High on Hydrogen!

2023 GATEWAY TO BLUE SKIES COMPETITION

Manhattan College

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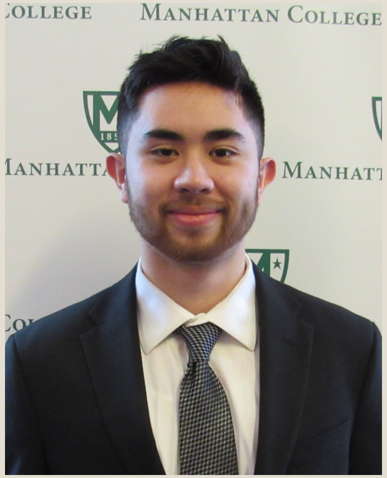
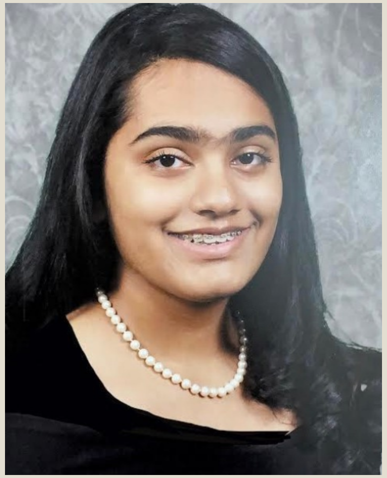
The Team



Aidan Downes
Mechanical Engineer



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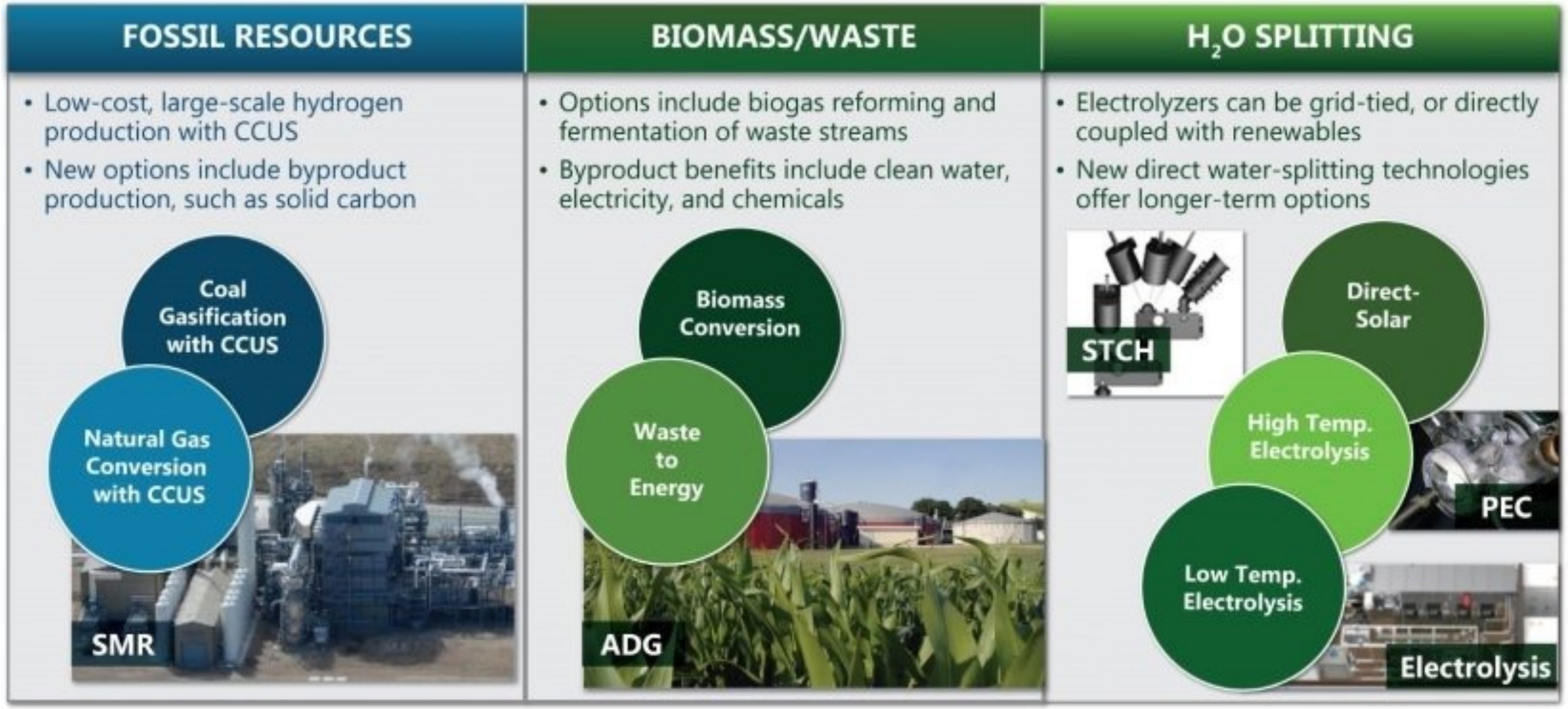
Generation Storage Transportation Into the Aircraft Safety Readiness Levels



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Generation

Types of Hydrogen Production

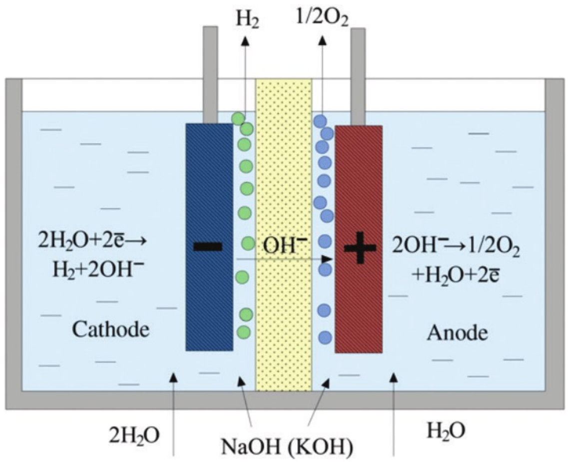
- Gray Hydrogen
  - 95% of all hydrogen produced today
  - Industrial processes (fossil fuels)
  - Carbon and Greenhouse gas emissions
- Blue Hydrogen
  - Similar industrial processes
  - Carbon Capture and Storage (Artificial and Biological)
  - Carbon gases stored in underground cavities
  - Ex. Biomass Gasification
- Green Hydrogen
  - Powered by renewable energy
  - No carbon or greenhouse emissions
  - Ex. Hydrogen Electrolysis

Green Hydrogen: Fukushima Hydrogen Energy Research Field [2]

Blue Hydrogen: Vassa Biomass Gasification Plant [3]

Types of Electrolyzers

- Alkaline
  - Simplest and Cheapest
  - Liquid electrolyte working fluid
  - Diaphragm separates product gasses
- Proton Exchange or Polymer Electrolyte Membrane (PEM)
  - More expensive option
  - Solid Electrolyte
  - Specially engineered membrane to separate hydrogen and oxygen
  - Current industry leader in efficiency and output
- Solid Oxide
  - In developmental stage
  - Uses steam not liquid water
  - Theoretically more efficient
  - Avoids phase change from liquid to gas



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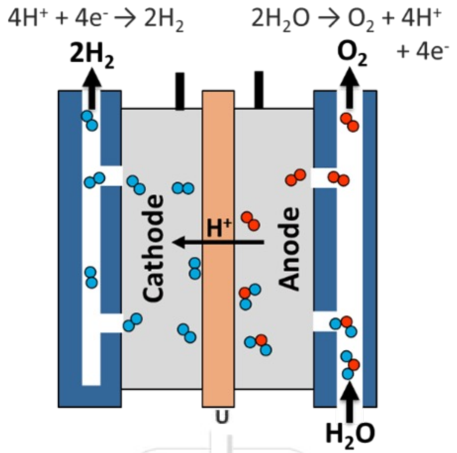

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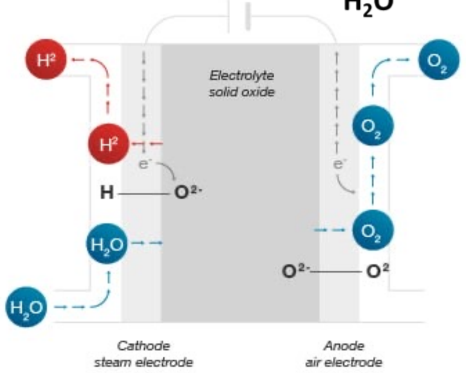

