Ammonia:
The inevitable
Fuel for future

AEA Boston dd 9-11-2021

By J.P. Vrijenhoef

Latest news

8 november 2021 04:20 | Laatste update: 8 minuten geleden

Nederland sluit op de klimaattop in Glasgow alsnog aan bij een groep landen die willen stoppen met wereldwijde investeringen in kolen, olie en gas. Dat zeggen betrokkenen tegen NU.nl. Later vandaag stuurt het kabinet een brief naar de Tweede Kamer.

COSCO reported receiving approval for a VLCC fueled with ammonia (COSCO)

PUBLISHED NOV 5, 2021 3:42 PM BY **THE MARITIME EXECUTIVE**

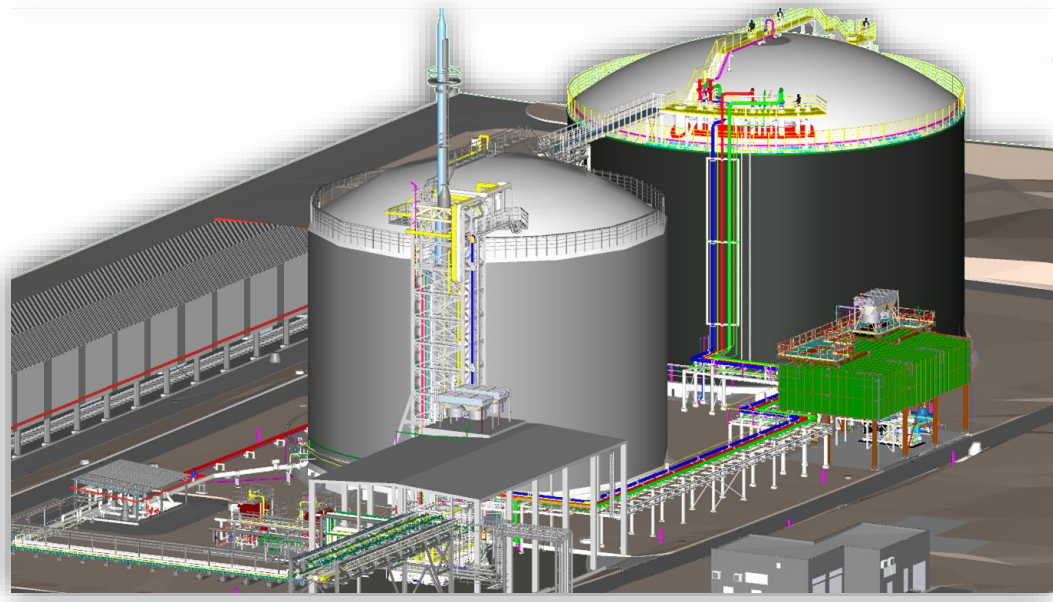
China's COSCO Shipping announced that it has received what could be China's first approval in principle from major classification societies for the design of an ammonia-fueled VLCC. Previously, the South Korean shipyards had been announcing their ammonia-fueled designs in the race to develop the first zero-emission shipping solutions.

Among the many alternative fuels currently being researched, ammonia, which does not produce

About Proton Ventures

EMPOWERING STORAGE SOLUTIONS.

Chemicals, green energy and beyond.



- **Mission:**
- We provide innovative engineering and turnkey solutions for world-scale storage terminals, decentralized ammonia production units and other related process applications. We enable our global partners to benefit from our safe, reliable, efficient and environmentally responsible solutions.

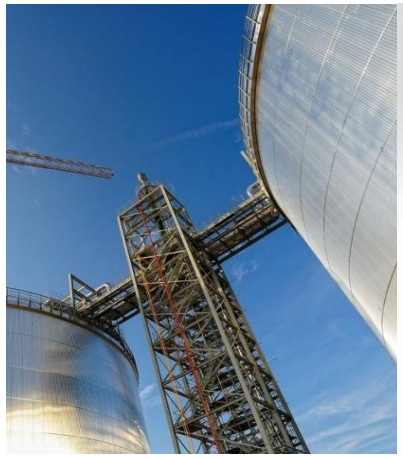
- **Vision:**
- We strive to be a key player in decentralized chemical energy storage making **renewable energy** accessible for everybody at an affordable price.

About Proton Ventures

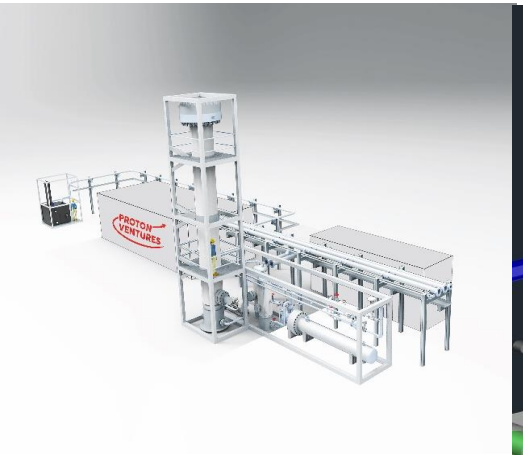
- 35 years experience in ammonia business
- Globally active in ammonia (storage) market, energy (storage) market
- Focusing on de-centralised green ammonia production
- Working towards the energy transition from the chemical (ammonia) perspective

