Accelerating Maritime Decarbonization via Multi-Sectoral Integration

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The **Low-Carbon Resources Initiative** (LCRI) is a five-year R&D commitment focused on the advancement of low-carbon technologies for large-scale deployment across the energy economy. This initiative is jointly led by **EPRI and GTI Energy**.

LCRI LOW-CARBON RESOURCES INITIATIVE

FOCUS

Multiple options and solutions to establish viable low-carbon pathways

Technologies for hard-to-decarbonize areas of the energy economy

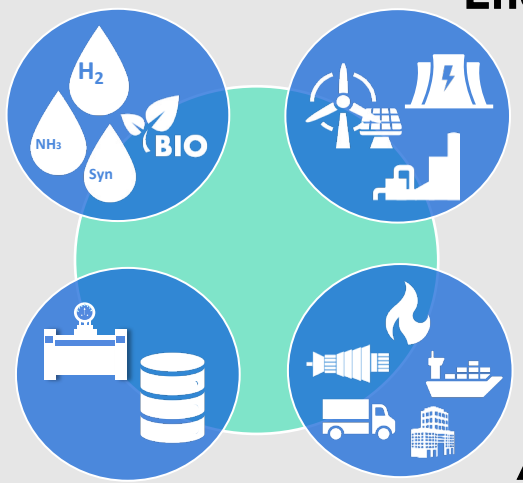
Affordable, reliable, and resilient integrated energy systems for the future

RESEARCH AREAS

Hydrogen **Ammonia** **Synthetic/ Derivative Fuels** **Biofuels**

Production Pathways

Integrated Energy Systems



Storage & Delivery

End Use Applications

VALUE

Independent, objective research leveraged by global engagement and collaboration

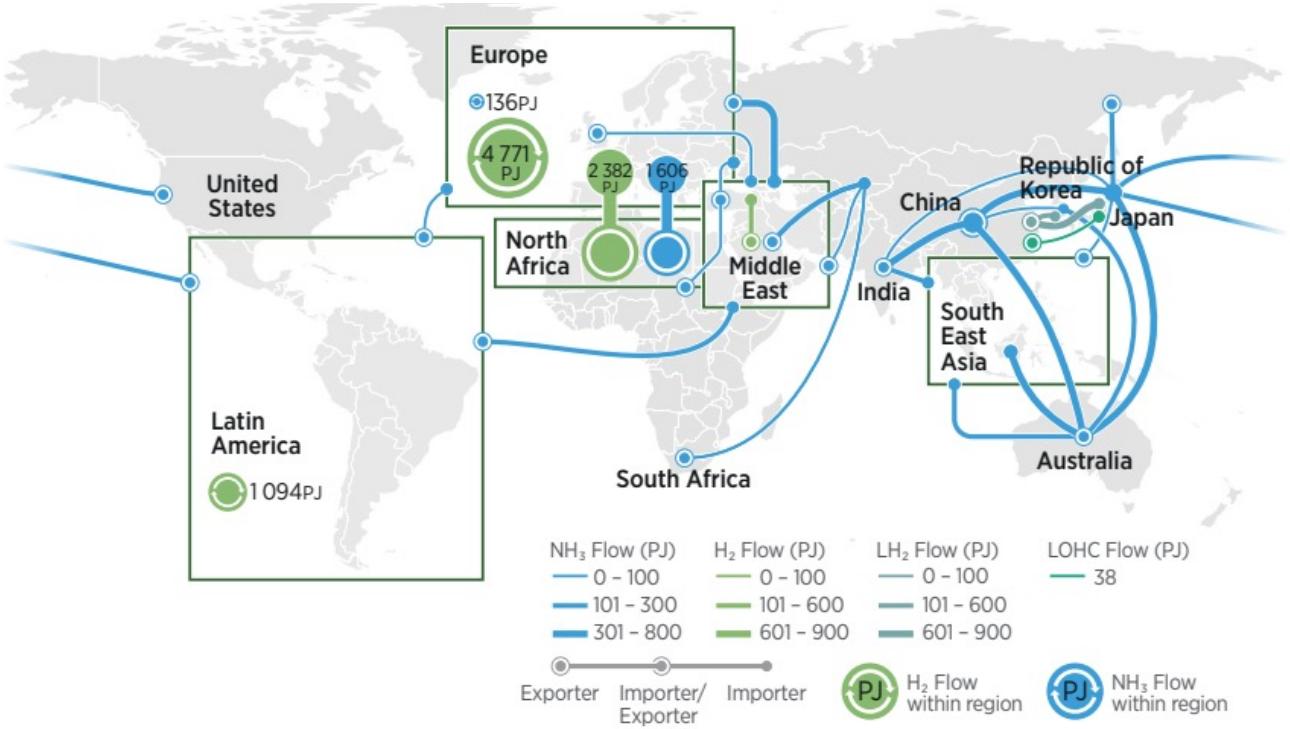
Comprehensive approach to low-carbon value chain and technology analyses

