WHEN TRUST MATTERS

Hydrogen Shipping and Demand Outlook

ECC Conference 2024

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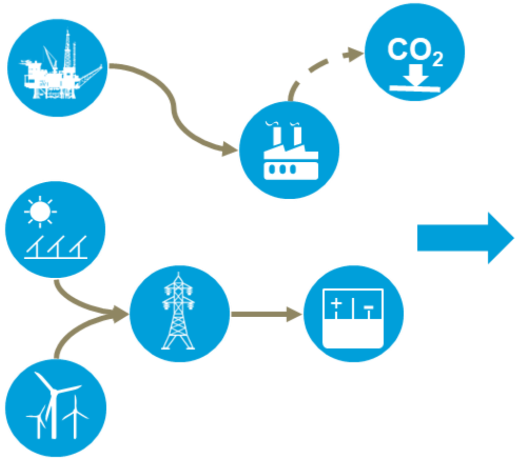
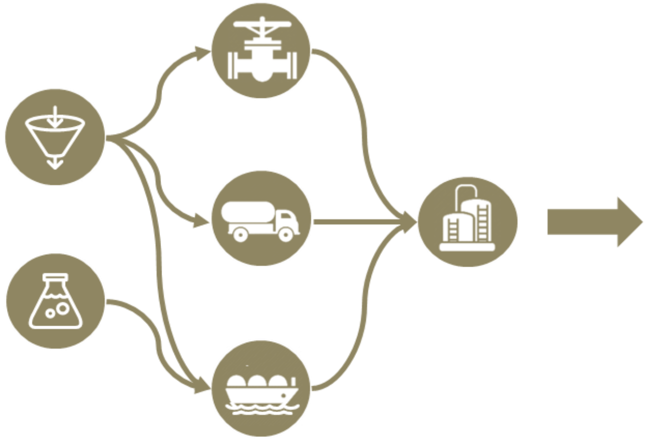
The Hydrogen Value Chain



Production

- Blue Hydrogen
  - Steam methane reforming (SMR) or Autothermal reforming (ATR) with carbon capture and storage (CCS)
- Green Hydrogen
  - Water electrolysis from renewable electricity
- Turquoise Hydrogen
  - Methane pyrolysis, producing hydrogen and solid carbon



Transportation and Storage

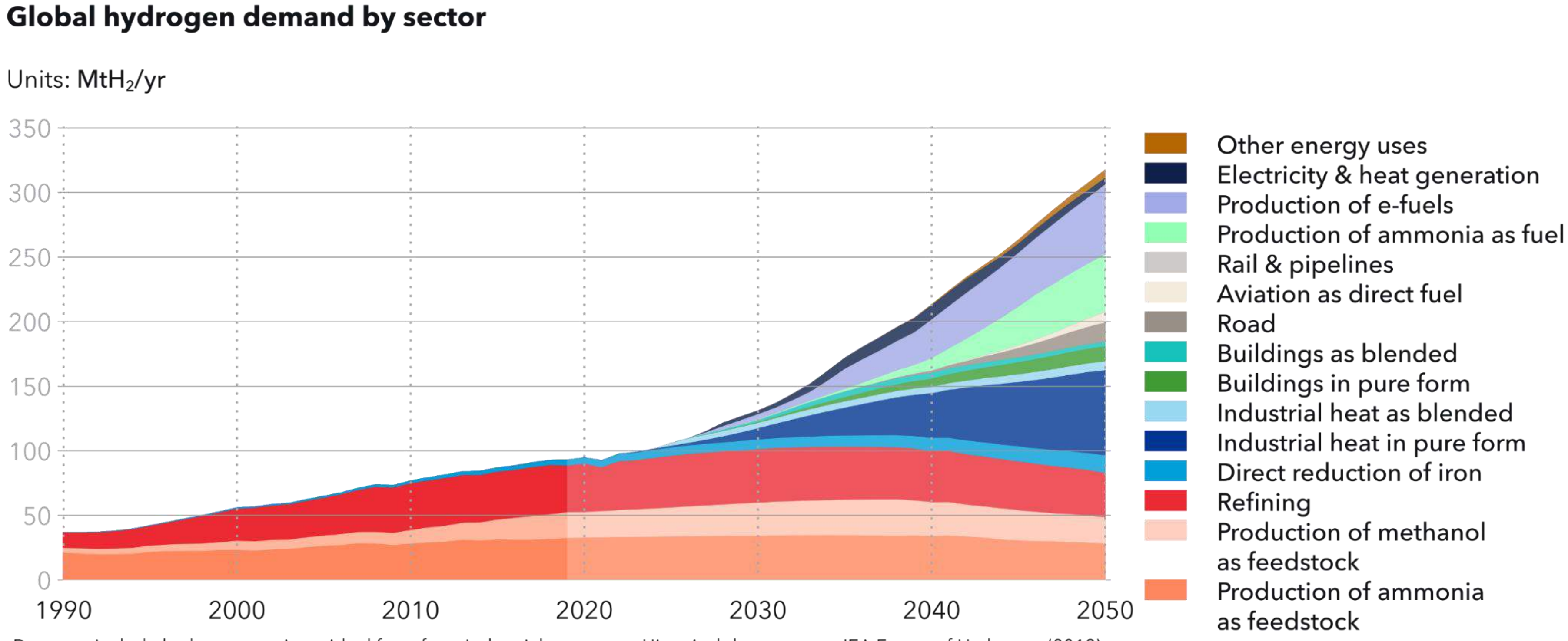
- Compression, liquification, chemical carrier
- Pipeline, Rail, Ship, Truck
- Tank storage, underground storage