Ammonia business segments

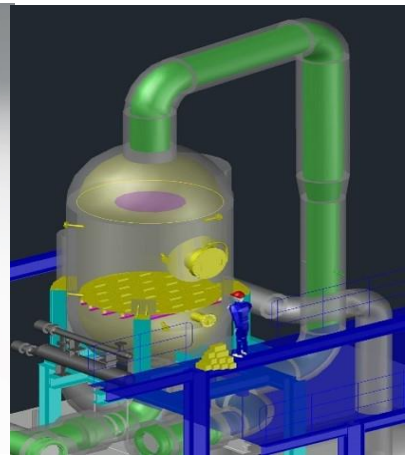
NH_3 storage



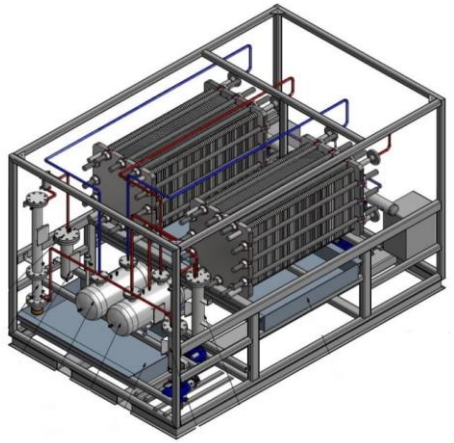
NH_3 Production



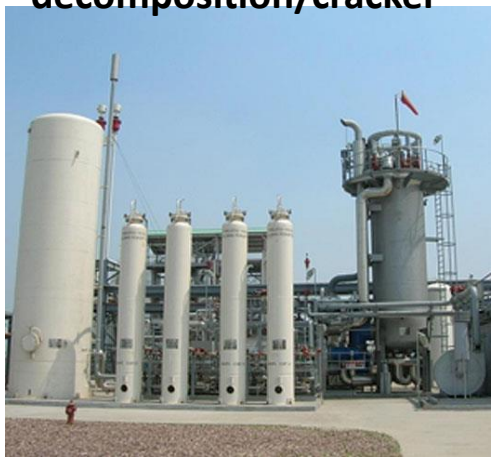
NO_x & N_2O removal



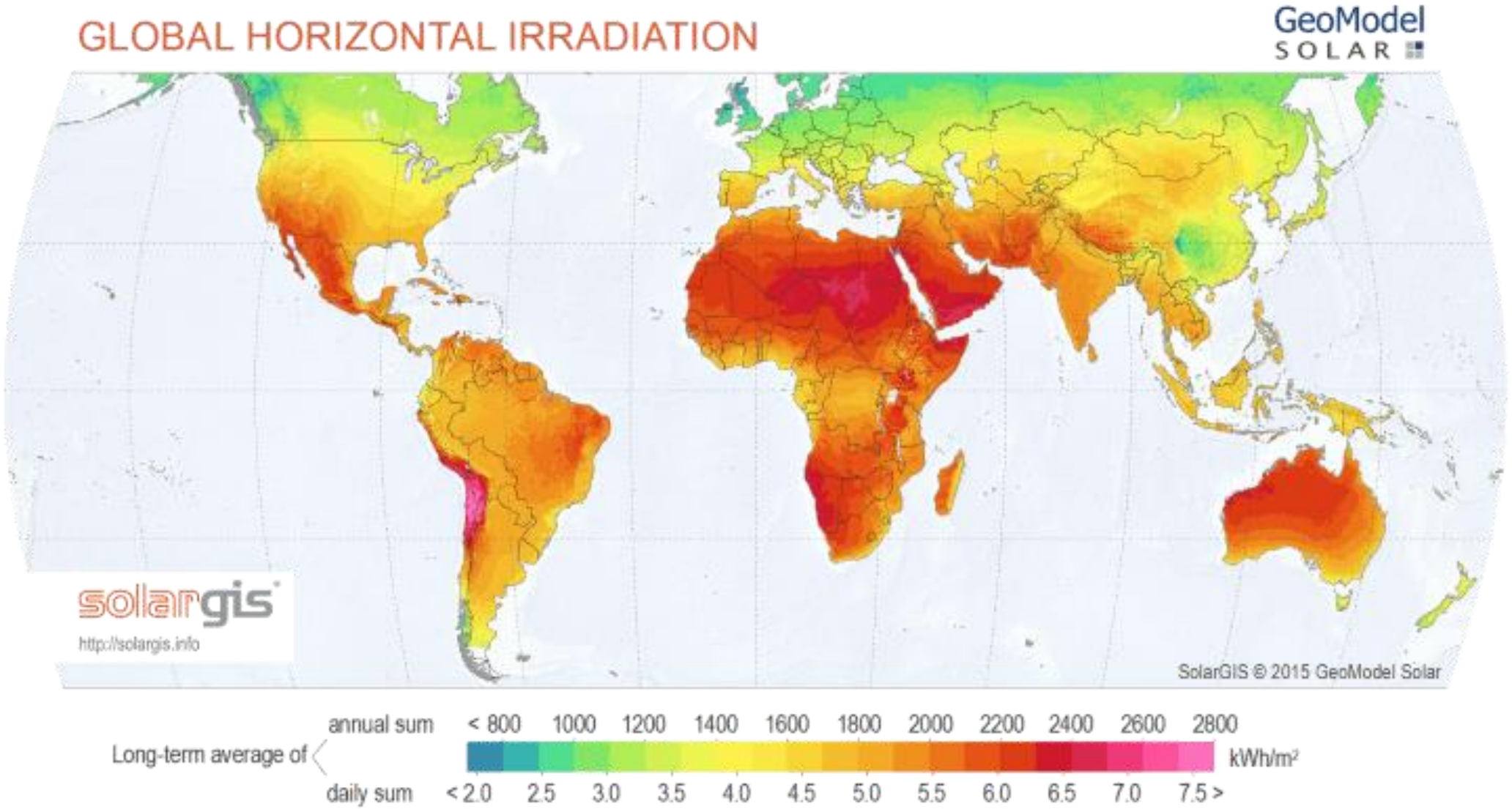
Battolyser



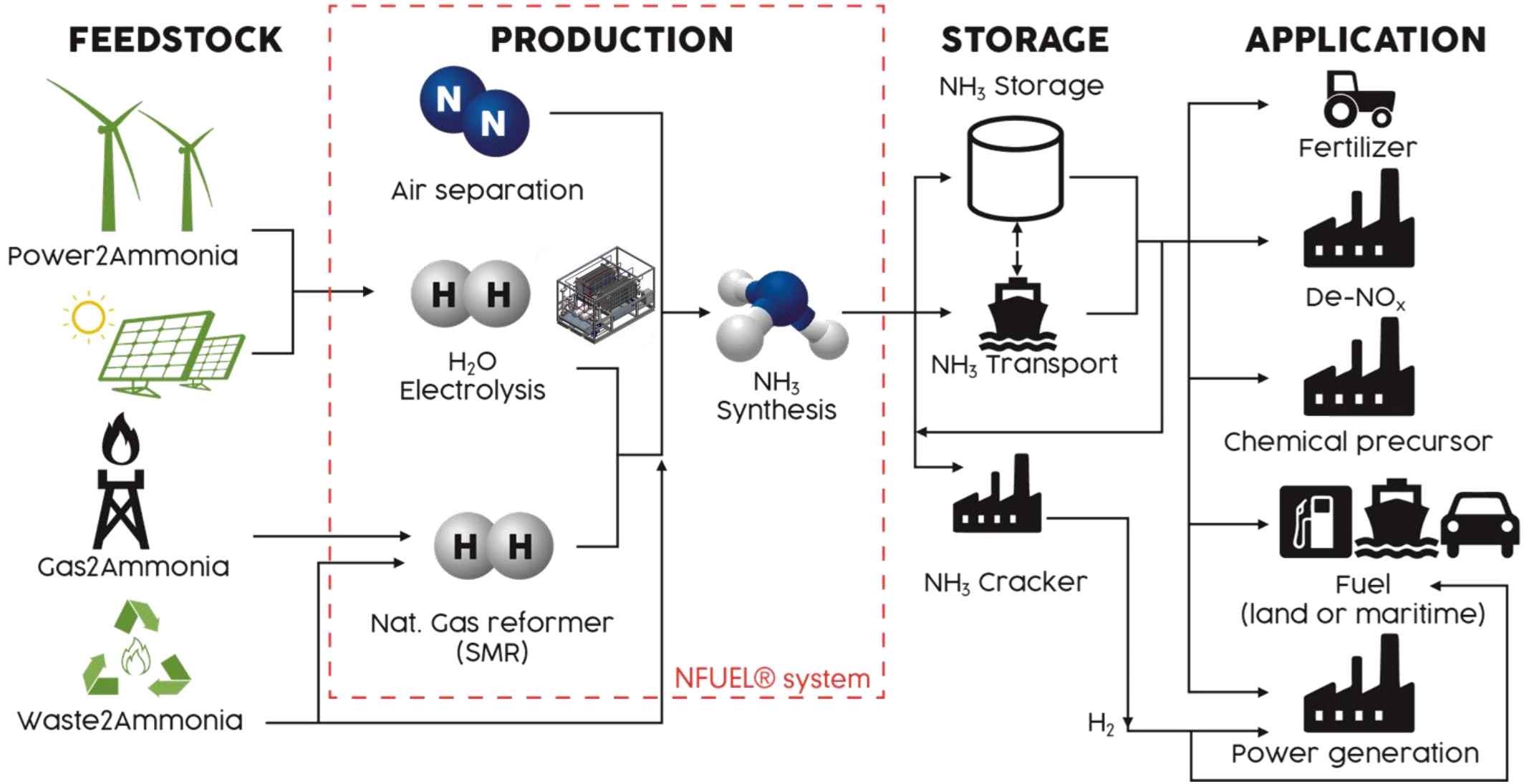
Ammonia decomposition/cracker



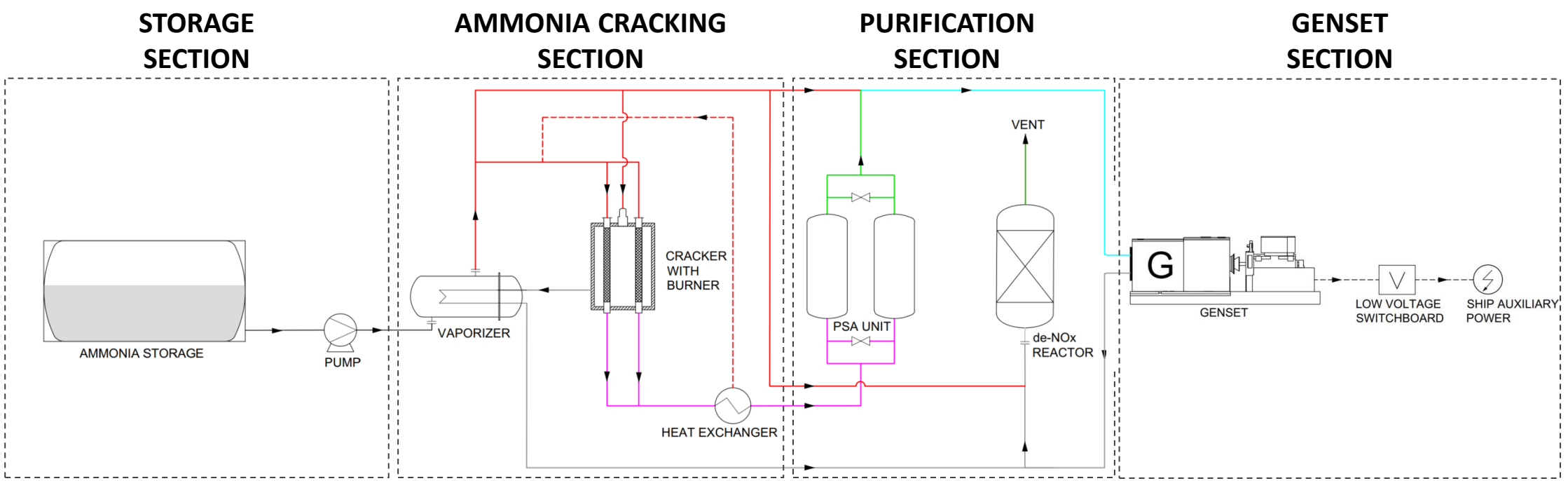
Ammonia, the new oil



Why Ammonia?


FEEDSTOCK
PRODUCTION
STORAGE
APPLICATION
Power2Ammonia
Gas2Ammonia
Waste2Ammonia
Air separation
H_2O Electrolysis
Nat. Gas reformer (SMR)
NH_3 Synthesis
NFUEL® system
NH_3 Storage
NH_3 Transport
NH_3 Cracker
H_2
Fertilizer
De-NO_x
Chemical precursor
Fuel (land or maritime)
Power generation

Genset process overview



- The integrated burner in the cracker design uses ammonia as combustion fuel.
- Purification requirements are less stringent because H_2 and NH_3 will blend into the combustion engine with a 5-95% weight percentage .
- Higher NOx emissions resulting from ammonia combustion in genset and burner need to be treated in the De-NOx reactor before venting to atmosphere.
- Combustion engine genset directly delivers AC power. It is intended to convert a conventional genset into an ammonia fuelled generator.

		Product categories					
