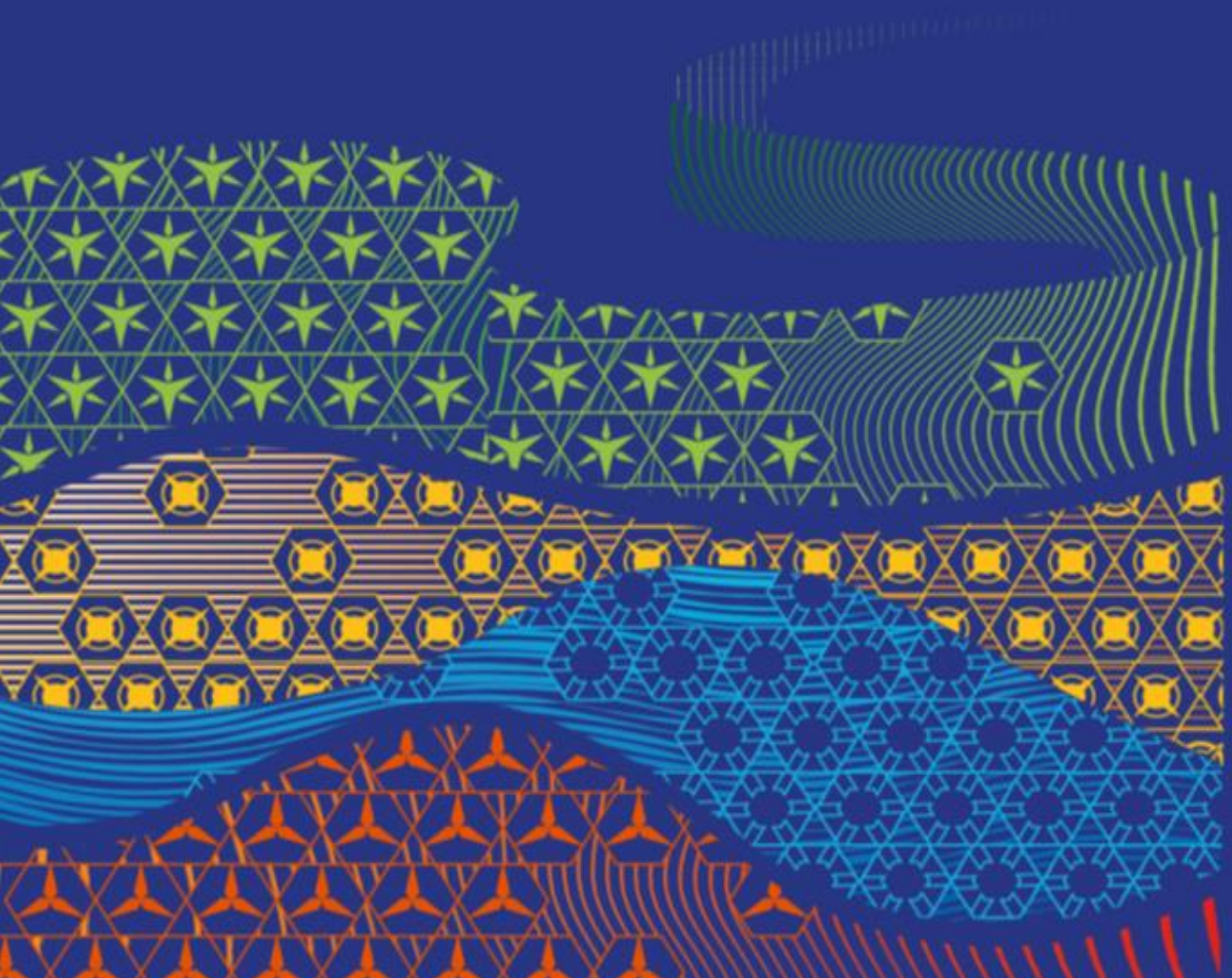


Green Hydrogen Development in Port

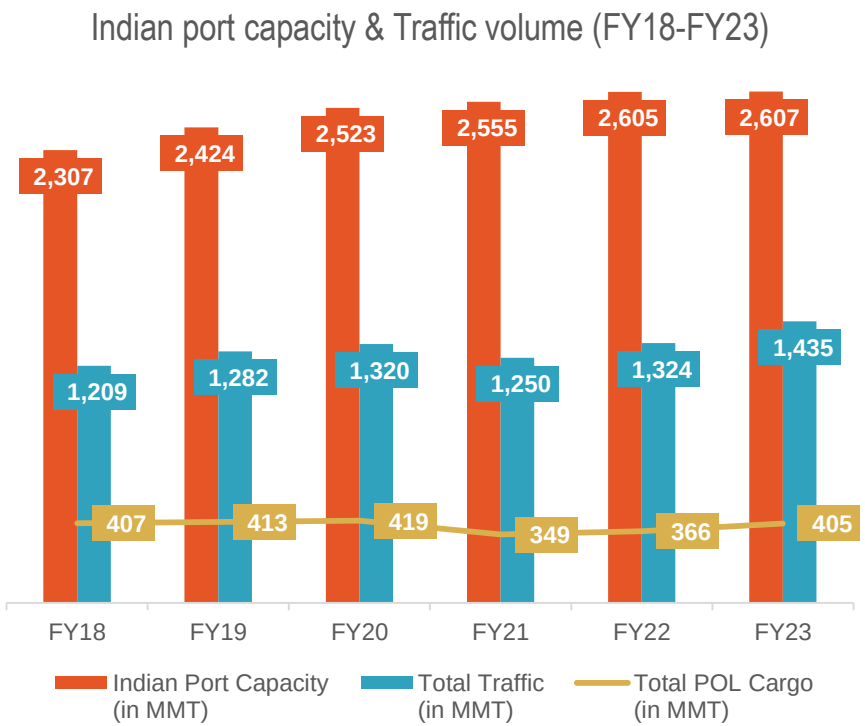
April 2024

Port Sector in India