End Use

- Industrial processes
- Transportation/mobility (road, maritime, aviation)
- Electricity generation
- Heating

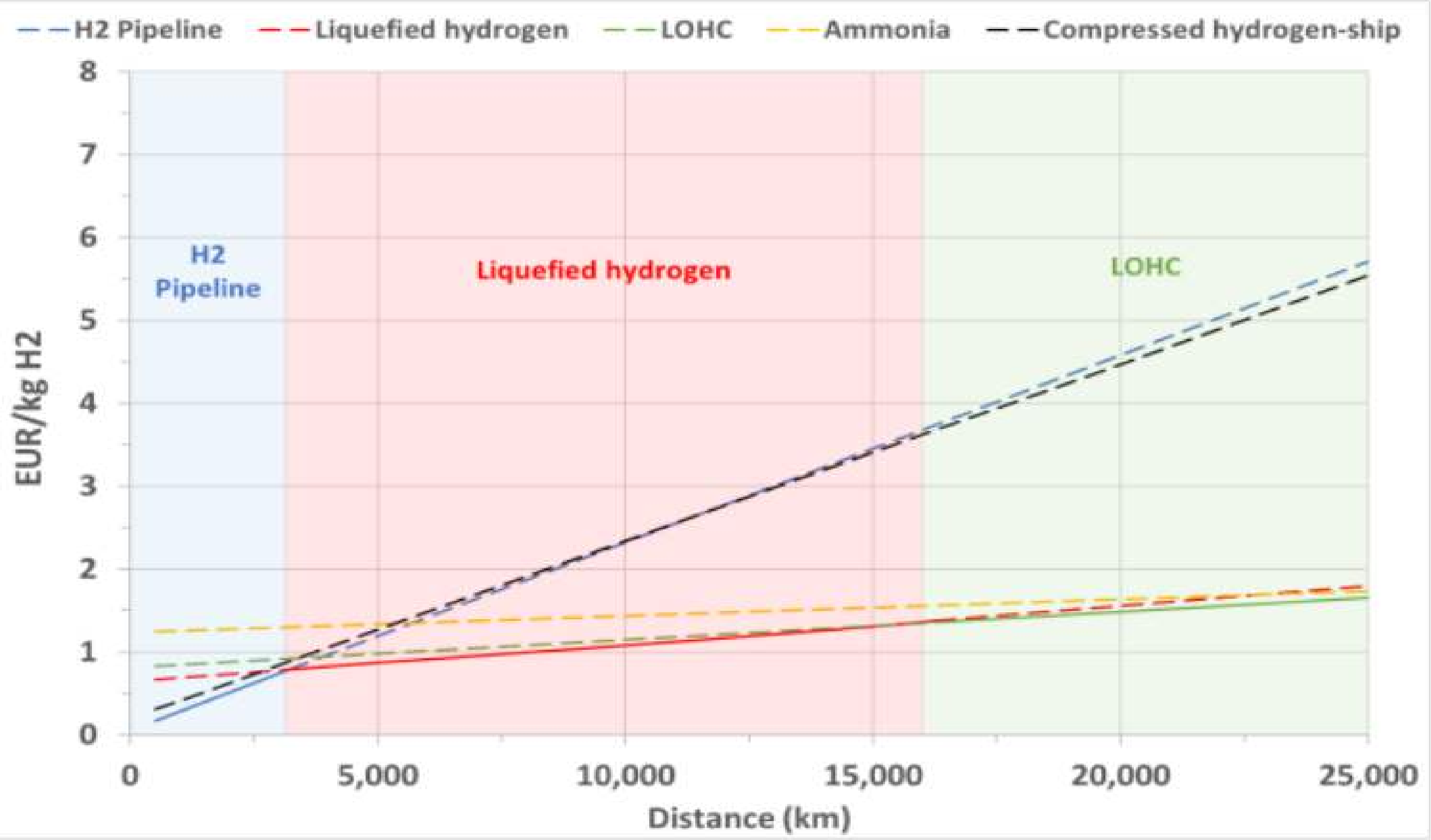
Global Hydrogen Demand Outlook

- Hydrogen and hydrogen-derivates are the most promising solution to decarbonize hard-to-electrify sectors but will still be only 5% of global final demand in 2050.
- Future hydrogen demand generally falls under three main categories: **decarbonizing existing use of hydrogen**, **fuel switching to hydrogen and hydrogen derivatives**, and **new uses of hydrogen**.



Does not include hydrogen use in residual form from industrial processes. Historical data sources: IEA Future of Hydrogen (2019), IEA Global Hydrogen Review (2021), USGS Mineral Commodity Summaries (1990-2022), IFA (2022)

Economics of Hydrogen Transportation



Hydrogen delivery costs for a point to point transport route for 1 Mt H_2 and low electricity cost scenario

Source: EU Joint Research Centre (2021), Assessment of Hydrogen Delivery Options

- **Transportation can add a significant percentage to the cost of hydrogen** depending on the method and distance.
- **Conversion to ammonia, methanol, or other liquid hydrogen carrier** for transport adds a further cost, but is generally considered the **best option for long distance export by ship**.

Hydrogen Pipelines

- Steel pipelines have been used to transport gaseous hydrogen for over a decade with over 2600 km of hydrogen pipelines currently existing in the US.
- **Re-purposing of existing gas pipelines is expected to be 10% to 35% of the cost of building new pipelines,** which will result in 50% to 80% of hydrogen pipelines being repurposed from existing pipelines.
- Effects of hydrogen service on steel pipes include **decreased toughness** and **increased crack growth rate**, which should be considered as part of feasibility assessments.
- **Changes in system risk, as well as safety and performance of end use equipment** must also be considered for applications of hydrogen blending.

