Overview of the PEM Silyzer Family

Siemens Energy NEB
2020-09-30 GIZ Workshop

Different storage technologies for different applications – hydrogen for large-scale and long-term energy storage

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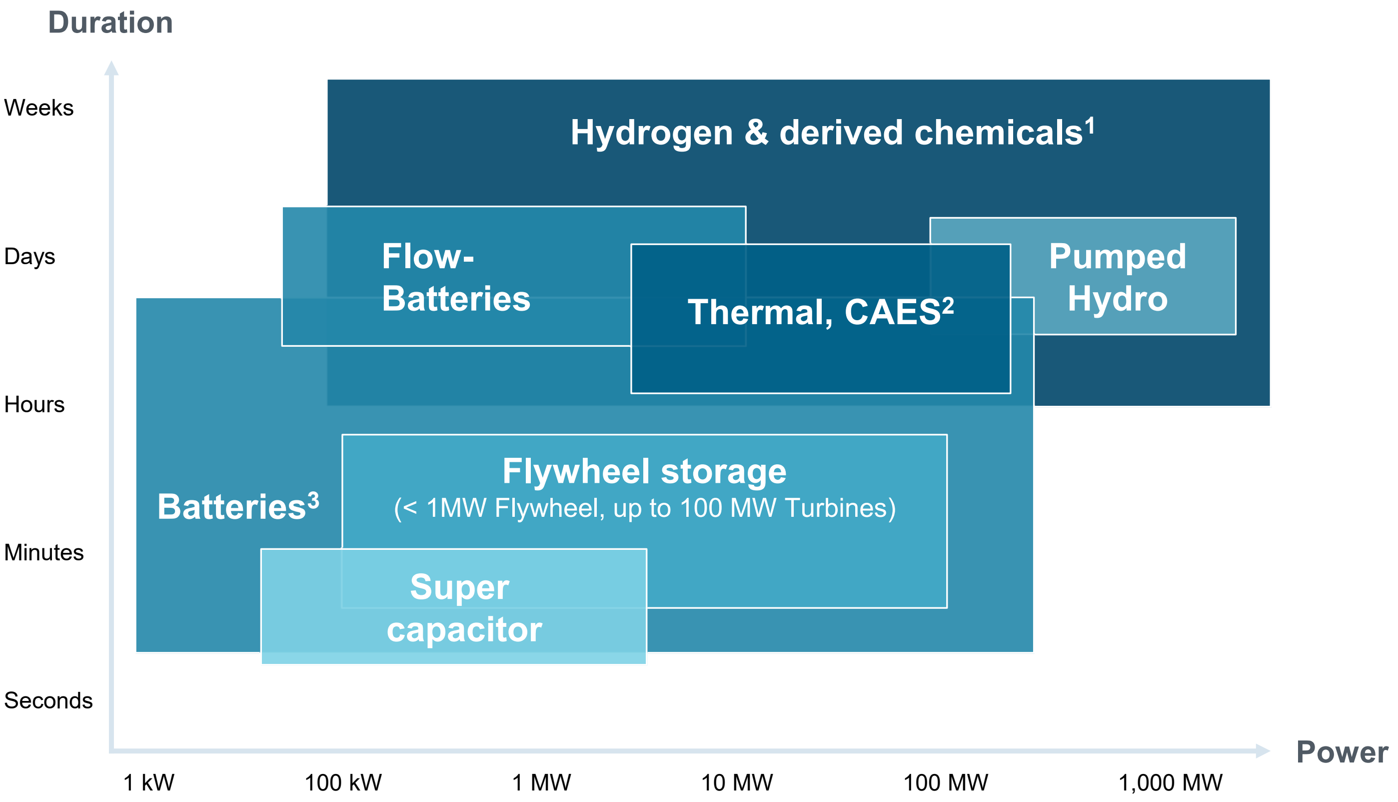
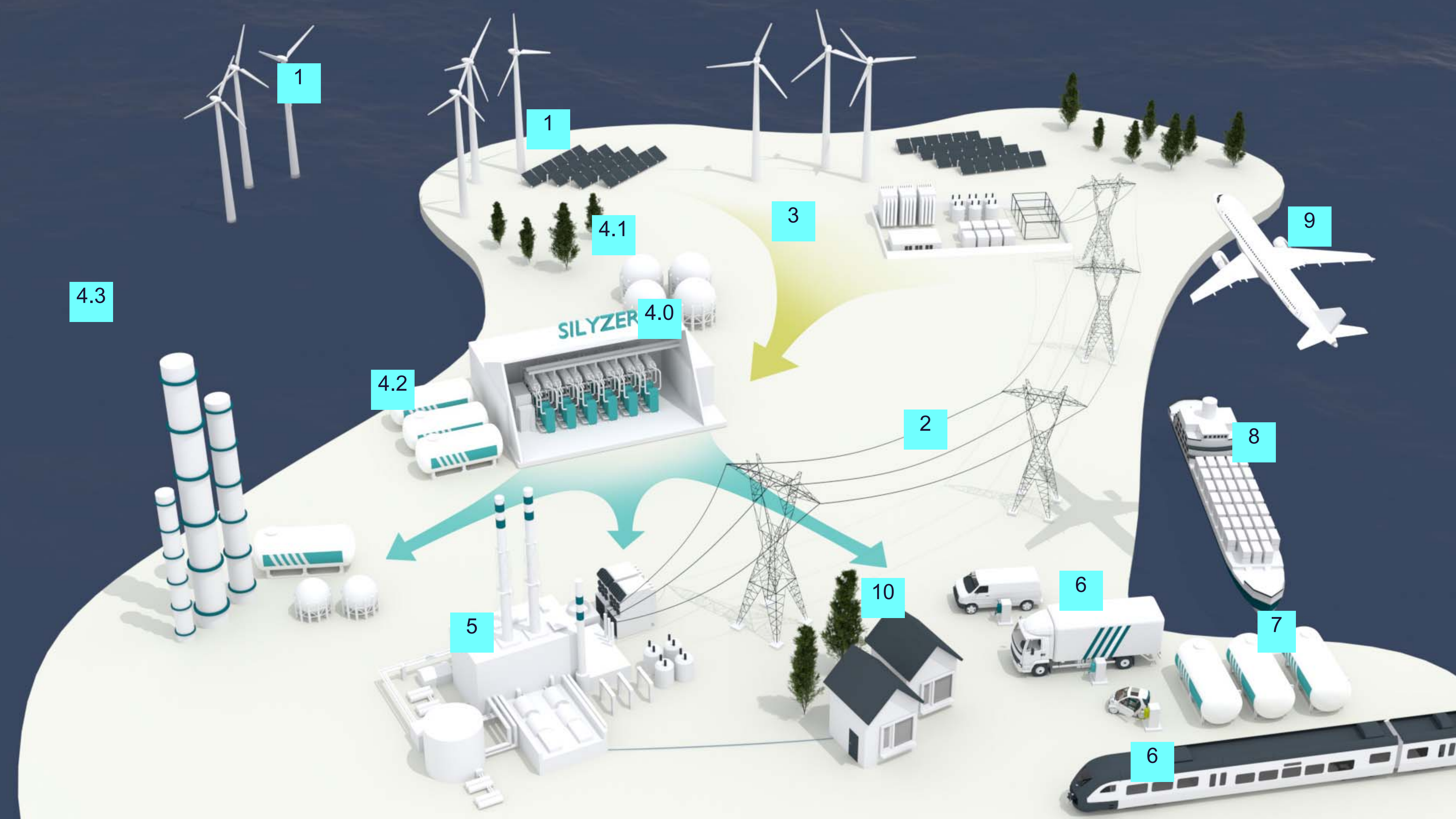


