H2-Aero: Leading the Way to Carbon-Free Aviation

By Jesse Schneider and Liviu Cosacescu

On March 29–31, the Vertical Flight Society hosted a groundbreaking, first-ever symposium and workshop on the potential for hydrogen (H2) to decarbonize aerospace. This first annual H2-Aero Symposium & Workshop was held as a hybrid event in Long Beach, California, to a sold-out venue — 100 attendees on-site and another 36 online — with participation by key aircraft and hydrogen industry and government representatives from around the world. The event had an agenda packed with highly informative presentations (see sidebar).

The main goal of the Symposium was to explore the cutting-edge progress of hydrogen for both aviation and ground vehicles. The follow-on Workshop was a “roll up your sleeves” interactive session toward starting the path for a common aircraft fuel and drafting a white paper for collaborative demonstration and scaling of hydrogen. To top it off, on the third day, Shell offered conference attendees a tour of their new heavy-duty hydrogen fueling facility at the Port of Long Beach.

The H2-Aero meeting expanded the VFS scope from hydrogen-electric vertical takeoff and landing (eVTOL), to include a wider spectrum of aircraft: electric short takeoff and landing (eSTOL) and conventional takeoff and landing (eCTOL) aircraft. The Symposium featured presentations from executives from aircraft manufacturers and developers, the hydrogen fuel cell (HFC) industry, and representatives from associations, academia and government organizations. Aside from the many innovative presentations, there were several announcements related to fuel-cell aircraft, hydrogen storage, hydrogen and electric aircraft demonstrations.

Aviation produces a billion tons (918 million metric tons) of carbon dioxide, according to Dr. Joseph Kallo CEO of H2Fly, which is approximately 2.5% of all sources. However, aviation contributes to a total 3.5% of global warming due to other, non-carbon-dioxide sources. There is much to be done to reach net zero in this sector, particularly as a Shell-Deloitte study published in September 2021 found that aviation could grow significantly to represent 22% of global emissions by 2050.

Jesse Schneider, CEO/CTO of ZEV Station and chair of the VFS H2-Aero Team, noted “for all the right reasons, the time to decarbonize aerospace with green hydrogen is now. There is an opportunity for us to learn together in H2-Aero from advances in both ground vehicle and fuel cell aircraft sectors working together with the goal to create a zero emissions airport.”

H2-Aero Project Goal and Scope

In his keynote talk, Schneider described the H2-Aero Team Vision, which is meant to accelerate the transition to renewable hydrogen and fuel cell aircraft at airports. The team is currently drafting a white paper inviting industry, government and academia on the H2-Aero Team project. The H2-Aero is co-led by a steering team of aerospace executives with subteams grouping the topics of hydrogen fuel and HFC-powered aircraft to help accelerate the consensus process.

The H2-Aero Team has the goal to develop a public-private partnership (PPP) with the scope of harmonizing requirements for aircraft and fuel; support the development of viable HFC aircraft with standards and demonstrations; develop a common
fueling infrastructure, interface and onboard storage technology; and scale the hydrogen solutions.

Both gaseous hydrogen (GH2) and liquid hydrogen (LH2) infrastructure have been standardized for automotive applications, but not yet at the scale needed for aviation. Other impediments include the cost and energy needed to generate hydrogen, the lack of existing infrastructure, transportation of hydrogen and high costs due to the prototype nature of the industry today.

The team of industry and government professionals plan to work towards: establishment of a definition for an aircraft and mobile hydrogen demonstration, with a prototype aircraft and hydrogen fueling (e.g., GH2 or LH2) to generate validation data for future standardization for both industries. This would include a pre-certification for electric aircraft, with a demonstration project bringing the latest in hydrogen-fuel cell aircraft and hydrogen fueling to an airport. Doing this will help validate capabilities in flight trials related to HFC aircraft and the relation to fueling beyond ground-vehicle experiences.

The lessons learned would be shared to enable a roadmap to a larger-scale airport project towards commercialization for the scaling of hydrogen and fleets of commercial aircraft.

Schneider showed the ultimate goal of H2-Aero vision of a zero-emissions airport with hydrogen generation at scale with renewable, gaseous hydrogen for small aircraft and ground vehicles. A portion of the gaseous hydrogen could be converted to liquid and stored at a massive scale (as proven with NASA’s current effort on the world’s largest LH2 storage sphere) and transported in liquid state in trailers for larger aircraft.

