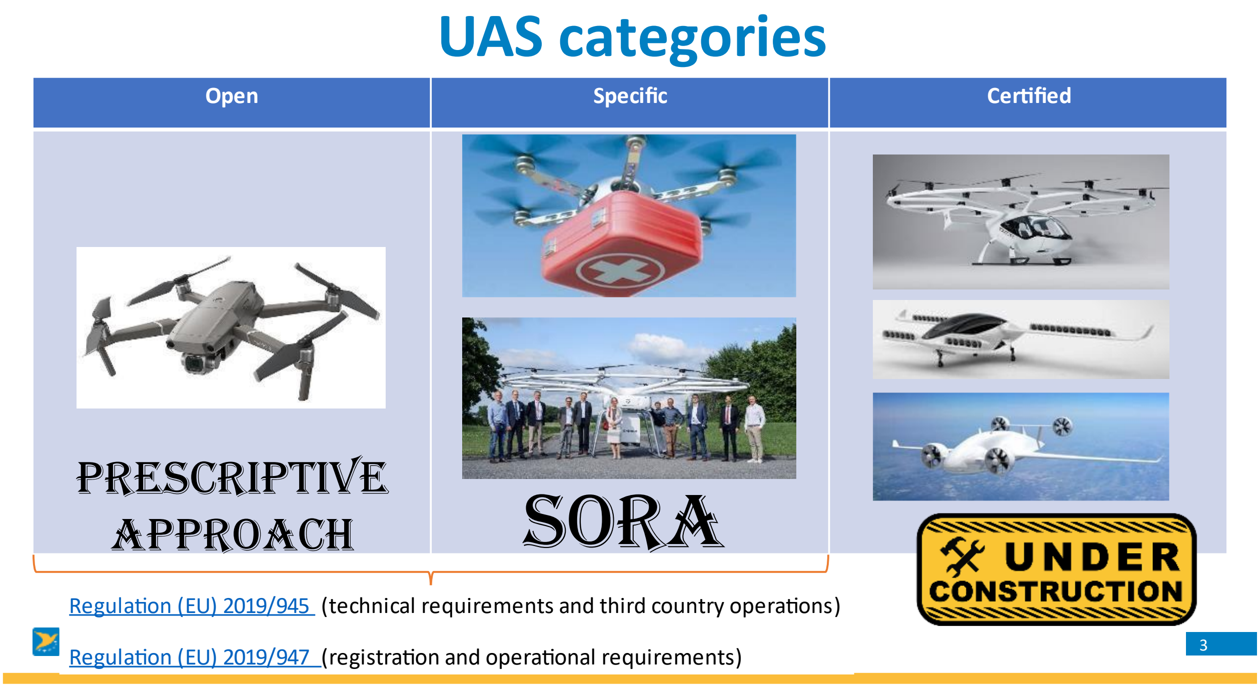

Illustration 6: EASA Drone regulation categories- As Presented by EASA on 31 May 2023, Cologne