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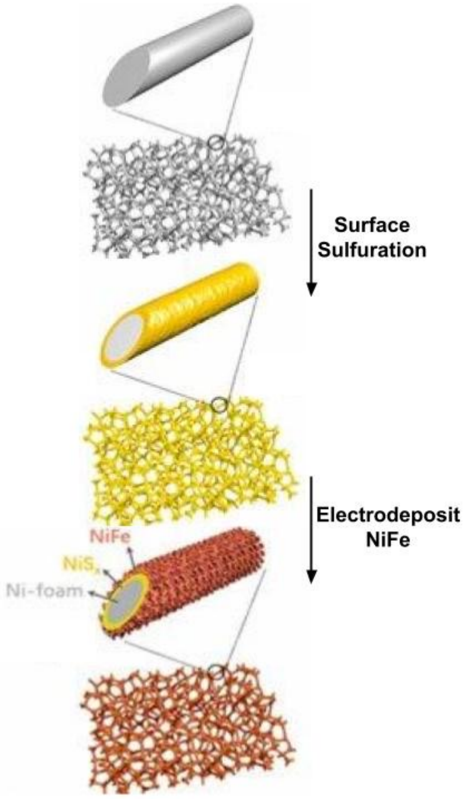
Seawater for Electrolysis

- Avoid putting a strain on world's purified water reserves
- Key to making Electrolysis possible on a large scale
- LDH (Layered Double Hydroxide) technology
  - Coating made of layered metal alloys
  - Slows breakdown of electrolyzer components
  - Applied to the electrodes
  - Mitigates surface area lost to oxidation/mineral deposits
  - Functions as an electrocatalyst
  - Promotes oxygen evolution not chlorine evolution



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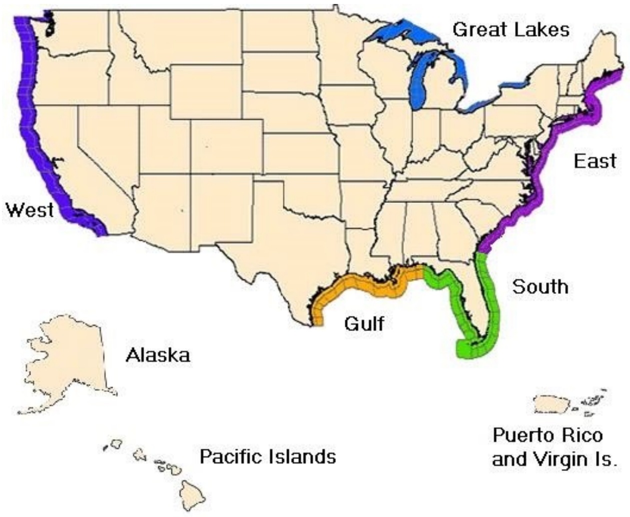
Proposition for Hydrogen Production based on Geographical Constraints

- Coastal Regions
  - Receive Green hydrogen from seawater electrolysis plants along coast
  - Plants will operate using PEM electrolyzers with LDH coated components
  - Plants will use hydro, solar, and wind power



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U.S. Map with Highlighted Coastal Regions

- Landlocked Regions
  - Receive Blue hydrogen from Biomass Gasification of local crop waste
  - Combination of biological and artificial carbon capture
  - Carbon dioxide byproduct to be used for photosynthesis of subsequent crop growth
  - Partially phased out as transportation technology advances

Liquefaction of Hydrogen Fuel

- Gaseous Hydrogen Fuel for short-range flights (<2 hrs)
- Liquid Hydrogen Fuel for long-range flights (>2 hrs)
- Completed via refrigeration cycle
- Storage and Liquefaction make use of cryogenic tanks
- Process includes heat exchangers and specialized valves
- Liquefaction reduces the energy content of the hydrogen fuel by about 30%

Leuna Hydrogen Liquefaction Plant in Germany [9]

Cryogenic Tank for Hydrogen Liquefaction [10]

[11]

Storage

Gaseous Hydrogen &
Liquid Hydrogen

Gaseous Hydrogen

- Low volumetric energy density (8 MJ/L) as compared to that of gasoline (32 MJ/L)
- High-pressure tanks
  - Achieve a higher storage density
  - Expensive process
  - Odorless- difficult to detect any leakage
- 1m³ LOHC
  - Store 57 kg of hydrogen at ambient temperature and atmospheric pressure

[12]

Gaseous Hydrogen

Liquid Organic Hydrogen Carriers (LOHCs)

- Oil medium - stored & transported as a regular fuel like gasoline
- Reversible hydrogenation and dehydrogenation cycles
- Reused multiple times

Gaseous Hydrogen

LOHC (Cont.)

Hydrogenation

- Hydrogen chemically bound to the LOHC at high temperatures and high pressures
- Exothermic process
  - Generates around 10 kWh/kg of H2
- Transported & used through the existing infrastructures

Dehydrogenation

- Hydrogen loaded LOHC+ is dehydrogenated through a catalytic reaction
- Endothermic
  - Requires around 11 kWh/kg of H2
- Unloaded LOHC- can be reused

Gaseous Hydrogen

- The Hydrogen Manufacturing to Utilization Cycle

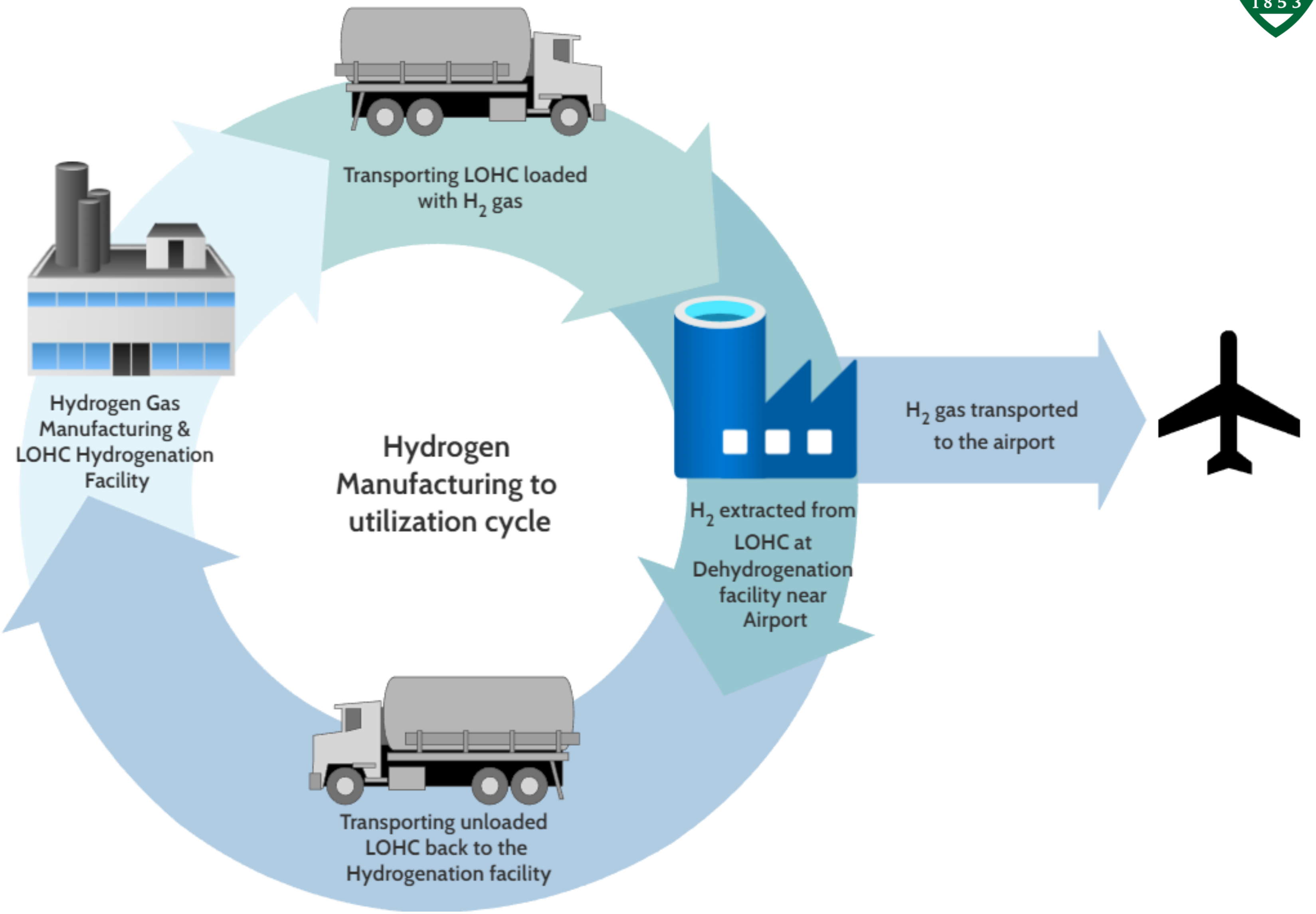

Figure 13

Ways to Use Generated Energy from Hydrogenation

- Immediate Usage
  - Electrolysis process (Coastal facilities)
    - Production of 1kg of hydrogen from water - 39 kWh of electricity
    - Thermoelectric generators - convert thermal energy into electrical energy
  - Domestic uses in the facility
- Same-Day Usage
  - Thermal stores
    - Insulated water tanks that store heat as hot water for several hours

Ways to Use Generated Energy from Hydrogenation (Cont.)

