

Power-to-X Wege und Erfahrungen strombasierter Synthesen

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Energiefachtagung und Wasserstoffnetzwerktreffen
Lausitz "DurchH₂atmen" 7th September, 2021

Mitsubishi Heavy Industries EMEA, Ltd.



Company Overview (related to H₂)



* This table is not exhaustive. It lists only companies and products related to hydrogen business

MITSUBISHI HEAVY INDUSTRIES GROUP

> 80,000 Employees
300 Subsidiaries
esp. in

- Renewable energy
- Thermal energy
- Nuclear energy
- Industrial machinery
- Power systems
- Metal manufacturing
- Commercial aviation.
- Electronics industry

Energy Systems	Plants and Infrastructure	Integrated Defense and Space Systems
 Jet Engines (Mitsubishi Heavy Industries Aero Engines, Ltd.) Compressors (Mitsubishi Heavy Industries Compressor Corp.) Gas Turbines (Mitsubishi Power Mitsubishi Heavy Industries) 	 Iron Making  Ammonia & Methanol Co-Production Plants CO₂ Capture Plants (Mitsubishi Heavy Industries Engineering, Ltd.) Gas Carriers (Mitsubishi Shipbuilding Co., Ltd.)	 Aircraft (Mitsubishi Aircraft Corporation) H-IIA Rocket

Research & Innovation Centre

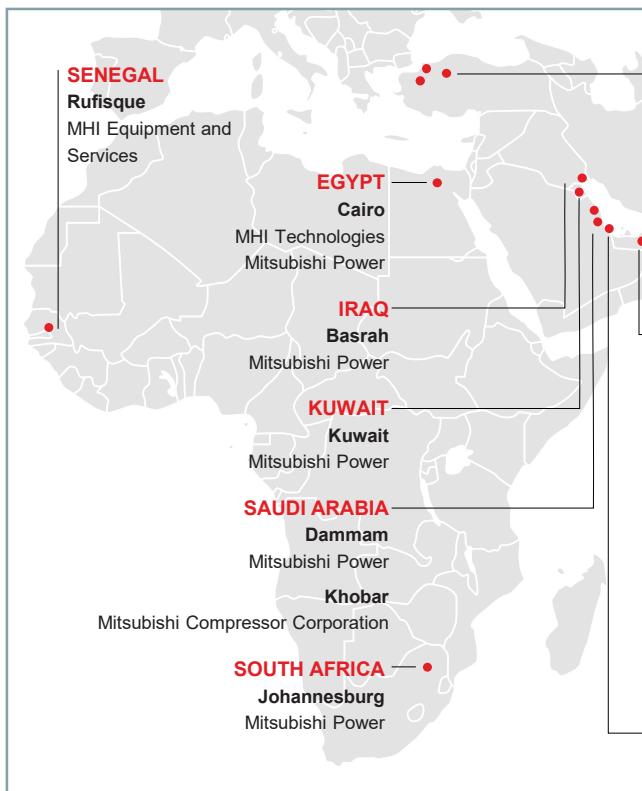
MHI Group Companies in Europe, Middle East & Africa



MHI Group across EMEA

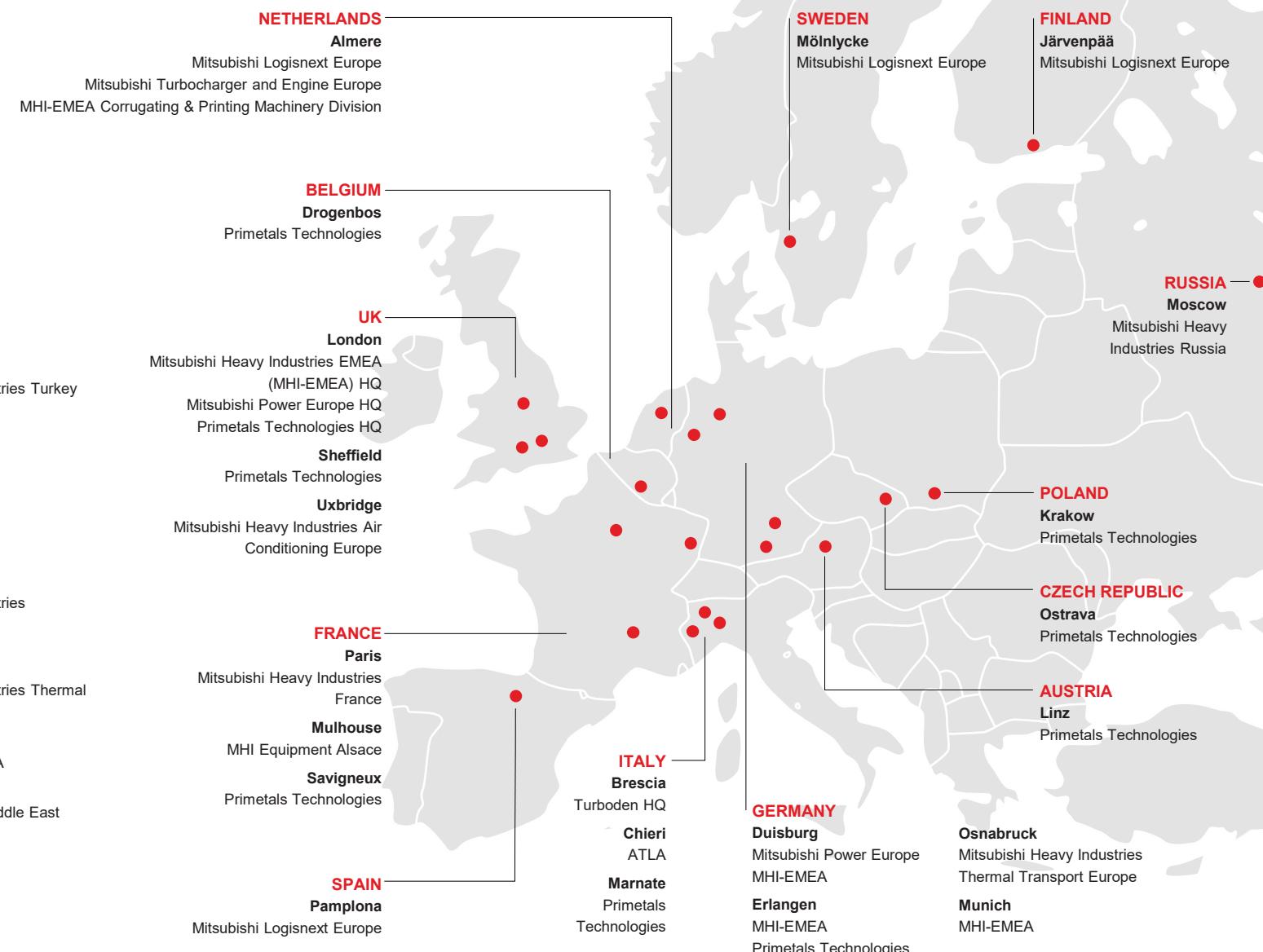
Mitsubishi Heavy Industries Group maintains a comprehensive presence across Europe, Middle East and Africa, operating a range of businesses in renewable, thermal and nuclear energy, industrial machinery and power systems, metal manufacturing services and commercial aviation.

The following map highlights key locations across the continent.



TURKEY: Istanbul (Mitsubishi Heavy Industries Turkey), Ankara (Turboden), Bursa (Mitsubishi Power)

QATAR: Doha (Mitsubishi Power)



MHI Group Capabilities in H₂ Supply Chain

The MHI Group has a vast range of technologies and end-to-end solutions for the hydrogen supply chain.



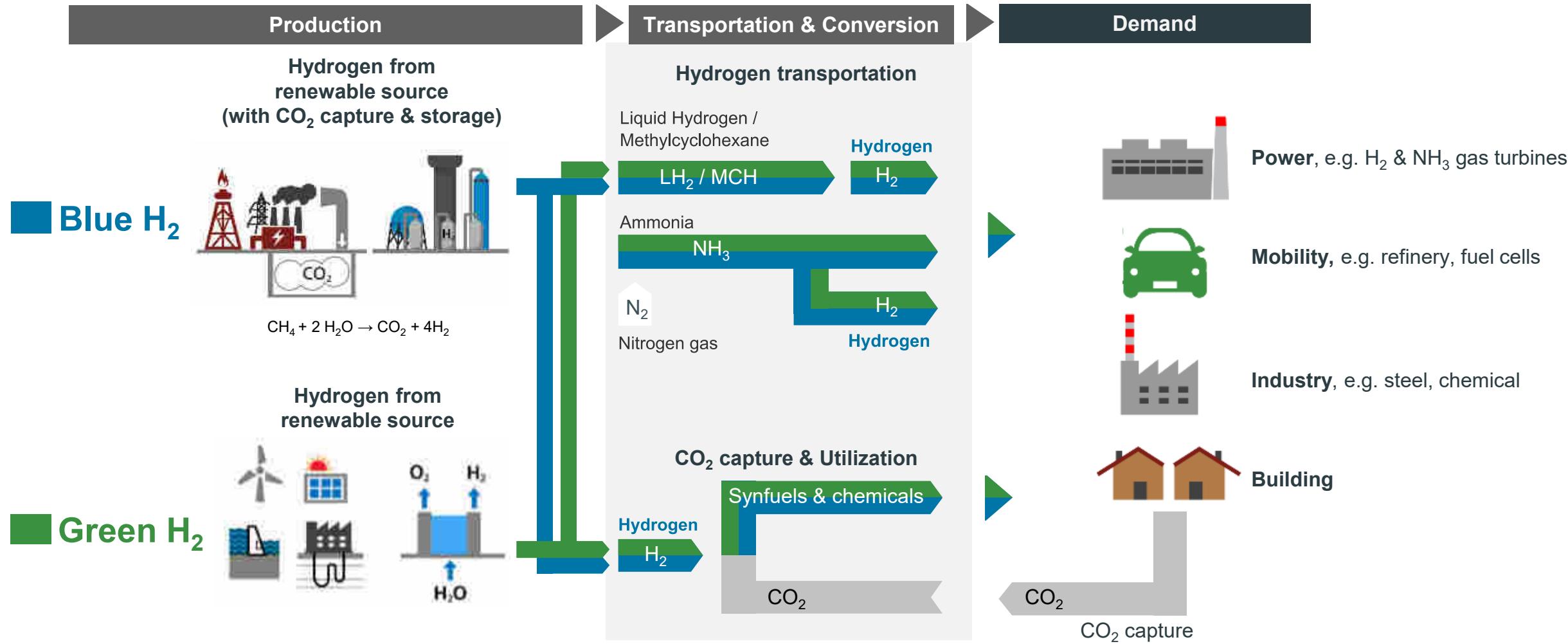
Plants and Infrastructure Domain

Energy Domain

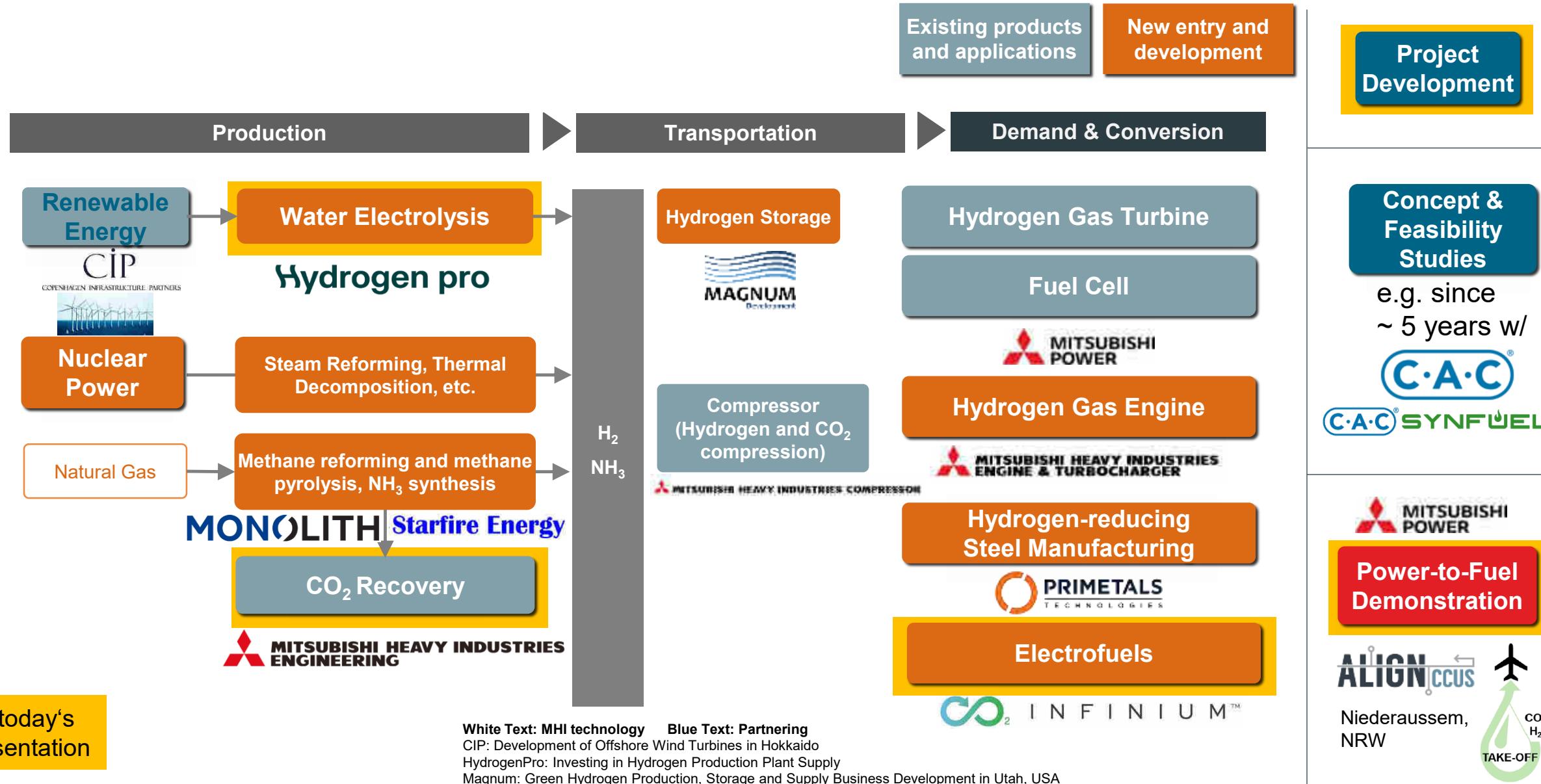
In addition, MHI Group has products for iron making, forklift, rocket, etc. that can be fueled by hydrogen.