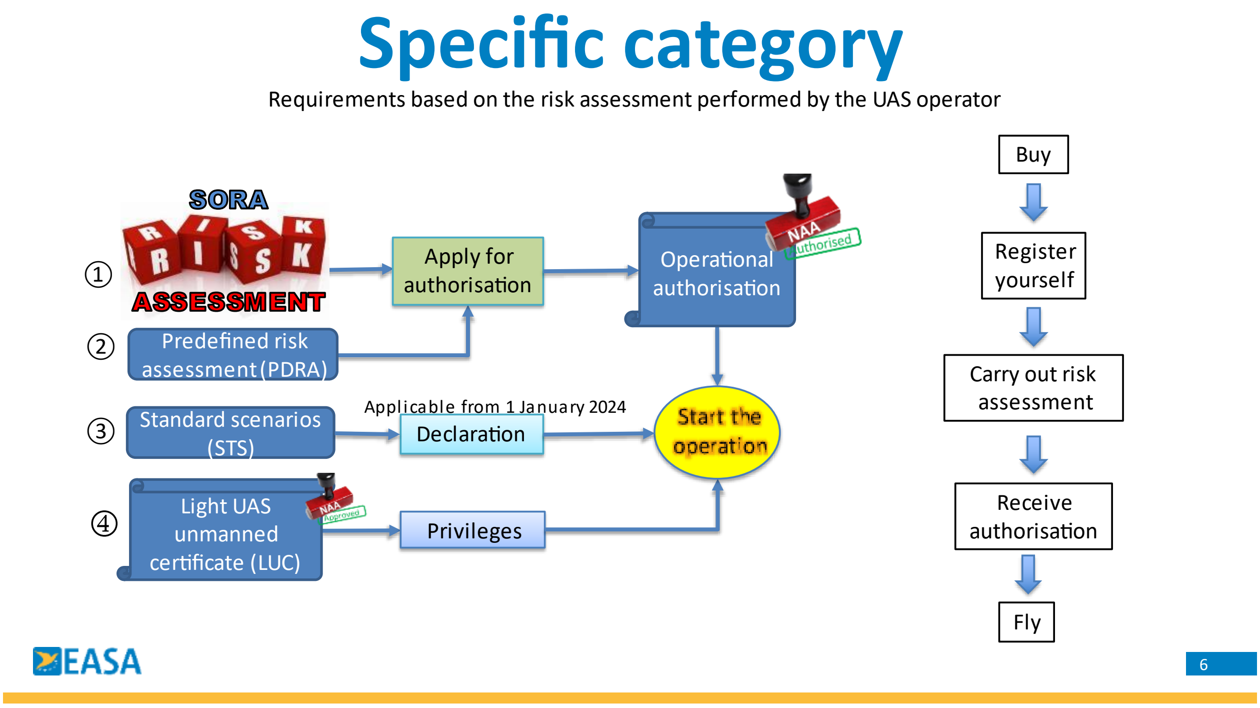

Illustration 7- Schematic Overview of procedure for the Specific Category, Illustration of the EASA Drone regulation categories- As Presented by EASA in informal presentation on 31 May 2023, Cologne

3.0 Tentative conclusions and follow-up.

On the basis of the very limited number of cases and the experiences with only a few developers that have progressed towards a demonstrator phase, in any case within the European Union and its Member States Finland and Belgium it

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can be said that there no real regulatory barriers or issues at the moment with authorisations for LTA unmanned carriers that aim to use hydrogen as a lifting gas.
In the time period where the carriers mentioned here were developing the 2016-2023 there were no incidents being encountered.
It seems that the barriers for the moment are from a rather different nature, notably being the lack of standardised suppliers and infrastructure for LTA carriers employing hydrogen as a lifting gas.

In addition, the current lack of knowledge and a lack of a standard supply sector means that the current innovators need to search for adequate suppliers themselves and develop procedures that in a routine form must have been existing in the 1920s and 1930s of the 20th Century, but that now need to be reinvented with 21st century possibilities, technologies and safety norms. Not an easy task, but one that can probably only be perfected by starting the activity and also by co-operation among the developer's using hydrogen.

One of these steps could be co-operation between the developers jointly the national authorities and EASA that have a key and strategic role in Europe in setting the conditions for safe design, operation, piloting, maintenance, and landing infrastructure. One of the first conclusions in the first discussions with EASA in Europe seems already that the smaller scale unmanned LTA Carriers for surveillance would be more closely fit into relatively simpler `specific` category.

The relatively `open` approach towards the use of hydrogen as a lifting gas in Europe, compared to the USA and Canada, means at least at this moment for LTA start-ups for unmanned carriers that hydrogen is on the table as a lifting gas, with safe handling protocols in place.

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[18] The Technology Platform `Upscaling Lighter -Than-Air Technology`- U-LTA initiated by the Institute for Infrastructure, Environment and Innovation, facilitated by EU DG Research and Innovation in 2018.

[19] See also www.kelluu.fi

[20] See also www.hylight.aero