Case Study considering Liquid Hydrogen for The Northern Netherlands

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HyEnergy:
Real World Hydrogen Understanding

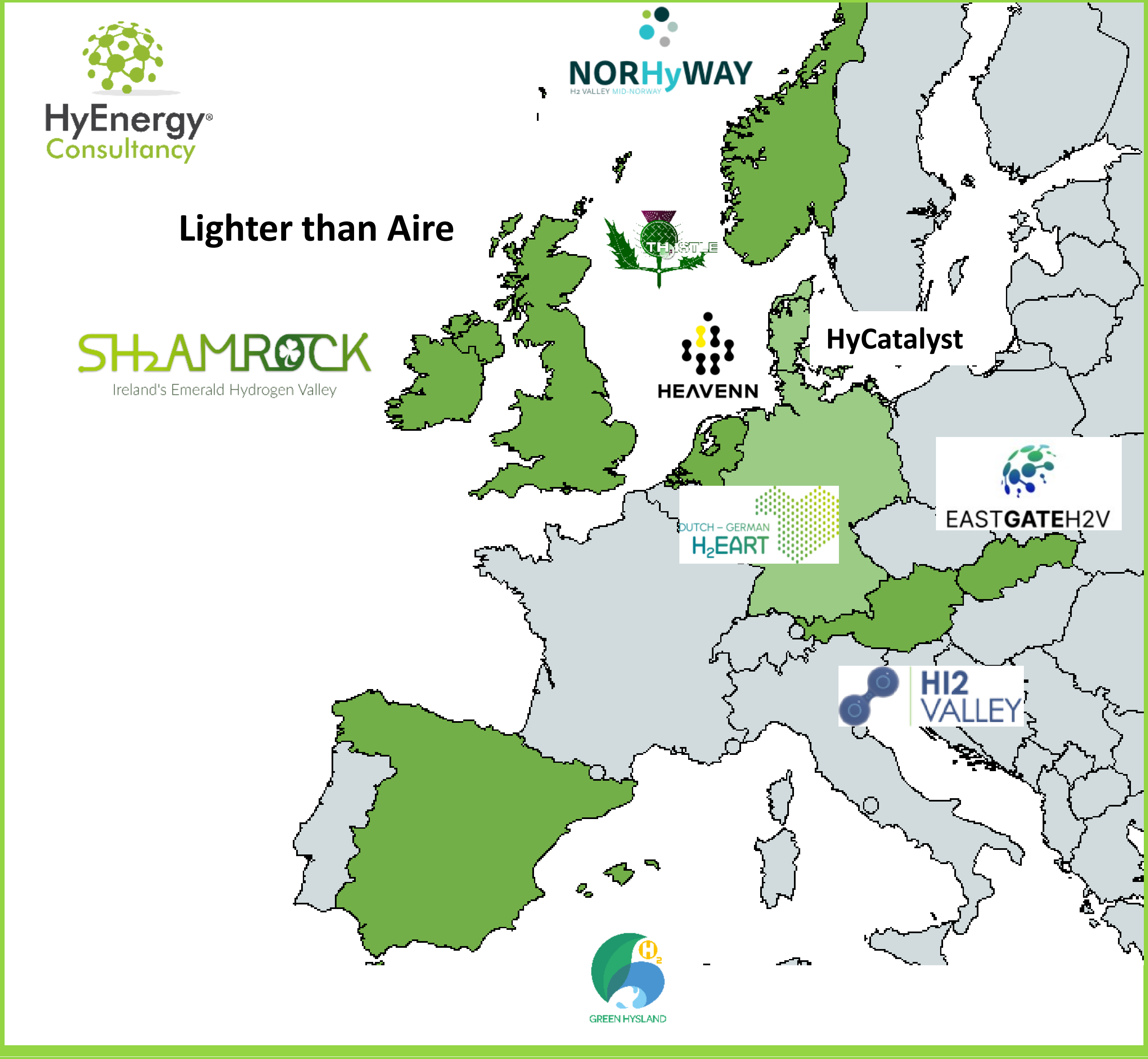
50	€180m+	60+
Key Customers	Public Funding and Investment	Years of H2 Sector Experience

Trusted advisors and knowledge specialists to the hydrogen sector for the for nearly 10 years

Supporting sector organisation in business model and sale channel development and management

Delivering project development, technology expertise, market insight, investment due diligence, training and funded proposal preparation

Customers range across from all forms of industry, regional public sector organisations, research institutions, national governments etc.



