H2SITE

Leveraging ammonia-cracking solutions to decarbonize the maritime industry:

The APOLO project

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Shipping industry responsible for ~ 13% of total CO_2 emissions from the EU transport sector

60% of maritime emissions in EU from international shipping

Key bottlenecks for the green transition

- **High prices** of alternative-fuel compared to fossil
- **Limited availability** of low-carbon fuels
  (supply chain, fuel transport and storage)
- **Low technical maturity** of marine power conversion solutions and relevant infrastructure
  (most green marine tech not yet fully-commercial)

State of the art | Fossil fuels & green alternatives

	Fossil Fuels		Green transition alternatives					
	Oil (MGO, HFO)	**LNG**	**Biofuels** (bLNG, HVO, bMeOH)	**Syn. Fuels** (eMeOH, eLNG)	**Ammonia**	**H_2** (CH_2, LH_2)	**Batteries**	**Nuclear**
Power Conversion Technology & TRL* **	- ICEs **(TRL 9)** - Turbines* **(TRL 9)** **large vessels*	- ICEs **(TRL 9)** - Turbines* **(TRL 9)** **large vessels*	ICE/Turbines **(TRL 9)**	- ICE/Turbines **(TRL 9)** - SOFC**	- Cracker+PEM FC** - ICEs (with pilot fuel) **(TRL 7)** - SOFC**	- ICEs** - Fuel Cells **(TRL 7-8)** - Turbines**	**(TRL 9)**	Steam Turbines **(TRL 9)**
Benefits	- Abundancy - Supply chain - Lower Price	- Abundancy - Supply chain - Emissions<Oil	- High **energy density** - **Drop-in** fuels	- High **energy density** - **Drop-in** fuels - Good option as transition fuel	- **Established** Storage and Supply tech - **Less energy to produce** than Syn-Fuels	- **Energy efficient** production process	- Most Energy Efficient option - High TRL - Low Emissions (grid-dependent)	- Energy density - No GHG - Unlimited range - Mostly used in large naval ships
Drawbacks/ Challenges	- Air quality (PMs, NOx, SOx) - GHG emissions	- Not "green" - CAPEX>Oil - Higher storage footprint than oil	- **Availability limited** by feedstock - Socio-economic challenges (for crop-based)	- Requires CO_2 to compose - **Requires CCS** onboard - **Energy intensive** production	- Safety risks to overcome due to NH_3 **toxicity**	- Complex & **Costly storage & transport** - Very **Low energy density**	- Very **low energy density** - Very **high charging power requirements** → Suitable only for small vessels	- High CAPEX - Safety risks - Nuclear waste - Best installed in land facilities - Public concerns

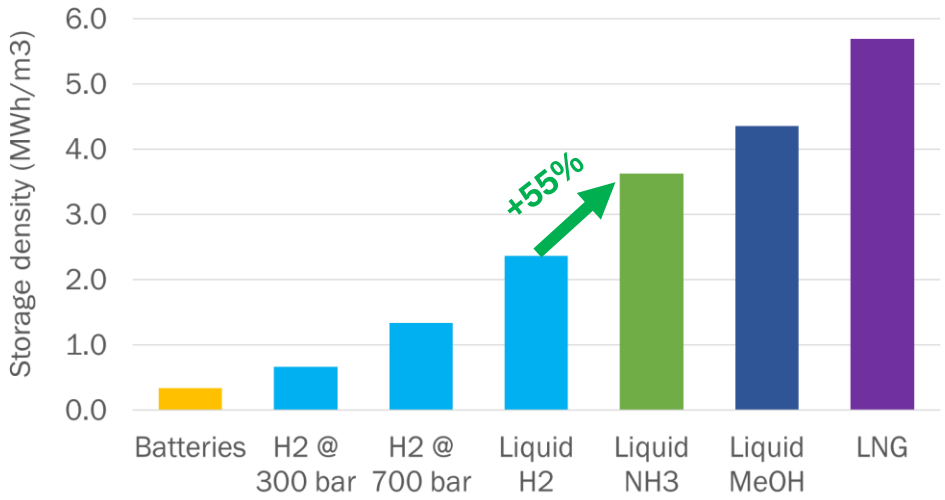
** Technologies at TRL 6 or lower

*** TRL referring to solutions available for maritime applications

Sources: Comparative report on alternative fuels for ship propulsion, Climate Action for the Shipping Industry, ETP Clean Energy Technology Guide

Low-C Ammonia as a fuel | A prominent energy carrier for maritime

Higher energy density, minimal emissions



- ✓ **High energy density**
  Ammonia is a prominent alternative to green H_2 due to lower storage space requirements
- ✓ **Near-zero onboard emissions**
  Ammonia-to-Power conversion does not produce CO_2 emissions.

