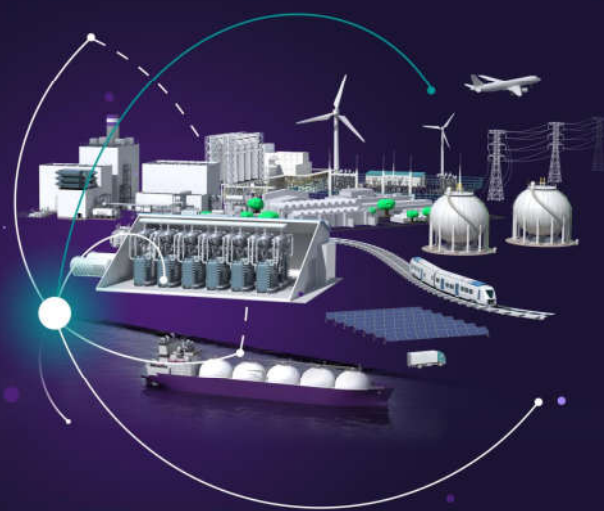


Vodik od proizvodnje do primjene

Saša Medved
Marko Babić

Listopad 2022.



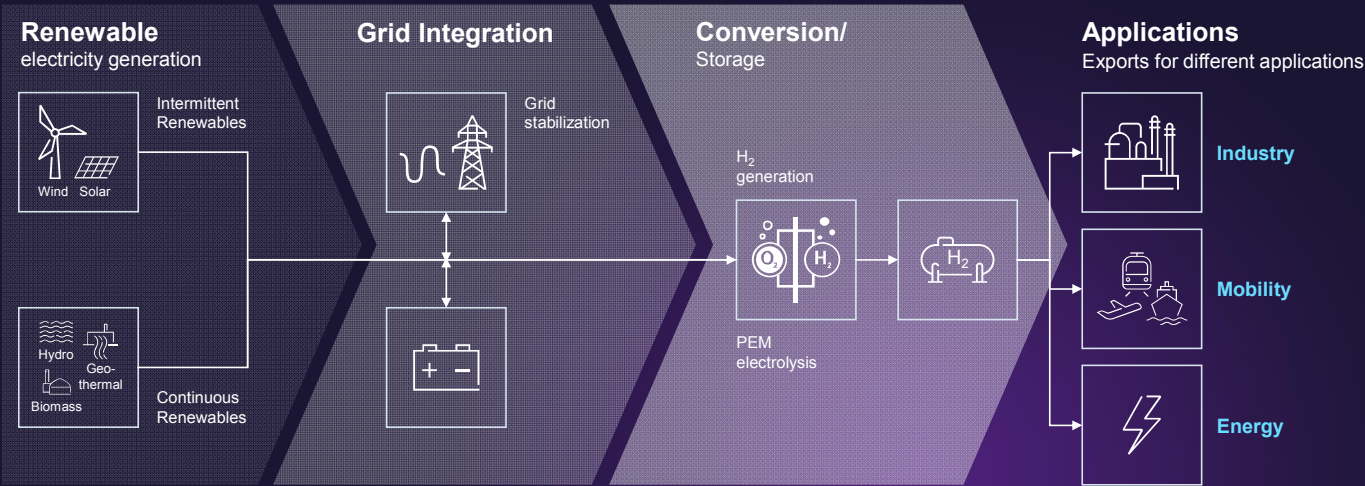
There are different ways to produce hydrogen



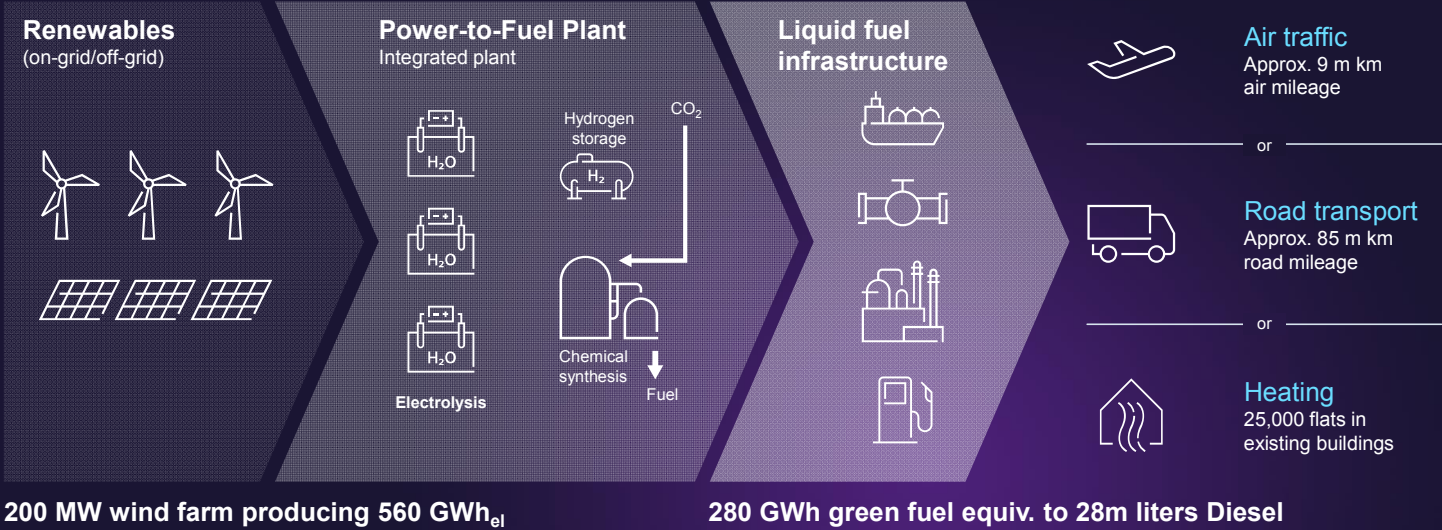
Colors	Overview	Country examples
 Grey/black Hydrogen: Produced from fossil hydrocarbons with CO ₂ emissions (traditional business)	98% of today's production at 1.5 – 2.5 \$/kg	All countries, which need hydrogen (US as largest grey hydrogen country)
 Blue Hydrogen: Produced from fossil hydrocarbons with CCS ¹	Low-carbon hydrogen. Can be a transitional technology, as still cheaper than green hydrogen	UK, Norway with gas resources, decarbonization ambitions and societal acceptance for CCS
 Turquoise² Hydrogen: Produced from methane via pyrolysis with pure carbon remaining	Technology not yet mature. Future solutions for gas production companies	Countries with abundant gas resources – not yet relevant
 Red³ Hydrogen: Produced from nuclear energy through electrolysis	Partly limited social acceptance. Potential for existing NPPs, but too expensive in the long term for new builds	Countries with excess nuclear power
 Green Hydrogen: Produced from renewable energy through electrolysis	Large RES requirement, higher price (2 – 6 \$/kg, but significant cost reduction potential), water source required	Chile, Morocco, ME, Australia with high renewables potentials EU to decarbonize energy system

