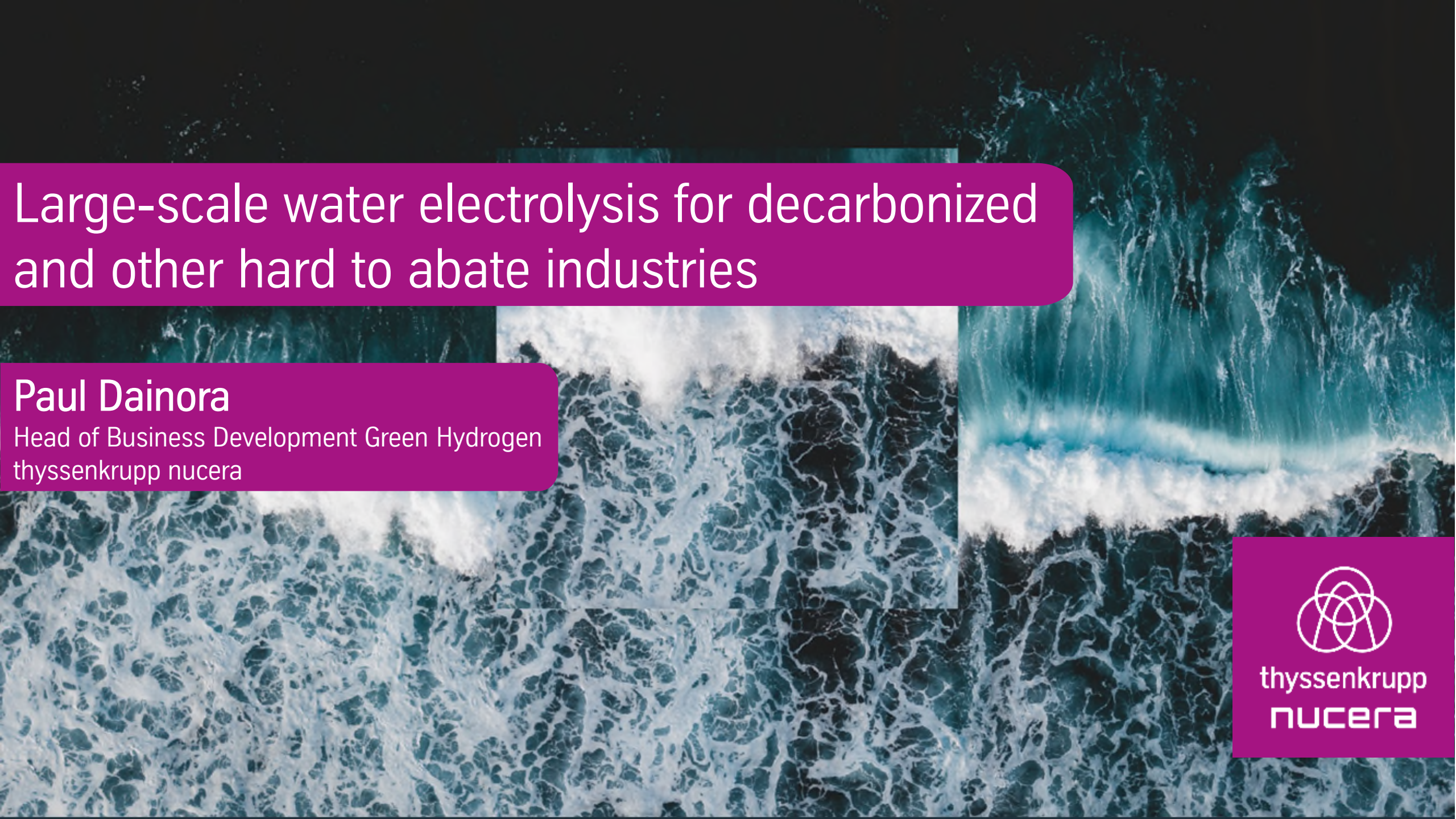

Large-scale water electrolysis for decarbonized and other hard to abate industries