- Hot Pressure Swing Reactor
  - Uses heat generated from hydrogenation directly for the dehydrogenation process
  - Both processes occur in the same reactor

Storing the Energy: Heat Batteries

Heat stored in batteries using Phase change materials (PCM)

Heat is stored

- PCM changes from solid to liquid

Heat is released

- PCM changes back into a solid

Liquid Hydrogen

Cryogenic Tanks

- Low boiling point of -253°C (-423°F)
- Cryogenic tanks
  - Extensive amount of energy
  - Maintain the low temperatures
- 0.3% – 3% hydrogen lost: boil-off

Reducing Boil-off

- Insulated cryogenic containers
- Double wall construction and evacuation of the space between the walls
  - Reduce heat transfer from convection and conduction
- Saves energy when compared to the 30% energy loss during liquefaction process

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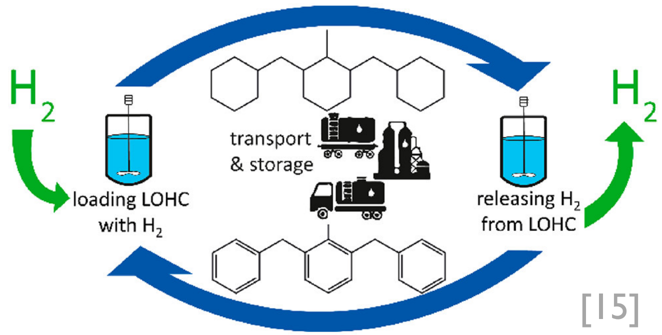
Transportation

Gaseous Hydrogen &
Liquid Hydrogen

Transporting Hydrogen



- Liquid Organic Hydrogen Carriers
  - Hydrogenation: Hydrogen is absorbed by LOHC
  - Dehydrogenation: Hydrogen is released by LOHC
- Insulated Cryogenic Pipelines
  - Liquid hydrogen can be transported using insulated cryogenic pipelines or special cryogenic tanks. However, this imposes a safety concern because liquid hydrogen is highly explosive.
- High-pressurized Tanks and Existing Pipeline Infrastructure
  - Gaseous hydrogen can be transported in pressurized tanks, or it can be transported through existing pipeline infrastructure by mixing hydrogen and natural gas.

Transporting Hydrogen

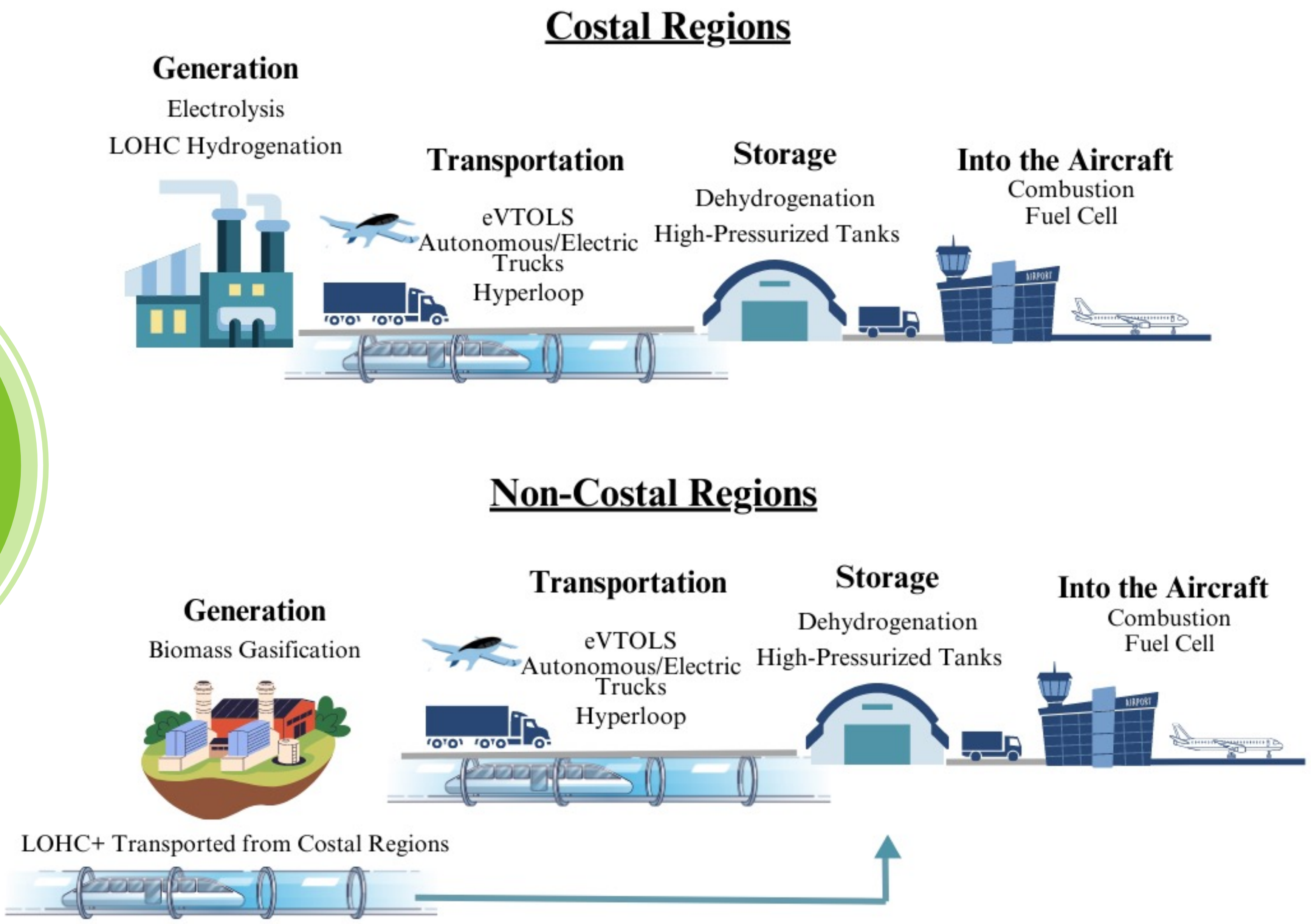


Figure 18

Electric Vertical Take-Off and Landing Vehicles (eVTOLS)

- EVTOLs carry up to six passengers or a total cargo weight of 1,500lbs with a range of around 289 miles


[19]

Fully Autonomous and Electric Trucks

- Provide transportation to the dehydrogenation facility located near the airport
- Transportation of heat batteries used to store energy during the hydrogenation process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Hyperloop

- Hyperloop is a proposed concept of a capsule inside vacuum-sealed tubes powered by magnetic tracks and a small electric current

