Making our world more productive

TIChE Asia 2023
Hydrogen Economy & Hydrogen Fuelling

June 22, 2023

Vishal Pandey, Linde plc

Overview about Linde Plc

World's largest industry Gas & Engineering company

- Formed in 2018 with the merger of Linde AG and Praxair, Inc – two world-class companies with nearly 140 years of shared history and successful achievements
- The leading industrial gases and engineering company. Two divisions Linde Gas and Linde Engineering

160 Bn USD$ Market Cap

$31 Bn Revenue 2021

One Linde

Uniting with a shared Vision, Mission and Strategic Direction, and demonstrating our Values and Behaviors in everything we do

2 million+

customers

Establishing a more diverse and balanced portfolio

100+

countries

Enabling strong, complementary positions in all key geographies and end markets

~80,000

employees

Achieving our full potential, individually and collectively

~$15 million

charitable giving and sponsorships in 2018

Supporting our communities through contributions and employee volunteerism

6,500+

active patent assets worldwide

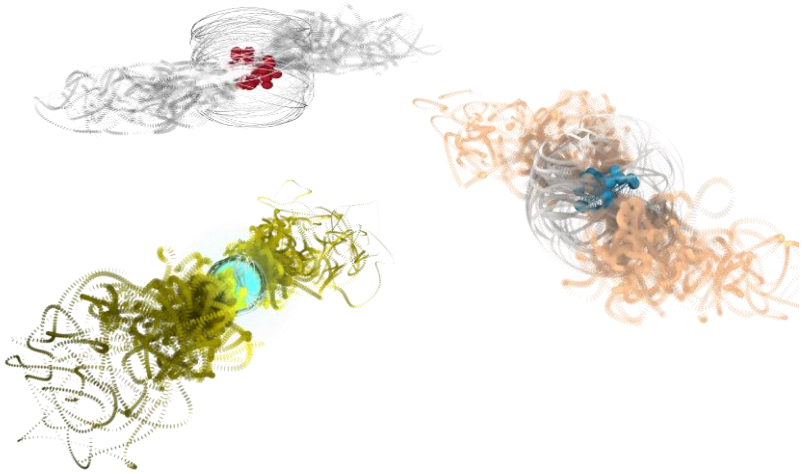
Leading with innovative products, solutions and technologies

Linde Industrial Gas Assets & Technologies

O2, N2, H2, NH3, Syngas, rare gases, specialty gases, LNG....

Gases

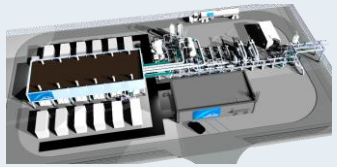
Linde's core business to produce oxygen, hydrogen.



World-class operations of over 1,000 plants

On-Site

Plants



Merchant

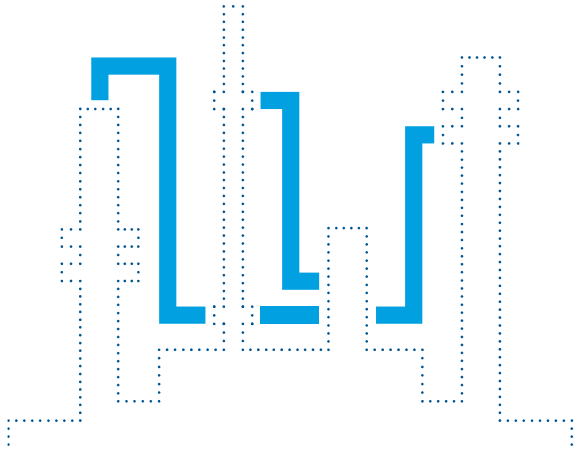
Equipment

Packaged

Service

Engineering & Technologies

Plant & Equipment Supply



Technology-focused with more than 4,600 plants built

Synergies

Linde already has a world-scale hydrogen asset portfolio

Hydrogen technologies and assets

H2 molecules sales today @$3 B

Production

- SMR, ATR, POX, …
  >8000 tpd H2 today
  158 large H2 plants
- …with CCU/S
- Ammonia & methanol plants
  11 plants
- Electrolysis
  80 electrolysers/40 MW in operation

Processing/Distribution

- Liquefaction
  200 tpd LH2
- H_2 refueling stations
  > 200 HRS built
- Trailers
  1600 trucks
- Underground storage
  Salt cavern *>6000 tons H2*
- Pipelines
  > 1000 km
- Equipment & Tech Offerings

Hydrogen assets across the globe;
100 years of experience building, owning and operating hydrogen assets

Gray H_2 Blue H_2 Green H_2 H_2 Distribution, Conditioning & Application

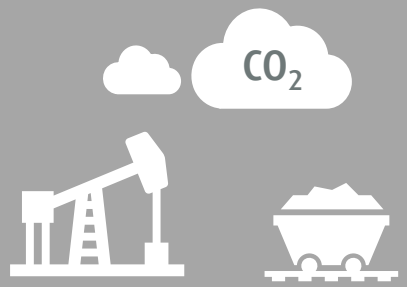
Ability to leverage existing infrastructure, technology & expertise – agnostic to the color of the molecule

Clean Energy Opportunity

Clean Energy = Carbon Solutions + Blue & Green Hydrogen

Today's Energy Market

Hydrocarbons



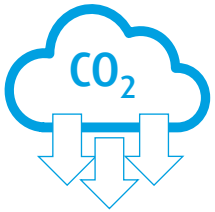
All traditional hydrocarbons with C02 footprint

$6T

Hydrocarbon Sales Today[1]

Clean Energy Opportunity in 2030[2]

Carbon solutions



CO_2 capture from industrial processes with CO_2 storage or utilization

Blue Hydrogen

Grey cycle with CO_2 capture, storage or utilization

Green Hydrogen

Electrolysis powered by Renewable Energy with no CO_2 emission

>$100B

Estimated Clean Energy Sales in 2030[2]

