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Hydrogen Infrastructure at Airports

- Requirements to support the future operation of hydrogen powered aircraft

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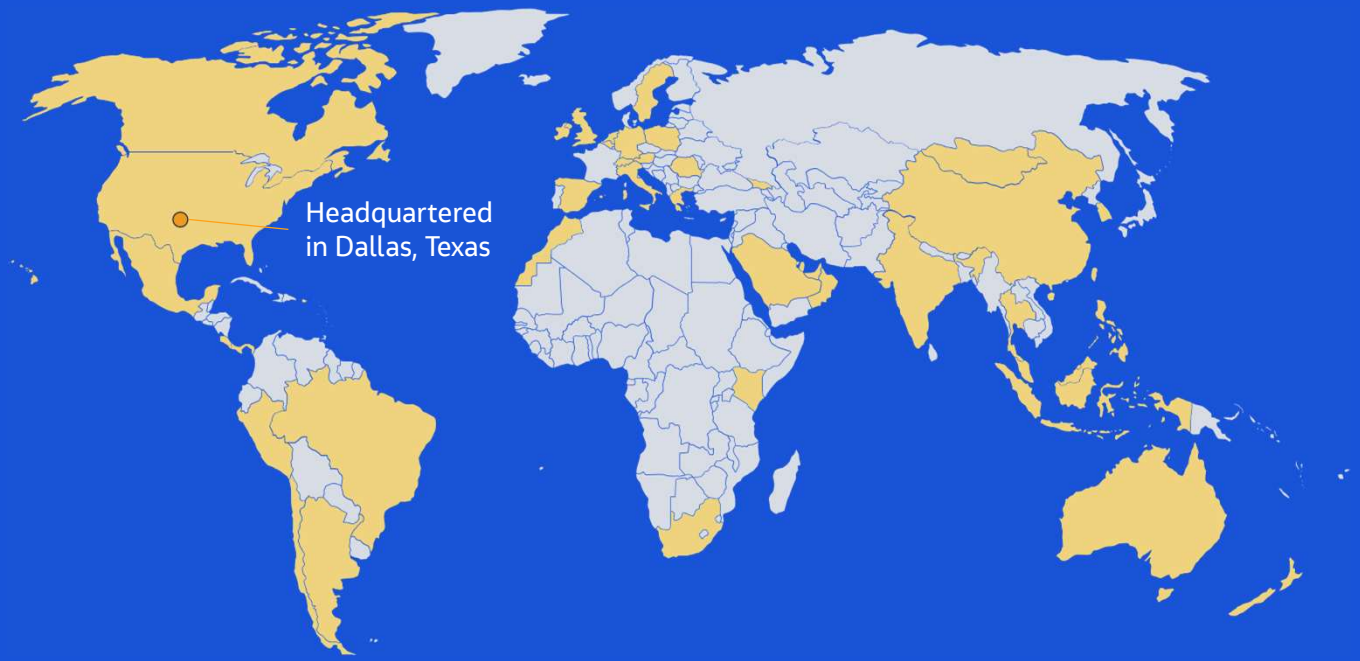
- Ports & Maritime
- Energy & Power
- Aerospace
- Automotive
- Aviation
- Pulp & Paper
- Transportation
- Industrial
- Advanced Facilities
- Consumer Goods & Manufacturing
- Water & Wastewater
- Defense
- Telecommunication
- Nuclear

Global Locations



Jacobs at a Glance

1947
Founded by
Dr. Joseph Jacobs

40+
Countries

$14B
Annual Revenue (USD)