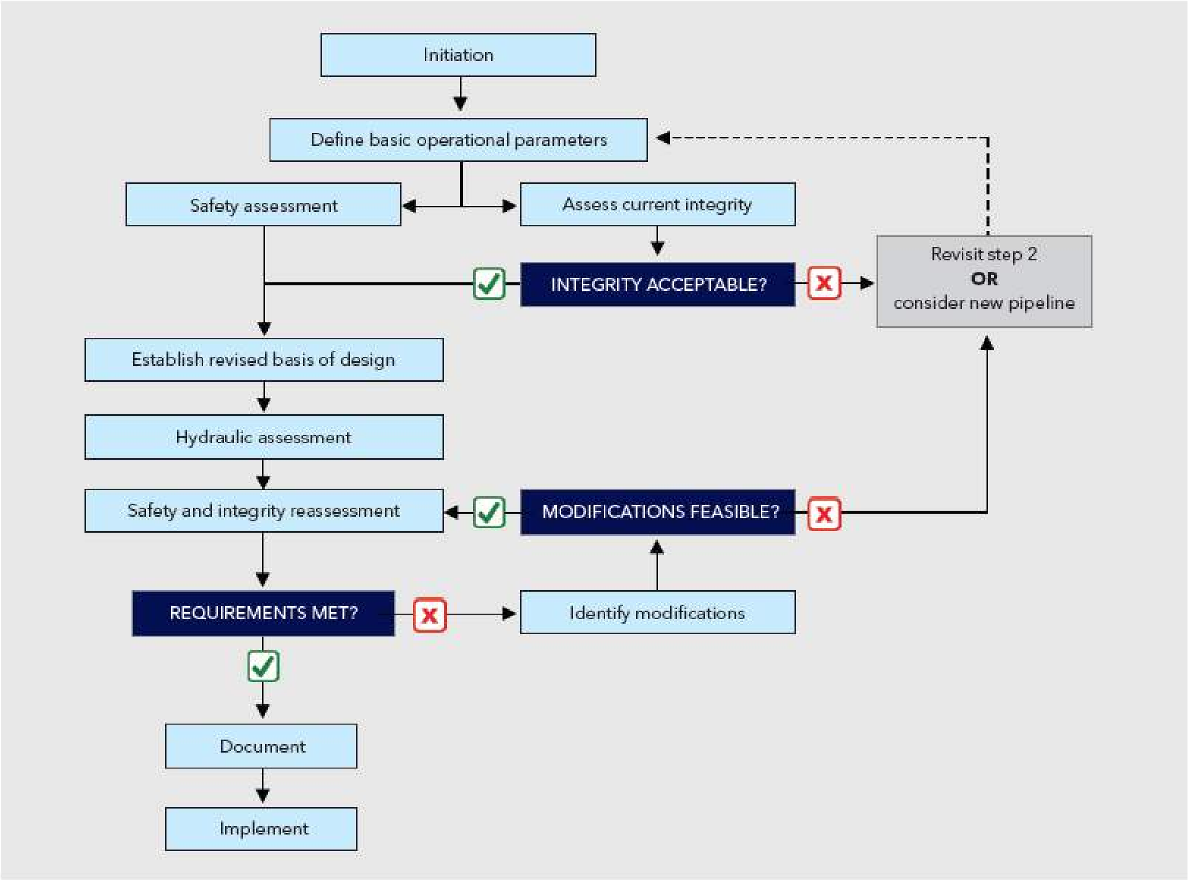


Figure 3 - DNV's Evaluation process for repurposing pipelines for hydrogen

Hydrogen Carriers

	Liquefied Hydrogen	Ammonia	LOHC	Methanol
Hydrogen density	Moderate barrier/s	No significant barriers	Moderate barrier/s	No significant barriers
Energy efficiency	No significant barriers	Moderate barrier/s	Moderate barrier/s	Moderate barrier/s
Technical maturity - export infrastructure	Major barrier/s	No significant barriers	Moderate barrier/s	Moderate barrier/s
Technical maturity - shipping	Major barrier/s	No significant barriers	Moderate barrier/s	No significant barriers
Technical maturity - import infrastructure	Moderate barrier/s	No significant barriers	Moderate barrier/s	Moderate barrier/s
Cost	Major barrier/s	Moderate barrier/s	Moderate barrier/s	No significant barriers
Environmental, Social, Health and Safety (ESHS)	Moderate barrier/s	Moderate barrier/s	Moderate barrier/s	Moderate barrier/s
Re-utilisation of existing infrastructure	Moderate barrier/s	No significant barriers	No significant barriers	No significant barriers
Existing market as commodity	Major barrier/s	No significant barriers	Major barrier/s	No significant barriers

Major barrier/s — Moderate barrier/s — No significant barriers

DNV

What Does this Mean for Canada?

- The Hydrogen economy seems poised to begin.