High-impact results from technology evaluations, and safety, environmental, and economic assessments

EPRI GTI ENERGY

Role of International Trade in the Hydrogen Economy

IRENA: 2050 Hydrogen Trade Flows Under Optimistic Technology Assumptions

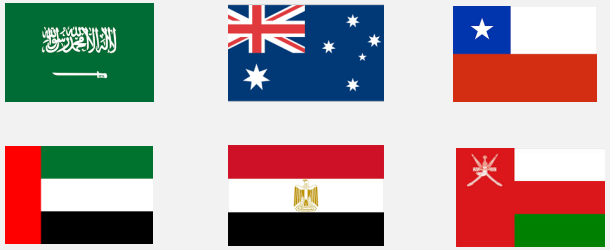


Source: IRENA 2022, "Global hydrogen trade to meet the 1.5°C climate goal: Trade outlook for 2050 and way forward". https://www.irena.org/publications/2022/Jul/Global-Hydrogen-Trade-Outlook

- Hydrogen provides an opportunity to address geographic disparities between low-carbon energy resource potential and energy demand
- At least half of net-zero fuels traded globally in 2050 expected to be moved by ships[1].

Major Importers

Major Exporters



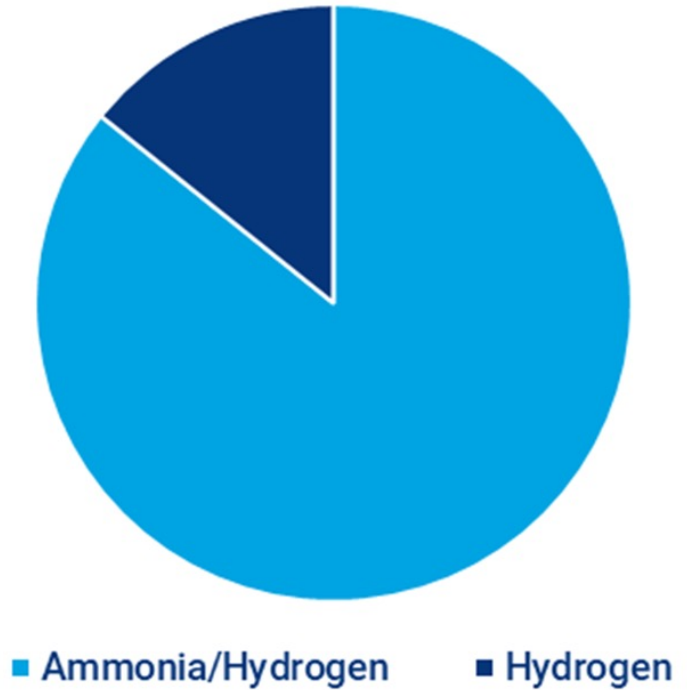
Ammonia Hydrogen Carrier for Seaborne Trade

Significant experience handling and shipping ammonia:

- 20 million metric tons of ammonia shipped per year [1]
- >100 ports already have ammonia import/export infrastructure [2]
- Shipped in standard LPG tankers

Ammonia is expected to be the predominant hydrogen carrier for shipping. Around half of global ammonia is expected to be internationally traded by 2050 [3].

