

Hydrogen Aviation Working Group (HAWG)
Proposed Early Discussion Materials
April 8, 2025
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Introduction

This material may be of use in facilitating initial discussions within the Hydrogen Aviation Working Group (HAWG). It is based on a comprehensive review of the following documents:

1. *ATI Hydrogen Infrastructure and Operations March 2022*
2. *H2 Aviation Study FCHJU Clean Sky May 2020*
3. *Transforming Aviation Report GAO-22-105020*
4. *FAA Aircraft FC and Safety TC20-9 January 2020*
5. *FAA Hydrogen Aircraft Safety and Certification Roadmap December 2024*

The Working Group has been asked to address a broad and critical set of questions surrounding the future of hydrogen-powered aviation. This includes evaluating the public, economic, and noise-related benefits of hydrogen-powered commercial aircraft, analyzing how hydrogen propulsion differs from conventional fuels in terms of operation, and identifying the primary safety barriers and risk mitigation strategies associated with hydrogen use. A key focus is also the prioritization of research and development activities necessary to address these challenges, and to support the development of clear, consistent certification pathways for emerging hydrogen technologies in aviation.

To facilitate this work, this material presents five high-level recommendations based on a synthesis of relevant FAA, industry, and international research documents. Each recommendation is accompanied by detailed findings and visual summaries in the form of infographics designed to support collaborative discussion. The intention is not to propose final policy, but to provide a common foundation of knowledge, allowing Working Group members to engage in evidence-based deliberations and ultimately contribute informed, actionable guidance for the certification and integration of hydrogen into the future of civil aviation.

Here's a synthesis of key findings that will assist the Working Group in its objectives.

Recommendation 1: Promote the Public, Economic, and Noise Benefits of Hydrogen-Powered Aircraft

Findings:

1. Hydrogen fuel has the potential to provide a cleaner, quieter alternative to conventional jet fuel, reducing noise pollution near airports. As hydrogen combustion does not produce carbon-based particulate matter, the reduction in noise pollution will benefit both airport workers and surrounding communities.
2. The operational efficiency of hydrogen-powered aircraft could result in lower long-term fuel costs compared to traditional kerosene, contributing to the reduction of overall aviation expenses. Additionally, the global push toward renewable energy sources may lower hydrogen production costs, making it more competitive against fossil fuels in the long term.
3. Hydrogen infrastructure development could create new jobs and stimulate economic activity in the aerospace and hydrogen industries. The demand for specialized skills, manufacturing, and construction related to hydrogen infrastructure could provide significant employment opportunities in both urban and rural areas.
4. Hydrogen's high specific energy per mass (3x that of kerosene) could allow for greater fuel efficiency and improved aircraft performance. This characteristic also means that hydrogen-powered aircraft will need to carry less fuel weight for the same range, potentially reducing operational costs and increasing fuel efficiency.



Action Steps:

1. **Advocate for policy support for hydrogen adoption in aviation.**
 - Engage with policymakers at both local and national levels to ensure clear pathways for funding hydrogen research and development. Propose new legislation or modifications to existing policies to incentivize the development of hydrogen-powered aviation.
 - Align with international aviation fuel technology goals to secure political and regulatory support. Collaborate with international aviation organizations to encourage the establishment of global hydrogen aviation standards.

2. Develop economic models showcasing cost savings and long-term benefits.

- Collaborate with economic analysts to project cost comparisons of hydrogen vs. traditional aviation fuel, factoring in long-term fuel price volatility. Conduct cost-benefit analysis studies to present the financial advantages of hydrogen-powered aircraft for airline operators.
- Work with airlines and infrastructure providers to estimate potential fuel savings and operational efficiency improvements. Use these findings to create financial models for airlines to evaluate the potential return on investment in hydrogen technology.