HyEnergy’s Hydrogen Valleys

- 8 CHP Funded Hydrogen Valley Projects
- 2 on the 2025 reserve funding list
- Most conceived and written with HyEnergy
- HyEnergy will also participate if requested
- Looking for next year’s projects now…

HyEnergy Consultancy

Some of our partners/customers…

HYGEAR
NOBIAN A Nouryon company
New Energy Coalition
enagas
bytesnet DATACENTEROPLOSSINGEN
EHA EUROPEAN HYDROGEN ASSOCIATION
PEP Pure Energy Professionals
OLLSCOIL NA GAILLIMHE UNIVERSITY OF GALWAY
Logan Energy hydrogen technologies
CANFORD RENEWABLE ENERGY
UKHFCA
IMI
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Energy Hydrogen Alliance www.h2euro.org
hydrexia
NPRC EST. 1935
HyEnergy TransStore
Hinicio
sunfire
GRONINGEN SEAPORTS
DCU Ollscoil Chathair Bhaile Átha Cliath Dublin City University
Systeng CONSULTING
energia group
Green Planet today for tomorrow
H2Tec BV
PLUG POWER
AIR PRODUCTS
HySA
SMART HYDROGEN CONSULTING
174 POWER GLOBAL
hydrogenious TECHNOLOGIES
EnerCy
elogen
EMEC THE EUROPEAN MARINE ENERGY CENTRE LTD
Hydrogen Ireland

Funding

Hy2Market is a collaborative project involving 38 partners from 10 countries across Europe, who have been brought together to investigate and develop a more mature hydrogen value chain across Europe on all market levels. Hy2Market is an EU I3 funded project.

HEAVENN is a large-scale programme of projects bringing together core value chain elements: production, distribution, storage and local end-use of hydrogen into a fully-integrated and functioning “Hydrogen Valley”, that can serve as a blueprint for replication across Europe and beyond. HEAVENN is an EU Clean Hydrogen Partnership funded project.

The province of Groningen as a municipality are fully behind the development of a hydrogen ecosystem in the northern Netherlands, keen to explore avenues to reduce greenhouse gas emissions in the region and develop greater fuel security.

A Short History of Liquid Hydrogen

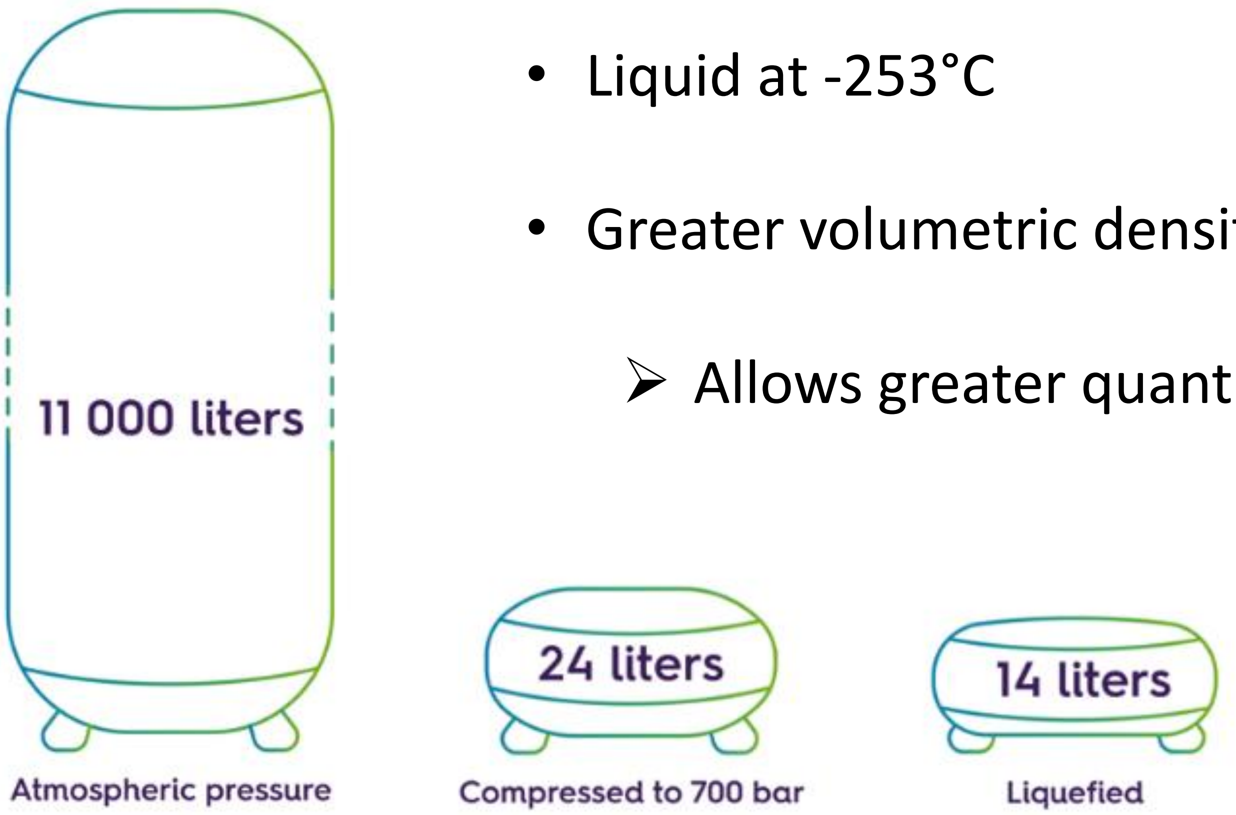
- In use since 1950s, mostly notably as a fuel for NASA's space programmes