1.5% of today's Hydrocarbon market …

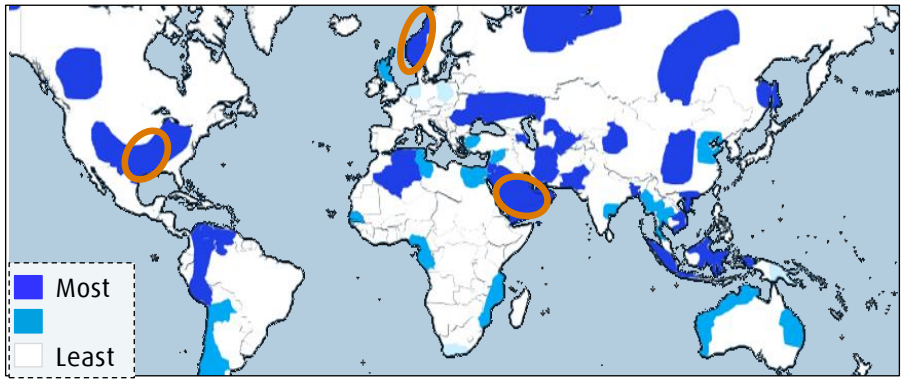
… and comparable to today's industrial gases market size

1. Source: IHS
2. Based on Hydrogen Council forecast of 24MMt H2 demand by 2030 and Linde price assumptions.

The best location for production of blue and green hydrogen

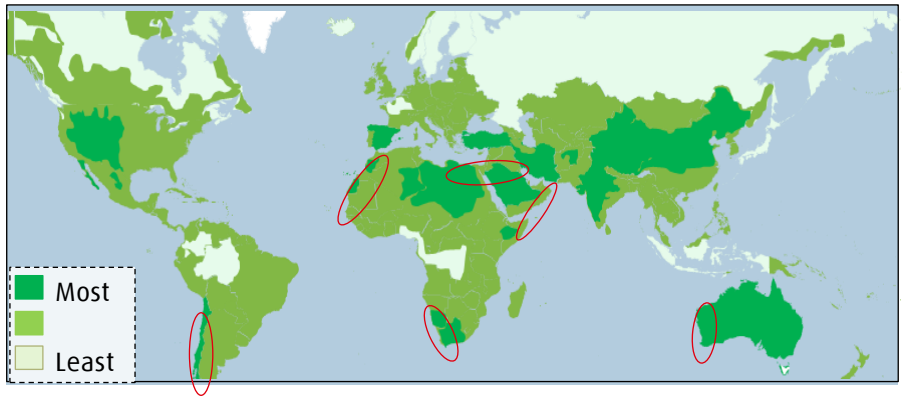
Energy vector of the future to support decarbonisation

Best locations for Natural Gas + CCS



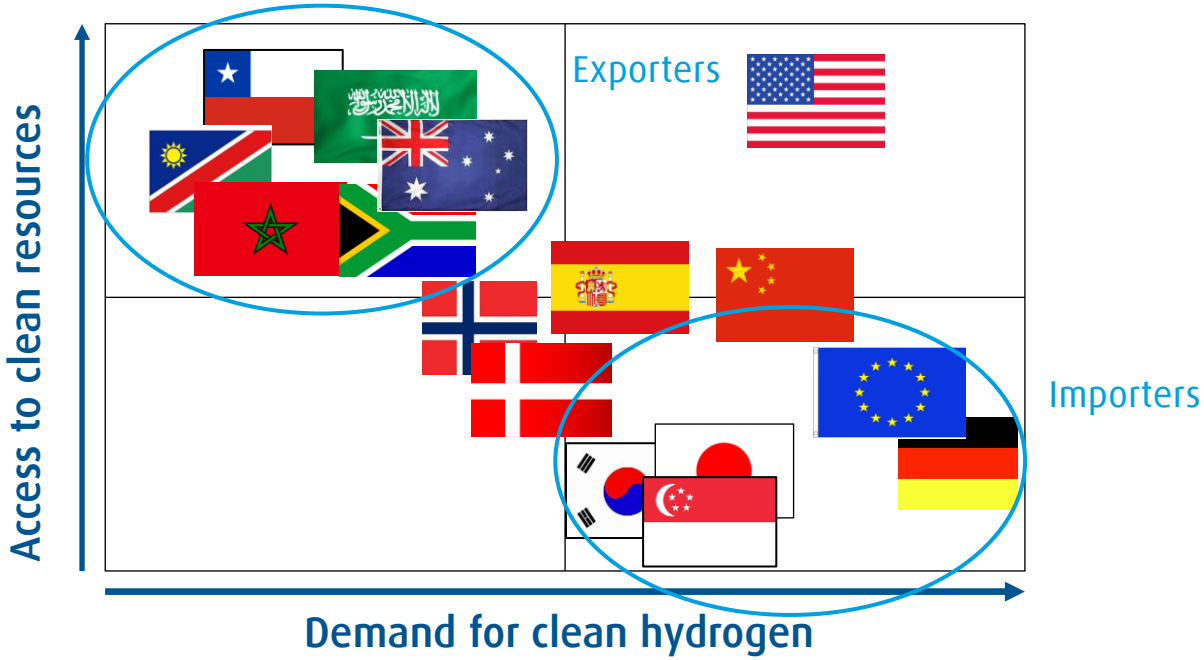
Best locations for projects

Best locations for Wind + Solar Use



Best locations for projects

Cross-country supply-demand combinations for Clean Hydrogen



- **EU** and **North-East Asia** will remain largely dependent on energy imports
- **Middle East** will remain a major exporter with Clean Energies
- New major export players expected with **Australia, Morocco, Namibia, Chile etc.**
- **US** self-sufficient with potential exporter globally