Wood Mackenzie: Announced Hydrogen Projects by Capacity*



*In Australia, the Middle East, Africa and Latin America.
Source: Wood Mackenzie Hydrogen Project Tracker

[1] WoodMackenzie (2022). *What role will ammonia play in global hydrogen trade?* https://www.woodmac.com/news/opinion/what-role-will-ammonia-play-in-global-hydrogen-trade/

[2] Alfa Laval, Hafnia, Haldor Topsoe, Vestas, Siemens Gamesa (2020). *Ammonfuel: An industrial view of ammonia as a marine fuel.* https://www.topsoe.com/hubfs/DOWNLOADS/DOWNLOADS%20-%20White%20papers/Ammonfuel%20Report%20Version%2009.9%20August%203_update.pdf

[3] IEA (2021), *Net Zero by 2050*, IEA, Paris https://www.iea.org/reports/net-zero-by-2050, License: CC BY 4.0

Decarbonization of Port Operations

Port electrification challenges:

- Lack of operational flexibility on when battery-powered equipment can be charged. Charging results in increased equip. downtime.
- Conversion to both direct electric (grid-connected) and battery electric eCHE likely to increase burden on power grid during peak demand hours.
- Port tenants hesitant to work directly with utilities on early electrification projects.

Hydrogen-powered solutions offer potential to mitigate issues with matching supply/demand in real time. Regardless, decarbonization of port operations will necessitate changes to operations, increased electricity demand, and significant infrastructure investment.

Estimated Power Requirements, Hydrogen Demand Potential for the Ports of Los Angeles and Long Beach

	Power requirements (MW)*[1]	H2 demand potential[2] (kg/day)
CHE	147.9-193.6	40,147
Drayage	107	774,322
Shore power	50.4	27,706

*2035 projections, only addresses container/RoRo terminals

[1] *Technical Memorandum: Electrification of California Ports*. K. Simpson, Moffatt & Nichol. June 2021.

[2] *Hydrogen Fuel Cell Applications in Ports: Feasibility Study at Multiple U.S. Ports*. L. Steele, C. Myers, Presentation at H2@Ports International Workshop, September 2019.

Net-Zero Solutions for Selected Port Equipment Categories

Rubber-tired gantry crane

Direct electric, hydrogen fuel cell (HFC)

Front end loader/top pick

Battery electric, hybrid HFC

Yard tractor

Battery electric, HFC

Straddle carrier

Battery electric, HFC

Drayage truck

Battery electric, HFC

Reefer power

Direct electric, *HFC*

Shore-to-ship power

Direct electric, *HFC*

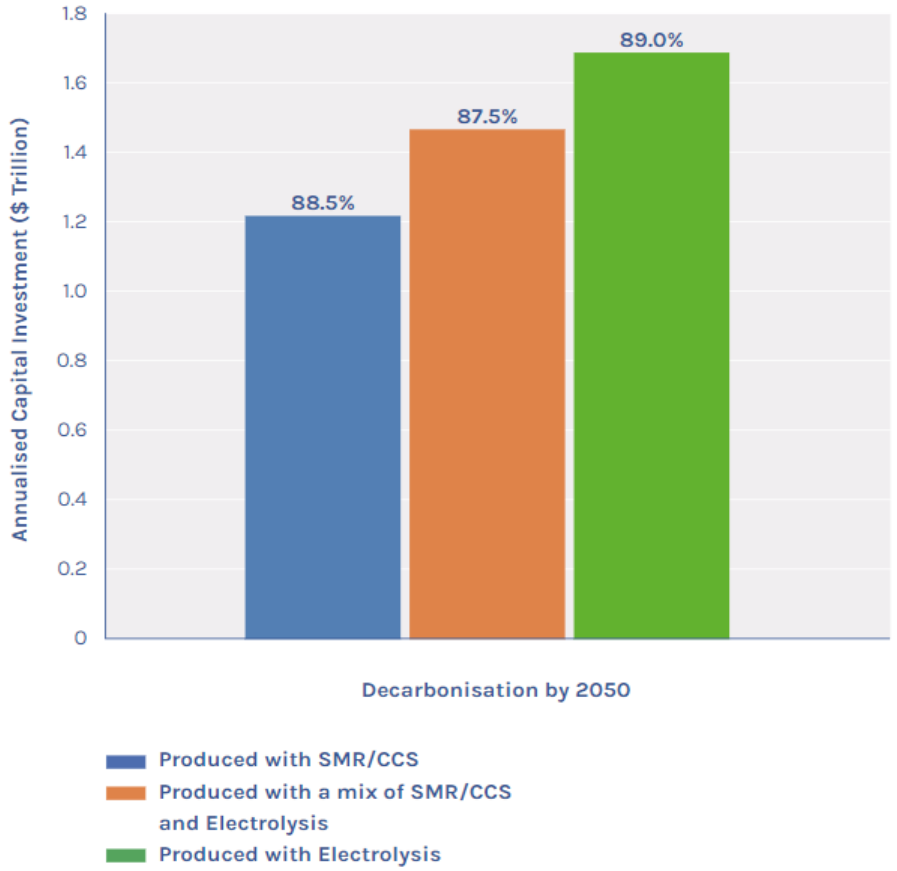
Hydrogen and electrification likely to play complementary roles in decarbonization of port operations. Achieving optimal solution will require close collaboration between port tenants and power suppliers.