- Domestically, we are seeing projects across transportation, heavy industry, and blending and energy storage sectors, as well as regional hydrogen hubs connecting producers and consumers.
- Internationally, MOUs signed for potential ammonia export projects from Eastern Canada to Europe and Western Canada to Asia.
- Existing projects do not approach the scale of what is planned, so significant technical and economic uncertainty still exists.

DNV

Thank you!

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Backup slides

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Dedicated research unit
focusing on researching and forecasting the energy transition

100+ internal experts
across supply and demand and transport infrastructure sectors

~25 external collaboration partners
in business and academia

Key assumptions

Population

9.3 bn

Projected global population in 2050 of 9.3 billion

- 4% lower than the UN median population forecast at 9.7 billion

Economy

>2×

Global economy will grow by 120% to 2050

- Reaching USD 295 trillion in 2050
- CAGR 2.7%/year from 2020-2050 (incl. 2020 COVID effects)

Technology

16-26%

Average % cost reduction per doubling of installed capacity

- Solar panels 26%, reducing to 17%
- Wind turbines 16%
- Batteries 19%

Policy

<135 USD/tCO_2

Carbon prices will be regional and in 2050 range between \$20-135/tCO_2 (USD 2019)

Other policy examples:
- Air pollution measures
- RE power support
- EV support
- Maritime environmental regulations

