Study on the Green Ammonia Supply Chain: Production, Storage and Export of Green Ammonia from India via seaborne transport

Knowledge Dissemination Workshop

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

H2Uppp
International Hydrogen Ramp-up Program

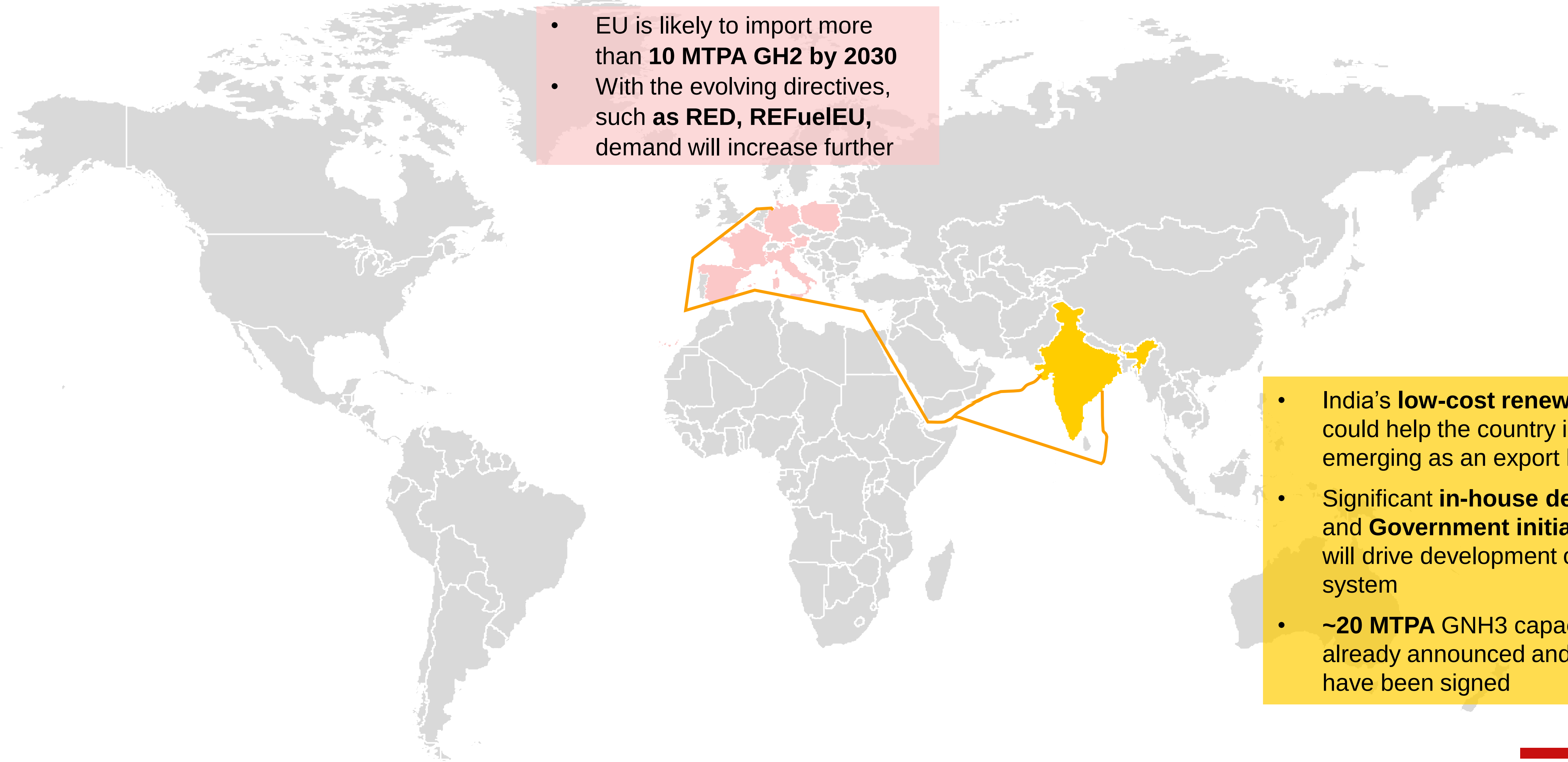
RWE

Indo-German Energy Forum

1. **Project Scope and Approach**
2. **Key findings on techno-economic assessment**
3. **Key Findings from Export Infrastructure Study**

Project Scope and Approach

Context: Green ammonia demand from EU offers export opportunity from India



- EU is likely to import more than **10 MTPA GH2 by 2030**
- With the evolving directives, such **as RED, REFuelEU,** demand will increase further

- India's **low-cost renewable** could help the country in emerging as an export hub
- Significant **in-house demand** and **Government initiatives** will drive development of eco-system
- **~20 MTPA** GNH3 capacity is already announced and MoUs have been signed

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Context: A techno-economic assessment of production, storage and export of GNH3 from India is required to assess the feasibility

Scope of Work

- **Review of RE market in India** pertaining to GNH3 production
- Overview **on land, water and infrastructure, local technology availability and sustainability dimensions along value chain**
- **Review of regulatory framework, certification scheme, trade regulations** in India and EU/Germany
- **Techno-economic scoping** for 600 kTPA green ammonia production facility
- Assessment of **export infrastructure, safety requirements** for seaborne transport

This study is intended to increase the knowledge and expertise in India, required for the market ramp-up of green hydrogen and PtX including the implementation of first green ammonia projects

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A modular approach was undertaken to assess the 5 potential states for ammonia exports to Europe