Infrastructure and Investment Requirements for Maritime Sector Decarbonization

- Supplying 100% of 2050 annual maritime fuel demand with *green* ammonia would require 5000 TWh electricity annually, corresponding with ~1300 GW wind and solar capacity*[1]

- Estimated investment between 2030 and 2050 to decarbonize shipping: $1.4-1.9 trillion[2, 3].
  - **>87% of total investments are for land-based infrastructure** including hydrogen and ammonia production and storage/distribution.

Global Capital Investment in Scalable Zero-Carbon Fuel Infrastructure by 2050 with % Share of Infrastructure



Source : *A Strategy for the Transition to Zero-Emission Shipping*, UMAS and Getting to Zero Coalition (2020). Available at: https://www.globalmaritimeforum.org/publications/a-strategy-for-the-transition-to-zero-emission-shipping.

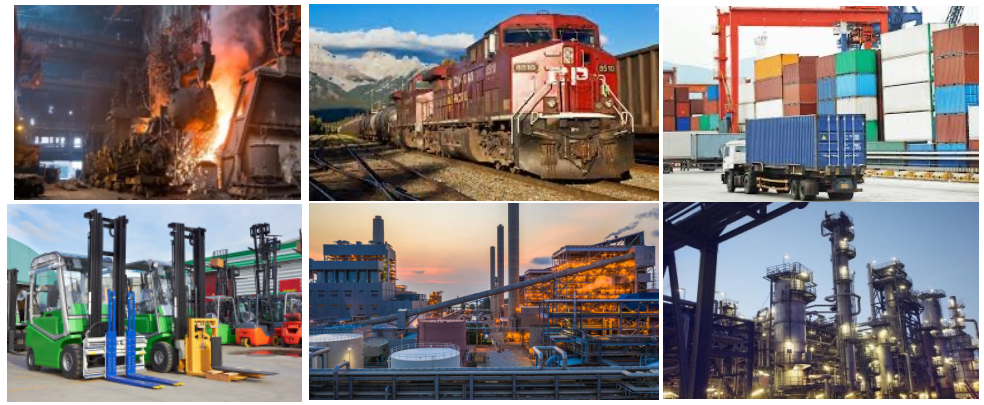
*Assumes half from wind at 60% capacity factor, half from solar PV at 30% capacity factor, 10 MWh/tNH_3

[1] Estimates calculated based on assumptions from: *Ammonfuel: An industrial view of ammonia as a marine fuel*. Alfa Laval, Hafnia, Haldor Topsoe, Vestas, Siemens Gamesa (2020).
[2] Raucci, C., Bonello, J.M., Suarez de la Fuente, S., Smith, T. & Søgaard, K. (2020) *Aggregate investment for the decarbonisation of the shipping industry*. UMAS. London. Available at: https://www.globalmaritimeforum.org/ content/2020/01/Aggregate-investment-for-the-decarbonisation-of-theshipping-industry.pdf
[3] Krantz, R., Søgaard, K. & Smith, T. (2020) *The scale of investment needed to decarbonize international shipping.* Global Maritime Forum. Available at: https://www.globalmaritimeforum.org/news/the-scale-of-investmentneeded-to-decarbonize-international-shipping

Accelerating Maritime Decarbonization via Multi-Sectoral Collaboration

Ammonia/hydrogen volume moving through marine ports as cargo and fuel has the potential to increase dramatically.