Groundbreaking Presentations

Below is the list of H2-Aero Symposium & Workshop talks. Briefing slides and video recordings are available at www.vtol.org/h2workshop. The videos can be viewed at no charge by all VFS members and meeting attendees.

- Welcome/Intro: Mike Hirschberg, VFS Executive Director
- KAirbus Hydrogen Vision: Amanda Simpson, VP R&T, Airbus Americas
- H2-Aero Team Vision (H2-Aero Chair): Jesse Schneider, CEO, ZEV Station
- ZeroAvia: Dr. Arnab Chatterjee, VP Infrastructure
- US DoE H2@Airports: Dr. Rajesh Ahluwalia, Argonne National Laboratory
- NASA Hydrogen & Fuel Cell Perspectives: John Cavolowsky, NASA & Ian Jakupca, NASA
- NASA Advances in LH2 Storage & Delivery at Scale: Adam Swanger, NASA
- US Air Force Hydrogen Perspective: Sterling Alley, Air Force AFWERX
- California Fuel Cell Partnership: Bill Elrick, Executive Director, CaFCP
- Massachusetts Hydrogen Coalition: Charlie Myers, President, Mass. H2 Coalition
- UK FlyZero: H2 Airports, Airlines & Airspace: Helen Leadbetter, UK ATI
- Fuel Cell Innovations: Dr. Alex Ivanenko, CEO, & Dietmar Trees, HyPoint
- Fuel Cell eVTOL Aircraft Integration: Dr. Ilya Khanykov, CEO, Bartini
- Fuel Cell Rotorcraft Integration: John Piasecki, CEO, Piasecki Aircraft Corp.
- H2 eCTOL Applications: Dr. Anita Sengupta, CEO, Hydroplane
- H2 eVTOL Applications: Yesh Premkumar, Sr. Manager, Supernal
- LuftCar & LuftPad — Accelerating H2 in Transportation: Santh Sathya, CEO, LuftCar
- Plug Power: Tim Cortes, CTO
- Universal Hydrogen: Arnaud Namer, Head of Strategy
- H2Fly: Dr. Josef Kallo, CEO
- The Promise & Challenge of H2eVTOL: Dr. Anubhav Datta, U. Maryland (VFS eVTOL Chair)
- Developing Hydrogen-Fueled Aircraft: Dr. Asif Ansar, Head of Energy System Dept., German Aerospace Center (DLR)
- Hydrogen Standards for Aerospace: Jonathan Archer, SAE International
- AIAA Sustainable Aviation Efforts: Ming Chang
- Methanol for H2 Private Capital: Michael Dyment, Managing Partner, NEXA Advisors
- Successful Past Aero Public-Private Partnerships: Bruce Holmes, NASA Emeritus
- Ground Vehicle H2 Fueling: Tom Mourmouras, Shell
- H2-Aero Workshop & Fuel Decision Matrix Discussion: Jesse Schneider and Anubhav Datta
- Draft H2-Aero Public-Private Partnership for H2 & Aerospace: Bruce Holmes, NASA Emeritus
- VFS thanks all those who participated in the success of the event, especially the sponsors: AIAA, Bartini, California Fuel Cell Partnership, HyPoint, Piasecki Aircraft, Toray Advanced Composites and ZEV Station.
Hydrogen-Powered Aircraft

The keynote by Amanda Simpson, Vice President of Research and Technology for Airbus Americas, highlighted the company strategy of offering a carbon-neutral commercial aircraft by 2035 and to pursue its net-zero ambition by 2050 through innovation and the Air Transport Action Group (ATAG) roadmap. She noted that Airbus holds more than 37,000 patents and has invested more than $35B in research and technology since 2000, including $3.5B just last year.

Simpson mentioned that on the path towards zero emissions, a 50% reduction in emissions per passenger mile (or kilometer) has been achieved in just the past 30 years due to improved and optimized aerodynamics, using advanced materials and high-efficiency engines. The remaining 50% reduction can be addressed by improved air traffic management (ATM) and aircraft operations, new engines and other technologies, and alternative fuels, all of which is targeted to be completed by 2060. Of all the fuels researched, hydrogen offers the most potential for both emissions offsetting and lower-cost fuel.

