

A 3D architectural rendering of a sustainable industrial complex. In the foreground, there are several wind turbines and solar panels. A yellow network of lines, representing energy or material flow, connects these renewable energy sources to various industrial buildings. One building has large white storage tanks, another has blue rectangular units, and a third has large white cylindrical tanks. In the background, a city skyline is visible under a bright sky.

# Large scale water electrolysis

## thyssenkrupp Uhde Chlorine Engineers

Energy Storage and Hydrogen | March 2019

engineering.tomorrow.together.



thyssenkrupp

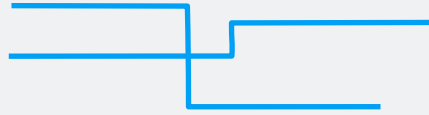
# Key value propositions of green hydrogen

## Climate Protection/ Sustainability

CO<sub>2</sub>

Reducing CO<sub>2</sub> emissions in the sectors mobility, heat & industry

## Use Gas Infrastructure Legacy



E.g. natural gas supply chains are valuable heritages to be preserved

## Limits for Local Emissions



Urban areas are lowering limits for NO<sub>x</sub>, fine dust and noise

## Diversification of Energy Supply



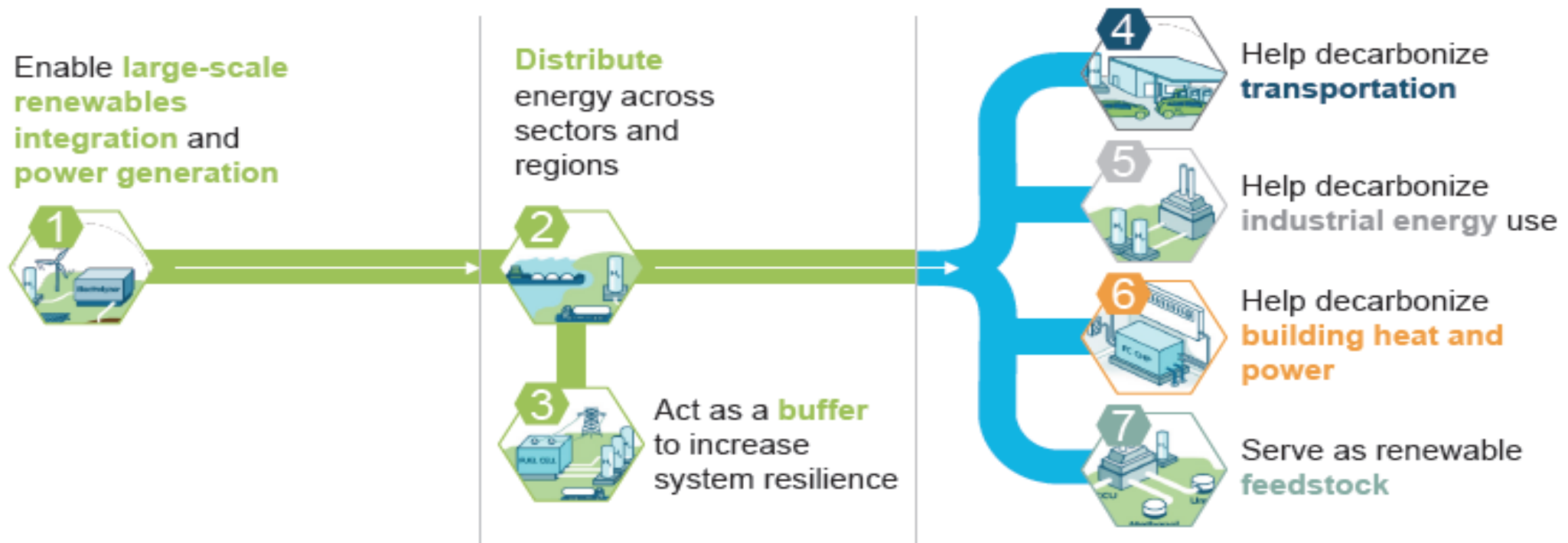
Countries decide strategically to diversify the import portfolio

- Sectoral connection and integration of heat, mobility, fuels and chemicals with power
- Balance of demand and supply (short to long-term)
- Connection of global sources and sinks