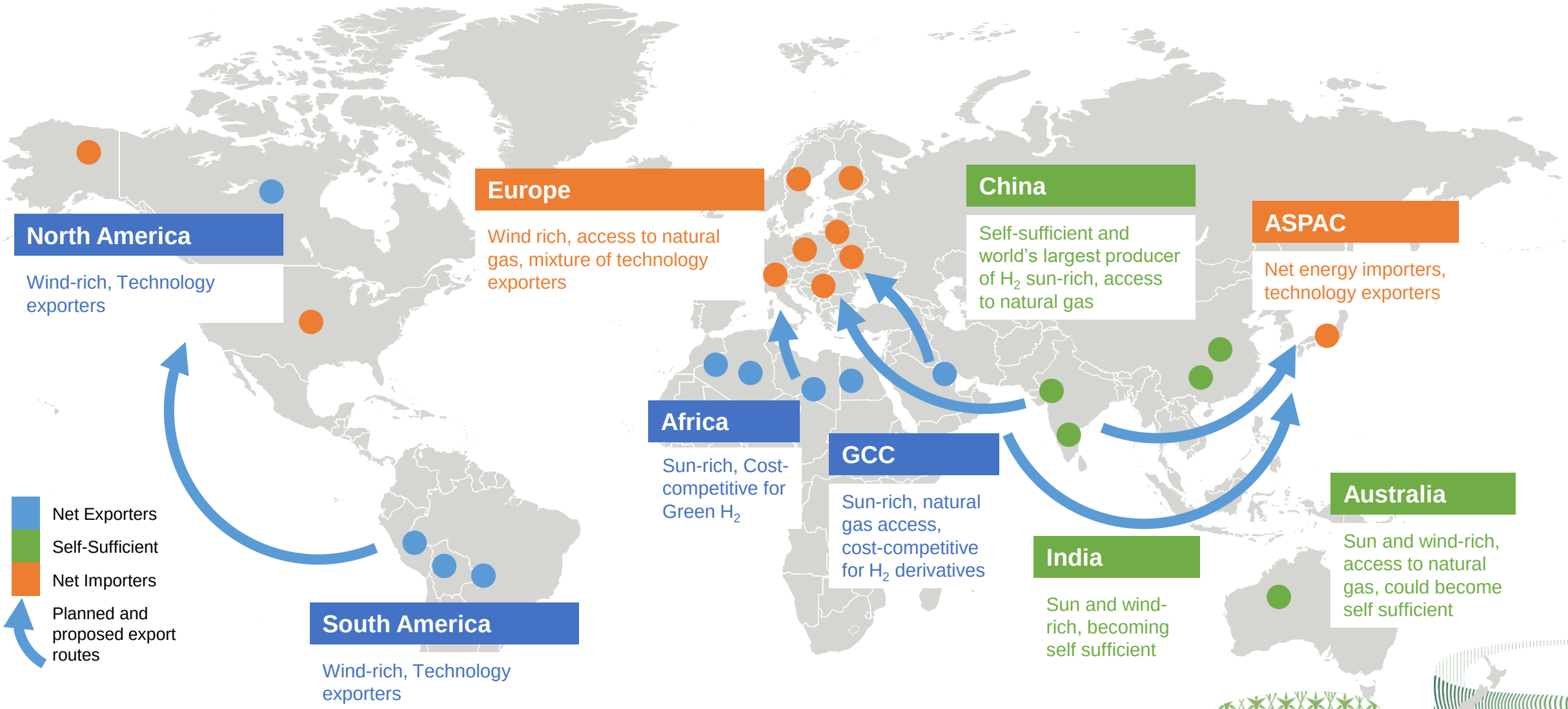
Primed for rapid expansion and a critical role in the clean energy transition for the nation