This presents potential for offtake opportunities in adjacent industries

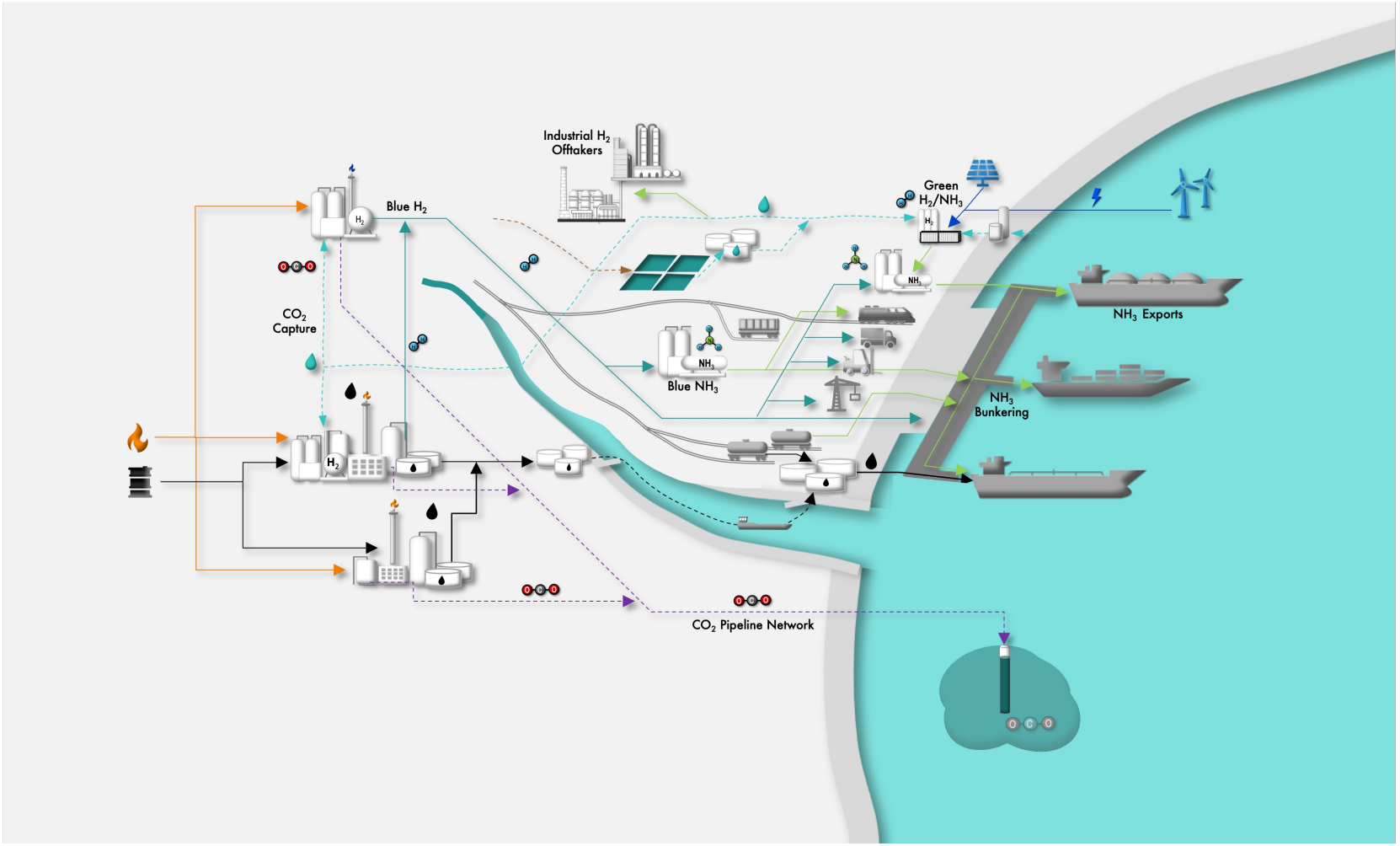


Industrial cluster benefits

- Joint investment in infrastructure development; coordinated strategy, planning, and operations
- Pooling of risk and resources, creates unique opportunities for integration and optimization
- Allows participants to benefit from the greater collective operating scale, diversity, and complexity of the cluster to accelerate decarbonization

Marine ports are multi-modal, global-scale trade and demand centers that can serve as an anchor and integrator for low-carbon ammonia and hydrogen industrial clusters

LCRI Port Low-Carbon Ammonia Cluster Value Chain Project



Example Port Low-Carbon Ammonia Cluster Configuration

PLCA Cluster Project objectives:

- Evaluate opportunities for integrated low-carbon ammonia and hydrogen supply and use within and export from an industrial cluster centered around a major shipping port,
- Characterize transition pathways and configuration of a PLCA cluster and identify the impacts that such a cluster may have on the port itself, local/regional industry, and energy and commodity markets.

LCRI

LOW-CARBON RESOURCES INITIATIVE

Enabling the Pathway to Economy-Wide Decarbonization

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