Hydrogen can be stored cost-effectively on a large scale.

[1] such as Ammonia, Methanol or others; [2] Compressed Air Energy Storage; [3] Li-Ion, NaS, Lead Acid, etc.



1
1
SILYZER
4.0
4.1
4.2
4.3
3
2
9
8
5
10
6
7
6

Explanation of previous slide

The previous picture summarizes a future sustainable society.

1 The energy will be supplied by Renewable Energy (RE) like wind and PV.
2 The transport and distribution of the energy occurs in TS and Distr. systems with intelligent logics to maximize the direct use of that fluctuating RE energy.
3 Common to those systems however is the fact, that frequently supply will be much higher than demand in the electrical system.
4 To store large amounts of surplus energy economically and without limitations in recourses one option is possible only. That is when H2 shows up at the scene.
4.0 To get from electrical energy into H2 the help of an electrolyzer is needed.
4.1 / 4.2 The produced gas H2 can be stored in low and high pressure gas tanks.
4.3 In future times large scale liquefaction will come in to the play also as this is a good option to improve the efficiency in H2 distribution without the presents of gas grids.
H2 offers a very wide range of applications where it can be used for.
5 With the help of fuel cells, IC engines and turbines H2 can be reconverted into electricity. That would present an energy storage system.
Of course:
6 H2 enables emission free road and rail based mobility.
7 It can be stored locally and
8 exported as valuable good world wide.
9 H2 is the best suitable fuel for air transportation as the gravimetric energy density is the highest of conventional fuels, 3 times higher than kerosene.
10 H2 can also be used locally in communities.

There are three considerable technologies of water electrolysis

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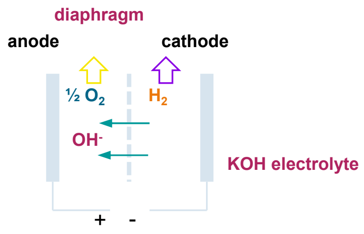
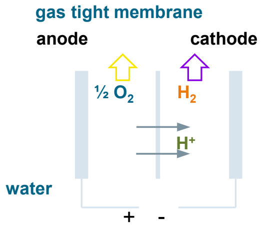
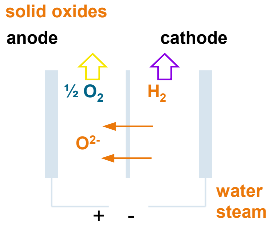
	Alkaline Electrolysis	PEM Electrolysis	High temperature
			
Electrolyte	KOH[3]	Polymer membrane	Ceramic membrane
Circulated medium	KOH[3]	Water	Steam
Operational temperature[1]	60 - 90 ºC	RT[4] - 80 ºC	700 - 900 ºC
Technical maturity[1]	Industrially mature	Industrially mature	Lab/ demo
Field experience[1]	Existing/ available	Existing/ available	Not possible, not available
Cold-start capability[2]	In development/ limited	Existing/ available	Not possible, not available
Intermittent operation[2]	In development/ limited	Existing/ available	In development/ limited
Scalability to multi Mega Watt[2]	Existing/ available	Existing/ available	In development/ limited
Reverse (fuel cell) mode[1]	Not possible, not available	Not possible, not available	Existing/ available

Source: 1) Fraunhofer, 2) IndWede; 3) KOH: Potassium hydroxide : 4) room temperature

● Existing/ available ● In development/ limited ● Not possible, not available

Evolution of Siemens' PEM Elektrolyzer

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0,1 MW

1 MW

10 MW

100 MW

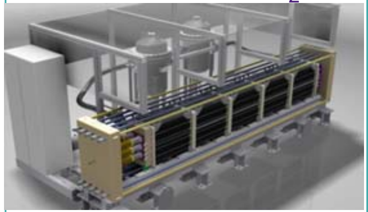
1000 MW

2011

Silyzer 100
Small-scale
~150k Nm³ H_2

2015

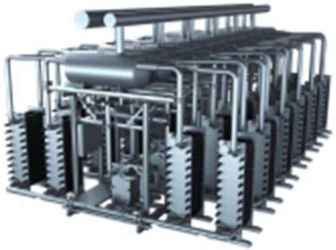
Silyzer 200
~86.500 Bh
~7.3 mio Nm³ H_2



Weltgrößte Power-to-Gas-Anlage

2018

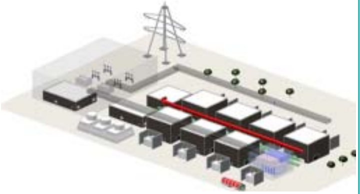
Silyzer 300



Weltgrößte PEM-Zelle

2023+

In Development



2030+

Feasibility & Market Studies

1) Bh.: Betriebsstunden; Daten Bh & Nm³ ab Jan. 2019

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

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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**

What is electrolysis?