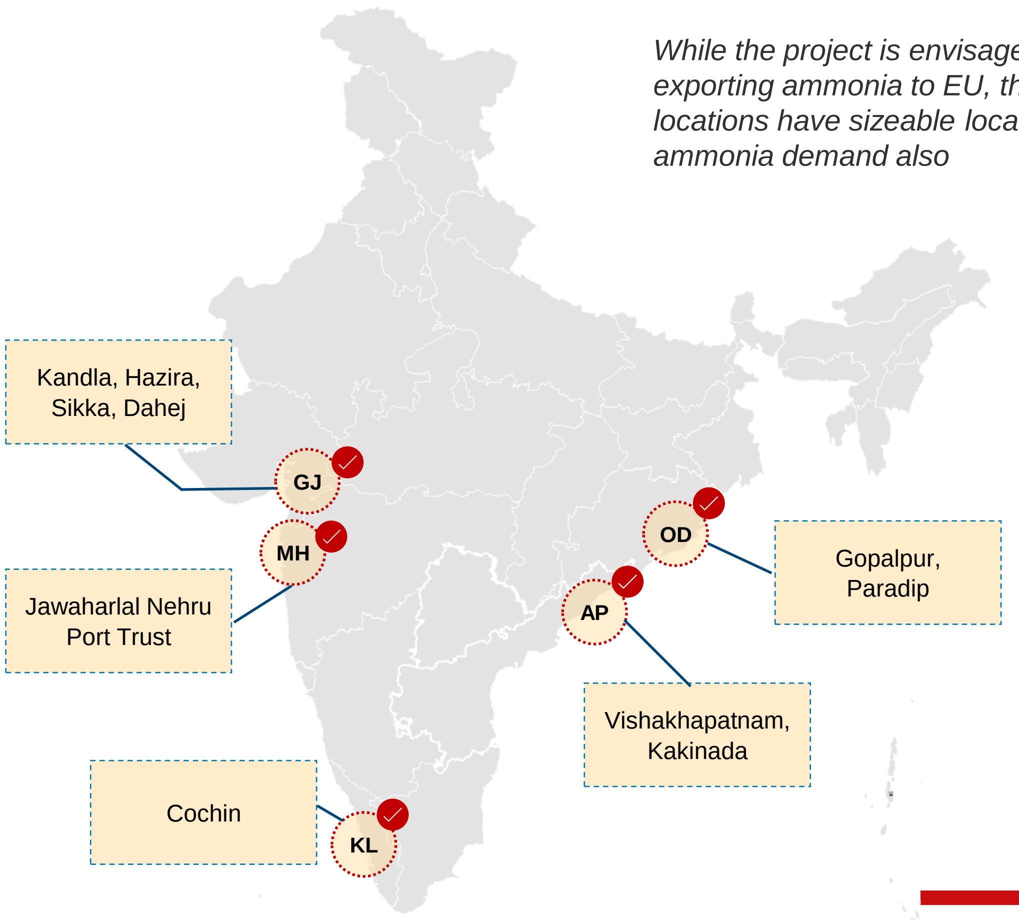
Step by step approach to assess feasibility of exports

1. **General framework conditions**
   - Overview of RE market, land, technology, and other aspects in India
2. **Specific framework for EU exports**
   - Regulatory framework and trade regulations for exporting to EU
3. **Techno-economic scoping for 600 ktpa GNH3 project**
   - Production setups and techno-economic assessments for shipping product to EU
4. **Export infrastructure assessment**
   - Identifying infrastructure required, its availability and associated layout

Assessment of the landed cost of ammonia in European ports

5 coastal states have been shortlisted for assessment

While the project is envisaged for exporting ammonia to EU, these locations have sizeable local ammonia demand also



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General and Specific Framework Conditions

RED-II and 1st set of Delegated Acts have specified criteria for labelling green hydrogen and ammonia

Additionality — Article 5 of Delegated Act Article 27

- **RES-E used for H2 production is:**
  - Generated in the same installation;

    OR
  - Sourced via renewables PPAs
- 5(a) RES-E plants must be new
  - Started operating no more than **36 months** prior to the installation of the electrolyser
- 5(b) RES-E plants must be unsupported
  - Has not received operating or investment support

Temporal Correlation — Article 6 of Delegated Act Article 27

- **H2 production takes place:**
  - In the same calendar month than the sourced RES E generation (till Dec 2029)
  - In the same hour than sourced RES E
  - generation (from Jan 2030)

  OR
- Storage option
  - Electricity is sourced from a storage facility with the same grid connection point than the electrolyser or RES-E plants
  - Storage facility is charged at the time of generation of the contracted RES-E plants

  OR
- H2 production takes place
  - during a one-hour period where the day ahead price of the concerned bidding zone is < 20 €/MWh; OR
  - Is < than 0.36 times the price for a certificate of 1 ton of CO2 equivalent

Geographical correlation — Location of electricity generating units and electrolysers

- **7(1a)** Electrolyser and RES E plants are
- located in the same bidding zone

  OR
- **7(1b)** Electrolyser and RES E plants are located in interconnected bidding zones
  - Electricity prices of the day ahead market in this zone are ≥ the prices in the electrolyser's bidding zone

  OR
- **7(1c)** RES-E generating plants are located in an offshore bidding zone interconnected to the electrolyser's bidding zone

As per RED-II and 2nd set of Delegated Acts, GNH3 having emission intensity up to 0.61 tCO2eq./t can be exported to EU

Hydrogen Production → **Haber-Bosch (NH3 conversion) and ASU operations** → **Liquid ammonia** → **Shipping** → **Liquid ammonia at destination**

GHG threshold requirement for Green Ammonia
~0.61 tCO2e/t

Energy Use	Renewable electricity/ GRID/ GDAM Electricity consumption: **56 kWh/kg H2 production**, **6 kWh/kg** for compression, **0.3 kWh/kg NH3** production (includes Haber-Bosch and ASU operations)	**MGO** used during shipping **16 MT/day** during shipping; **9 MT/day** during port call, anchorage Boil off-rate of ammonia: **0.04% per day** Reliquification: **0.224 kWh/kg** Pumping: **0.25 kWh/m3 NH3** (at both source and destination)
Emission Intensity	**0 tCO2e/t** for RE power; **State grid intensity** for Grid power and **NIL** for GDAM	**3.15 tCO2/t** emissions from **MGO combustion** **0.711 tCO2eq./MWh** for Indian Grid **0.59 tCO2eq./MWh** for EU/German Grid