Linde's Developments for Decarbonization

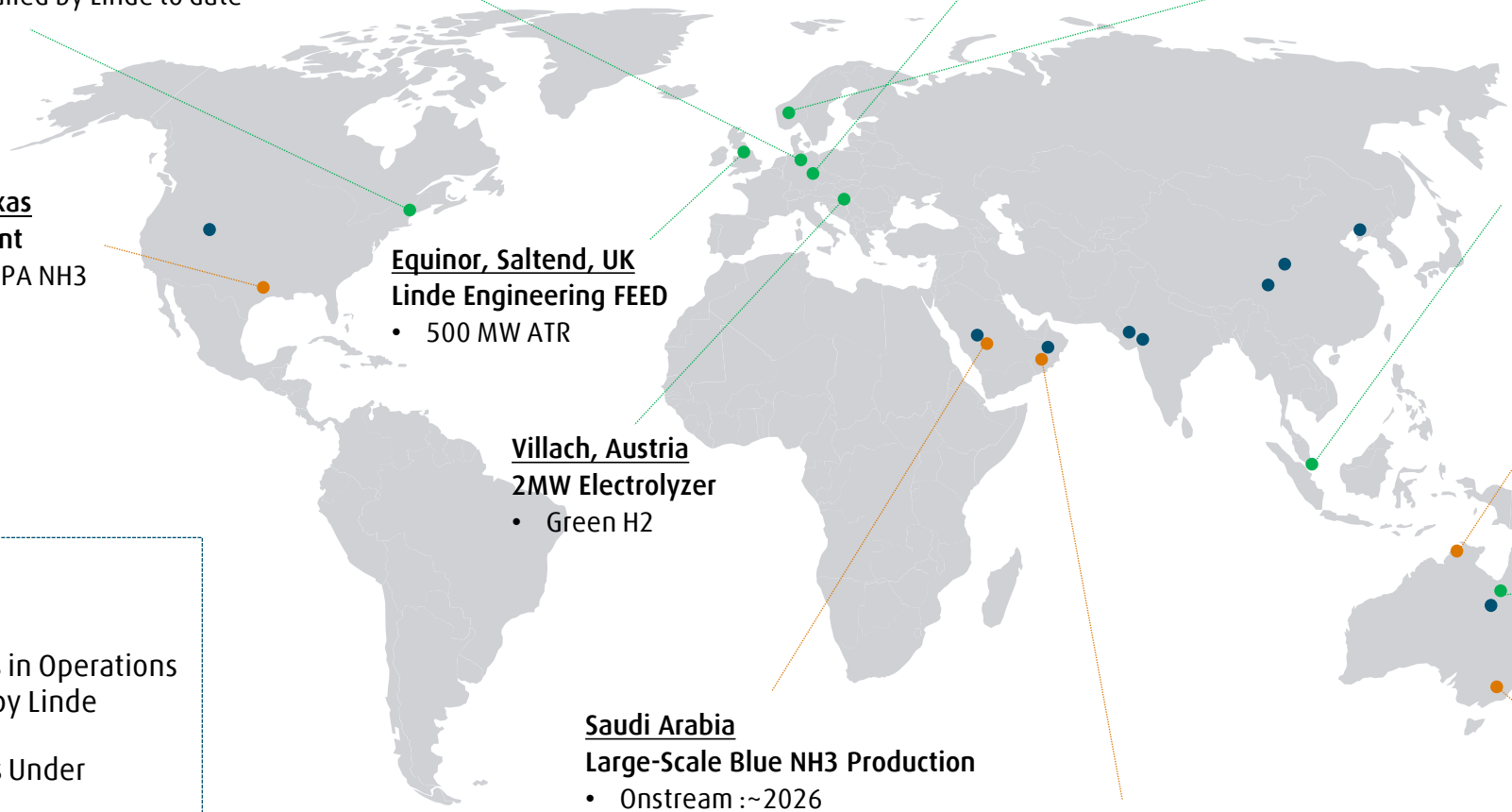
Global Examples[1] of Linde's Investment in H2 and NH3

Leuna, Germany
24MW Electrolyzer for Mobility (liquid H2) & Existing Industries
- To supply world's first H2-fueled ferry
- Onstream: 2022

Niagara Falls, New York
35MW Electrolyzer (w Hydropower)
- Largest electrolyzer installed by Linde to date
- Onstream :~2025

Energiepark Mainz, Germany
6MW Electrolyzer (w Wind Power)
- Onstream: 2015

Porsgrunn, Norway
24MW Electrolyzer for Yara's NH3 Production
- 20,500 tpa of ammonia
- Online 2023



OCI, Beaumont, Texas
1.8b USD investment
- To supply 1.1 MTPA NH3

Equinor, Saltend, UK
Linde Engineering FEED
- 500 MW ATR

Singapore
9MW Electrolyzer for Chemical Feedstock
- Onstream: ~2025

Villach, Austria
2MW Electrolyzer
- Green H2

Northern Territory
Large-Scale Blue NH3 Production
- Onstream :~2027

Queensland, Australia
Australia's First Green H2 Refuel Station
- Linde-BP collaboration
- H2 supplied from electrolyzers using solar

Saudi Arabia
Large-Scale Blue NH3 Production
- Onstream :~2026

Oman
Large-Scale Green NH3 Production
- Onstream :~2027

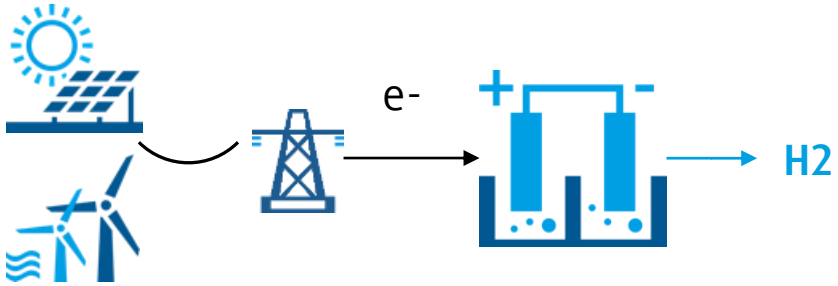
Southern Australia
Large-Scale Green NH3 Production
- Onstream :~2027

- H2 Projects
- 10 NH3 Production Plants in Operations (up to 1000 TPD); 2 BOO by Linde
- Low-Carbon NH3 Projects Under Development

