FULL CONTAINMENT STEEL-STEEL LNG TANK RESEARCH

PERFORMANCE CRITERIA AND EXTREME EVENT RESPONSE

Onder Akinci, Ph.D., P.E.

Project Director, Vice President

14 October 2022

Rice Global E&C Forum
Engineering & Construction

"This research was funded in part under the Department of Transportation, Pipeline and Hazardous Materials Safety Administration's Pipeline Safety Research and Development Program. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Pipeline and Hazardous Materials Safety Administration, or the U.S. Government."

Project Home Page:
https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=947

Agenda

- Research Objectives
- Methodology
- Preliminary Findings
- Summary

Background

- In the 2019 edition of NFPA 59A (NFPA 59A-2019), a full-containment tank system, as defined in Section 3.3.5.4.2 and the Annex, consists of a secondary container designed to contain spilled LNG from the inner container which can be constructed of either metal or pre-stressed concrete.
- PHMSA's current regulations require that if the outer wall is used as a dike serving as a storage tank impounding system, then it must be constructed of concrete (49 C.F.R. § 193.2161).

Research Objectives

- Determine whether a metal secondary container provides an adequate level of safety and operational integrity comparable to that of an alternative secondary container constructed of concrete.
    - External impacts including overpressure, projectiles (VCE and windborne), and radiant heat effects.
    - Internal impact to include thermal shock due to inner tank leak.

Project Activities and Methodology

- Literature Review
- Review of Previous Projects
- Identification of Typical Tank Designs
- Loads from Previous LNG Projects
- Development of Performance Criteria – Structural Integrity and Leak Tightness of External Tank
  - Non-linear FE Analysis to check response against fire, blast, projectile, and thermal shock load cases
  - Acceptance criteria based on strength and plastic strain limits
- Fire and Blast Fragility Analysis

SGH

LNG Tank Database

Tank No.	Containment Type	Facility Type	Location	Inner Tank	External Tank	Foundation Type	Design Code	Thermal Shock
1	Single	Import	Caribbean	9% Ni St.	Carbon Steel	Unanchored	API 620	No
2	Single	Liquefaction	Asia	9% Ni St.	Carbon Steel	Anchored	API 620	No
3	Single	Liquefaction	Oceania	9% Ni St.	Carbon Steel	Anchored	API 620	No
4	Full	Gas-to-Power	Asia	9% Ni St.	9% Ni Steel	Anchored	API 620	No
5	Full	Receiving	Asia	Stainless St.	Stainless Steel	Anchored	API 620	No
6	Full	Receiving	Asia	9% Ni St.	9% Ni Steel	Unanchored	EN 14620	No
7	Full	Receiving	Asia	9% Ni St.	9% Ni Steel	Unanchored	EN 14620	No
8	Full	Liquefaction	Asia	9% Ni St.	Conc. Wall	Unanchored	API 620 / BS 8110	Yes
9	Full	Liquefaction	Asia	9% Ni St.	Conc. Wall	Unanchored	API 620 / EN 14620	Yes
10	Full	Liquefaction	N. America	9% Ni St.	Conc. Wall	Unanchored	API 620 / ACI 376	Yes
11	Full	Liquefaction	N. America	9% Ni St.	Conc. Wall/Roof	Unanchored	API 620 / ACI 376	Yes
12	Full	Export	N. America	9% Ni St.	Conc. Wall/Roof	Unanchored	API 620 / ACI 376	Yes
13	Full	Import	Asia	9% Ni St.	Conc. Wall/Roof	Unanchored	EN 14620	Yes
14	Full	Peakshaving	Asia	9% Ni St.	Conc. Wall/Roof	Anchored	EN 14620	Yes
15	Full	Import	N. America	9% Ni St.	Conc. Wall/Roof	Unanchored	API 620	Yes

Fire, Blast and Projectile Loads

- Blast and fire loads depend on facility size and separation
- Design fire scenarios were typically on the order of 32 kW/m^2 heat flux with a duration of 2 hours
- Design projectile was typically considered as a valve

Summary and Preliminary Findings

- We developed a full containment steel-steel LNG tank design in collaboration with JIP partners
- Steel-steel LNG tank design checked against wind and operating loads
- Obtained initial analysis results considering dead load, live load, internal pressure, and blast loads
- Blast response of steel-steel tank is within the acceptance criteria, but higher than that of comparable steel-concrete tank
- Concrete external shell has higher resistance to external loads compared to steel external shell, but this can be accounted for in the design development
- Roof response (due to platform loading) governs the blast response of steel-steel tank
- Fire and projectile impact analyses are in progress

Önder Akinci, Ph.D., P.E.

Project Director, Vice President

D: 713.265.6423 **C:** 346.377.8514

Email: noakinci@sgh.com

SIMPSON GUMPERTZ & HEGER

2050 W. Sam Houston Parkway S., Suite 1625
Houston, TX 77042

sgh.com

RICE GLOBAL FORUM – STORAGE INNOVATIONS IN TANKS & TERMINALS

RECENT DEVELOPMENTS IN AMMONIA AND HYDROGEN STORAGE

Rama Challa, Ph.D., P.E.
Projects Director, Storage Solutions

AGENDA AND PRESENTATION OUTLINE

- Why Hydrogen
- Hydrogen Codes and Standards, Storage Concepts, Current Challenges
- Ammonia Storage Tank Codes and Standards, Storage Concepts, Current Challenges
- Miscellaneous Safety System

Acknowledgement:

This presentation is put together by the members of Matrix PDM Engineering – Project Engineering, Shell & Plate and Process Engineering Teams

Rice Global E&C Forum
Engineering & Construction

MATRIX PDM ENGINEERING

MATRIX SERVICE COMPANY CORPORATE OVERVIEW

Matrix Service Company **(NASDAQ: MTRX)** is a top-tier, publicly-traded Plant Services & EPC contractor to the Energy and Industrial markets

MATRIX SERVICE COMPANY

MATRIX PDM ENGINEERING

MATRIX NAC
Union Subsidiary

MATRIX SERVICE
Merit Subsidiary

MATRIX APPLIED TECHNOLOGIES
AST Products

ASME CERTIFIED FABRICATION FACILITIES

HEAVY STEEL PLATE

- **CATOOSA, OK**
  One of the largest & most modern heavy steel plate fabricating facilities in the U.S.
- **ORANGE, CA**