¹ CCS: Carbon Capture and Storage | ² Sometimes also referred as "cyan" hydrogen | ³ Sometimes also referred as "purple", "pink" or "yellow" hydrogen

Hydrogen from renewables enables large scale, long term storage and sector coupling



Power-to-Fuel plants as missing link for electricity based fuels and utilization of existing liquid fuel infrastructure



Numbers per annum derived from own assumptions

Hydrogen is multi-functional and applications can be combined tailored to customer demands





Energy



Add-on





Mobility



Industry

Electrolysis of water is the separation of water into oxygen and hydrogen gas with an electric current



1800

William Nicholson and Anthony Carlisle discovered electrolysis, the separation of water into hydrogen and oxygen by direct current and established a new field in chemistry: The electrochemistry.

1888

A method of industrial synthesis of hydrogen and oxygen through electrolysis was developed by Dmitry Lachinov.

What is electrolysis?

- A DC electrical power source is connected to two electrodes which are placed in the water
- An **electrolyte** allows the charge exchange and is the **namesake** of the various technologies
- **Hydrogen** will appear at the cathode, **Oxygen** at the anode
- The **production rate** is **proportional to the total electrical charge**

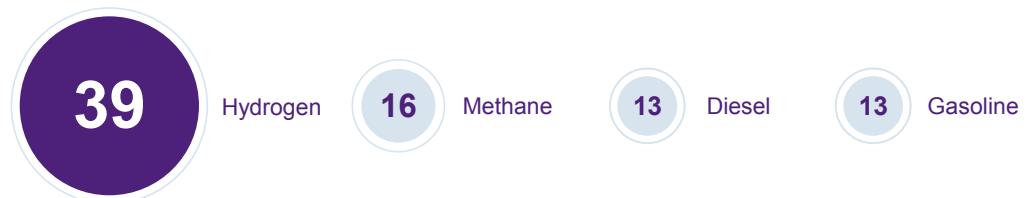


Current + $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 2\text{H}_2$

Facts and figures

- 1 **kg** hydrogen needs stoichiometrically **9 liters water**
- The **energy content** of 1 **kg** hydrogen amounts for **39.4 kWh**

Upper heating value in kWh/kg¹

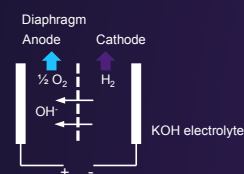


¹ http://www.linde-gas.at/internet.lg.lg.aut/de/images/1007_rechnen_sie_mit_wasserstoff_v110550_169419.pdf

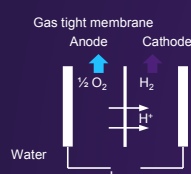
There are three considerable technologies of water electrolysis

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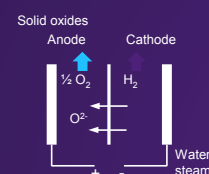
Alkaline Electrolysis



PEM Electrolysis



High temperature



	Alkaline Electrolysis	PEM Electrolysis	High temperature
Electrolyte	KOH ³	Polymer membrane	Ceramic membrane
Circulated medium	KOH ³	Water	Steam
Operational temperature ¹	60 – 90 °C	RT ⁴ – 80 °C	700 – 900 °C
Technical maturity ¹	Industrially mature	Industrially mature	Lab/demo
Field experience ¹	●	●	●
Cold start capability ²	●	●	●
Intermittent operation ²	●	●	●
Scalability up to multi Giga Watt ²	●	●	●
Reverse (fuel cell) mode ¹	●	●	●

● Existing/available ● In development/limited ● Not possible, not available
Source: 1 Fraunhofer | 2 IndWede | 3 KOH: Potassium hydroxide | 4 Room temperature

The Silyzer 300 offers a simple process technology with natural circulation



Zero

pumps only one heat exchanger
simple water refilling

Zero

hydrogen loss during
stand-by mode

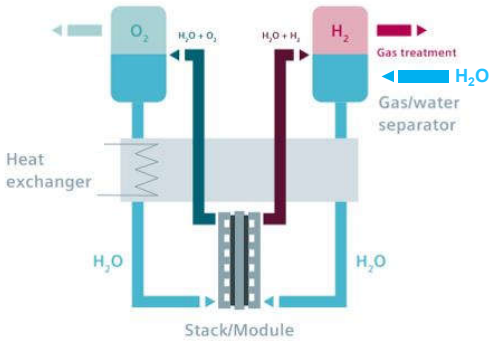
Zero

pressurized vessel

Zero

nitrogen consumption during
operation

Several advantages due to the Silyzer 300 process technology:



Siemens Energy DNA

- + Robust design for industrial-grade application
- + Producing our own Membrane Electrode Assembly (MEA)
- + Both membrane sides cooled

Proton exchange membrane (PEM) electrolysis

The efficient way for green hydrogen

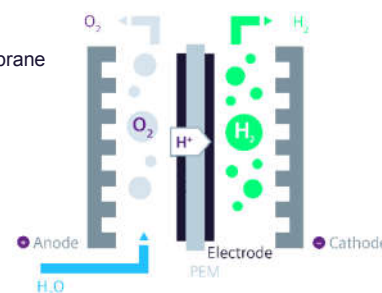
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1973