Paul Dainora

Head of Business Development Green Hydrogen
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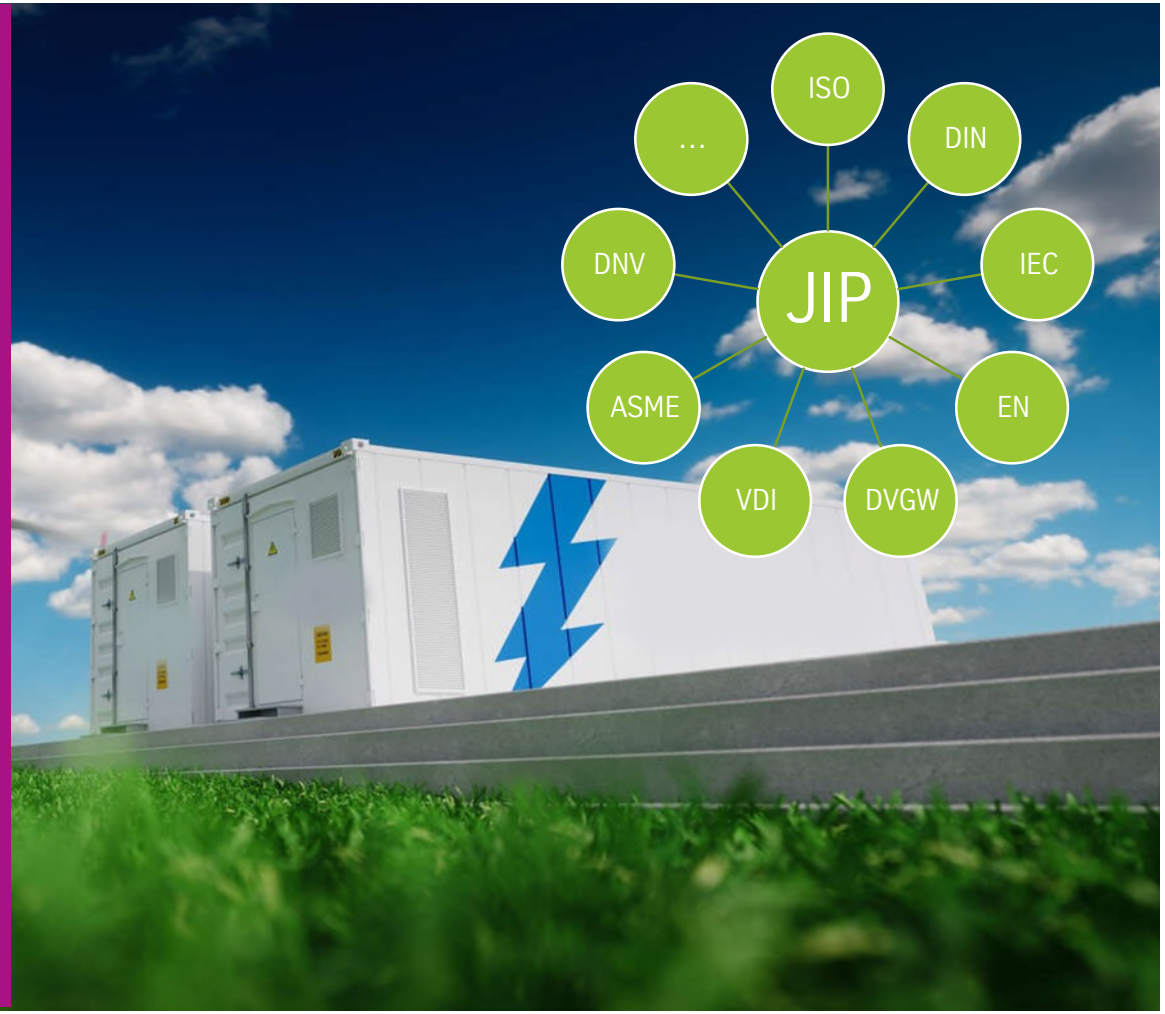
thyssenkrupp
nucera

Objective - H2 Production System Certification

- Establish a **Certification Process**
  - Regulation and design
  - Safety aspects
  - Performance & Quality
- **Basis for** an international technical **Standard**

With 25+ industry partners



Focal points for the Joint Industry Project partners

1	Acceleration of authorization procedure by certification and test
2	Quality and service life of electrolysers
3	High hydrogen quality
4	Safe production and storage
5	Efficiency/performance/comparability parameters of electrolysers
6	Control/safety technology, converters, balance management
7	Safe structures and transport systems
8	Support safety and reliability standards for planning, construction and operation of the plants

Project deliverable description, by 2023

1	Evaluation and defining existing standards and guideline
2	Identify current gaps for Certification
3	Refinement of the components/systems and classification of applications (onshore, offshore, offshore floating)
4	Report for Service Document (Draft / Standard, Recommended Practice, Service Specification)

Partners of the DNV-led JIP

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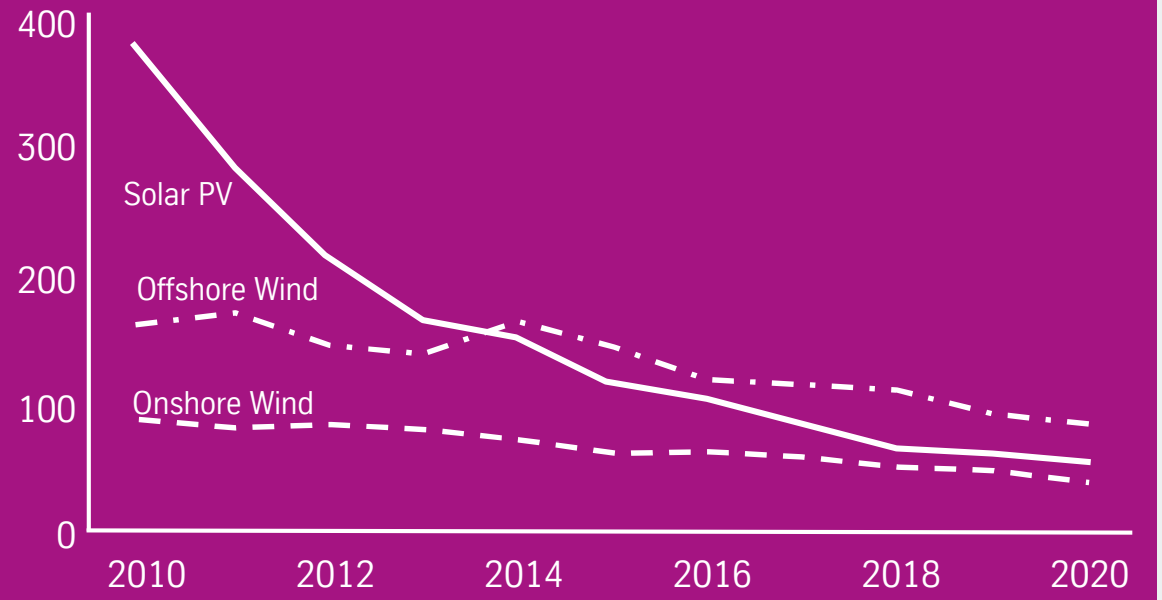
We need to save the global climate