PIPE SPOOLING & MODULES

- **BELLINGHAM, WA**
- **LEDUC, AB**

PRODUCT FABRICATION/ASSEMBLY
PAJU (SEOUL) KOREA

Certified System ™
ISO 9001
QMI-SAI Global

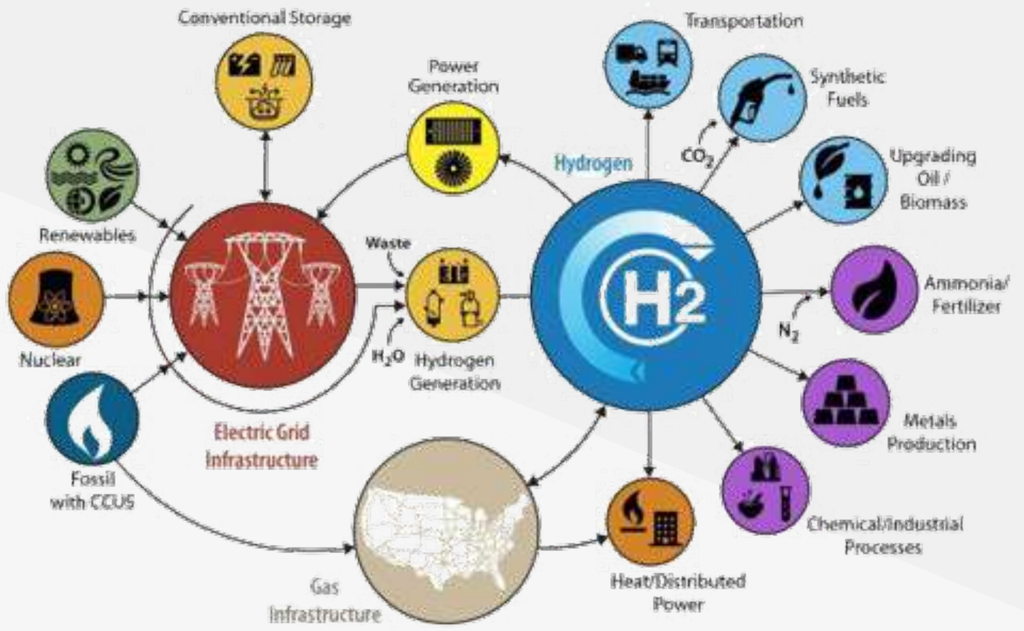
matrixservicecompany.com

MATRIX PDM ENGINEERING

H2 IN NEWS

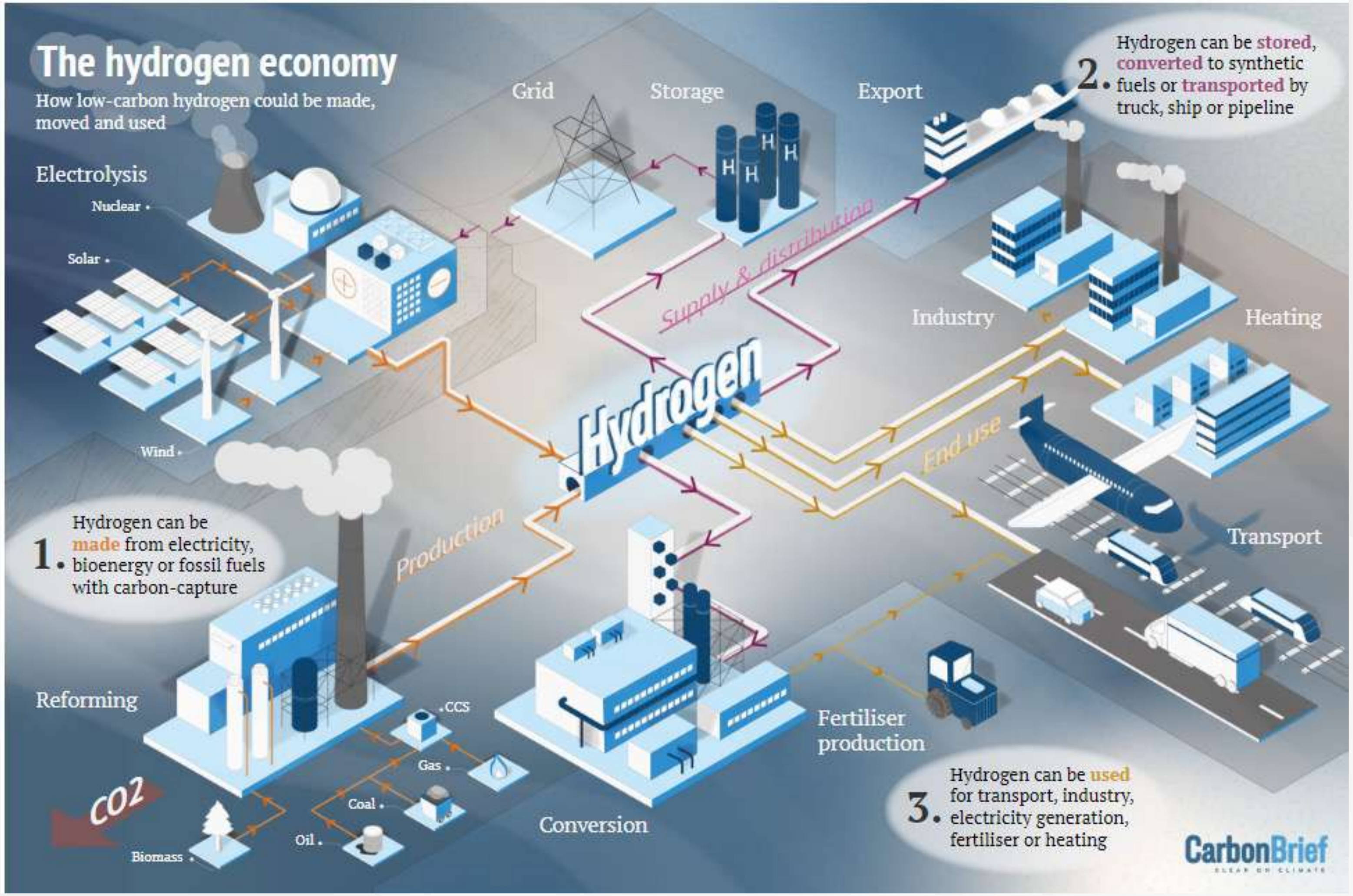
$9.5 billion in federal clean hydrogen Funds

- $500 million clean hydrogen projects,
- $1 billion for R&D into electrolyzers
- $8 billion for four clean hydrogen hubs.
    - One Hub to use nuclear energy
    - One Hub to use fossil fuels as a feedstock along with CCUs.
    - Two Hubs could be powered by renewables.