Established supply chain

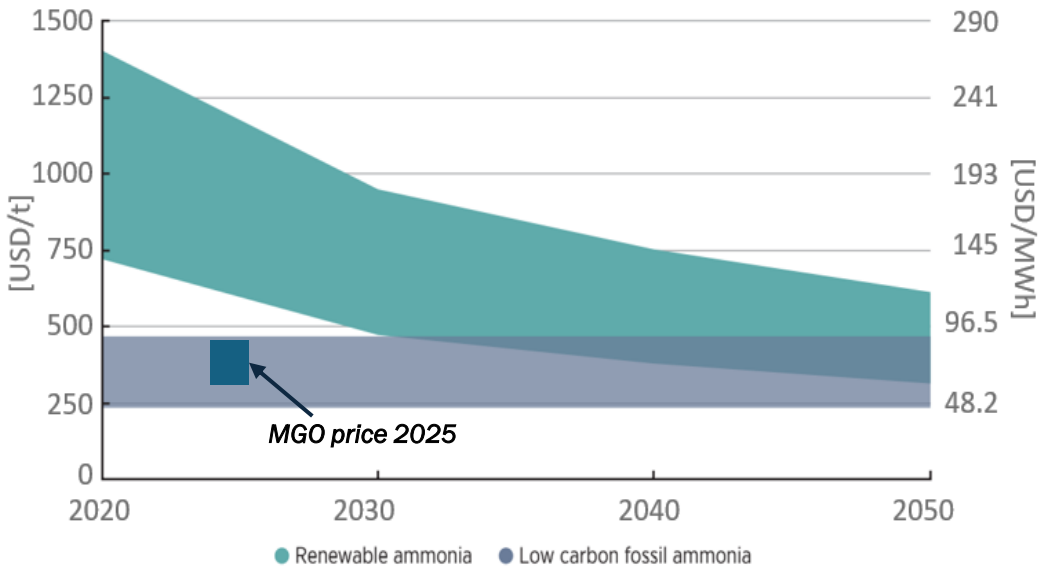
- ✓ **Production & Distribution**
  Infrastructure for production, transport and storage of NH_3 available and well-understood
- ✓ **Availability**
  150+ terminals in ports worldwide can handle and supply NH_3

Sources: IEA Global Hydrogen Review 2024, [1]Innovation Outlook: Renewable Ammonia

Economic challenges

- Low-carbon ammonia fuel cost
  Currently 2-3x the cost of MGO, requires scaling to become competitive

- Capital Expenditure for alternative-fuel Storage and Power Conversion
  Increased cost of low-carbon solutions both for retrofit and new-builts since they are newly introduced technologies



Technical challenges

- Availability of Bunkering infrastructure
  Ammonia terminals already available, but bunkering infrastructure is still limited

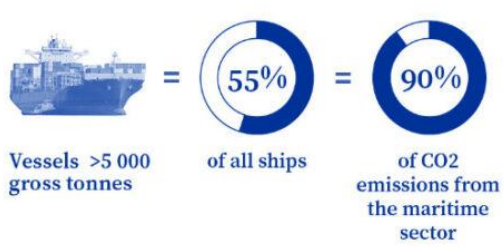
- Toxicity
  Safety risks well known and mapped, but a common maritime safety framework for bunkering and onboard infrastructure is still pending

Photo of first vessel-to-vessel ammonia bunkering operation

Sources: IEA Global Hydrogen Review 2024, [1]Innovation Outlook: Renewable Ammonia, Platts Ammonia Price,

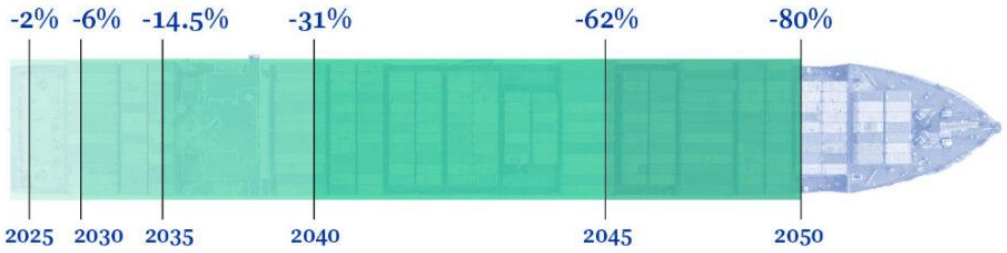
Carbon penalties | Financial incentives to enable low-carbon solutions

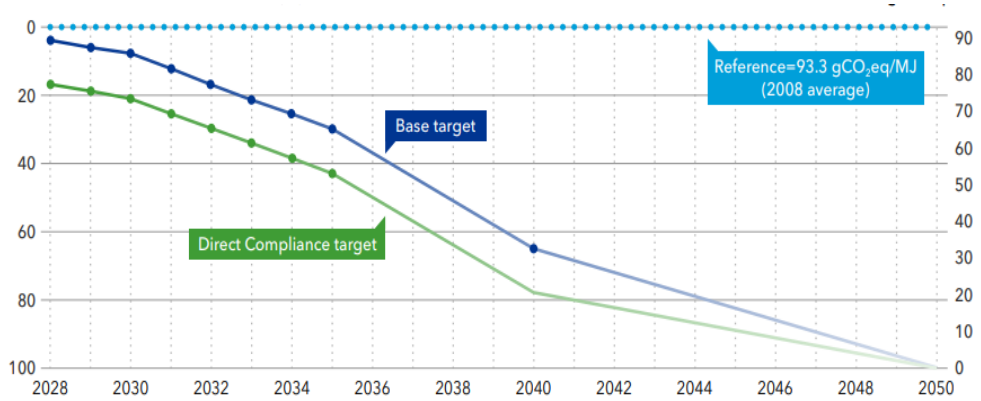
The FuelEU maritime regulation will oblige vessels above 5000 gross tonnes calling at European ports (with exceptions such as fishing ships):



