Hydrogen's role in Shell's Journey
Liquid Hydrogen in Emerging Large-Scale Markets

DOE Liquid Hydrogen Technologies Workshop

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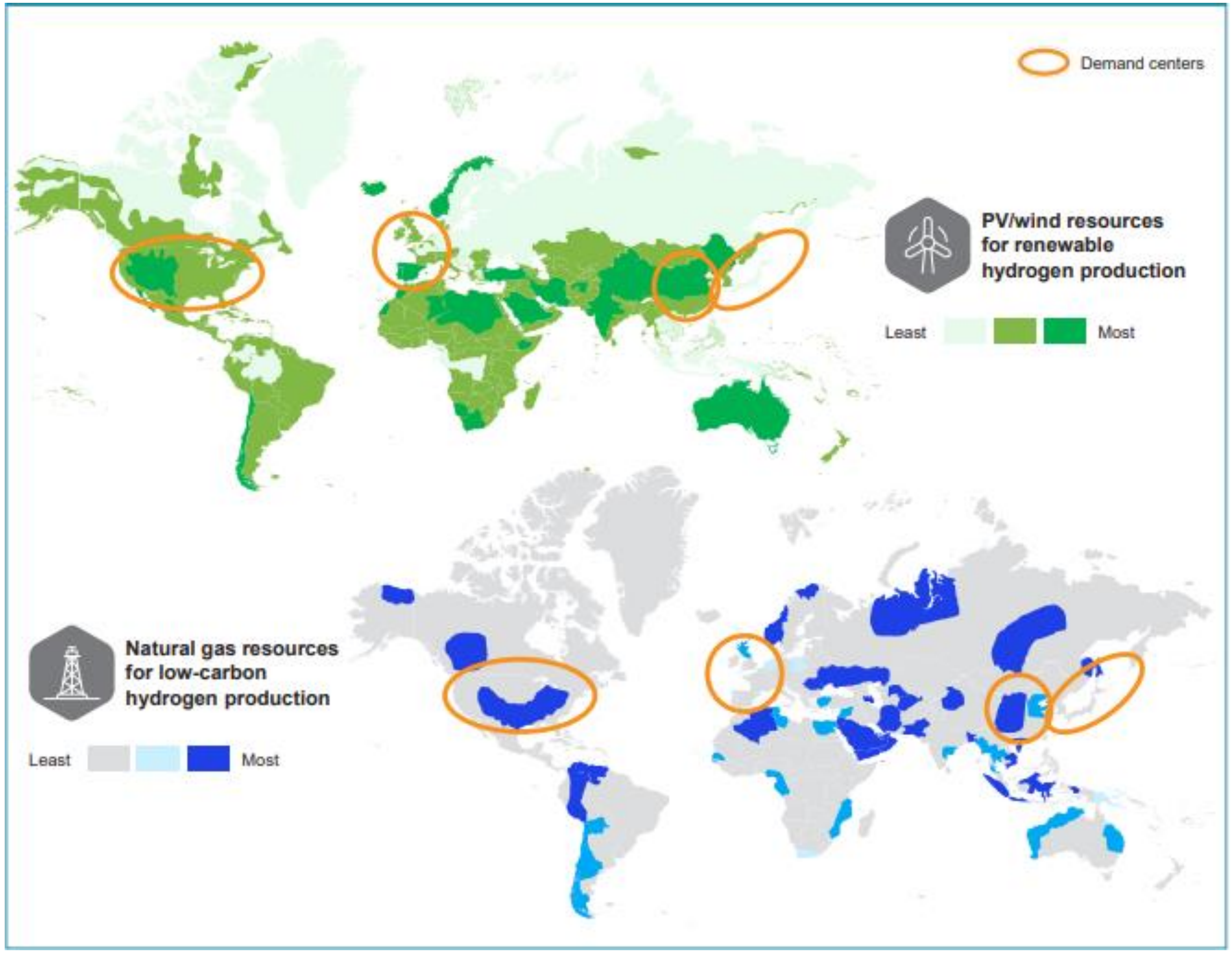
Emergence of International Distribution