Low cost renewable energy is the basis for competitive green hydrogen production

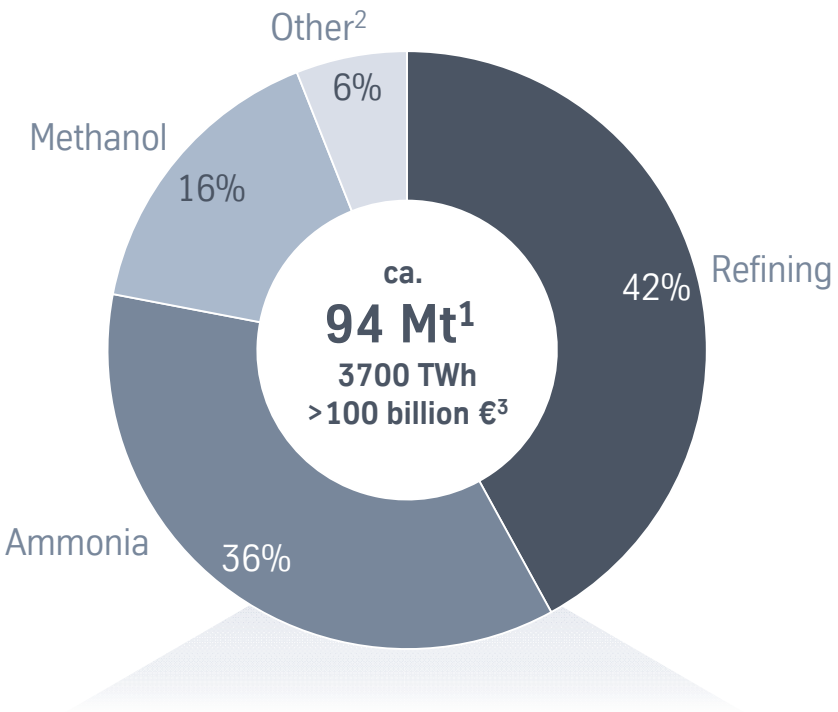


- Solar and wind power costs continue to decline at a rate of c.11% per year[1]
- Hydrogen costs expected to decline accordingly, as electrical power constitutes majority of total cost
- Record prices as low as 10.4 USD/MWh[2] for solar PV

LCOE = Levelized Cost of Energy
1. Source: IRENA (2021), Renewable Power Generation Costs in 2020, International Renewable Energy Agency, Abu Dhabi 2. ACWA Power, Price achieved in Saudi Arabia's Shuaibah Project

Today’s hydrogen market volume is already 94 Mt

Hydrogen market 2021[1]



Nearly all deployed in industry[3]

Current gray H_2 market generates

940

Mt of CO_2 emissions per year[4]…

… Total industry[5] generates 24% of global emissions

2021

~1000 GW

electrolysis

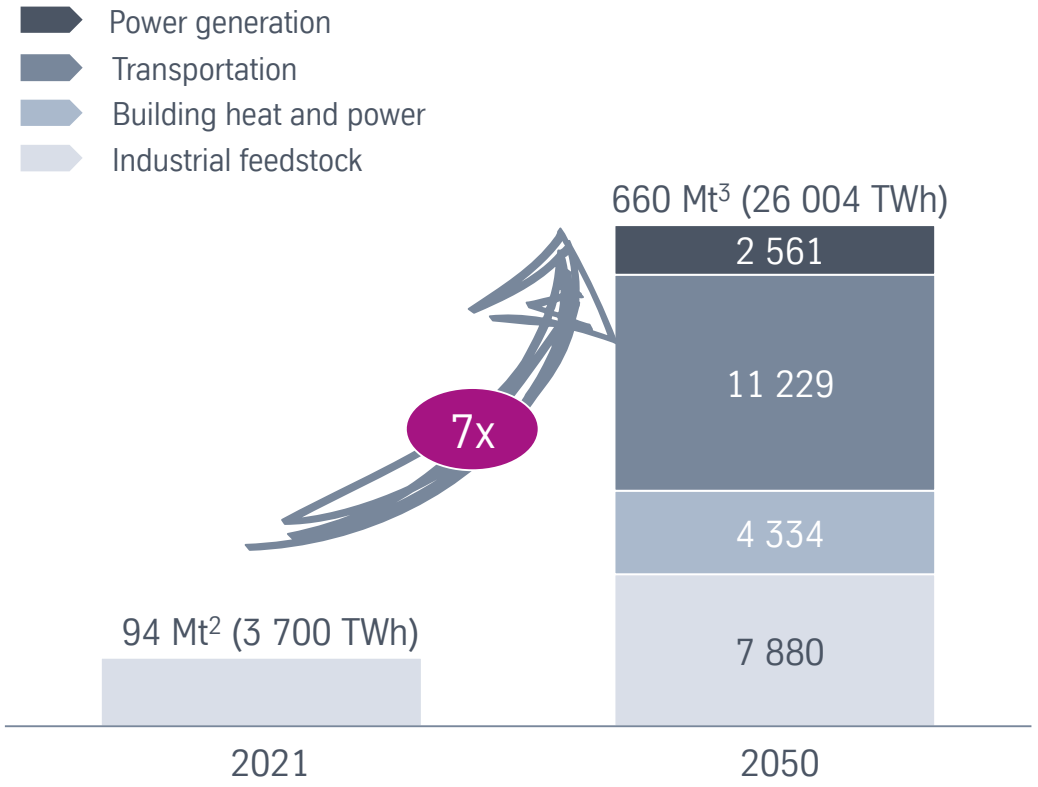
…assuming 94 Mt of green H_2 production with 75% energy efficiency and 4,900 full load hours of operation p.a.