MATRIX PDM ENGINEERING

VERSATILITY OF H2



https://www.carbonbrief.org/in-depth-qa-does-the-world-need-hydrogen-to-solve-climate-change/

MATRIX PDM ENGINEERING

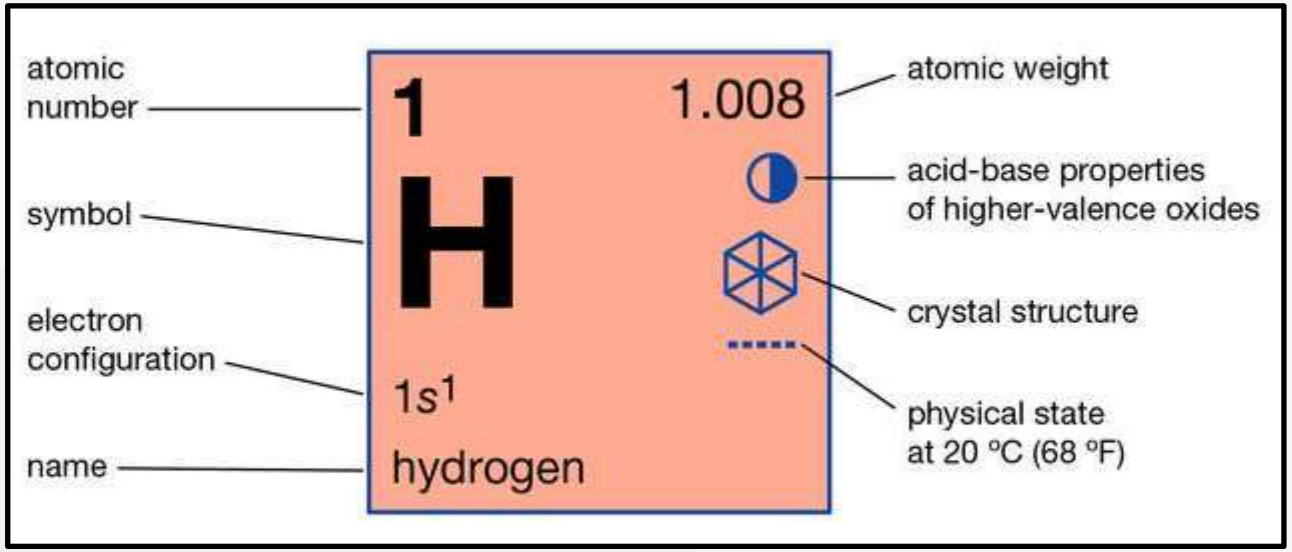
WHY HYDROGEN?

Zero Carbon Emission

Hydrogen Combustion vs Methane Combustion

$$2\,H_2 + O_2 \rightarrow H_2O \qquad \text{vs} \qquad CH_4 + O_2 \rightarrow H_2O + \cancel{CO_2}$$

- Hydrogen is the most abundant element in the universe
  - Use of hydrogen powered vehicles is on the rise



- Physical Properties
- Molecular Weight: 2.016
- Boiling Point @ 1 atm: -423.0°F (-252.8°C)
- Freezing Point @ 1 atm: -434.5°F (-259.2°C)
- Critical Temperature: -399.8°F (-239.9°C)
- Critical Pressure: 188 psia (12.9 atm)

WHY LIQUID HYDROGEN?