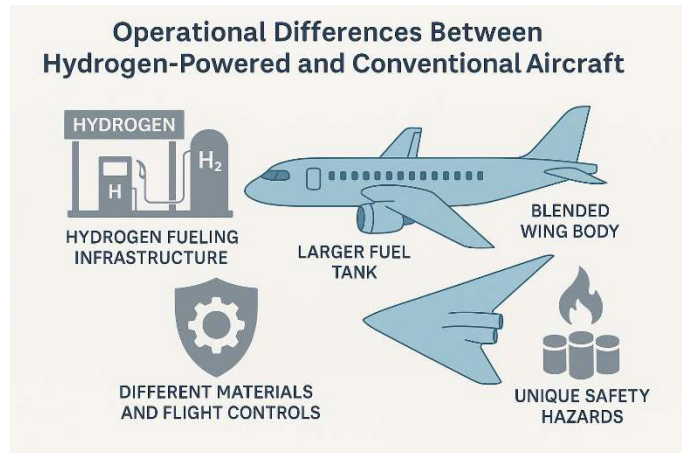
3. Launch public awareness campaigns on the environmental and economic advantages of hydrogen aviation.

- Develop informational materials to educate the public and key industry stakeholders about hydrogen aviation's potential for reducing carbon emissions and noise pollution. Prepare media kits, brochures, and online content for distribution at aviation and environmental events.
- Partner with aviation and environmental organizations to amplify the message and create engaging content for public outreach. Organize public webinars, conferences, and social media campaigns to spread awareness and generate interest.

Recommendation 2: Address Operational Differences Between Hydrogen-Powered and Conventional Aircraft

Findings:

1. Hydrogen aircraft require significant adjustments in infrastructure, including specialized fueling systems and storage tanks. Airports will need to develop new hydrogen storage and refueling stations, potentially creating bottlenecks during the transition phase.
2. Hydrogen fuel cells operate at a lower temperature and pressure compared to conventional jet engines, necessitating different materials and safety protocols. Specialized materials that can withstand low temperatures and pressures without becoming brittle or compromising structural integrity will be critical for safe aircraft operations.
3. The energy density of liquid hydrogen is much lower by volume than kerosene, requiring larger and heavier fuel tanks. These larger tanks may compromise available space for passengers or cargo, impacting the design and overall efficiency of hydrogen-powered aircraft.
4. Hydrogen aircraft design, such as the Blended Wing Body, may offer better aerodynamics but also presents new engineering challenges. While these designs may optimize fuel efficiency, they introduce complexities related to structural integrity and integration of new technologies.
5. Hydrogen combustion engines require modifications in flight control systems to accommodate different fuel dynamics and characteristics. Engine management systems will need to adjust to the unique properties of hydrogen combustion to ensure efficient and safe operations across varying flight conditions.



Action Steps:

1. **Develop a comprehensive comparison of hydrogen aircraft vs. conventional aircraft.**
 - Perform detailed performance and safety assessments to identify operational challenges in transitioning from conventional fuels to hydrogen. Collect data from prototype aircraft and current hydrogen projects to assess the viability of operational changes.

- Create a reference document that outlines operational shifts required for hydrogen aircraft integration. Distribute the document to key stakeholders, including airline operators and airport managers, to ensure widespread understanding of the required operational changes.

2. Create standards for hydrogen fueling infrastructure at airports.

- Collaborate with airport authorities and infrastructure developers to develop refueling protocols and infrastructure guidelines. Work with engineers and industry experts to design refueling systems that meet safety standards and minimize operational downtime.
- Design a certification process for hydrogen refueling infrastructure that ensures safety and compatibility with existing airport operations. Develop training materials and certification programs for airports to ensure compliance with hydrogen refueling safety standards.

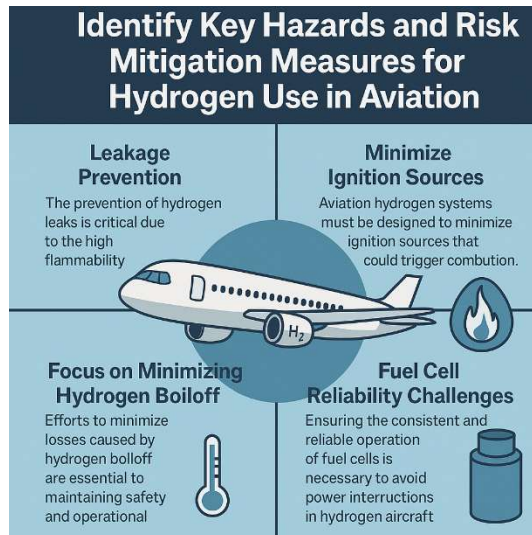
3. Test hydrogen-powered aircraft prototypes under real-world conditions.

