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

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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

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<td>1</td>
<td>Acceleration of authorization procedure by certification and test</td>
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<td>Efficiency/performance/comparability parameters of electrolysers</td>
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<td>Quality and service life of electrolysers</td>
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<td>Control/safety technology, converters, balance management</td>
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<td>High hydrogen quality</td>
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<td>Safe structures and transport systems</td>
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<td>4</td>
<td>Safe production and storage</td>
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<td>Support safety and reliability standards for planning, construction and operation of the plants</td>
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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)
Partners of the DNV-led JIP
We need to save the global climate

Food & water
Renewable energy
Clean air
Healthy planet
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
2. ACWA Power, Price achieved in Saudi Arabia’s Shuaibah Project
Today’s hydrogen market volume is already 94 Mt

Hydrogen market 2021

- Nearly all deployed in industry

Current gray H₂ market generates

- 940 Mt of CO₂ emissions per year

... Total industry generates 24% of global emissions

2021

- ~1000 GW electrolysis

...assuming 94 Mt of green H₂ production with 75% energy efficiency and 4,900 full load hours of operation p.a.
The worldwide hydrogen market is expected to grow sevenfold by 2050.

Hydrogen market development until 2050 in Mt\(^1\) (TWh)\(^2\)

- **Power generation**
- **Transportation**
- **Building heat and power**
- **Industrial feedstock**

### 2021
- **94 Mt\(^2\) (3 700 TWh)**

### 2050
- **660 Mt\(^3\) (26 004 TWh)**
  - **2 561**
  - **11 229**
  - **4 334**
  - **7 880**

- **2050: green hydrogen will account for** **60 – 80%**
- **80 Gt of CO\(_2\)** cumulatively abated by 2050\(^2\)

- **2030:** >200 GW electrolysis sold

- **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.

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1. Converted from Mt with an energy content of 1kg of hydrogen equal to 141.9 MJ (HHV) = 39.4 KWh
Projected hydrogen production volume in 2030\(^3\)

(TWh\(^1\) p.a.)

<table>
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<tr>
<th>Years of projection</th>
<th>2019P</th>
<th>2020P</th>
<th>2021P</th>
<th>2022P</th>
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<tr>
<td></td>
<td>90</td>
<td>244</td>
<td>717</td>
<td>~1,030</td>
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1. Converted from Mt with an energy content of 1 kg of hydrogen equal to 141.9 MJ (HHV) = 39.4 kWh
2. Green market share not given for 2019 and 2020

Tremendous momentum for hydrogen projects globally

2022

60% of announced volumes feature green hydrogen, corresponding to ~163 GW\(^3\) electrolysis
The hydrogen economy has broad-based secular support for growth

| Government policy and consumer demand | 93 countries have adopted net-zero targets\(^1\)  
| + Green hydrogen driven by net zero targets and green recovery policies | 39 countries have adopted hydrogen strategies\(^3\)  
| + Increasing CO\(_2\) emission costs promotes innovative green energy solutions |

| Cost and availability of renewable energy | C.11% global annual decline rate of renewable power\(^2\) prices between 2010 and 2020\(^3\)  
| + Continuous decline of renewable energy costs |  
| + Growing installed base of renewable energy (wind and solar) |

| Diversification of energy supply | 10 mn t of gH2 imports planned for import to Europe  
| + Energy crisis in Europe triggered diversification |  
| + Synergetic approach with new green value chains |

| Opportunity for scalable green H\(_2\) solutions | >40 giga-scale production projects announced as of Nov 2021\(^1\)  
| + Seen as the only viable solution to decarbonise hard to abate industries |  
| + Large business potential in all market sectors |
Electrolysis connects the renewable energy sector with a wide range of industries and enables industry decarbonization.

**Green hydrogen economy drivers**

- Climate & environmental protection
- Growing renewable energy sector at low cost
- Appropriate legal frameworks
Investments into hard to abate sectors

- Refining
- Ammonia
- Simple fuel switch
- Steel
- Aviation
- Heavy duty

Further potential

- Heat
- Power
- Passenger cars
Environmental regulations and end-consumer put pressure on industries …

- **Fertilizer & Industrial**
  - Pressure across regions with end of free CO₂ allowances in EU ETS most significant
  - End-consumer demand for climate-friendly food

- **Maritime fuel**
  - Industry push to decarbonize, as indicated by IMO¹ 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

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

Downstream fit
New downstream PtX\textsuperscript{4} process as well as transport vessels for global supply chains are only competitive at large scale

Assuming 3,546 TWh at 100 % green H\textsubscript{2} at 75% energy efficiency (HHV\textsuperscript{3}) and 5,000 full load hours of operation p.a.

Illustrative cost down curve

1. Includes DRI and other industrial uses
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
Refining, ammonia, and steel are the focus applications the market is starting with

- **Refining**
  - Profitable from $1 > 100 \text{ USD/tCO}_2$
  - Substitution of grey H$_2$ feed

- **Ammonia**
  - Profitable from $1 > 100 \text{ USD/tCO}_2$
  - Substitution of grey H$_2$ and green energy vector

- **Steel**
  - Profitable from $1 \approx 50 \text{ USD/tCO}_2$
  - Substitution of coke for reduction of iron ore

No alternative to green hydrogen in hard to abate sectors with exposure to carbon tax
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.
Steel plays a pivotal role in Europe’s decarbonization due to its 2.5% contribution to Germany’s CO₂ reduction target.

**CO₂ impact of the steel industry in Germany**

- **65%** CO₂ reduction target 2030 in Germany\(^1\)

- **7%** Steel industry share of CO₂ emissions in Germany

- **2.5%** tkSE’s contribution to Germany CO₂ reduction target\(^2\)

Decarbonizing steel operations results in significant progress to achieve Germany’s decarbonization target.

**Hydrogen demand comparison in TWh**

- Available hydrogen in Germany 2030
- tkSE’s hydrogen demand in 2030

software

\(^1\) Greenhouse Gas reduction; Base year 1990 | \(^2\) Base year 2020 until 2030 | \(^3\) Scope 3 emissions | \(^4\) Battery electric car in the c-segment

| Source: Company information, McKinsey analysis |
Scale up technology for efficient operations

1. Substitution of gray hydrogen in existing value chains already requires **gigawatt scale**
   - $\text{H}_2$: $\sim 950$ GW
   - $\text{NH}_3$: $\sim 300$ GW
   - Steel*: $\sim 800$ GW

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

* Direct reduction of iron ore.
Scale up technology for efficient operations

3. Scaling up electrolysis plants shows significant cost reduction

- 2 MW (400 Nm³/h H₂)
- 20 MW (4,000 Nm³/h H₂)
- 100 MW (20,000 Nm³/h H₂)
- 1,000 MW (200,000 Nm³/h H₂)

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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