32°F: ICE

-260°F: LNG

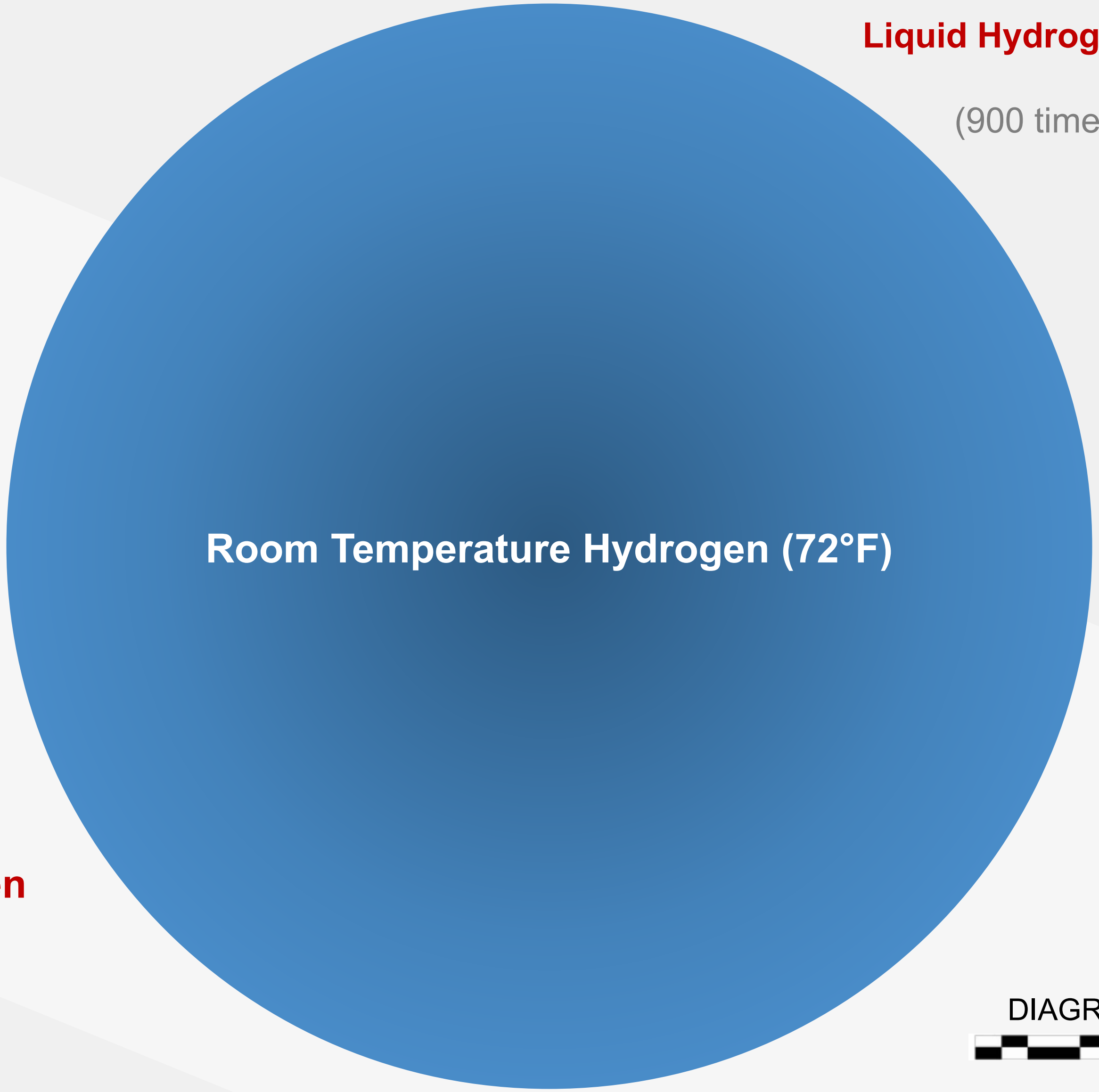
-318°F: Liquid Air

-355°F: FROZEN Air

-423°F: Liquid Hydrogen

-459°F: Absolute Zero

NOTE: All temperatures listed
are at atmospheric pressure

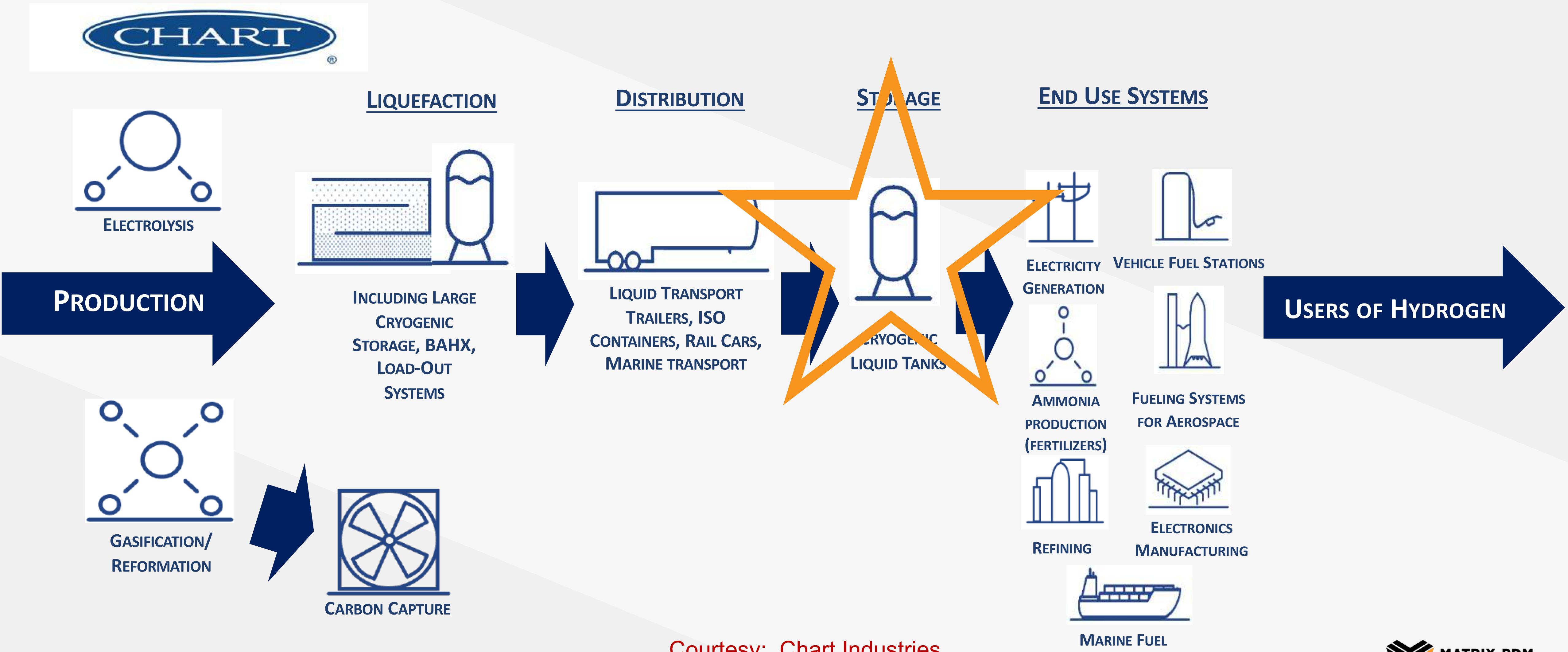


Liquid Hydrogen (-423°F)

(900 times less Volume)

DIAGRAM TO SCALE

HYDROGEN SUPPLY CHAIN



Courtesy: Chart Industries.

MATRIX PDM ENGINEERING

LIQUID HYDROGEN STORAGE
U.S. CODES AND STANDARDS

NATIONAL REGULATIONS

Supplemental Codes Standards

Other Standards

NATIONAL REGULATION
29 CFR § 1910.103
Hydrogen

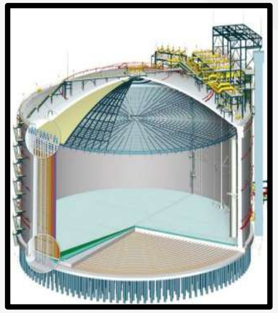
- NFPA – 2
  Hydrogen Technologies Code
- CGA H – 5
  Standard for Bulk Hydrogen Supply Systems

- Piping Standards
  ASME B31.12
  Hydrogen Piping and Pipelines
- PRESSURIZED STORAGE
  PRESSURE > 15.0 PSI
  - ASME Section VIII Divisions 1 and 2
- Refrigerated Liquefied Gas Storage
  - API 620
    Design and Construction of Large, Welded, Low-pressure Storage Tanks

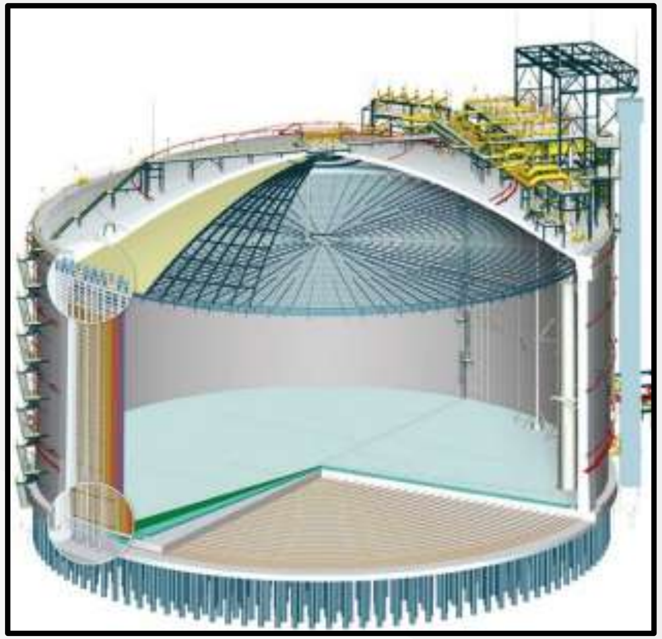
HYDROGEN STORAGE

LIQUID HYDROGEN STORAGE
FUTURE DEVELOPMENTS ON THE HORIZON

LH2 storage spheres



40,000 Cu. M
LH2 storage tank



100,000 Cu.M +
LH2 storage tank

TODAY
(AVAILABLE FOR IMMEDIATE APPLICATION)