58K+
Employees Worldwide

The FlyZero Project

- UK government funded project
- Objective – to create a pathway to zero-carbon emission commercial aviation
- Compared zero-carbon emission energy sources:
  - batteries,
  - hydrogen, and
  - ammonia
- Concluded that **liquid hydrogen** is the most viable fuel for powering large aircraft
- Public reports can be accessed at:

https://www.ati.org.uk/flyzero-reports/

FlyZero Concept Aircraft

Midsize – 280 seats

Narrowbody – 180 seats

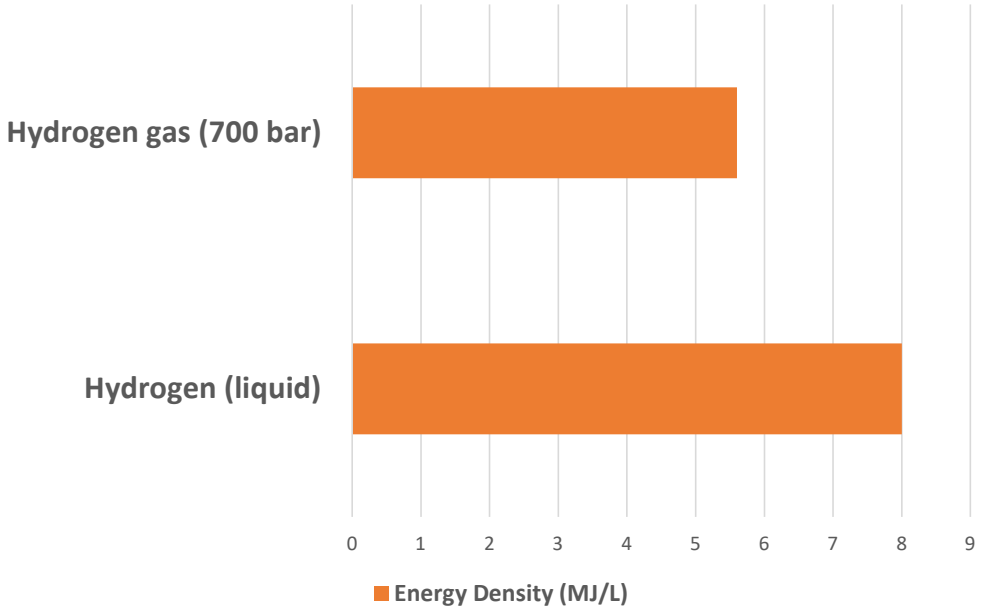
Regional – 75 seats

Midsize range is 5,200nm - one stop to any destination

Facts about Hydrogen

- Safety risks are different to kerosene
- Used in a **fuel cell** to generate electricity
  - Only water emitted
- Burnt in a **gas turbine** to generate thrust
  - Only water and NOx generated
- Hydrogen is a gas at ambient temperature
- Liquid at **-253°C**
- **1:850** volumetric ratio when liquid hydrogen vaporizes to ambient temperature
  - Generates risk of explosion
  - Can be used to move liquid hydrogen through pressure differential control

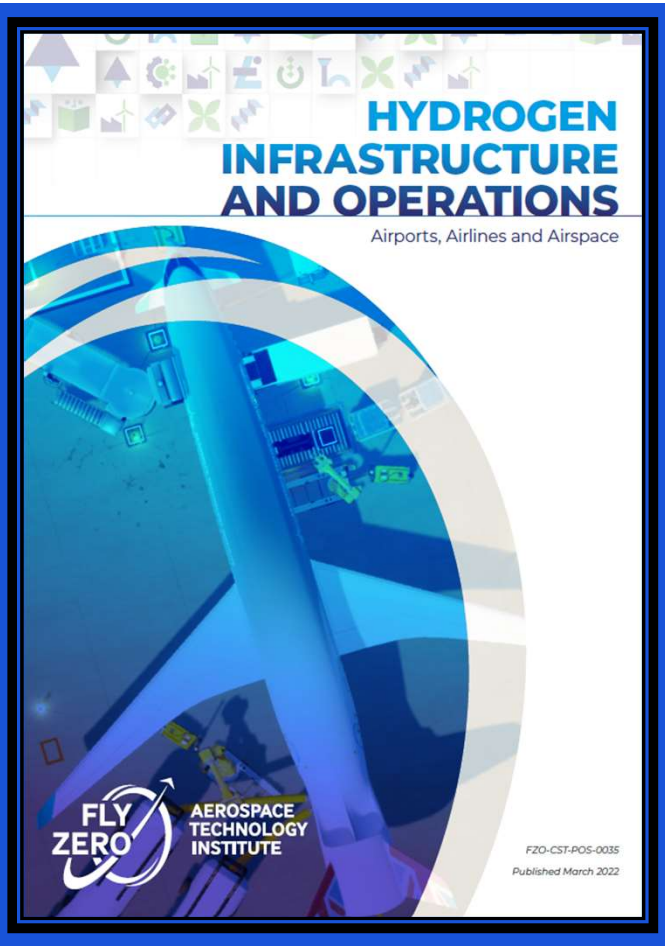
Liquid Hydrogen vs. Compressed Gas Hydrogen