Overview of Global H₂ Supply Chain

All 3 stages (Production/Carrier/Demand) are the key to realize hydrogen society.



MHI Group Involvement across H₂ Value Chain



Beispiel: Technologien entlang der Power-to-X-Wertschöpfungskette

Erneuerbare Energien



Hydrogen pro



CO₂ Recovery

MITSUBISHI HEAVY INDUSTRIES
ENGINEERING

in today's presentation



PRESS INFORMATION

MHI Group Undertakes Investment in HydrogenPro of Norway,
Leading Producer of Advanced Electrolyzers
-- Move Will Contribute to Creation of a Sustainable Society through Hydrogen Energy --

2020-10-14

New entry and development

Existing products and applications

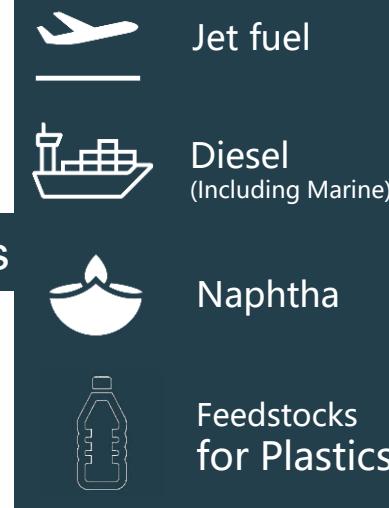


CO₂ INFINIUM™

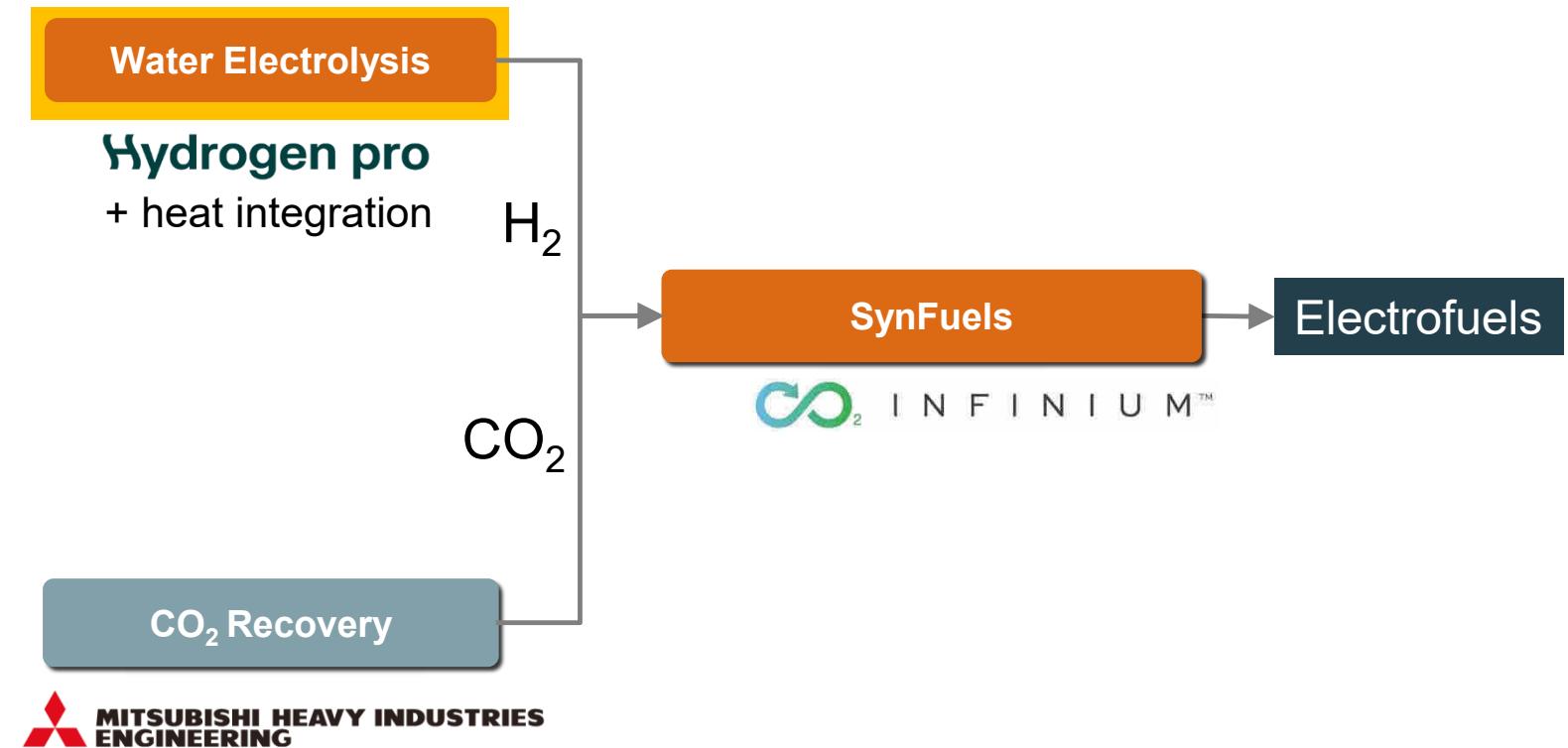
PRESS INFORMATION

MHI Invests in Infinium, an Electrofuels Solution Provider, to Accelerate Efforts to Decarbonize the Transportation Sector
-- Additional investors include Amazon's Climate Pledge Fund, AP Ventures, Neuman & Esser Investments, and the Grantham Foundation --

2021-01-27



Hydrogen



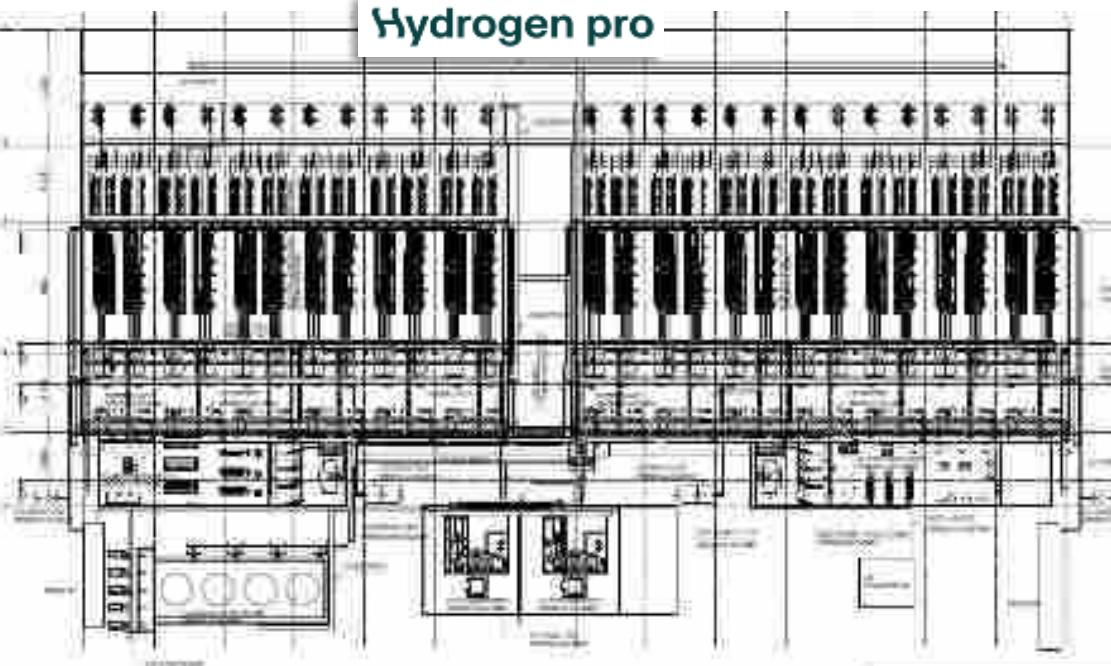
Green H₂ Production by Water Electrolysis

PRESS INFORMATION

MHI Group Undertakes Investment in HydrogenPro of Norway,
Leading Producer of Advanced Electrolyzers
-- Move Will Contribute to Creation of a Sustainable Society through Hydrogen Energy --

2020-10-14

Hydrogen pro



- Collaboration towards 100 MW scale green hydrogen plants
- Scaling up technology and ramp-up of manufacturing

Type	Op.- Pressure bar	Spec. Power kWh/Nm ³
Pressurized Alkaline Electrolyzer	15–30	4.5–4.7 (AC)