Margin available for use of fossil fuel
~0.51 – 0.55 tCO2e/t NH3

Permissible grid power could be in range of 7.8 – 8.0%

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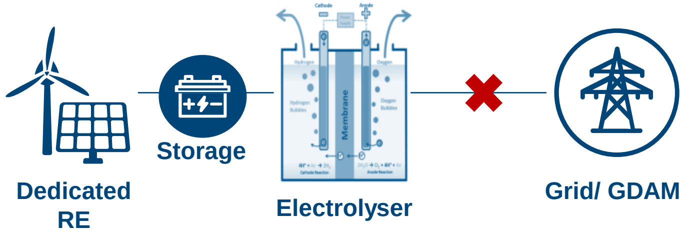
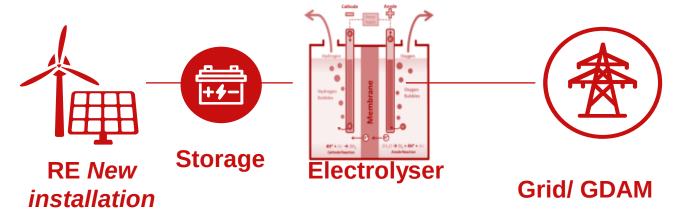
Three production setups have been assessed for GNH3 production and export to EU

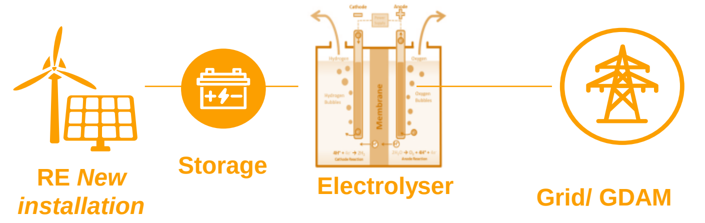
Option 1:
Electricity produced off-grid



Option 2:
Co-located RE + BESS + Permissible Grid + GDAM



Option 3:
Co-located RE + BESS + Optimized Grid + GDAM



- 100% RE based electrolyser and ammonia loop operations
- Lowest emission intensity among all options for green ammonia production
- RE and BESS setup is considered to be captive

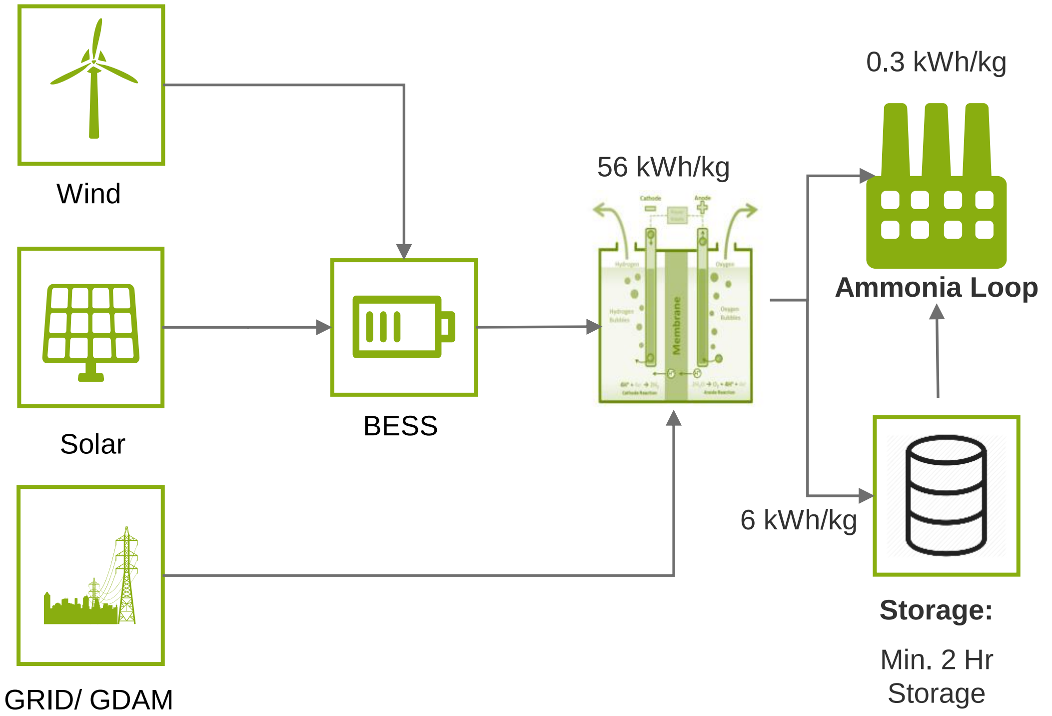
- Permissible Grid electricity (as per emission thresholds and state emission intensity), RE+BESS and GDAM (Green Day Ahead Market) are utilized for the electrolyser and ammonia operations.

- Optimized Grid electricity (basis optimization of annual fixed cost) and RE+BESS and GDAM (Green Day Ahead Market) are utilized for the electrolyser and ammonia operations.