- Liquid hydrogen's energy density is 43% greater than hydrogen gas compressed to 700 bar
- Also, the weight of liquid hydrogen storage tanks are significantly less than 700 bar storage tanks
- Mass fraction of hydrogen + tank:
  - Liquid hydrogen = 30%
  - Compressed gas = 10%

Studying Hydrogen Infrastructure at Airports

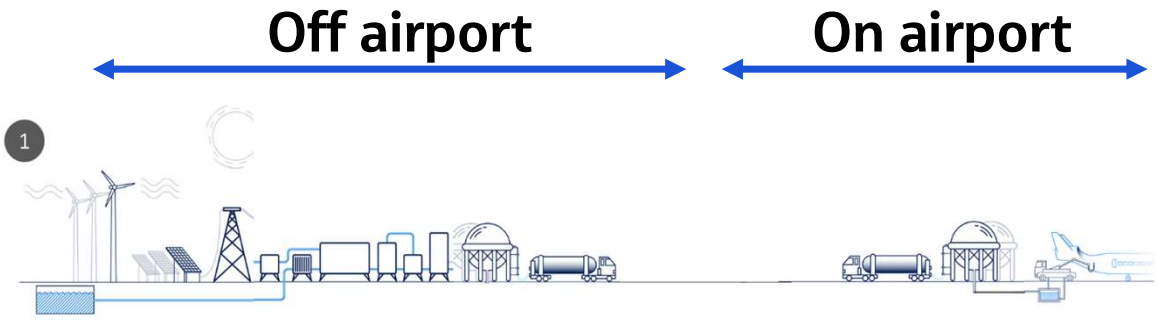
- July 2021 - Jacobs engaged by FlyZero to study the infrastructure required at airports to support the future operation of hydrogen powered aircraft
- Scope – five airports in the UK with sizes that ranged from 7.5 MPPA to 110 MPPA (2035 forecast)
- Jacobs would like to acknowledge our clients for this study:
  - Chris Pickard
  - Helen Leadbetter
  - Alejandro Block



Three Hydrogen Supply Scenarios

Three Hydrogen Supply Scenarios

- **Scenario 1**
  - Truck delivery of LH_2



Example of Scenario 1

- Launch Complex 39B at Cape Canaveral, Florida
- 3.5 million litre storage tank
- 40,000 litre delivery truck
- The tank is a vacuum jacket double wall construction