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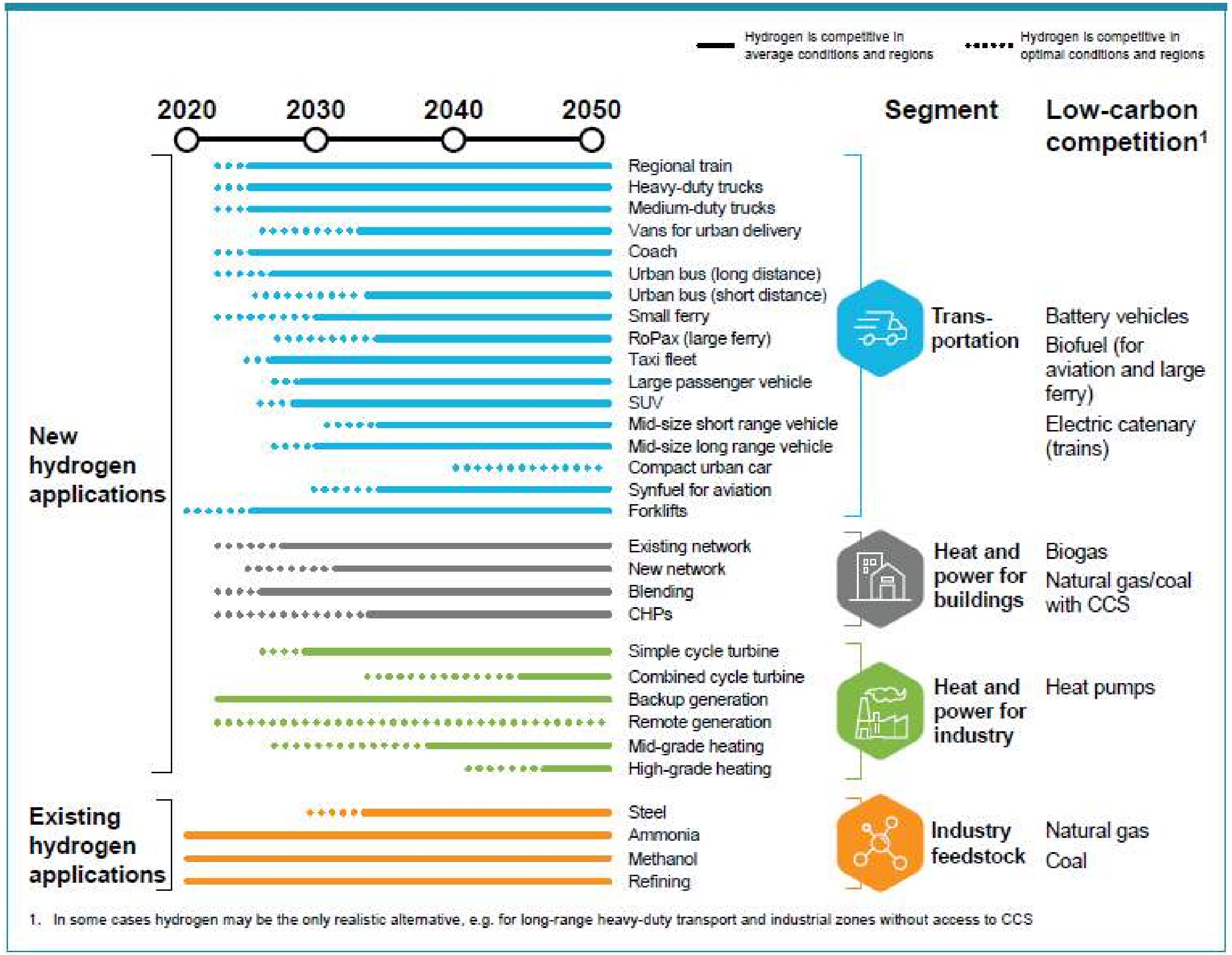
Hydrogen End Uses

- Industry feedstocks is currently #1
- Hard to abate industrial applications
  - Green Steel
  - Cement Production
- Transportation:
  - Attractive for long-haul heavy
  - Value-add for fleet vehicles with infrastructure
  - Uncompetitive for urban passenger vehicles
- Power applications:
  - Coupled with renewables for 24/7 Green Option, but at a cost.