- Large liquid H2 plants built to provide fuel also provided commercial supply of industrial hydrogen gas in North America

- Liquid hydrogen the dominant form of hydrogen in North America, but not in Europe for 2 reasons:
    1. Geography (longer distribution distances)
    2. Scale (larger delivery quantities)

***Apollo* 11 Saturn V liftoff, July 16, 1969**
Photo by Kipp Teague, Courtesy Apollo 11 Image Library (KSC-69P-597)

Liquid Hydrogen Properties

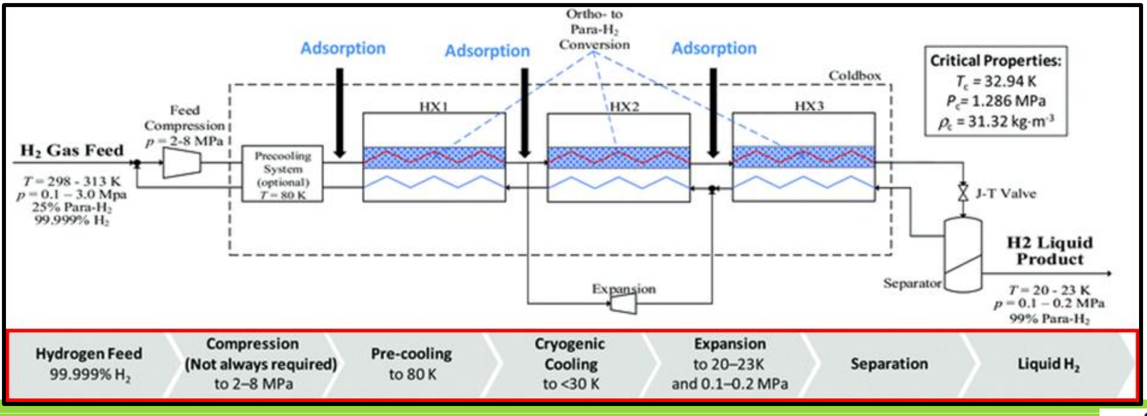


- Liquid at -253°C
- Greater volumetric density than gaseous H_2
  - ➢ Allows greater quantities of storage and distribution