Respective regional solar and wind generation profiles of the 5 target states have been considered for optimizing RE, BESS and storage sizing

Approach: The sizing of each production setup has been determined using an Excel based optimization tool

System Configuration



The ammonia loop is run constantly throughout the day basis which the sizing of RE, Electrolyser, BESS, and Storage are optimized

Objective function and key assumptions/constraints

- The objective function targets to minimize the annual expenditure of the electrolyser, storage, RE and BESS setup.
- $AFC = f(Solar, Wind, BESS, Electrolyser, Storage)$
- $Opex = f(Electricity\ from\ grid, Electricity\ from\ GDAM)$
- $\boldsymbol{Objective\ function = Min\ (AFC + Opex)}$
- **Maximum Grid offtake** ~7 – 8% % based on EU import criteria
- Minimum load of electrolyser – 30%

Particular	Unit	AFC value	Capex
Annualized solar capex	INR Cr/MW	0.59	INR 4.5 Cr/MW
Annualized Wind capex	INR Cr/MW	0.88	INR 7.5 Cr/MW
Annualized 2hr BESS capex	INR Cr/MW	0.58	INR 3.5 Cr/MW
Annualized Alkaline electrolyser capex	INR Cr/MW	0.9	USD 600k/MW
Annualized storage capex	INR Cr/tonne	2	USD 1 Mn/ton
Landed cost from GDAM	INR/kWh	~8 – 9	-

* Energy figures are towards consumption in the process

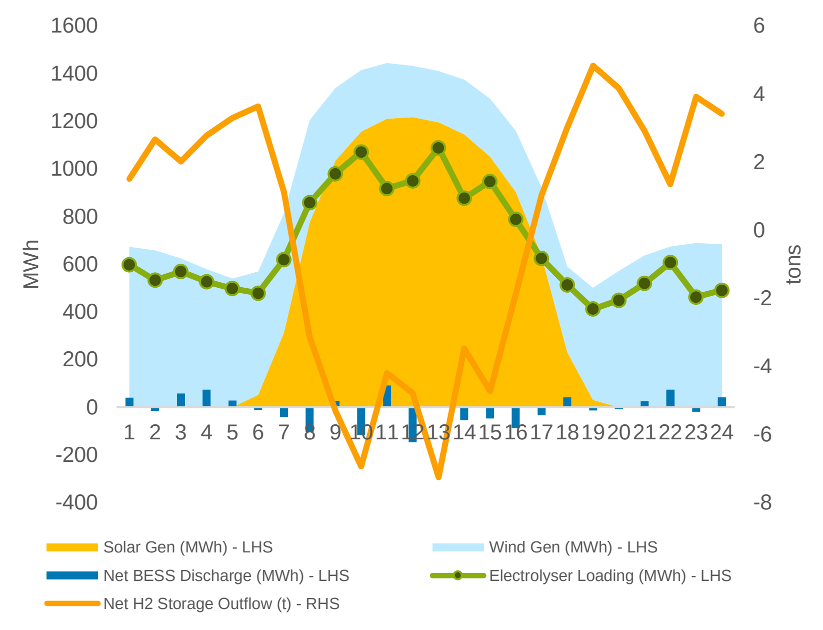
Sample output of optimization modelling (for Gujarat location)

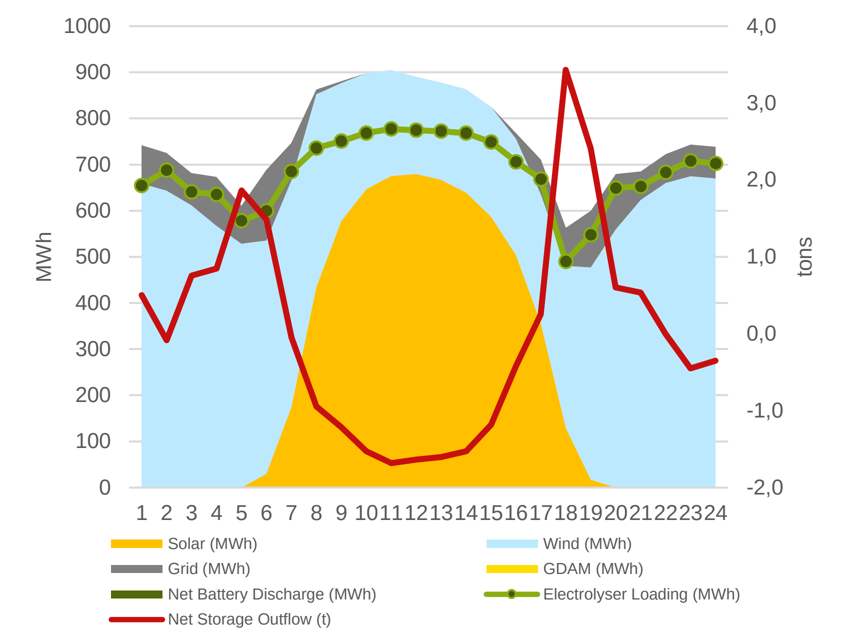
GJ solar and wind profile

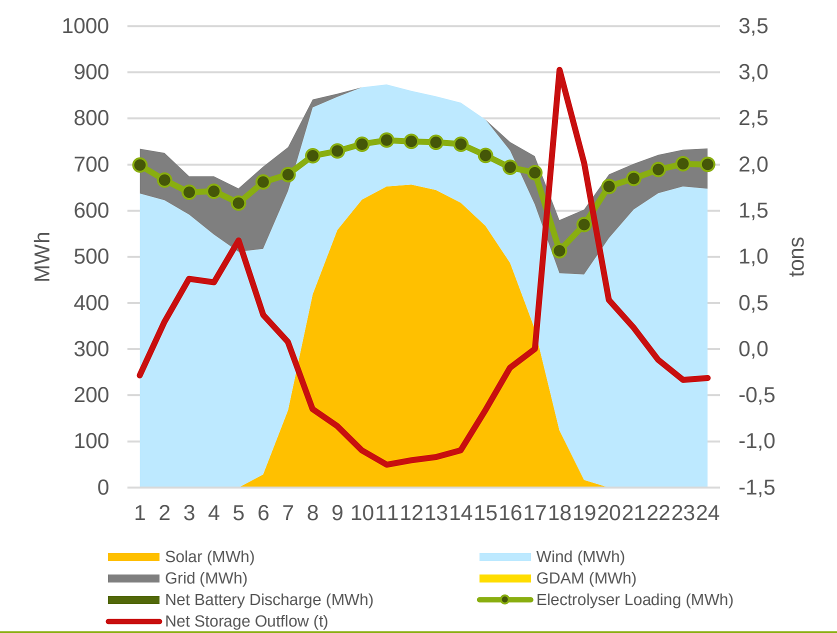
Particular	Unit	Offgrid (RE+BESS)	RE+BESS+7.8% Grid	RE+BESS+GRID
GRID Power	*%*	0%	7.8%	10 – 12%
Electrolyser Capacity	*MW*	1050 - 1150	750 - 900	730 - 800
Solar	*MW*	1400 - 1600	800 - 1000	800 - 900
Wind	*MW*	1500 - 1700	1400 - 1600	1450 - 1550
H2 Storage Capacity (GH2)	*Tonnes*	70 - 90	20 - 30	20 - 30
Electrolyser CUF	*%*	**60 – 70%**	**80 – 90%**	**85 – 90%**
BESS (2 hr)	*MW*	**400 - 500**	**0**	**0.0**
Landed Cost of electricity	*INR/kWh*	3.8 – 4.5	3.30 – 4.00	3.30 – 4.00
LCOA	*USD/ton*	**900 - 1050**	**900 - 1000**	**850 - 1000**