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

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



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

Focus on Proton Exchange Membrane (PEM) electrolyzer system technology



Operational performance



- **Fast start-up** and shut-down
- Highest **operational flexibility**
- **Cold start capability**

Clean by nature



- Highest **hydrogen purity >99.9%**
- **No aggressive chemical electrolyte**
- **No contaminants** – only water, hydrogen and oxygen in the system

Competitiveness



- **Small footprint** compared to alkaline systems
- **Lower OPEX** compared to alkaline systems due to maintenance free stack
- **Competitive hydrogen price** per kg at green electricity prices below 3 ct/kWh

Technology expertise in Electrolysis
Our electrolyzer portfolio scales up by factor 10 every 4 – 5 years



0.1 MW

1 MW

10 MW

100 MW

1,000 MW

2011

Silyzer 100
Lab-scale demo

2015

Silyzer 200



2018

Silyzer 300



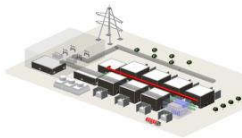
2023+

Silyzer 300 plant



2028+

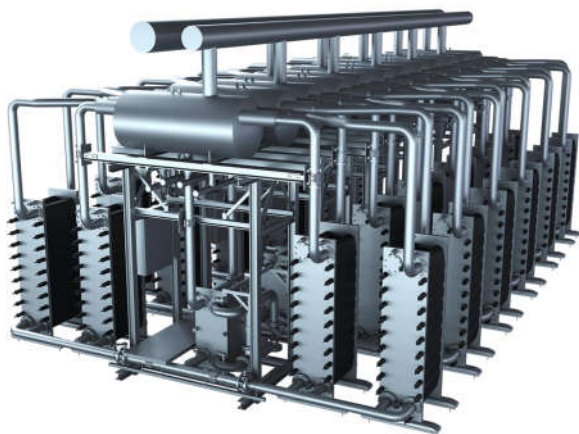
Co-Development with
partners in verticals



Silyzer 300 – Full Module Array

The next paradigm in PEM electrolysis

Silyzer 300 – full module array (24 modules)



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17.5 MW

plant power demand

>75.5 %

plant efficiency

24 modules

to build a full module
array

335 kg

hydrogen per hour

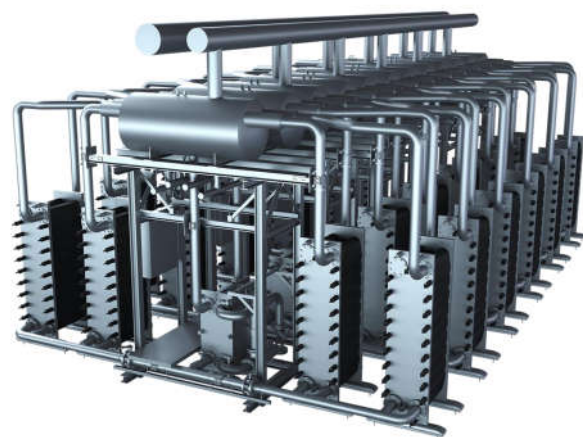
Silyzer 300 Fact Sheet

	Hydrogen production	335 kg/h
	Plant efficiency (HHV¹)	>75.5%
	Power demand	17.5 MW
	Start-up time	<1 min, enabled for PFRS ²
	Dynamics in range	10%/s in 0 – 100%
	Minimal load	20% single module
	Dimension full Mod. Array	15.0 x 7.5 x 3.7 m
	Module design lifetime	Optimized for 80 kOH ⁴
	Plant availability	~95%
	Demin water consumption	10 l/kg H ₂
	Dry gas quality³	99.9999%
	Delivery pressure	Customized

¹ Plant efficiency includes rectifier, transformer, transformer cooling and gas cooling
² Primary Frequency Response Service | ³ With DeOxo | ⁴ Operating Hours

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New Energy Business 13
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Silyzer 300