1. Source: IEA (2022), Hydrogen, IEA, https://www.iea.org/reports/hydrogen 2. Includes DRI and other industrial uses 3. H2 kg value from: Bloomberg News, Hydrogen Generation Market Worth $201 Billion by 2025, February 16, 2021
4. Assuming emissions from steam methane reforming of 10 tons of CO2 per ton of hydrogen 5. Refers to 2019 Other Energy Industries and Industry uses

The worldwide hydrogen market is expected to grow sevenfold by 2050

2030:
>200 GW electrolysis sold

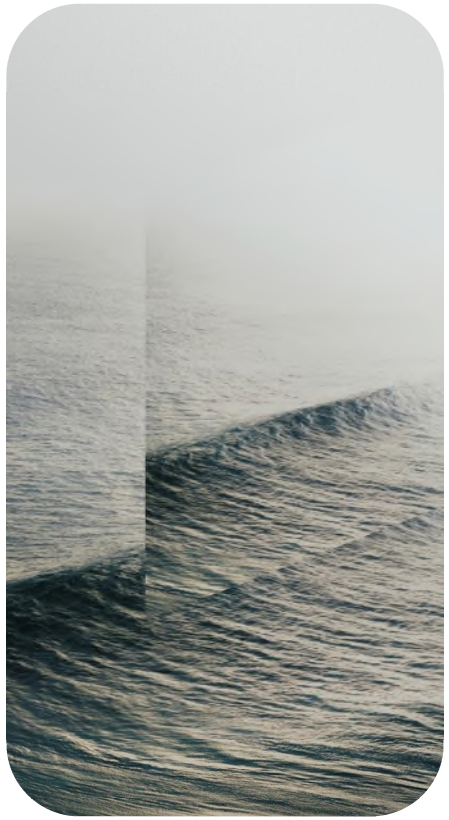
Hydrogen market development until 2050 in Mt[1] (TWh)[2]



2050: green hydrogen will account for[2]
60 – 80%

80 Gt of CO_2
cumulatively abated by 2050[2]

2050
about
~5,500 GW
electrolysis
…assuming 660 Mt at 80% market share of green H_2 at 75% energy efficiency and 5,000 full load hours of operation p.a.

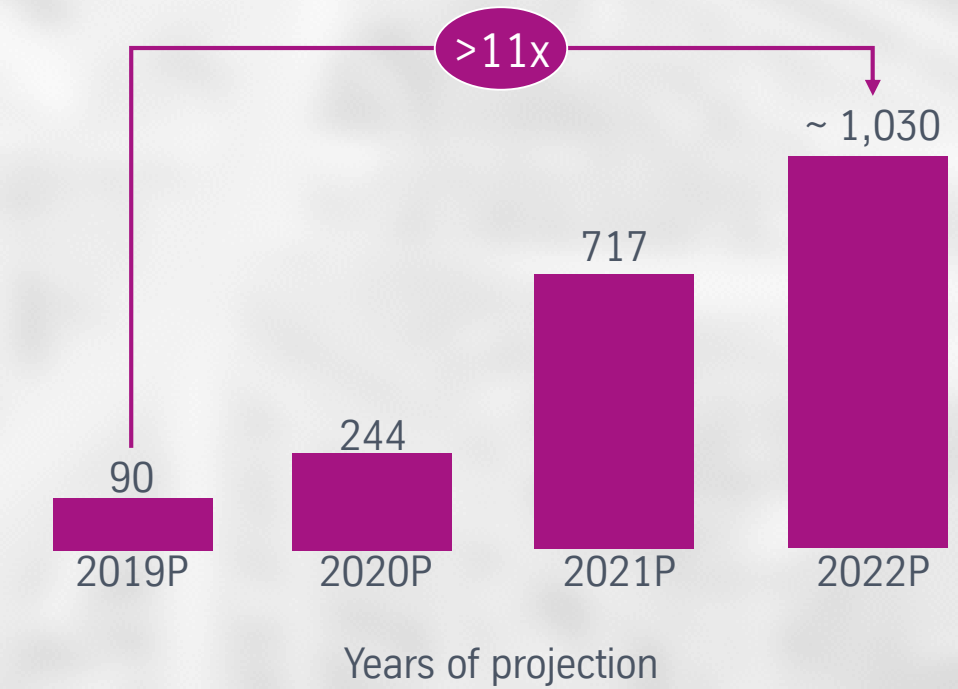


1. Converted from Mt with an energy content of 1kg of hydrogen equal to 141.9 MJ (HHV) = 39.4 KWh 2. Source: IEA (2022), Hydrogen, IEA, https://www.iea.org/reports/hydrogen
3. Source: Hydrogen Council in collaboration with McKinsey & Company, Hydrogen for Net Zero Report, November 2021

Tremendous momentum for hydrogen projects globally

Projected hydrogen production volume in 2030[3]

(TWh[1] p.a.)