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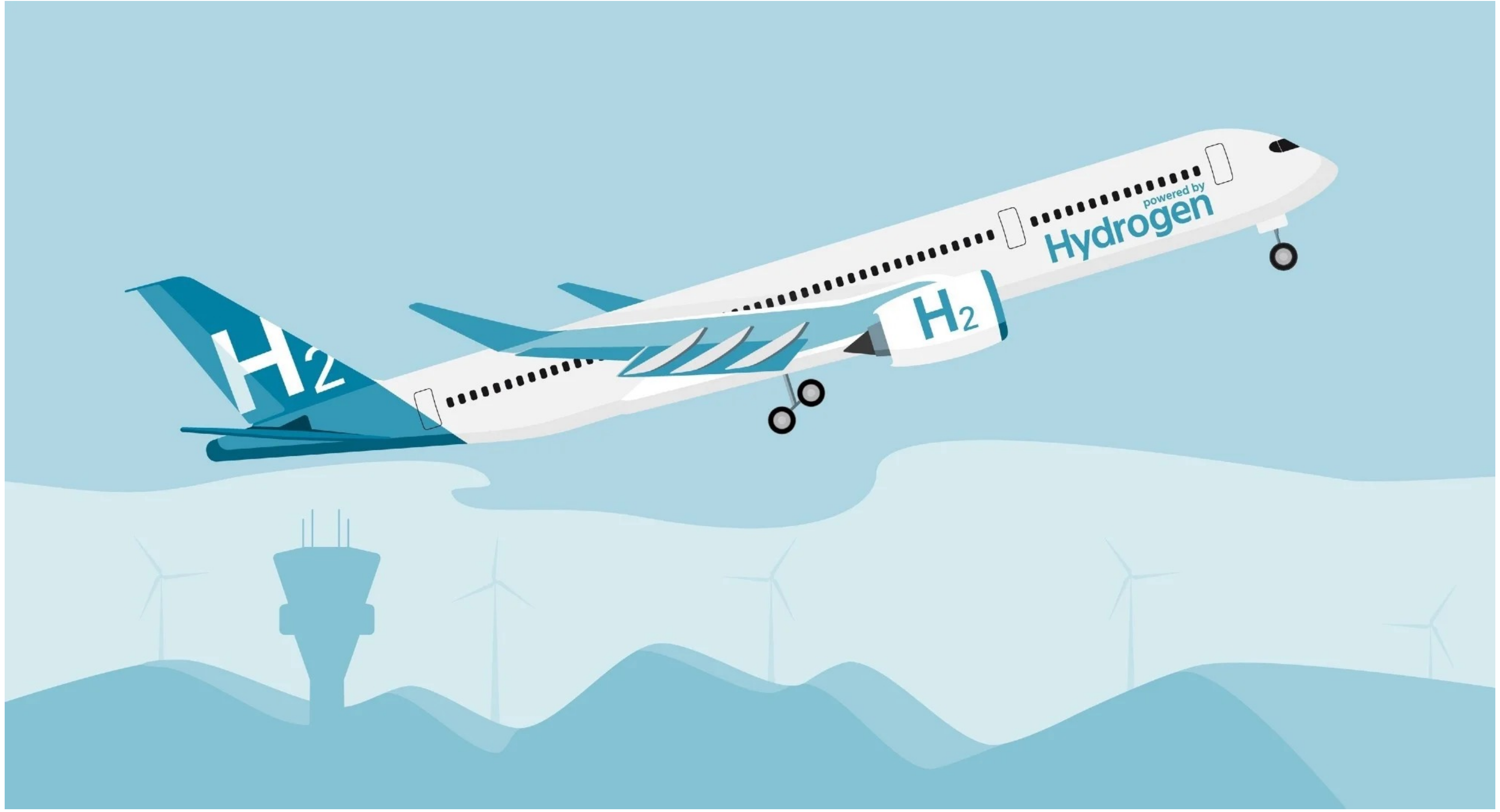

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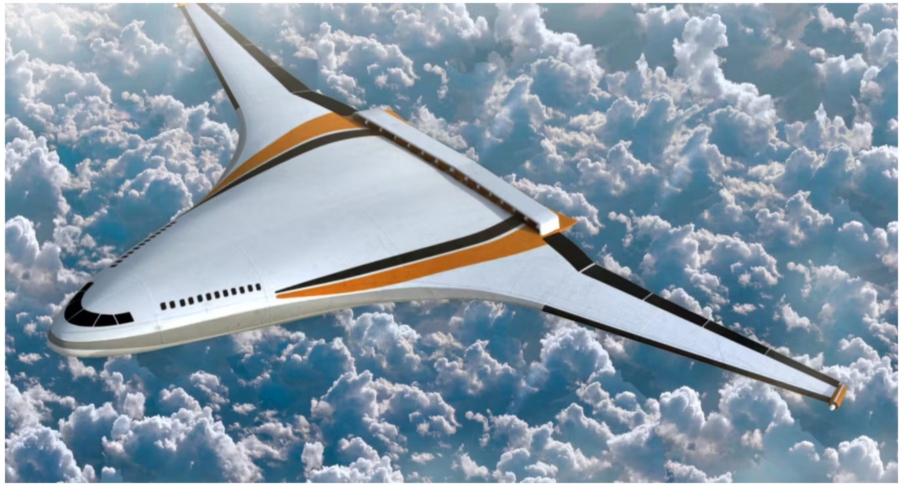
Into the Aircraft

Gaseous Hydrogen &
Liquid Hydrogen

Gaseous Hydrogen Into the Aircraft

- Hydrogen has three times higher specific energy than traditional aviation fuel
- The volumetric energy is four times lower
- More space needs to be assigned to hydrogen tanks in an aircraft



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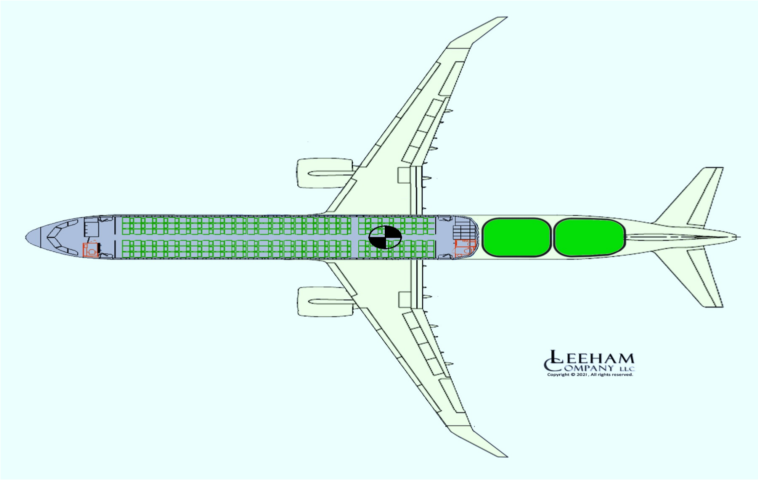

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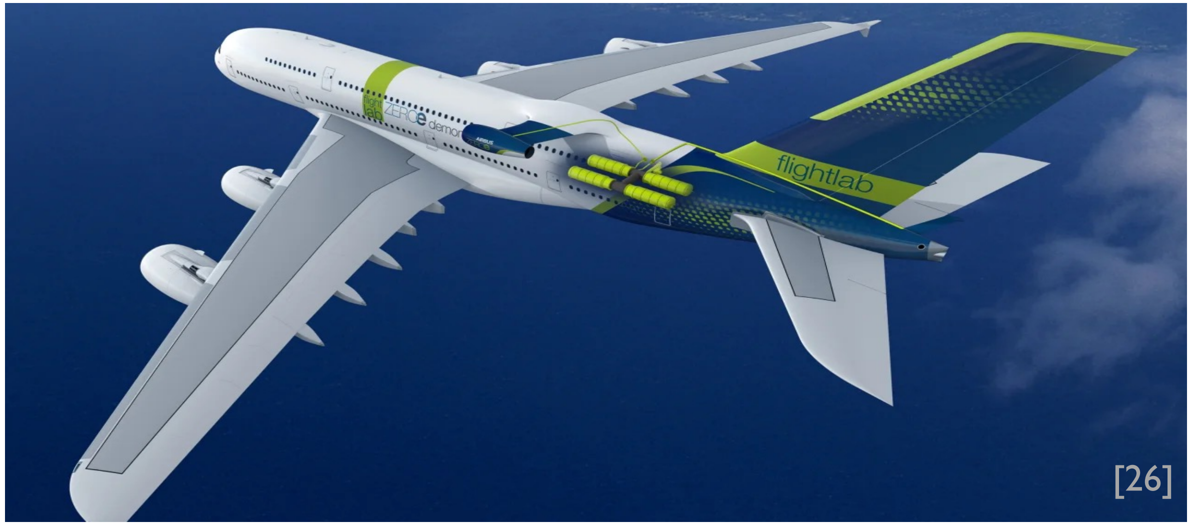