Fact Sheet

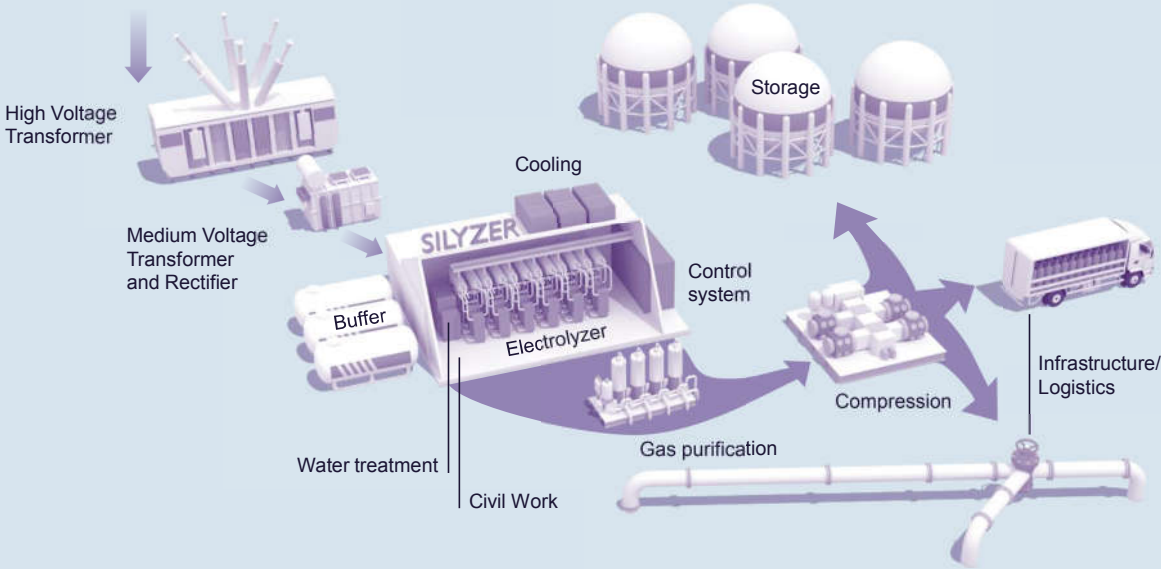


Main technical data

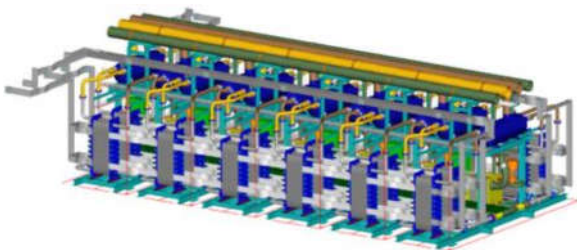
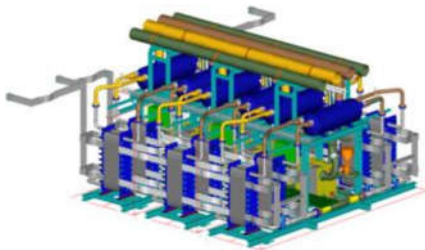
Electrolysis type/principle	PEM	Rated H ₂ production	335 kg/h
Rated Silyzer 300 power	17.5 MW	System efficiency	>76%
Dimension full array	15.0 x 7.5 x 3.7 m	Plant efficiency Silyzer 300	>75.5%
Start-up time until full load	<1 min, enabled for grid support	Module design lifetime	Optimized for 80 kOH ^{1,4}
Output pressure	100 mbar	Module weight	2.1 t (water included)
Purity H ₂	Up to 99.9999%	CE conformity	Yes
H ₂ quality 5.0 ²	DeOxo/Dryer option	Rated tap ³ water requirement	4,700 l/h

All values calculated for ISO conditions: T_{amb} = 15 °C, 60% rel. humidity, 1,013 bar, air cooled, new and clean, HHV (Higher Heating Value) of hydrogen= 39.45 kWh/kg
1 1 kOH = 1,000 Operating Hours | 2 99.999% purity | 3 about 600 – 1,000 µS/cm | 4 after >80 kOH operation still possible

Hydrogen generation
More than just an electrolyzer



Cost-optimized and pre-engineered solutions for Silyzer 300
Can be multiplied up to Gigawatt scale solutions



	Half Array – 12 Modules	Full Array – 24 Modules
Rated H ₂ production	167 kg/h at rated power	335 kg/h at rated power
Rated Silyzer 300 plant power ¹	8.7 MW	17.5 MW
Plant efficiency Silyzer 300 ¹	>75.5%	>75.5%
Dimension array	8.0 x 7.5 x 3.7 m	15.0 x 7.5 x 3.7 m
Output pressure	Array: 100 mbar(g); Plant: project specific	
Hazard concept	Standard industrial building, only water no additional chemicals	

¹ Power demand and efficiency calculated for the air cooled plant, new and clean, T_{amb} = 15 °C, HHV = 39.45 kWh/kg

Pre-engineered Balance of Plant packages for faster time-to-market

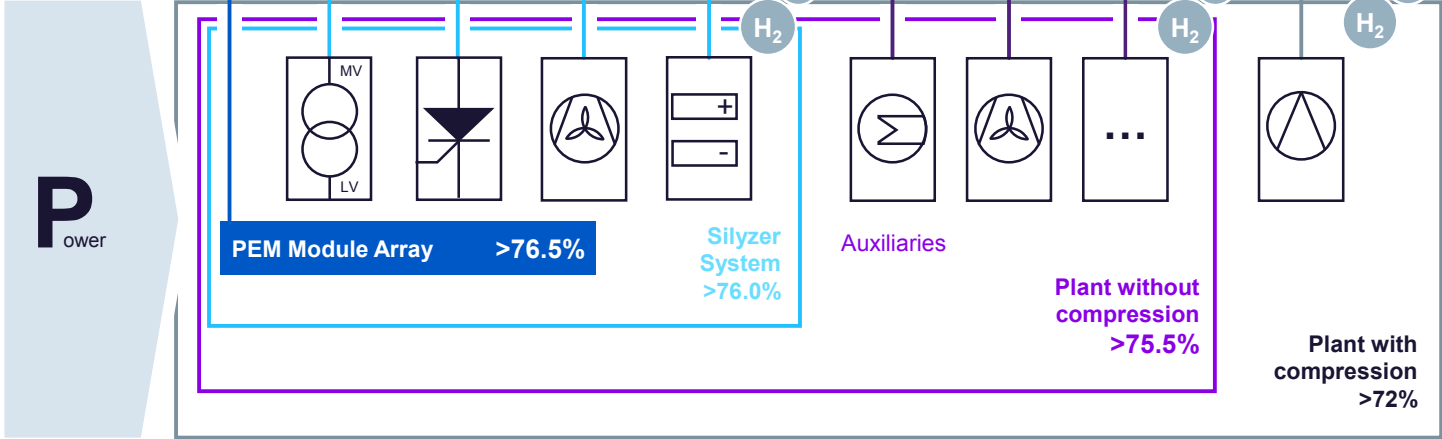
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We distinguish different efficiency levels depending on solution scope



View for 17.5 MW
24 modules:
Air cooled
ISO conditions¹



¹ ISO conditions: 15 °C, 1013 mbar, 0 m, 60% rel. hum.

Future-proof flexible hydrogen production – Silyzer 300 plant supports renewable sources and offers grid services



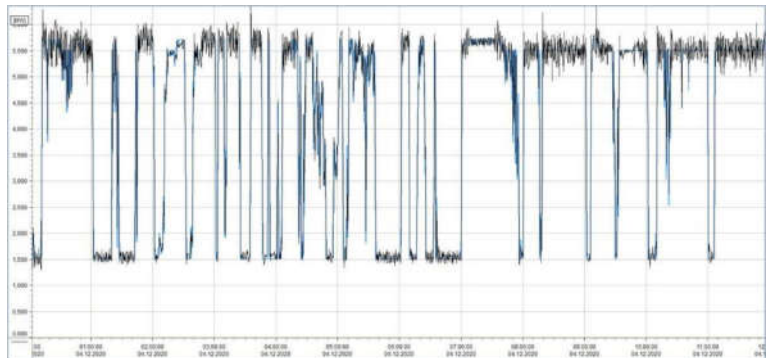
Infinitely variable plant operation

- Power controlled operation based on real power price with 15 min time frames (see example on right side)
- Dynamics: Maximal ramp rate in array 10% per second power change possible
- Always fast ramp-up