# Enable the renewable energy system → Decarbonize end uses

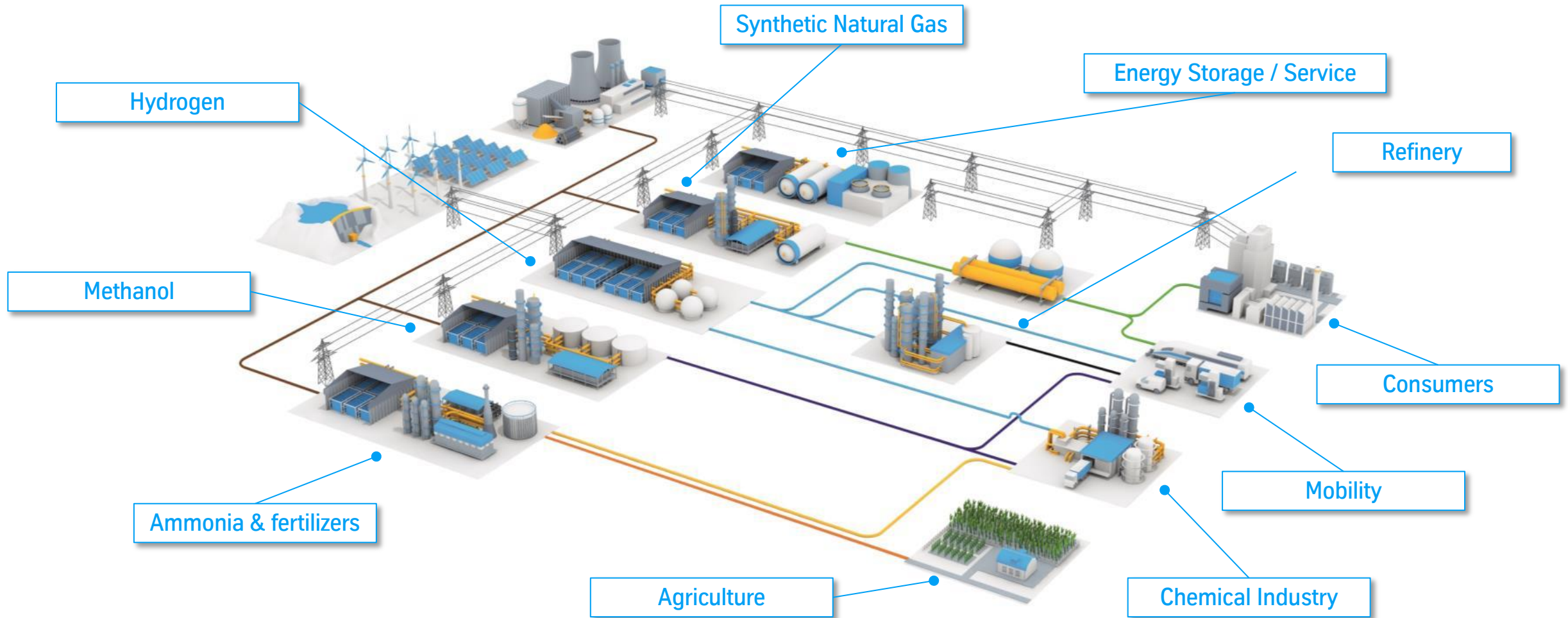


SOURCE: Hydrogen Council

- annual demand for hydrogen could increase **tenfold by 2050** – from 8 EJ in 2015 to almost 80 EJ in 2050
- **5% of the global production of methanol** and derivatives could be based on renewable feedstock by 2035.
- By 2030, **250 to 300 TWh of surplus renewable electricity** could be stored in the form of hydrogen for use in the other end-use segments



# New markets & Value chains.



We deliver EPC solutions including downstream processes such as ammonia, methane or methanol production