→ to **reduce** the **greenhouse gas intensity** of the energy used on board as follows

Annual average carbon intensity reduction compared to the average in 2020





EU´s carbon pricing frameworks

ETS (Emissions Trading System)

1) Poses a cap on EU GHG emissions (across all industries)
2) Maritime: costs proportional to onboard (TtW) emissions
3) Applies to vessels > 5000GT since 2024
4) Only 50% of penalties for trips betwen EU/non-EU

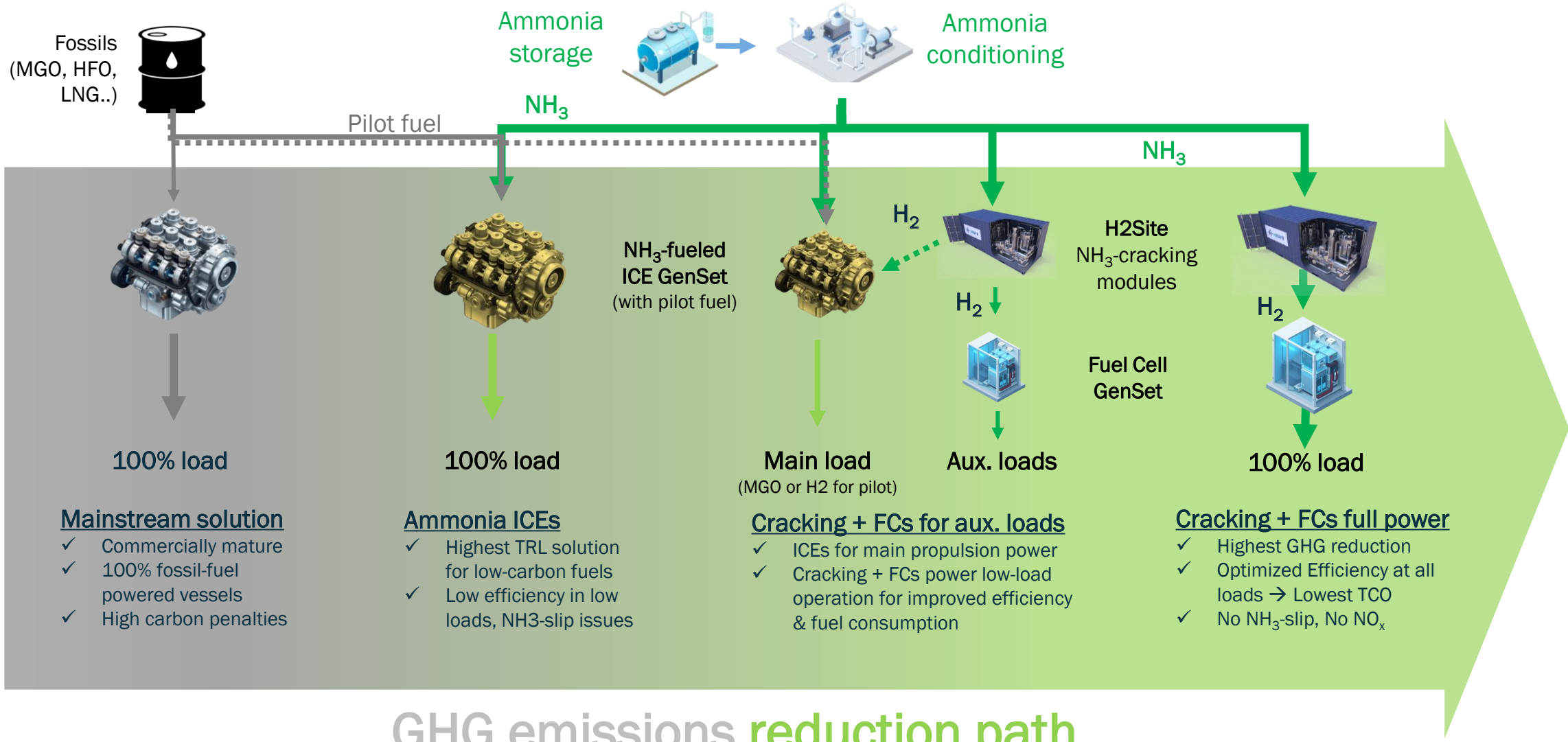
FuelEU Maritime

1) Regulates the fuel´s GHG intensity ($gCO2_{eq}$/MJ)
2) Penalties only if limit values exceeded
3) Applies to vesselts > 5000 GT, full-effect since 2026
4) Only 50% of penalties for trips betwen EU/non-EU

IMO´s Net-Zero framework (pending voting)

1) 1st global framework for international shipping
2) Regulates the fuel´s GHG intensity (gCO2eq/MJ)
3) Penalties for exceeding limit emissions
4) Applies to vesselts > 5000 GT