Simpson introduced three future aircraft and powertrain concepts being studied, a twin-engine hydrogen-powered turboprop for up to 100 passengers and greater than 1,000-nm (1,850-km) range; a hydrogen hybrid turbofan; or a blended-wing body (BWB) twin-engine airliner for up to 200 passengers and a range of more than 2,000 nm (3,700 km). All three concepts would use a liquid-hydrogen storage and distribution system.

Airbus hopes to make a final determination on a feasible concept for a hydrogen-powered aircraft by 2025 — a critical deadline if it is to meet its goal of having an operational aircraft by 2035. Airbus also expects to have a hydrogen-powered helicopter(s) available around the same time, in the mid-to-late 2030s.

Other development tools in Airbus’s arsenal include the Airbus UpNext ASCEND (Advanced Superconducting & Cryogenic Experimental powertraIn Demonstrator) — a ground demonstrator to explore the feasibility and application of “cold” electrical technologies for low-emission aircraft propulsion — and the ZEROe hydrogen combustion demonstrator. This latter is an A380-based multimodal test platform (the first A380 prototype, MSN001, which is used as a testbed) with four LH2 tanks in the rear of the fuselage, a hydrogen combustion engine located along the rear fuselage and a liquid-hydrogen distribution system.

Simpson also presented the concept of “Airports as Hydrogen Hubs,” with both air and ground transportation based on hydrogen and bringing economies of scale.

John Piasecki, CEO of Piasecki Aircraft Corporation (PiAC), said that active engagement by aviation regulators is needed for adoption. Piasecki said that his company was in early dialogue with the Federal Aviation Administration (FAA), noting that the pathway to adoption will be an education process, one that will involve bringing regulators on board at each step. They cautioned that premature regulation before technology readiness will be counterproductive in the long run. Schneider highlighted this point, emphasizing that “active engagement by aviation regulators is needed for adoption.”
Piasecki Aircraft has partnered with HyPoint for the development of a high-temperature PEM fuel cell system for its PA-890 compound helicopter. (Piasecki)

PiAC is developing a hydrogen fuel cell-powered, slowed-rotor, winged compound helicopter, the PA-890 (see “Future Fuel: HyPoint’s Hydrogen Revolution,” Vertiflite, Sept/Oct 2021). While most eVTOL aircraft have a range limited to intra-city travel, Piasecki is seeking to develop an aircraft with a range of 200 nm (370 km), using a HyPoint high-temperature polymer electric membrane (HTPEM) fuel cell system.

“A lot of our customers are demanding a capability that is well beyond battery power capacity,” Piasecki said. “When you talk about introducing a new fuel like hydrogen, you’ve got to be able to do the mission.”

The emergency medical services (EMS) sector could be a great opportunity to introduce hydrogen into aviation because the mission is such a high priority, said Piasecki, particularly for vertical flight applications like first responders, where cost is less of a barrier. The company plans to conduct a small-scale flight demonstration with a two-seat edm aerotec coaxial helicopter (see “Piasecki to Fly World’s First Hydrogen Helicopter,” pg. 58).

Hydroplane is converting a four-seat Piper Cherokee to hydrogen fuel cell power. With an advertised range of 540 nm (1,000 km), its Protium aircraft would offer users the same range they would expect from a traditional general aviation (GA) aircraft. Flight tests this year will indicate what kind of cost, performance and payload will be possible. The advantages of decarbonizing a small GA aircraft, said Dr. Anita Sengupta, CEO of Hydroplane, is that it is easier to get the aircraft into operation than a larger regional aircraft.

**Aerospace Hydrogen Developments**

From NASA, there were several knowledgeable presentations from the aerospace agency with decades of experience in using hydrogen and fuel cells in safety-critical applications in space travel.

From NASA headquarters, John Cavolowsky, the Director of the Transformative Aircraft Concepts Program (TACP) — part of the Aeronautics Research Mission Directorate (ARMD) — noted that the change in administration last year, there is a strong drive for sustainability from the federal government, including NASA. “That has clearly changed our posture,” he said, “in terms of the opportunity that hydrogen can serve as a way to address some of the 2050 net-zero carbon goals of the Administration.” He also highlighted that there are a number of challenges to realize hydrogen propulsion for aviation.