- Coordinate test flights for hydrogen aircraft to identify operational differences in hydrogen versus conventional fuel-powered aircraft. Use these test flights to collect real-time data on fuel consumption, engine performance, and refueling times.
- Document and analyze results to create a database of best practices and lessons learned. Share the results of these tests with aviation stakeholders to improve hydrogen aircraft design and operational protocols.

Recommendation 3: Identify Barriers to the Safe Use of Hydrogen as Aviation Fuel

Findings:

1. Hydrogen presents unique safety hazards, including the risk of fire and explosion due to its flammability and lower ignition energy. Hydrogen's wide flammability range makes it more susceptible to ignition from even minor sparks, presenting challenges in its storage, transport, and handling.
2. The highly cryogenic nature of liquid hydrogen requires specialized insulation and venting systems to prevent boil-off and pressure build-up. These systems must be engineered to prevent catastrophic failures in the event of tank failure or leakage, ensuring the aircraft's safety under extreme conditions.
3. High-pressure storage systems for gaseous hydrogen present mechanical hazards, such as potential rupture or leaks. Robust containment systems must be designed to prevent over-pressurization and minimize the risk of hydrogen leaks in high-density areas such as airports.
4. The fuel cell power systems (FCPS) used in hydrogen aircraft could face reliability challenges and require rigorous safety measures for integration. Special attention must be paid to the durability and failure modes of FCPS components, which may be more susceptible to extreme environmental conditions than traditional engines.
5. Regulatory frameworks are not yet fully equipped to address the novel challenges posed by hydrogen-powered aircraft. Existing airworthiness standards must be revisited and adapted to include hydrogen-specific systems, materials, and safety measures.



Action Steps:

1. **Develop comprehensive safety regulations for hydrogen-powered aircraft.**
 - Collaborate with the FAA to create new standards and guidelines specific to hydrogen technologies. Ensure that these regulations cover all aspects of hydrogen fuel handling, including refueling and storage, to address the safety concerns of hydrogen-powered aviation.
 - Assess existing regulations for their applicability and adapt them to account for the unique properties of hydrogen. Modify existing fuel system safety

standards to address the risks associated with hydrogen fuel, such as leakage, combustion, and cryogenic hazards.

2. Establish risk assessment protocols specific to hydrogen fuel hazards.

- Conduct extensive hazard analysis and define critical areas for safety research. Focus research on identifying high-risk areas such as fuel storage, fuel cell systems, and hydrogen leakage prevention.
- Develop and implement safety measures for hydrogen handling, storage, and transportation. Introduce mandatory safety procedures for hydrogen fueling stations and storage facilities, ensuring consistent hazard mitigation across the aviation industry.

3. Implement ongoing safety training for aviation personnel.

- Offer certification programs focused on the safe handling of hydrogen and fuel cells. These programs should be mandatory for airport ground staff, flight crews, and maintenance personnel, covering all hydrogen-related safety procedures.
- Ensure that airport ground crews and pilots are trained in hydrogen-specific safety procedures. Conduct regular refresher courses and emergency response drills to keep all personnel up to date on the latest safety protocols.