Indian ports have experienced significant growth, playing a crucial role in facilitating trade and economic development

- Port traffic has grown at 14.8%% in last two years (from 1250 MMT in FY21 to 1435 in FY23) and expected to grow at 7.5% in FY24.
- Liquid / POL Cargo (Petroleum, Oil and Lubricants) remains a major commodity for the Indian ports, with approximately 405 MMT handled in FY23. This underscores the sector's continued reliance on liquid petroleum products for energy needs.
- India has consumed 89.6 MMT of HSD and 37.2 MMT of Gasoline in FY24. Green Hydrogen, LNG and Batteries will compete with HSD while Ethanol, methanol, CNG and battery will compete with Gasoline.
- This liquid cargo consumption is expected to shift significantly in the medium to long term.
- The Government's National Green Hydrogen Mission signals a strategic shift towards clean energy, which will change the cargo characteristics and infrastructure requirement at Ports.



Green Hydrogen hotspots and distribution corridors



Transportation of Green Hydrogen (1/2)

Navigating the complexities of moving green hydrogen`

- As per the McKinsey report, Clean Hydrogen (Green & Blue) demand is expected to reach 375 MMTPA globally by 2050.
- Green hydrogen presents unique challenges for transportation due to its low density (as shown in the table) and high flammability.
- Pipeline is the best means of transportation on land; however, due to potential embrittlement effects, existing pipeline networks may not be readily compatible with hydrogen transportation.

Green Hydrogen Density (Gas)	
1 atm at 20°C	0.083 kg/m^3
350 barg at 20°C	23.71 kg/m^3
700 barg at 20°C	39.75 kg/m^3
Green Hydrogen Density (Liquid)	
1 atm at -253°C	70.9 kg/m^3
Ammonia Density	
1 atm at -40°C	730 kg/m^3
Methanol Density	
1 atm at 20°C	791 kg/m^3
SAF Density (Depending on the blend)	
1 atm at 20°C	775 - 840 kg/m^3

Pipelines:

- The most energy-efficient option for transporting large volumes of hydrogen.
- However, dedicated pipelines might be needed for green hydrogen.
- Pipeline has a limited role in cross border hydrogen transportation

Liquid Hydrogen and Green Ammonia:

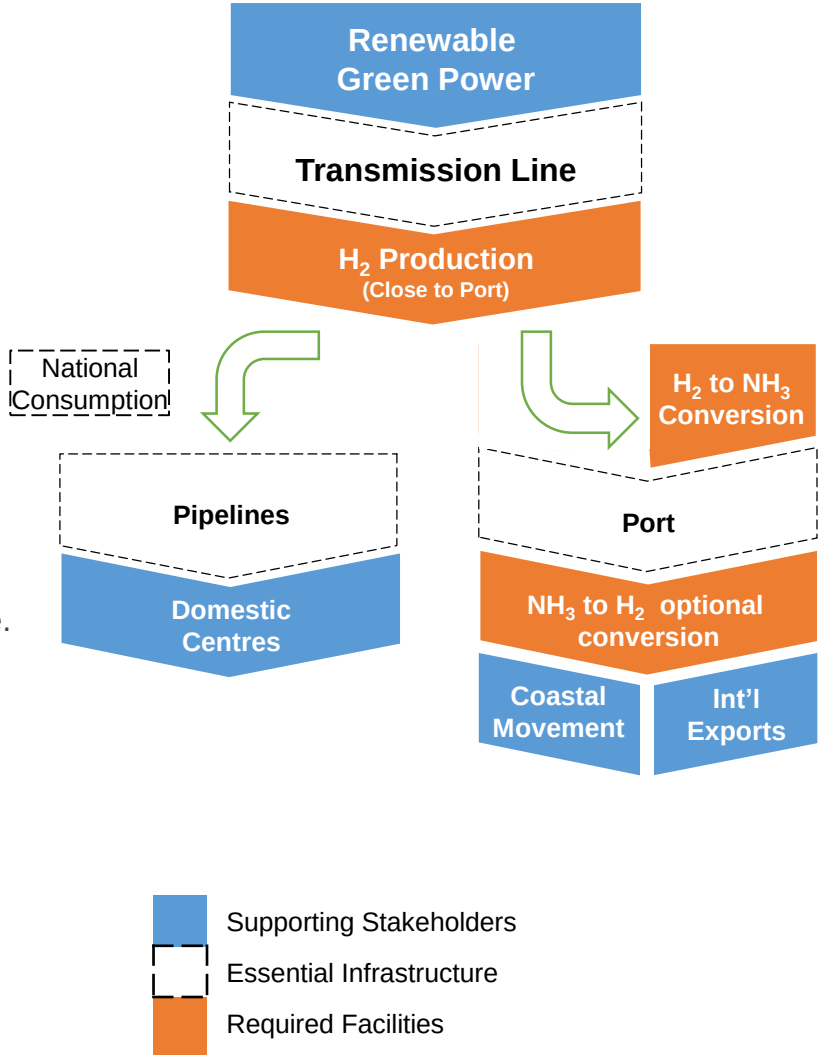
- Liquid hydrogen density is 1/6th of LNG and 1/10th of Ammonia. While its energy value is 2.5 times of LNG and 6 times that of Ammonia. So, the Energy value per cubic of liquid hydrogen is 40% of LNG and 50% of ammonia.
- Liquid hydrogen is at -253°C while liquid ammonia is at -40°C at atmospheric pressure. The cost of hydrogen storage is very high compared to ammonia.
- Hydrogen can be converted into ammonia using the Hyber-Bosch process and transported. Ammonia will be cracked to regain green hydrogen or used directly as fuel.

Transportation of Green Hydrogen (2/2)

Green Ammonia – A Promising Solution for Green Hydrogen Transport

World is already familiar with Ammonia Transportation, Storage and Handling

- Among various derivatives of hydrogen, green ammonia is among the most favored as it does not contain any carbon. Green Methanol is another option by using CO_2 captured from the waste gas.
- Green ammonia presents unique advantages as a carrier for Green Hydrogen. Critical advantages of Green Ammonia for the transportation of Green Hydrogen:
  - Ammonia is already transported primarily for fertilizer manufacturing – the value chain is in place.
  - The existing value chain may be disrupted or augmented for green ammonia transportation.
  - Ship sizes will increase because of long-distance transportation in larger quantities.
  - Port infrastructure needs to be developed based on export and import requirements of green ammonia.
  - Port infrastructure will also decide the ship size to be used by the customers; hence, it will play an important role in logistics costs.



Source: International Energy Agency (IEA) - The Future of Hydrogen | Hydrogen Council - A guide to hydrogen carriers | DNV - Ammonia as a Marine Fuel

Indian Ports – Facilitate the Green Hydrogen Revolution

From strategic hubs to export gateways

Abundance of Solar and Wind Power will power the Green Hydrogen Revolution in India where port must play an important role in terms of developing infrastructure for trade of green hydrogen.