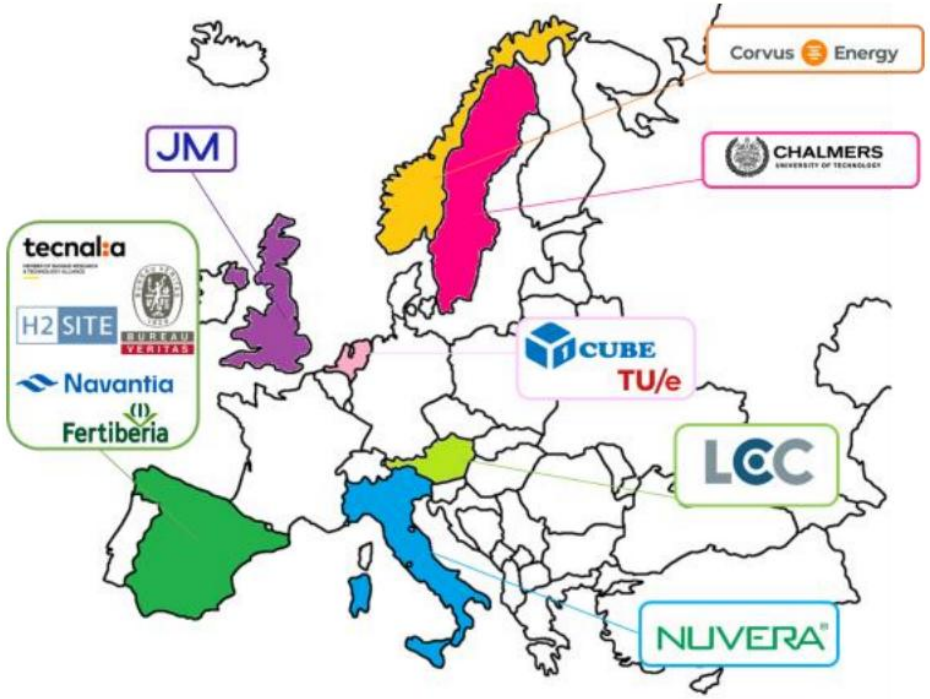
Onboard ammonia-to-power | Emissions reduction roadmap



GHG emissions reduction path

APOLO

ADVANCED **PO**WER CONVERSION TECHNO**L**OGIES BASED ON **O**NBOARD AMMONIA CRACKING THROUGH NOVEL MEMBRANE REACTORS



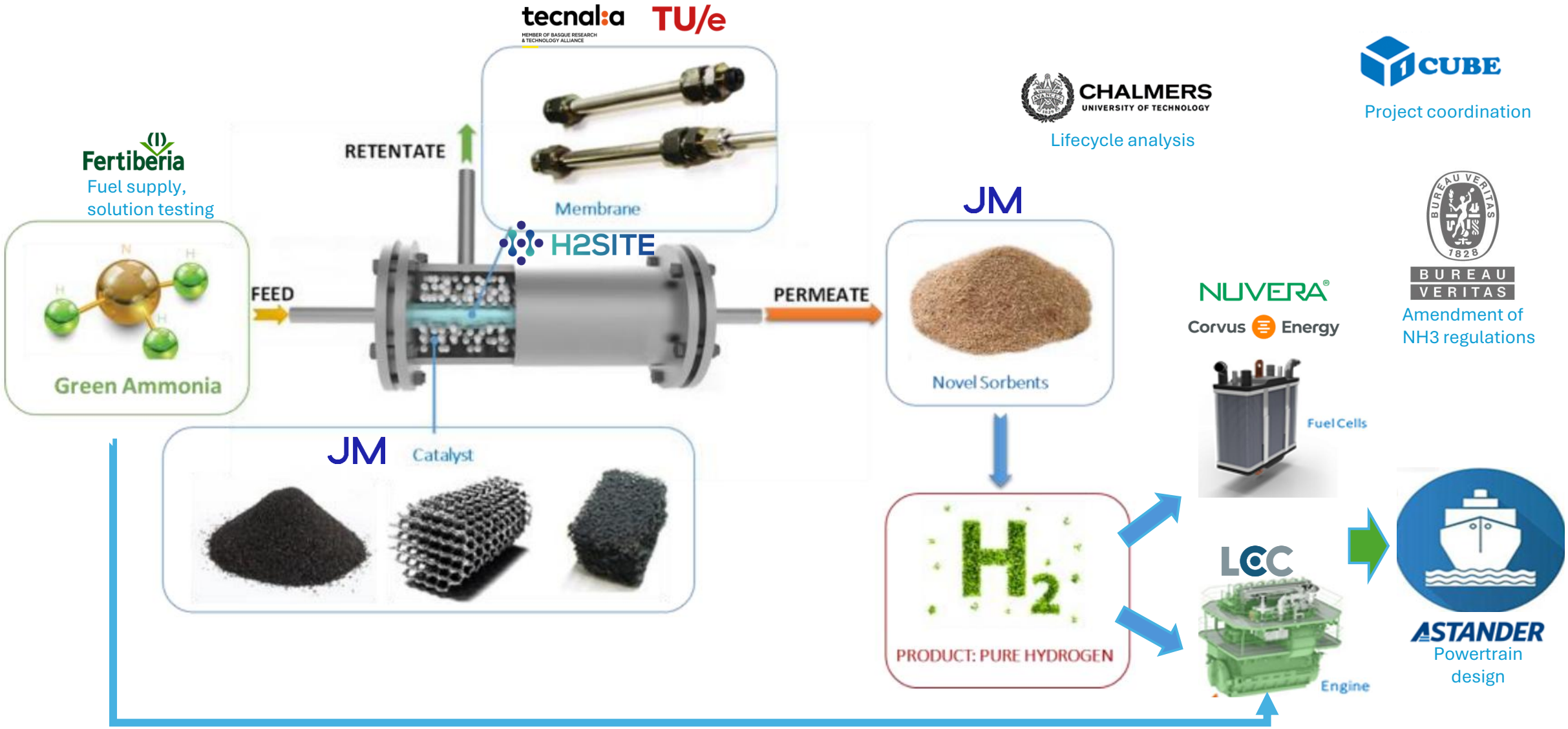
Technical Scope

Development and testing of 2x novel Ammonia-to-power ($125kW_e$) solutions:

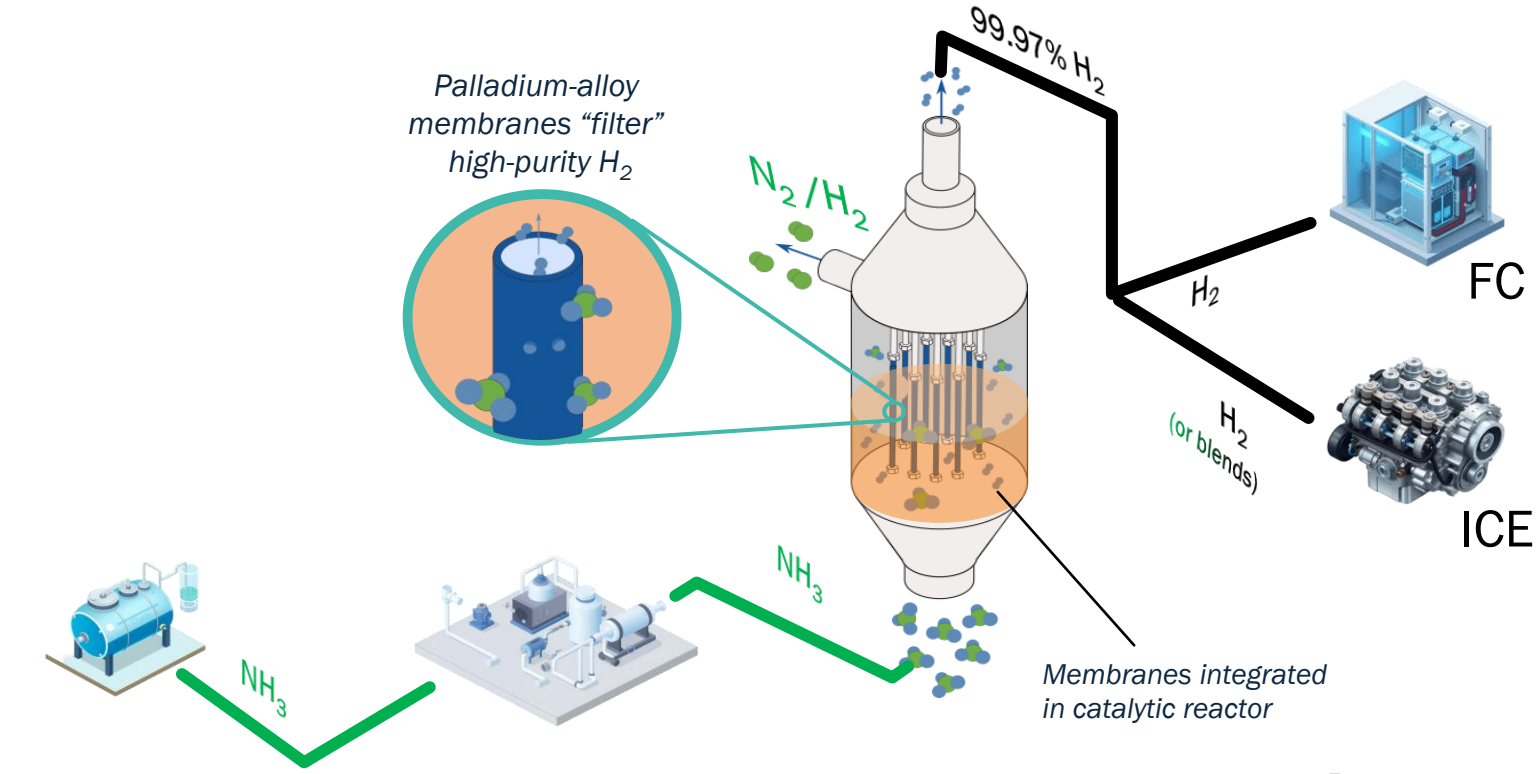
- ✓ FoaK NH_3-cracker + H_2-powered PEM Fuel Cell
- ✓ Partial NH_3-cracking to fuel a H_2/NH_3-powered 4-stroke ICE

Project Objectives

- Develop & validate 2x modular and scalable NH3-to-power configurations, reaching **TRL 5**
- Demonstrate an **LCOH reduction of 17-22%**
- Prove scalability for onboard **power up to 3MW**
- Amend EU/IMO NH3-fuel regulations
- Integrate full value chain stakeholders and develop LCA studies for the proposed solutions


tecnalia
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE
TU/e
Membrane
RETENTATE
H2SITE
Fertiberia
Fuel supply, solution testing
Green Ammonia
FEED
PERMEATE
JM
Novel Sorbents
JM
Catalyst
PRODUCT: PURE HYDROGEN
CHALMERS UNIVERSITY OF TECHNOLOGY
Lifecycle analysis
CUBE
Project coordination
NUVERA®
Corvus Energy
Fuel Cells
BUREAU VERITAS
Amendment of NH3 regulations
LCC
Engine
ASTANDER
Powertrain design