thyssenkrupp Group

€42.7 bn sales in '17/18

200+ years of heritage

79 countries, ~2,000 sites

161.000 employees





# thyssenkrupp Industrial Solutions - a global footprint with world-scale plants

Fertilisers

130 plants



Nitric acid

185 plants



Refineries

380 plants



Aromatics

75 plants



Hydrogen, ammonia, methanol

120 plants



Org. Chemicals/petrochemicals

375 plants



Plastics, synthetic fibres

115 plants



Polyester / polyamides

400 plants



Electrolysis / Electrochemical Technologies

600 plants



Coke Plant Technologies

500 plants



Tank storage facilities

105 plants

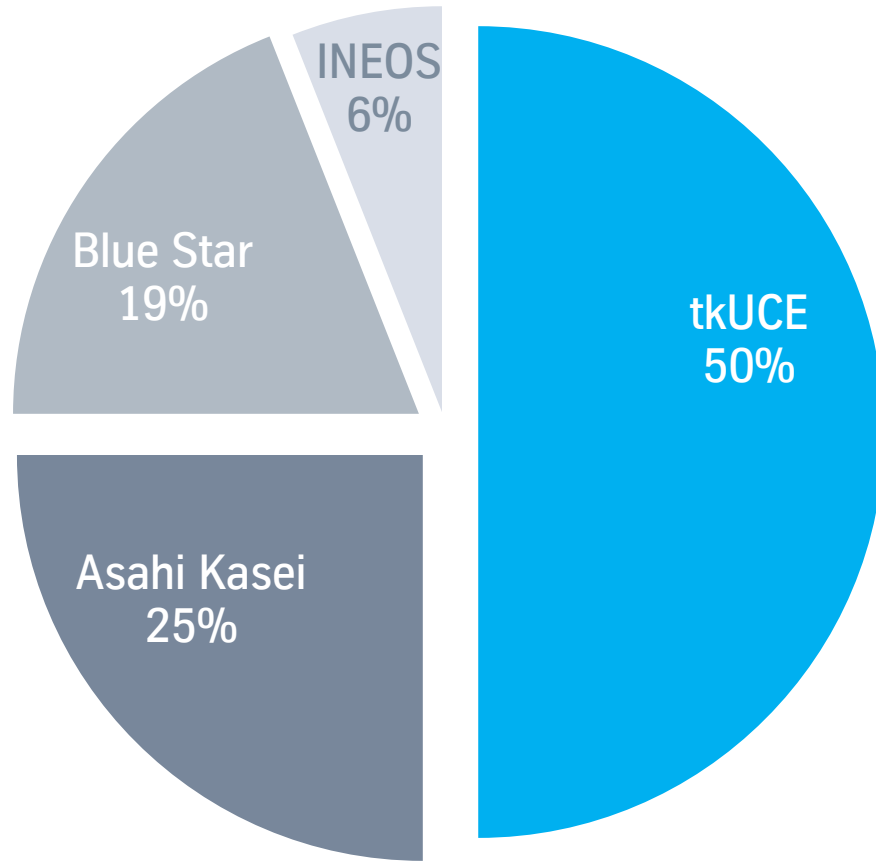


Industrial plants

150 plants



## tkUCE – Market leader in membrane electrolysis processes



Main suppliers

### Accumulated contract awards

**42 mn. mt/year  $\text{Cl}_2$**   
# 10GW and 1 Million t  $\text{H}_2$ /year

**2 mn. mt/year  $\text{Cl}_2$**   
from HCl-ODC

Global IEM CA Market Shares based on installed capacity; (CA = Chlor-alkali); free accessible Markets only; source: tkUCE database (as of 2017).



# Water Electrolysis by thyssenkrupp – proven technology with established supply chain

>200,000

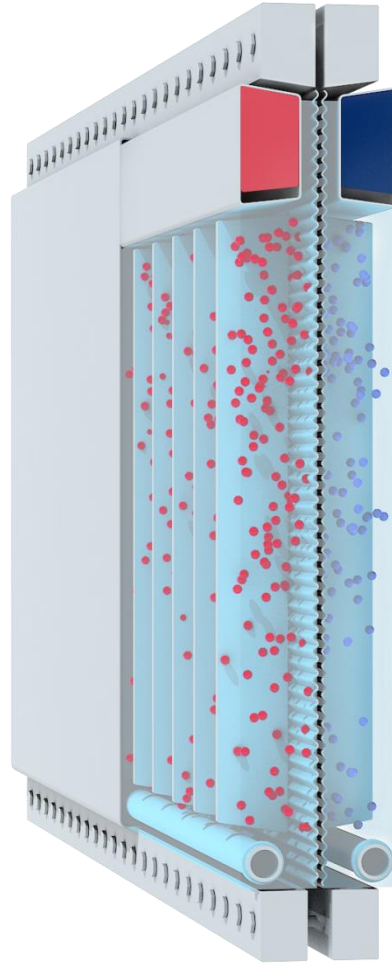
of elements manufactured<sup>1</sup>

>1.2 million m<sup>2</sup>

of electrodes produced<sup>1</sup>

>600 MW (>1bn Nm<sup>3</sup>/a)

can be installed each year<sup>2</sup>



- Proven zero-gap technology
- Introduction of **high efficiency cathode design and coating** (with De Nora) for hydrogen evolution, proven in chlor-alkali technology
- Introduction of **high efficiency anode design and coating** (with De Nora) based on proven chlorine technology
- **Optimized high-performance separators and diaphragms** based on proven design

<sup>1</sup>for chlor-alkali plants producing hydrogen as co-product, <sup>2</sup>for electrolytic hydrogen production

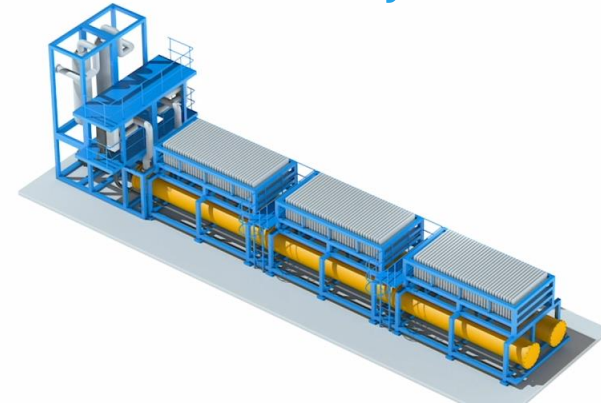




# Water electrolysis is the key technology for green hydrogen

Being market and technology leader in world-scale electrochemical plants for chlorine and caustic