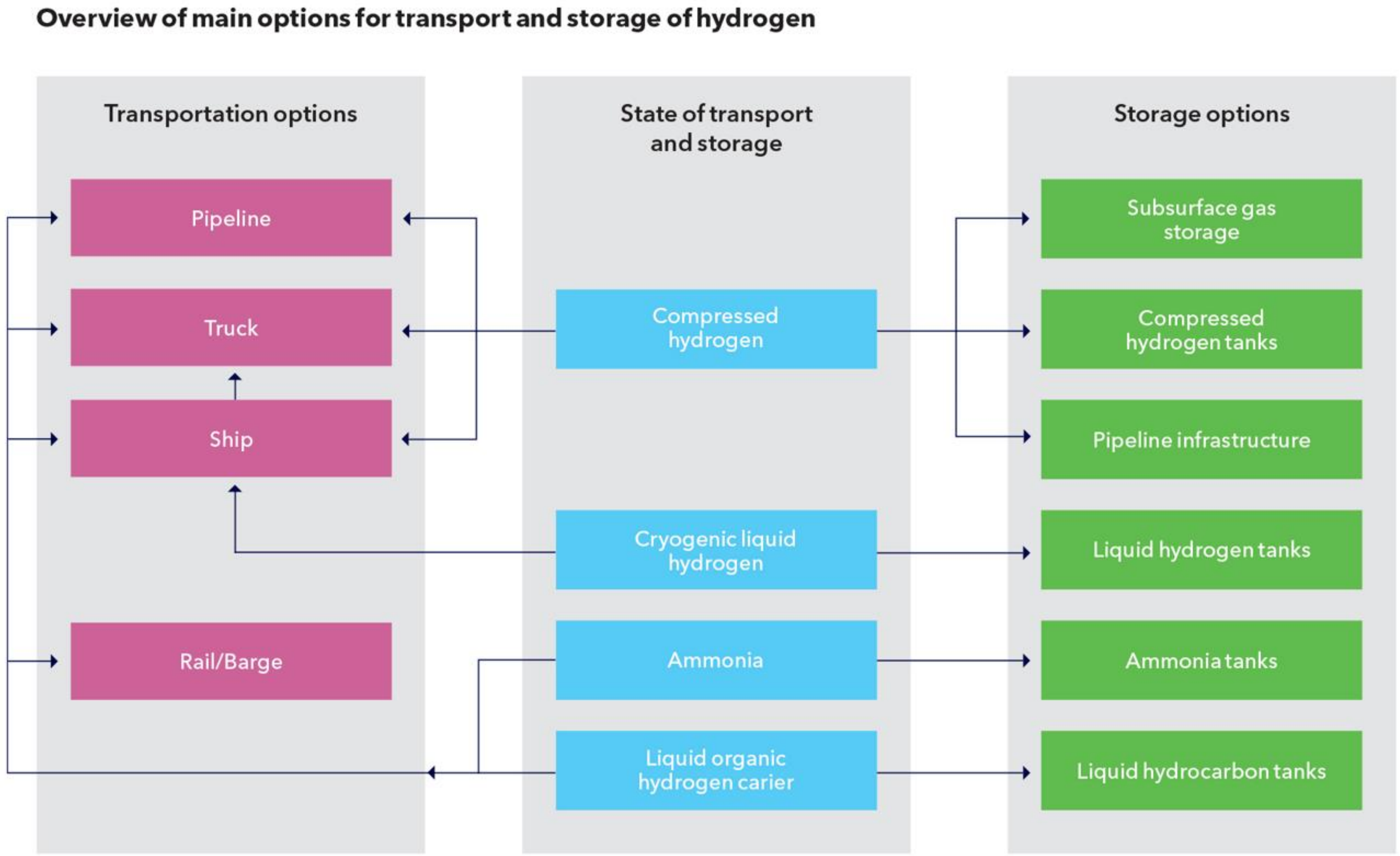


Source: Hydrogen Council - 2020

Hydrogen Shipping Methods and Challenges

Transportation Method	Ideal Application	Challenges	Opportunities
Truck	Short distance transportation (<100 km) of small volumes of compressed gaseous hydrogen or liquefied hydrogen.	Emissions from conventional trucks add to overall project footprint. Gaseous hydrogen trucking requires more trucks/trailers and storage tanks than liquefied hydrogen trucking, while liquefied hydrogen trucking requires investment in hydrogen liquefiers. High-capacity liquefier technology is still maturing.	Road tankers and tube trailers to transport hydrogen are commercially available due to current use of hydrogen as feedstock in existing industries.
Pipeline	Intraregional transportation (<3,000 km) of high volumes of hydrogen and hydrogen blended natural gas.	Technical challenges associated with qualifying existing pipelines for hydrogen blended natural gas include consideration of hydrogen embrittlement and hydrogen assisted fatigue crack growth. Older pipeline construction materials and methods (e.g., cast iron components, ERW welds), and availability of records pose challenges to requalification.	Re-use of existing pipelines for hydrogen and hydrogen blended natural gas is projected to be 10% to 35% of new pipeline construction costs.
Interregional Shipping	Interregional transportation of liquid hydrogen carriers.	Toxicity of ammonia, cracking back to hydrogen at import location is not cost effective.	Existing domestic and international supply chains and infrastructure.