Segment	Subsegment	**Feasibility study**	**FEED (BEP+)**	**Engineering (BEP, DEP)**	**EPCM**	**EPC**	**PD engineering**
Ammonia solutions	*Storage & loading*	✓	✓	✓	✓	✓	
	Green ammonia production	✓	✓	✓	✓	✓	
	DeNOX			✓	✓	✓	
Other applications		✓	✓	✓	✓	✓	
Project development		✓					✓

Project activities (from business concept to operational facility)

STEP 01

- **Feasibility study:**

  Client's Site visit, Quick Scan-Financial Analysis, Definition of ISBLs & OSBLs → Greenlight for further steps

STEP 02

- **Feed Study:**

  Basic & Detailed engineering, Fixed turn key price ISBL & OSBL

STEP 03

- **Procurement:**

  Optimised procurement of complete system equipment, quality assurance through in-house inspection → cost optimisation and less overhead

STEP 04

- **Construction & Commissioning & Training:**

  EPC approach and fast start up with experienced in-house personnel

STEP 05

- **Operations & maintenance:**

  Remote monitoring, plant management, maintenance contracts

Why Ammonia? And not Hydrogen!

How many energy is stored in this storage tank?

225.000 Gigajoule (GJ)

~

62.5 million Kwh

How many solar panels are needed to produce this amount of energy in a month?

1.8 million solarpanels

~

500 MW installed capacity

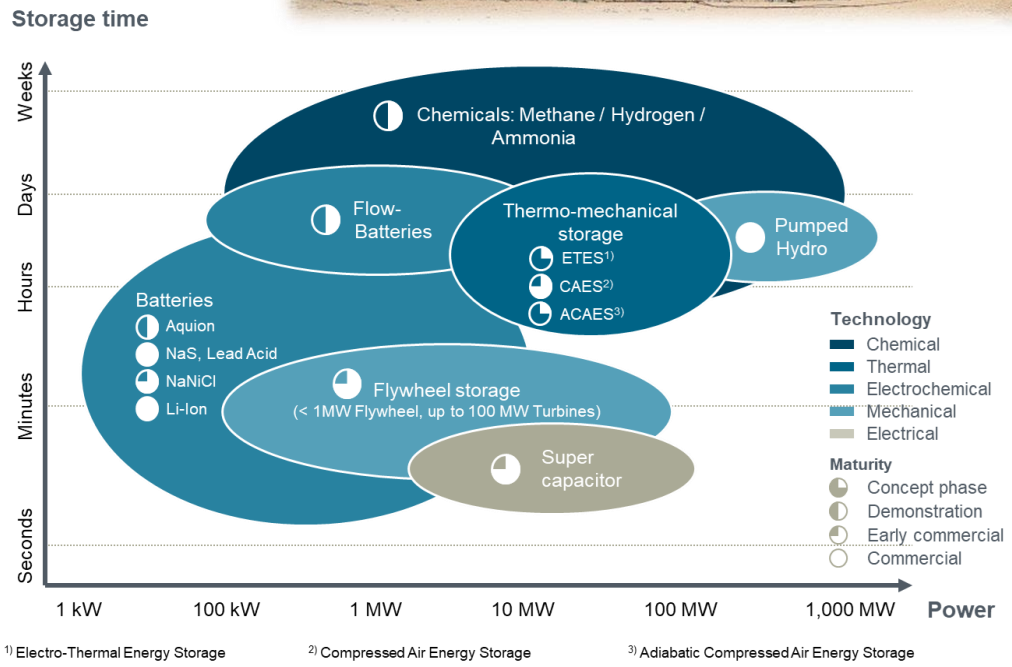
Which surface is needed for this production?