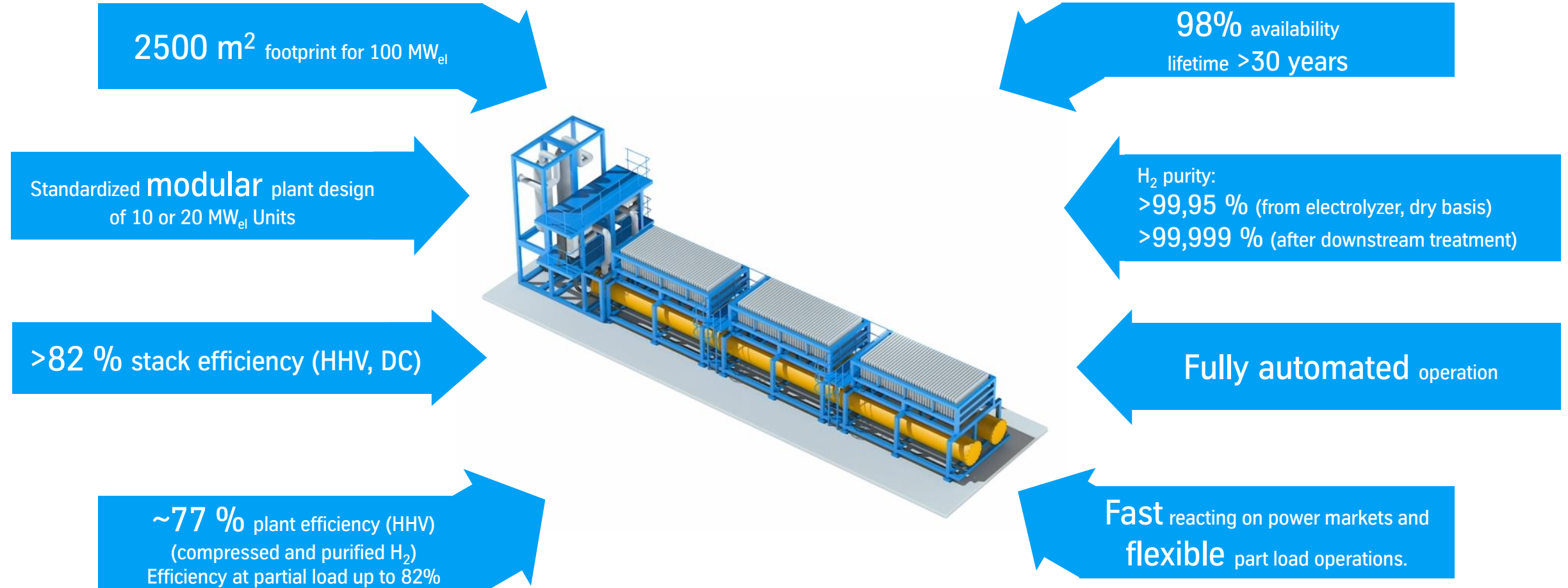
...we developed a lean and cost effective solution for large scale water electrolysis for H<sub>2</sub>-production



Background picture: 100 MW Chlorine plant Tessenderlo, Belgium



# Water electrolysis by thyssenkrupp - key features and system performance data



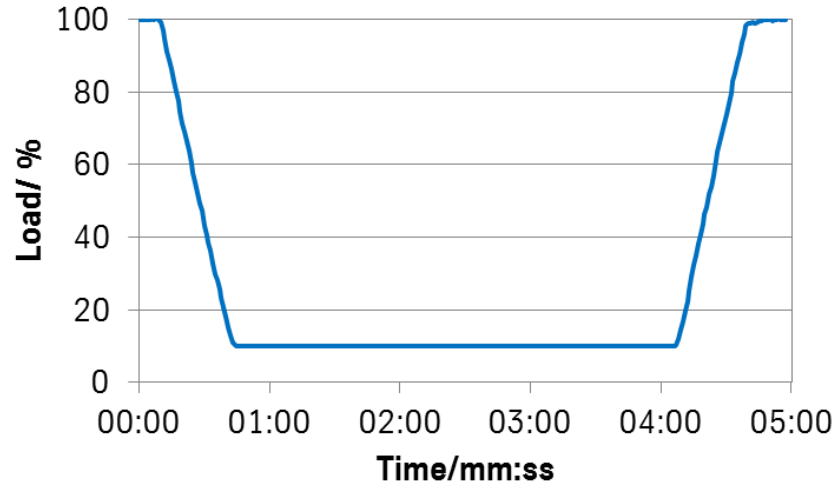


# thyssenkrupp water electrolysis system is validated at industrial scale for dynamic operation



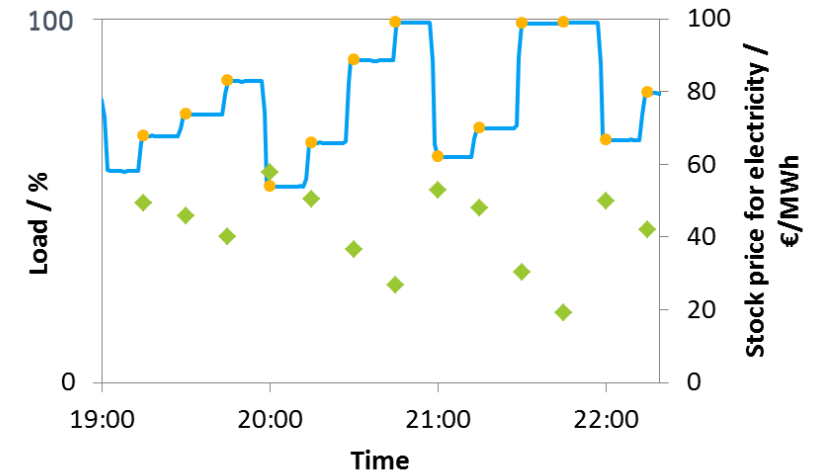
## Operation of technical evaluation plant at Carbon2Chem, Duisburg

- Capacity: up to 2 MW
- H<sub>2</sub> production: 440 Nm<sup>3</sup>/h
- H<sub>2</sub> purity: > 99.95 % (dry basis)



## Fast ramping capabilities proven

- Load changes between 10% and 100% in less than 30sec
- Enables utilization for primary control reserve