- **Fueling Exports and Energy Security**: Green hydrogen production powered by India's abundant renewable resources (solar, wind) can significantly reduce dependence on Crude oil imports and minimize the environmental impact of petroleum products.

- **Important part in the Hydrogen Ecosystem** – by providing key logistics support.
- Drive port based hydrogen production - strategically allocating land for crucial infrastructure components essential for green hydrogen production, distribution, and utilization.

Green H_2 Production Facilities:

- Ports can provide designated areas for companies to establish green hydrogen production facilities and connectivity with renewable energy sources (solar, wind) to ensure a truly green supply chain.

Hydrogen Pipelines:

- Ports can dedicate land to construct a robust hydrogen pipeline network, connecting production facilities, distributors, bunkering stations, and end-users within the port and surrounding industrial areas.

Bunkering Facilities:

- Ports can allocate land for specialized bunkering facilities, enabling the refueling of H_2-powered vessels and promoting clean maritime transportation.

- This will drive a transition to zero-emission operations within the port, improving air quality and lowering the port's overall carbon footprint.

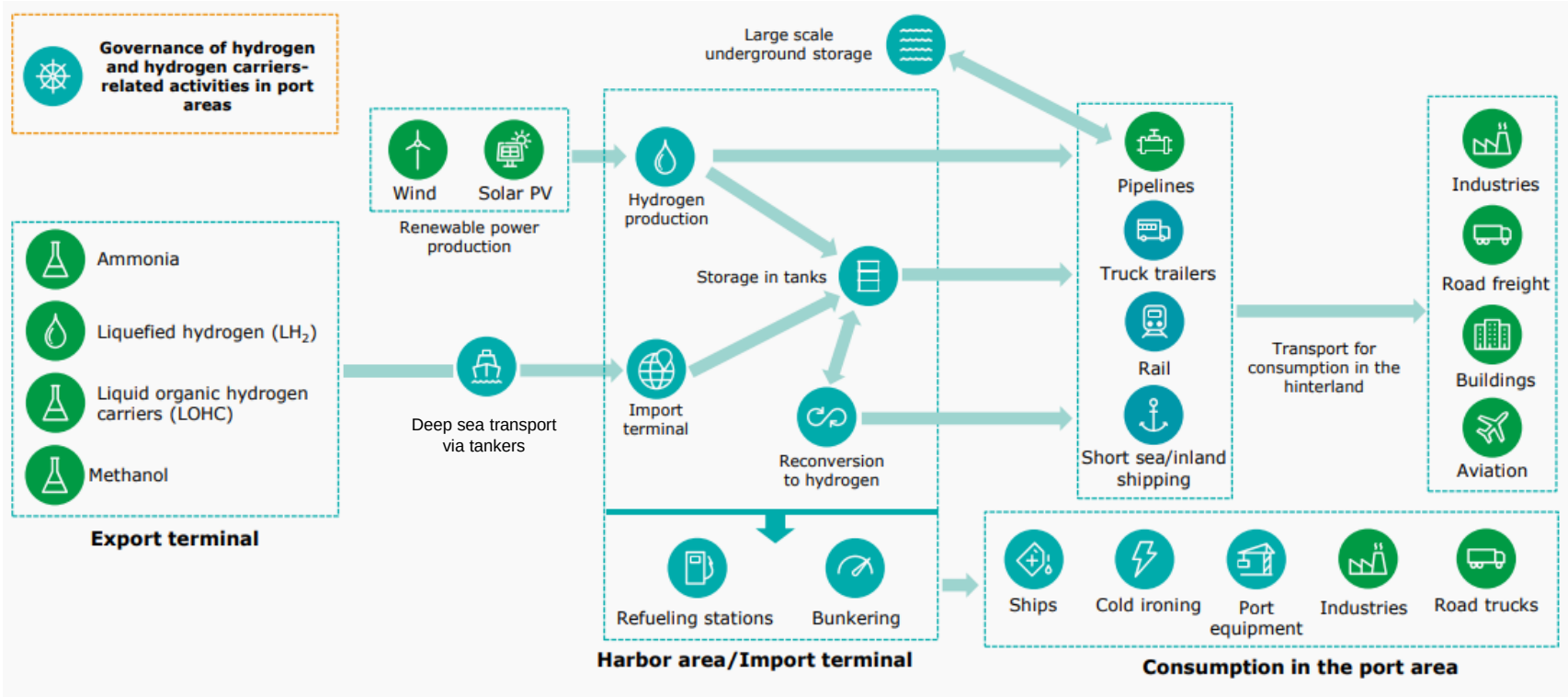
Source: Roland Berger - Ports and green hydrogen