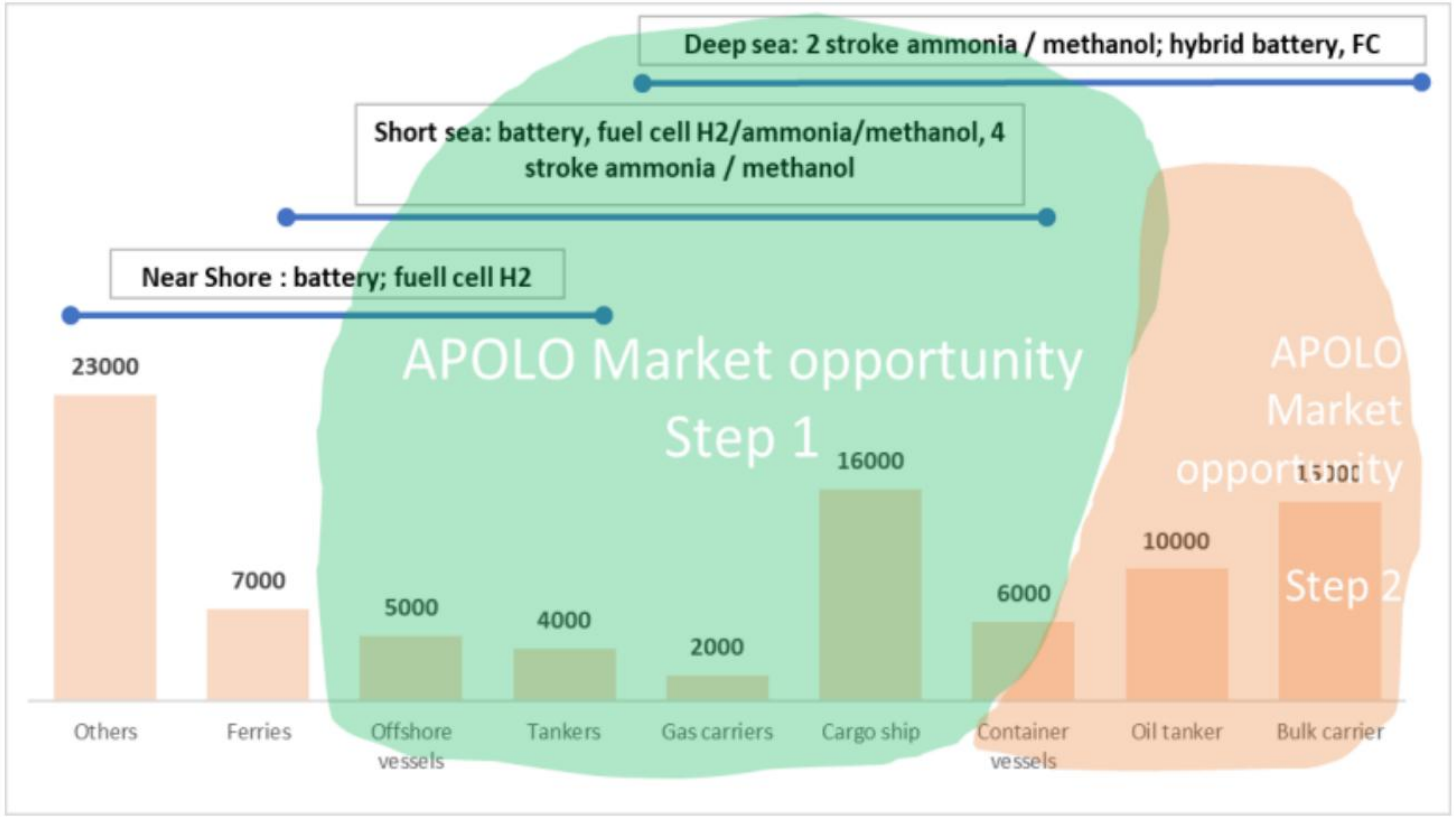
Advanced membrane reactors for high-efficiency ammonia cracking



Ammonia-to-H2 process KPIs

- ✓ NH_3 conversion: **up to 99+%**
- ✓ H_2 recovery: **up to 98%**
- ✓ LHV conversion efficiency: **85-90%**

