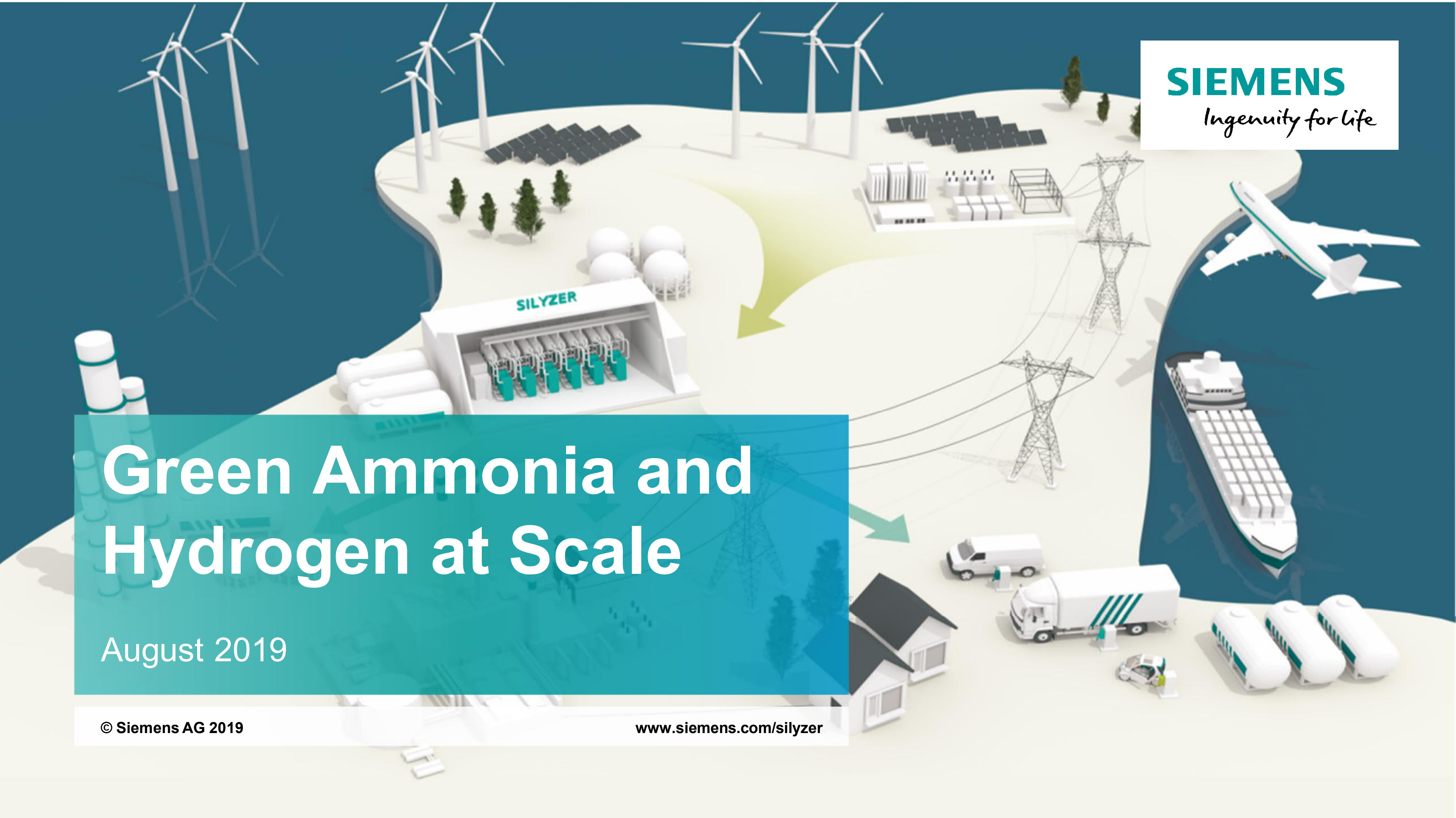

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Green Ammonia and Hydrogen at Scale

August 2019

www.siemens.com/silyzer

Green Ammonia – Key Messages

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- One of the attractions of ammonia as an (hydrogen) energy vector is that it **can be deployed at scale**.
- The technology required to do this exists at a **high readiness level**.
- One of the key technical challenges is designing a synthesis plant that can cope with the **intermittency** of renewable power.
- Siemens has built an **energy storage demonstration system**, based on Green Ammonia, to explore the possibility of using ammonia as an energy vector.