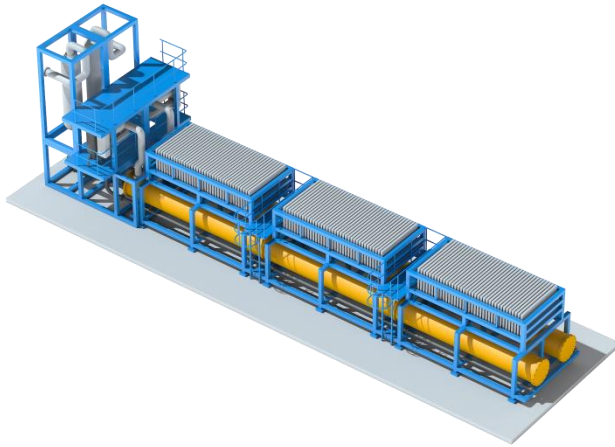


## Power price optimized operation

- Power price based load management established
- Enables optimization of average power price

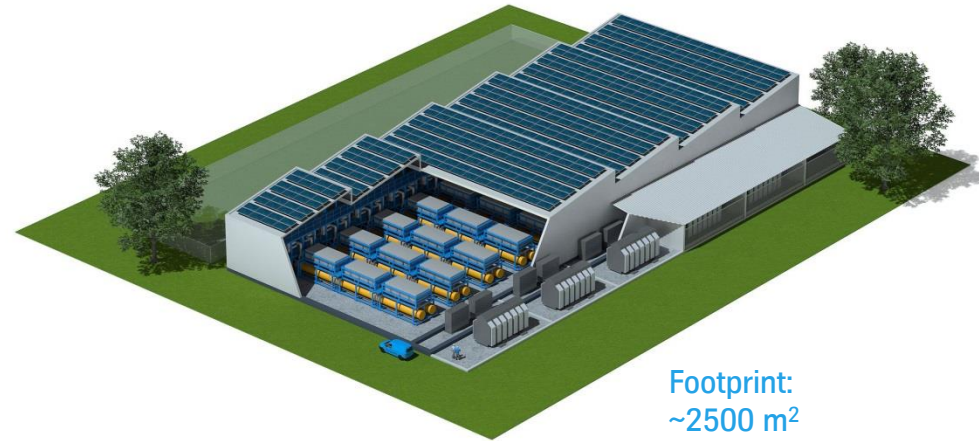
# Our design philosophy: standardized, prefabricated units as basis for large installations

## 10 MW electrolyzer units



Standardized & skid-mounted

## 100 MW plant design



Turnkey solution including:  
transformer/rectifiers | compression and purification | utilities





# Membership

We are providing solutions to the hydrogen society.