Hydrogen transport and storage



Major barrier/s

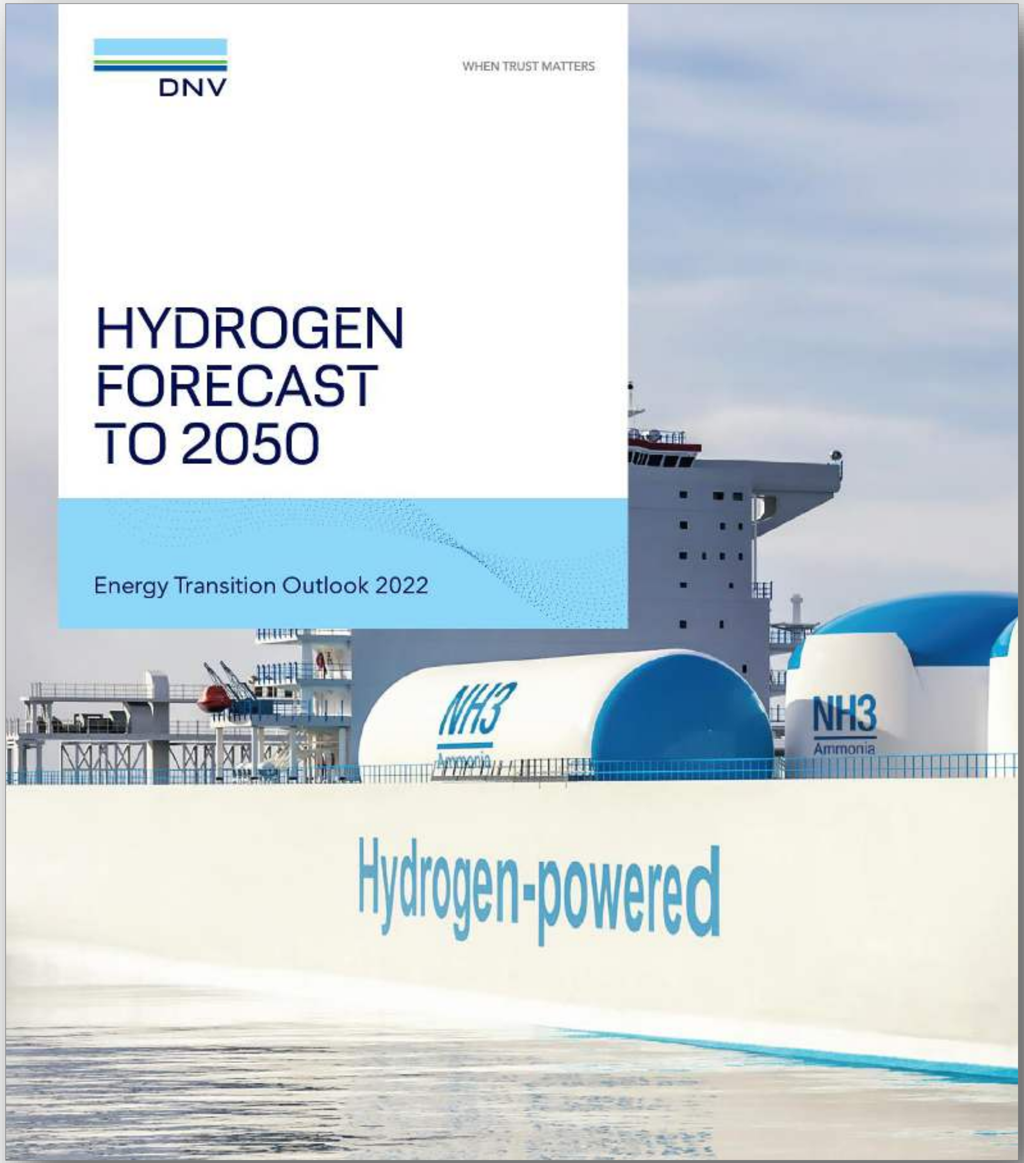
Moderate barrier/s

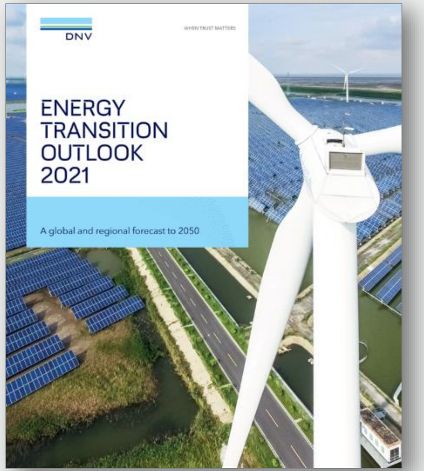
No significant barriers

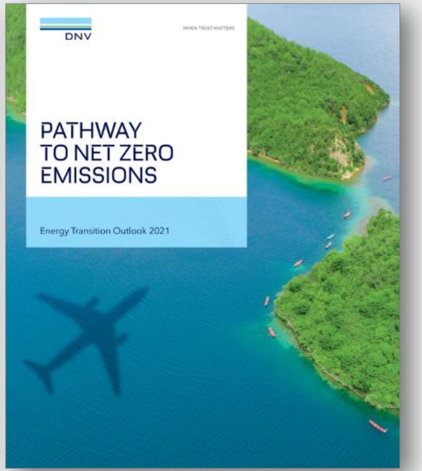
Transport Carriers Comparison

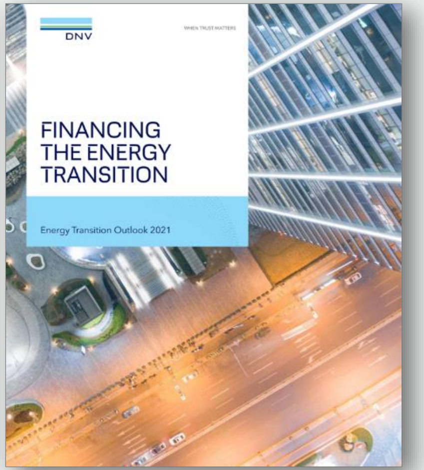
A comparative table with main KPIs for each type of carriers selected is presented below. Depending on the value chain, it may be relevant to convert the hydrogen carrier back to hydrogen. Note that these assessments show the current state of technology readiness and market development, which is likely to change in future

	Liquefied Hydrogen	Ammonia	LOHC	Methanol
Hydrogen density	71 kg/m³	121 kg/m³	48-57 kg/m³	99 kg/m³
Energy efficiency	High purity hydrogen Less conversion losses	Energy losses for hydrogen conversion	Energy losses for hydrogen conversion	Energy losses for hydrogen conversion
Technical maturity - export infrastructure	Nonexistent (only experimental), even though liquefaction process is relatively mature for other liquefied gases	Existing and mature	Nonexistent but can easily use existing technology for hydrocarbon products.	Biogenic/sustainable CO_2 capture and use has low maturity (methanol synthesis in itself is mature)
Technical maturity - shipping	A few new ship designs proposed, where the first could be built within 2025	Existing and mature	Toluene is already shipped in a large scale. Unclear whether when enriched with H2 the same regulations for carriage can be applied directly.	Existing and mature
Technical maturity - import infrastructure (hydrogen released if necessary)	Regasification of LH2 is done at small scale	Existing infrastructure (ammonia cracking has low maturity)	Nonexistent but can easily use existing technology for hydrocarbon products	Methanol reforming has still a medium maturity
Cost	In general, the most expensive mainly for long distances	In general, medium costs compared to the others	In general, medium costs compared to the others	In general, the lowest costs
Environmental, Social, Health and Safety (ESHS)	High Flammability Carbon Free	High Toxicity	High flash point. Not flammable in room temperature. Medium toxic effects	High flammability Biodegradable
Re-utilisation of existing infrastructure	Potential for LNG infrastructure, but still under study	LPG infrastructure can be used. Only some modification needed for LNG infrastructure.	Can easily use existing liquid hydrocarbons infrastructure	Can easily use existing liquid chemicals infrastructure
Existing market as commodity	Only niche applications	Existing	LOHC carrier material needed for hydrogen transportation	Existing









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