Electrolyzer Size

Past 1

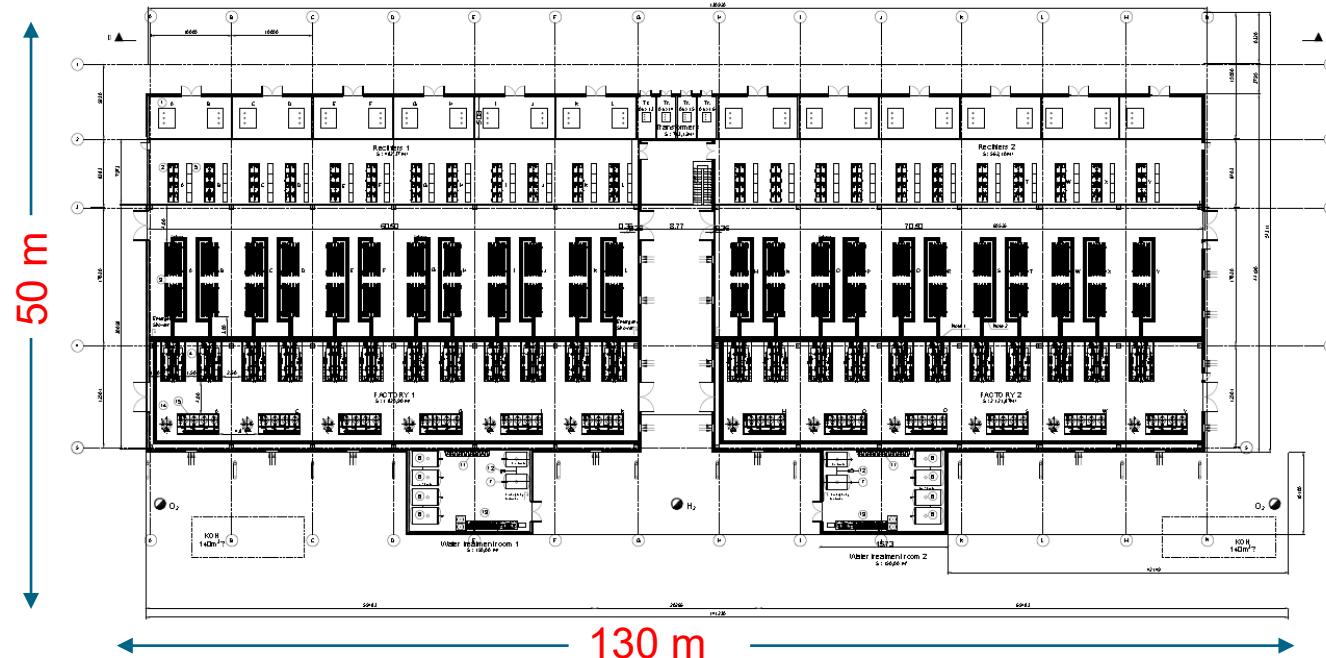
Today 2

Tomorrow 3

MITSUBISHI
HEAVY INDUSTRIES

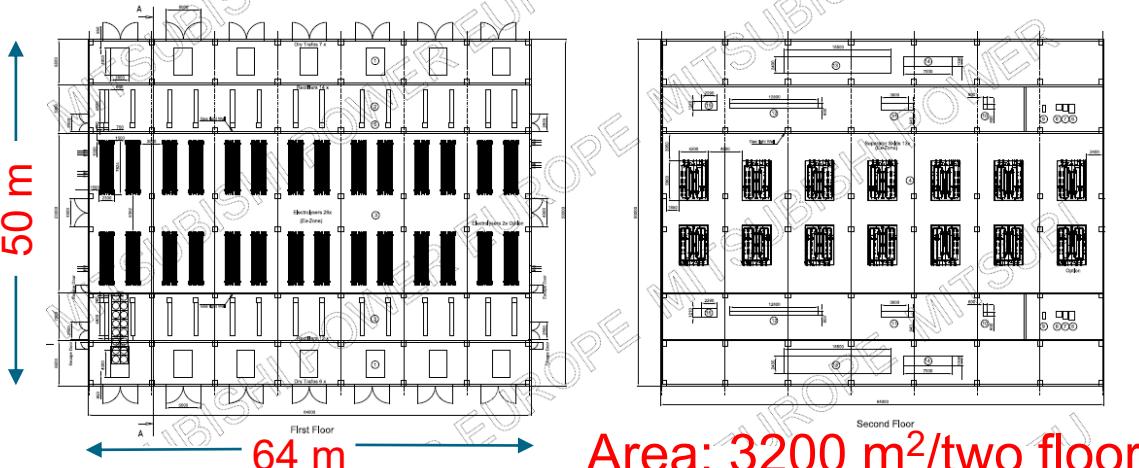
1)

100 MW based on 4.5 MW modules



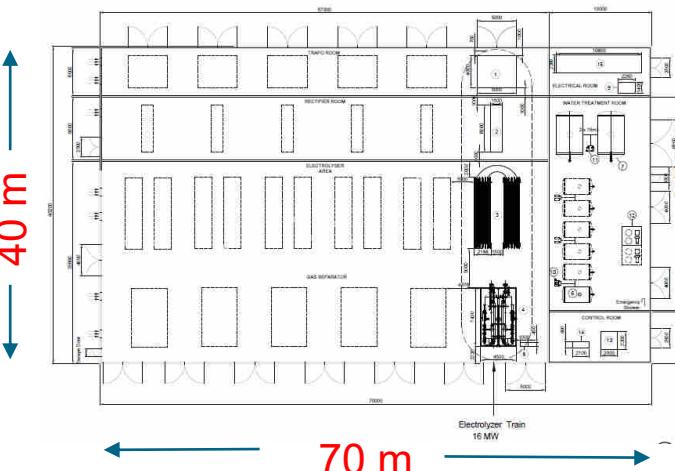
2)

140 MW based on 10 MW modules



3)

100 MW based on 17 MW modules



2

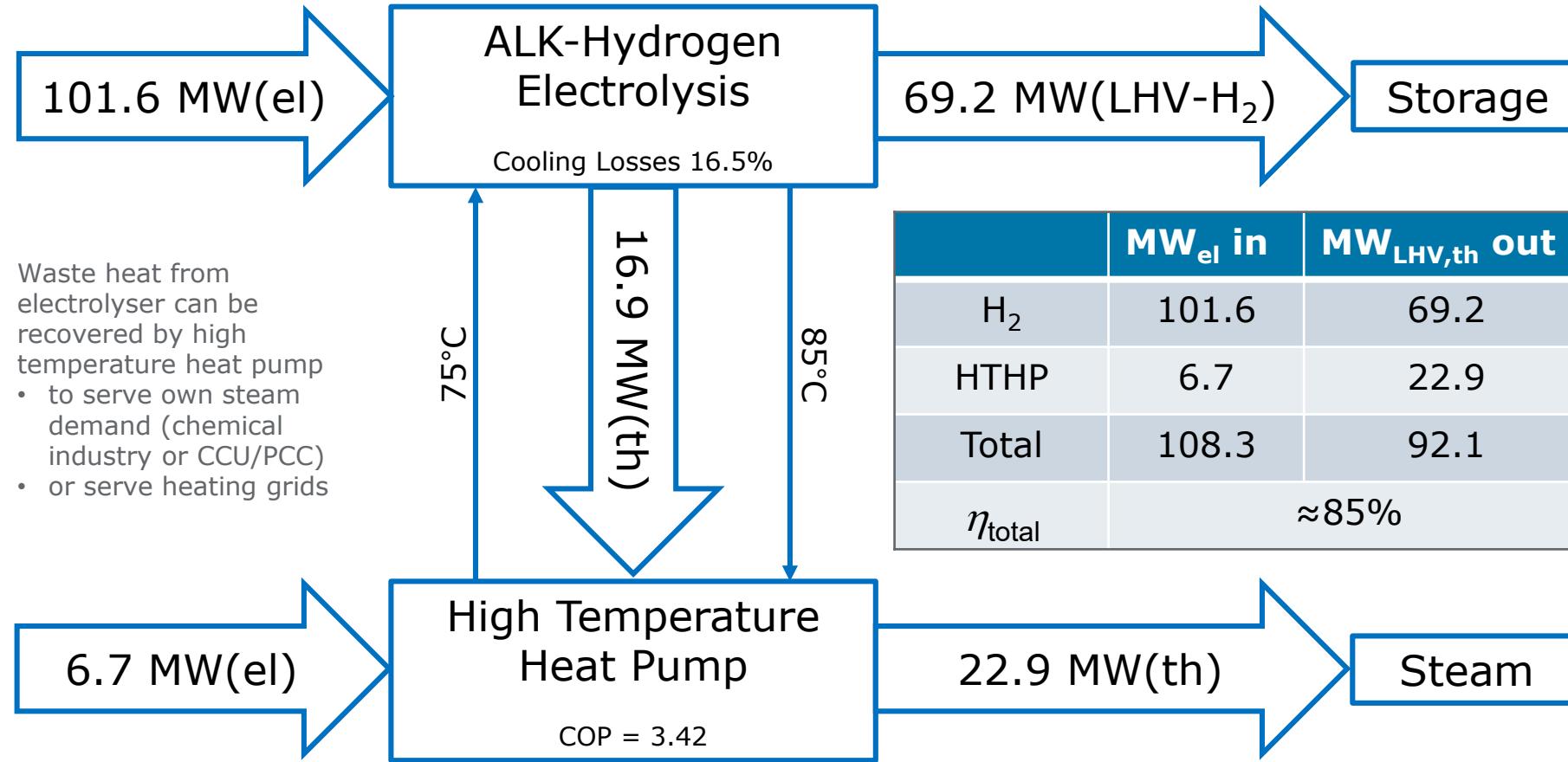
Larger stacks, two-floor building

3

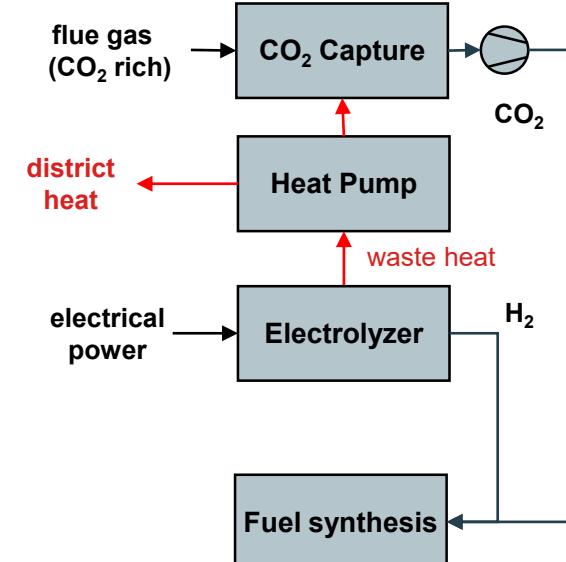
A/m² ↑ ⇒ Area ↓ w/ ~30 % EPC cost reduction potential

- Buildings incl.
- MV trafos
- BOP

Plant Integration Example: Heat Pump: Electrolyser waste heat to steam

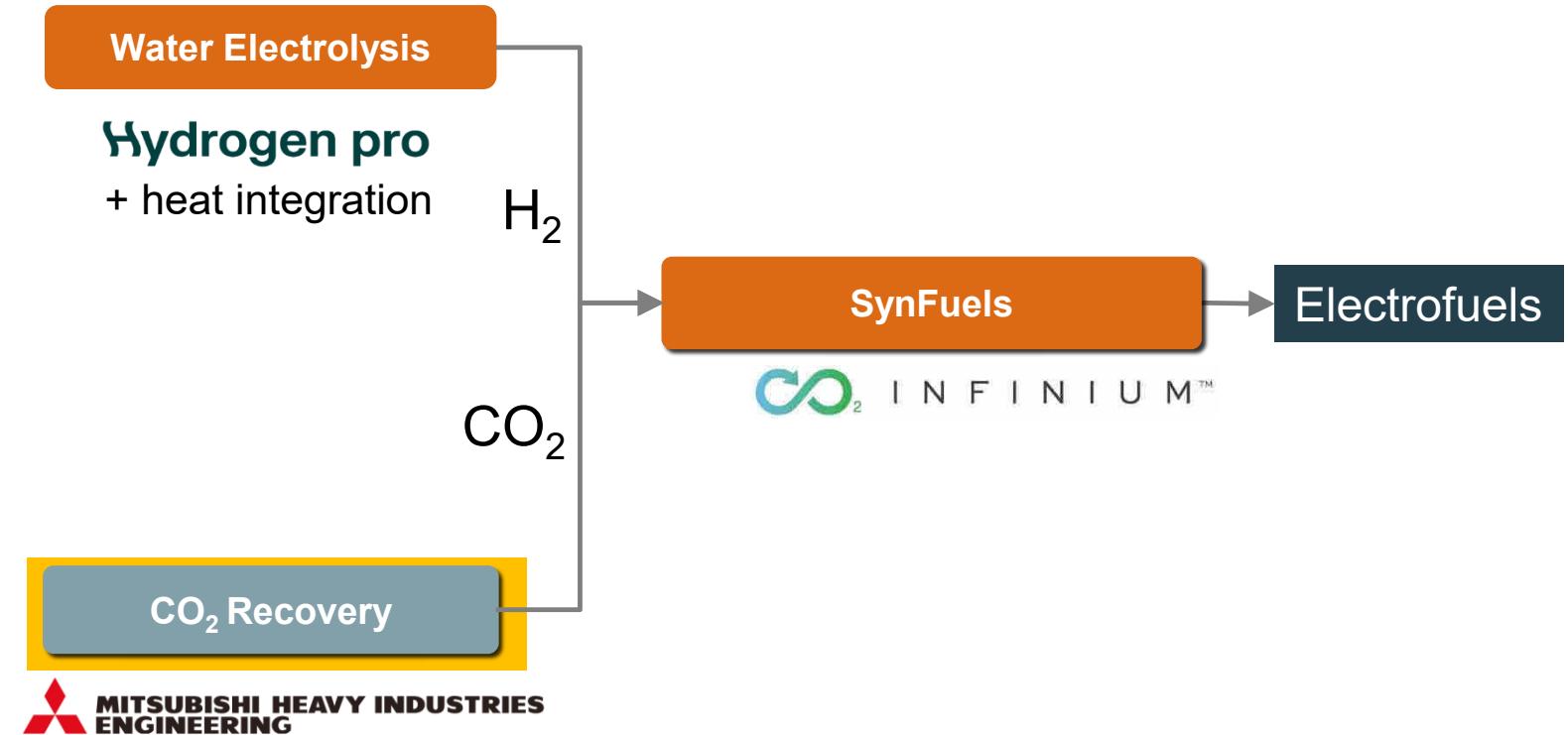


Application Example:

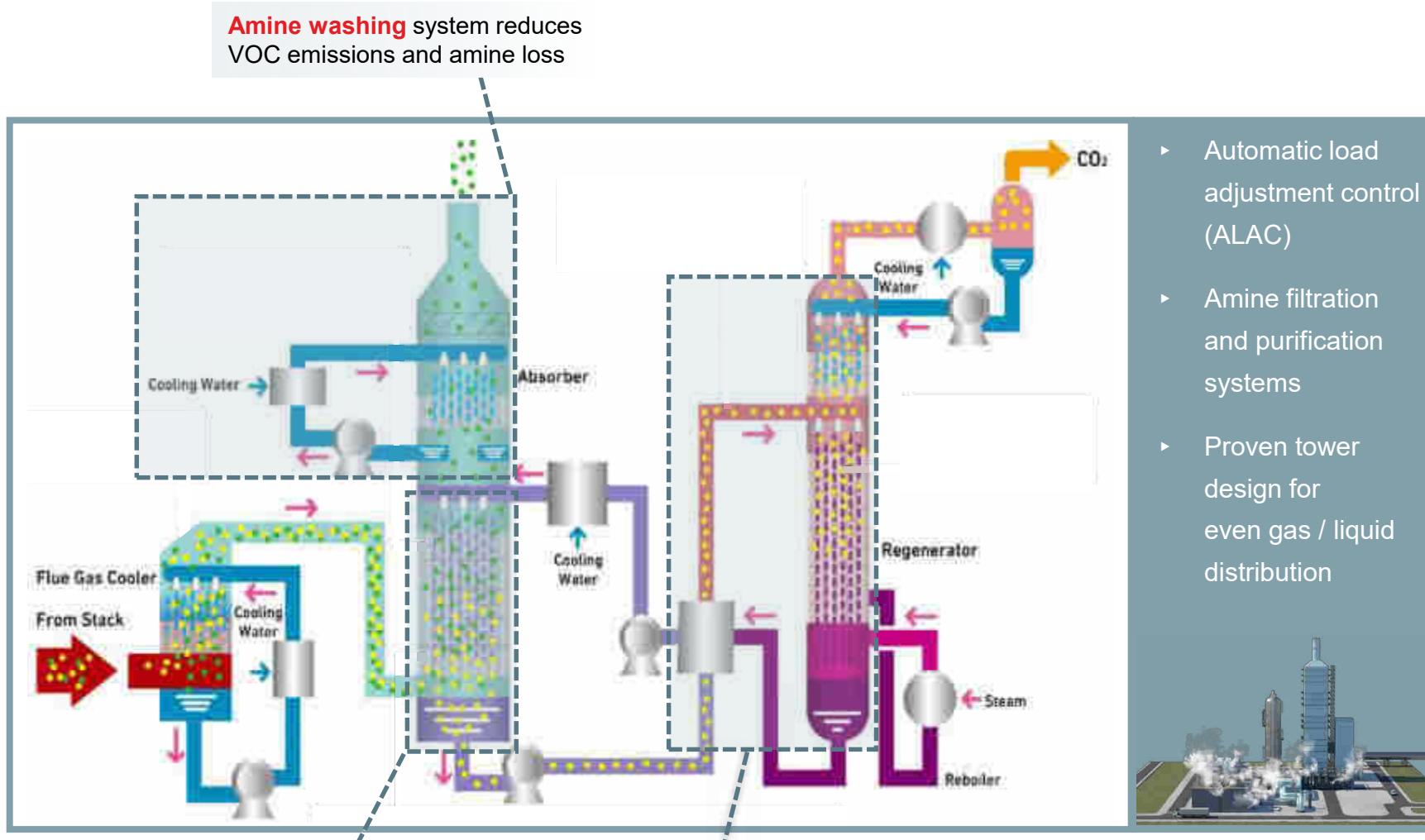


✓ Electrolyzer waste heat sufficient to supply CO₂ capture

CO₂ Capture



MITSUBISHI HEAVY INDUSTRIES
ENGINEERING



KS-1™ solvent with high CO₂ capacity, low degradation, and low regeneration energy

Heat integration system to reduce steam consumption

- ▶ Automatic load adjustment control (ALAC)
- ▶ Amine filtration and purification systems
- ▶ Proven tower design for even gas / liquid distribution



In **Power-to-Fuel** concepts, required heat demand of carbon capture unit can be covered by heat integration

- ▶ Electrolysis (via heat pump)
- ▶ Reactor excess heat (e.g. MeOH reactor, MtG reactor)

KM CDR Process™ =
Kansai Mitsubishi Carbon Dioxide Recovery Process

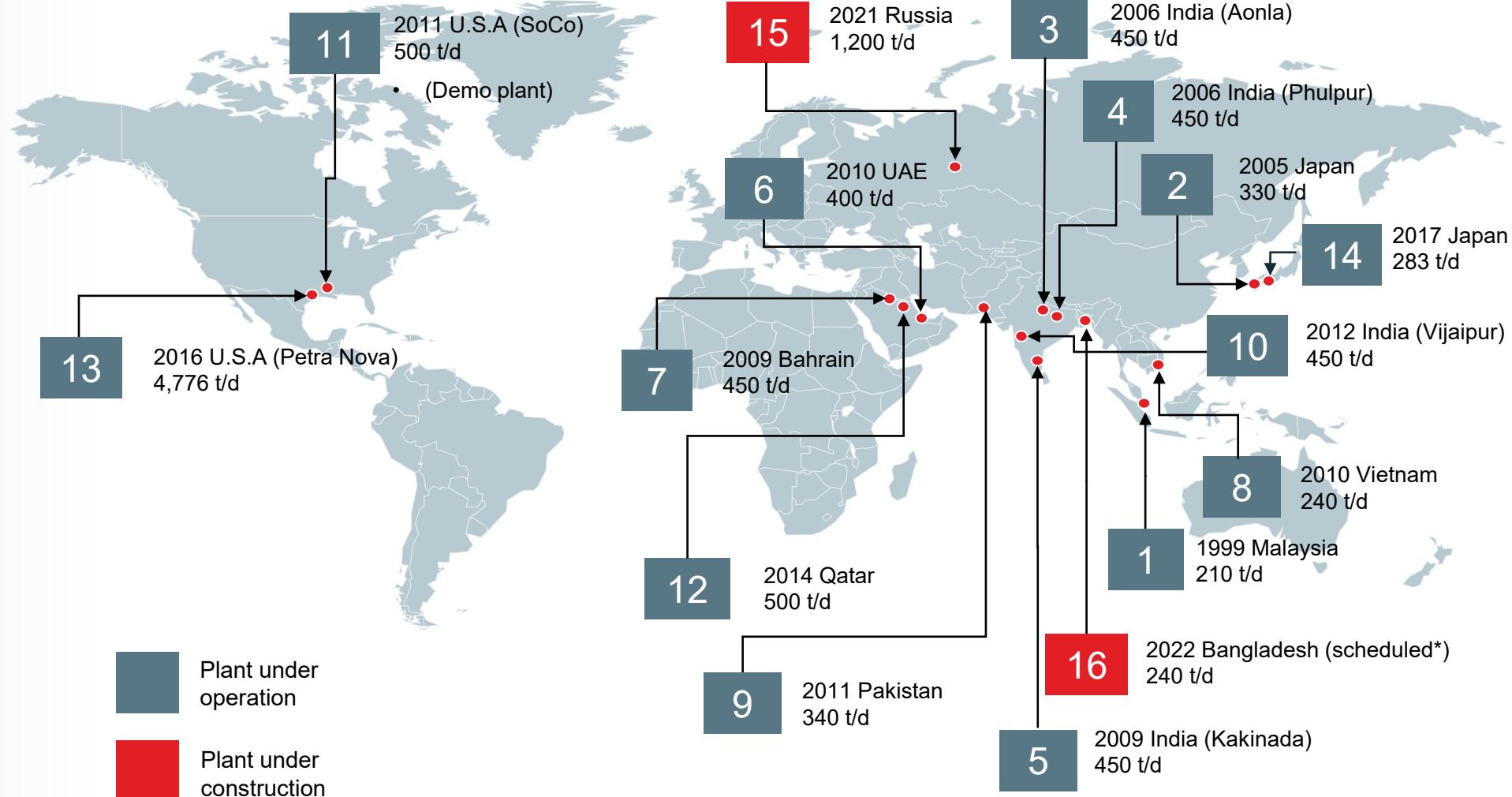
- ▶ Amine-based technology
- ▶ Capable of capturing ~90% CO₂ from combustion gas sources, up to 99.5% possible
- ▶ Purity of CO₂ > 99.9%
- ▶ Carbon Capture from Flue Gases with 3% of CO₂ or more
- ▶ 1–1.2 tons of saturated 3 bar(a) steam per ton of CO₂
- ▶ 50–65 kWh electrical power per ton of CO₂

Worldwide Commercial Experience



MHI's experienced KM
CDR Process™ team
supports customers
globally

- ▶ Feasibility studies for commercial CO₂ capture plants
- ▶ Conceptual design through detailed engineering
- ▶ Project execution
- ▶ Plant Service



*Signed a contract for fertilizer plant construction on Oct 2018, subject to finance close.

Kraftwerk Drax und MHI haben einen langfristigen Vertrag über die Nutzung der CO₂-Capture-Technologie von MHI im Drax BECCS-Projekt abgeschlossen.

- ✓ Größtes CO₂-Abscheidungsprojekt der Welt:
Mehr als 5 x Größe von Petra Nova
- ✓ Weltweit erstes Projekt mit negativen Emissionen
- ✓ Großbritanniens erstes groß angelegtes CO₂-Capture-Projekt
- ✓ Verwendung neuster Technologie: **Advanced KM CDR Process™**



PRESS INFORMATION

DRAX AND MITSUBISHI HEAVY INDUSTRIES SIGN PIONEERING DEAL TOWARDS DELIVERY OF THE WORLD'S LARGEST NEGATIVE EMISSIONS PROJECT

2021-06-10

Projektinformationen

Ort	North Yorkshire, UK
Eigentümer	Drax Power Limited
CO ₂ -Quelle	Rauchgas aus Biomassekessel
CO ₂ -Kapazität	mindestens 8 Mio. t/a
Technologie	Advanced KM CDR Process™ KS-21™ Solvent

Advanced KM CDR Process™ w/ KS-21™ Solvent – Overview & Features



Parameters Relative to KS-1™	KS-1™	KS-21™
Volatility	100	50-60
Thermal degradation	100	30-50
Oxidation rate	100	70
Heat of absorption	100	85

Thermal stability

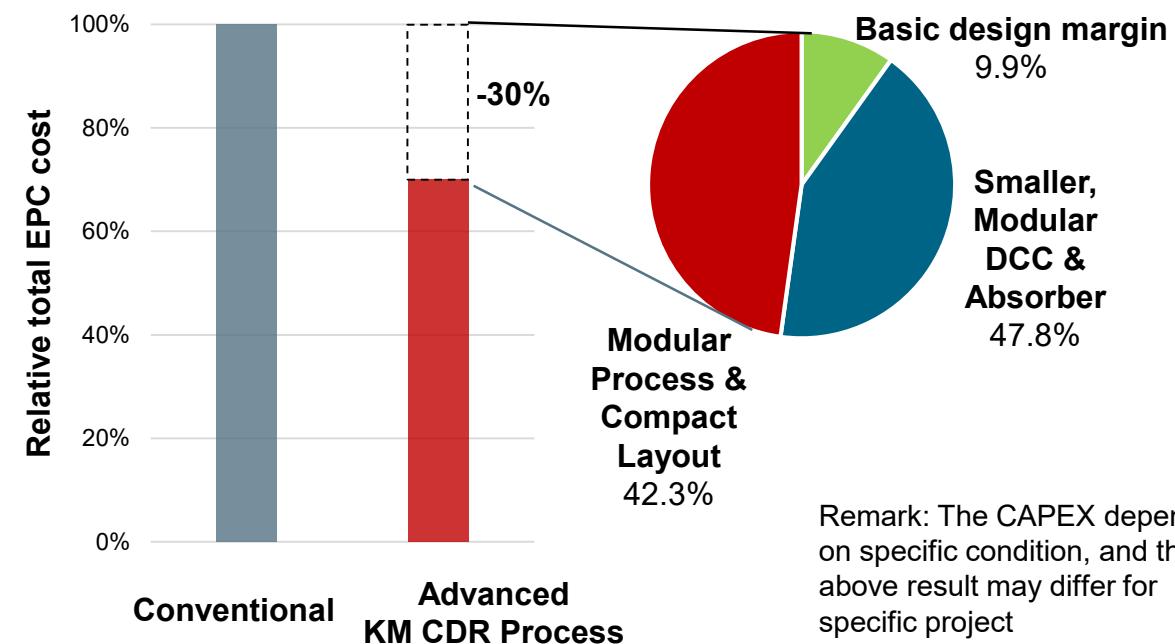
- Reduce thermal degradation and allow higher stripping Temperature and Pressure, reducing compression work

Oxidative stability

- Potentially more tolerant to impurities
- Reduce amine oxidation and HSS formation rate

Volatility

- Reduce amine loss from emission and cost of water wash system
- Steam consumption savings outweigh cost increases due to higher solvent circulation