425 hectare

~

>660 soccer fields

Assumptions: Yield PV 0.3; 275 Wp per solar panel; 4300 panels per hectare;



1) Electro-Thermal Energy Storage 2) Compressed Air Energy Storage 3) Adiabatic Compressed Air Energy Storage

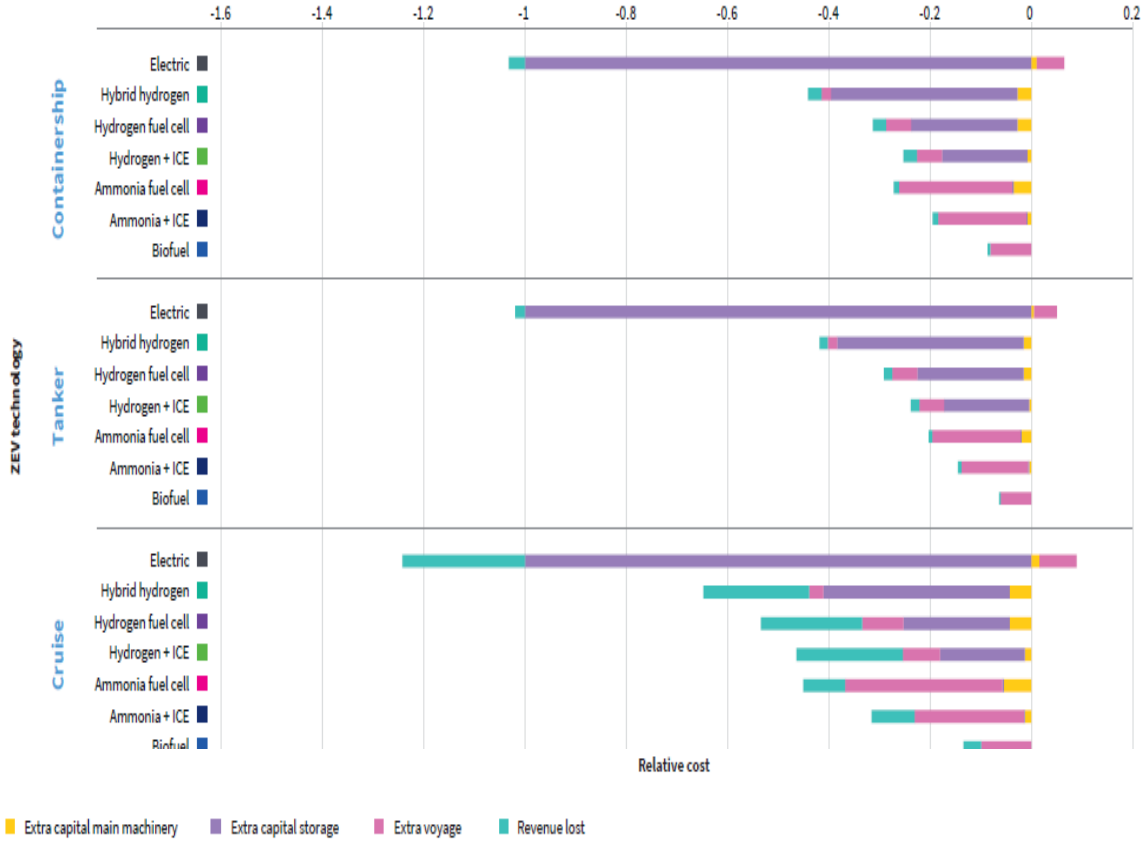
Source: Siemens presentation, 1st European NH_3 Conference, 19/05/2017

Ammonia storage and transport

With Ammonia, There's no "Chicken or Egg" dilemma;
existing business and new markets easily and safely supplied over 100 years

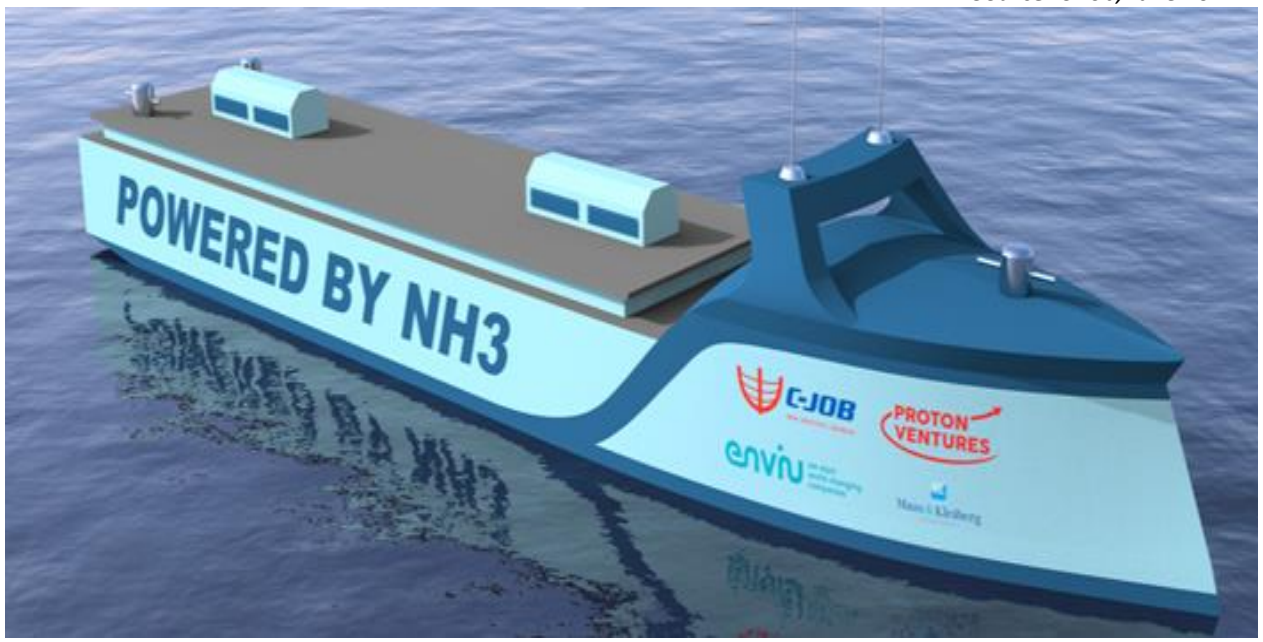
Ammonia fertilizer applications (conventional)

Ammonia future applications as maritime fuel



Source: Lloyds Register Presentation, December 2017

Source: *C-Job, June 2017*



- C-Job – Ammonia as ship's fuel
- MAN Energy Solutions' ammonia engine
- Korean register – Ammonia Preferred Maritime Fuel
- World's first high-power fuel cell powered by green ammonia

NH_3 is so far the only potential zero-emission fuel candidate

Solution

- NH_3 is the only potential zero-emission fuel with H_2, other alternative fuel still contains carbon and will involve GHG emission.