[1]Selected references; non-exhaustive

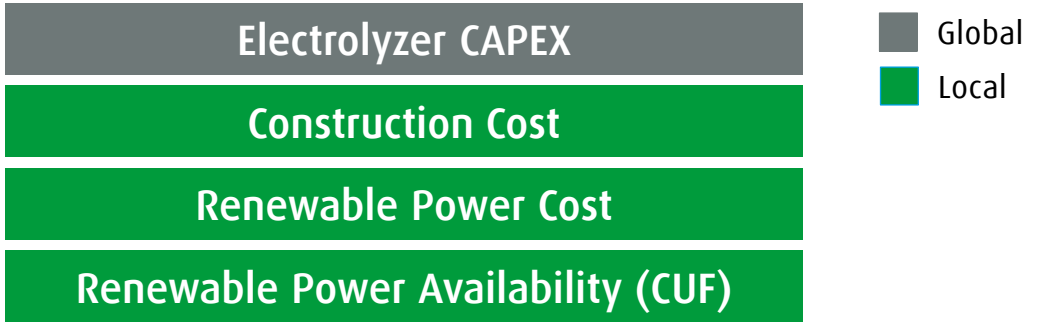
Clean Hydrogen Imports
Green Hydrogen Production

Green Hydrogen Production Route



Renewable Energy (RE) Electrolysis (AEL/PEM)

Green Hydrogen Main Cost Factors



Green Hydrogen Cost Sensitivity Model for Power Price and Renewable Availability

Green hydrogen production today

Power Cost ($/MWh) / RE Availability (CUF)	20%	40%	60%	80%
$20/MWh	7.3	4.3	3.2	2.7
$40/MWh	8.4	5.4	4.4	3.9
$60/MWh	9.6	6.5	5.5	5.0
$80/MWh	10.7	7.7	6.7	6.2

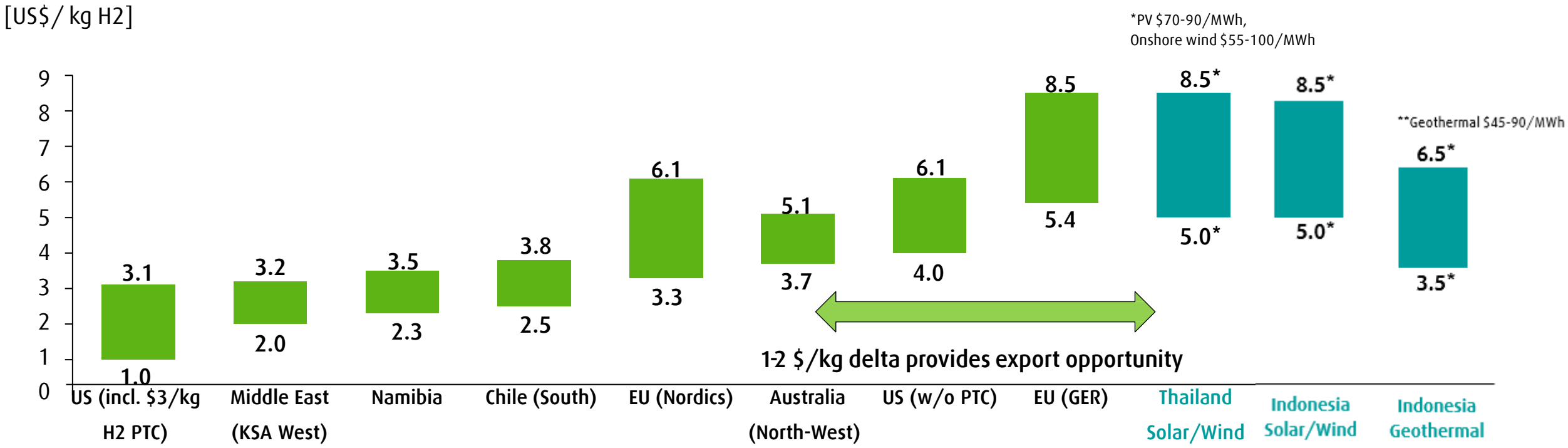
Mid-long term target green hydrogen production

Power Cost ($/MWh) / RE Availability (CUF)	20%	40%	60%	80%
$20/MWh	4.0	2.6	2.1	1.9
$40/MWh	5.2	3.8	3.3	3.0
$60/MWh	6.3	4.9	4.4	4.2
$80/MWh	7.5	6.1	5.6	5.4

w/o public incentives, green H2 below $2/kg not realistic today... and will remain a challenge for the future

Clean Hydrogen Production - Green

Renewable power cost is key for green hydrogen



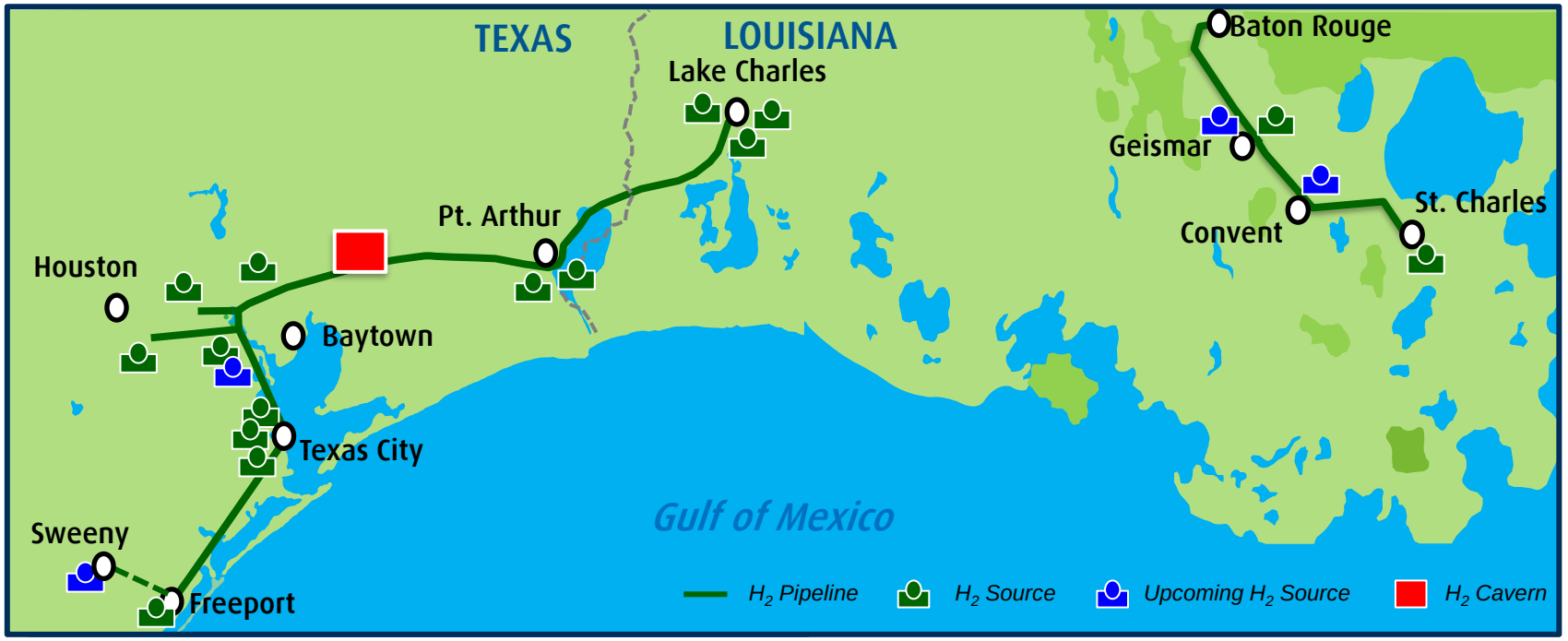
*Variables are Levilised Cost of Electricity ($20-100/MWh), utilization factor (20-80%) & Capex for hydrogen production