Siemens has built a Green Ammonia energy storage demonstration system in the UK

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- Constructed at the Rutherford Appleton Laboratory, near Oxford, UK.
- Project 50% supported by Innovate UK.

- Objective: to evaluate an all-electric synthesis and energy storage demonstration system based on Green Ammonia.

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CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Science & Technology Facilities Council

The system demonstrates the complete cycle of renewable power, storage as ammonia, and conversion back to electricity

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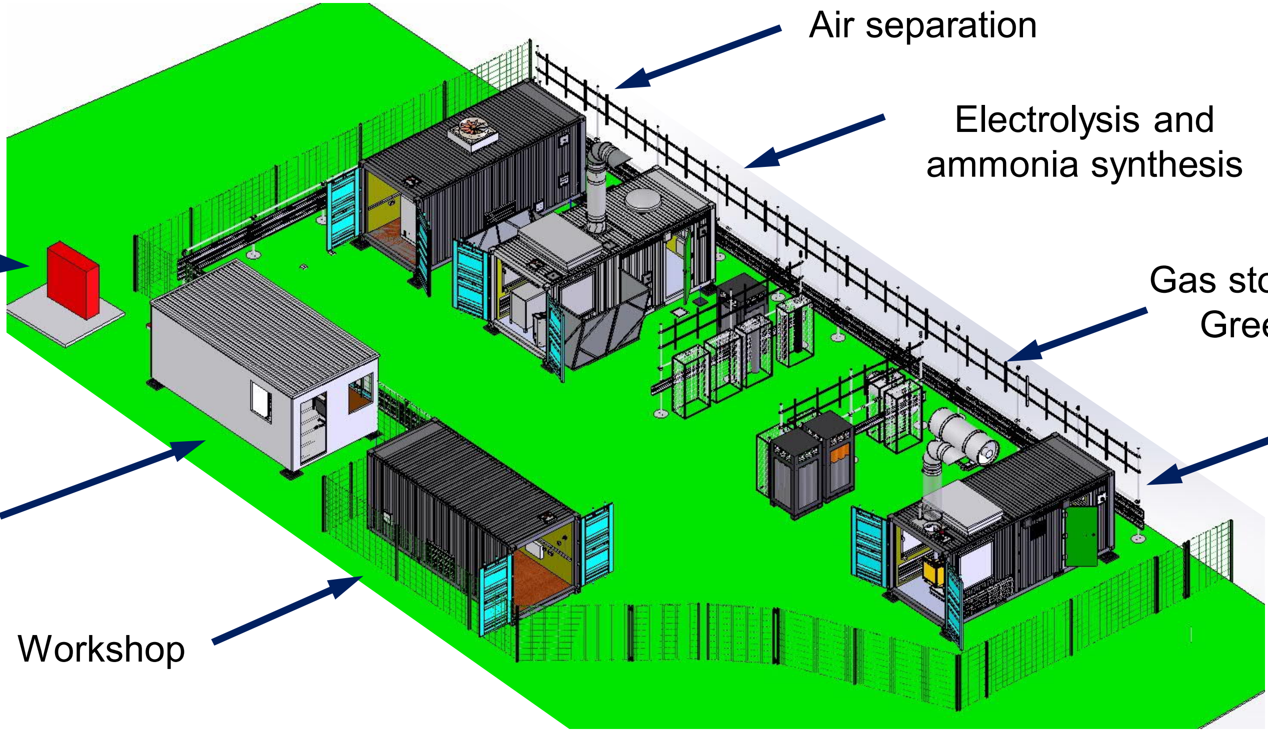

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The main components of the Green Ammonia Energy Storage System demonstrator

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Wind Turbine

Air Separation Unit

Electrolyser

Ammonia Synthesis Reactor

Ammonia-fuelled Generator Set

Siemens Green Ammonia Demonstrator – vital statistics

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- 20kW wind turbine.
- 13kW Electrolyser, producing approx. 2.4 Nm^3/hr H_2.
- 7kW ASU (pressure-swing absorption) producing 9 Nm^3/hr N_2.
- 30kg / day Haber-Bosch synthesis capacity for NH_3 (output limited by H_2 production capacity).
- 350kg on-site NH_3 storage.
- 30kW_e Generator set (reciprocating spark-ignition engine) running on ammonia.
- Siemens PCS7 Control system for unattended operation.