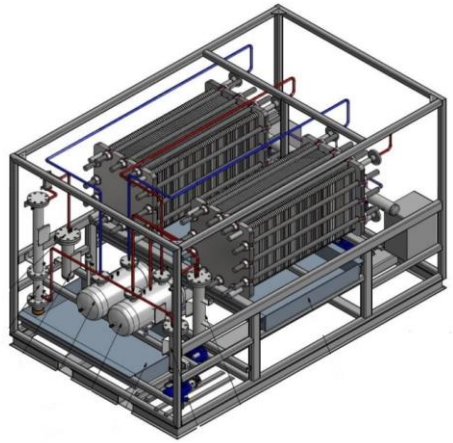
Fuel Property	Unit	HFO	Compressed Hydrogen (350 bar)	Liquid Hydrogen	Liquid Ammonia
Low heating value	MJ/kg (kWh/kg)	40.2 (11.17)	120.00 (33.33)	120.00 (33.33)	18.6 (5.17)
Volumetric energy density	MJ/m^3 (kWh/m^3)	39,564–42,036 (10,990–11,677)	5040 (1400)	8500 (2361)	14,100 (3917)
Min. auto-ignition temperature	°C	250	500–577	500–577	650–657
Boiling temperature at 1atm	°C	N/A	N/A	−253	−33.4
Condensation pressure at 25 °C	atm	N/A	N/A	N/A	9.90
Hydrogen content	% by mass	N/A	100.0	100.0	17.8

1,7x the energy density of liquid H_2

- Production, transportation, storage and safety technologies for NH_3 already exists.
  - 180 Millions tonnes produced per year from which 10% are shipped across the world

Why ammonia?

- Transport and storage of renewable energy a key topic
  - “Opex” costs mostly focussed on production costs
    - Forgtting logistic costs
    - Forgetting
  - storage costs, energy losses, losses in general, piping costs



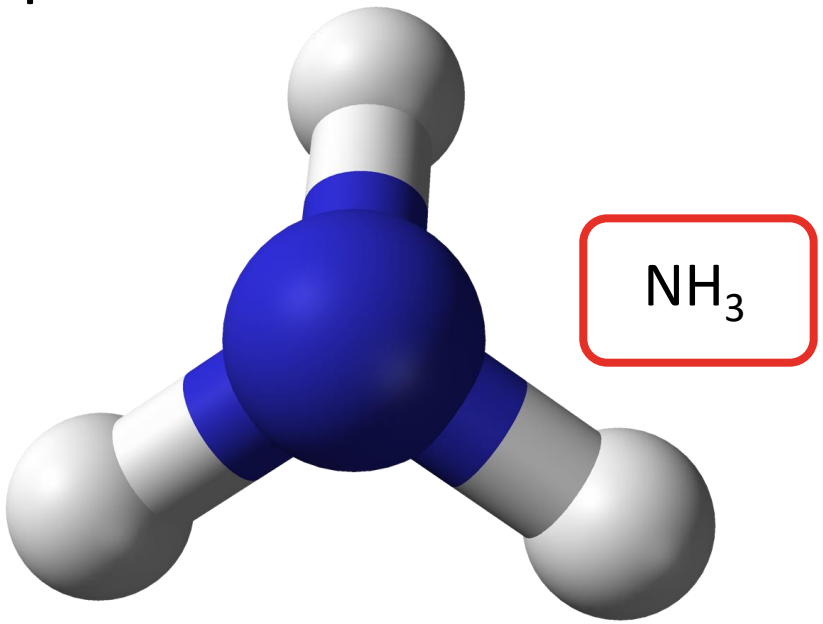
- Intermittancy “to be tackled”
  - Should be renewable capex costs / but no CCS (blue)
  - New technology SOEC/Battolyser)
  - Battery storages for part load during periods of shortage

Situation overview

- Maritime transport emits ≈ 940 millions tonnes of CO_2 [(1)], annually responsible for 2,5% of global greenhouse gas (GHG) emissions
- GHG emission from maritime transport are projected to increase significantly if mitigation measures are not put in place.

- EU Strategy :
  - MRV Monitoring Reporting Verification since 2018
  - GHG reduction first measures to be decided between 2020 and 2023

- Possible measures:
  - Operational measure : Advance route planning, slow steaming…
  - Technical measure : **Alternative fuel**



(1) 3rd IMO GHG study

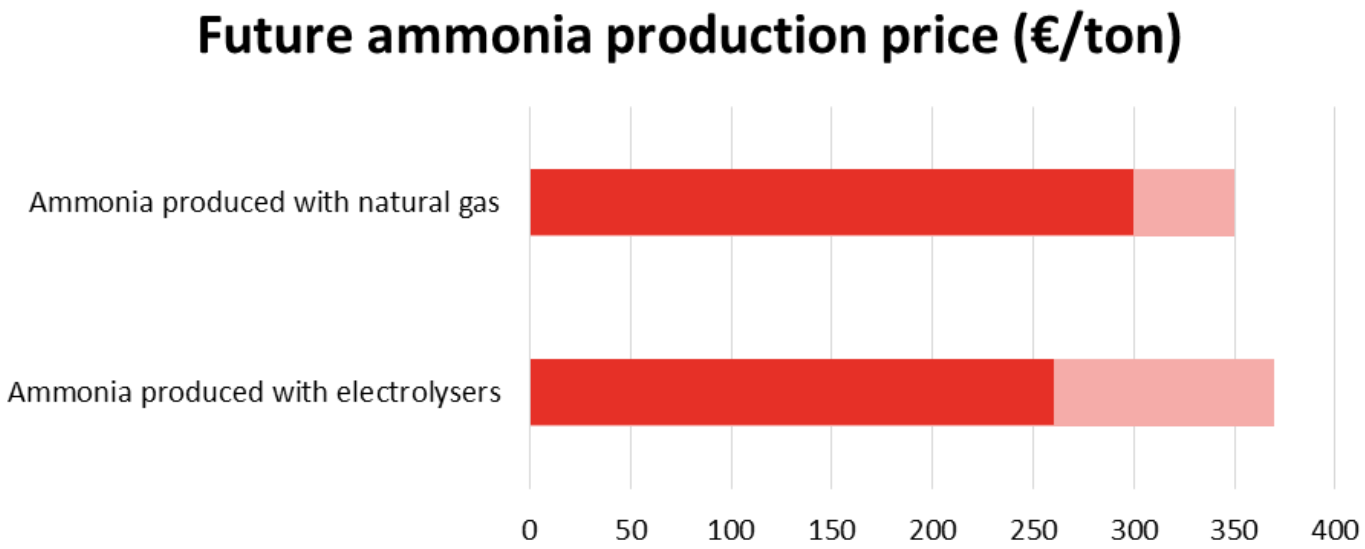
Ammonia, the ideal hydrogen carrier

- Sustainable energy can be stored in the form of ammonia as a hydrogen carrier.
- Ammonia has a relative high energy density in general but as a carbon free component one of the highest.
- Ammonia contains in fact more hydrogen per molecule than the product hydrogen and that has advantages in storage and logistics (108 kg H_2/m^3 NH_3^{warm} or 121 kg H_2/m^3 NH_3^{cold}).
- Ammonia can be easily stored and transported with excellent track record by pipeline, truck, rail or ship.