Real plant data from an exemplary electrolyzer

Target power selection

Power consumption electrolyzer



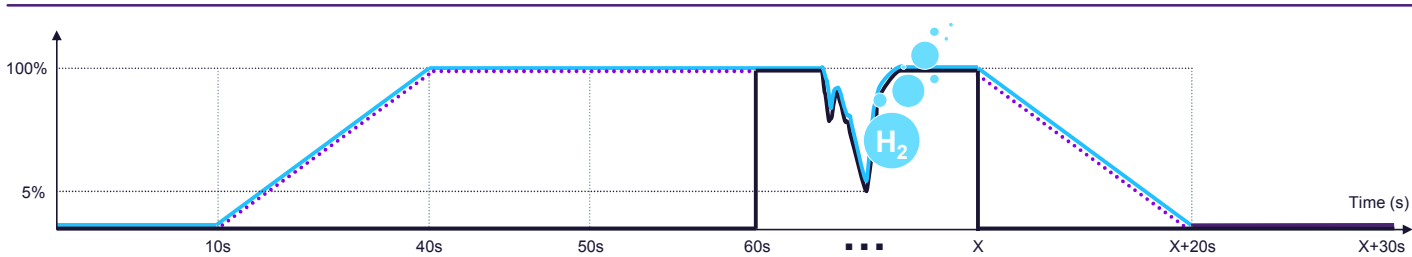
— Operating — Set point

The Silyzer 300 enables grid support services
with efficient hydrogen yield and maximum dynamics

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 Start 0 – 100% H₂ | <1 min, enabled grid support

 Dynamics in range | 10%/s in range 0 – 100%



TP = Terminal Point Rectifier load H₂ Delivery to TP H₂ Ventilation

Designed for
Future-Proof
Flexible
Hydrogen
Production



3.75 MW

Power demand/6.0 MW peak power (limited in time) based on three Silyzer 200

October 2022

ENERGIEPARK MAINZ World's largest PEM electrolysis facility in 2015

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Project

Partners: Energiepark Mainz (JV of Linde and Mainzer Stadtwerke)
Country: Germany
Location: Mainz
Installation: 2015
Product: Silyzer 200

Challenge

- Installation of world's first PEM electrolysis plant in the multiple megawatt range
- Provision of balancing energy
- High degree of automation

Use cases

-  Green hydrogen is fed into the local natural gas grid
-  Hydrogen for regional filling stations
-  Delivery to surrounding industrial companies

Solutions

- Installation of three Silyzer 200 with a maximum power consumption of 6 MW
- Highly dynamic power consumption
- State-of-the-art process control technology based on SIMATIC PCS 7
- Hydrogen processing, condensing, and storage (provided by Linde)



750,000 liters
of e-methanol per year from 2022
(130,000 liters of e-gasoline)

>55 m liters
e-fuel per year planned from 2024

>550 m liters
e-fuel per year
planned from 2026

October 2022

Supported by:



Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

HARU ONI PILOT PROJECT SIEMENS ENERGY

First integrated plant for climate-neutral e-fuel production from wind and water

Project

Customer: HIF (Highly Innovative Fuels)
Off-taker: Porsche AG
Country: Chile, Patagonia
Installation: 2021
Product: Power-to-methanol solution based on SE Electrolyzer

Challenge

- Huge wind energy potential in Magallanes
 - Existing industry and port infrastructure
- Perfect conditions to export green energy from Chile to the world

Use cases

-  E-Fuel for Porsche cars
-  Potential for adding Kerosene or Diesel production in future phases
- Methanol for ship motors

Solutions

- Production of e-gasoline and e-methanol at one of the best spots worldwide for wind energy
- Co-developer Siemens Energy realizing the system integration from wind energy to e-fuel production
- International Partners like Porsche and AME



1.25 MW

Power demand based on
Silyzer 200

228 Nm³

of green hydrogen per hour

October 2022

GREEN HYDROGEN PROJECT

The first solar-powered green hydrogen plant in the Middle East

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ENERGY

Project

Partners: DEWA and Expo2020
Country: UAE
Location: Dubai (MBR Solar Park)
Installation: 2021
Product: Silyzer 200

Use cases



Re-electrification with a 280 kW hydrogen gas engine

Challenge

- Integrated H₂ plant for multiple purposes, incl. mobility and re-electrification with the largest pure hydrogen gas motor today (280 kW)
- Installation of world's first PEM electrolysis plant in the hot and harsh conditions of the UAE
- R&D nature of the project in combination with a very tight implementation period (MoU signed Feb. 2018, commissioning May 2021, Expo since Oct 2021)

Solutions

- One Silyzer 200
- Production of green hydrogen via photo voltaic during daytime, storage of hydrogen (93 m³ @ 35 bar) and re-electrification during nighttime



6 MW
Power demand based on
Silyzer 300

1,200 Nm³
of green hydrogen per hour



H2FUTURE



FCH

October 2022

H2FUTURE

A European Flagship project for generation and use of green hydrogen

SIEMENS
ENERGY

Project

Partner: VERBUND (coordination),
voestalpine, Austrian Power
(APG), TNO, K1-MET
Grid
Country: Austria
Installed: 2019
Product: Silyzer 300

Use cases



Hydrogen for the steel making process



Supply grid services

Challenge

- Potential for “breakthrough” steelmaking technologies which replace carbon by green hydrogen as basis for further upscaling to industrial dimensions
- Installation and integration into an existing coke oven gas pipeline at the steel plant
- High electrolysis system efficiency of 80%