Photo credit: Linde

Three Hydrogen Supply Scenarios

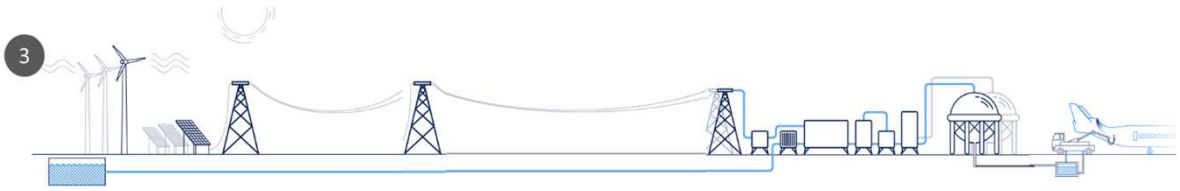
Off airport | On airport

- **Scenario 2**
  - Gas pipeline delivery of LH_2

Three Hydrogen Supply Scenarios

Off airport ⟷ **On airport**

- **Scenario 3**
  - Production of hydrogen gas on-site



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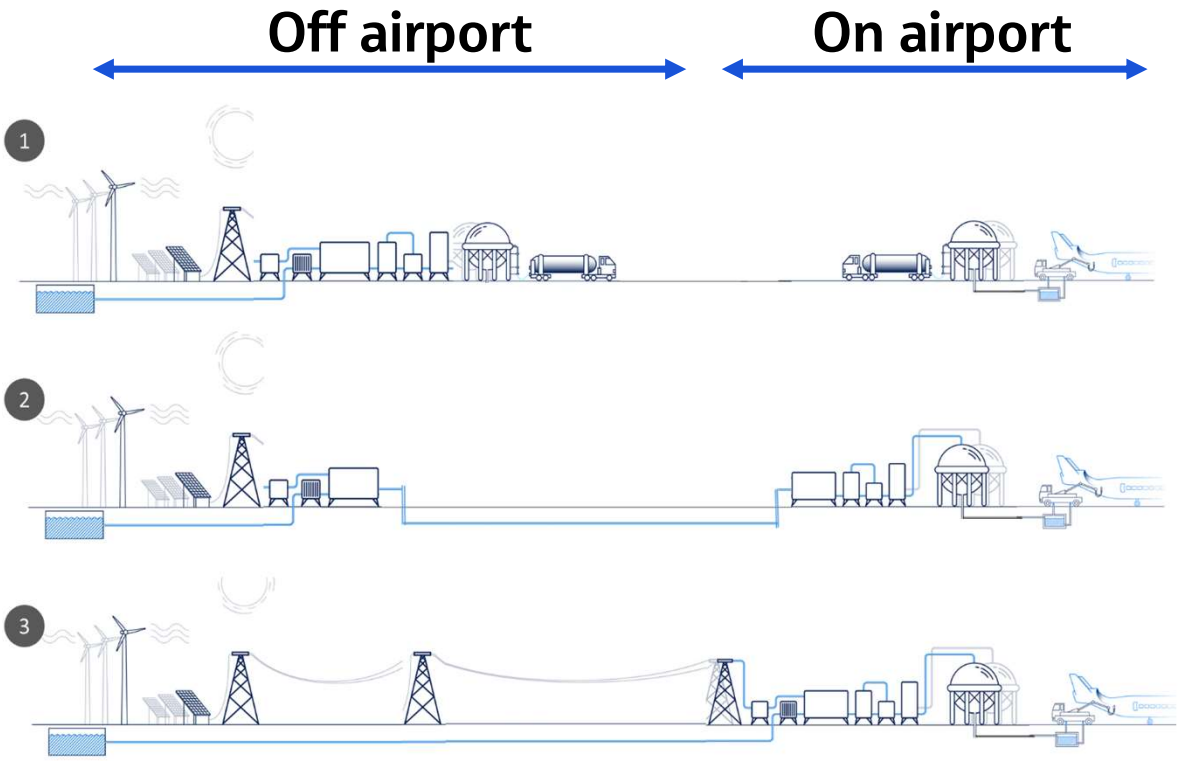
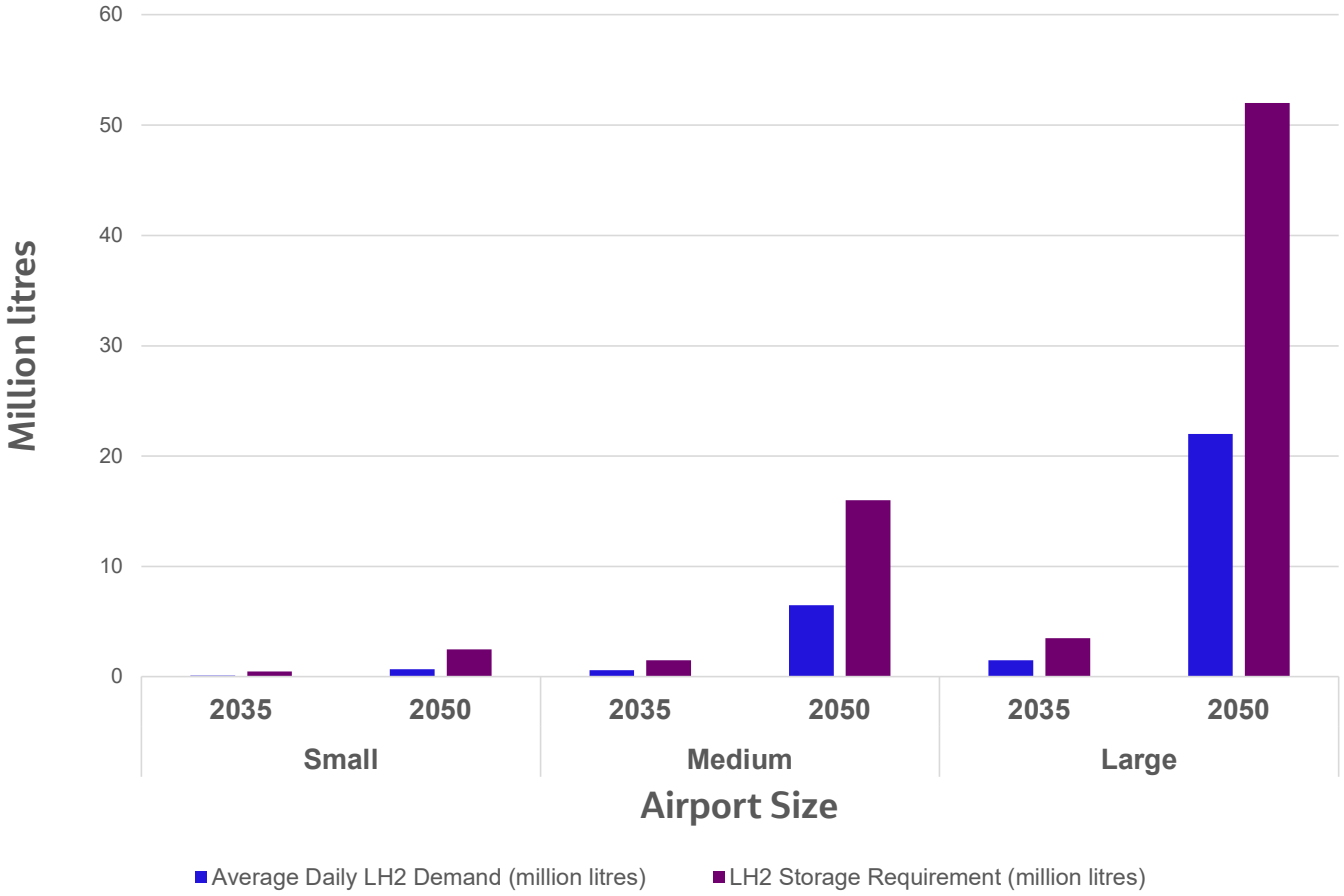