Remark: The CAPEX depends on specific condition, and the above result may differ for specific project

➤ The Advanced KM CDR Process reduces total EPC cost by 30% and is ready for new commercial projects

Mitsubishi Heavy Industries Engineering to Test Carbon Capture Technology at Technology Centre Mongstad in Norway
➤ KS-21™ commercial since 2021



<https://www.mhi.com/news/210304.html>

Discover the CO₂ Capture Technology



<https://www.youtube.com/watch?v=9PtnuRWOQAY>

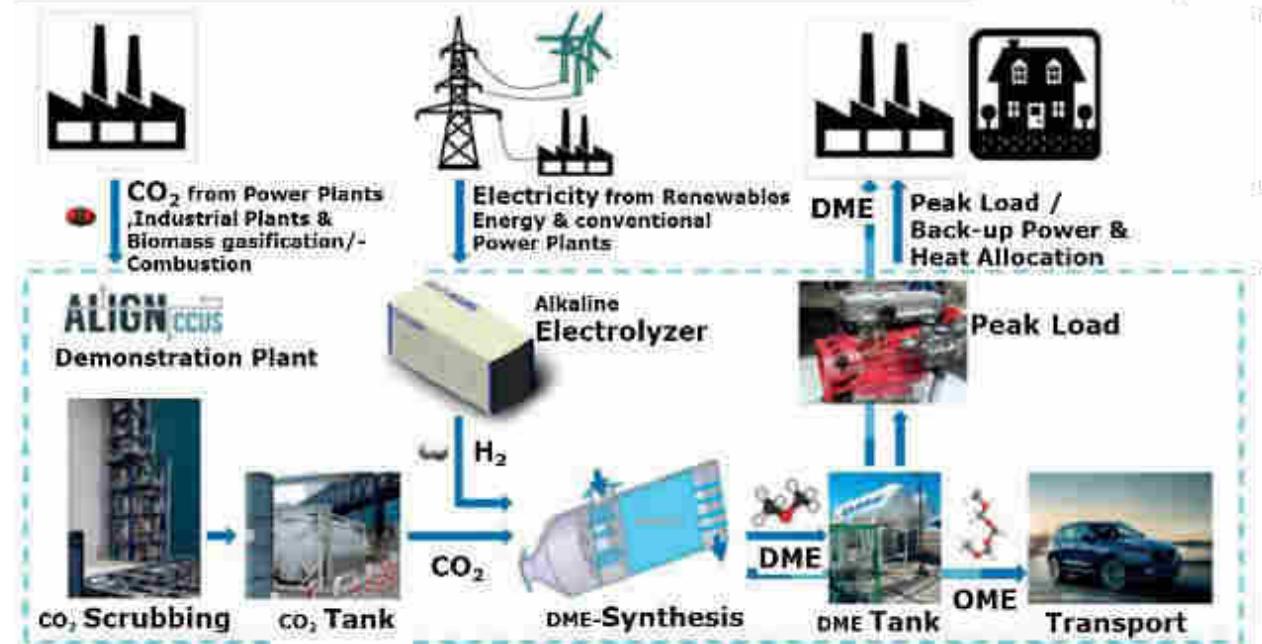
Power-to-Fuel Demonstration



Power-to-Fuel-Demonstration: $H_2 + CO_2 \rightarrow$ Dimethylether (DME) (1/2)



- Accelerating Low Carbon Industrial Growth through – Carbon Capture Utilization Storage
- EU funded RD project Cofund ACT 691712 – Theme: Chain Integration
- 34 partners from 5 EU countries



Dimethylether: substitute for diesel and LPG

Methanol: C1-building block

- **intermediate for olefines** (essential for plastic), **fuels** (gasoline, aviation fuel)
- **long-term chemical energy storage**



new project: TAKE-OFF



Mitsubishi Power:
own synthesis demo plant,
reactor and catalysts

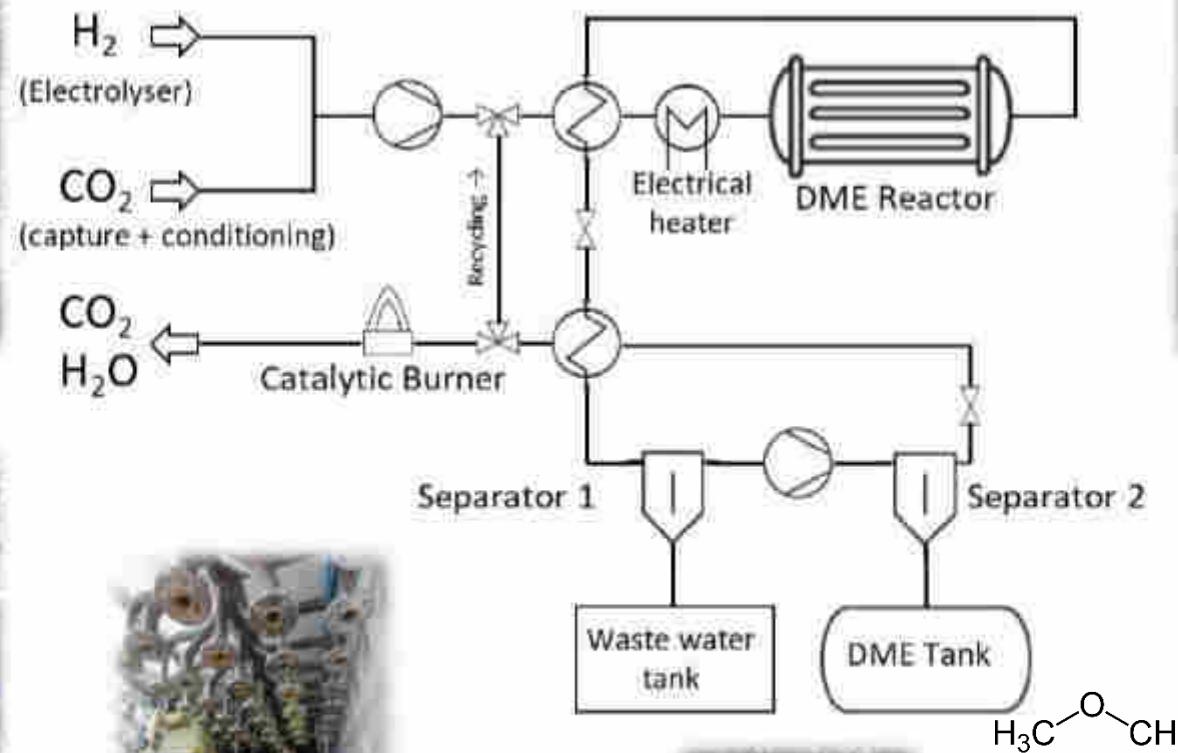
Demonstration Site at
RWE Niederaussem
(Germany)

- > www.ALIGNCCUS.eu
- > <https://takeoff-project.eu/>

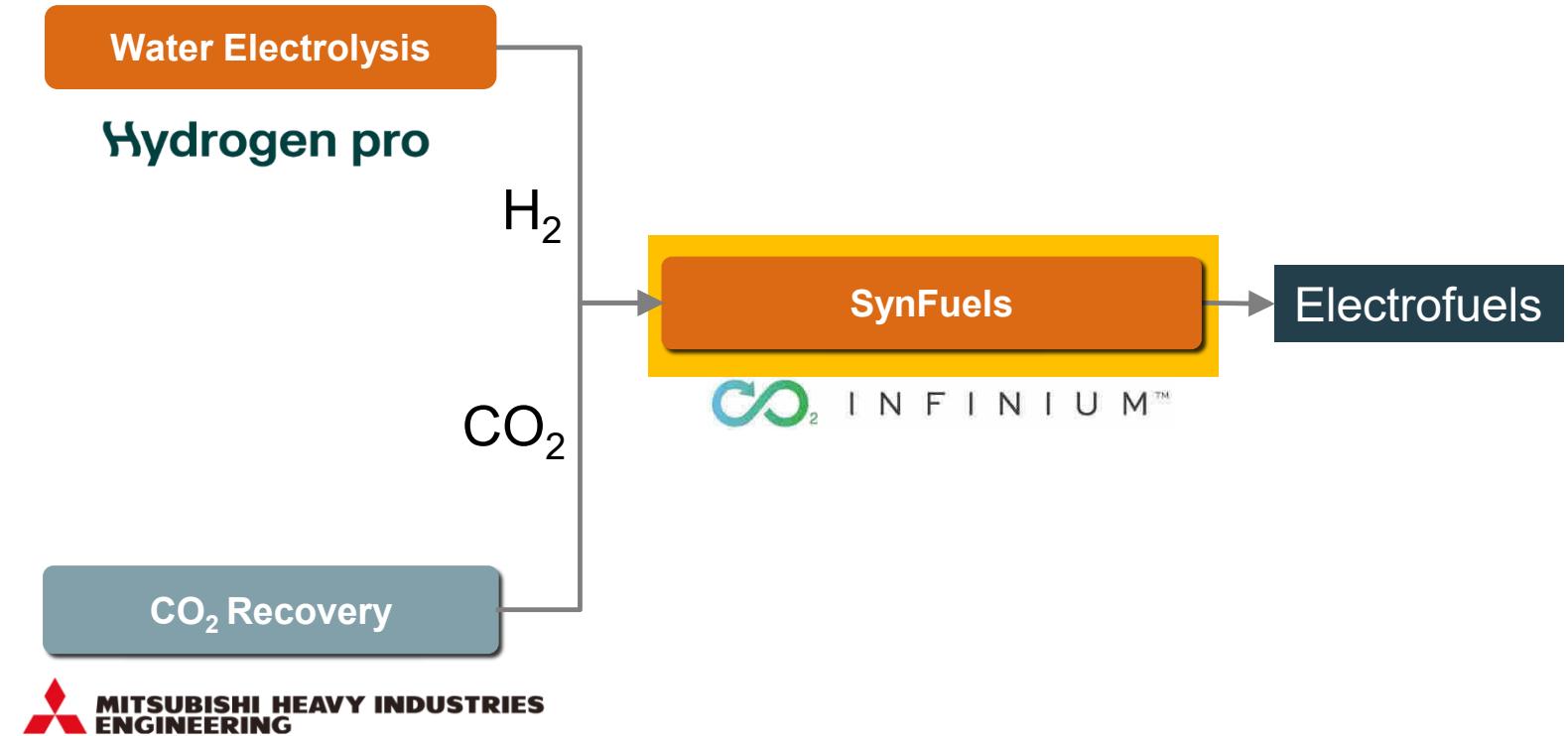
Power-to-Fuel-Demonstration: $H_2 + CO_2 \rightarrow$ Dimethylether (DME) (2/2)