## Hydrogen Council

3M

AIRBUS

AirLiquide

PRODUCTS

AIR

ENERGY

ALSTOM

AngloAmerican

BMW GROUP

BOSCH

Invented for life

国家能源集团

CHN ENERGY

Cummins

DAIMLER

edf

ENGIE

equinor

faurecia

inspiring mobility

GM

Great Wall

HONDA

HYUNDAI

Iwatani

JM

Johnson Matthey

inspiring science enhancing life

JXTG

Nippon Oil & Energy

Kawasaki

KOGAS

THE LINDE GROUP

OP

PLANT OIL

Shell

SINOPEC

thyssenkrupp

TOTAL

TOYOTA

WEICHAI

AFC Energy

BALLARD

Faber

GORE

HEXAGON

HYDROGENICS

Marubeni

McPhy

Mitsubishi Corporation

MITSUBISHI HEAVY INDUSTRIES

NISSEI

nel\*

PLUG POWER

RE-FIRE

SeChlor

SMB

Sumitomo Corporation

TOYOTA TOYOKU

VOPOK



PLATINUM

YARA

Knowledge grows

GOLD

KBR

PROTON VENTURES

ReactWell

thyssenkrupp

SILVER

Airgas

CASALE

HALDOR TOPSOE

nel\*

MEMBER

BA6F

C-JOB

ITM POWER

Starfire Energy

TERRESTRIAL ENERGY



# Experience cannot be copied.

# #1

49% market share

supplier for electrolytic  
hydrogen production

# 600 MW

Production capacity/year  
Expandable to 3GW

over

# 10 GW

of power installed  
#1000 kt/year of H<sub>2</sub>

Hydrochloric  
acid  
diaphragm  
electrolysis



Hydrochloric  
acid ODC<sup>1</sup>  
membrane  
electrolysis



Chlor-alkali  
membrane  
electrolysis



<sup>1</sup> ODC: Oxygen Depolarized Cathodes





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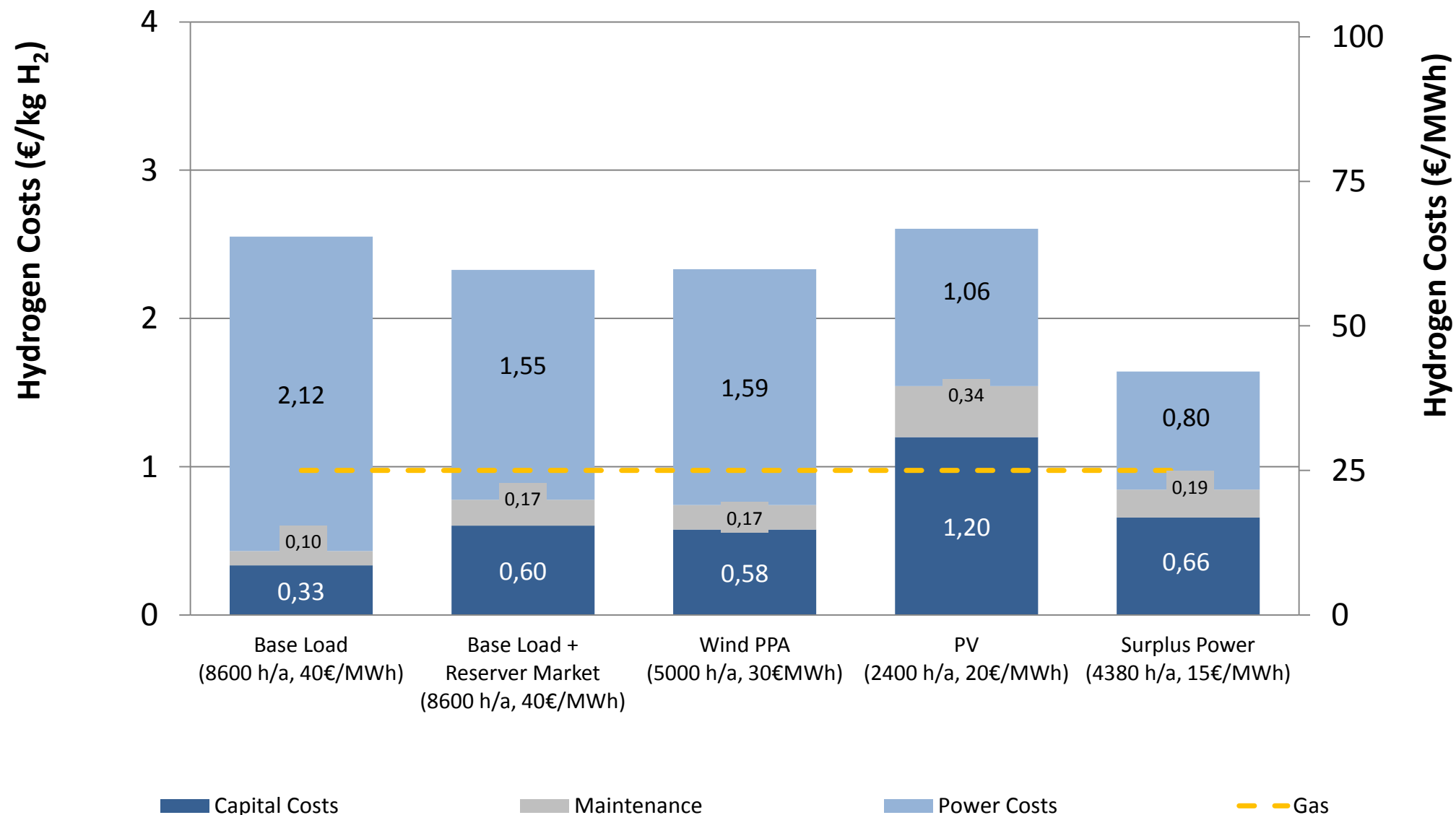
adamo.screnci@thyssenkrupp.com