without public incentives, green H2 below $2/kg not realistic today... and will remain a challenge for the future

Source: Linde Internal analysis based on International Energy Agency Special Reports

Hydrogen pipeline distribution and storage

Linde's Gulf Coast Hydrogen Networks and Infrastructure



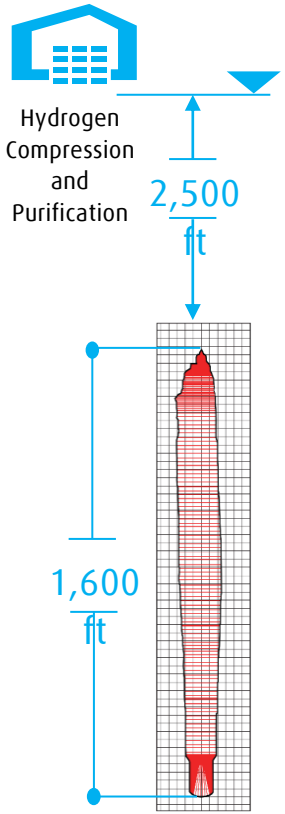
Location: Texas

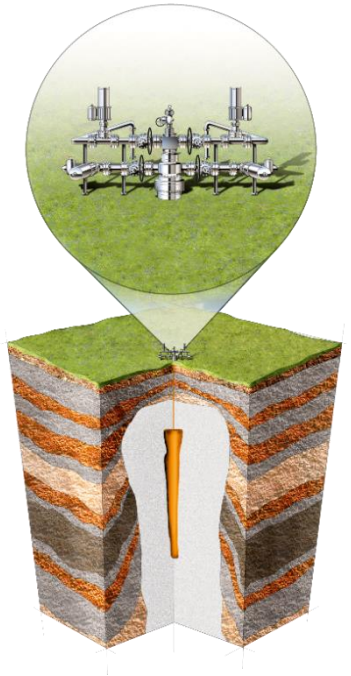
Pipelines: > 1000 km

Multiple sources provide high reliability of supply

	H2 Pipeline
H2 Sources/HMUs (>3000 tpd)	>20
Customers	>40

Linde's H2 storage cavern provides a buffer for daily and seasonal storage





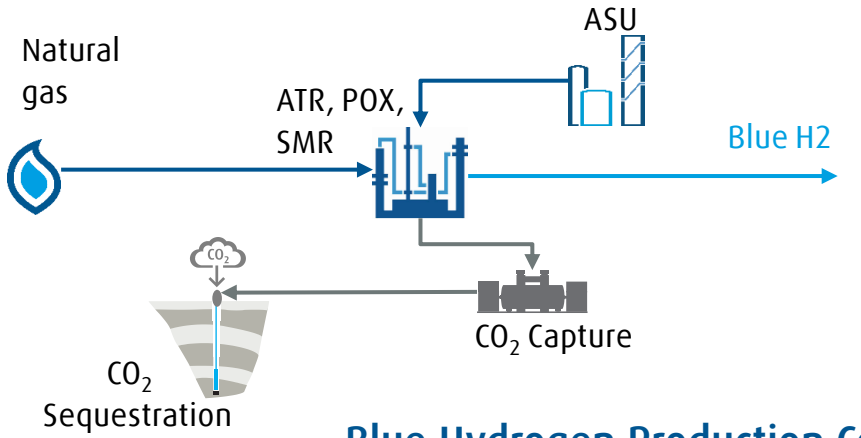
H2 storage: 6000 Tonnes

Operational: 2007

Clean Hydrogen Production - Blue

Blue Hydrogen remains a viable pathway for the foreseeable future

Blue Hydrogen Production Route

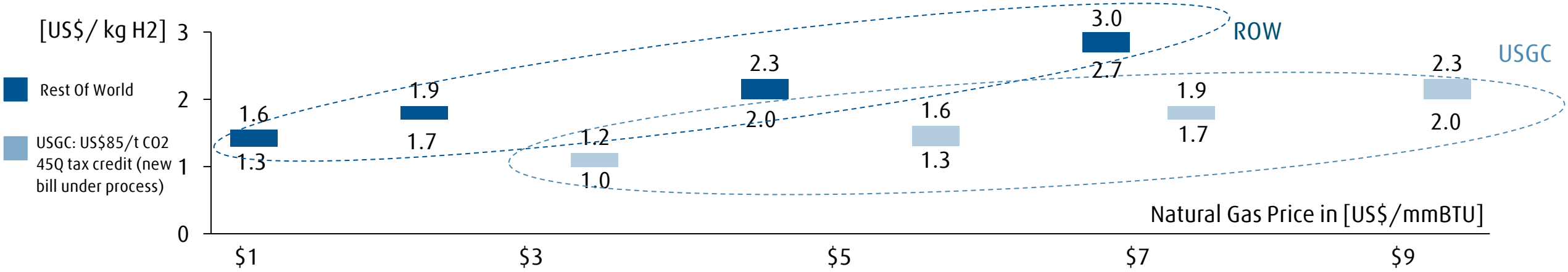


Blue Hydrogen Cost Factors

- Construction Cost
- Natural Gas Cost
- Carbon Sequestration Cost
- Carbon Tax / Carbon Tax Credit