Recommendation 4: Prioritize Research and Development to Overcome Hydrogen Aircraft Barriers

Findings:

1. There is a need to advance hydrogen storage and distribution technologies to improve aircraft fuel tank design and refueling efficiency. Significant breakthroughs in lightweight, high-capacity hydrogen storage are necessary to make hydrogen aviation feasible for commercial use.
2. Fuel cell technology must be scaled and optimized for use in aviation, focusing on higher efficiency and reduced weight. Achieving these goals will require targeted research to enhance fuel cell performance, durability, and integration into aircraft systems.
3. Improved cryogenic storage solutions are critical for reducing weight and increasing efficiency of hydrogen-powered aircraft. Innovations in materials and insulation technologies will be key to achieving the necessary weight reductions without compromising safety.
4. Further research into hydrogen combustion engines is needed to adapt them for aviation applications while minimizing emissions. Developing low-NOx hydrogen combustion engines will ensure that hydrogen-powered aircraft meet environmental standards and improve performance.
5. The integration of hydrogen systems into aircraft must account for safety and operational reliability, requiring significant R&D in materials science and fuel cell durability. Research into materials that resist hydrogen embrittlement and improve fuel cell longevity will be critical to the safe use of hydrogen in aviation.



Action Steps:

1. **Establish hydrogen R&D hubs focused on aviation applications.**
 - Partner with universities and research institutions to focus on hydrogen-specific propulsion and safety technologies. Establish dedicated research centers to push the boundaries of hydrogen fuel cell efficiency and hydrogen aircraft design.

- Secure government and private funding to accelerate R&D efforts. Collaborate with industry partners to ensure that R&D activities are aligned with the latest technological needs and can be rapidly commercialized.

2. Support collaboration on cryogenic and high-pressure hydrogen storage technologies.

- Collaborate with manufacturers and experts to enhance storage materials and technologies. Focus research on developing new storage technologies that can safely and efficiently handle the large volume of hydrogen needed for aviation.
- Prototype advanced storage systems to address volume and weight concerns. Test new materials and storage designs to evaluate their performance in real-world conditions and ensure they meet safety standards.

3. Prioritize testing of fuel cell and hydrogen combustion systems.

- Set up dedicated test facilities for aviation-specific hydrogen combustion research. These facilities will focus on testing hydrogen engines and fuel cells to simulate flight conditions and identify potential improvements.
- Develop collaboration platforms to share findings and enhance development timelines. Establish a network of researchers and industry experts to share progress on hydrogen-powered aviation systems and accelerate the certification process.

Recommendation 5: Strengthen Collaborative Efforts to Ensure the Safe Certification of Hydrogen Aircraft

Findings:

1. Collaboration between international aviation regulators, such as the FAA and EASA, will help harmonize standards for hydrogen aircraft certification. This cooperation will ensure that hydrogen aviation certification processes are consistent across borders and reduce regulatory uncertainty.
2. The FAA has started collaborating with industry experts to address safety concerns and certification gaps related to hydrogen aviation. By working with hydrogen aircraft manufacturers, the FAA can ensure that certification processes are both safe and efficient.
3. Existing certification processes for aviation fuel systems and aircraft components must be adapted for hydrogen applications. These changes will involve revising current standards to accommodate the unique properties of hydrogen and integrating new technologies into existing frameworks.
4. Extensive testing and demonstration flights are essential to provide the data needed for hydrogen aircraft certification. These tests will help verify the safety, performance, and feasibility of hydrogen systems in real-world aviation environments.
5. Cross-sector collaboration will be key to addressing challenges in fuel cell, propulsion, and hydrogen storage system certification. These collaborative efforts will help build a unified approach to certification, ensuring that all aspects of hydrogen-powered aviation meet safety and operational standards.



Action Steps:

1. **Develop a collaborative certification framework for hydrogen aircraft.**
 - Coordinate with international aviation bodies to harmonize hydrogen fuel-related standards. Facilitate discussions between the FAA and international regulators to develop a unified set of certification criteria for hydrogen aircraft.

- Share certification processes between aviation stakeholders to streamline approval timelines. Create a common framework for certification that allows hydrogen aircraft manufacturers to navigate the approval process smoothly.