Liquefaction Process

An AL deployed hydrogen liquefier and storage

Chinese company Fullcryo's hydrogen liquifier



State of The Market

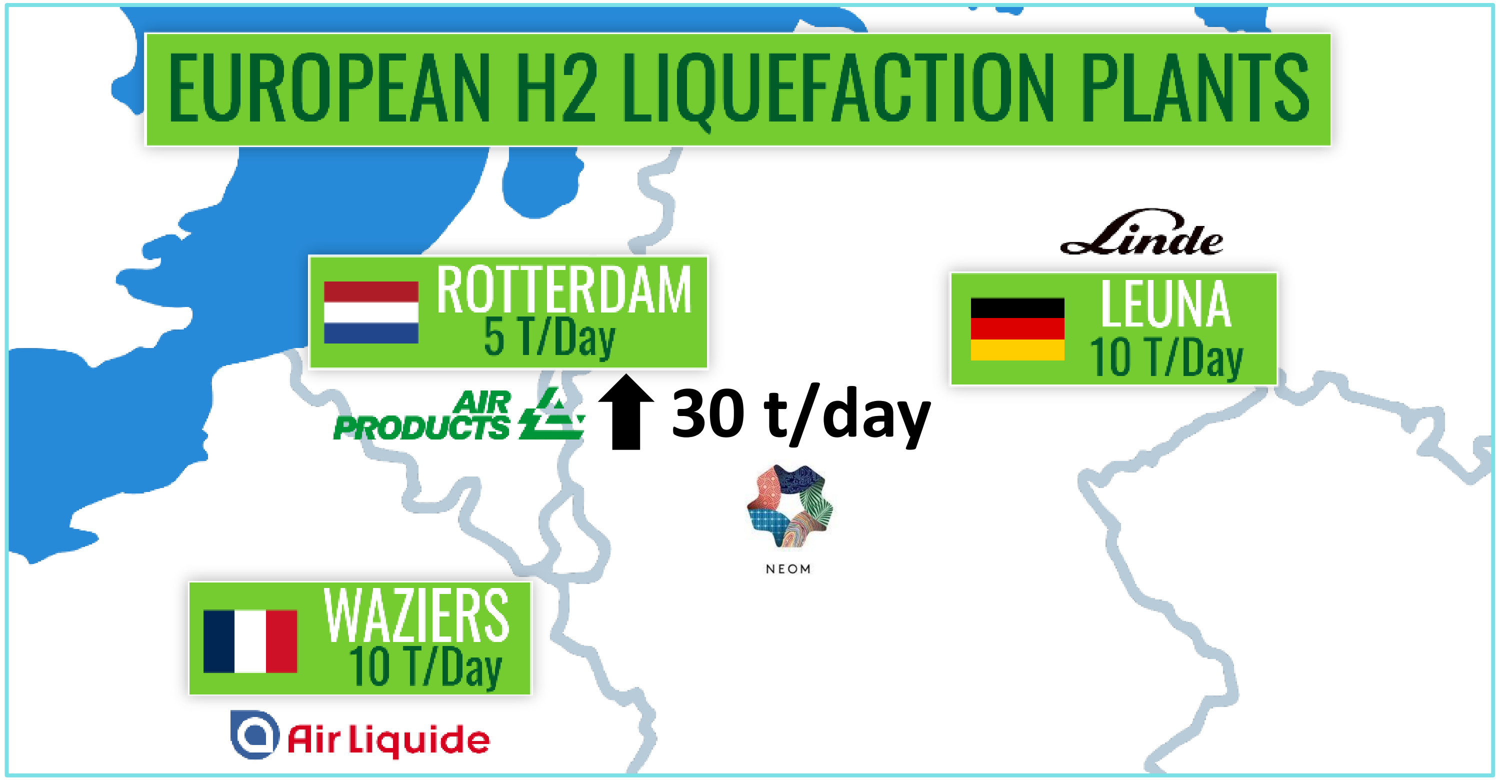
- **Small existing market**
  - Total global hydrogen demand is 97 Mt/a
  - Liquid H_2 is capacity globally is ~200kt or <0.2% of global market (mostly in North America)

- **Co-located approach:** Liquefaction plants range in size (0.25 – 80 tpd) frequently coupled to existing large-scale gaseous hydrogen production/end-uses

- **High energy intensity of liquefaction**
  - 10 – 20 kWh/kg, but 6 kWh/kg possible

- **International distribution**
  - The Suiso Frontier prototype can carry <100t and has completed a shipment from Australia to Japan
  - Commercial phase aiming for 128 times greater carrying capacity

Liquid H2 Investments in Europe



N.B. Further investment in development in Norway for local maritime use and intra-regional energy transfer
Expected to be c. 30tpd