- Drive by the cost differential for clean hydrogen production - renewable resources, existing infrastructure, natural gas and carbon storage availability, and land use constraint
- Demand centres such as **EU, Korea, Japan and part of China** may meet H2 demand more effectively by importing rather than local production

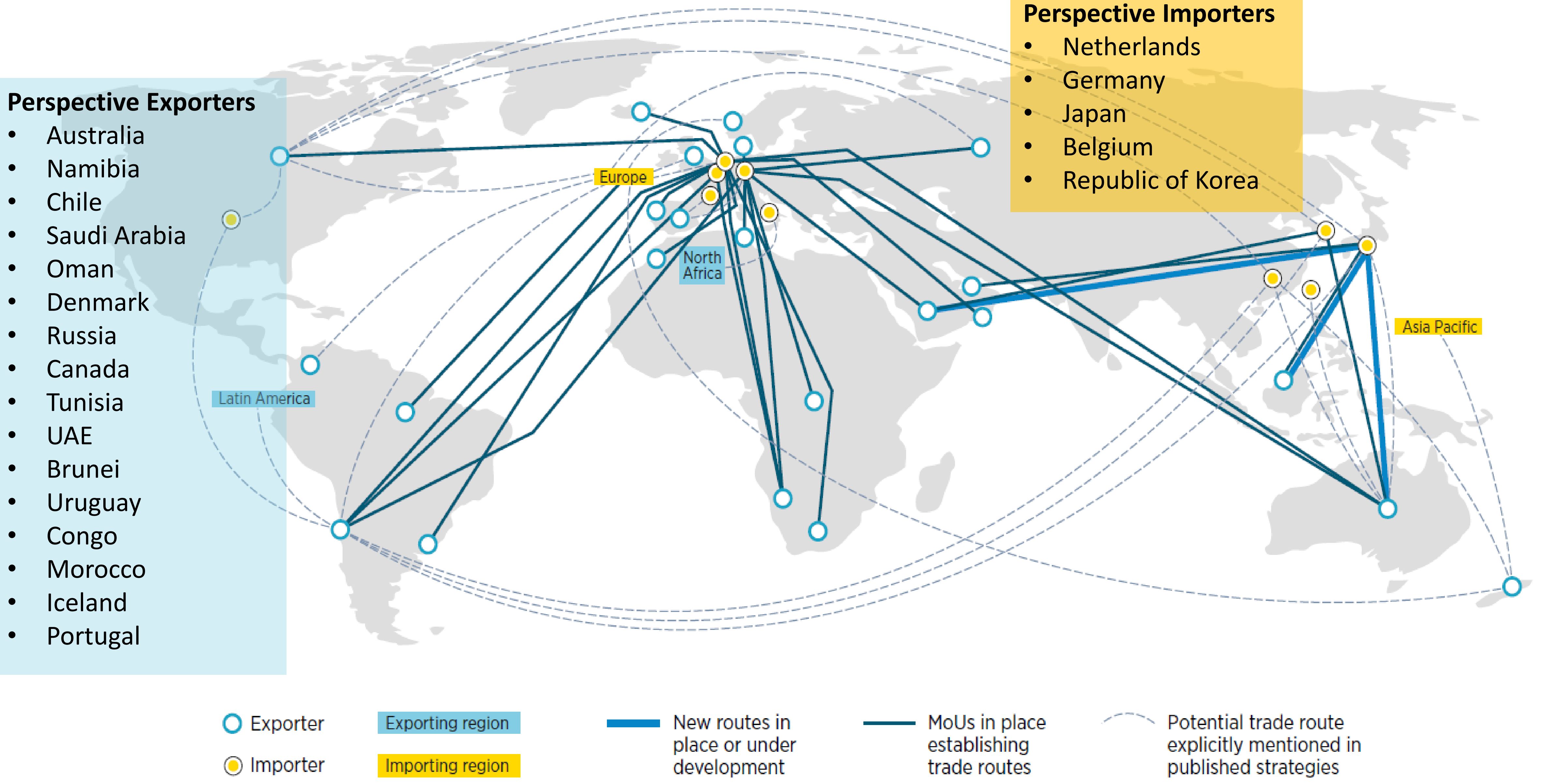
Source: Hydrogen Council 2021

An expanding network of hydrogen trade routes, plans and agreements

IRENA
International Renewable Energy Agency

Perspective Exporters
- Australia
- Namibia
- Chile
- Saudi Arabia
- Oman
- Denmark
- Russia
- Canada
- Tunisia
- UAE
- Brunei
- Uruguay
- Congo
- Morocco
- Iceland
- Portugal

Perspective Importers
- Netherlands
- Germany
- Japan
- Belgium
- Republic of Korea



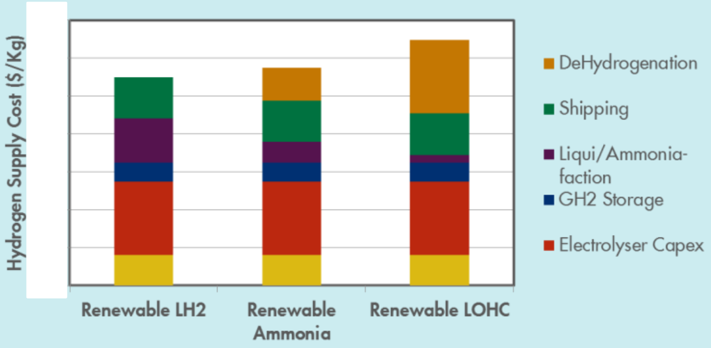
(# bilateral trade agreements and MOUs (November 2021)

Hydrogen Carrier Comparisons – Long Distance Transport

LH2

- ✓ Highest delivery efficiency
- ✓ Versatile product, high purity