2. Ensure a clear, transparent certification timeline for hydrogen aircraft.

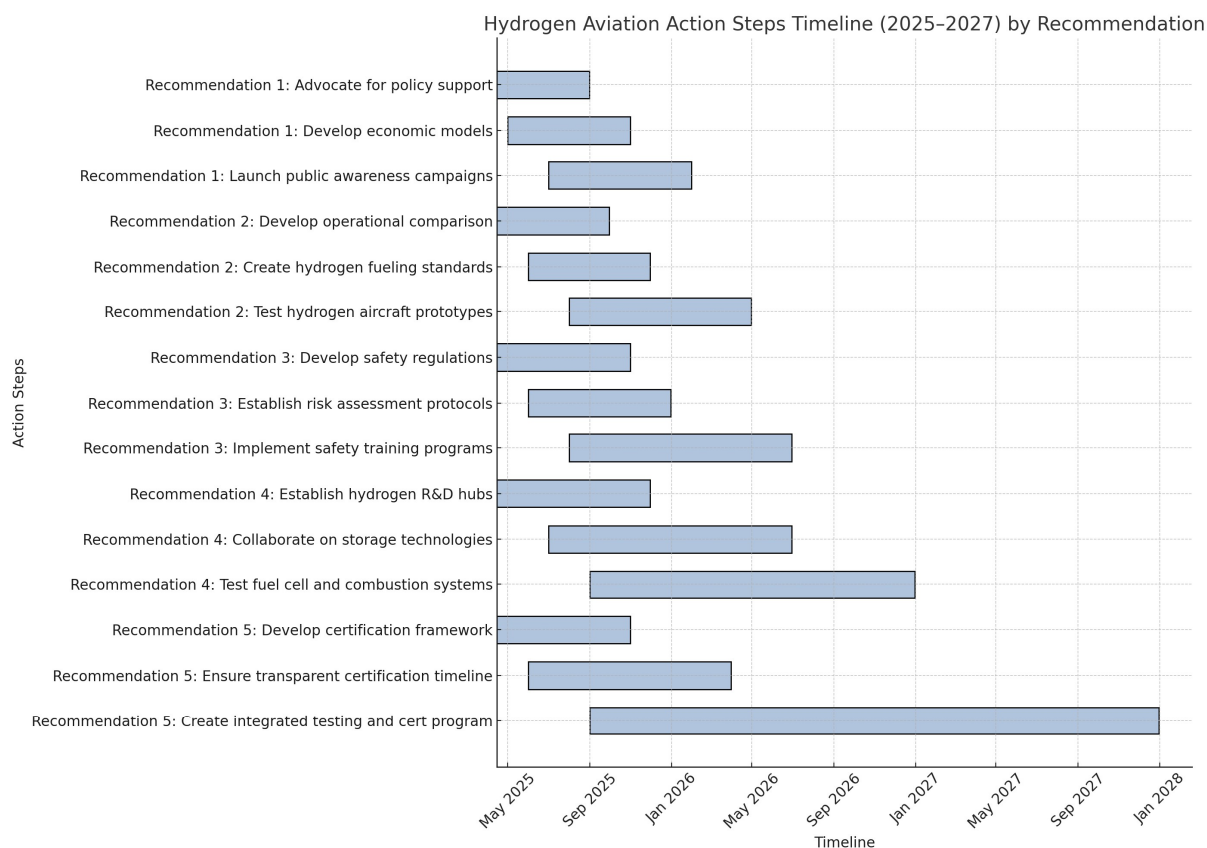
- Work with the FAA to create milestones for each phase of the hydrogen aircraft certification process. These milestones should include clear deliverables and deadlines to help all parties involved track progress.
- Regularly update stakeholders on certification progress and requirements. Provide periodic updates to hydrogen aircraft developers, operators, and regulators to ensure alignment and avoid delays.

3. Create an integrated testing and certification program.

- Establish partnerships with research organizations to provide real-world data. These partnerships will provide the necessary testing infrastructure to validate hydrogen-powered aircraft in live operational environments.
- Pilot full-scale testing programs to validate hydrogen systems before full aircraft certification. Conduct comprehensive testing of hydrogen storage, propulsion, and safety systems to ensure readiness for large-scale deployment.

Proposed Implementation Timeline for Hydrogen Aviation Action Steps (2025–2027)

The following timeline provides a visual overview of the proposed action steps associated with each of the five key recommendations developed for the FAA Hydrogen Working Group. Organized by recommendation, this project-style chart outlines the sequencing and duration of tasks across a structured three-year window, with all activities scheduled for completion by the end of 2027. The timeline is intended to help guide implementation planning, facilitate coordination among stakeholders, and support the Working Group in prioritizing near-, mid-, and long-term efforts to enable the safe and efficient integration of hydrogen-powered aircraft into civil aviation.