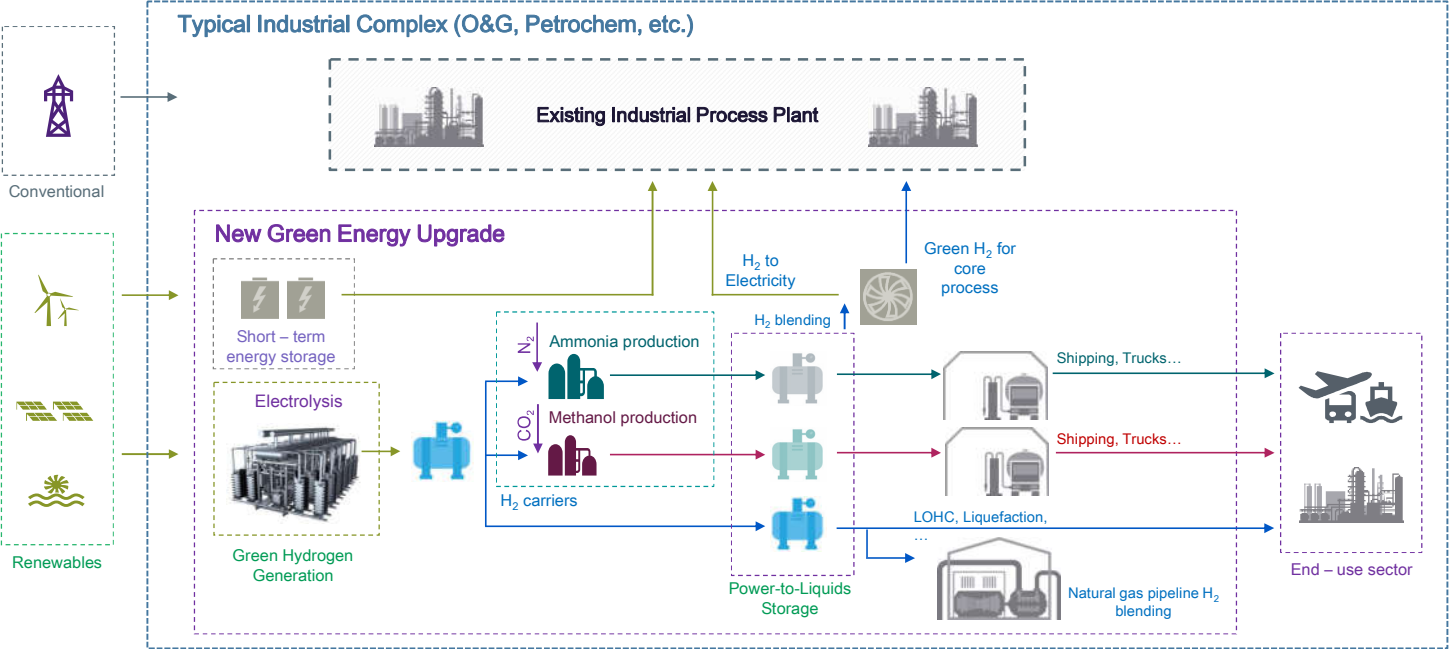
Solutions

- Operation of a 12-module array Silyzer 300
- Highly dynamic power consumption – enabling grid services
- State-of-the-art process control technology based on SIMATIC PCS 7

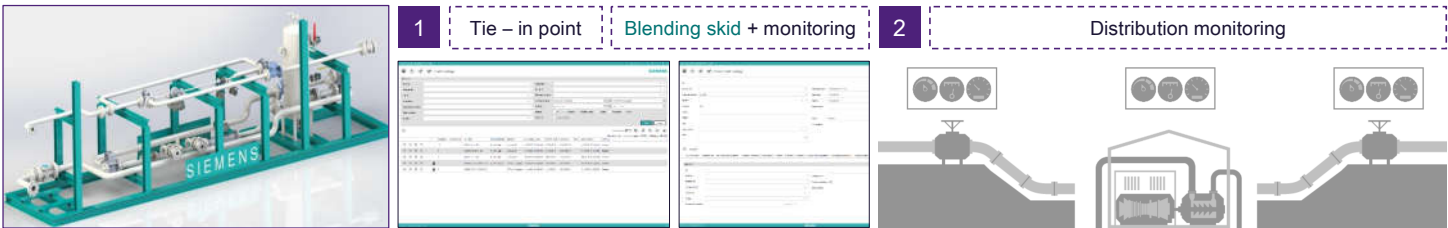
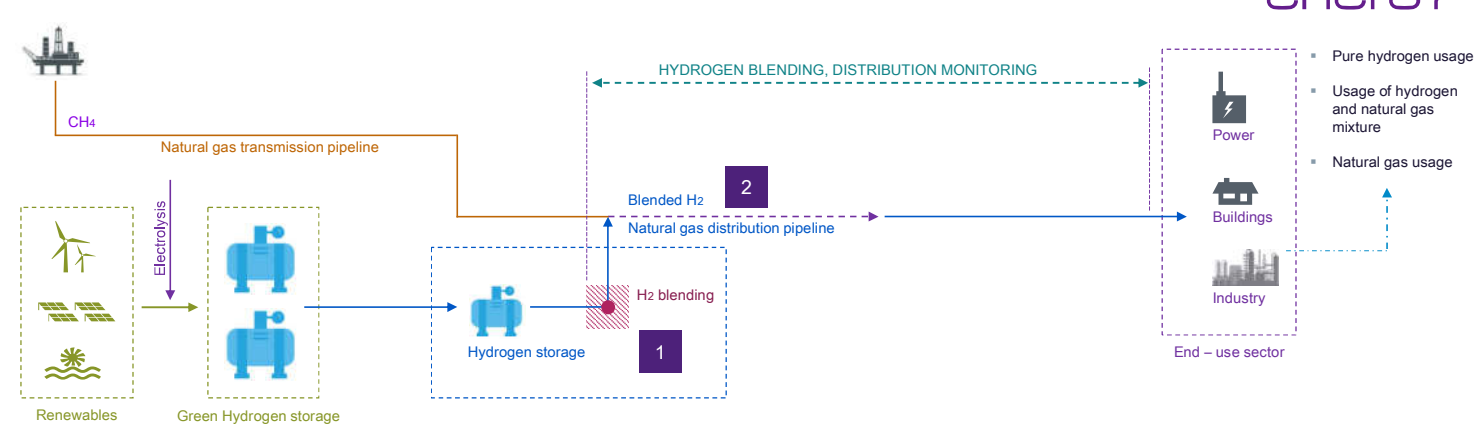