Sample output of optimization modelling (for Gujarat location)

System loading







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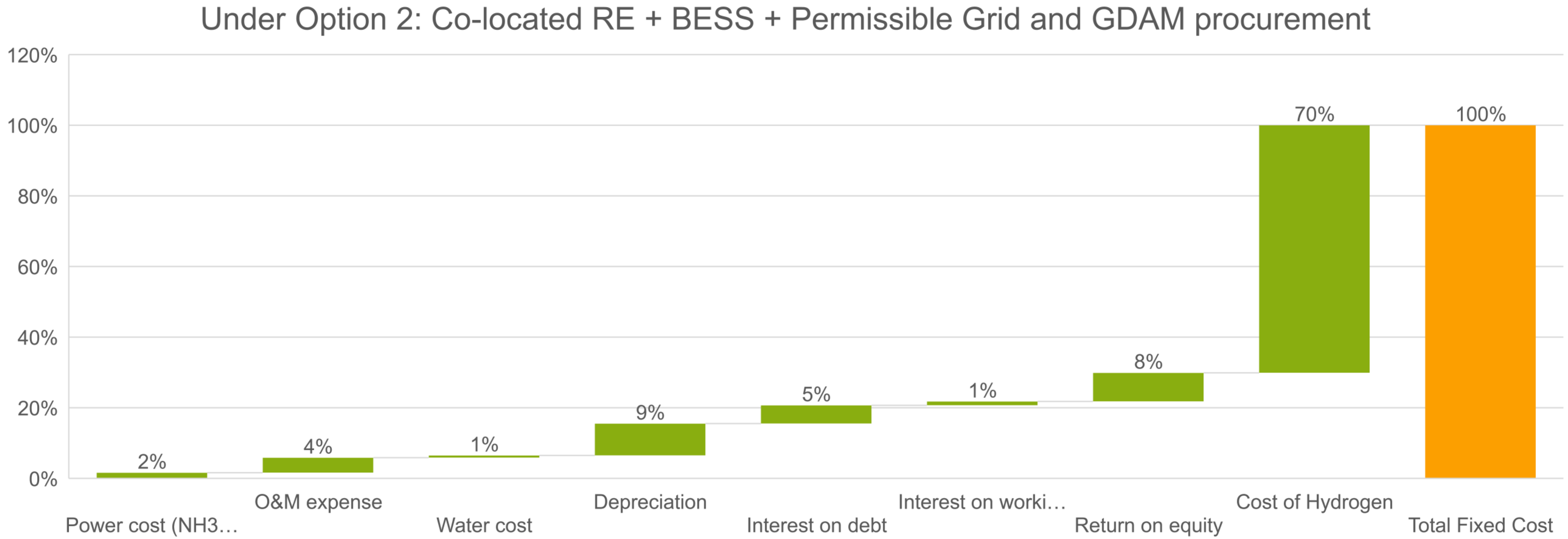
Ammonia cost breakdown



Reduction in LCOH is critical to bridge the LCOA gap between grey and green ammonia