Storage properties	H_2 (gas)	H_2 (gas)	H_2 (liquid)	NH_3 (Pressurised)	NH_3 (Cooled)
Pressure (bar)	300	700	1	8.6	1
Temperature (°C)	20	20	-253	20	-33
Density (kg/m^3)	23.7	41.6	70.8	611	681.6
H_2 (kg/m^3)	**23.7**	**41.6**	**70.8**	**107.8**	**121**

Cost of green ammonia (CFR)

- NH_3 produced in an electrochemical way from sustainable electricity will be a feasible alternative in the longer term
- In case cost-effective baseload renewable electricity is available (25 EUR/MWh)



	Ammonia produced with electrolysers	Ammonia produced with natural gas
Maximum price	370	350
Minimum price	260	300

Source: ISPT, Power to Ammonia Feasibility study, 2017

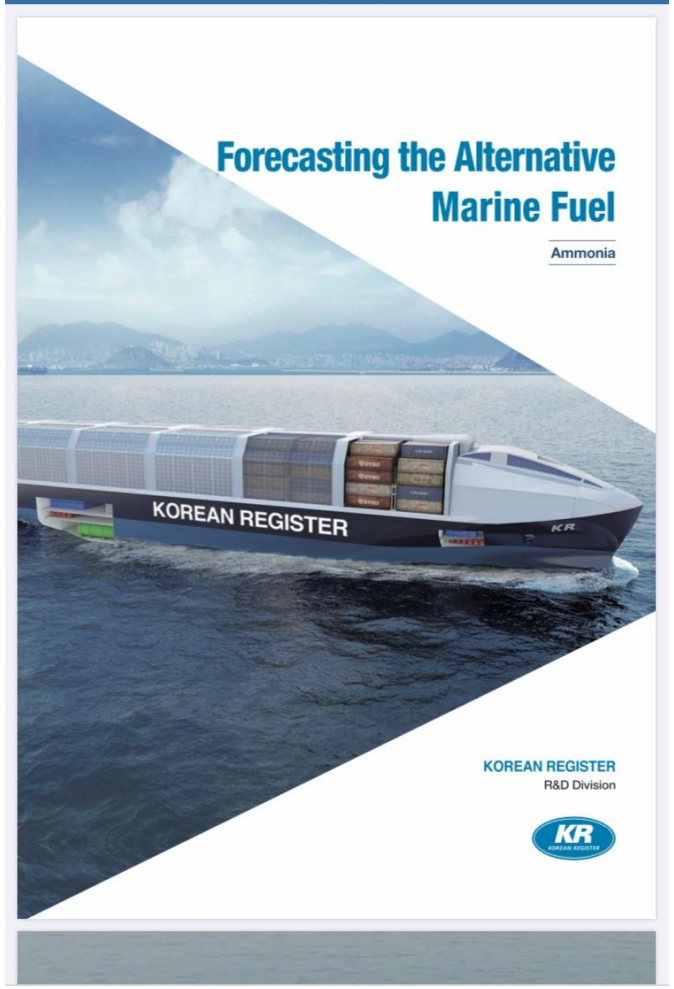
Need for transport is essential

- ❖ Solar areas are not abundant everywhere in the world

- ❖ Transport to import areas required
- ammonia
- hydrogen
- other
- ❖ Should be carbon neutral / no CO2 or and low Nox fuels

- ❖ Ammonia is easy to transport, but
- can not place at every port an ammonia production unit (Nfuel)
- should be optimised in say 100 production locations and 6000 distribution areas

- **Proton works with ship owners to optimise bunkering of Nfuel in relation to production!**



Delen

Alternative Routes for 2670 ton H2

transport per ship

- NFuel (**GREEN Ammonia**) **2670 ton H2**
  - **3 H_2** + N_2 => 2 NH_3 or **1,5** molecule H_2 gives 1 molecule NH_3 (**no loss** of H_2 in the formation reaction)
  - Approx. 178 kg H_2 per ton NH_3
  - Cracking NH_3 to H_2 takes approx. 25% of initial H_2 quantity (***Why do this and not use directly the NH_3?)***
  - 15,000 ton NH_3 requires some **22,500 m^3** storage volume on ship
- LOHC (Liquid Organic Hydrogen Carrier) **2670 ton H2**
  - Thermo-chemical bonding of H_2 to organic hydrocarbons (e.g. MCH)
  - Approx. 62 kg H_2 per ton LOHC
  - Thermal energy needed to release H_2 from LOHC required, typically 25% energy loss
  - Re-use existing infrastructure related to Oil & Petro Chemical Industry
  - 45,000 ton LOHC requires some **58,500 m^3** storage volume on ship
- LH_2 **2670 ton H2**
  - Liquid at -253 °C, requiring some 3.9 (theoretical minimum) up to 16 kWh/kg H_2 in energy (12 - 50% of energy value is lost)
  - 2,670 ton **liquid** H_2 requires some **38,000 m^3** storage volume on ship
  - Compressed H_2 **gas** at 200 barg would require for the same 2,670 ton of **22,000,000 m^3** storage volume on ship
- CH_4 – CH_3OH (MeOH) **2670 ton H2**
  - The formation reaction requires CO_2 and generates consumes H_2 due to H_2O being formed
  - **4 H2** + CO2 ➔ 1 CH4 + **2 H2O** (loss is 50% in H2) Equals **200% Capex** for solar or wind compared to NFuel/LOHC
  - **3 H2** + CO2 ➔ 1 CH3OH + **1 H2O** (loss is 33% in H2) Equals **150% Capex** for solar or wind compared to NFuel/LOHC
  - But lower transport costs! But also no CO2 available cheap in solar or wind rich areas

TransHydrogen Alliance

Developing the logistics infrastructure to facilitate the Energy Transition together

01/11/2021

PROTON VENTURES · GES · VARO · Trammo · Port of Rotterdam

Supporting partner

Content

- The **THA** Consortium
- The Objective of the **THA** Consortium
- The Unique Features of the **THA** Consortium
- The Best Solution: An integrated approach
- Technical Solution Details
- All Supply Chain Roles Covered
- The project: Multiple stage approach
- Local Partners, how can we co-operate?