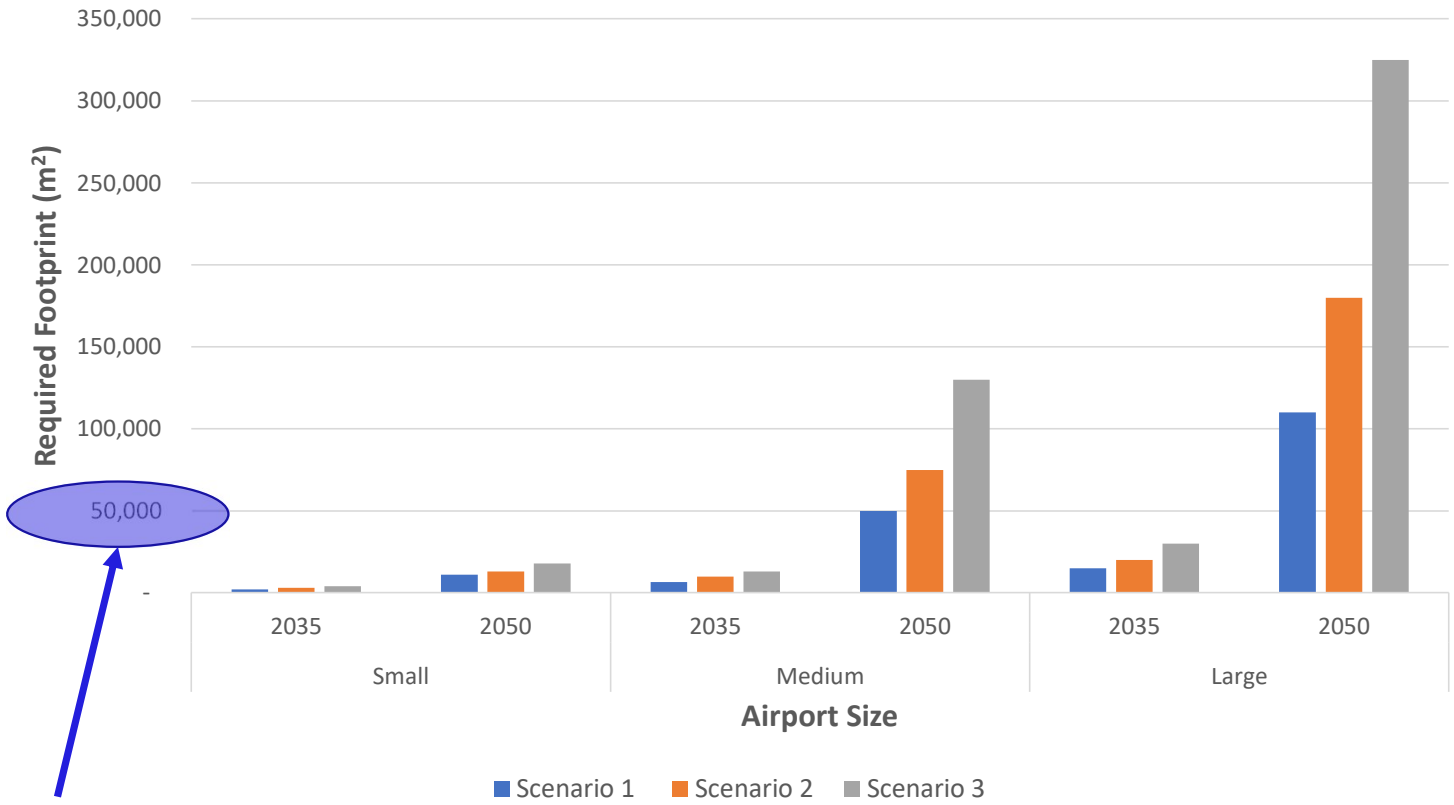
Demand and Storage of LH2



Required storage is based on the peak daily demand + two days of average demand

The Footprint Challenge

- Can be built incrementally
- Can be split over multiple locations
- Optimum location is a balance between best external delivery option and best internal distribution option



Size of the Allianz stadium, Munich

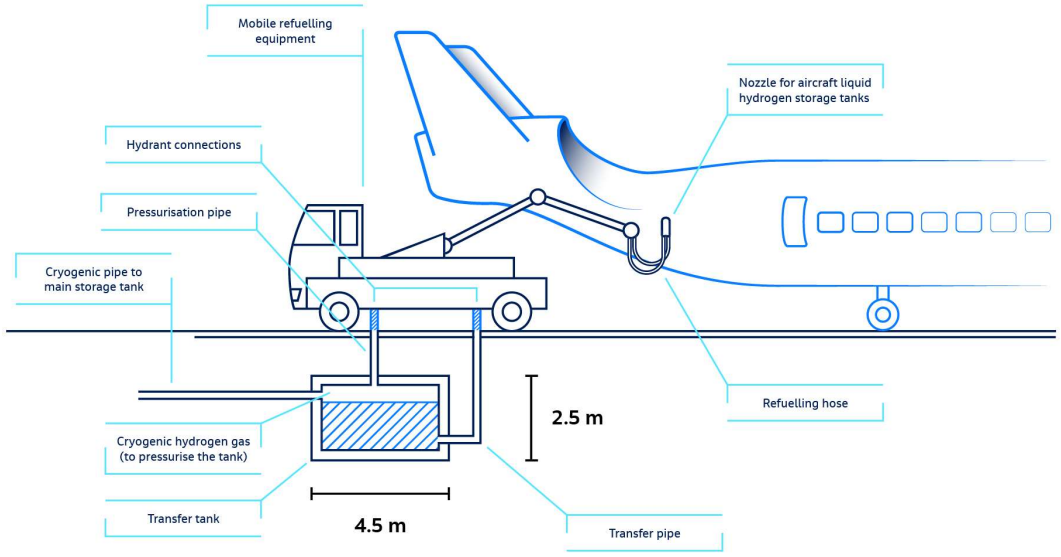
Recommended Roll-out of Supply Scenarios