Market opportunity segmented by vessel size and route range



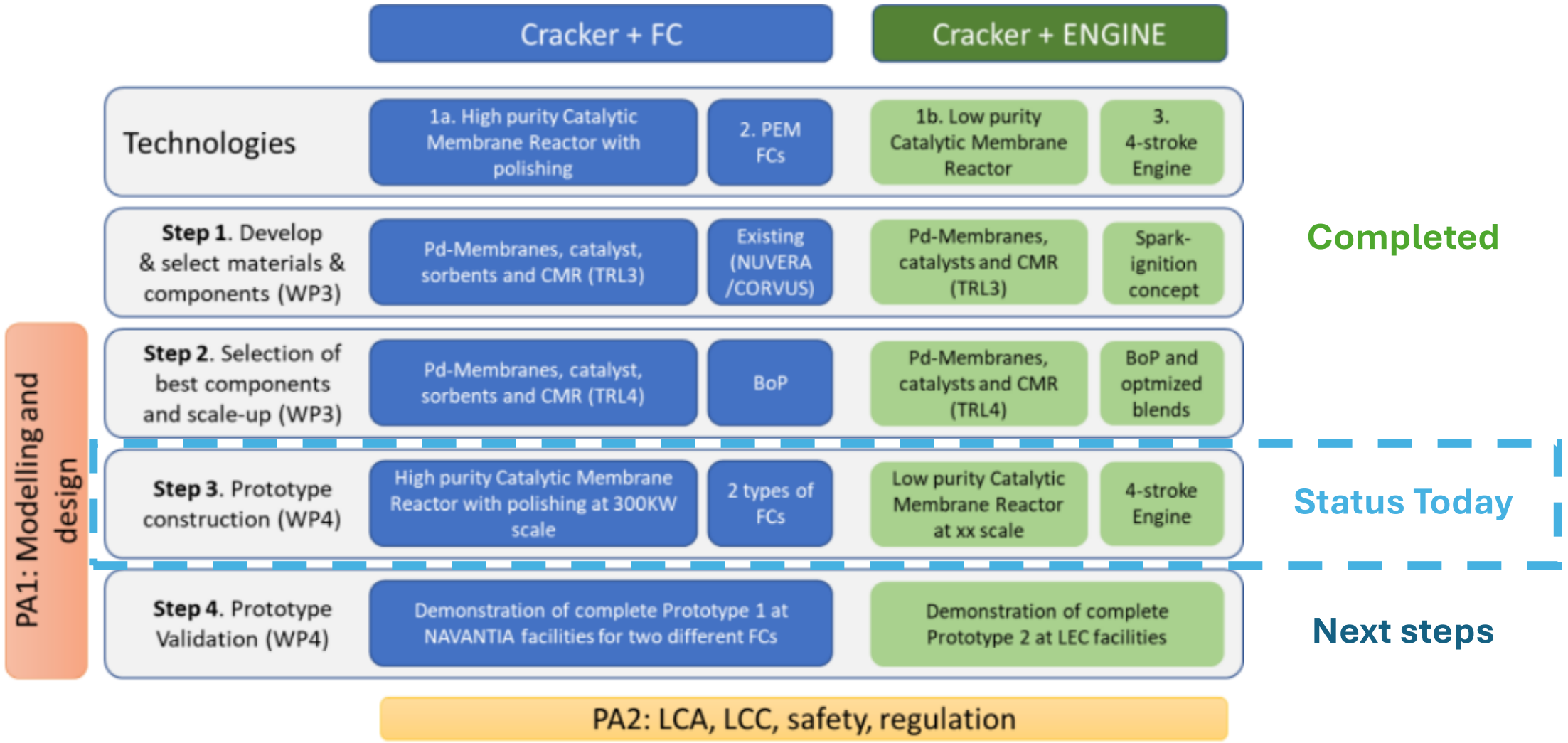
Most prominent early-adopters of ammonia-to-power solutions:

- ✓ Up to 3MW auxiliary loads
- ✓ Short-mid sea routes
- ✓ Ammonia carriers & ammonia bunkering vessels

More than 30000 vessels fit these categories

Additional market opportunities once commercial maturity achieved

- ✓ Bulk carriers
- ✓ Container vessels
- ✓ Oil tankers


Cracker + FC
Cracker + ENGINE
Technologies
1a. High purity Catalytic Membrane Reactor with polishing
2. PEM FCs
1b. Low purity Catalytic Membrane Reactor
3. 4-stroke Engine
Step 1. Develop & select materials & components (WP3)
Pd-Membranes, catalyst, sorbents and CMR (TRL3)
Existing (NUVERA /CORVUS)
Pd-Membranes, catalysts and CMR (TRL3)
Spark-ignition concept
Step 2. Selection of best components and scale-up (WP3)
Pd-Membranes, catalyst, sorbents and CMR (TRL4)
BoP
Pd-Membranes, catalysts and CMR (TRL4)
BoP and optmized blends
Step 3. Prototype construction (WP4)
High purity Catalytic Membrane Reactor with polishing at 300KW scale
2 types of FCs
Low purity Catalytic Membrane Reactor at xx scale
4-stroke Engine
Step 4. Prototype Validation (WP4)
Demonstration of complete Prototype 1 at NAVANTIA facilities for two different FCs
Demonstration of complete Prototype 2 at LEC facilities
PA1: Modelling and design
PA2: LCA, LCC, safety, regulation
Completed
Status Today
Next steps

H2SITE

Founded in 2019

35% PhDs

>60 FTEs

>20 H_2 Projects Executed

7 registered patents

>25,000 hours of proven operation

INVESTORS

TECH PARTNERS

THE PRODUCT

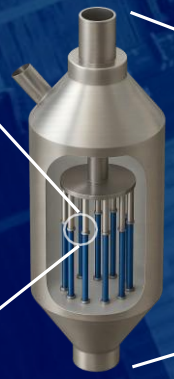
H2SITE

THE MOST ADVANCED TECHNOLOGY TO MAKE **HIGH-PURITY HYDROGEN** AVAILABLE.

SUPERIOR PERFORMANCE

Recovery from	H_2 Recovery	Pure H_2
2% H_2	**98%**	**>99,97%**
concentration	of the input	Fuel Cell-grade

Palladium Alloy Membranes



Advanced Membrane Reactor/Separator

Complete plant (Containerized or modular)

MEMBRANE SEPARATORS

Our membranes **recover hydrogen from gas streams**, even at very low concentrations, ensuring maximum efficiency.