Source: Deloitte analysis

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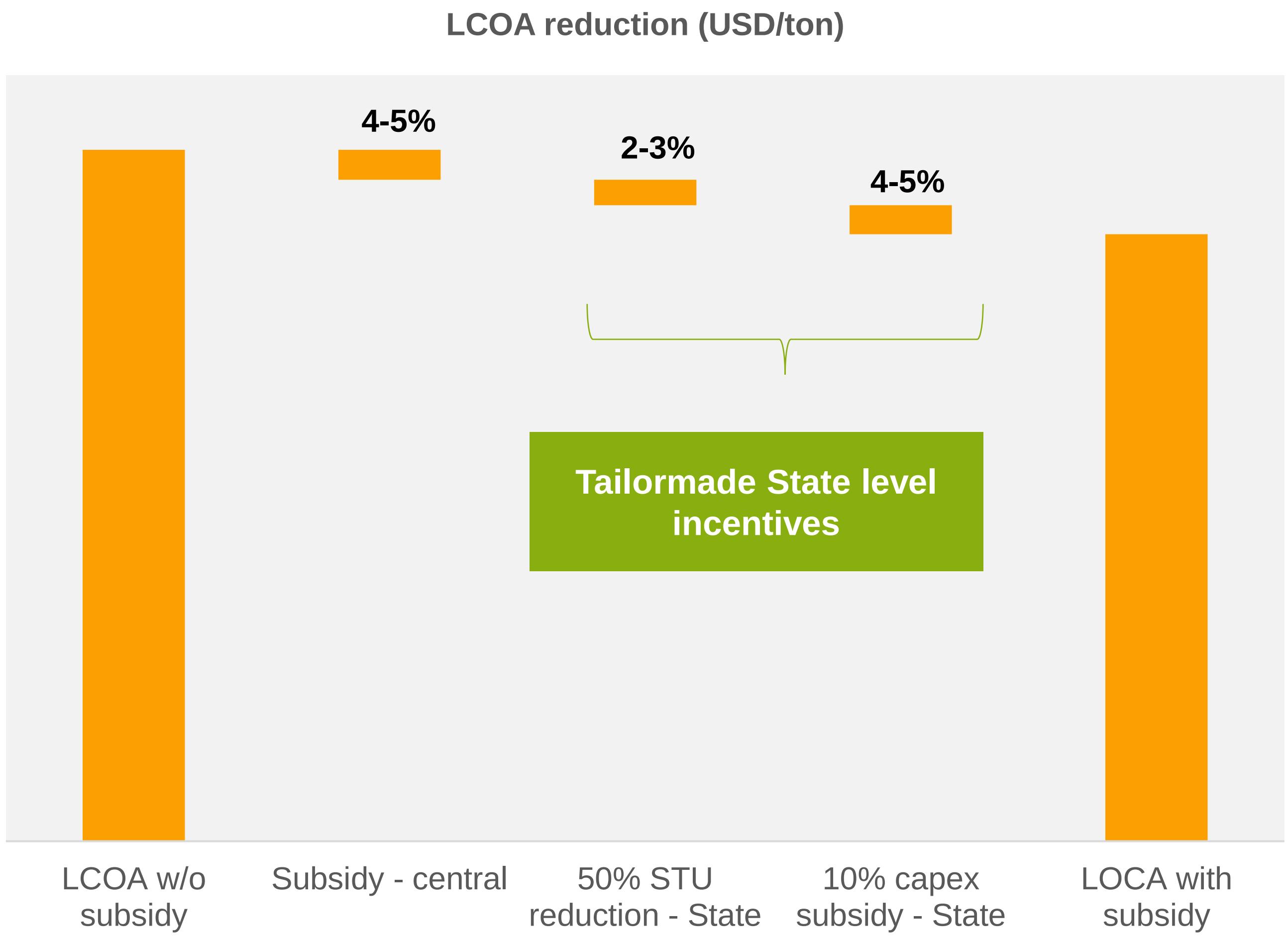
Impact of subsidies on Green Ammonia – Cost of production can be reduced by 10 – 12% through central and state level subsidies



Gross Impact on LCOA

- Average subsidy of **INR 30/kg** can reduce the **LCOA by 2-3%**
- Electrolyzer PLI can reduce the **LCOA by 1-2%**
- STU charge waiver and Capex subsidy can further reduce **LCOA by 6-8%**

Source: Deloitte analysis

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Key findings from techno-economic assessment

01 Selection of RE plant location and optimization of RE and BESS sizing are critical to optimize the LCOH and LCOA

02 Leveraging grid power to the permissible limit is important to optimize BESS capacity

03 Optimization Hydrogen storage capacity is critical to ensure continuous flow of hydrogen to Ammonia loop

04 Support measures would help in increasing India’s regional competitiveness.

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Export Infrastructure Study

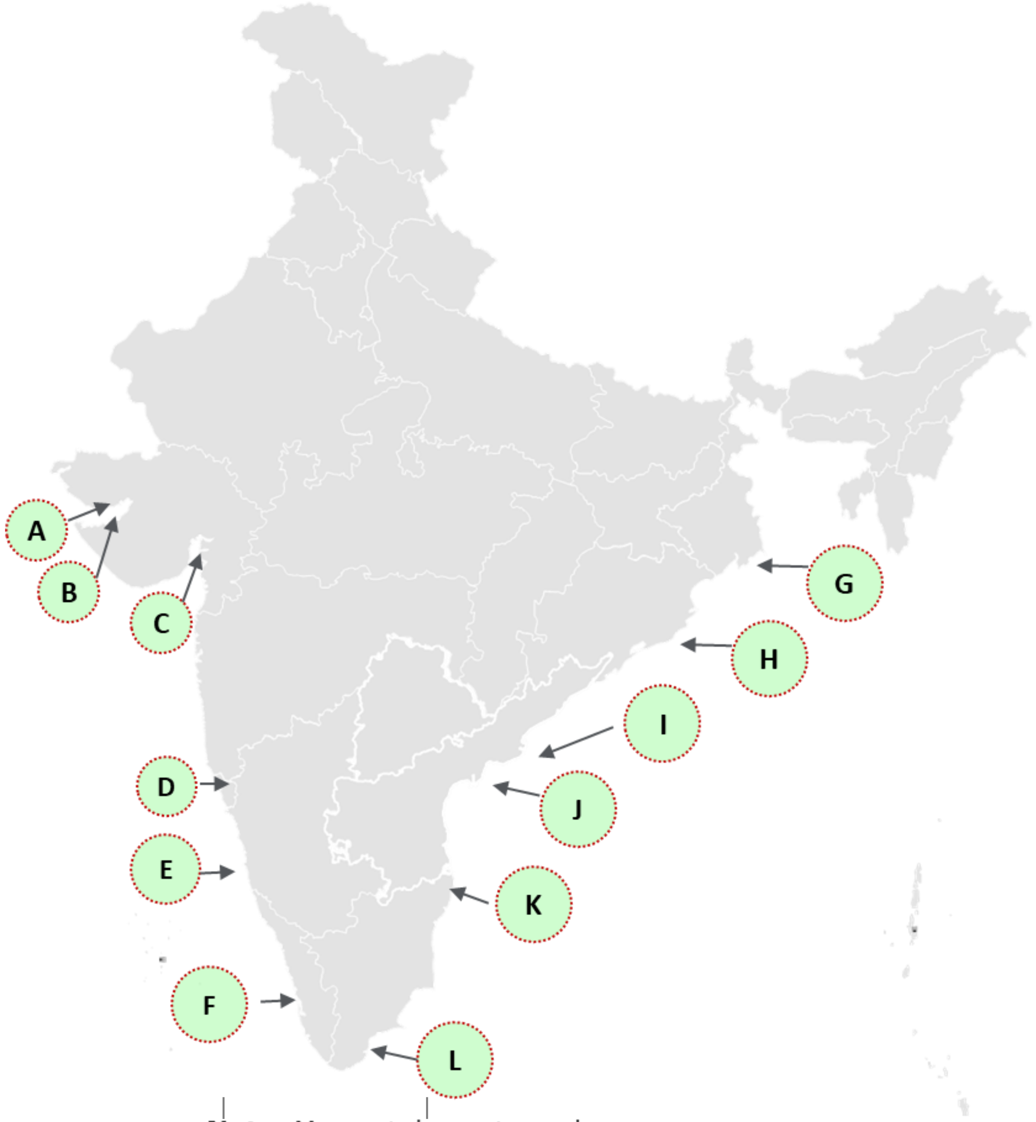
Options for seaborne transport of green ammonia from India to Europe