Summary

As we look to the future of hydrogen in aviation, this document offers a set of ideas and insights intended to support the FAA Hydrogen Working Group in its thoughtful and collaborative discussions. We've drawn from a range of technical and policy sources to build a picture of where things stand today—and where the biggest opportunities and challenges may lie. The five recommendations presented here reflect themes that consistently emerged across the literature, and we've paired each with findings and visual summaries to help guide productive conversation among Working Group members.

Our goal has been to provide a shared starting point, not a finished roadmap. Each section is meant to spark dialogue, encourage questions, and offer structure as the group works through complex issues like certification pathways, safety strategies, and operational shifts. Whether it's considering public acceptance or tackling technical challenges in fuel storage and cell reliability, these recommendations are intended to support informed and practical counsel for ARAC consideration.

Ultimately, this material is a resource—one of many—that the Working Group can draw on as it crafts its advice. We hope it offers both clarity and flexibility, and that it contributes meaningfully to the group's ongoing efforts. With continued collaboration and insight from each of you, the FAA will be well-equipped to shape a safe and sustainable future for hydrogen-powered aviation.

Summary of Key Documents Reviewed

The following summary paragraphs provide an overview of key documents reviewed by the Hydrogen Aviation Working Group (HAWG) to inform discussions and recommendations on the safe and efficient integration of hydrogen into civil aviation. These summaries highlight critical insights from each document, focusing on the technical, regulatory, and infrastructure challenges and opportunities for hydrogen-powered aircraft. The information presented is aimed at guiding the working group's efforts to provide advice and recommendations to the Aircraft Certification Advisory Committee (ARAC) on the most effective ways to enable the safe use of hydrogen in aviation.

1. ATI Hydrogen Infrastructure and Operations March 2022

<https://www.ati.org.uk/wp-content/uploads/2022/03/FZO-CST-POS-0035-Airports-Airlines-Airspace-Operations-and-Hydrogen-Infrastructure.pdf>

This report, part of the FlyZero initiative led by the Aerospace Technology Institute, investigates the feasibility of hydrogen as a zero-carbon emission fuel for aviation. It focuses on the infrastructure required to support hydrogen-powered aircraft, with the conclusion that green liquid hydrogen is the most viable option for large-scale aviation decarbonization. It covers key areas such as hydrogen generation, storage, and airport infrastructure, as well as the technical and operational challenges of adopting hydrogen in commercial aviation. The report also highlights the need for extensive research into the properties of hydrogen, including its impact on aircraft design and fuel handling systems, which must be adapted to accommodate the large storage volumes required for hydrogen fuel.

In addition, the report stresses the importance of developing a robust hydrogen supply network, including refueling infrastructure at airports, to support the widespread adoption of hydrogen-powered aircraft. It also considers the integration of hydrogen aviation within the broader air traffic management (ATM) system, discussing how the evolving airspace design will facilitate hydrogen aircraft operations while minimizing energy use. The report recommends a concerted effort from industry, government, and academia to scale hydrogen aviation technologies and infrastructure, positioning the UK at the forefront of sustainable aviation .

2. H2 Aviation Study FCHJU Clean Sky May 2020

https://www.clean-hydrogen.europa.eu/media/publications/hydrogen-powered-aviation_en

This study evaluates the potential of hydrogen propulsion to decarbonize the aviation industry by 2050. It examines the technological, economic, and climate impacts of hydrogen-powered aircraft, including both hydrogen combustion and fuel cell technologies. The report highlights that hydrogen could significantly reduce aviation's climate impact, particularly by eliminating CO₂ emissions during flight. However, it also

notes the challenges in scaling hydrogen technologies, including the development of efficient fuel cell systems, lightweight hydrogen tanks, and refueling infrastructure. The study presents hydrogen propulsion as most suited for smaller aircraft such as commuter, regional, and short- to medium-range flights, where fuel cell technology offers the highest energy efficiency.