Demonstrator Test Site

UK Demonstrator Test Site

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UK Demonstrator Test Site

Intermittency of renewable power is an additional design requirement on ammonia production plant designers

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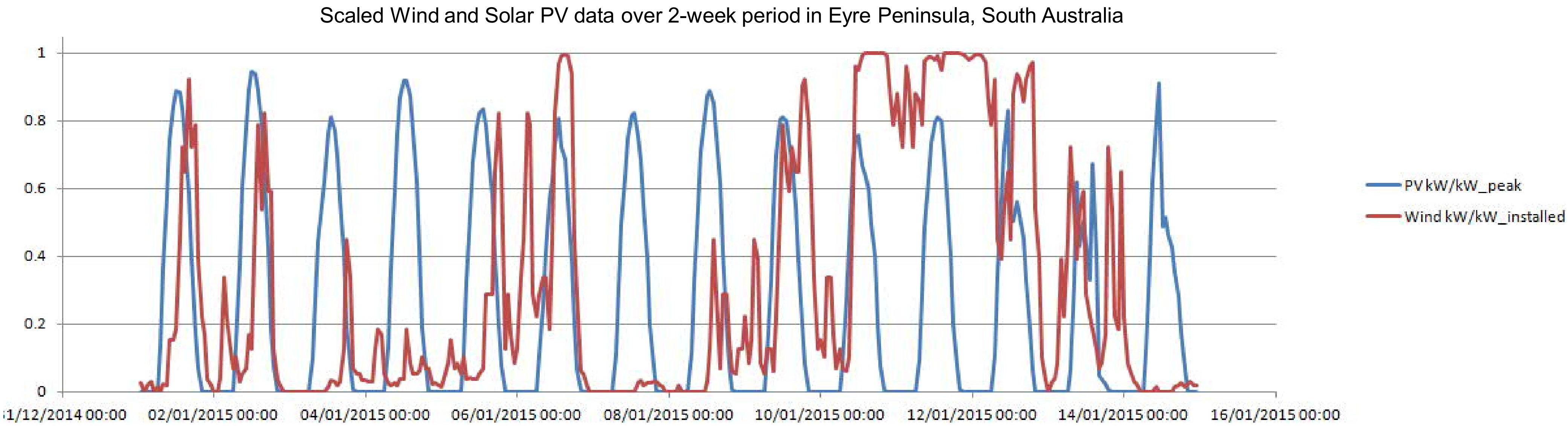

Instructive plant sizes to consider (annual NH3 output and nameplate power requirement)