Liquid Hydrogen into the Aircraft

- Liquid Hydrogen reduces the required fuel tank space by 80%
- The volume ratio of liquid to gas is approximately about 1:848
- The liquid hydrogen has to be stored at a low temperature for twelve hours or more
- The onboard cryogenic systems have to serve 10000-hour working lifetimes

Gaseous Hydrogen vs. Liquid Hydrogen

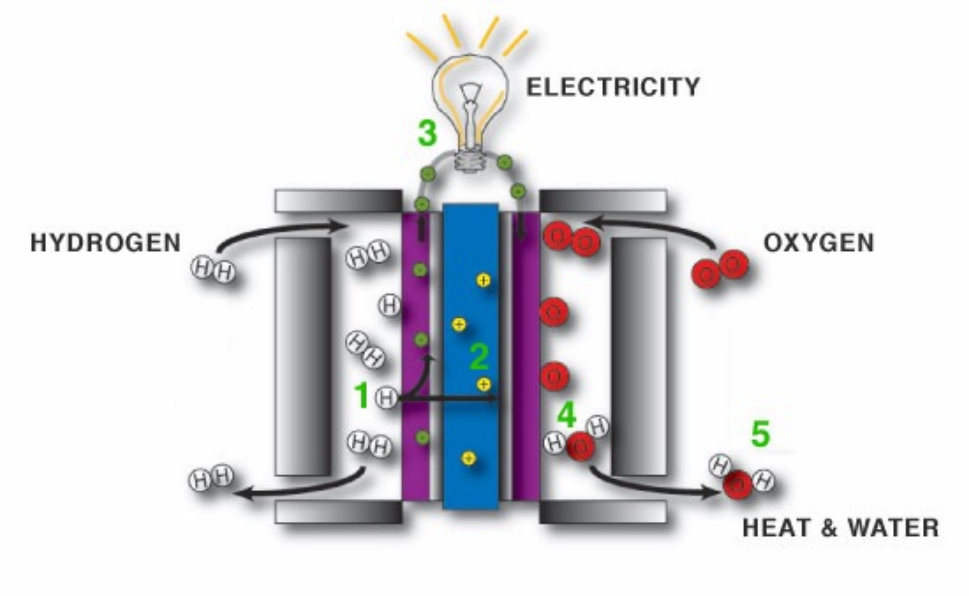
	Gaseous Hydrogen	Liquid Hydrogen
Pros	• Doesn't incur energy losses of 30% • Storage requirments are simple and less expensive	• Less space is needed for the fuel tank • More fuel can be stored in the fuel tank
Cons	• More space is needed for the fuel tank • Less fuel can be stored in the fuel tank	• About 30% of the energy is lost during the process of liquefaction • Storage requirements are complicated and more expensive

Final Thoughts: Gaseous Hydrogen vs. Liquid Hydrogen

Fuel	Density(kg/L)	Energy Density(MJ/L)	Price($/kg)	
Gaseous Hydrogen	0.0012	0.144	1.70	[27]
Liquid Hydrogen	0.0700	8.000	5.00	[28]

- Gaseous Hydrogen is a viable option for short range flight due to the limited space in the aircraft for the large tank
- Liquid Hydrogen is better for long range flight due to its higher energy density and significantly reduced fuel tank space requirements

Power Fuel Cell Into the Aircraft



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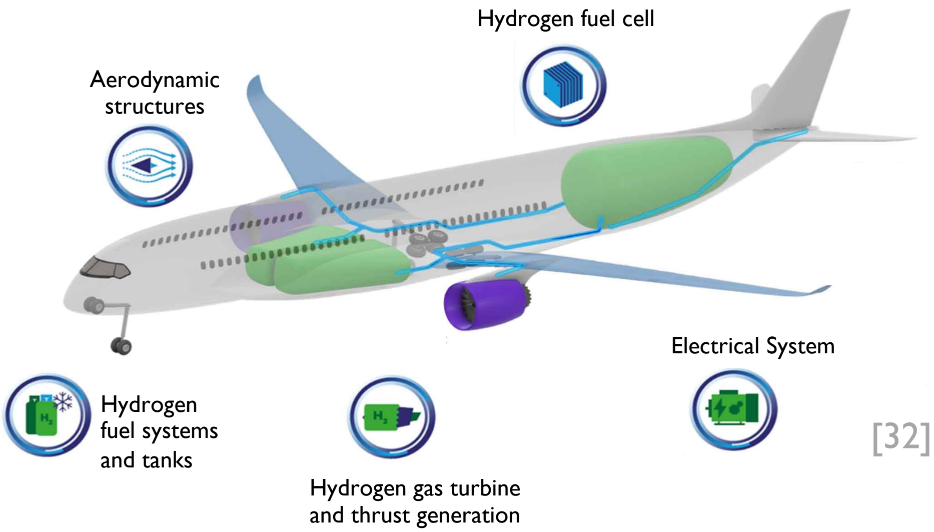

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- Using a power fuel cell produces no emissions except water vapor and heat as by-products.
- Power fuel cell can convert hydrogen into electricity at an efficiency rate up to 60%.
- It has superior durability.

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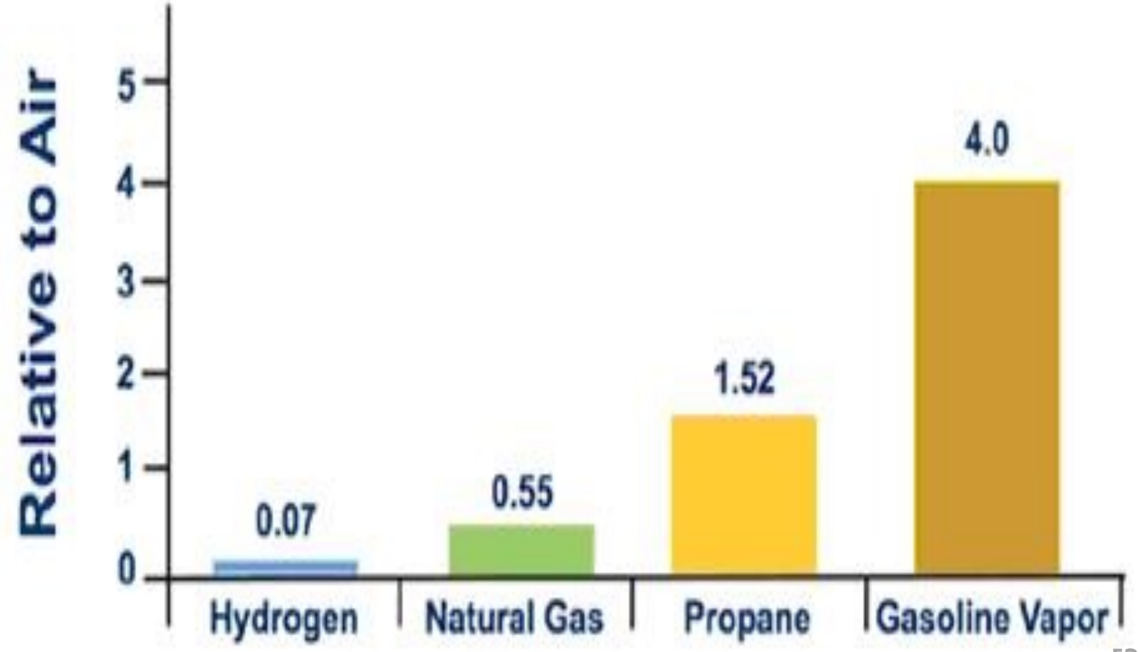
Safety

Gaseous Hydrogen & Liquid Hydrogen

Safety of hydrogen



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- Low molecular weight
- More difficult to confine due to rapid dispersion
- Non-toxic and non-poisonous