Global
Local

Blue Hydrogen Production Cost @ different NG prices compared to the US Gulf Coast



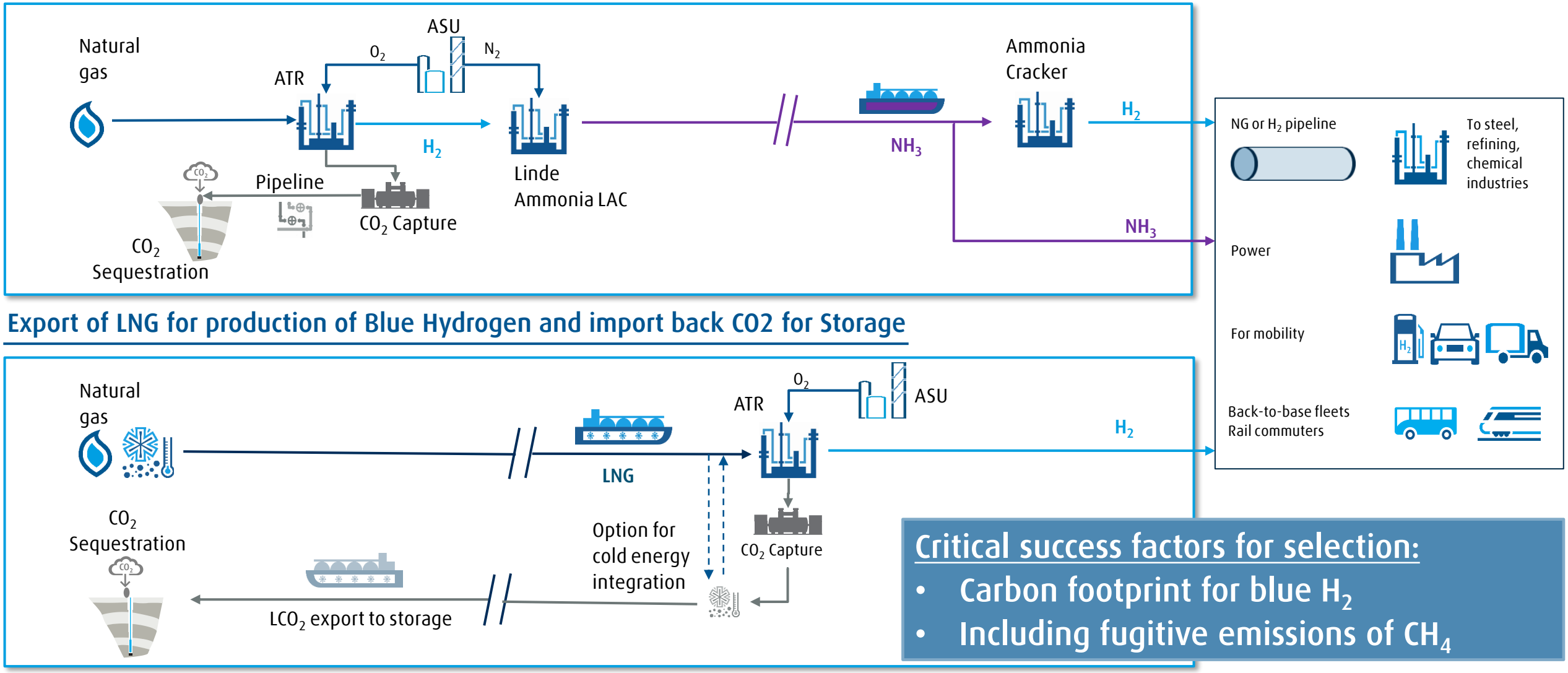
Blue H2 expected in the range of 1.5-3.0 US$/kg within typical cost range for Natural Gas, and USGC 1.0-2.5 US$/kg

Source: Linde Internal analysis

CCS opportunities for Blue Hydrogen in Thailand

Export i. Blue ammonia or ii. Export LNG with CO2 return?

Export of Blue Ammonia for direct use or Cracking to Hydrogen



Export of LNG for production of Blue Hydrogen and import back CO2 for Storage

Critical success factors for selection:

- Carbon footprint for blue H_2
- Including fugitive emissions of CH_4

Linde & SLNG to develop CO_2 facility for Singapore CCS

Integration of LNG cold energy for CO_2 liquefaction

SLNG and Linde team up for CO2 facility in Singapore

BUSINESS DEVELOPMENTS & PROJECTS

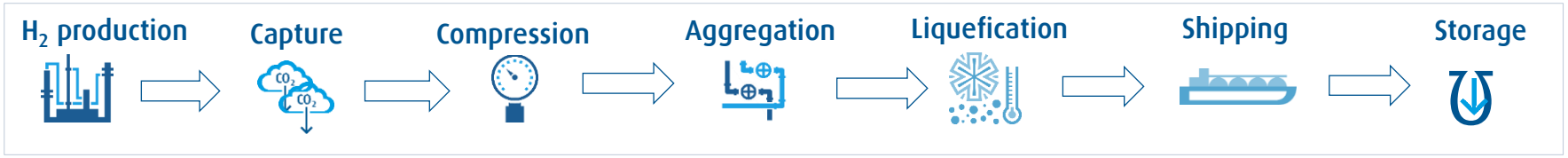
December 1, 2021, by Sanja Pekic

Singapore LNG (SLNG) and Linde Gas have signed a memorandum of understanding (MoU) to explore options of a CO2 liquefaction and storage facility at the SLNG terminal on Jurong Island.