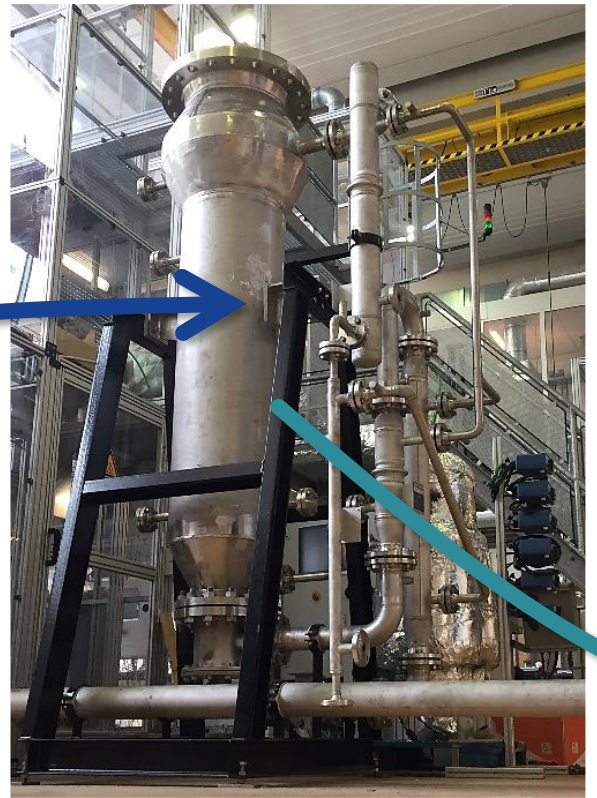
INTEGRATED REACTORS

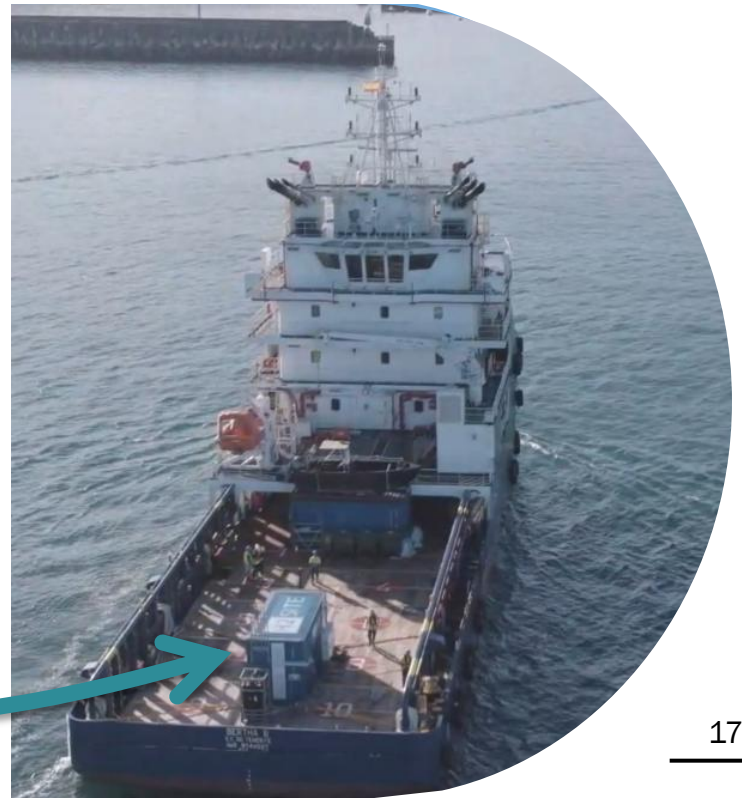
Adding catalyst to **convert molecules** (Ammonia or Methanol) **into pure H_2**, combining reaction and separation in a single and highly efficient step.

We manufacture Palladium-alloy membranes that produce **high-purity hydrogen** (99.97%)...

… to **efficiently recover 98% of hydrogen** from multiple sources...

… for **onboard and in-port generation** in compact equipment





Tested technology | Increasing running hours, AiP by Lloyd's, onshore demonstration

- ✓ 7 months
  of continuous operation of our crackers
- ✓ +6 000 h
  accumulated in H_2 production from ammonia
- ✓ 425 °C
  operating temperature of the cracker
- ✓ Delivering 99.97% H_2
  pure hydrogen to maximize fuel cell life
- ✓ Up to 5 MW system in 2028/29
  sailing for propelling or power auxiliary units
- ✓ Approval in principle awarded

Our three steps forward | Business opportunities in the maritime sector

1

Find **early-adopters of the technology & partners** to fully develop integrated onboard **ammonia cracking** solutions

H2SITE aims to offer **clean solutions** to increase efficiency and **reduce the overall costs** of energy transition

2

Deploy commercial-scale pilots based on the requirements of ship owners and operators

Technology integration is key to optimize Tank-to-Wake efficiency and emissions

3

Fully define product with main ship designers and **kickstart commercial adoption** of our maritime solutions

H2SITE fosters a **holistic approach** for sustainable fuels **infrastructure development**

Thank you for your attention

H2SITE

Markos Charsoulas, Product Engineer
+34 679617950
markos.charsoulas@h2site.com