This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735503. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovative program and Hydrogen Europe and NERGHY

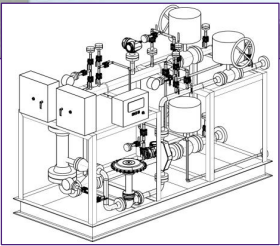
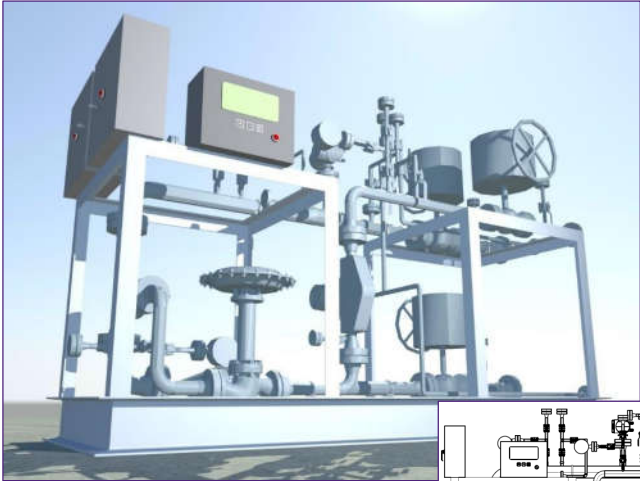
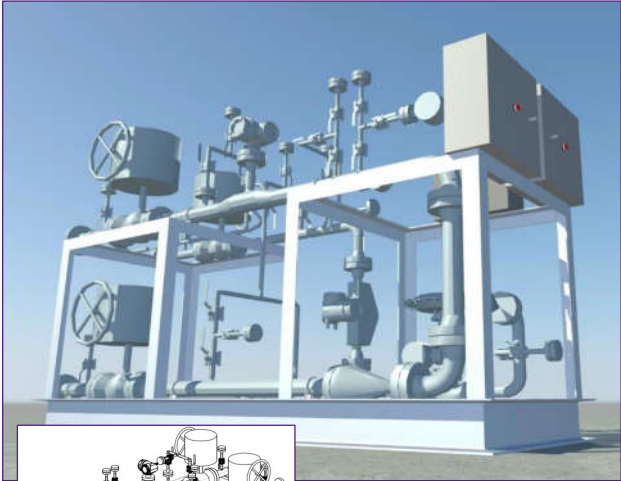
Green Hydrogen utilization in Industry



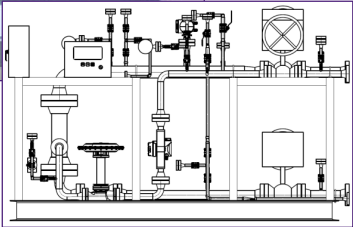
Hydrogen blending



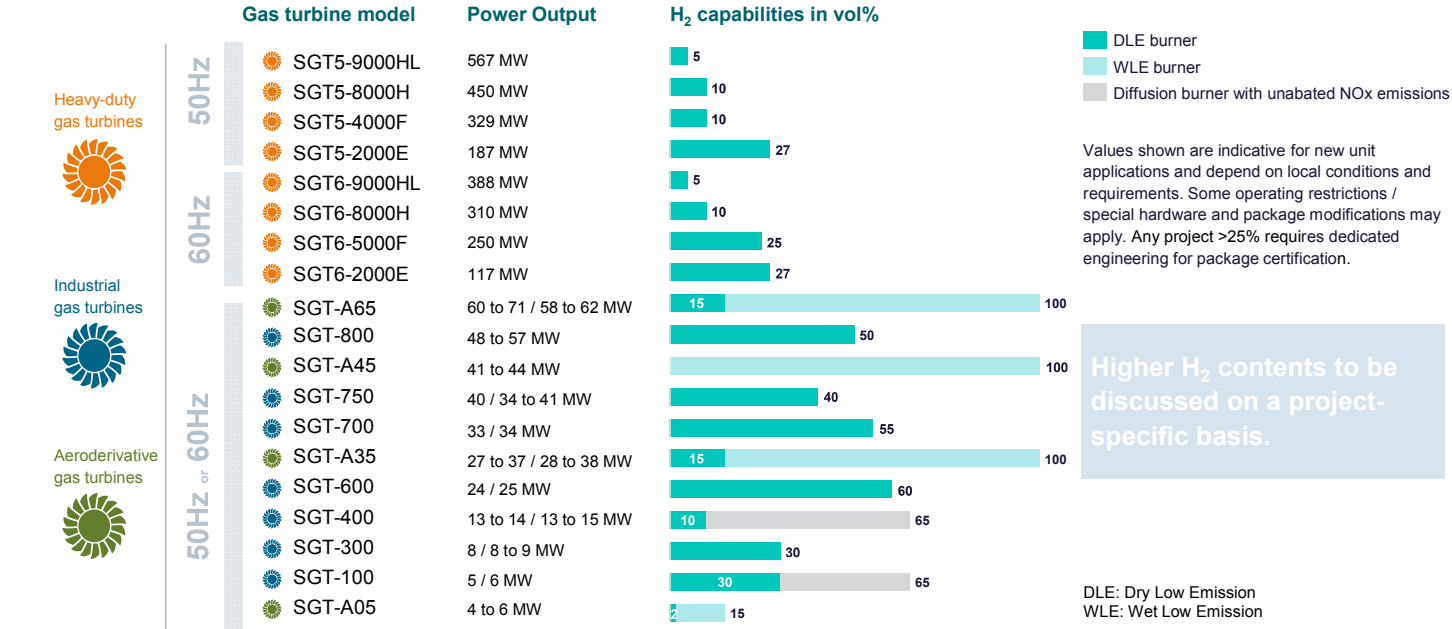
Hydrogen blending skids



- Coriolis hydrogen **flow metering – mass metering** is to be converted into volume
- Pneumatically actuated control valve and ESD valve for skid isolation
- **Mixture control** based on flow data in real time, protection function from **Analyzer**
- Static mixer & gas analyzer for outdoor installation
- Unit Control Panel (UCP)
- **Protection from natural gas back flow** to hydrogen line