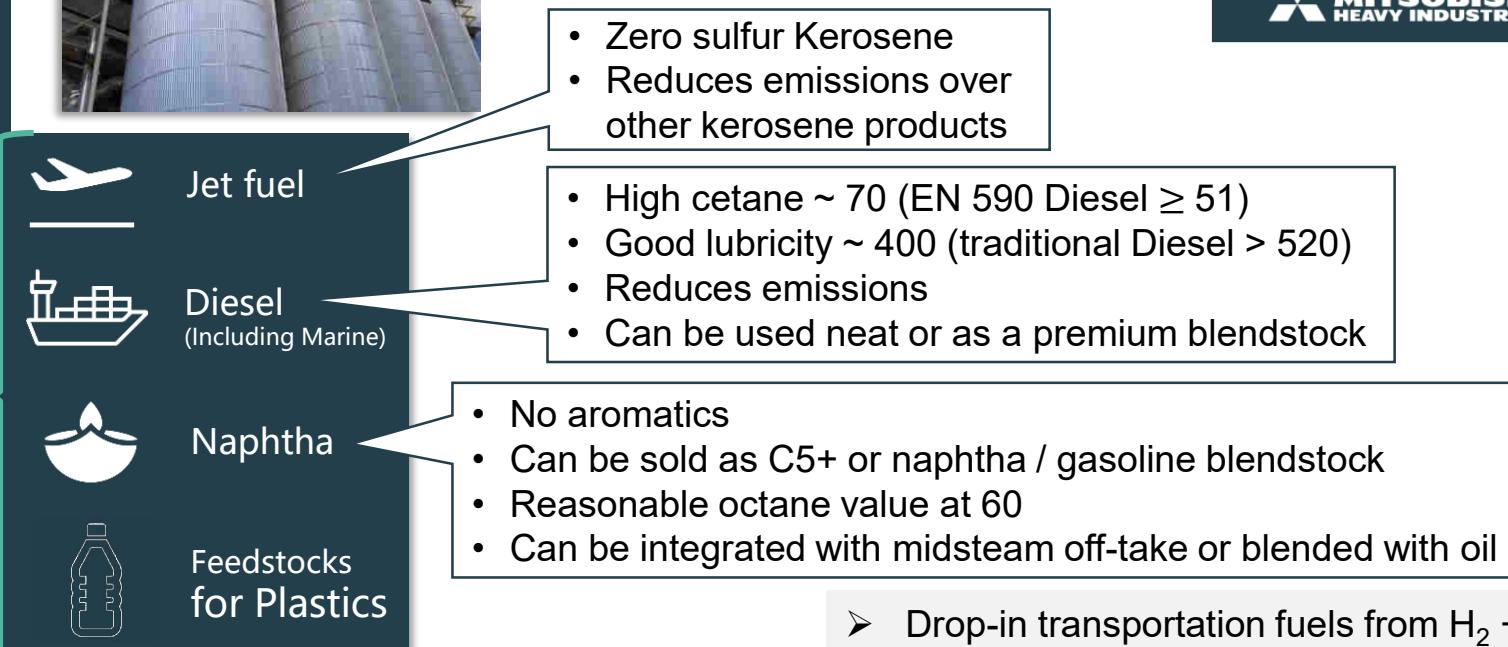
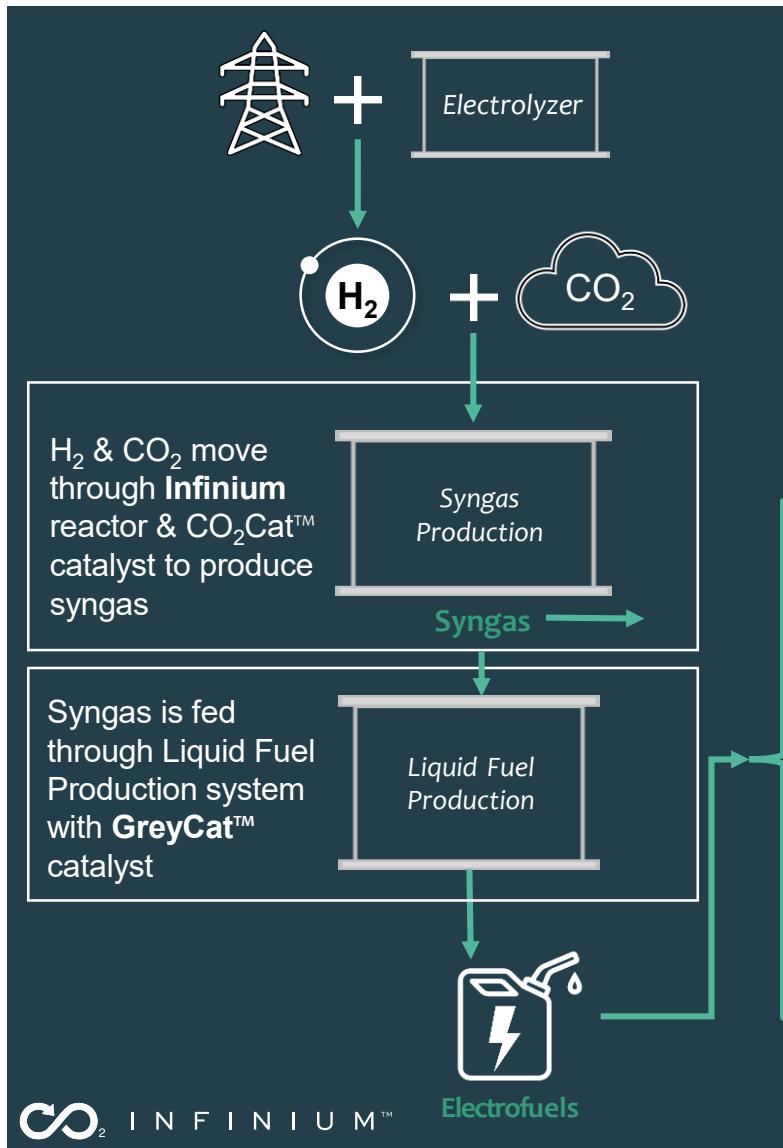
I&C coupled w/ electrolyzer and CO₂ conditioning



Fuel Synthesis



 MITSUBISHI HEAVY INDUSTRIES
ENGINEERING



Greyrock's GreyCat™ catalyst **eliminates** the "**wax refining**" step associated with traditional Fischer-Tropsch.

- Drop-in transportation fuels from H₂ + CO₂
- Higher value products w/o wax refining
- Ongoing R&D program to improve productivity
- Commercial project development underway e.g. w/ MHI EMEA

Investors



Water Electrolysis

Project
Development

Hamburg Green Hydrogen Hub

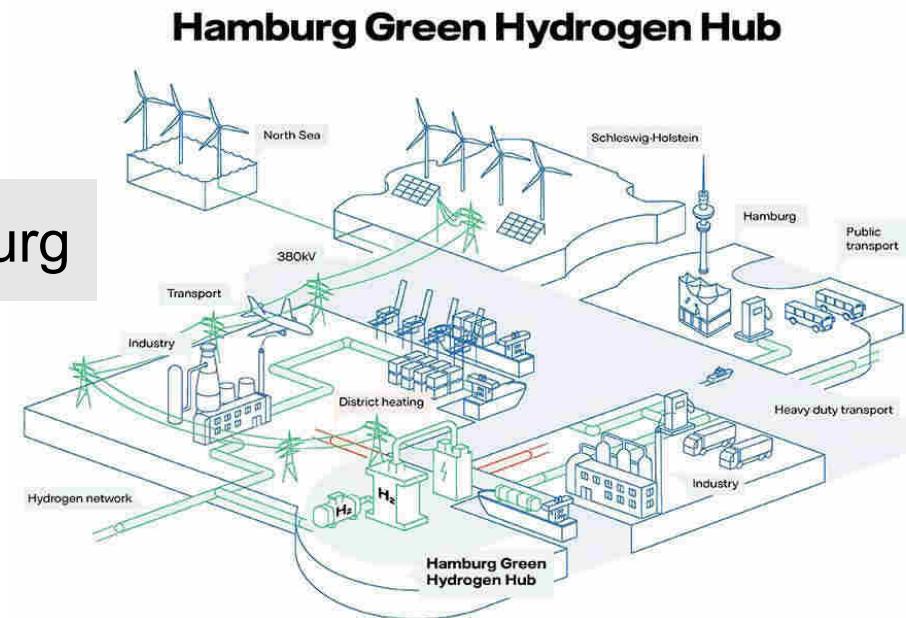
Großskalige Dekarbonisierung von
Industrie und Verkehr (grüner H₂) und
Integration in Fernwärme, industrielle
O₂-Nutzung

- Beispiel für Projektentwicklung durch MHI-EMEA, Duisburg

PRESS INFORMATION

Shell, Mitsubishi Heavy Industries, Vattenfall and
Wärme Hamburg sign Letter of Intent for 100MW
Hydrogen Project in Hamburg

2021-01-22



Hamburg Green Hydrogen Hub – Überblick



Dekarbonisierung von Industrie und Verkehr im großen Maßstab durch die Produktion und Nutzung von grünem Wasserstoff



100 MW Elektrolyse
11.500 t H₂ pro Jahr



Bau 2023-24

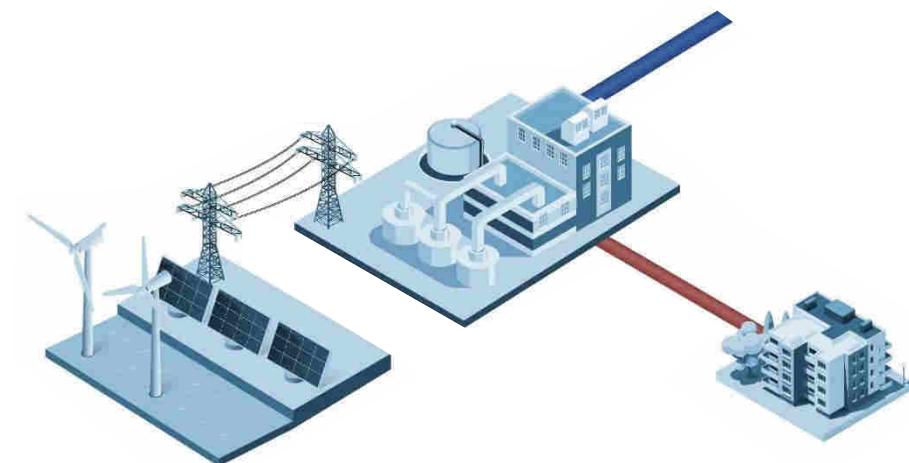


Inbetriebnahme
2025



erneuerbare Energien

- direkte Kopplung
 - On-/Offshore Wind
 - Solar
- Bestehender 380 kV-Netzanschluss



VATTENFALL

MITSUBISHI
HEAVY INDUSTRIES



Wärme
Hamburg



THG-Reduktion
92.000 t CO₂/Jahr

in den Sektoren

- Industrie
- Verkehr/Transport
- Haushalt



End-to-End-Integration

- Weitreichende Vernetzung, insb. Industrie und Logistik
- H₂-Einspeisung: Wasserstoff-Industrienetz
- Abwärme: Integration in Fernwärmesystem
- Sauerstoff: potenzielle industrielle Nutzung

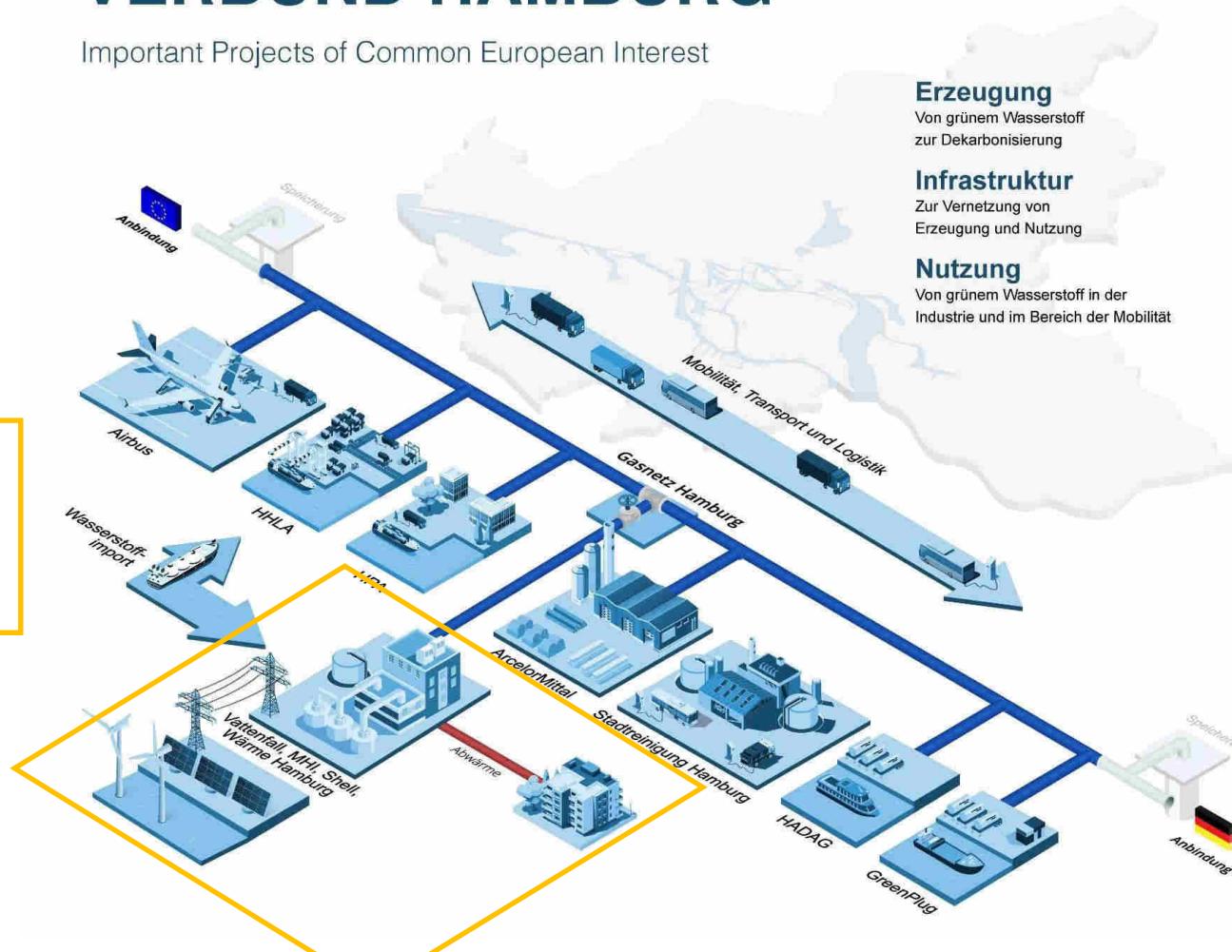


Booster für Markthochlauf

- Tankstellennetz und Distribution zu Kunden
- Ausbauoption Wasserstoffspeicher
- Ausbauoption Import/Export-Terminal