Ian Jakupca of NASA Glenn Research Center provided insights into the nearly 70 years of use of hydrogen for space applications. He also made a comparison between fuel cells and rechargeable batteries; the known aeronautical technical gaps, such as the large thermal loads for high-power applications; and needs for system integration, in order to put it all together in a cost-effective package for commercial applications. To investigate these challenges, NASA is supporting a study by the University of Illinois Center for High-Efficiency Electrical Technologies for Aircraft (CHEETA), under the NASA University Leadership Initiative (ULI). This is a clean-sheet assessment of what is needed to develop, mature and design disruptive technologies for a hydrogen fuel cell electric commercial flight.

Adam Swanger of NASA Kennedy Space Center showed how more than a half-century of experience in liquid-hydrogen usage has resulted in the development of a new LH2 sphere with a 1.25-million-gallon (4.7-million-liter) capacity. To reduce nearly 50% in LH2 loss by boil-off to a very low rate, two technologies were developed: the glass bubble fill insulation and the Integrated Refrigerated and Storage (IRAS) heat exchanger.

Hydrogen fuel cell-powered eVTOL (H2eVTOL) designs are expected to have far greater capabilities than battery-powered eVTOL aircraft, should certain key requirements be met. The promises and challenges were described quantitatively by Dr. Datta, University of Maryland, in the NASA Contractor Report last year, “PEM Fuel Cell MODEL for Conceptual Design of Hydrogen eVTOL Aircraft” (NASA CR-2021-0000284). Datta is the technical advisor to the H2-Aero Team.

At the Symposium, Datta highlighted that 15% weight-fraction storage would achieve performance on par with a piston engine aircraft; this metric would be enabled by LH2 storage. A 5.7% weight fraction would achieve half the performance, but this is still beyond what might be expected from batteries in the near future. A 1-kW/kg fuel cell stack system including balance of plant would be needed in both cases. Datta’s NASA report presented the detailed analysis for these numbers.

**Hydrogen Partnerships Learnings**

Bill Elrick, Executive Director at CaFCP, presented the status and plans for California’s fueling stations — 100 stations achieved in 2020, with a target of 1,000 GH2 filling stations in California by 2030, which would be able to service 1,000,000 H2 FC vehicles. He also shared the lessons learned, which include the importance of leadership, planning and commitment. Partnerships between government and industry are critical to achieving the green commitment. Elrick announced that the CaFCP is now expanding across the US to become a national partnership.

Tom Mourmouras of Shell presented his company’s roadmap towards a ground vehicle hydrogen fueling station network,
starting with light-duty hydrogen vehicles but expanding to heavy-duty trucks.

Charlie Myers, President of the Massachusetts Hydrogen Coalition, presented the hydrogen infrastructure in the northeastern United States, including for airports and mass transit at Boston Logan International Airport in Massachusetts and T.F. Green International Airport in Rhode Island. The Massachusetts Department of Transportation’s Aeronautics Division has already been investigating corridors for drones and potential sites for air taxi operations.

Both Ehrick and Myers highlighted the importance of reaching out to stakeholder groups, such as first responders and maintenance technicians. Ehrick noted that despite initial concern among the first responder community, the efforts his organization made to educate first responders gave them confidence that hydrogen was safe, which in turn helped instill confidence in the public.

Live from the UK, Helen Leadbetter — an airport operations and requirements specialist for the UK Aerospace Technology Institute (ATI) FlyZero project — provided an in-depth presentation on how green hydrogen might support zero-emissions transatlantic flight within a generation. She noted distribution is a major concern of airports. Different airports are likely to take different approaches to supply fuel, depending on their size and traffic, said Leadbetter.

ATI’s FlyZero project, which aims at realizing zero-carbon emission commercial aviation by 2030, published a key report in March, entitled, “Hydrogen Infrastructure and Operations: Airports, Airlines and Airspace.” Concept aircraft — ranging from HFC propeller-driven regional aircraft (75 passengers) to hydrogen-burning gas turbines for narrowbodies (179 passengers) and midsize airliners (279 passengers) were presented as the path to implementing hydrogen technologies. Different scenarios for H2 delivery to the airport were shown: LH2 tankers, GH2 pipelines and onsite generation on-airport were presented. On-airport distribution was also discussed, with diagrams of both bowser-type refuel tanker trucks and underground liquid hydrogen hydrant delivery solutions.