New Applications Coming

Existing market

- Global H2 demand is 97 Mt/a
- LH_2 is capacity globally is ~200kt
- <0.2% of global market (mostly US)

New Demand

- Aviation
- Maritime
- Heavy Duty Vehicles
- Regional Energy Transfer
- Superconductor Cooling

NASA's 370t liquid hydrogen tank (above), space shuttle (R)

MF Hydra ferry in Norway

Airbus's hydrogen passenger aircraft concepts

Diamler liquid H2 truck

Barriers and Future Developments

Previous large-scale liquid hydrogen projects have been shelved due to a lack of demand, blaming insufficient policy support and incentives (e.g. Aurora – Equinor and Air Liquide project for maritime)

This may be changing with the introduction of legislation at EU level in recent years mandating the use of clean fuels with specific targets:

- **RED III**
- **FuelEU Maritime**
- **ReFuelEU Aviation**

Lack of knowhow and technical expertise outside of North America

Liquefaction capacity and demand must scale together

Liquid hydrogen can take **learnings and skills from LNG** industry scale-up

Liquified natural gas (LNG) tanker ship

Expected Progress

Increased production and handling New Rotterdam site ~30tpd in construction, others planned (Norway) and sites worldwide expect to expand capacities to between 100 – 300 tpd

Import routes from medium-distance locations, or into direct end-use locations expected to utilise LHY (e.g. Morocco)

Technological advancements Progression across liquefaction value chain

- energy efficiency (~6kWh/kg), road-tanker capacity (3.9t), storage vessel sizes, integrated cryo-storage and compression

Demand increases arise from scaling existing industrial end-uses, aviation, maritime (inc. inland shipping) and higher capacity mobility hubs

Liquid H_2 in Delfzijl – a Northern Netherlands Case Study

Netherlands has **existing knowledge and expertise** with liquid hydrogen

Chemical cluster at Delfzijl with existing demand for hydrogen

Connections to port at Eemshaven for

- access to offshore renewable energy
- potential for hydrogen import

Number of other **potential end-users** in region:

- AFIR refuelling stations
- Groningen Airport Eelde and others
- Maritime and inland waterway vessels

Case Study Context/Demand Assumptions

Liquefaction facility of 30tpd located in Delfzijl Chemical Cluster

- Supplied by H_2 produced from offshore wind

Regional Airport (ie Groningen) – 50km from Delfzijl, 14tpd demand est. to realise 10% tot. fuel switch

- Liq H_2 aircraft operate over short-to-medium distances
- Existing links to locations such as Copenhagen and Tallinn, Estonia (EnableH2)

Refuelling Stations – 17 AFI locations in 150km radius of Delzijl, some well positioned to be supported by existing supply locations, 5-10tpd demand est. to be supported by Delfzijl site

Maritime – ferries and inland waterways considering LHY (5-10tpd)

- Inland Water Way connections at Delfzijl provide significant demand pot.
- 1000km/day of sailings from Eemshaven area (e.g. Groningen Seaports) at peak

Cost Analysis

Cost	Expected (€ Millions)	Low (€ Millions)	High (€ Millions)
CAPEX			
Facility Cost	€ 127.00	€ 114.30	€ 139.70
Storage Cost	€ 27.00	€ 18.00	€ 36.00
Trailers (N. 10)	€ 10.00	€ 7.50	€ 12.50
Total	**€ 164.00**	**€ 139.80**	**€ 188.20**