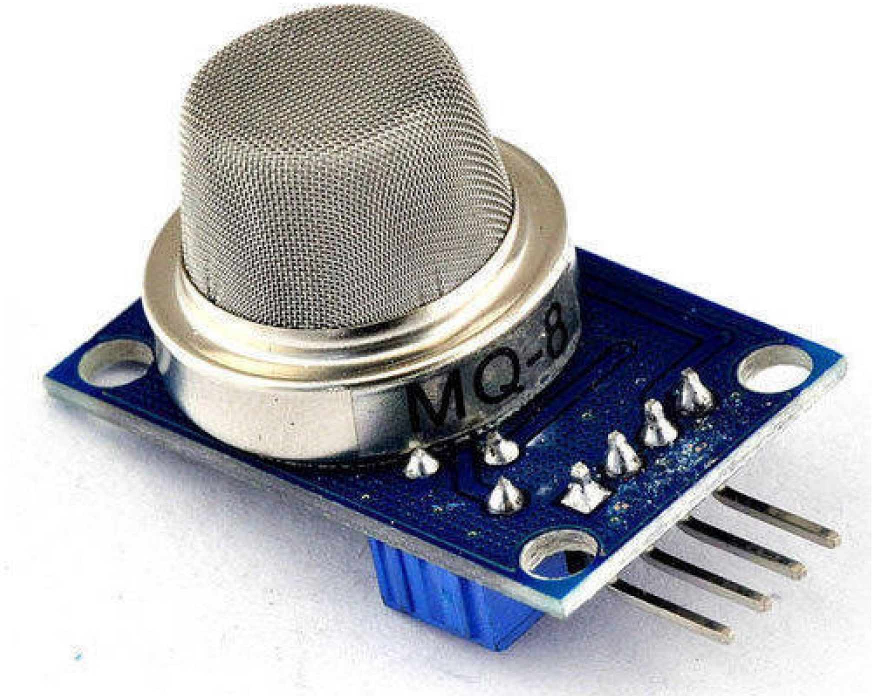
Additional Considerations for Liquid Hydrogen

- Low boiling point
- Conversion of ortho-hydrogen to para-hydrogen releases heat
- "Burn-off" gas can cause:
  - Burns to skin
  - Structural failure in materials such as carbon steel, plastic and rubber

[35]

Hydrogen Detection

- Colorless, odorless, tasteless; difficult for humans to detect alone
- Development of hydrogen sensors allow for hydrogen to remain purified and useable in fuel cells
  - Mercaptan (contains sulfur) used for detection of gasoline and natural gas
  - Odorants such as this are known to contaminate fuel cells



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Hydrogen Skepticism

- Unwarranted reputation
  - 1937 Hindenburg disaster
    - Hydrogen blamed for fire
    - Later found that outer layer coated in reactive chemical resembling rocket fuel, which was the actual cause
- Easy to be misinformed
- Can be one of the safest and most effective alternative selections

[37]

Potential Climate Impacts

- Unlikely to completely eliminate carbon emissions.
- Using carbon as fuel in the production of consumer goods i.e. soaps, fabrics and perfumes
    - Gas fermentation
- Process in conjunction with use of hydrogen would further minimize carbon footprint from the aviation industry.

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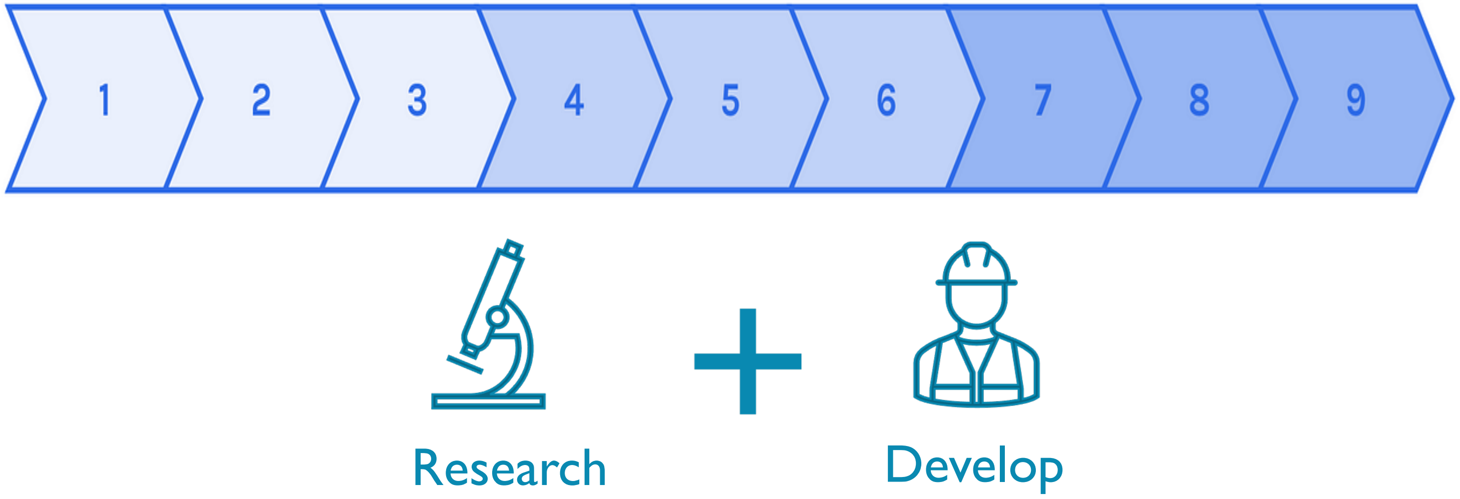
Readiness Levels



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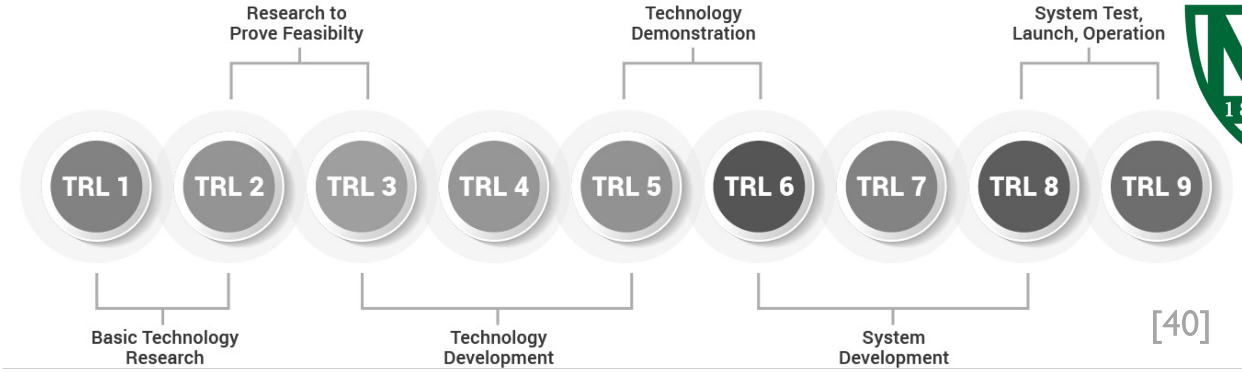
Our Readiness Timeline