- ✓ High cost reduction potential
- ✓ No energy requirement at receiving end

- × Relatively low volumetric energy density
- × 270 degree C uphill battle
- × New technology required
- × New infrastructure required
- × Currently niche market



NH3

- ✓ Can be used as energy carrier directly
- ✓ Existing technology
- ✓ Mild handling conditions
- ✓ Traded commodity

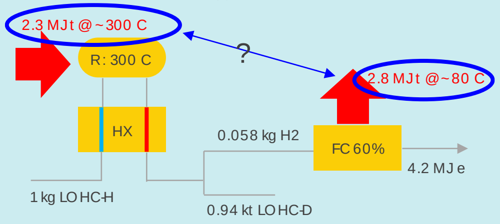
- × Acutely toxic – Not suitable for on board
- × Ammonia cracking not available at scale
- × Cracking delivers low pressure H2, substantial compression required
- × Substantial energy required to release hydrogen.
- × Need ASU to provide nitrogen.

LOHC

- ✓ Existing technology
- ✓ Potentially use existing infrastructure
- ✓ Efficient only if energy recovery is feasible

- × very large volume of carrier (~1 bln$ worth of carrier in 500 tpd supply chain)
- × Very sensitive to contamination
- × Practical dehydrogenation conversion around 90 - 95 %
- × Massive energy demand at receiving end