Appendices

Consortium Partner Details

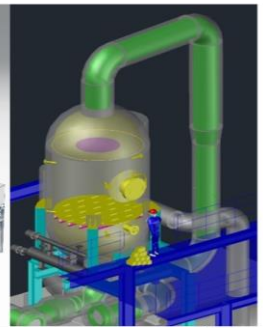
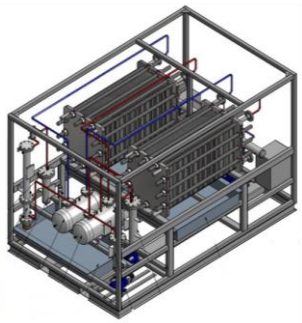
The Parties of the TransHydrogen Alliance

PROTON VENTURES

Experts in design & development of H_2 and ammonia facilities, including: NH_3 modular production units, terminals for storage and handling, De-NO_X and N_2O removal systems and partner in Battolyser technology.

NH_3 & Energy storage | NH_3 Production (NFuel) | NO_x & N_2O removal | Battolyser



Proton Ventures developed the NH_3 modularized concept next to its access to several unique technologies which allow allow for the development of a competitive green fuel or fertilizer.


Trammo

Experts in transport and sales and marketing of ammonia & NFuel in existing markets making use of their existing fleet and customer base.

GES

Experts in Liquid Storage Solutions & Operations worldwide.

VARO

Oil & Gas experts in distribution and marketing and sales of green fuels in captive markets making use of their existing infrastructure.

Port of Rotterdam

Supporting partner

Offering support and assistance to develop a terminal location in the Port of Rotterdam.

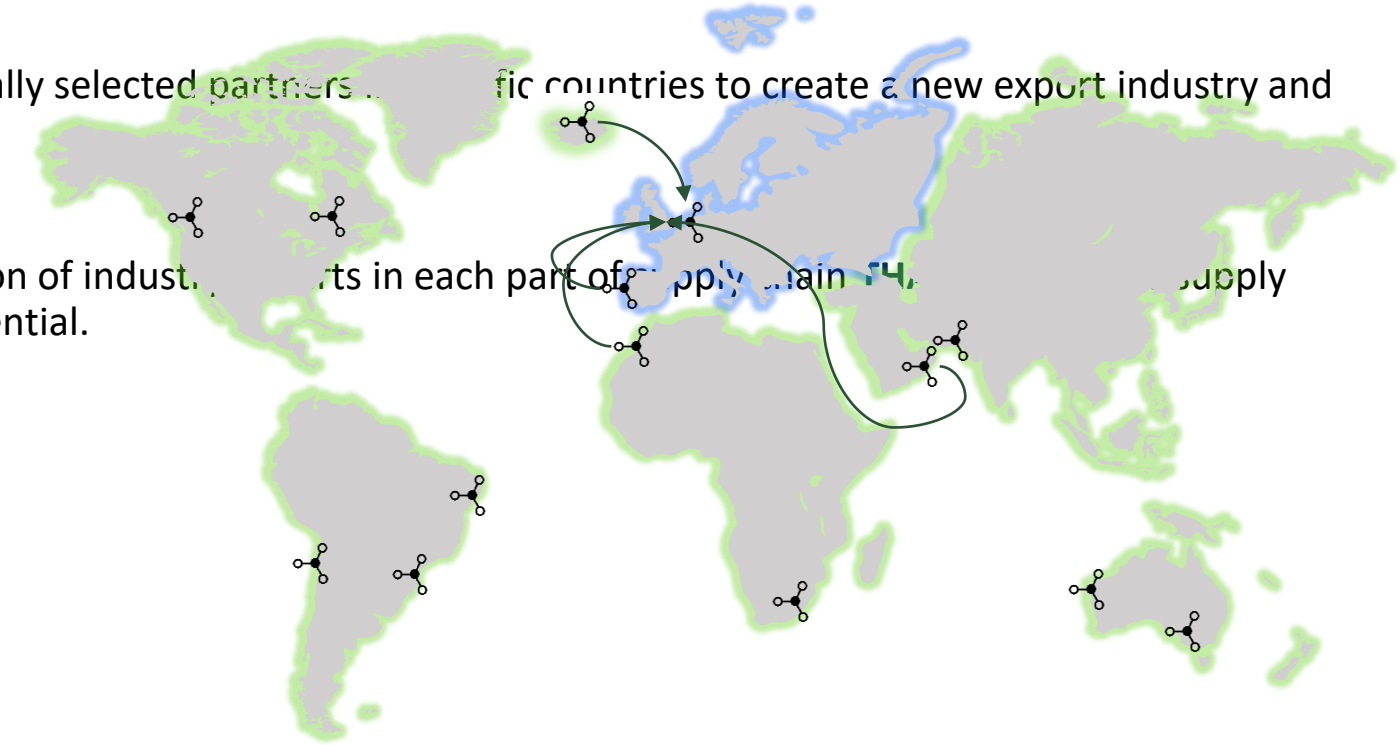
The Objectives / Opportunity

- Through recent political and technological developments there is an opportunity to set up new green energy supply chains between sun-and wind rich countries that bring future supply and demand together.

- The **THA** consortium wants to work together with specially selected partners in specific countries to create a new export industry and all related benefits.

- Thanks to unique technical solutions and the combination of industrial parts in each part of the supply chain THA can supply chain within 3 years from today, with large scale up potential.

- **Let's build the future together.**



The Unique Features of the TransHydrogen Alliance

1. The **THA** supply chain embraces a number of **unique technologies** allowing for the production of cost-competitive green hydrogen & green ammonia.
2. Together, the **THA** consortium **partners cover all elements of this new supply chain.**
3. Acting as a consortium which develops the supply chain allows for **single point responsibility and risk sharing / mitigation.**
4. The **THA** consortium aims to **serve two main markets** with two products:
    - Green Hydrogen for the upcoming NW European market – by VARO
    - Green Ammonia for the existing global ammonia market – by Trammo

These features ensure the **THA** supply chain development to be cost-effective, reliable, fast and flexible.

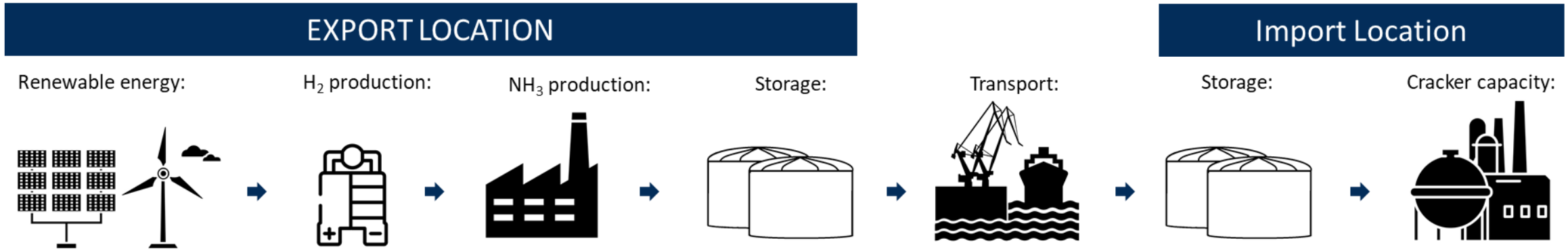
Immediate start of deployment is possible thanks to scalable and modular design

The consortium seeks collaboration with local partners at carefully selected various export locations.