2022

60% of announced volumes feature green hydrogen, corresponding to ~ 163 GW[3] electrolysis

1. Converted from Mt with an energy content of 1kg of hydrogen equal to 141.9 MJ (HHV) = 39.4 KWh 2. Green market share not given for 2019 and 2020 3. Source: Hydrogen Council in collaboration with McKinsey & Company, Hydrogen for Net Zero Report, November 2021; Hydrogen Council in collaboration with McKinsey & Company, Hydrogen Insights, September 2022

The hydrogen economy has broad-based secular support for growth

Government policy and consumer demand	• Green hydrogen driven by net zero targets and green recovery policies • Increasing CO_2 emission costs promotes innovative green energy solutions	**93** countries have adopted net-zero targets[1] **39** countries have adopted hydrogen strategies[1]
Cost and availability of renewable energy	• Continuous decline of renewable energy costs • Growing installed base of renewable energy (wind and solar)	**c.11%** global annual decline rate of renewable power[2] prices between 2010 and 2020[3]
Diversification of energy supply	• Energy crisis in Europe triggered diversification • Synergetic approach with new green value chains	**10 mn t of gH2 imports** planned for import to Europe
Opportunity for scalable green H_2 solutions	• Seen as the only viable solution to decarbonise hard to abate industries • Large business potential in all market sectors	**>40 giga-scale** production projects announced as of Nov 2021[1]

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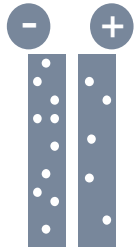
1. Source: **Hydrogen Council in collaboration with McKinsey & Company, Hydrogen for Net Zero Report, November 2021** 2. Including Solar (PV), Offshore and Onshore Wind 3. Source: IRENA (2021), Renewable Power Generation Costs in 2020, International Renewable Energy Agency, Abu Dhabi

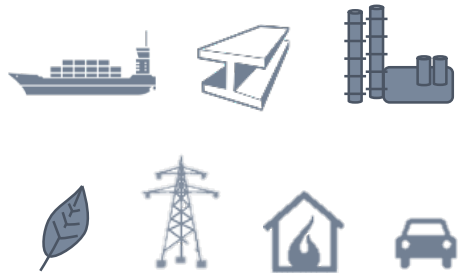
Electrolysis connects the renewable energy sector with a wide range of industries and enables industry decarbonization

Renewable energy

Green hydrogen via electrolysis



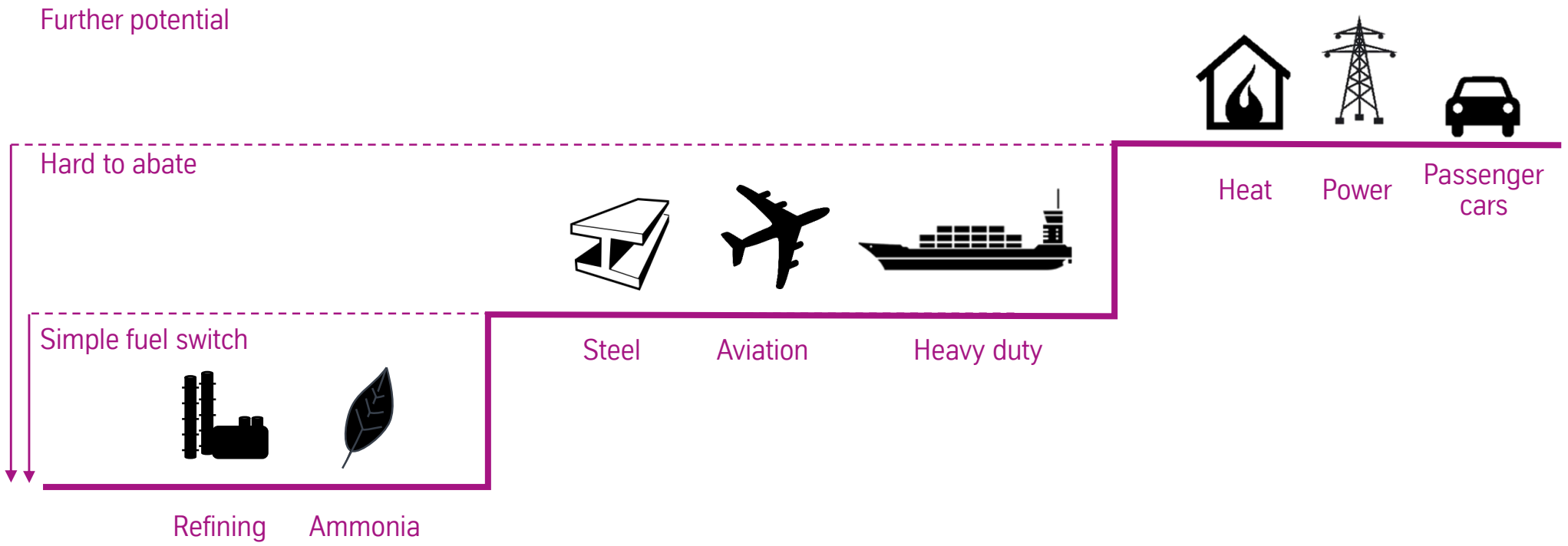
Hydrogen markets



Green hydrogen economy drivers

- Climate & environmental protection
- Growing renewable energy sector at low cost
- Appropriate legal frameworks

Investments into hard to abate sectors



Infrastructure

Enabling clean technologies to meet the Paris climate agreement targets by 2050

Environmental regulations and end-consumer put pressure on industries …

Fertilizer & Industrial

Pressure across regions with end of free CO_2 allowances in EU ETS most significant