Dehydrogenation energy balance



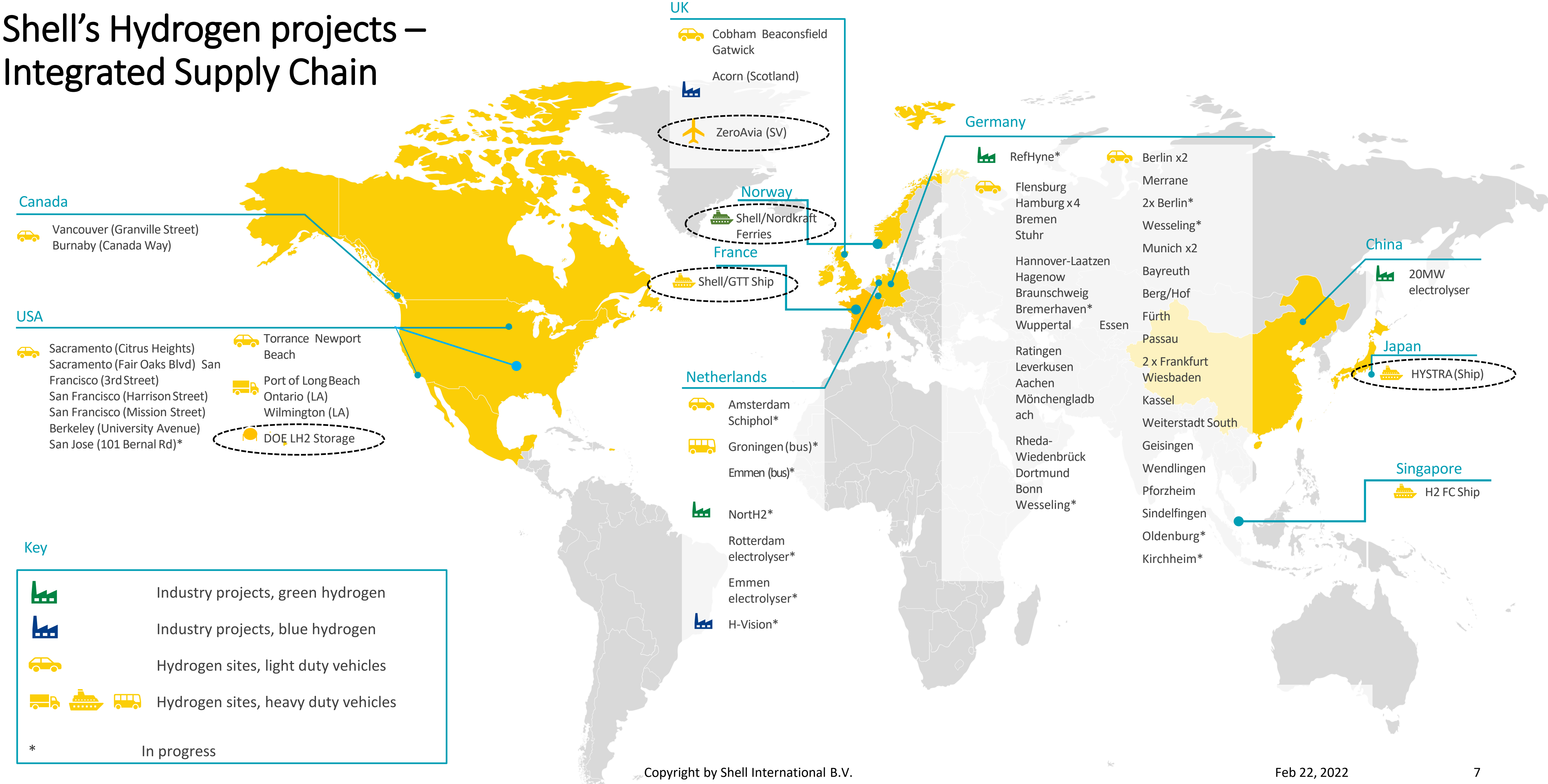
Existing and Emerging Demands for Hydrogen

	Transportation Applications	Chemicals and Industrial Applications	Stationary and Power Generation Applications	Integrated/Hybrid Energy Systems
Existing Growing Demands	• Material-Handling Equipment • Buses • Light-Duty Vehicles	• Oil Refining • Ammonia • Methanol	• Distrubuted Generation: Primary and Backup Power	• Renewable Grid Integration (with storage and other ancillary services)
Emerging Future Demands	• Medium-and Heavy-Duty Vehicles • Rail • Maritime • Aviation • Contruction Equipment	• Steel and Cement Manufacturing • Industrial Heat • Bio/Synthetic Fuels	• Reversible Fuel Cells • Hydrogen Combustion • Long-Duration Energy Storage	• Nuclear/Hydrogen Hybrids • Gas/Coal/Hydrogen Hybrids with CCUS • Hydrogen Blending