The Unique Technological Solutions

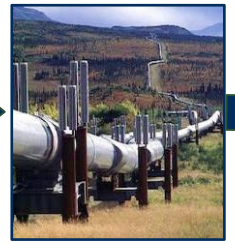
The modular **THA** supply chain is a combination of unique and integrated technical solutions:

1. Unique renewable power storage technology and hydrogen production applying i.e. Battolyser technology.
2. Unique distributed hydrogen production, i.e. direct from solar energy through CPV solar technology.
3. **Green ammonia** production through the NFuel concept of Proton Ventures' **NFuel concept** which is an optimized compact version of the Haber-Bosch technology. Through modularity this system is easily scalable allowing for initial small production capacities scaled to large capacities in time.
4. Dehydrogenation of the **THA** through state-of-the-art de-composition technology.



All Supply Chain Roles Covered








Renewable Power | **H_2 Production & Conversion** | **Local gas distribution** | **Storage & Export** | **Transport** | **Storage Design & operation** | **Local distribution** | **Decomposition H_2 or NH_3 sales**

RE Park developer & operator | GNH_3 plant operator | Gas transport operator | Export Terminal Operator | Fleet Owner / GNH_3 Trader | Import terminal operator | Gas transport operator | Sales & marketing

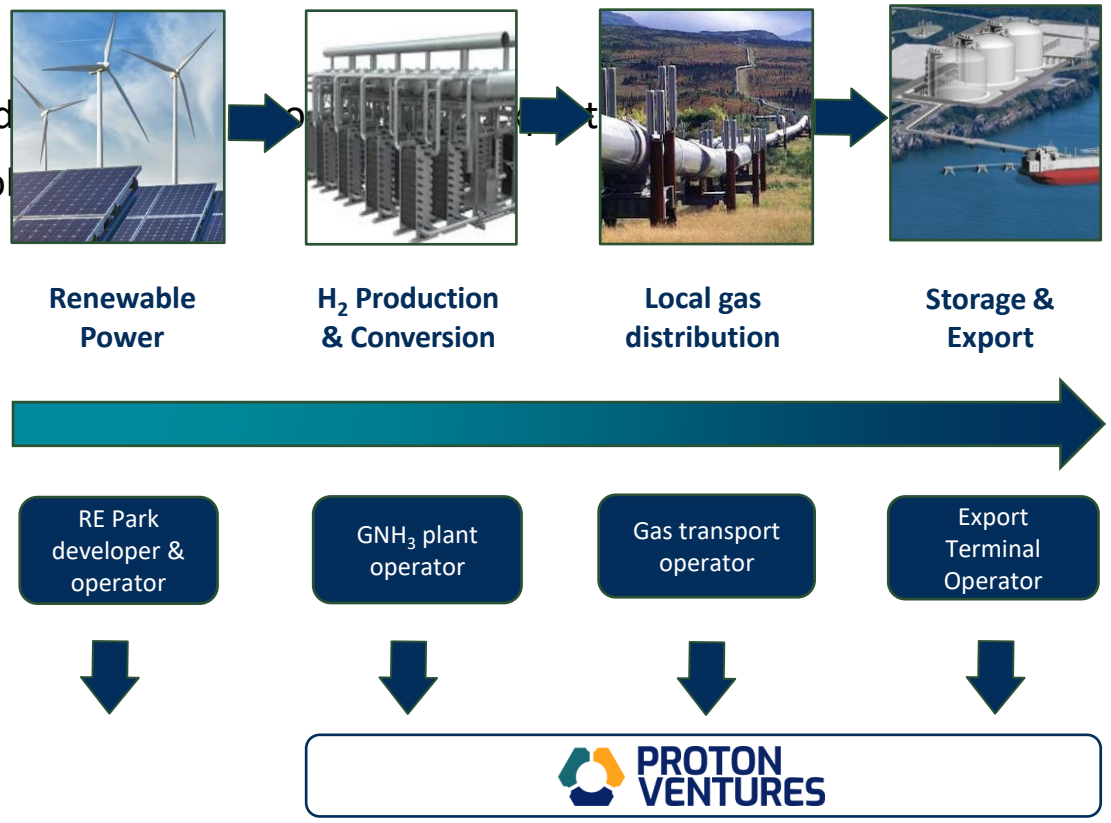
Local Partner(s)

GES, PROTON VENTURES | Trammo | GES, PROTON VENTURES, Port of Rotterdam | VARO, Port of Rotterdam | Trammo, VARO

Local partners, how can we cooperate?

The THA consortium will enable:

- Your country to become one of the first movers of green hydrogen prod
- The development of a new export industry with related financial and jo
- Build up a local skill set and knowledge industry
- Possible development of related equipment industry



Local Stakeholder support is being investigated for:

- Provision of renewable energy, where? By whom?
- Provision of land for RE, conversion facilities, export terminal
- Connection between RE park and port
- Provision of demineralized water
- Local support to operation the plant
- Local ammonia distribution
- Local support to operations of export terminal
- Investor in local assets
- Local subcontracting support (for assembly & construction)

The Project: A Scalable Approach

1

Phase 1 – Entry project Kickstart the H_2 economy

- Small scale unit(s) allowing for **80,000 - 100,000 MTPA** of green ammonia production.
- Timeline for demonstration. facilities deployment is 2023 – 2024.
- Allows for gradual expansion in case allocated land is available and permits for expansion are arranged.

2

Scale up phase Entry project

The entry project plant will be extended through 2024 – 2027 up to a NH_3 production of 500,000 MTPA.

3

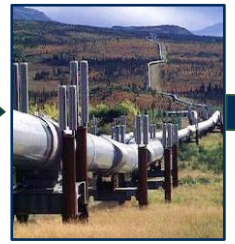
Larger scale projects

Other locations will be evaluated in parallel of phase 2, to expand the total installed capacity up to 1,000,000 – 2,000,000 MTPA through 2024 – 2030.

All Supply Chain Roles Covered


Renewable Power


H_2 Production & Conversion


Local gas distribution


Storage & Export


Transport


Storage Design & operation


Local distribution


Decomposition H_2 or NH_3 sales

RE Park developer & operator

GNH_3 plant operator

Gas transport operator

Export Terminal Operator

Fleet Owner / GNH_3 Trader

Import terminal operator

Gas transport operator

Sales & marketing

Local Partner(s)

PROTON VENTURES

GES

Trammo

GES

PROTON VENTURES

Port of Rotterdam

VARO

Port of Rotterdam

Trammo

VARO

NH3 event 2022

- Find out more at the 2022 NH3 Event, 2-3 June, Rotterdam.
- IFS and AEA Members can get a discount.
- hashtag#internationalfertilisersociety
- info@NH3event.com
- www.protonventures.com