Sample Port Infrastructure for 1 MMTPA Ammonia Export

Adapting infrastructure for the green energy transition for a transformative fuel

Infrastructure:

- 1 No Jetty / Berth of 300 Mtrs Water Front and 14 Mtrs Draft
- Average Parcel size of 40,000 MT
- Handling of 2 Vessels per Month
- Cryogenic Storage Facilities of 50,000 MT at Port
- Loading of each vessel at Port in 36 Hours using 2000KLPH Marine Loading Arm's
- Road Gantry – 8 Bays
- Rail Gantry – 1 No



Source: Study on hydrogen in ports and industrial coastal areas by Clean Hydrogen Partnership co-funded by the European Union

Plans of Various Ports in India for handling Green Hydrogen

Upcoming Green Hydrogen Hubs in India

India aims to create a capacity for exporting around 5 Million Tonnes of Green Hydrogen and its derivatives annually by 2030

- The Indian government aims to have green hydrogen bunkering facilities at all 12 major ports by 2035.
- The Ministry of Shipping has identified 3 ports to set up Green Hydrogen Hubs:

Tuticorin Port:

- VOC will be India's first Green Hydrogen Hub for large-scale production
- 500 acres of land has already been earmarked, and an MoU has been signed with NTPC on 8th Sept 23 for a Green Hydrogen production facility

Paradip Port:

- Investing 235 Crs. to set up port facilities for handling Green Hydrogen / Green Ammonia
- 1 berth will exclusively handle Green Ammonia / Green Hydrogen

Kandla Port:

- A Green Hydrogen Hub is being developed at Kandla
- Work order for the Techno-Commercial feasibility study & work finalization has been floated

- Private Ports are also working on developing ecosystem and port infrastructure for handling of green hydrogen and green ammonia

Source: *https://paradipport.gov.in/future_project.aspx* , *https://ntpc.co.in/media/press-releases/ngel-chidambaranar-port-collaborate-develop-green-hydrogen-hub* , *https://www.deendayalport.gov.in/wp-content/uploads/2023/05/Work-Order-dated-29052023.pdf*

Global Developments in Green Hydrogen Handling Enabled Ports

Early lessons and best practices for Indian ports – The European Union Case Study

Ports around the world are actively developing green hydrogen capabilities to decarbonize operations and become energy hubs

Port of Tilbury (UK):

Unlocking potential carbon savings for port infrastructure and fuel the green future of the Thames Freeport at Tilbury

- Mitsui, RWE, and the Port of Tilbury are collaborating on a 2-phase hydrogen project: a small-scale demonstrator and an initial 10-megawatt plant, with potential to scale up to 100 megawatts.

DP World (Globally):