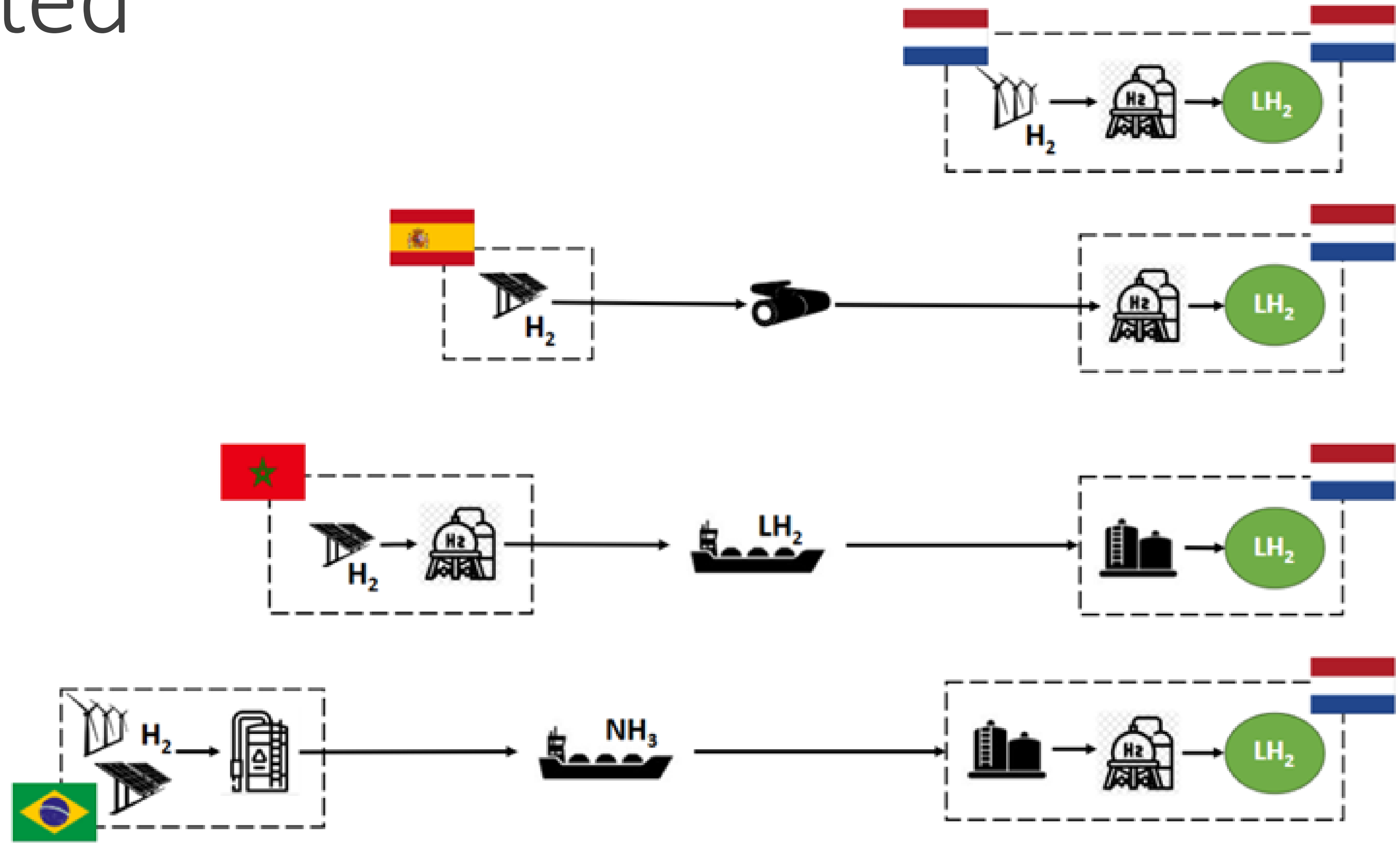
Cost	Expected (€ Millions/year)	Low (€ Millions/year)	High (€ Millions/year)
OPEX			
Maintenance	€ 6.56	€ 5.59	€ 7.53
Energy Cost	€ 4.08	€ 2.26	€ 6.44
Total	**€ 10.64**	**€ 7.85**	**€ 13.97**

	Expected (€/kg)	Low (€/kg)	High (€/kg)
Total Cost of Liquefaction	€ 2.22	€ 1.68	€ 2.86

Distribution via road vehicle in trailers (€/kgh2/km)			
	Expected (€/kg)	Low (€/kg)	High (€/kg)
LH_2 Tankers	€ 0.0050	€ 0.0025	€ 0.0075