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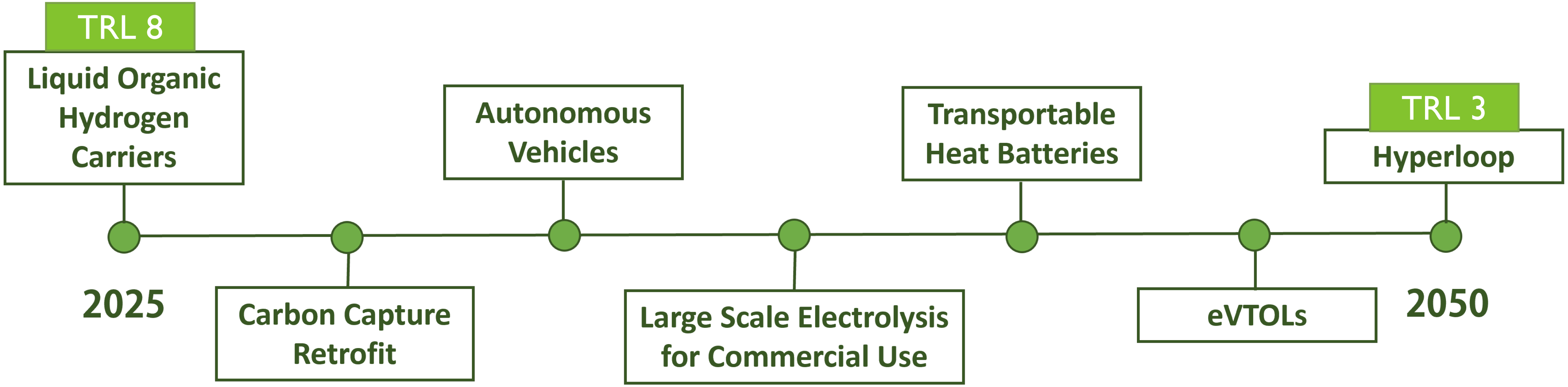
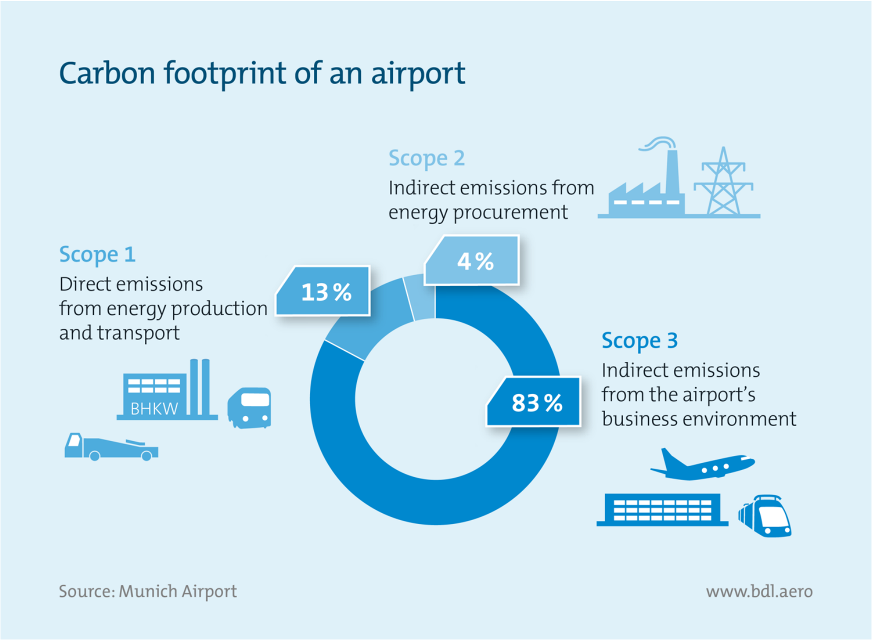


Figure 41

Government Impact

- Intergovernmental Panel on Climate Change states that if rise in carbon emissions don't stop by 2025, damages may be irreversible
- Many governments have stepped in to create initiatives towards cutting the use of fossil fuels
  - The Green Hydrogen Catapult Initiative (2020) (UN)
  - Aerospace Global Forum (2022)(UK)
  - Target True Zero initiative (UK)
  - The Aerospace Technology Institute formed FlyZero
  - The Department of Energy intendeds to fund the Bipartisan Infrastructure Law (2020)



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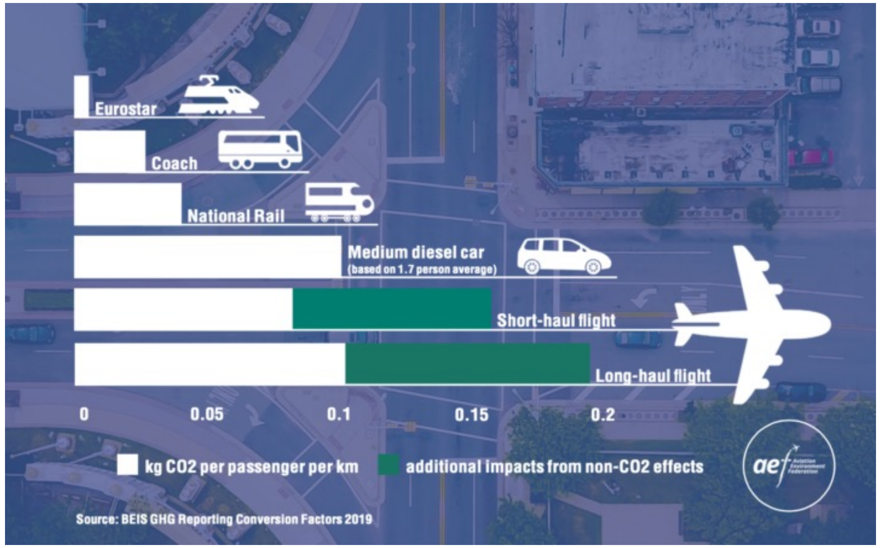

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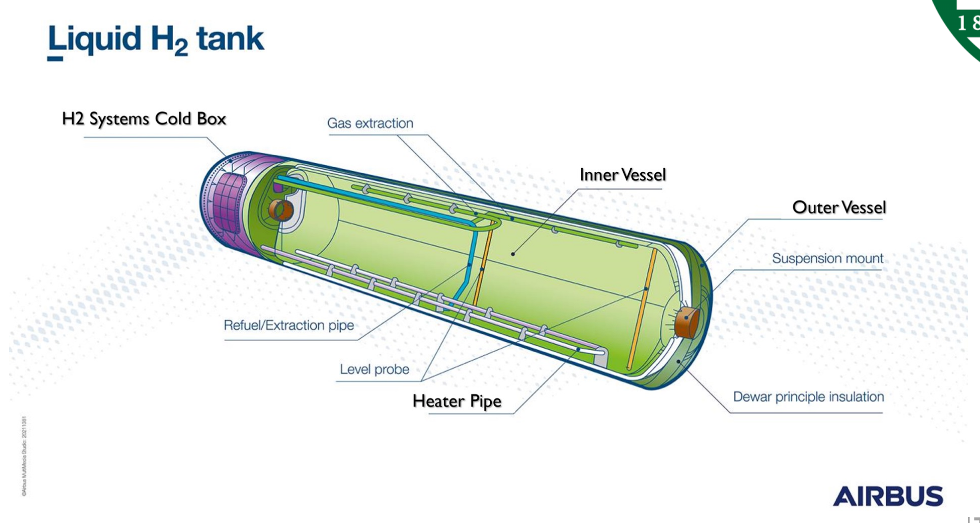
Airbus

- Joint initiative with Air New Zealand to research hydrogen-powered aircrafts for the airline(Sept 2021)
- Opened a Zero Emission Development Centre for hydrogen technologies (May 2022)
- Signed an agreement with "Linde," an industrial gas company, to work on developing hydrogen infrastructure at airports (May 2022)
- Have a demonstration flight for the A380 passenger airplane using hydrogen fuel cells and burning hydrogen directly in an engine (2026)



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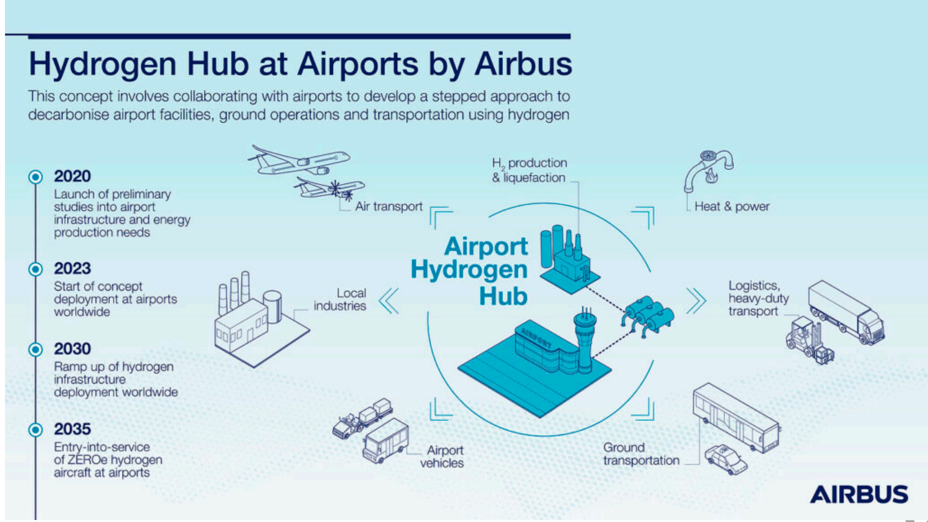