IMMEDIATE FUTURE

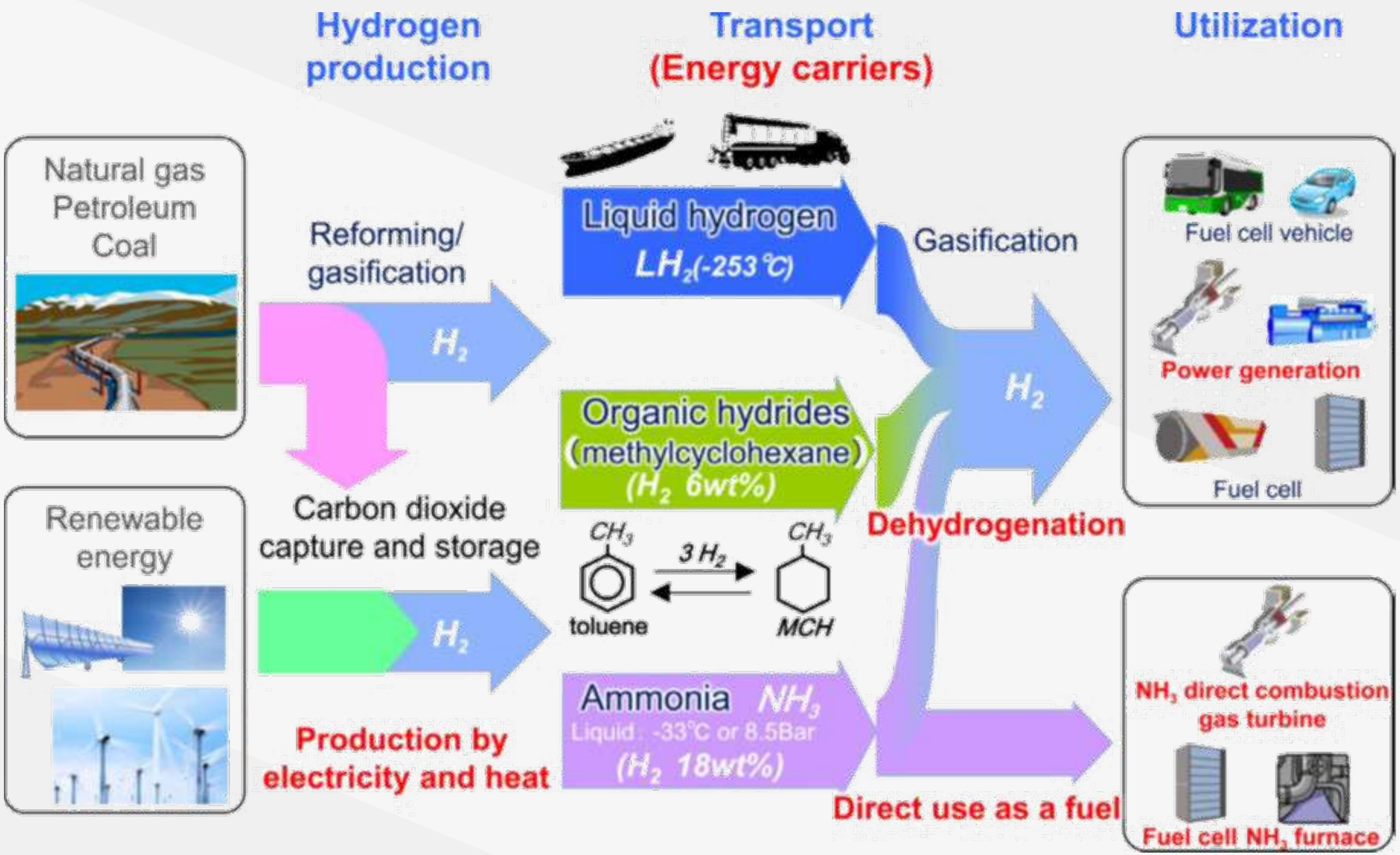
NEXT GENERATION

CHALLENGES ASSOCIATED WITH H2

- Gaseous hydrogen storage requires high pressure vessels of up to 70 MPa
- liquid storage needs cryogenic tanks maintained at -253° C
- Cost of Liquefaction needs to be considered
- Boil Off Gas (BOG) considerations remain a challenge
- Ortho Vs Para Hydrogen

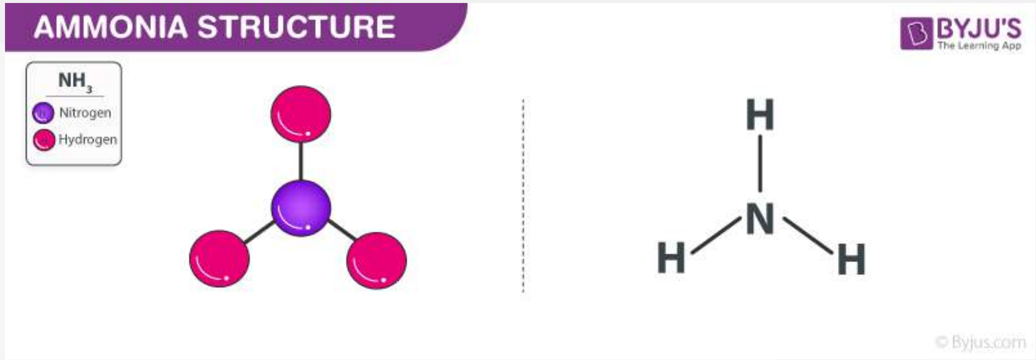
https://www.thechemicalengineer.com/features/h2-and-nh3-the-perfect-marriage-in-a-carbon-free-society/

ALTERNATE H2 CARRIERS



Ref: H. Kobayashi et al. / Proceedings of the Combustion Institute 37 (2019)

WHY AMMONIA?