- A **DC electrical power source** is connected to two **electrodes** which are placed in the **water**
- An **electrolyte** enables the charges exchange and is the **eponym of the technology**
- Hydrogen will appear at the **Cathode**, Oxygen at the **Anode**
- The **production rate** is **proportional** to the **electrical charge**

Facts and figures

- 1 **kg** hydrogen needs stoichiometrically **9 liter** of **water**
- The **energy content** of **1 kg** hydrogen amounts for **39.4 kWh_{HHV}**

1888

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

Gravimetric Energy Density Higher heating value in kWh/kg[1]

39 Hydrogen

16 Methane

13 Diesel

13 Gasoline

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

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

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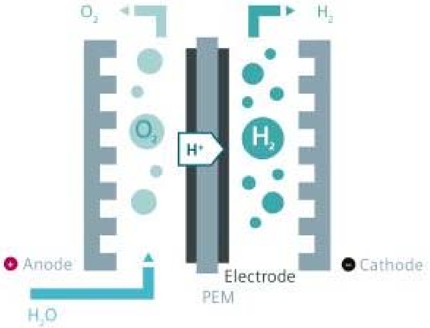
1973

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

How does PEM electrolysis work

- **Proton exchange membrane** is the **electrolyte**
- Electrodes are connected on both sides of the proton exchange membrane
- Proton exchange membrane acts as separator to prevent mixing of the gases produced



Advantages of PEM electrolysis

- High **power density**
- Extended **dynamic operation** range and direct coupling to renewables (rapid response)
- High **efficiency**
- High **gas purities**
- H_2 and O_2 at **pressure** (up to 35bar(g))
- **Mixing of the gases**, even at differential pressure, **not possible**
- Absence of acidic or caustic liquids, “Just add water”
- Up to 80.000h of **maintenance free electrolyzer stack** operation, high reliability

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

65 % Efficiency

System

20 kg

225 Nm³

Hydrogen production per hour

1.25 MW

Rated stack capacity

Silyzer 200 –
high-pressure efficiency in the megawatt range

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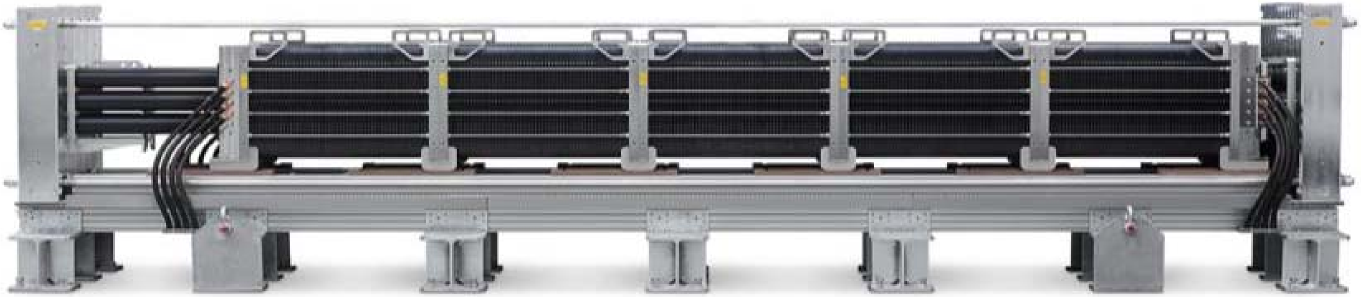

Main technical data			
Electrolysis type / principle	PEM	Rated H_2 production	20 kg/ h
Rated Stack Power	1.25 MW	Overall Efficiency (system)	60 – 65 %
Dimension Skid	6.3 x 3.1 x 3.0 m	Design Life Time	> 80,000 h
Start up time (from cold stand-by)	< 10 sec	Weight per Skid	17 t
Output pressure	Up to 35 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 200
Energiepark Mainz world's largest PEM electrolysis facility in 2015

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3.75 MW

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

Facts & figures

- Customer: Energiepark Mainz (JV of Linde and Mainzer Stadtwerke)
- Country: Germany
- Installed: 2015
- Product: Silyzer 200

Use cases

Green hydrogen is fed into the local natural gas grid.