Source: DOE Hydrogen Program Plan 2020

- Global LH2 market size was valued at $33.5B in 2019. Expect to reach $50.8B by 2027 – CAGR 5.6%
- Global Hydrogen powered transport market is expected to grow from $2.09B in 2020 to $20.04B in 2025 (CAGR of 58%)
  - North America was the largest region in the Hydrogen Powered transport Market in 2020
  - California in the U.S. committed endows for the development of 100 hydrogen refueling stations to meet its goal of 1.5 million zero-emission vehicles by 2025

Shell's Hydrogen projects – Integrated Supply Chain



Key

- Industry projects, green hydrogen
- Industry projects, blue hydrogen
- Hydrogen sites, light duty vehicles
- Hydrogen sites, heavy duty vehicles
- * In progress

Source: H2 Slide Deck (approved for external use)

First Demonstration of a Commercial Scale Hydrogen Storage Tank Design for International Trade Applications

DOE Award: DE-EE0009387

Objective

- To develop a first-of-its-kind **affordable** large-scale LH2 storage tank for international import and export applications. The project aims to design a large-scale tank that can be used in the range between **20,000 m^3 and 100,000 m^3**.

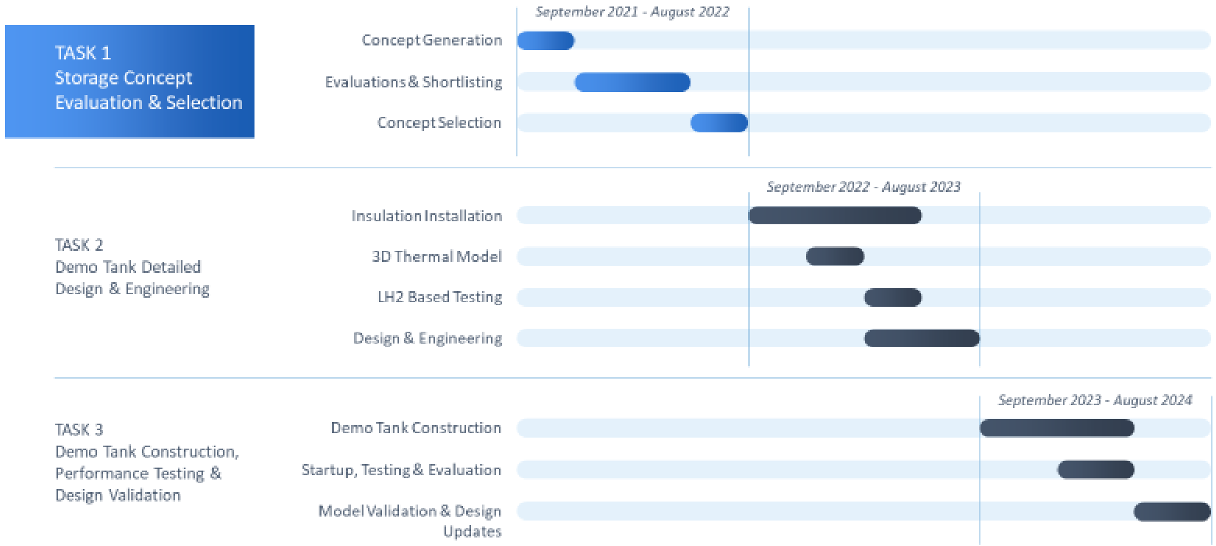
Key Success Criteria for Design

- Boiloff rate of 0.01– 0.1%/day
- CAPEX below 150% of LNG storage cost
- Safety & integrity regulatory bodies

End-of-Project Deliverables (3 years)