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thyssenkrupp

# Today @ 200MW

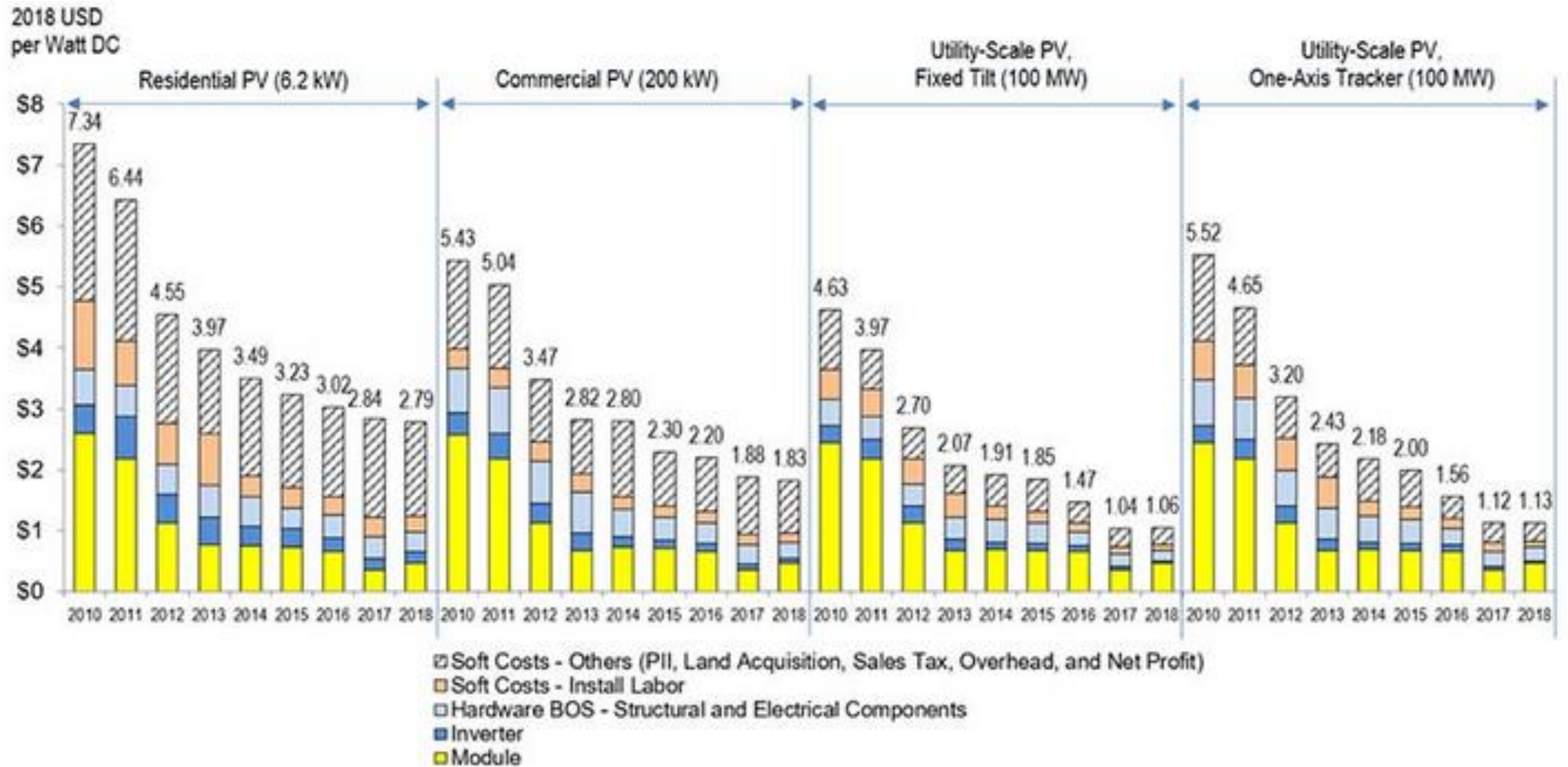


# Cable versus pipeline cost

	Cable (BritNed)	Pipeline (BBL)
Capacity	1 GW	15 GW
Construction Cost	€ 500 mln	€ 500 mln
Volume (year)	8 TWh	120 TWh



## Large scale vs small ?



Large vs small ?

## Planned 5 GW Indian solar plant will be 'the world's largest'

Known as the “roof of the world,” the scenic Ladakh region of the Indian state of Jammu and Kashmir could soon host the world's largest single-location PV plant.

JANUARY 14, 2019 **UMA GUPTA**

### 1. Tengger Desert Solar Park – 1500MW – China



# These huge new wind turbines are a marvel. They're also the future.

The latest model has blades longer than football fields.