End-consumer demand for climate-friendly food

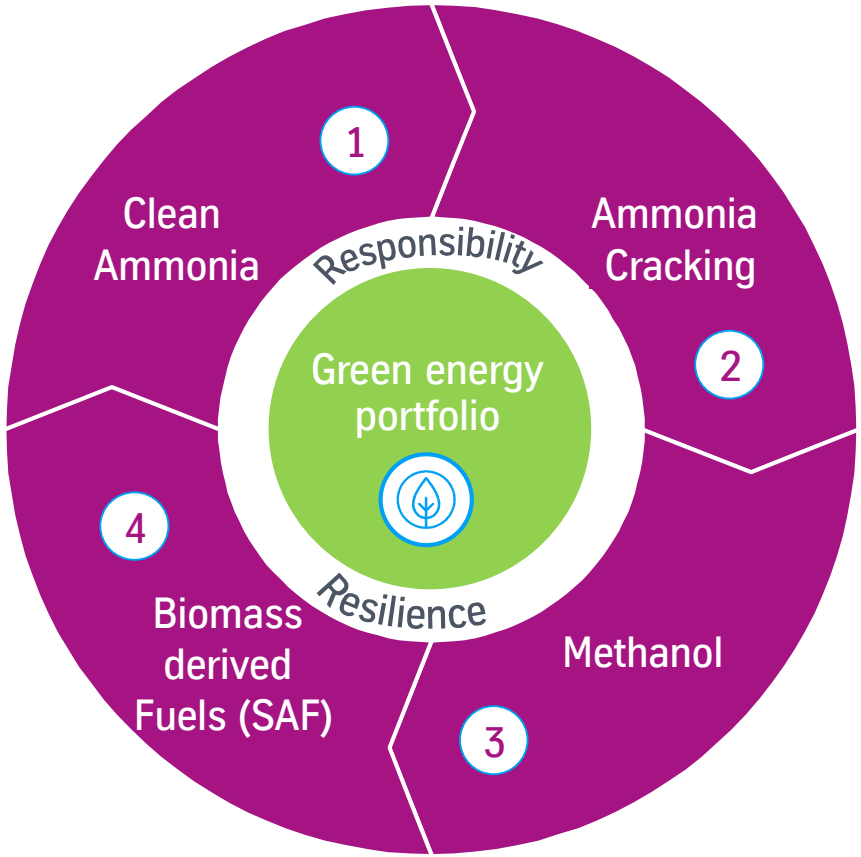
Maritime fuel

Industry push to decarbonize, as indicated by IMO[1] target of 50% GHG reduction by 2050

Power generation

Government-mandated quotas in Japan/Korea with aim to meet stringent decarb targets while utilizing existing coal assets

… require clean technologies to meet the Paris Climate Agreement targets

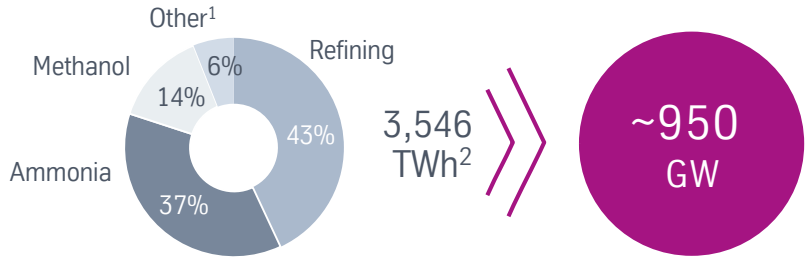


1. International Maritime Organisation

Efficient production of hydrogen requires industrial scale hydrogen plants

Substitution

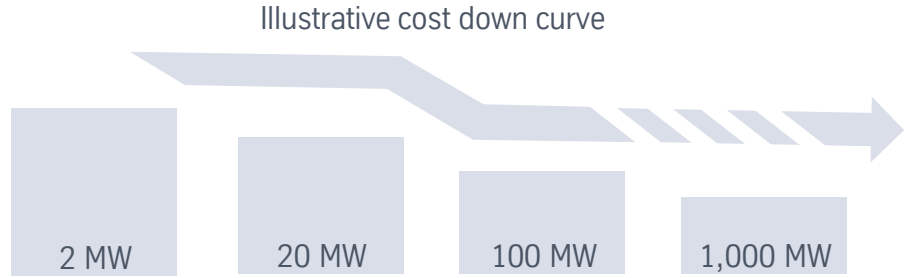
Substitution of grey hydrogen in existing industrial value chains requires industrial scale solutions



Assuming 3,546 TWh at 100 % green H_2 at 75% energy efficiency (HHV[3]) and 5,000 full load hours of operation p.a.

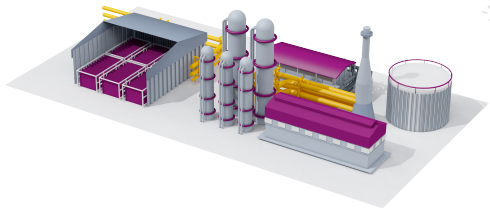
Economies of scale

Large scale electrolysis needs materially lower investment in project development, engineering, and construction



Downstream fit

New downstream PtX[4] process as well as transport vessels for global supply chains are only competitive at large scale



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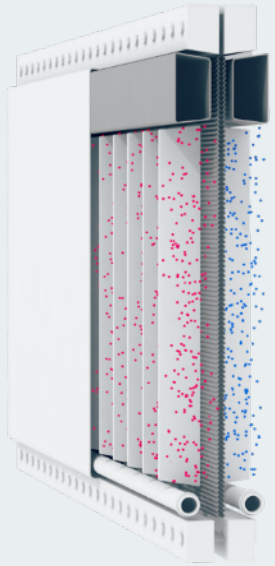
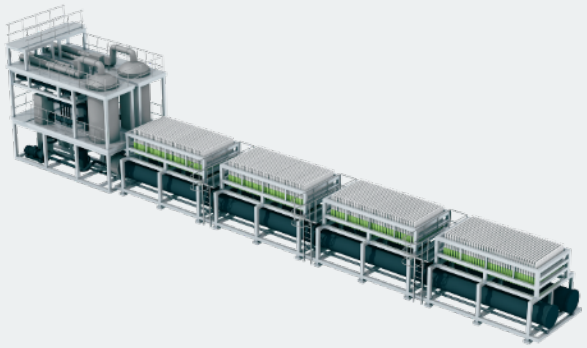
1. Includes DRI and other industrial uses 2. Source: IEA (2021), Hydrogen, IEA, Paris https://www.iea.org/reports/hydrogen 3. High Heating Value 4. Power to X