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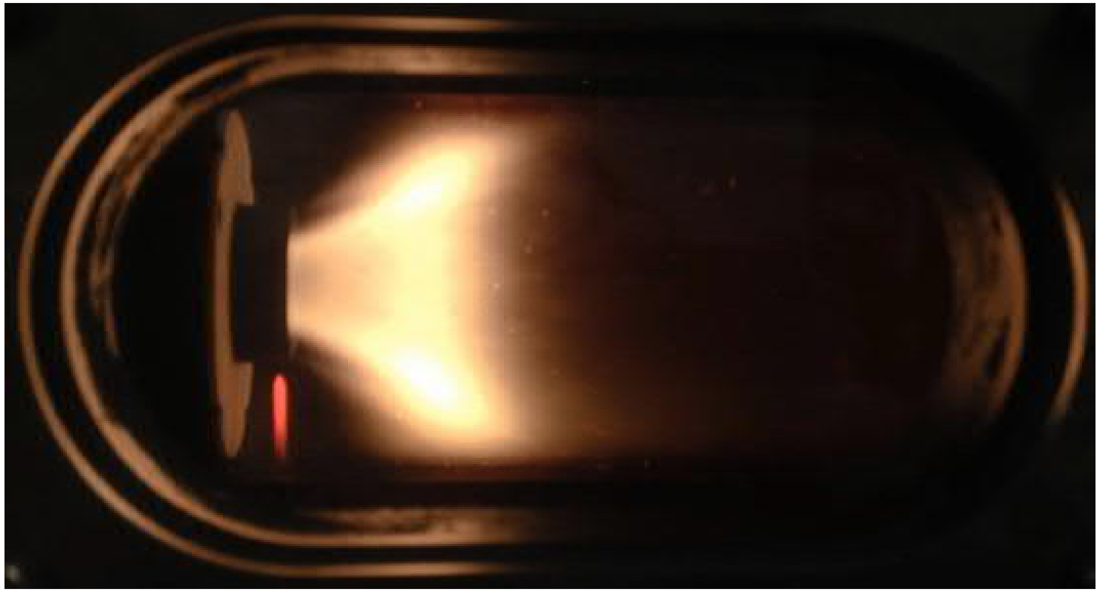
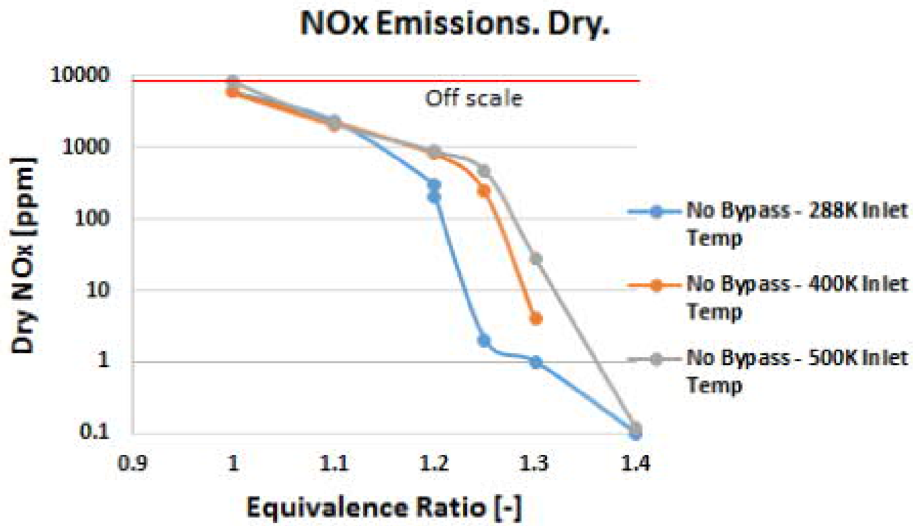
- 40 ktpa – “small scale”, requires 100 – 150 MW renewable power.
- 150 ktpa – “distributed production”, requires 400 – 500 MW renewable power.
- 800 ktpa - “world scale” requires, 2 – 2.5 GW renewable power.
- Note – round trip efficiencies of ammonia energy storage are in the region of 30-40% (dominated by combustion efficiencies). Combining this with “typical” capacity factors gives an order of magnitude indication of the energy stored.

Combustion studies at Cardiff University show stable flames with NH_3 / H_2 blends, and reducing NO_x emissions at high equivalence ratios.



70%$_{vol}$ NH3, 30%$_{vol}$ H2



NO_x comparison between cases at different inlet temperature.

With thanks to Dr. Agustin Valera-Medina, Cardiff University, for providing these results.

Hydrogen Electrolysis at Scale – Key Messages

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- Double-digit Megawatt scale water electrolysis technology to produce hydrogen **is available today**.

- Increasingly larger scale deployments are required to build **skills, capability and capacity** in the industry and **reduce costs**.

- Siemens are in the preliminary stages of planning for **triple-digit Megawatt electrolysers**, in support of GW scale projects currently being developed.

Proton exchange membrane (PEM) electrolysis – the efficient way for green hydrogen

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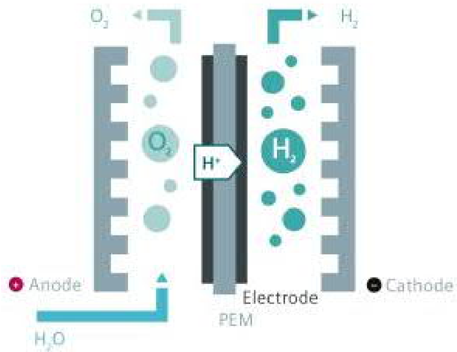
How does PEM electrolysis work

- Electrodes are attached on both sides of the proton exchange membrane
- Proton exchange membrane is the electrolyte
- Proton exchange membrane acts as separator to prevent mixing of the gas products



1973

J. H. Russell released his works to PEM electrolysis and the high potential

Advantages of PEM electrolysis

- High power density
- Extended dynamic operation range and direct coupling to renewables (rapid response)
- High efficiency
- High gas purities
- Low maintenance needs

Silyzer 200
High-pressure efficiency in the megawatt range

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5 MW

World's largest operating PEM electrolyzer system in Hamburg, Germany

60 kWh

Specific energy consumption for 1 kg hydrogen

20 kg

Hydrogen production per hour

1.25 MW

Rated stack capacity

South Australia – Australian Gas Infrastructure Group
Largest PEM electrolyser in Australia

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1.25 MW

rated power based on Silyzer 200

Facts & figures

- Customer: AGIG
- Country: Australia
- Installed: under delivery
- Product: Silyzer 200

Use cases

Green hydrogen is fed into the local gas network.