In its analysis, the study compares hydrogen to other decarbonization options, such as sustainable aviation fuels (SAF), and stresses the need for large-scale technological advancements to make hydrogen viable in aviation. The findings suggest that hydrogen combustion could reduce aviation's climate impact by 50-75%, while fuel-cell propulsion could achieve reductions of 75-90%. The report outlines a roadmap for the development of hydrogen technologies and infrastructure, emphasizing the need for investment in research and development to overcome the technical barriers and commercialize hydrogen aviation.

3. FAA Aircraft FC and Safety TC20-9 January 2020

<https://rosap.ntl.bts.gov/view/dot/57843>

This document explores the safe implementation of three fuel cell power system (FCPS) technologies to provide auxiliary power for commercial air transport aircraft. It examines polymer electrolyte membrane (PEM) fuel cells, regenerative fuel cell power systems (RFCPS), and solid oxide fuel cell power systems (SOF CPS). The study evaluates the technical feasibility and safety implications of each system, with a focus on addressing new safety hazards introduced by these technologies. The report highlights key challenges, including the safe integration of fuel cells into aircraft systems, the need for specialized training for maintenance crews, and the development of reliable fuel cell power systems that can function in aviation environments.

The study also identifies critical areas for further research, particularly regarding fuel cell integration with existing aircraft power systems, and the associated risks of fire, explosion, and material degradation. It discusses the need for new certification processes for aircraft utilizing fuel cells, as well as the importance of establishing standardized safety protocols for their implementation. The report calls for continued collaboration between the FAA, industry, and research institutions to ensure the safe and efficient adoption of fuel cell technologies in aviation.

4. FAA Hydrogen Aircraft Safety and Certification Roadmap December 2024

https://www.faa.gov/aircraft/air_cert/step/disciplines/propulsion_systems/hydrogen-fueled_aircraft_roadmap

This roadmap outlines the FAA's strategy for enabling the safe and efficient use of hydrogen in civil aviation. It addresses the key regulatory and safety challenges posed by

hydrogen as a fuel source for aircraft, including the need to develop new certification standards and guidelines for hydrogen-powered aircraft. The document identifies the primary hazards associated with hydrogen, such as fire and explosion risks, and outlines the steps necessary to mitigate these risks through research and safety standards. It also emphasizes the need for collaboration with international aviation regulators to harmonize certification requirements and ensure the safe integration of hydrogen technologies into global aviation systems.

The roadmap is divided into short-term (2023-2028) and medium-term (2028-2032) actions, with a focus on addressing knowledge gaps, conducting research, and developing regulatory frameworks for hydrogen aircraft. It highlights the importance of workforce training and collaboration between the FAA, industry, and academic institutions to build the necessary skills and knowledge base. The roadmap also discusses the need for significant investment in hydrogen infrastructure, including fuel production, storage, and distribution systems at airports, to support the adoption of hydrogen-powered aircraft.

5. Transforming Aviation Report GAO-22-105020

<https://www.gao.gov/products/gao-22-105020>

The report from the Government Accountability Office (GAO) examines the potential of Advanced Air Mobility (AAM) to transform the aviation industry. AAM refers to small, electric, and highly automated aircraft capable of vertical takeoff and landing (eVTOL), which could reduce urban congestion, improve cargo delivery, and provide emergency medical transportation. The GAO report identifies several challenges to the widespread implementation of AAM, including the need for new regulatory frameworks to address the unique features of AAM aircraft, such as electric propulsion and vertical flight. It also emphasizes the importance of public acceptance and the development of infrastructure, particularly the need for standards for landing facilities and charging stations.

The report further explores workforce issues, noting that AAM will require a new generation of pilots, maintenance technicians, and engineers trained in electric propulsion and automation technologies. It points out that there is a significant gap in training capacity and that the industry will need to invest in education and workforce development to meet these needs. The GAO report concludes that while AAM has the potential to revolutionize aviation, its success will depend on how quickly industry and government address these regulatory, infrastructure, and workforce challenges.