The CO2 facility project concept involves using cold energy from the SLNG terminal's operations to liquefy CO2. It will also use both companies' combined expertise in carbon capture, liquefaction, as well as cryogenic storage and handling solutions.

They will store the liquefied CO2 (LCO2) in tanks onsite before they transport it later for end-use.

If feasible, this could be the first such facility in Singapore and the region. This refers to using existing cold energy from SLNG to liquefy CO2; thereby directly capturing CO_2 which would otherwise be emitted into the atmosphere.



Linde – SLB Global CCS Partnership announced 31st October 2022.

Joint value proposition.

	Offering of an **integrated end-to-end CCS solution** enabling a simplified path to decarbonization
	Proven **CO_2 capture technology** portfolio
	**Full value chain technology, EPC & operation capabilities**
	20+ years of experience in **CO_2 geological storage** (subsurface characterization & modelling), project development & execution, operations & monitoring
	**Flexibility of business & operating models** to maximize value for all stakeholders
	Strong **international relationships** across multiple sectors/industries

Linde, SLB & Saudi Aramco partnership to leverage CCS value chain

Development of a 9 MTPA CO_2 storage hub by 2027

Linde Signs Agreement to establish CCS Hub with Saudi Aramco

ENVIRONMENTAL SUSTAINABLE BUSINESS

Saudi Aramco Signs Agreement with SLB and Linde to Establish Carbon Capture and Storage Hub

ESG. news **ESG News** · November 11, 2022

Saudi Aramco signed a joint development agreement with SLB and Linde to establish a carbon capture and storage hub which will potentially be able to safely store up to 9 million tonnes of carbon dioxide a year by 2027, the company's CEO, Amin Nasser, said on Thursday.

Aramco is set to contribute around 6 million tonnes, he added, with the rest to come from other industrial sources.

See related article: Saudi Aramco Launches $1.5 Billion Fund To Support Global Energy Transition

The facility will be located in Jubail on the east coast of Saudi Arabia with a goal of making a significant contribution to the 44 million tonnes the kingdom plans to capture by 2035.

Linde in the Kingdom of Saudi Arabia

- ≥40 references in T-EPC projects in petrochemicals & gases


NIGC/PRC/SIGAS ASUs


UNITED CO2 plant


TASNEE Steam Cracker


SHARQ PE 3/4


UNITED Linear Alpha Olefins


Linde-SIGAS


Linde Surface Technologies

Linde Arabian Contracting


Linde Jubail HyCO & NH_3

- 4 operating companies with ≈400 full-time employees
- 700 Million USD direct investments until today
- Leader in bulk & packaged gases, gas applications incl. oil & gas services

Linde Engineering - Hydrogen Fueling
Hydrogen Fueltech GmbH for Hydrogen Mobility

Technology and product portfolio

GH_2 supply – ionic compressor

Outlet pressures	500 or 900 bar
Inlet pressure	5–200 bar
Capacity	28 or 56 kg/h
Efficiency	1–3.3 kWh/kg

Ionic compressor based hydrogen refueling stations

LH_2 supply – cryo pump

Outlet pressures	500 or 900 bar
Inlet pressure	2–2.5 bar
Capacity	40 or 100 kg/h
Efficiency	1.3–1.5 kWh/kg

Cryo pump based hydrogen refueling stations

Applications

Material handling

Light vehicles

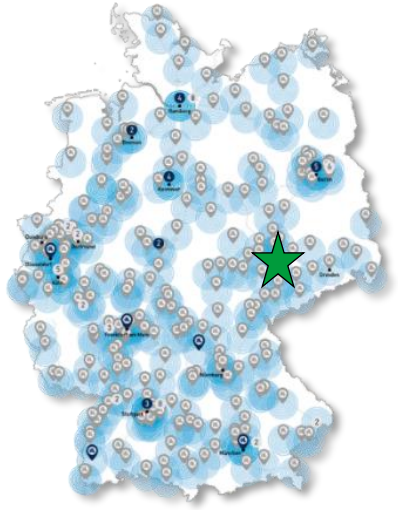
Buses

Trucks

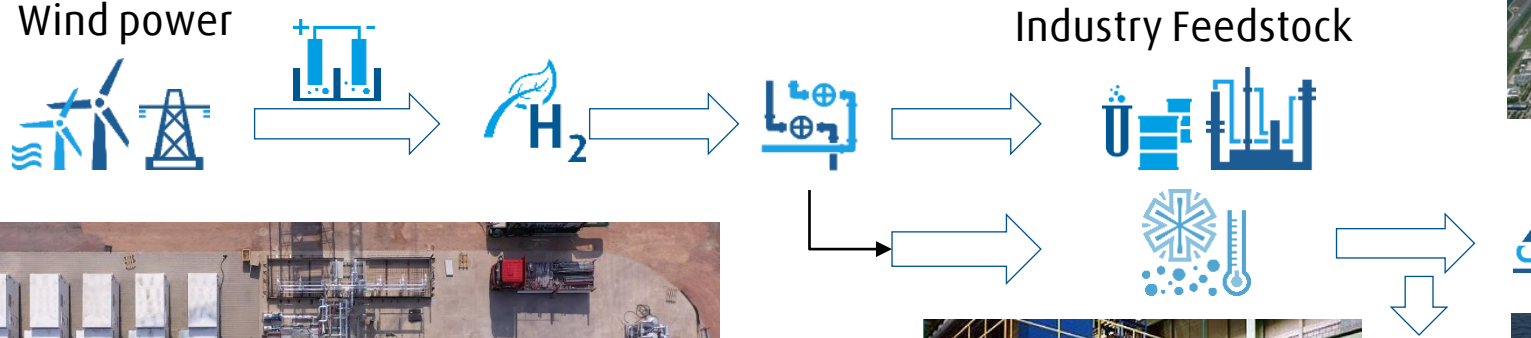
Trains

Hydrogen Transportation Fuel Concept

Integrated Green H_2 for Petrochemical Cluster and Mobility



- Today, Linde owns and operates ~200 tpd of hydrogen at the Leuna Petrochemical cluster
- Regulatory framework in the EU and Germany (RED II – Renewable Energy Directive) is driving low carbon transportation
- Linde is investing in the largest PEM Electrolyser globally @24 MW to produce 10 tpd Green H2
- Linde has also invested in Linde proprietary hydrogen liquefiers, to supply its European network by trailer