Zero Carbon Emission

Hydrogen Combustion

$4\ NH_3 + 3\ O_2 \rightarrow 2\ N_2 + 6\ H_2O$

Vs

Methane Combustion

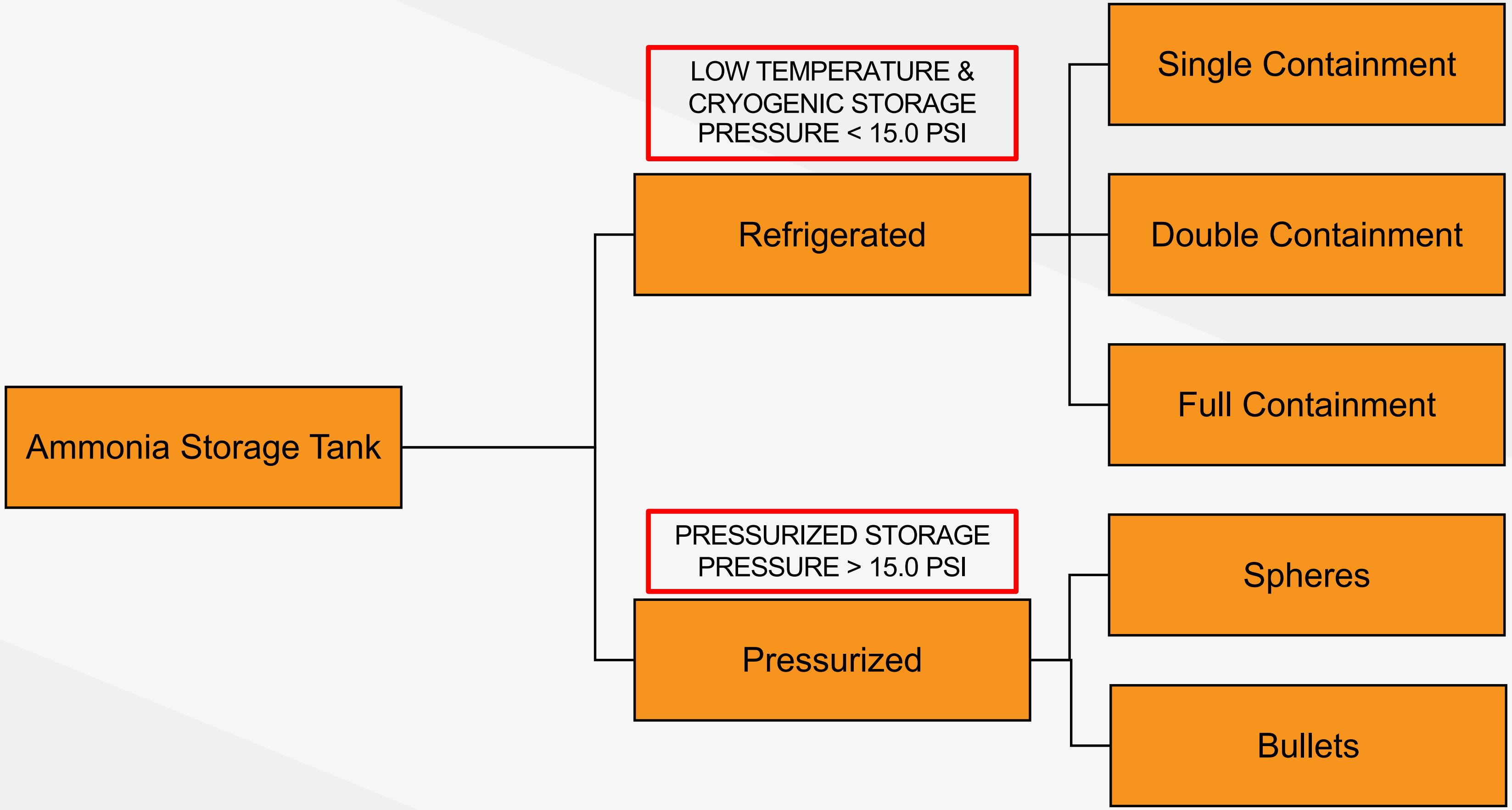
$CH_4 + O_2 \rightarrow\ H_2O + CO_2$

Properties of Ammonia – NH_3

NH_3	Ammonia
Molecular Weight/ Molar Mass	17.031 g/mol
Density	0.73 kg/m³
Boiling Point	-33.34 °C
Melting Point	−77.73 °C

MATRIX PDM ENGINEERING

METHODS TO STORE AMMONIA



AMMONIA STORAGE – DESIGN PARAMETERS

Description	Value
Storage Tank Gross Capacity	5,000 MT to 50,000 MT (Can go to 70,000 MT or higher.)
Design Pressure	1.0 psig to 4.0 psig (Typ. 2.0 psig)
Design Temperature	-35 deg. F

MATRIX PDM ENGINEERING

FULL CONTAINMENT STEEL TANKS

Two 74,000 m³ Ammonia Tanks – Orascom – Wever, IA

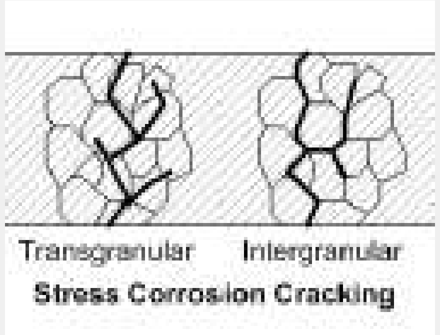
Designed by Matrix PDM Engineering,
Constructed by Matrix Service Inc.

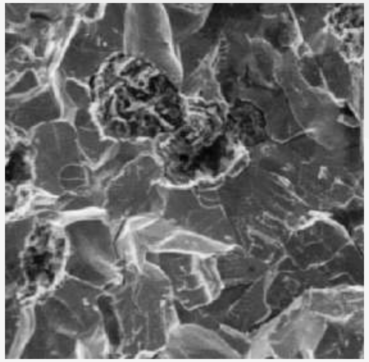
AMMONIA STRESS CORROSION CRACKING (NH3-SCC)

- NH3-SCC affects mechanical integrity
- Oxygen + Stress enables SCC
- SCC is less prevalent in low temperature storage tanks

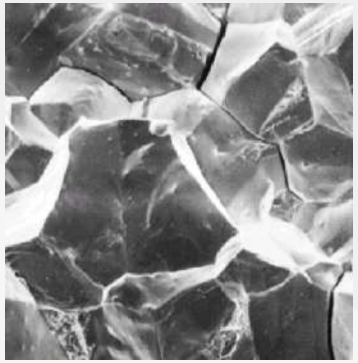
- **Prevention**
- Design, fabrication and construction details
- Minimization of oxygen contamination during commissioning and operation
- Providing a small amount of moisture (0.2%) during operation

- **Inspection**
- Wet Magnetic Particle Testing
- UT Testing (Shear Wave + TOFD)
- Acoustic Emissions





Transgranular Fracture



Intergranular Fracture

Reference
Dettmers, Reindell; Stress Corrosion Cracking Update, Presentation, www.irc.wisc.edu
Nyborg, Lunde; Measures for Reducing SCC Anhydrous Ammonia Storage Tanks, AIChE, Aiche-35-005, 1994
Mortenson; In-service inspection of welds in atmospheric ammonia storage tanks, https://www.semfa.eu/Portals/6/Presentations/Inspection%20of%20Ammonia%20Storage%20Tanks

CURRENT CHALLENGES

- Thickness considerations (> 2 inches thickness)
- Associated welding and weld processes
- Hardness requirements on the finished welds (Typical 225 Brinell)
- Cost of Green Ammonia is high.
- Ammonia is an expensive fuel
- Ammonia produces NOX and N2O gases when used to produce H2 (296* More green houses compared to CO2)

https://sustainability.crugroup.com/article/green-ammonia-fuel-faces-three-big-challenges

SUMMARY

- Developments are underway for scale-up challenges are associated with LH2 storage with solutions.

- Ammonia is mature from a storage perspective. Certain incremental changes need to be made to increase the storage sizes.