Airport Size	2035	2040	2045	2050
Large	Scenario 1 or 2	Scenario 2	Scenario 2	Scenario 2
Medium	Scenario 1	Scenario 2	Scenario 2	Scenario 2
Small	Scenario 1	Scenario 1	Scenario 1	Scenario 1

- Scenario 1 is preferred due to smaller footprint and lower on-site infrastructure cost
- However, as demand volume grows delivery by truck to the airport becomes impractical and expensive
- Scenario 3 is not generally preferred due to the large infrastructure costs of bringing electricity to the airport
- Bringing hydrogen to the airport as a gas in a pipeline is the preferred long-term option for Medium and Large airports

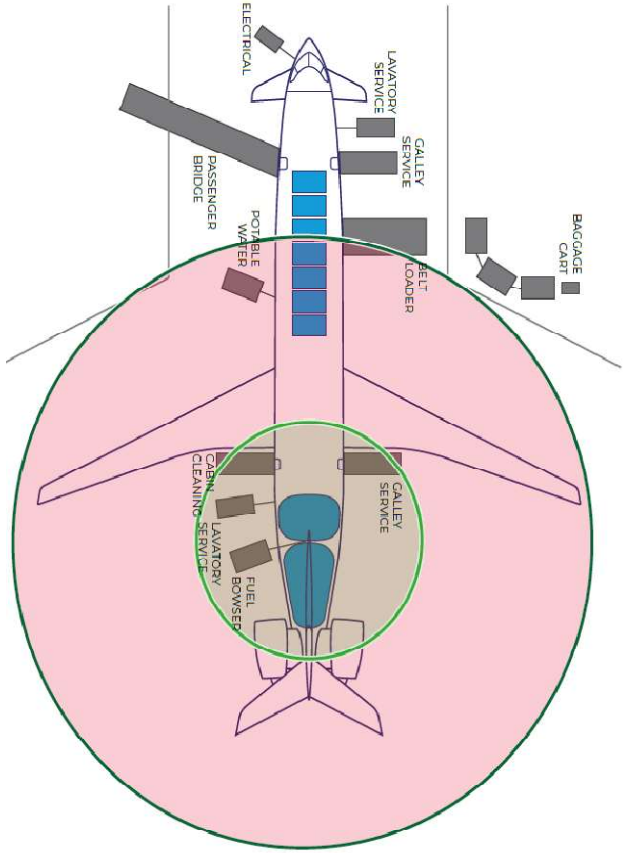
Distribution and Refuelling Options

- Distribution to the refuelling stand can be by Bowser or Hydrant
- Bowsers are preferred initially due to their lower infrastructure costs
- However, as demand volume grows operating Bowsers becomes impractical
- For Medium and Large airports, in the long-term a Hydrant system is preferred
- However, the technical challenge is to limit 'boil-off' during the distribution and refuelling:
  - requires vacuum jacket or solid insulation pipes
  - distribution through pressure differential control



Refuelling Options

- Refuelling can take place at the terminal stand
- Transfer will take place using the pressure differential created as liquid hydrogen is vaporized
- Fill times could be less than 30 mins for the Midsize aircraft
- Exclusion zone of 20m during connection/disconnection and 8m during the refuelling operation
- Safety risks require detailed analysis



Conclusion

- Hydrogen-powered, zero-carbon flights are a step closer as a result of FlyZero's study
- To become a reality, airports and the aviation fueling sector need to evolve to meet the needs of hydrogen-fueled planes
- Can start with hydrogen transported by trucks and bowsers, but as demand grows more on-site investment will be required
- Can be achieved through the integration of hydrogen infrastructure into airport masterplans and capital planning

Thank You

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