Clear conclusions from the ATI presentation: countries are moving fast on hydrogen aircraft and infrastructure, and the UK has a clear directive to organize zero-carbon hydrogen for international jet travel.

**Hydrogen Aircraft Developments**

Dr. Kallo, CEO of H2Fly, attended from Germany. He presented their 10-year experience in flying HFC aircraft, beginning with the Antares DLR-H2, the first crewed, purely hydrogen-electric aircraft, through the HY4, and onto the present development partnership with Deutsche Aircraft. Their goal is to convert a Dornier Do328 aircraft with a 1.5-MW fuel-cell powerplant with 1,100 lb (500 kg) of LH2 on board. Kallo shared valuable lessons learned and made recommendations based on direct experience in developing and testing HFC-powered aircraft. Kallo also...
welcomes all those interested in shorter distances. Looking to the future, Plug Power has also high-pressure gaseous hydrogen can also be economical at most economical, said Plug Power’s CTO, Tim Cortes, while Distribution of hydrogen in liquid form is currently the expected for wide-scale use, remains a significant challenge. Transporting hydrogen, particularly in the quantities that are

Hydrogen Initiatives

Dr. Alex Ivanenko, the CEO of HyPoint championed reducing the mass, volume and complexity of fuel cell stacks and systems by using HTPEM fuel cells, and using air-cooled fuel cell stacks to simplify the cooling system. The company also announced a collaboration with Tullahoma, Tennessee-based Gloyer-Taylor Laboratories (GTL) — developers of ultralight LH2 hydrogen fuel tanks, which will enable lighter aircraft.

Bartini Aero, meanwhile, is working on an eVTOL design with a capacity of two- or four- passengers and a range of 300 nm (550 km), powered by a HyPoint HTPEM system.

Yesh Premkumar of Supernal, Hyundai’s eVTOL subsidiary, highlighted the company’s battery-electric S-A1 eVTOL aircraft and announced that Hyundai was also developing a hydrogen-powered eSTOL aircraft for regional air mobility (RAM) — ranges of 125–625 miles (200–1,000 km). Premkumar noted a Hyundai is very interested in partnering for key aspects in developing hydrogen-powered aircraft, building on the strengths of the company and those of others. Hyundai has the background from the automotive sector to develop zero-emission aircraft powertrains — with a design for manufacturability, which Premkumar felt was a key strength for the company. Hyundai has three thrusts for building the advanced air mobility ecosystem: partnerships, policy and regulation, and public acceptance.

In addition, VFS also holds monthly H2eVTOL Council webmeetings, with “brown bag” educational seminars looking across the ecosystem. These meetings are held on the third Monday of each month at 11:30 am ET (UTC-4).

Learn more about VFS hydrogen initiatives at www.vtol.org/hydrogen.
Shell Tour of H2 Refueling Station

By Anubhav Datta

In addition to the talk at the Symposium, Shell also provided a technical tour of their heavy-duty hydrogen fuelling station at the nearby Port of Long Beach on the morning of March 31.

Shell engineers Stephen Leff and Kate Miner explained the intricacies of the station, which fuels zero-emission fuel-cell electric trucks. Trucks (FCET) for drayage operators at the port and transportation to the Inland Empire area of Southern California.

Leff showed attendees the hydrogen 450 bar (6,500 psi) steel storage tubes that are currently reloaded by tanker trucks that deliver compressed hydrogen from generation plants elsewhere in California. The fuel delivery is not unlike any regular gas station (see image of the supply panel, right). From the storage cylinders, the hydrogen is compressed and chilled to –40°C (–40°F) for dispensing to vehicles. Depending on the design of the vehicle, hydrogen can be dispensed either at 350 bar (5,000 psi) or 700 bar (10,000 psi). The fueling nozzle is similar to any gas pump nozzle in appearance (see image).