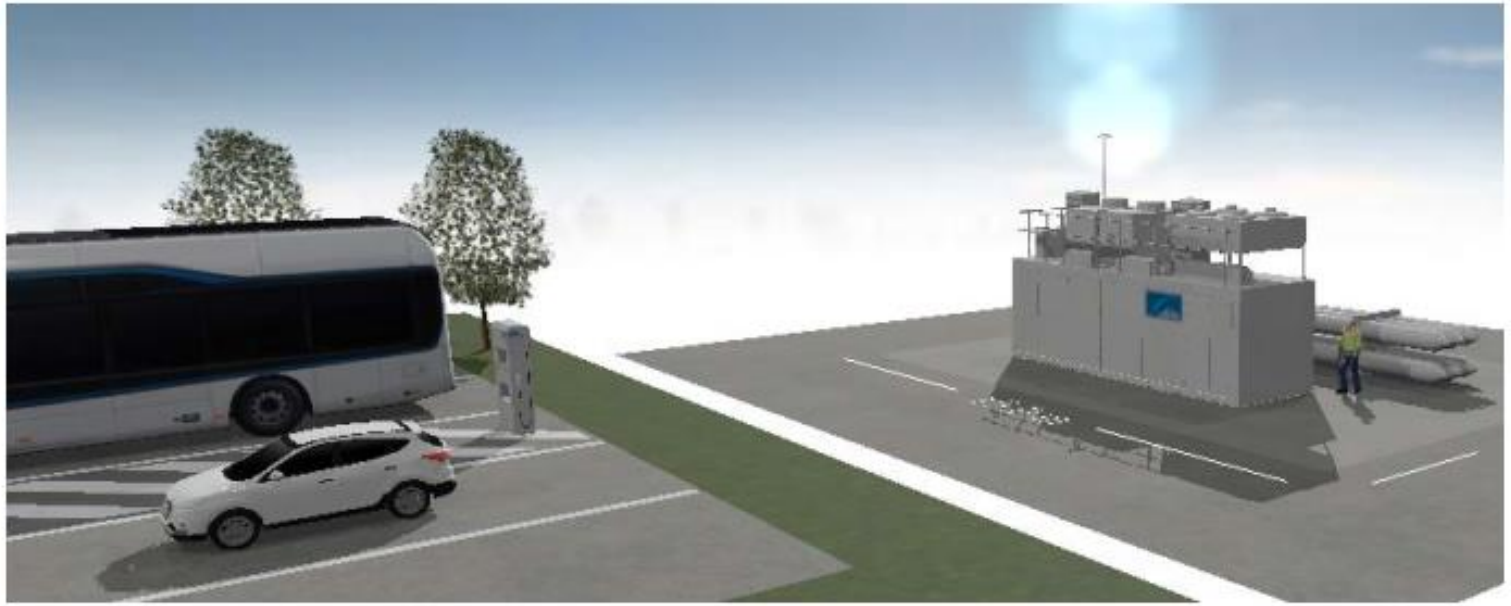
From Leuna, Linde to Supply World's First Hydrogen-Powered Ferry by Norled.

Example for an Ionic Compressor HRS supplied by tube trailer (GH2)

10 passenger cars & 15 trucks per day

Key assumptions & parameters:

- 10 passenger car fuelings & 15 trucks fuelings per day (5 kg resp. 30kg per vehicle, type IV tanks)
- Five passenger cars and four trucks per hour (max.)
- 18 hours fueling window
- Pre-cooling for trucks -10°C (Linde recommendation)
- Dispensing at 350bar & at 700 bar
- Distance to dispenser <30m (recommended)
- Trailer supply



Delivery time (Ex Works):

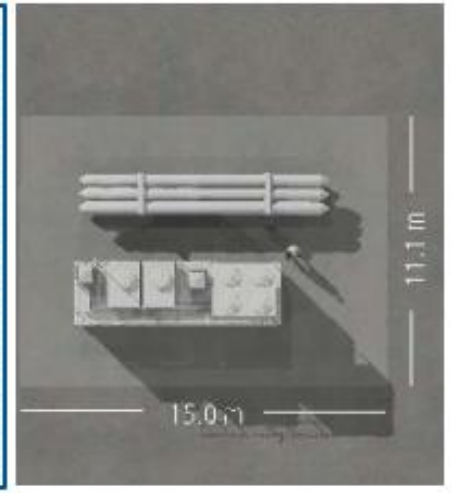
- Standard station: ~12 months

Delivery time to Start-Up:

- Standard station: ~15 months

Technical details

- 1x IC container incl. 1x IC90/30 and 1x IC-P50/60 (56kg/h @ 50MPa & 28kg/h @ 90MPa; 8 x 2,4 x 4,1m)
- High pressure storage for 700 bar (1000 bar; **24x 50 l**)
- Medium pressure storage for 500 bar (550bar; **4x 1200 l**)
- 1x Dual 350/350 bar dispenser & 1x 700 bar dispenser
- Elec. power input: 186kW compressor container (w/o cooling)



Journey for Hydrogen Economy
Reality Check

Today

Tangible projects are few

Costs remain high

New technologies/scaleup are busy but need more time

Standards lacking on low carbon

More regulatory support is required

Enablers for Future

Policy & Regulations — Government levers: carbon tax, grant, mandate, CfD etc; industries need certainty

Technologies — New application technologies; partnerships; scaleup

Costs — Scaleup; integration and optimization

Standards & Certifications — Universal standards to trade low carbon molecules; essential to operationalize low carbon solution

Making our world more productive

Enabling the energy transition

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