Efficient and highly scalable standardised module concepts are needed to match industrial scale market requirements

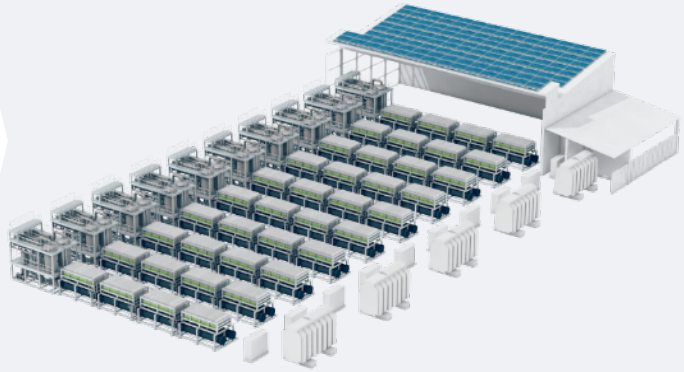
AWE single element



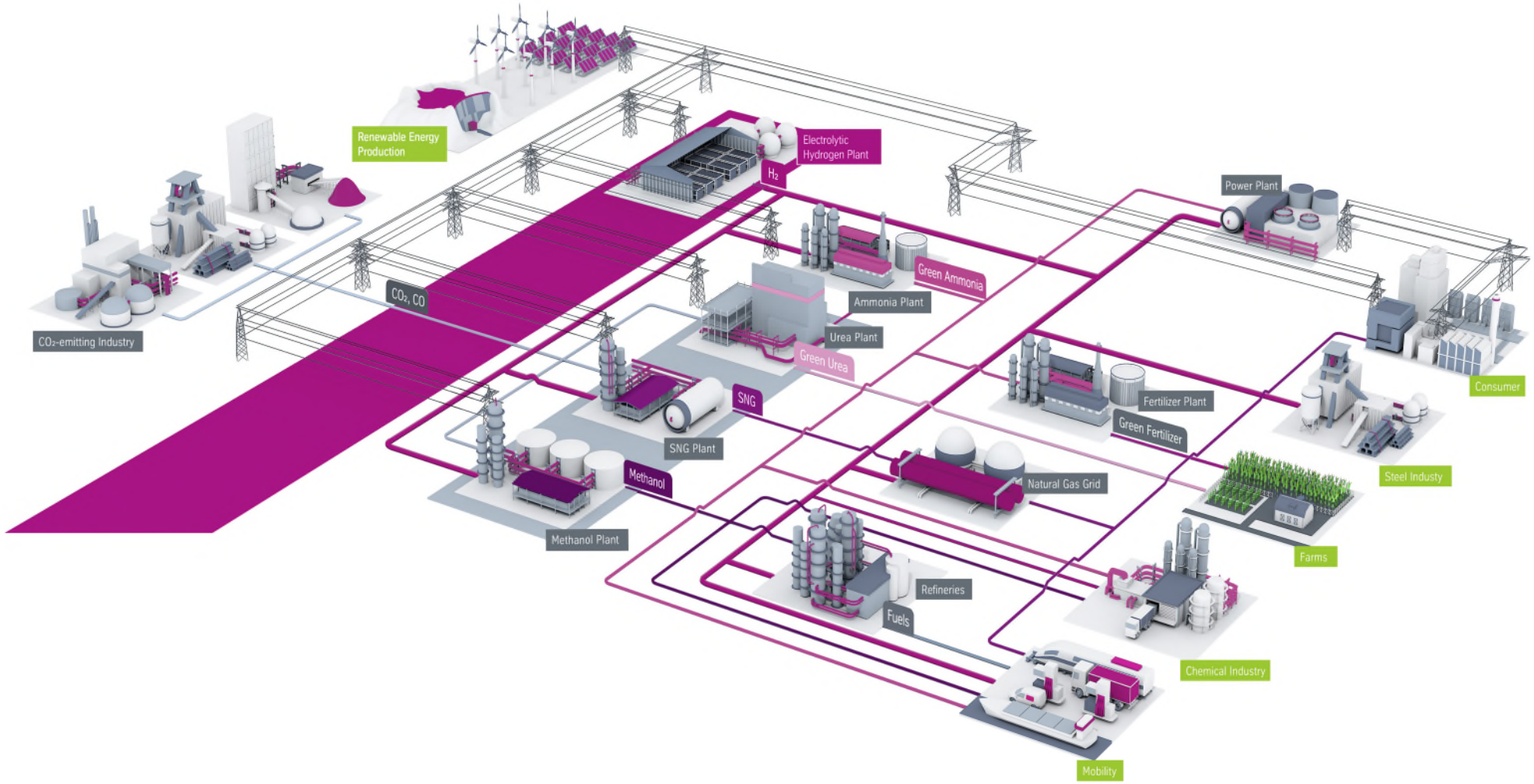
20 MW electrolyzer unit



Highly scalable to GW plant size



Changing industries with clean energy



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Refining, ammonia, and steel are the focus applications the market is starting with

	Refining	Ammonia	Steel
			
Profitable from[1]…	>100 USD/tCO_2	>100 USD/tCO_2	~50 USD/tCO_2
H_2 use	Substitution of grey H_2 feed	Substitution of grey H_2 and green energy vector	Substitution of coke for reduction of iron ore

No alternative to green hydrogen in hard to abate sectors with exposure to carbon tax

Source: Hydrogen Council in collaboration with McKinsey & Company, Hydrogen Insights Report, February 2021
1. Actual breakeven cost dependent on several factors, incl. cost of renewable power and cost of gray alternatives.