The future delivery system will be very different. An on-site hydrogen production facility is currently under construction by FuelCell Energy, Inc., and nearing completion to begin operations later this year. This facility is a fuel-cell based trigeneration plant that converts renewable biogas to hydrogen at low pressure, plus carbon dioxide, electricity and heat. The hydrogen generation capacity is about 60 kg/hr (130 lb/hr) — a hydrogen fuel cell car refills in about 5 kg (11 lb) and a truck refill is around 50 kg (110 lb). The generated electricity will be used by the onsite offices. The hydrogen will be compressed to 450 bar into the same storage tubes.

The first tour was video recorded and edited; it too is available free to members in the VFS Video Library at www.vtol.org/videos.

NEXA Capital’s Michael Dyment highlighted use of methanol (CH3OH) as a transport medium for hydrogen. Since existing, ambient temperature tanker trucks can transport 21 times more hydrogen than an equivalent-sized truck carrying GH2, methanol could be an interim feedstock with the hydrogen reformed onsite.

H2-Aero Workshop

The H2-Aero Workshop on the afternoon of the second day helped clarify the two main forms of hydrogen for use in aircraft: gaseous and liquid. A preliminary collaborative table was developed showing the initial input towards a whitepaper with gaseous hydrogen for near-term and smaller-scale applications, whereas liquid hydrogen to be used in long distance, larger aircraft. Other hydrogen carriers like methanol or ammonia were not deemed as feasible alternatives for conversion onboard.

Bruce Holmes, as executive strategic advisor for the H2-Aero Team, spoke about his decades of experience in creating successful PPPs to lay the groundwork for hydrogen in aviation during the Symposium. During the Workshop, he focused on the steps necessary to create a PPP between government, industry and academia for H2-Aero.

Conclusion

There is great potential for governments, industry and academia to work together to accelerate the path towards hydrogen in aviation, greatly reducing greenhouse gas emissions. Hydrogen fuel cells are emerging at a rapid pace.
Launching a PPP for
1. Demonstration of an H2 Prototype Aircraft & Fueling (2023-2025); and
2. Airport H2 Hub Roadmap (>2025)

**Purpose (for example***):
A systemic advancement from prototype to scale in deploying H2 Fuel and H2 Aircraft for the Aeronautics Industry

**Outcomes (for example***):
- Industry Airport System Design Guidelines for H2 hubs at airports and flight service operations (White Paper)
- Validation of H2 systems flight applications
- Technical data reports supporting industrialization including Codes, & Standards

**Value Propositions (for example***):
- Development of H2 technology deployment in Aeronautics
- Accelerate technology maturation
- Leverage and align scarce resources
- Stimulate commercialization of both Fuel Cell Aircraft and Green Hydrogen Fuel at Scale

*To be refined by collaboration partners

NASA veteran Bruce Holmes provided sage guidance on how to start a public-private partnership to overcome the challenges of hydrogen for aero applications. (Holmes Consulting)

as the real replacement for multiple aviation applications and offer advantages over existing powertrain technologies, such as piston and gas turbines, as well as battery-electric and hybrid-electric propulsion.

However, for hydrogen and fuel cells to become a widespread success, industry-government-academia partnership is vital. Both industry and government need to collaborate with organizations and people with direct experience in both hydrogen and fuel cells development and deployment programs. Academia can break fundamental barriers and train the much-needed workforce of the future. The H2-Aero Team is striving to bring these entities together and produce tangible results towards commercialization of hydrogen fuel cell aircraft and renewable hydrogen at scale.

The H2-Aero Team was humbled by the immense efforts of the presenters to show off their latest advancements and the collaborative discussions.

The results of the 1st H2-Aero workshop concluded with consensus towards two common fuels. The overwhelming consensus was that using hydrogen fuel-cell technology powered by liquid or gaseous hydrogen would support the development of hydrogen aviation infrastructure. The H2-Aero workshop resulted in 11 companies volunteering to help draft the whitepaper to define demonstration and the roadmap to a green hydrogen airport.

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Liviu Cosacescu is the VP of Electrolysis and Fuel Cell at ZEV Station. He brings more than 30 years of experience in research and development of fuel cell programs at Ballard Power Systems, AFCC, Mercedes-Benz and Ford Motor Company. He has run multiple testing and demonstration projects from stack to system level on test stands and vehicles.