Future plans to add refueling capability.

Challenge

- Installation and integration into the local gas network
- Remote control of electrolyser to integrate with local microgrid and solar power generation
- Potential for future addition of refueling facility and/or tube trailer

Solutions

- Operation of a SILYZER 200
- Highly dynamic power consumption
- State-of-the-art process control technology based on SIMATIC PCS 7

Silyzer 200 –
high-pressure efficiency in the megawatt range

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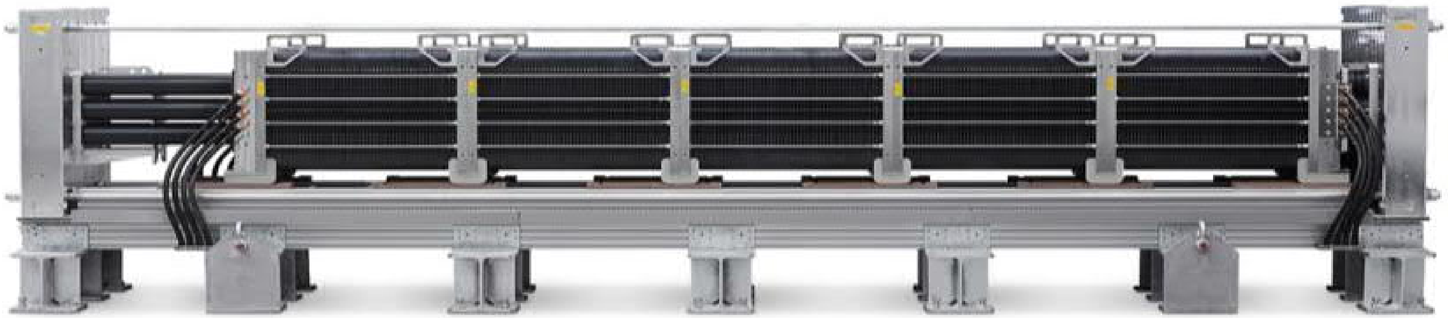

Main technical data			
Electrolysis type / principle	PEM	Rated H_2 production	20 kg/ h
Rated Stack Power	1.25 MW	Overall Efficiency (system)	60 – 65 %
Dimension Skid	6.3 x 3.1 x 3.0 m	Design Life Time	> 80,000 h
Start up time (from cold stand-by)	< 10 sec	Weight per Skid	17 t
Output pressure	Up to 35 bar	CE-Conformity	yes
Purity H_2 (depending on operation)	99.5% - 99.9%	Tap Water Requirement	340 l/ h
H_2 Quality 5.0	DeOxo/Dryer option		

Silyzer 300 –
the next paradigm in PEM electrolysis

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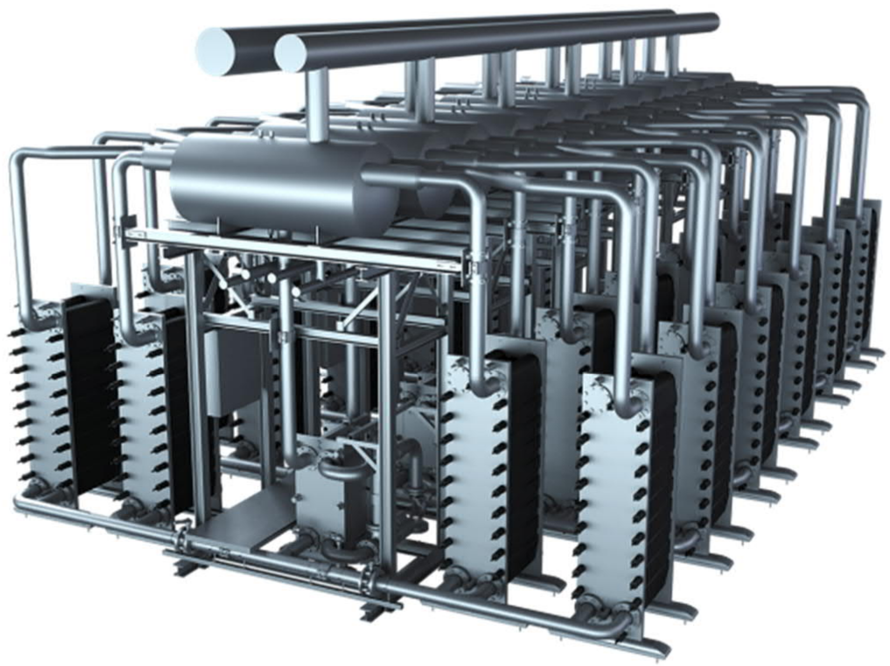
17.5 MW	per full Module Array (24 modules)
75 %	System efficiency (higher heating value)
24 modules	to build a full Module Array
340 kg	hydrogen per hour per full Module Array (24 modules)