- Affordable large-scale (up to 100,000 m^3) LH2 storage tank design
- 3D thermal model for both the demonstration and large-scale LH2 tanks.
- Build an LH2 based cryogenic testing apparatus to measure insulation thermal properties down to 20 K
- Technology demonstration through construction, startup and testing for a small-scale LH2 storage tank

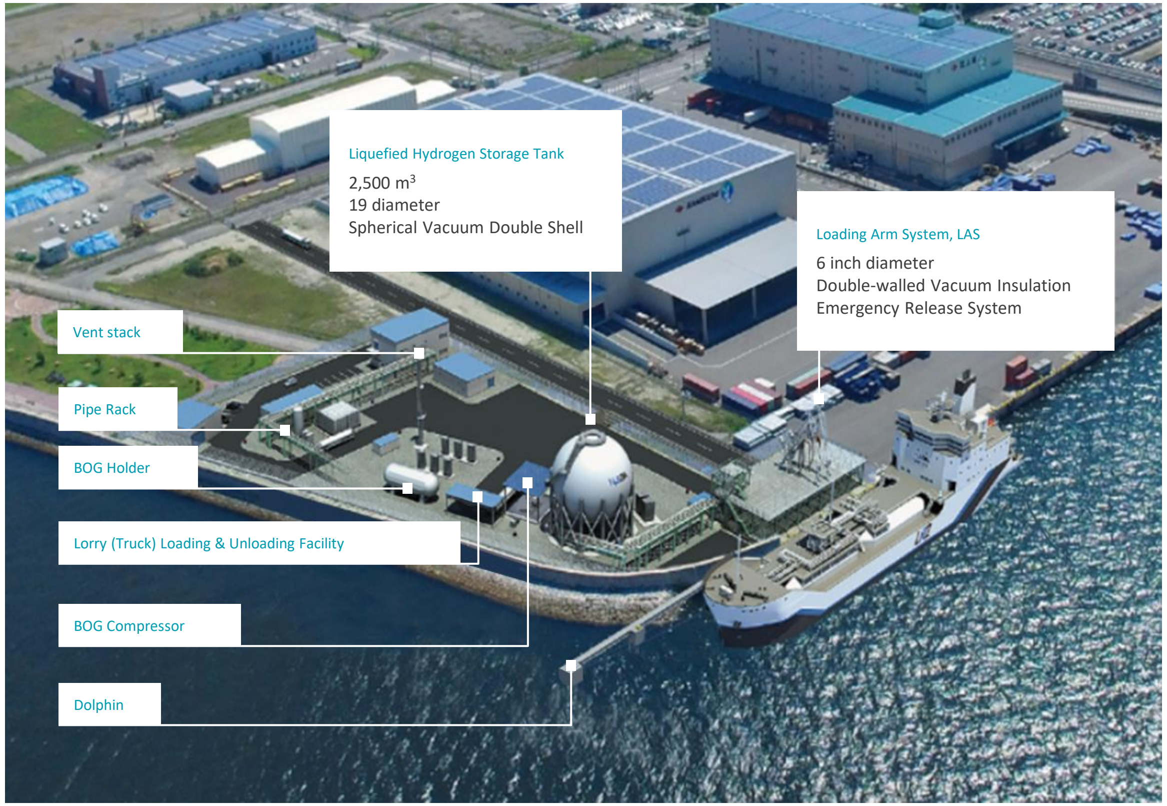
Project Timeline

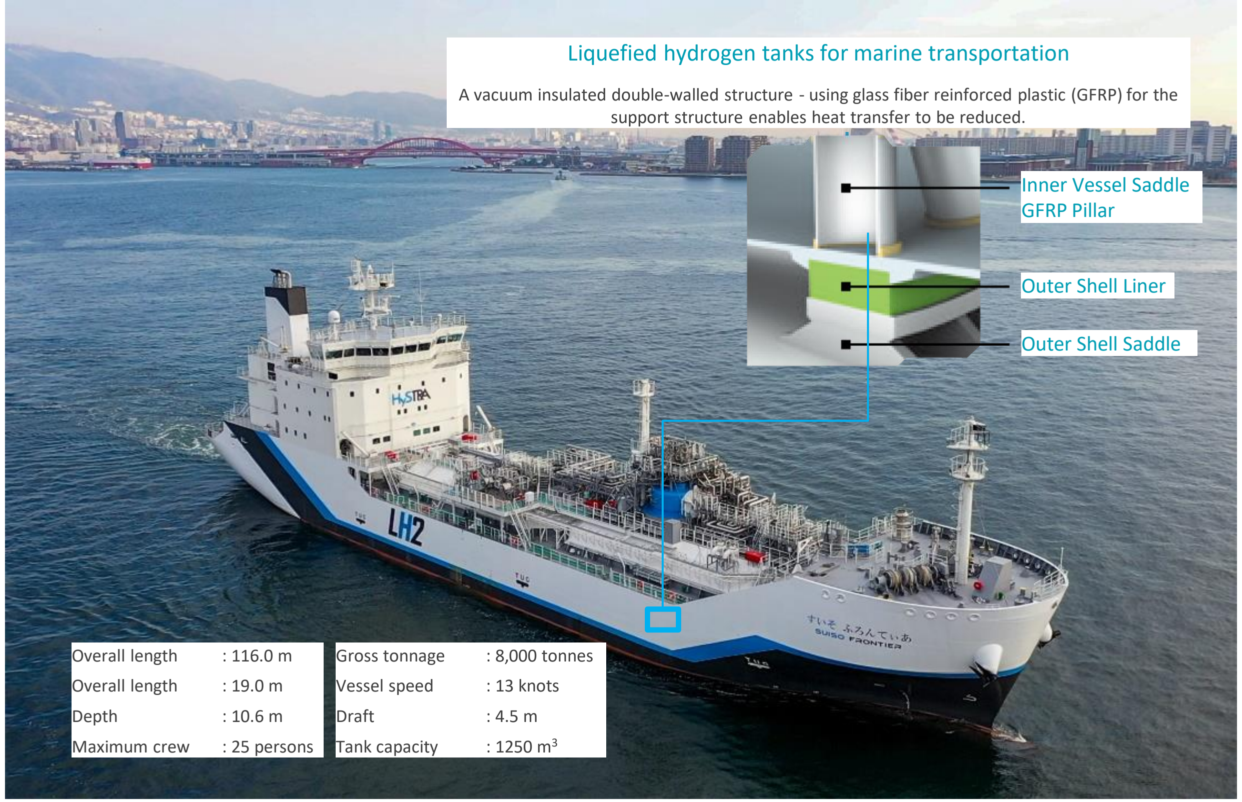


Impacts

- Advance LH2 storage tank technology from TRL 3 to 6, ready for commercialization for scale application
- Develop thermal model, insulation technology, installation techniques, LH2-based cryostat with widespread benefits for all LH2 applications and promote LH2 R&D
- Provide U.S. technology leadership in LH2 based international supply chain development and facilitate the commercialization of natural gas and renewable energy-based hydrogen exports

HySTRA – Terminal and Ship





- Hy touch Kobe – completed construction Jan 2021
- 10,000 m² area of land in the northeast section of Kobe Airport Island in the Port of Kobe

- Suiso Frontier – Maiden Voyage 2021
- Maintaining temperature of -253C
- Japan to Australia – 9,000km

Developing and integrating technologies of the LH2 value chain – Cost and Scale challenge

H2 Production

- Green H2 production
- Gaseous H2 sub-surface storage
- Large Scale H2 Liquefaction

Storage

- Large Scale LH2 Tank designs

Transport

- Large Scale Liquid H_2 Shipping

Distribution

- Downstream LH2 distribution
- Safe and easy-to-use dispensers

Energy System Integration

- Feasibility studies to integrate electrolyser in energy system (local grid or industrial sites)