Siemens Hydrogen Gas Turbines for our sustainable future – The mission is to burn 100% hydrogen



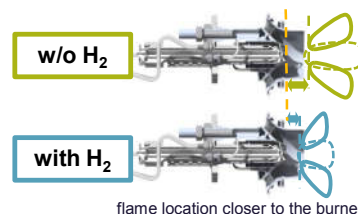
Gas turbines can burn hydrogen after implementation of some modifications in burner and combustion systems



Differences of using hydrogen and natural gas as fuel in gas turbines

Physics of burning hydrogen in a gas turbine compared to methane

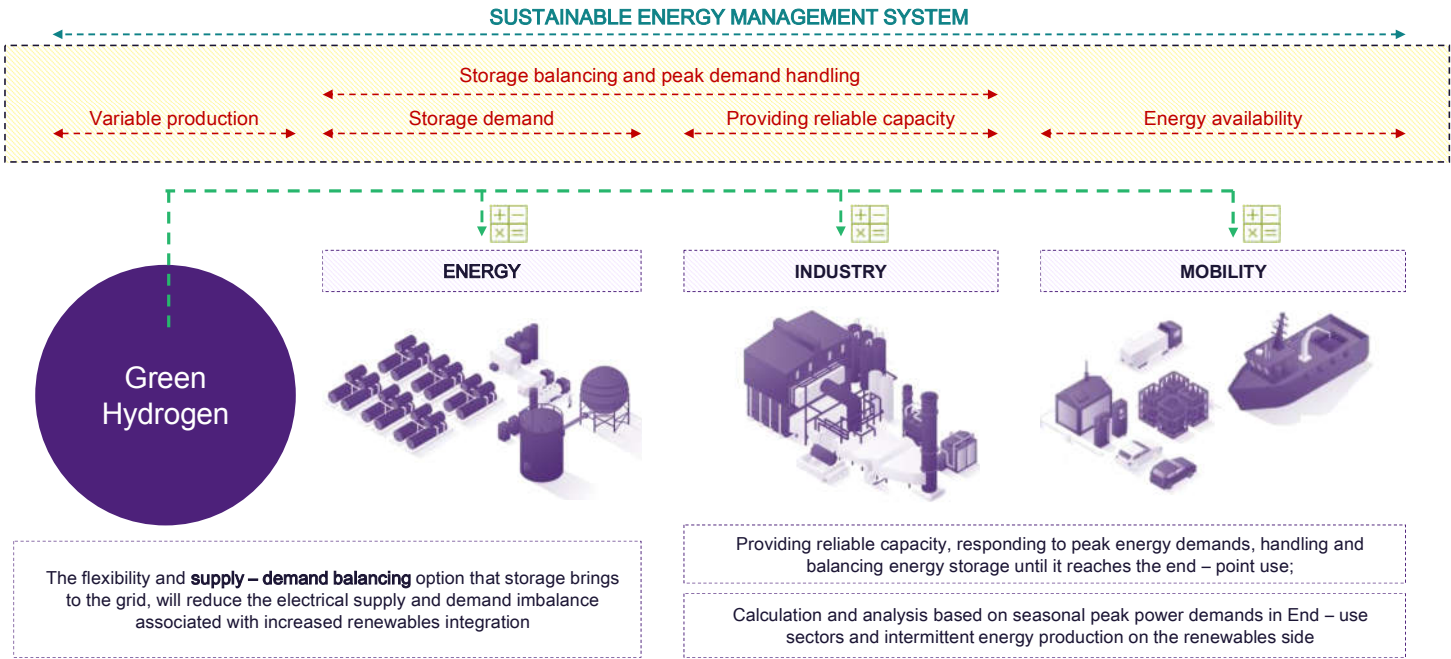
- Higher flame temperature/velocity
- Lower Wobbe index (40.6 vs. 48.5 MJ/Nm³) > larger volumes for same energy content
- Different behavior of hydrogen/air mixtures compared to gas/air
- Unstable flame for very low loads



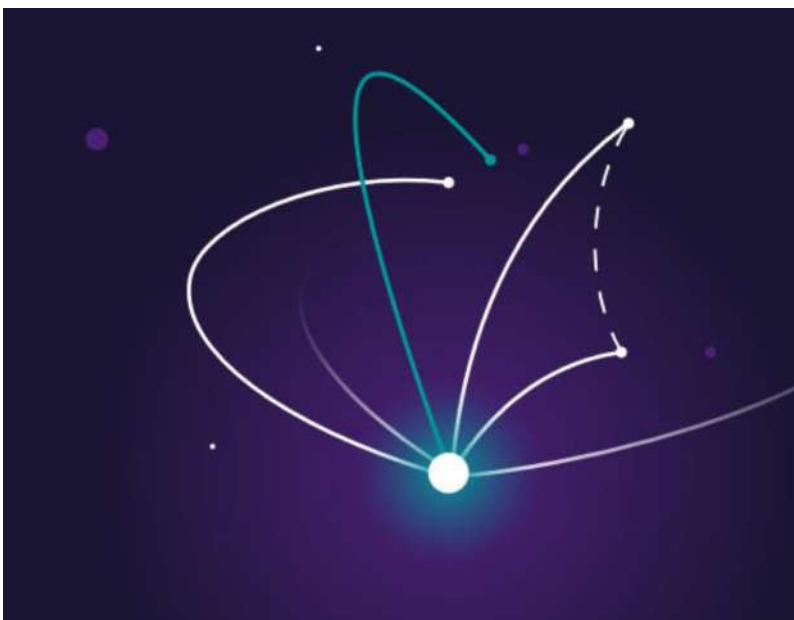
Resulting effects to be managed

- Increased creation of NOx for high amounts of H₂
- Risk of flashbacks for high amounts of H₂
- Larger fuel flows to be handled in fuel system
- Change of explosion risk characteristics
- Requirement to use a standard fuel for startup and shutdown (for 100% H₂)

Sustainable Energy Management System Managing Customer Energy mix



Contact page



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