Demand

A clear concept for decarbonizing our steel production

- The decarbonisation of the steel industry is a very big lever to quickly achieve significant progress towards climate neutrality.
- Clear concept for decarbonising production that is both technologically mature and scientifically recognised.
- A plan to reduce emissions in steel by 30 percent by 2030. Climate neutrality is envisaged by 2045 at the latest.
- But gigantic quantities of hydrogen will be needed: For the complete conversion to climate-neutral steel production, we will need 720,000 tons of green hydrogen per year.
- The electricity consumption required for hydrogen production corresponds to the current consumption of 25 percent of German households – approximately 36 TWh

Examination of a stand-alone solution of our steel business

Demand

Steel plays a pivotal role in Europe's decarbonization due to its 2.5% contribution to Germany's CO_2 reduction target

CO_2 impact of the steel industry in Germany

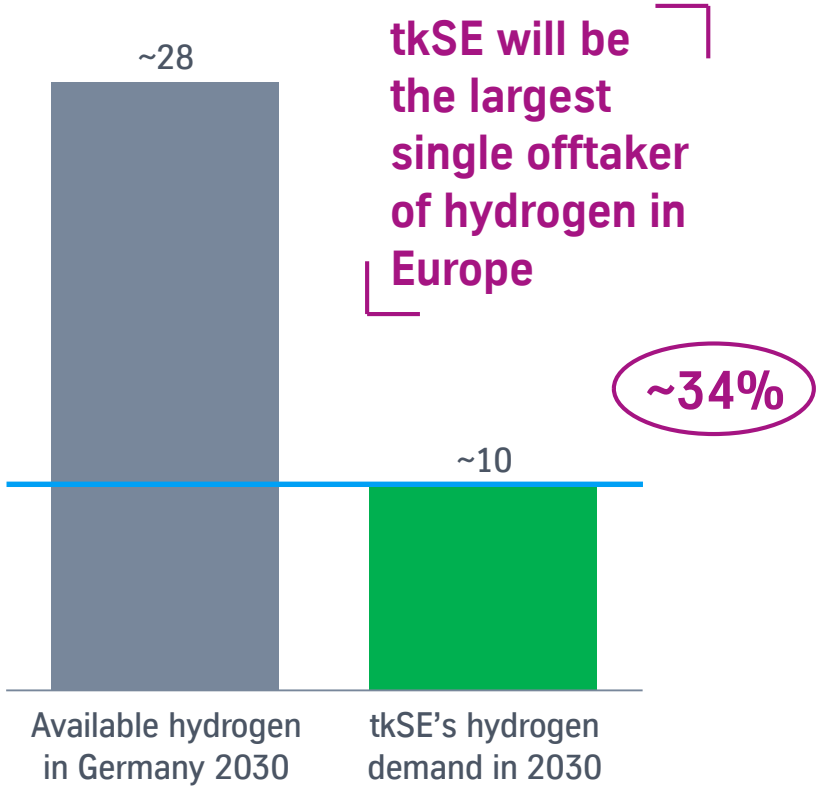
65% CO_2 reduction target 2030 in Germany[1]

7% Steel industry share of CO_2 emissions in Germany

2.5% tkSE's contribution to Germany CO_2 reduction target[2]

Decarbonizing steel operations results in significant progress to achieve **Germany's decarbonization target**

Hydrogen demand comparison in TWh



1. Greenhouse Gas reduction; Base year 1990 | 2. Base year 2020 until 2030 | 3. Scope 3 emissions | 4. Battery electric car in the c-segment | 5. Washing machine with <15kg capacity, 225kg | 6. 5,500 sqm warehouse Source: Company information, McKinsey analysis

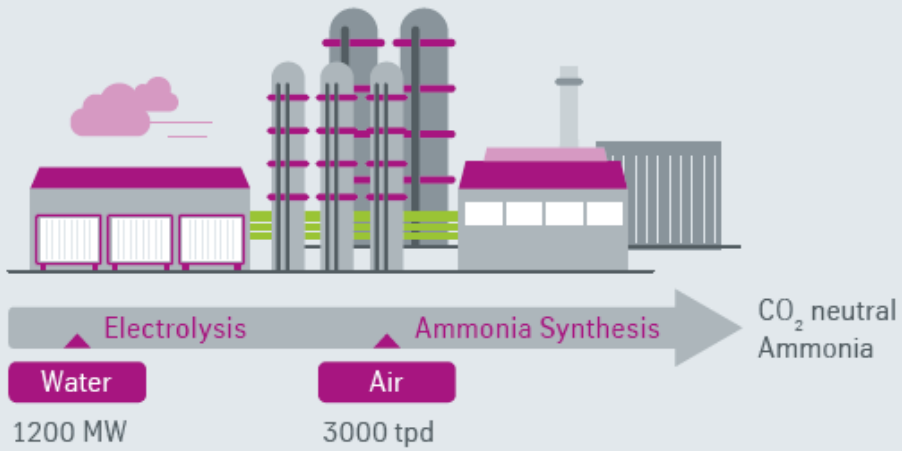
Scale up technology for efficient operations

1 Substitution of gray hydrogen in existing value chains already requires **gigawatt scale**

H_2	NH_3	Steel*
~ 950 GW	~ 300 GW	~ 800 GW

* Direct reduction of iron ore.

2 **Power-to-X applications require scale** to compete against gray commodity prices



Scale up technology for efficient operations

3

Scaling up electrolysis plants shows **significant cost reduction**

4

Only at gigawatt scale **global transport chains** operate efficiently

Certified GW-technology with proven supply chain for green hydrogen production is available today

Any questions which need to be further addressed?

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World