1. Gas carriers with onboard refrigeration system offer an economical and proven mode of shipping ammonia.
2. For long distance ocean shipments of ammonia; Large Gas Carriers and Mid Size Gas Carriers with refrigerated cargo tanks are used. Very Large Gas Carriers are not currently being used for ammonia shipments.

View on vessels availability for globally shipping ammonia

- 114 unique vessels (with a cumulative 2.5 Million DWT) were deployed for shipping ammonia over last 2 years
- Cumulative ammonia carrying capacity of the unique vessels deployed in CY 2023 and in CY 2022 add to 1.9 MMT
- 200 LPG tankers in operation with typical storage capacity of ≥ 40,000 MT are cable of carrying ammonia at full refrigeration
- 20 Large Gas Carriers and 140 Mid Size Gas Carriers in service
- 1,200 LPG tankers could also become suitable for carrying ammonia shipments
- Existing fleet of more than 600 LNG vessels could also handle ammonia post retrofitting
- 19 Very Large Ammonia Carriers new building ships orderbook of 88,000/93,000 CBM each with deliveries commencing from 2026 onwards.

Summary of Export infrastructure



Note: Map not drawn to scale

List of seaports handling ammonia imports in bulk

West Coast India		East Coast India	
A	Kandla	G	Haldia
B	Sikka	H	Paradip
C	Dahej	I	Visakhapatnam
D	Mormugao	J	Kakinada
E	Mangalore	K	Ennore
F	Cochin	L	Tuticorin

Export terminal may comprise of Marine Loading Arms with related cargo transfer marine infrastructure including a dedicated pipe rack at an existing port berth. Storage tanks at port premises may not be mandatorily established. Direct transfer of green ammonia from storage tanks set up at the production facility to vessels may likely be a more viable proposition.

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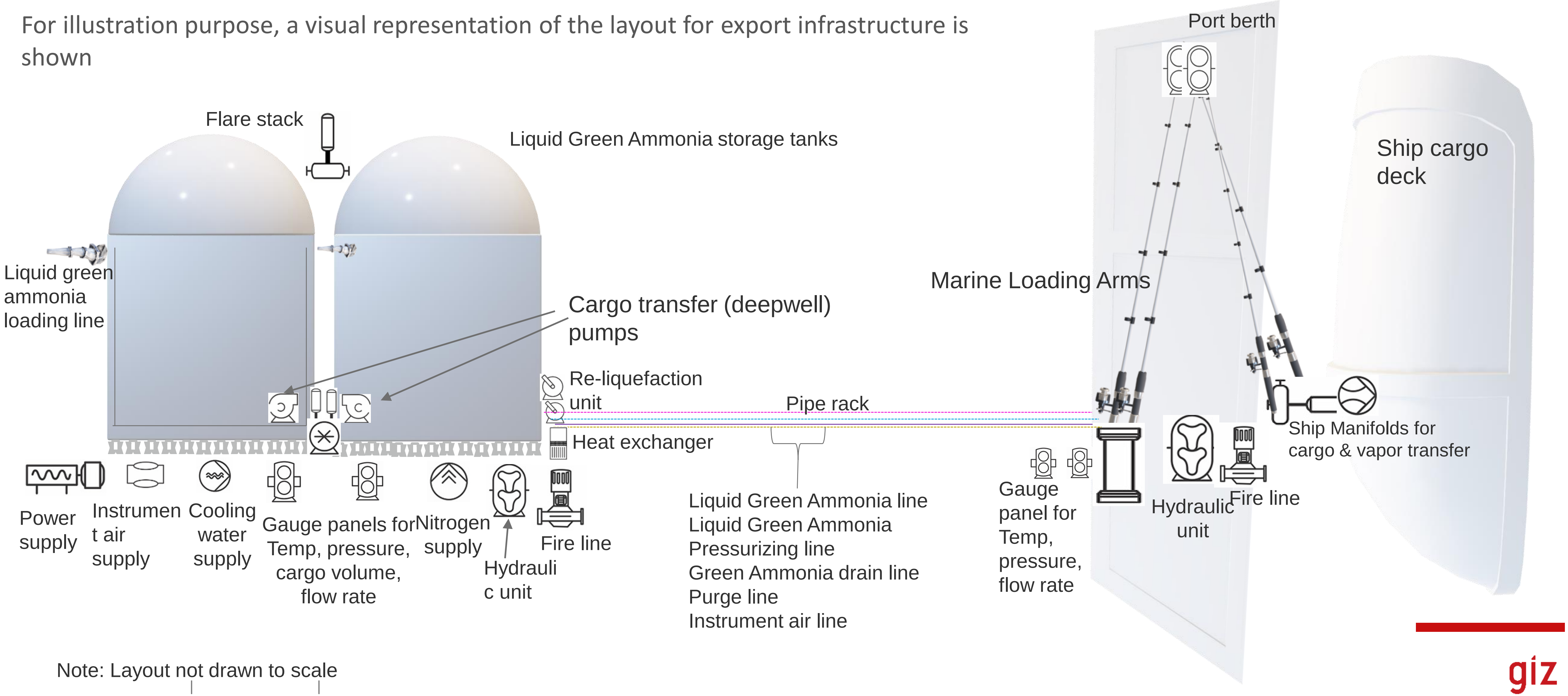
Layout of Export infrastructure