Silyzer 300 – Module Array (24 modules)

Silyzer 300
Fact Sheet

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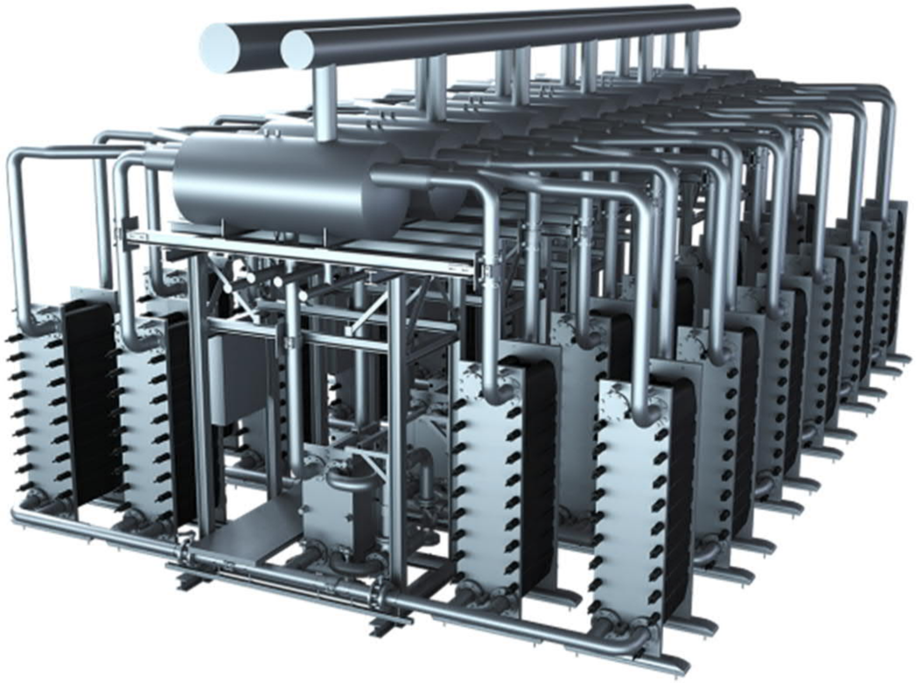
Hydrogen production	100-2,000kg/h
Plant efficiency (HHV[1])	> 75 %
Start up time	<1min, enabled for PFRS[2]
Dynamics in range	10%/s in 0-100%
Minimal load	20 % single module
Nominal plant footprint	70MW/1,300kg/h H_2: 70x25m
System lifetime	> 20 a (Module ≈ 10 a)
Plant availability	~ 95 %
Demin water consumption	10 l/kg H_2
Dry gas quality[3]	> 99.9 H_2; > 99,5 O_2
Delivery pressure	customized



1) Plant efficiency includes rectifier, transformer, transformer cooling and gas cooling 2) Primary Frequency Response Service
3) w/o DeOxo

Silyzer portfolio scales up by factor 10 every 4-5 years driven by market demand and co-developed with our customers

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Silyzer portfolio roadmap

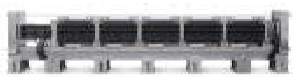
0,1 MW → 1 MW → 10 MW → 100 MW → 1000 MW

2011

Silyzer 100
Lab-scale demo
~4.500 op.h[1]
~150k Nm³ of H_2

2015

Silyzer 200
~43.000 op.h
~6.0 mio Nm³ of H_2



World's largest Power-to-Gas plants with PEM electrolyzers in 2015 and 2017 built by Siemens!

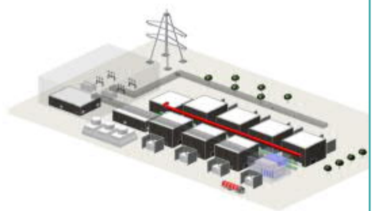
2018

Silyzer 300

Biggest PEM cell in the world built by Siemens!

2023+

Next generation
Under development



2030+

First investigations in cooperation with chemical industry

1) op.h.: operating hours

Contact page

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