WASSERSTOFF-VERBUND HAMBURG

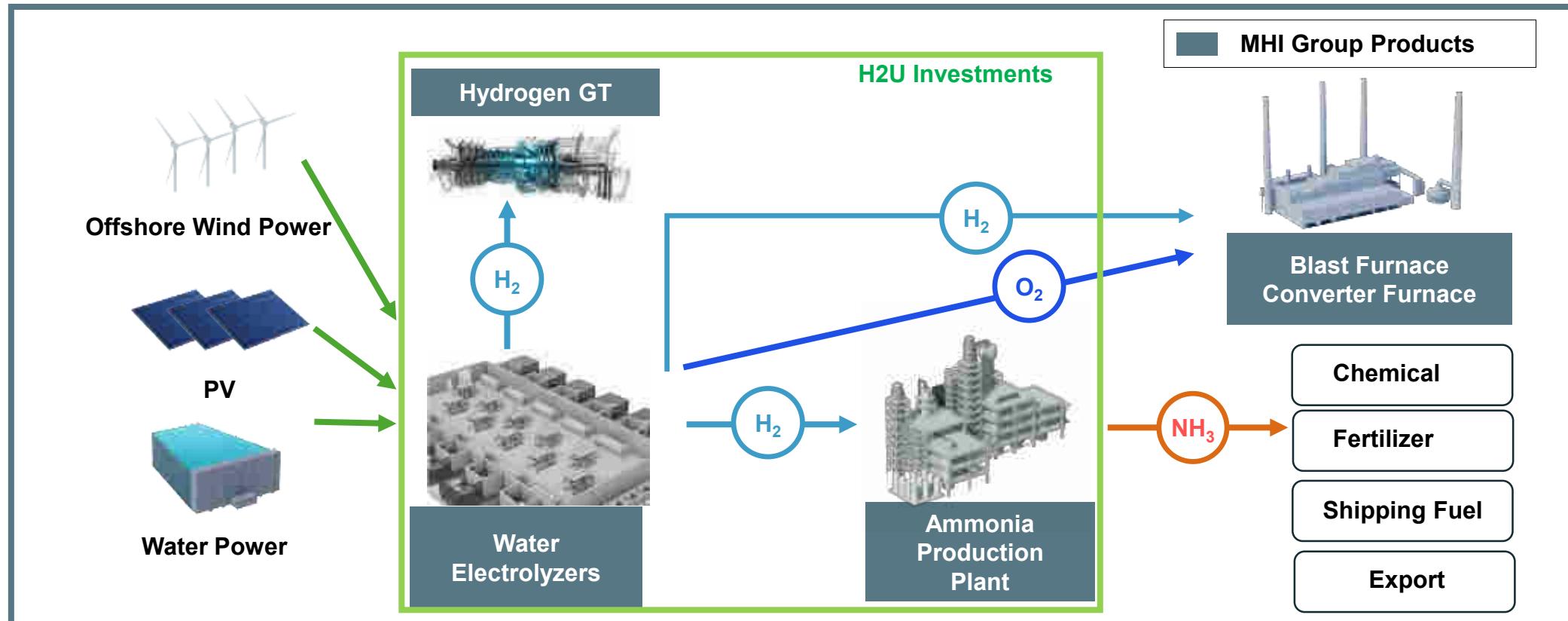
Important Projects of Common European Interest



Die meisten Projekte, wie Arcelor Mittal „H2 for Hamburg“, sind potenzielle H₂-Offtaker für den Hamburg Green Hydrogen Hub

HGHH
Hamburg Green
Hydrogen Hub

Making use of abundant renewable energy in the area, MHI will produce hydrogen and ammonia. In addition to contributing to the region's industries such as nearby steel mills, we will try to export carbon-free ammonia



- 75 MW electrolysis plant, 120-tonne per day ammonia production
- 40,000 tonnes of green ammonia per year.

Advanced Clean Energy Storage Project (USA)

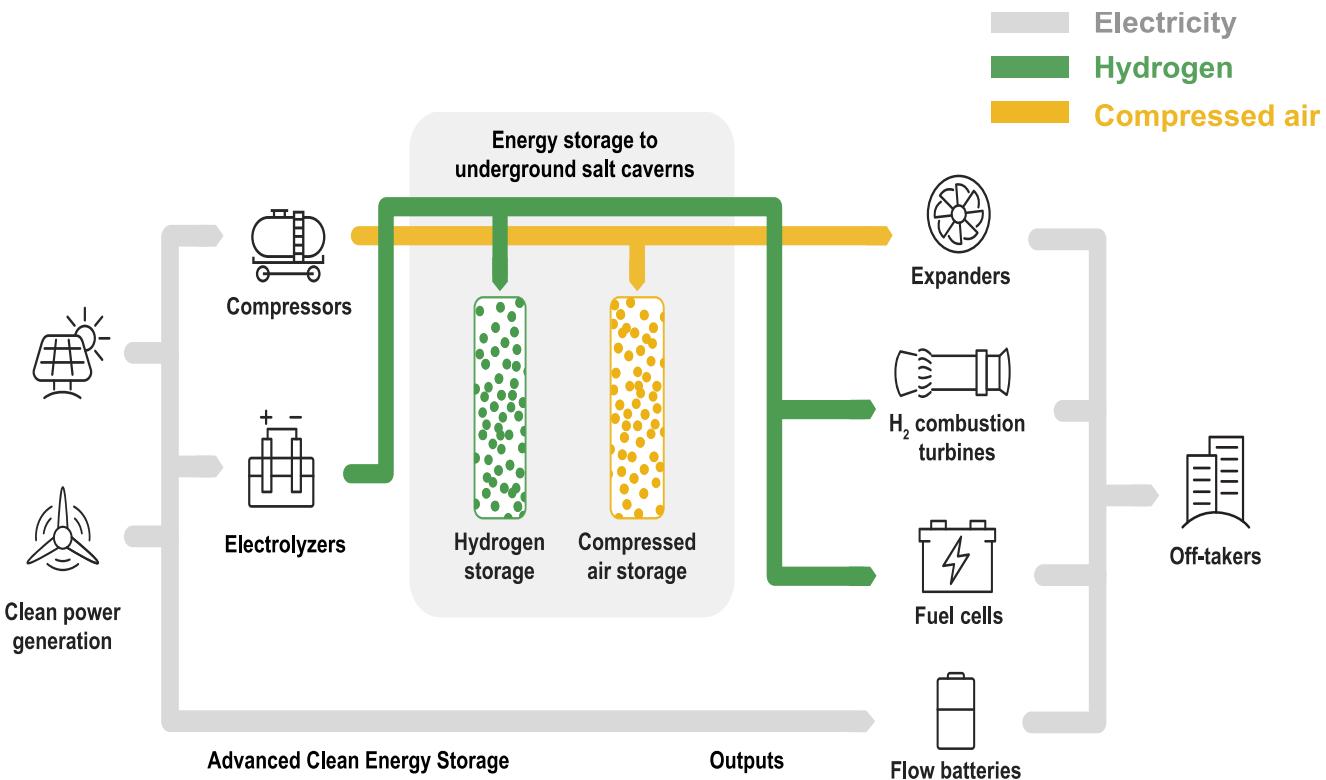
Project
Development



The Advanced Clean Energy Storage (ACES) Project is the world's largest renewable energy storage project

Storage Capacity 1,000 MW

Location Utah, USA



- Project launched in May 2019 by Mitsubishi Power, Magnum Development and the Governor of Utah
- Different storage technologies in use: renewable hydrogen, compressed air, large scale flow batteries and solid oxide fuel cells.
 - Plan to store hydrogen and/or compressed air in underground salt caverns in Utah
- Replicability potential in Europe

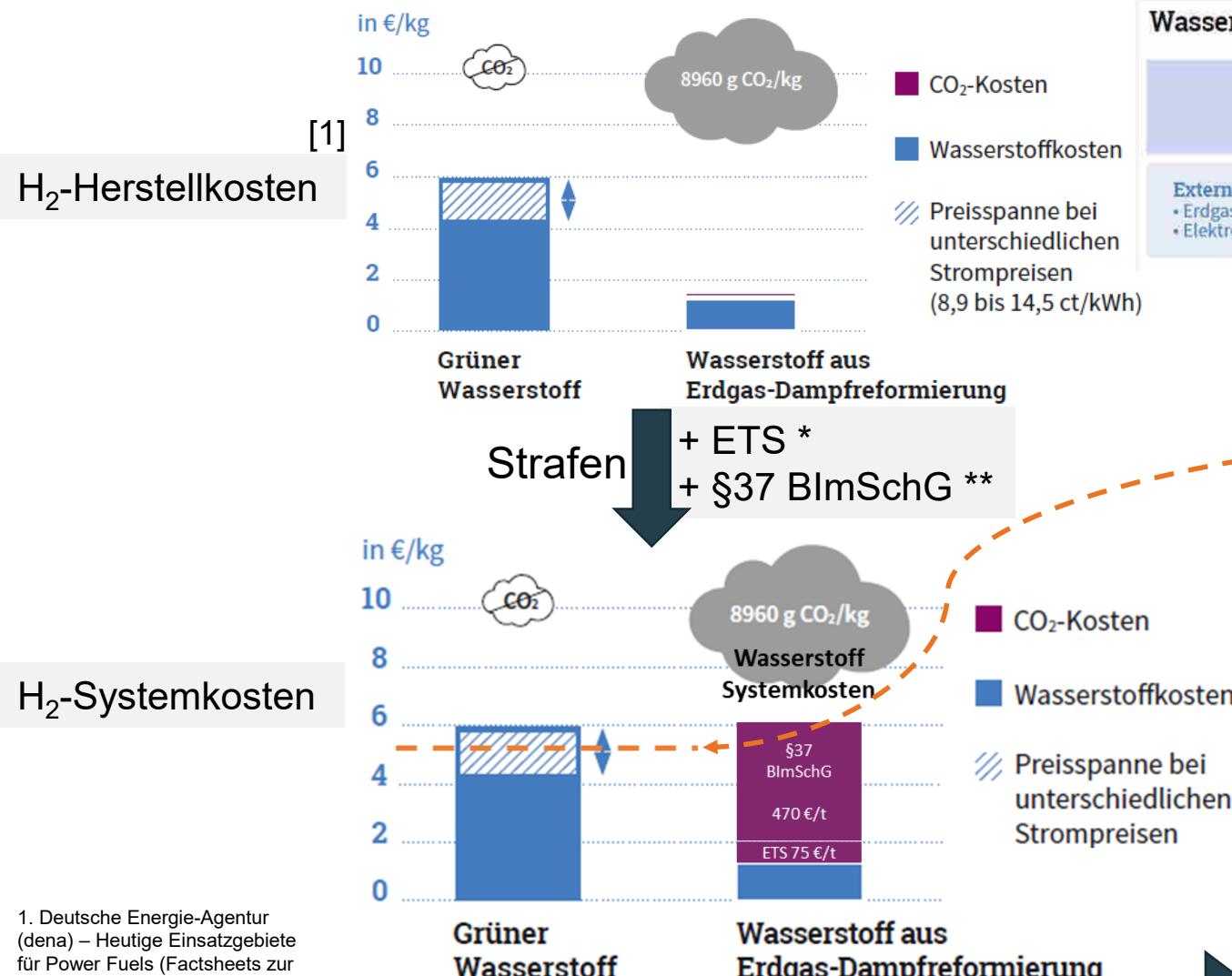
H₂ Business Case in Raffinerie

Beispiel

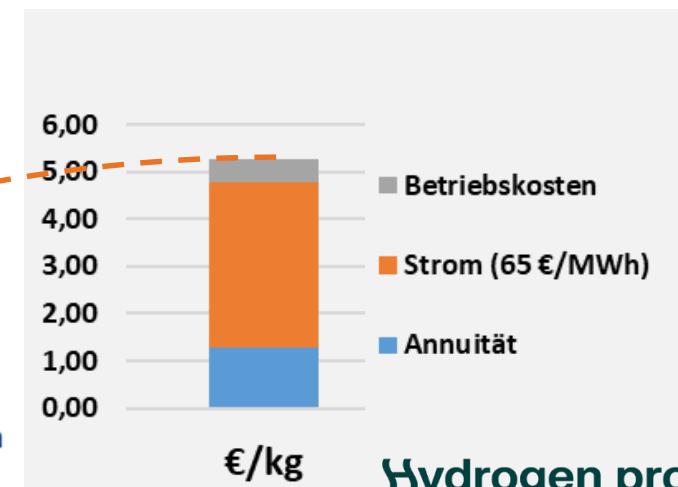
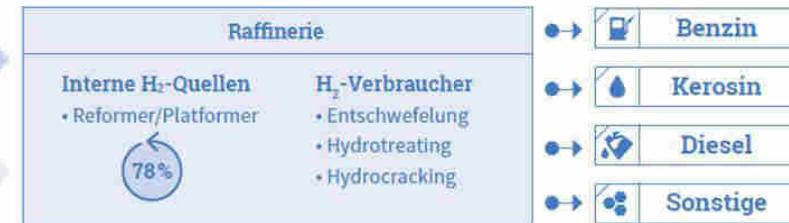
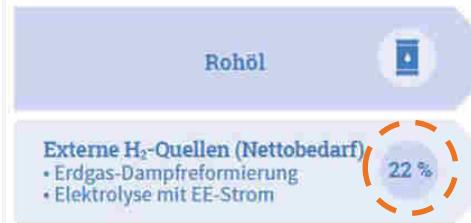
Water Electrolysis

Hydrogen pro





Wasserstoff im Raffinerieprozess [1]



Annahmen

- 5000 Stunden/a
- 17 MW_{installiert}
- 4,8 kWh/Nm³ (AC; incl. Compr.)
- 800 €/kW_{installiert}
- Abschreibung 15 a
- WACC 5,2 %

CAPEX/OPEX turn-key inkl.