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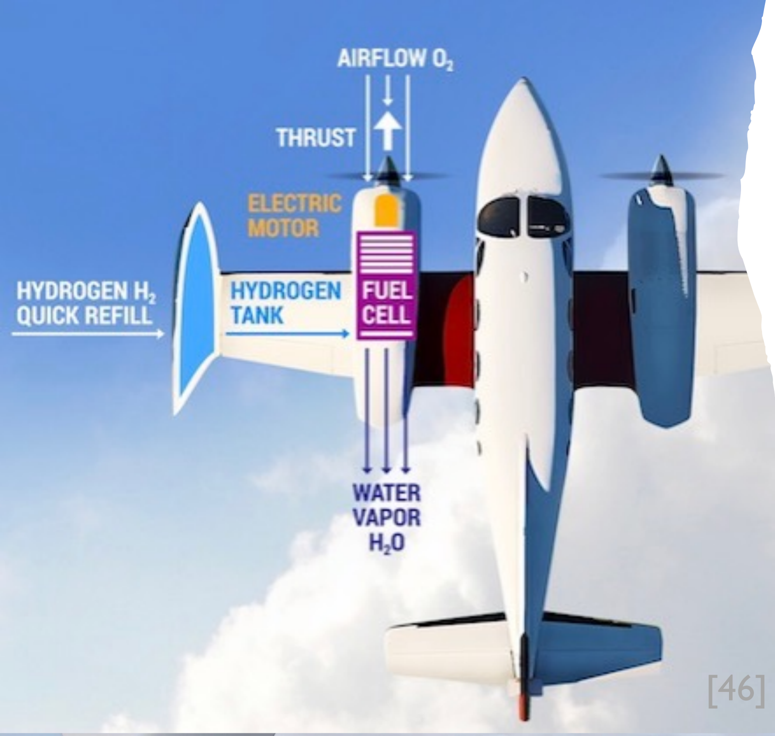

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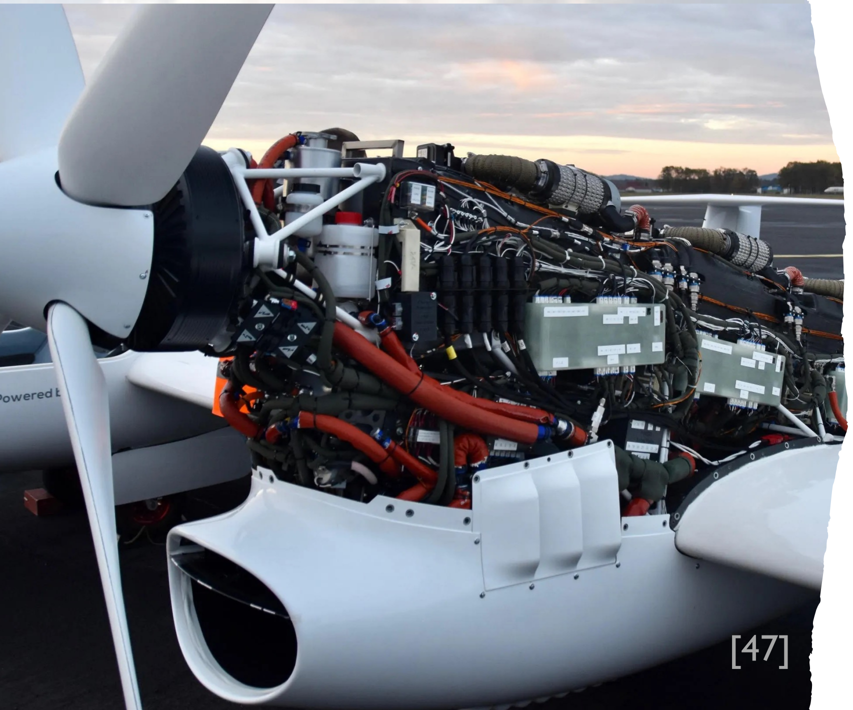

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Start Ups

- Universal Hydrogen and ZeroAvia both have tested aircrafts
- Liquid-hydrogen tanks onboard causes airliners to only travel about half of gas-fueled plane's range

Universal Hydrogen

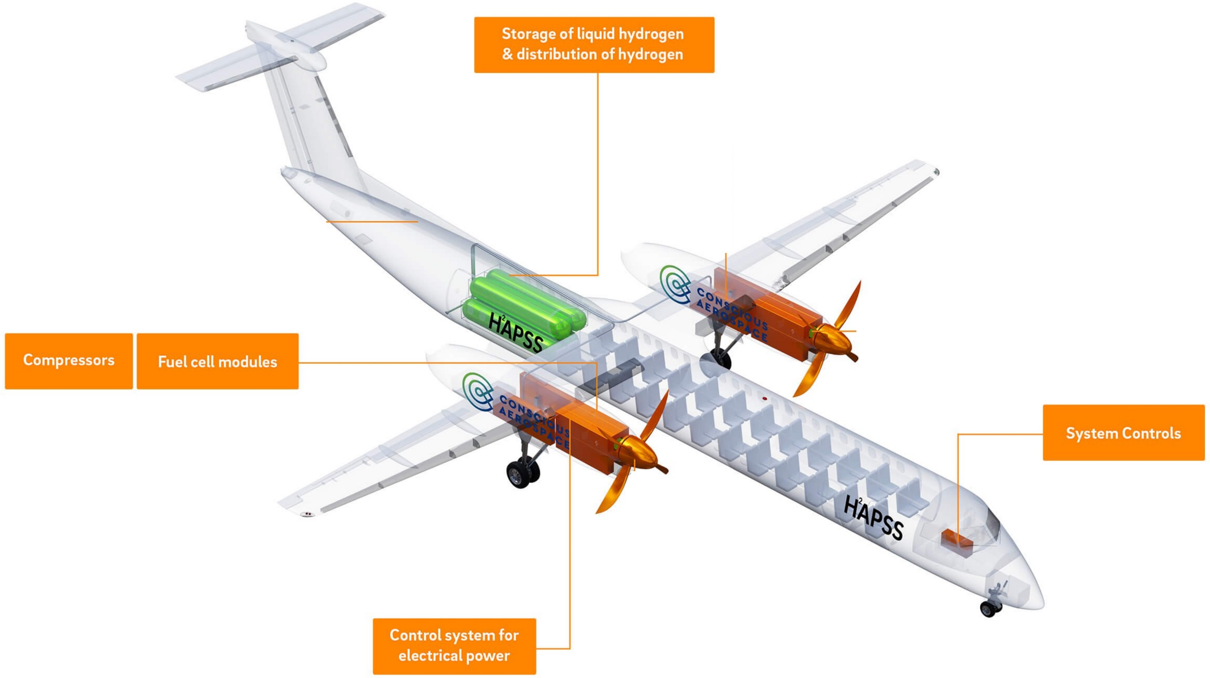
- Universal Hydrogen used a modified ATR-72 regional airliner to turn a turboprop-powered plane into a hydrogen one
- Universal Hydrogen is developing a jet engine that can burn hydrogen for longer-haul aircraft

ZEROAVIA

- ZeroAvia used a19-seat aircraft
- ZeroAvia has raised over $140 million in funding from investors

Research

- A Dutch association is retrofitting passenger propeller planes
- Honeywell International Inc announced new technology to produce lower-carbon aviation fuel
- Hydrogen Aircraft Powertrain and Storage System (HAPPS) was stared to build hydrogen systems that retrofit existing regional aircrafts
- H2FLY is preparing fuel cell aircrafts to integrate liquid hydrogen tanks



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References

[1] Office of Energy Efficiency & Renewable Energy
[2] Toshiba
[3] Renewable Technology
[4] Research Gate
[5] Office of Energy Efficiency & Renewable Energy
[6] Cummins
[7] The Proceedings of the National Academy of Sciences
[8] National Weather Service
[9] FuelCellsWorks
[10] Office of Energy Efficiency & Renewable Energy
[11] FuelCellsWorks
[12] GreenBiz
[13] N/A
[14] MIT News
[15] ITP Interpipe
[16] ACS Publications
[17] Science Direct
[18] N/A
[19] TransportUP
[20] Tesla
[21] HyperloopTT
[22] AZO materials
[23] The Conversation
[24] Leeham News and Analysis
[25] Tank Storage Magazine
[26] CNN Travel
[27] Iea
[28] Department of Energy
[29] Simple Flying
[30] Business Airport international
[31] GreenSpec
[32] Aerospace Technology Institute
[33] Baldwin Aviation
[34] Hydrogen Tools
[35] The Economic Times
[36] MrWatt
[37] History
[38] Forbes
[39] Slidesgo
[40] Abaco Systems
[41] N/A
[42] Bdl.aero
[43] Aviation Environment Federation
[44] Airbus
[45] Airbus
[46] Sustainable Skies
[47]TechCrunch
[48]Conscious Aerospace
[49] Honeywell Aerospace


H2 HYDROGEN POWER
ZERO
emission
H2
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