By David Roberts | @drvox | david@vox.com | Updated Oct 23, 2018, 12:20pm EDT

**1 single turbine = 12 MW**



The GE Haliade-X, a big-ass wind turbine. | GE



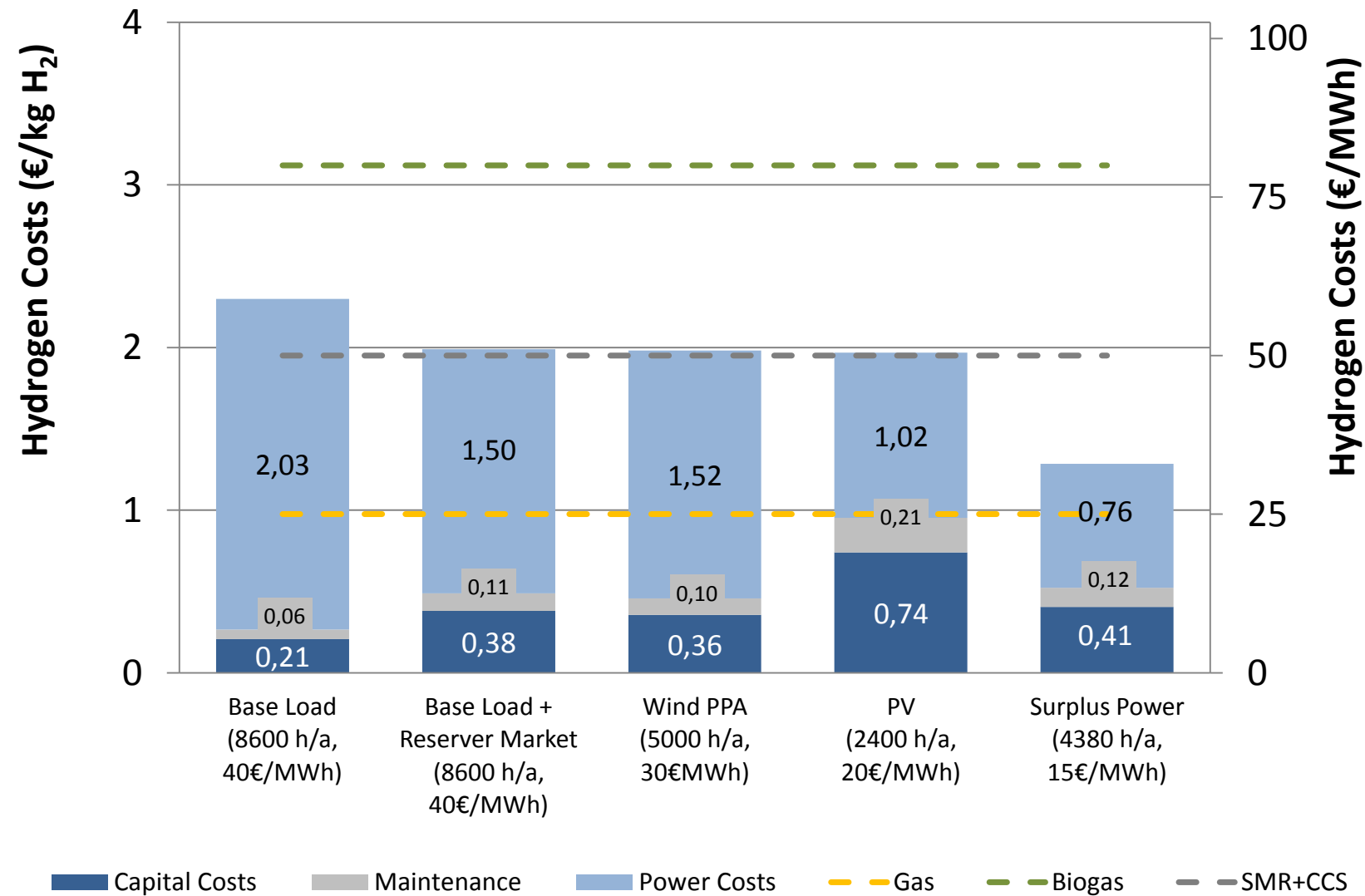


## Mass production vs Economy of scale

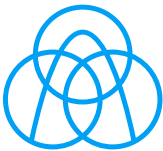


Figure 7. Comparison of a mining truck with a conventional pick-up truck to illustrate even mass production cannot beat economies of scale

2020 @ scale >500 MW



To ensure excellent support on a global scale  
thyssenkrupp Industrial Solutions and Industrie De Nora joined forces



thyssenkrupp

thyssenkrupp  
Industrial Solutions

66%

thyssenkrupp Uhde Chlorine Engineers

Technology, Plant Business (EPC), Services

Support:  
Engineering, Procurement,  
Construction, Financing,  
etc.



Industrie De Nora

34%

Supplies:  
Coating and cell  
manufacture





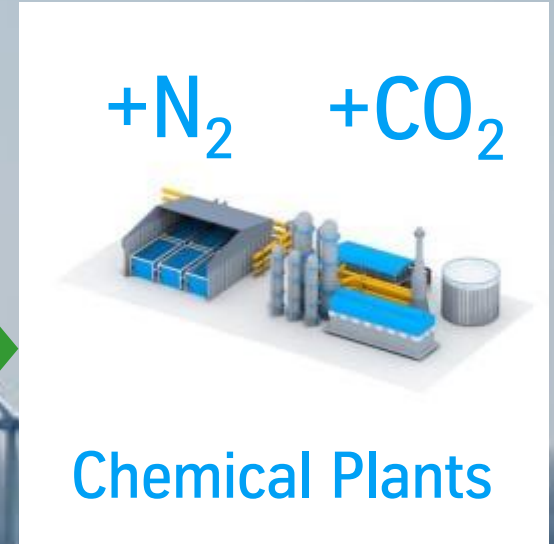
# Conversion of „green“ electrons into „green“ molecules



Green  
electrons



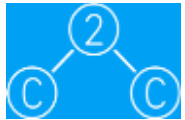
Green H<sub>2</sub>



Green Molecules: Hydrogen, Ammonia, Methanol, Methane



# We have the key technologies under one umbrella



Carbon Capture  
Gas Separation



“Green”  
Ammonia  
& Methanol



Green hydrogen  
from  
renewable energy  
and  
advanced alkaline  
water electrolysis



Synthetic  
Methane from  
H<sub>2</sub> and CO<sub>2</sub>



## Our experience and capabilities: large EP/EPC plants

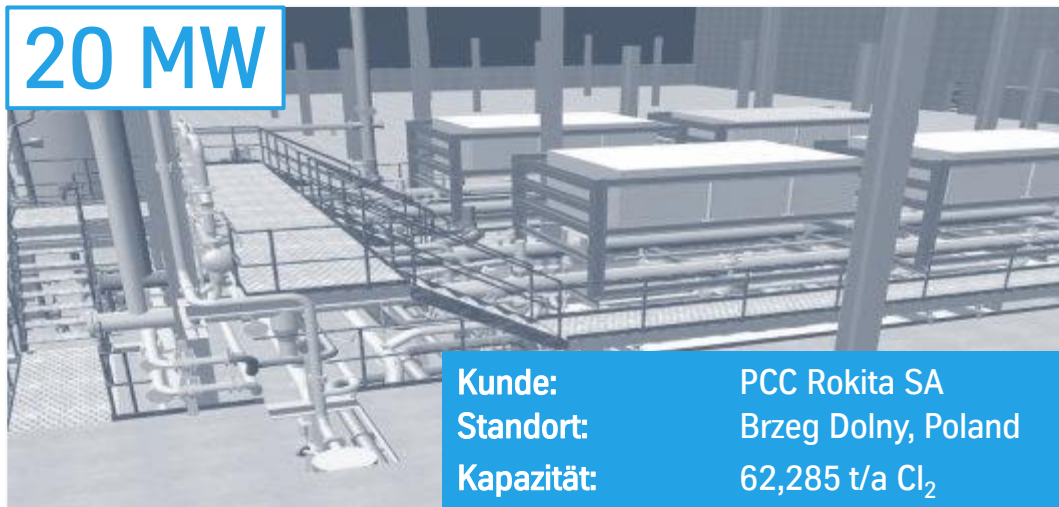
120 MW



100 MW



20 MW



80 MW