- MV-Anbindung
- Einbindung in Raffinerie
- Speicher
- Stack&KOH-Replacement
- 0 % Förderung

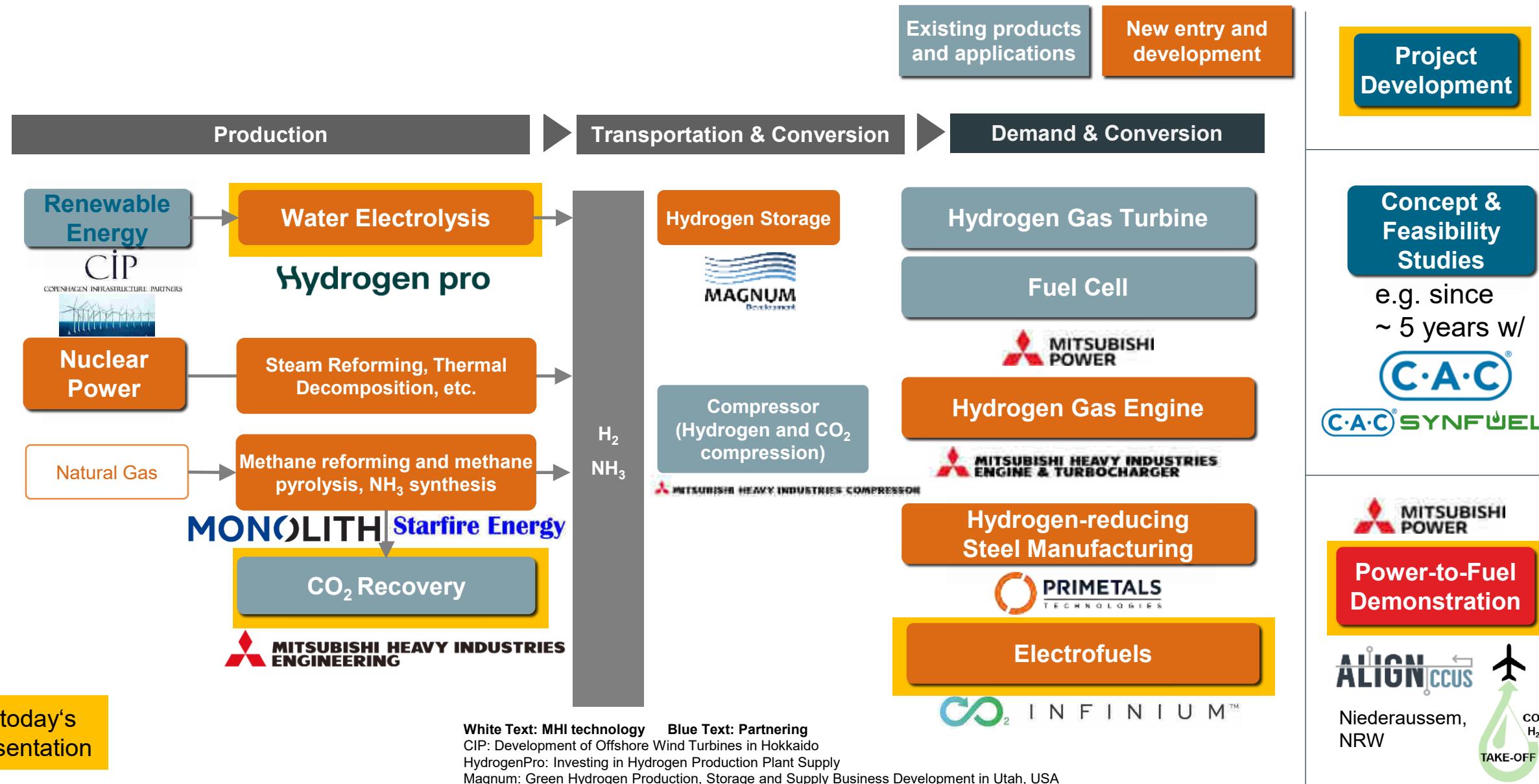
* CO₂-Preis 2030 durch EU ETS

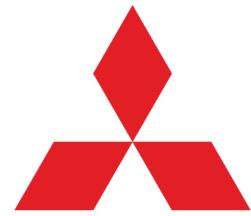
** Pönale, wenn THG-Minderungsverpflichtung (ab 2020: 6 %; bis 2030: 25% [§REDII]) nicht erfüllt (zukünftig 600 €/t_{CO2} mit ggf. Double-Counting)

Business Case spätestens valide, sobald Strafzahlung für Nicht-Erfüllung auf 600 €/t_{CO2} steigt (REDII).

1. Deutsche Energie-Agentur (dena) – Heutige Einsatzgebiete für Power Fuels (Factsheets zur Anwendung von klimafreundlich erzeugten synthetischen Energieträgern, 2018)

MHI Group Involvement across H₂ Value Chain





mitsubishi
HEAVY INDUSTRIES

MOVE THE WORLD FORWARD

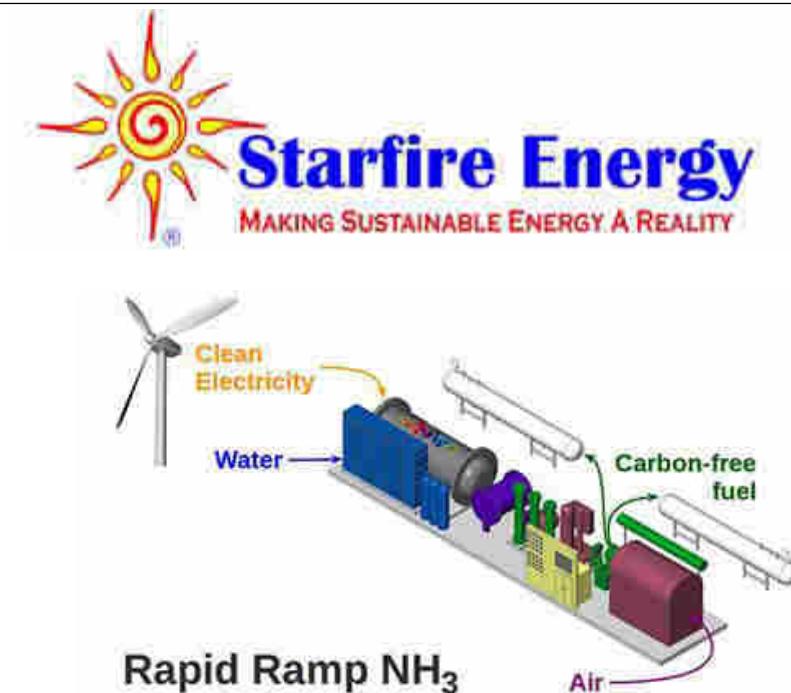
MITSUBISHI
HEAVY
INDUSTRIES
GROUP

PRESS INFORMATION

MHI Invests in Starfire Energy, a Modular Green Ammonia Solution Provider, to Accelerate Efforts to Energy Transition -- Additional Investors Includes AP Ventures, Chevron, New Energy Technology and Osaka Gas --

2021-04-09

<https://www.mhi.com/news/210409.html>



Rapid Ramp NH₃

Technology

- Proprietary catalyst, reactor and adsorber technology
- Fast heating to operating temperature allows for direct use of renewable energy sources such as wind, solar and hydro
- Low pressure operation means lower costs
- Flexible process follows variable power and results in documentably carbon-free ammonia
- One US/PCT patent granted | Six US/PCT patents pending
- Working 10kg/day system | Building 100kg/day system
- Scaling to 50 tonne/day system

Mitsubishi Heavy Industries Invests in Monolith Materials

-- Leader in Innovative Technology for Reducing Environmental Impact --

2020-11-30



- turquoise hydrogen and carbon black from natural gas
- plasma-based methane pyrolysis technology, which uses renewable energy as its heat source.

MHI Invests in Infinium, an Electrofuels Solution Provider, to Accelerate Efforts to Decarbonize the Transportation Sector

-- Additional investors include Amazon's Climate Pledge Fund, AP Ventures, Neuman & Esser Investments, and the Grantham Foundation --

2021-01-27



- Converting carbon dioxide and renewable power into net-zero carbon fuels
- ElectrofuelsTM can be used in today's air, maritime, and surface transportation fleets

PRESS RELEASE

Mitsubishi Power Commences Development of World's First Ammonia-fired 40MW Class Gas Turbine System -- Targets to Expand Lineup of Carbon-free Power Generation Options, with Commercialization around 2025 --

2021-03-01

- Utilizing technology that enables 100% direct combustion of ammonia will contribute to formation of ammonia fuel supply chain
- Commercialization will also support decarbonization systems for small to medium-scale power plants in industrial applications, on remote islands, etc.



H-25 Series gas turbine

YOKOHAMA, JAPAN (March 1, 2021) - Mitsubishi Power, a subsidiary of Mitsubishi Heavy Industries (MHI) Group, has commenced development of a 40-megawatt (MW) class gas turbine that is fueled by 100% ammonia (NH_3). The project was started in response to the increasing global focus on decarbonization. As firing of ammonia produces no carbon dioxide (CO_2), carbon-free power generation is achieved. Going forward, after combustion and other testing, Mitsubishi Power is targeting commercialization in or around 2025. When achieved, it will mark the world's first commercialized gas turbine to make exclusive use of ammonia as fuel in a system of this scale, and will aid in the promotion of decarbonization of small to medium-scale power stations for industrial applications, on remote islands, etc.

PRESS INFORMATION

MHI to Invest in Green Hydrogen & Green Ammonia in South Australia -- To Deliver Project Engineering, Hydrogen Gas Turbines and Compressors to Decarbonize Local Industries, Targeting Green Hydrogen and Ammonia Exports to Japan and Other Countries Going Forward --

<https://www.mhi.com/news/201126.html>

2020-11-26

- H2U is developing Eyre Peninsula Gateway Hydrogen project, a **75 MW electrolysis** plant and a 120-tonne per day ammonia production facility
- It will have the capacity to produce nearly **40,000 tonnes of green ammonia per year.**
- MHI will support H2U's projects and business development initiatives along with its involvement in the front-end engineering and design (**FEED**) study for the Eyre Peninsula project in South Australia.
- **MHI will provide key plant equipment**

Range of H₂ Combustion Technology

Mitsubishi Power has 3 types of combustors catering to individual project requirements and hydrogen densities.

Large Frame Gas Turbines				
Type	Low NOx tech	Turbine inlet temperature (°C)	H ₂ density (volume %)	Schedule
Type 1: Diffusion	N ₂ dilution, Water/ Steam injection	1200~1400	100%	1970 Cogen/IGCC → 2025 Magnum H ₂ conversion
Type 2: Pre-Mix (DLN)	Dry	1600	30%	1982 DLN → 2018 30% co-firing test completed NEDO
Type 3: Multi-Cluster (DLN)	Dry	1650	100% (target)	→ Mar, 2025 Rig test completion target NEDO

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Mitsubishi Power Commences Development of World's First Ammonia-fired 40MW Class Gas Turbine System
-- Targets to Expand Lineup of Carbon-free Power Generation Options, with Commercialization around 2025 --

2021-03-01



H-25 Series gas turbine

- Today delivered gas turbines are “hydrogen ready” for 30 vol.-% co-firing. Small GT can use up to 100%
- Development towards 100% for all GTs finished ~2025
- Ammonia combustion and ammonia splitting developed in parallel

*This presentation is based on results obtained from a project commissioned by NEDO that is a government organization in Japan.
(NEDO: New Energy and Industrial Technology Development Organization)
**DLN : Dry Low NOx