For illustration purpose, a visual representation of the layout for export infrastructure is shown



Note: Layout not drawn to scale

Green Shipping: Investigation on multipurpose use of ammonia terminal for fueling of ammonia powered ships

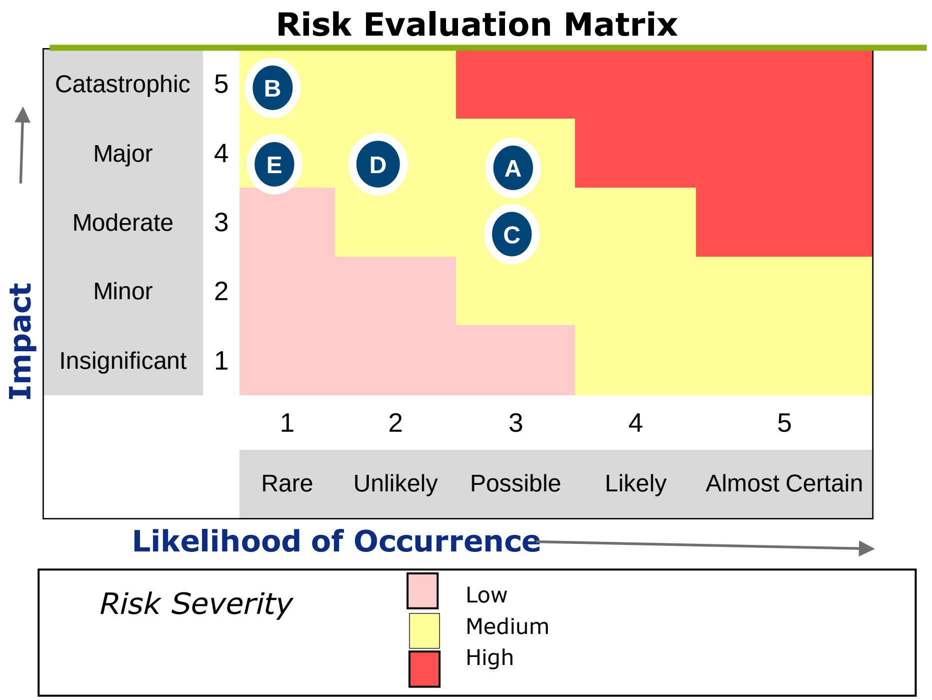
Bunkering options

- Green Ammonia as bunker is supplied using marine loading arms at terminal for ships brought alongside
- Green ammonia is filled in bunker supply vessels for bunkering ammonia powered ships located at alternate berths/offshore locations. Green ammonia is filled in bunker supply vessels from marine loading arms.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Bunkering vessel	Pressurized tanks	Semi-refrigerated tanks	Pressurized tanks	Semi-refrigerated tanks
Ship to be bunkered	Pressurized tanks	Pressurized tanks	Semi-refrigerated tanks	Semi-refrigerated tanks
Green ammonia transfer arrange-ments	Bunkering vessel transfers green ammonia using general transfer pumps. Vapor return system from ship taking bunkers to the bunkering vessel will be needed.	Bunkering vessel transfers green ammonia using installed heater (sea water heated system) and booster pump. Vapor return system from ship taking bunkers to the bunkering vessel will be needed. Re-liquefaction system on bunkering vessel is needed to handle high pressure vapor return.	Bunkering vessel will need liquefaction plant to reduce pressure by lowering temperature. Vapor return system from ship taking bunkers to the bunkering vessel will be needed. Compressor on bunkering vessel is needed to increase pressure of vapor return.	Bunkering vessel may need cooling arrangement. Vapor return system from ship taking bunkers to the bunkering vessel will be needed.

Sources: Assessments from IACS member firms

Analysis of safety aspects for exporting green ammonia via seaborne transport



A

Risk: Non-compliance to safety protocols during ship loading and unloading, cargo changeover (i.e. changing from LPG to ammonia)
Mitigation: Regular training of seafarers wrt SOPs for cargo operations, flushing and draining systems, etc.

B

Risk: Severe collision or stranding that could lead to cargo tank damage and uncontrolled release of ammonia
Mitigation: Compliance to traffic separation schemes be ensured, spill containment systems to be placed on board the vessels, remote stations for monitoring, etc.

C

Risk: Operating personnel come in contact with ammonia vapors
Mitigation: Operating personnel to adopt safe working practices and ensure wearing Personal Protective Equipments (PPE). Functional emergency showers and eyewash

D

Risk: Breach in ammonia tank and associated piping
Mitigation: Dry drip tray (with a drain leading to enclosed tank), foam/dry chemical powder spill mitigation system to be placed onboard, etc.

E

Risk: Cargo comes in contact with parts containing Cu, Zn or alloys
Mitigation: Compliance to IGC Code for ships structural aspects to be ensued, Ammonia test for stress corrosion resistance as per ISO 6957:1988/IACS

Compliance to the Rules and Regulations as per the IGC Code, OCIMF,SIGTTO Guidelines, ISGOTT, IACS , etc.
is mandated for safely exporting green ammonia via seaborne transport.

Sources: The International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code), Oil Companies International Maritime Forum (OCIMF), Society of International Gas Tanker and Terminal Operators (SIGTTO), International Safety Guide for Oil Tankers and Terminals (ISGOTT), International Association of Classification Societies (IACS)

Questions?

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We will be sharing the presentation with the webinar participants

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