HyEnergy analysis based on a 30tpd liquefier

Regional H_2 Import Options Investigated



Resulting Liquid H_2 Cost

Source: Gen2 Energy

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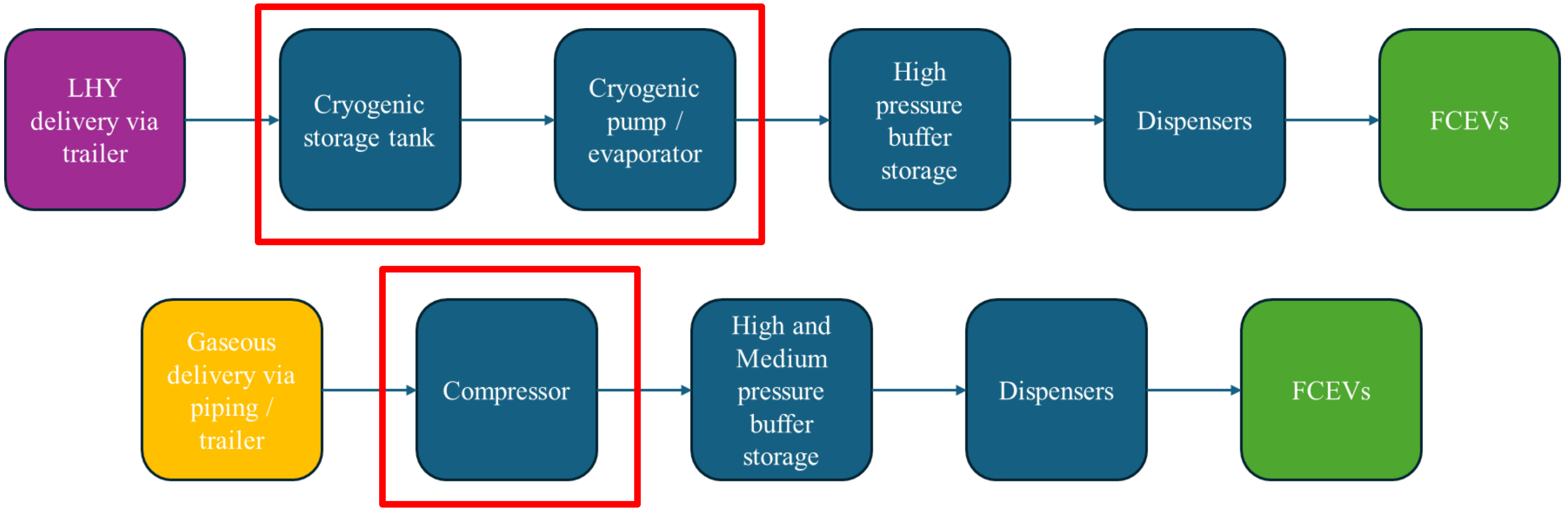
Location	Distribution Method	H_2 Production Cost(€/kg)	H_2 Distribution Cost(€/kg)	Liquefaction Cost (€/kg)	Total Cost of Liquid Hydrogen (€/kg)
Netherlands	Onsite production	3.25 - 4.55	[redacted]	1.55-3.05	4.80 - 7.60
Spain	Pipeline	3.00 - 3.20	0.25 - 0.50	1.55-3.05	4.80 - 6.75
Morocco	LH2 Ships	2.50 - 2.75	2.25 - 2.50	[redacted]	4.75 - 5.25
Brazil	NH3 Ships	1.60 - 2.30	2.00 - 2.25	1.55-3.05	5.15 - 7.60

Liquid H_2 for HRS Distribution

***Significant footprint/noise/cost (capital and operational) reduction**



Total Estimated Costs (nameplate dispensing capacity)	On-Site GH_2 Station (700 bar dispensing) (2022$)	LH_2 Station (700 bar dispensing) (2022$)
Capital Cost (2022$) (2TPD)	$11.0 million ($5,500/kg/day	$5.92 million ($2,960/kg/day)
Capital Cost (2022$) (4TPD)	$20.7 million ($5,170/kg/day)	$10.9 million ($2,730/kg/day)

Source: NREL

Conclusions

- Liquid hydrogen represents a **small segment of overall hydrogen market**, but with **significant opportunities**

- **Improvements in technology and technical knowledge and expertise needed**, especially in Europe

- **Further policy measures required** to drive clean fuels adoption (including liquid hydrogen)

- **Opportunity for the Netherlands**, including Delfzijl, to lead on liquid hydrogen **due to legacy infrastructure/industry, skills, geography**

- **Liquid hydrogen for HRS distribution** represents interesting opportunity due to savings on compression requirements = lower footprint, lower cost

Full Report is/will be available at these locations:

https://hy2market.eu/results and https://heavenn.org/downloads

Thanks for your attention

QUESTIONS?

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