Storing vital products with care

Vopak - Rice Global Forum Roundtable
14 October, 2022

Historic overview
Vopak and its main precursors

1616
De ‘**Blaauwhoedenveem**’ was founded

1818
Establishment of **Pakhuismeesteren** van de Thee in Amsterdam and Rotterdam

1839
Founding of the **Phs. Van Ommeren** shipbroking company

1967
Merger of Pakhuismeesteren and Blaauwhoed into **Pakhoed**

1999
Merger of Pakhoed and Van Ommeren into **Vopak**

2016
400th anniversary of Vopak

We serve multiple end markets through different products and customer offerings

End markets	Energy		Manufacturing	
Products	Gas	New energies & sustainable feedstocks	Oil	Chemicals
Customer offerings	Industrial	Multifunctional	Distribution	

Unrivalled network of strategic locations, capabilities and partnerships

Vopak

Network

Strong base in industrial locations around the globe

78
Terminals

18
Industrial

90%
Market share in industrial terminals

Capabilities

Safely and efficiently design, build and operate global infrastructure

250+
Products

2 million+
Cbm of gaseous storage

Nr. 1
Independent LNG infrastructure provider

Partnerships

Vital infrastructure partner, developer and operator

1,000+
Long standing relationships with customers

25+
Joint venture partners

China & India
Nr. 1 independent provider with 18 terminals

Leading locations

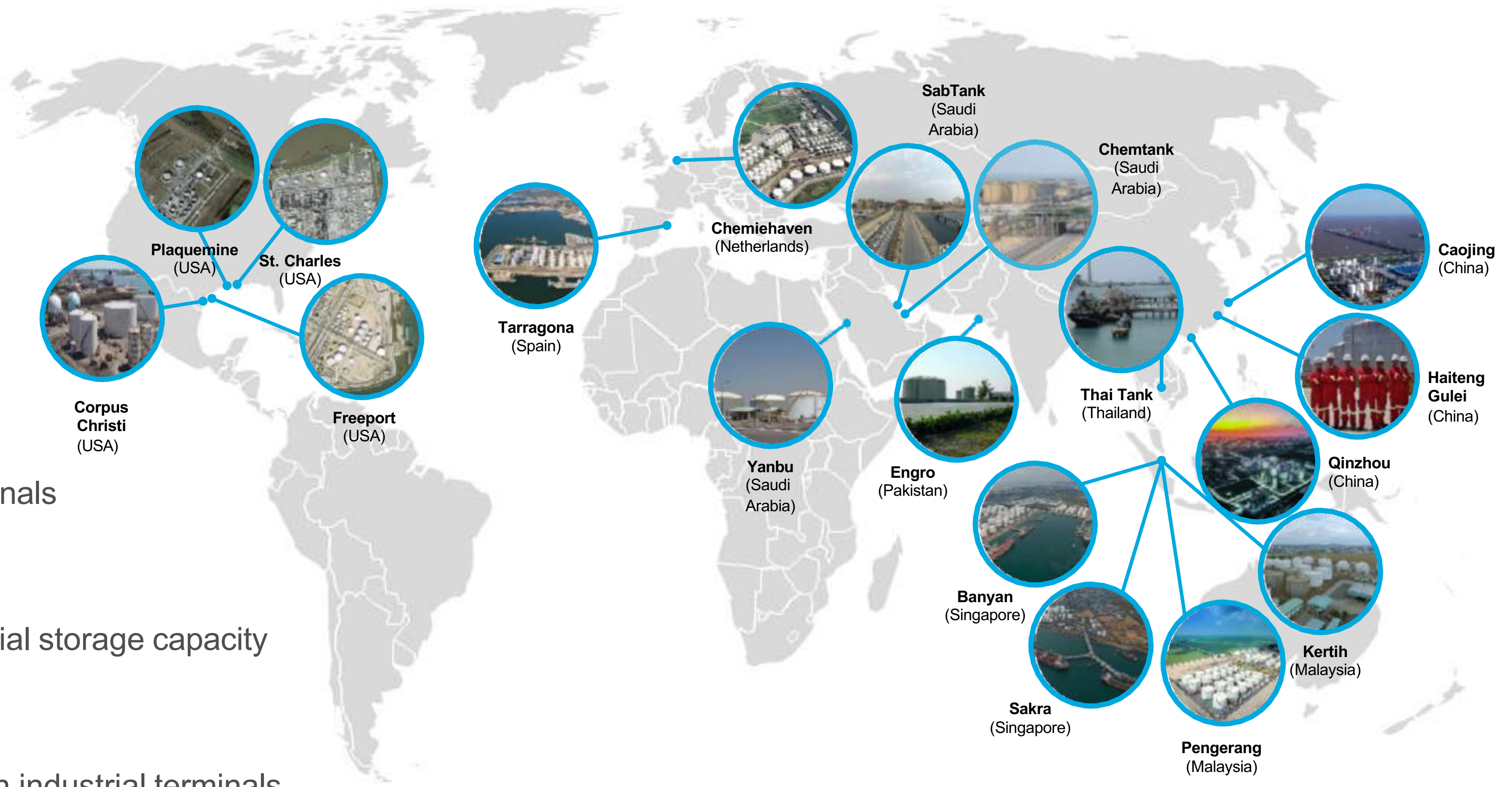
Vopak

78
terminals

Hub terminal

Terminal

Strategically positioned industrial terminals in the world's key seaports and hubs



18

Industrial terminals

9m

Cbm of industrial storage capacity

90%

Market share in industrial terminals

Vopak Industrial Infrastructure Americas

Product: chemicals, oil products, biofuels, base oils and lubricants

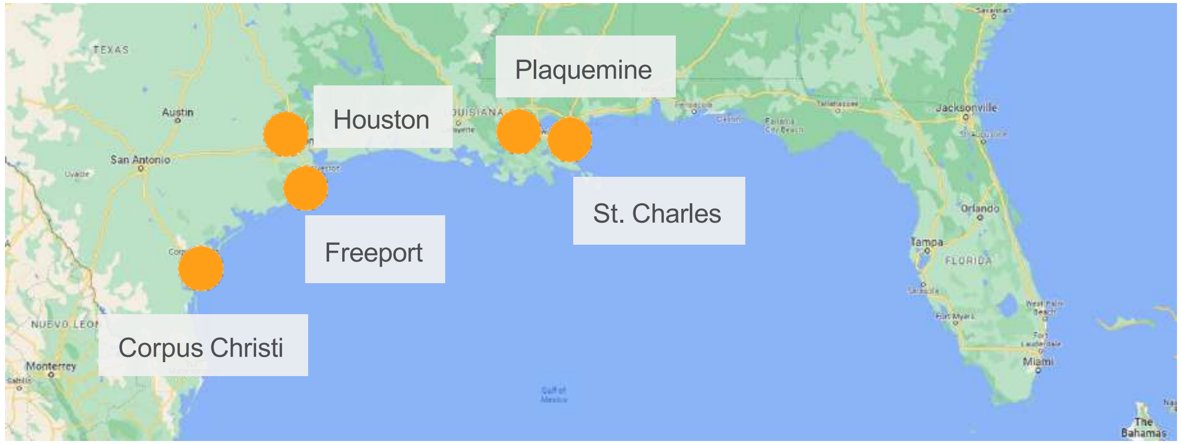
Shareholding: BlackRock (50%) and Vopak (50%)

Services: storage, blending, integrated pipeline systems with industrial complex

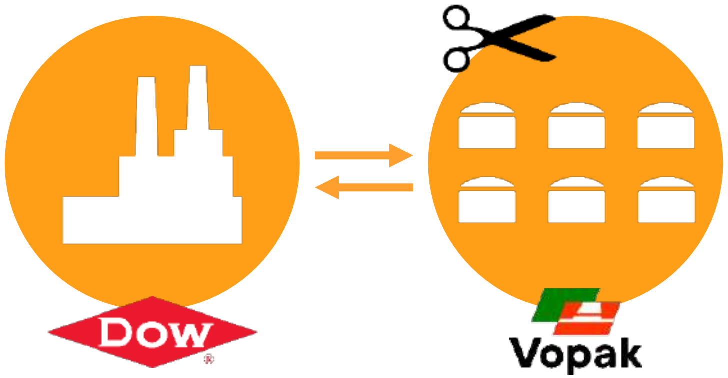
End-use: manufacturing, wide range of consumer goods