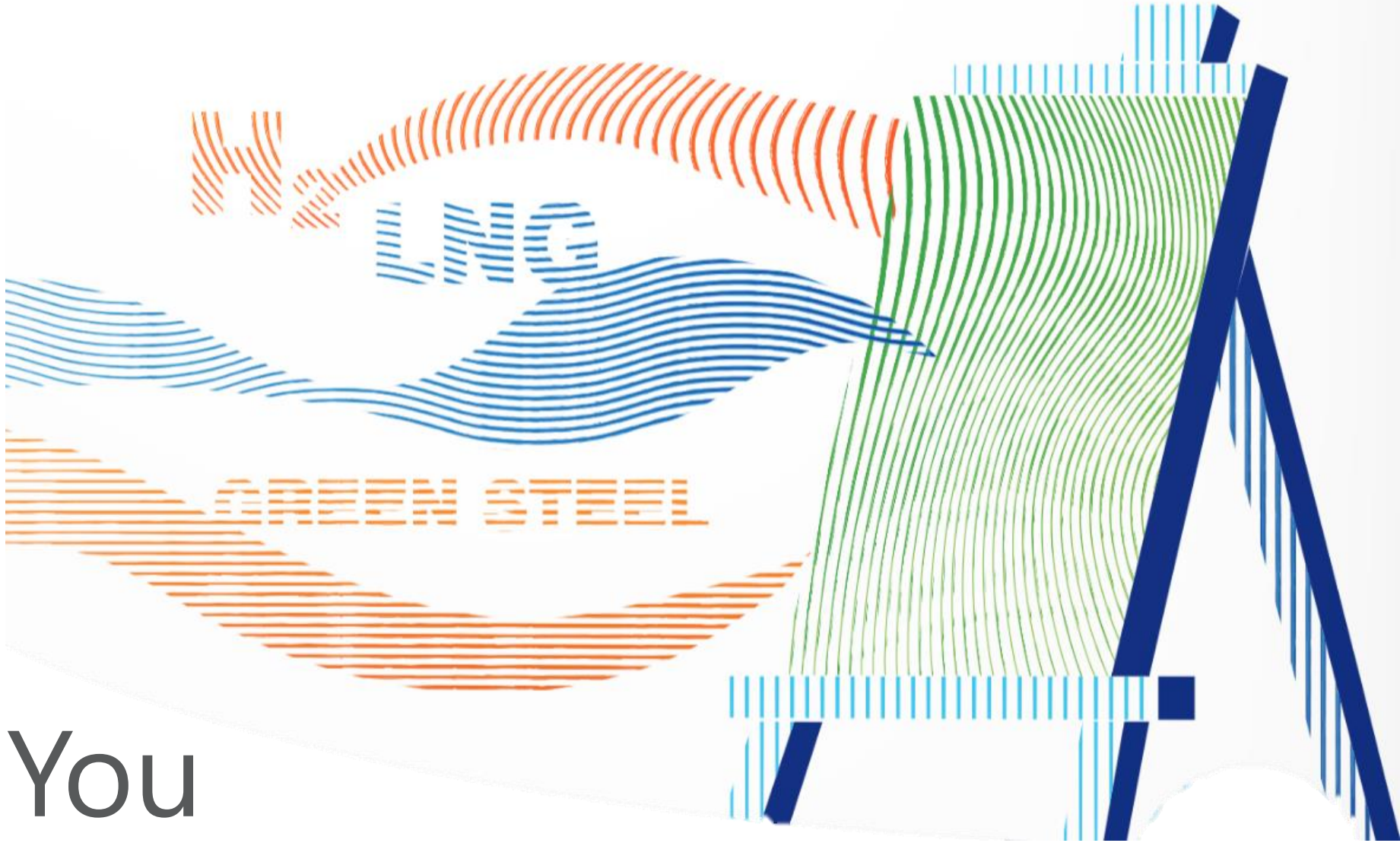
To invest in hydrogen-electric technology for port machinery.

- **Pilot Project**: Hydrogen-powered rubber-tired gantry crane in Vancouver.
- **Future Plans**: Wider electrification of the company's vehicle fleet if the pilot is successful.

Port of Rotterdam (Netherlands):

To become a green hydrogen hub and achieve carbon neutrality by 2050. Port started collaboration with universities and startups to develop green hydrogen technologies.

- Key Initiatives:
  - **Battolyser®**: Combines a battery and hydrogen plant to store energy from renewables and produce green hydrogen when electricity prices are low.
  - **HyTrucks**: Consortium of Hyzon Motors, Air Liquide, DATS 24 to deploy 1,000 hydrogen trucks and 25 fueling stations by 2025
  - **Gunvor**: Partnership with AirProducts to build a green hydrogen import terminal in Rotterdam.
  - **Wattlab**: "Solar hatches" to produce solar energy for sustainable maritime operations. Reducing reliance on generators and dependence on oil.
  - **QuinteQ Energy**: Flywheel energy storage to provide peak power for port infrastructure, while maximizing the use of existing electrical infrastructure.



Thank You