Storage: 737 thousand cbm (150+ tanks)

Vopak's US Gulf Coast footprint



Carve out concept



Gate terminal in the Netherlands

Product: high-calorific liquefied natural gas (LNG)

Shareholding: Gasunie (50%) and Vopak (50%)

Services: storage, regasification, truck and vessel loading, ship-to-ship transfer, bio-LNG

End-use: power and industry

Storage: 540 thousand cbm (3 tanks)

Send-out: yearly 12 BCM (baseload), 4 BCM (interruptible), meeting more than 30% of the Netherlands’ gas needs

*In preparation

Growing LNG network

- Land based and FSRU
- Project in Zhangjiagang
- LNG-bunkering
- Multi-purpose
- Open for quick go-to-market solutions
- Joint Ventures

Vopak Sakra terminal in Singapore

Industrial terminal integrated with petrochemical complex

10+
customers

Product: chemicals and base oils

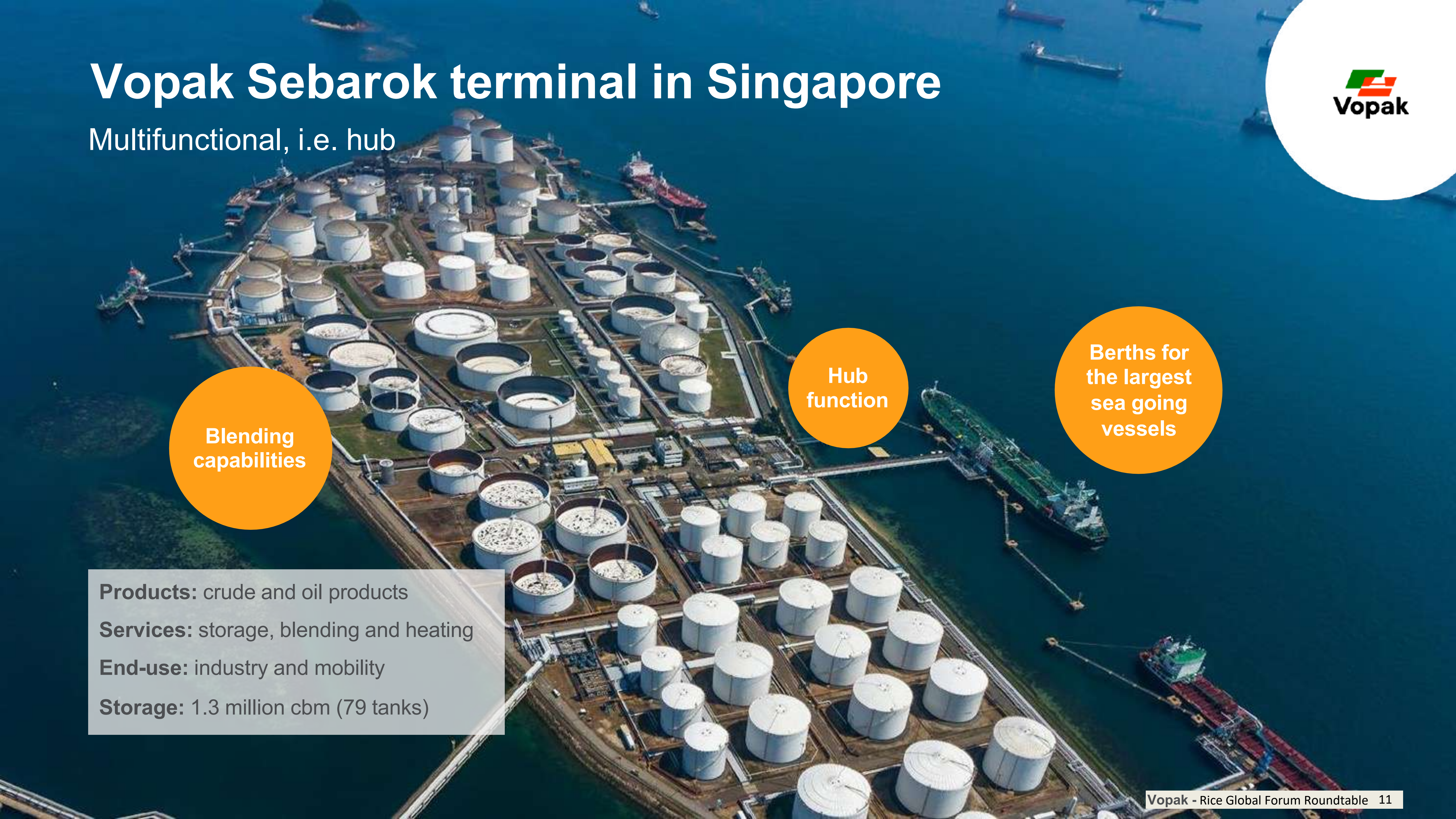
Services: storage, blending, integrated pipeline systems with industrial complex, trucking, drumming, heating and chilling

End-use: manufacturing, wide range of consumer goods

Storage: 288 thousand cbm (71 tanks)

Vopak Sebarok terminal in Singapore

Multifunctional, i.e. hub



Products: crude and oil products

Services: storage, blending and heating

End-use: industry and mobility

Storage: 1.3 million cbm (79 tanks)

Vopak TTR terminal in the Netherlands

Products: chemicals, oil products and biofuels

Services: storage, blending, heating and break-bulk

End-use: manufacturing, wide range of consumer goods

Storage: 325 thousand cbm (89 tanks)

Vopak Lesedi terminal in South Africa

Distribution

Products: oil products

Services: storage, distribution and truck loading

End-use: mobility

Storage: 100 thousand cbm (6 tanks)

Our New Energy focus areas

Vopak currently pursues 10+ infrastructure projects and studies

Hydrogen

- H-vision: blue hydrogen in the Netherlands. ACE Terminal ammonia
- Pilot: Green liquid organic hydrogen (LOHC) from Germany to the Netherlands
- Import of green (liquefied) hydrogen, LOHC and ammonia in Southern Europe, Middle East, Australia and South America.

Sustainable feedstocks

- Import green ammonia from Morocco or Middle East
- Xycle: Chemical recycling of plastic waste in Rotterdam
- Good progress building new tanks for waste based feedstocks in Rotterdam

CO2 infrastructure

- Independent liquid CO2 hub in Rotterdam
- Export terminal opportunities in Antwerp, Flushing and Singapore

Long Duration Energy Storage

- Pilot: Hydrogen bromide redox flow battery in the Netherlands together with Elestor
- Pilots: Vanadium redox flow battery in Singapore and Australia