Delivery to surrounding industrial companies.

Hydrogen for regional filling stations.

Challenge

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

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)

Silyzer 300
the next paradigm in PEM electrolysis

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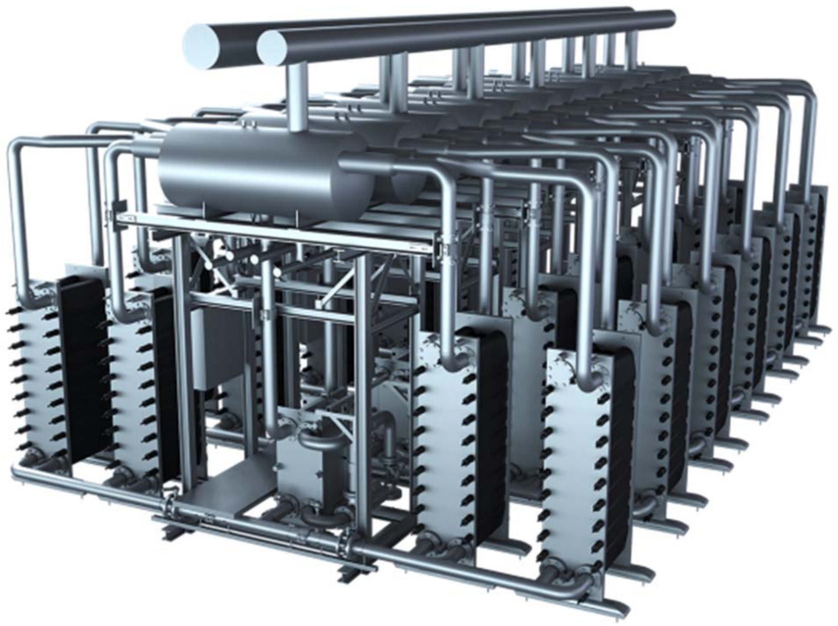
17.5 MW	Power demand per full Module Array (24 modules)
75 %	System efficiency (higher heating value)
24 modules	to build a full Module Array
340 kg	hydrogen per hour per full Module Array (24 modules)



Silyzer 300 – Module Array (24 modules)

The Silyzer 300 offers a simple process technology and a unique natural circulation

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Several advantages due to the Silyzer 300 process technology:

zero pumps

only one heat exchanger
simple water refilling

hydrogen lost due to venting

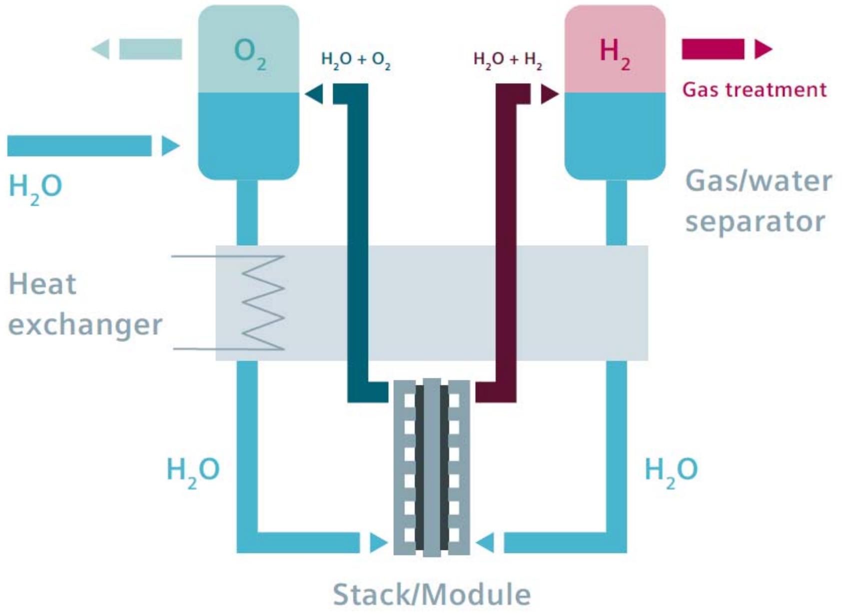
zero

pressurized vessel

zero

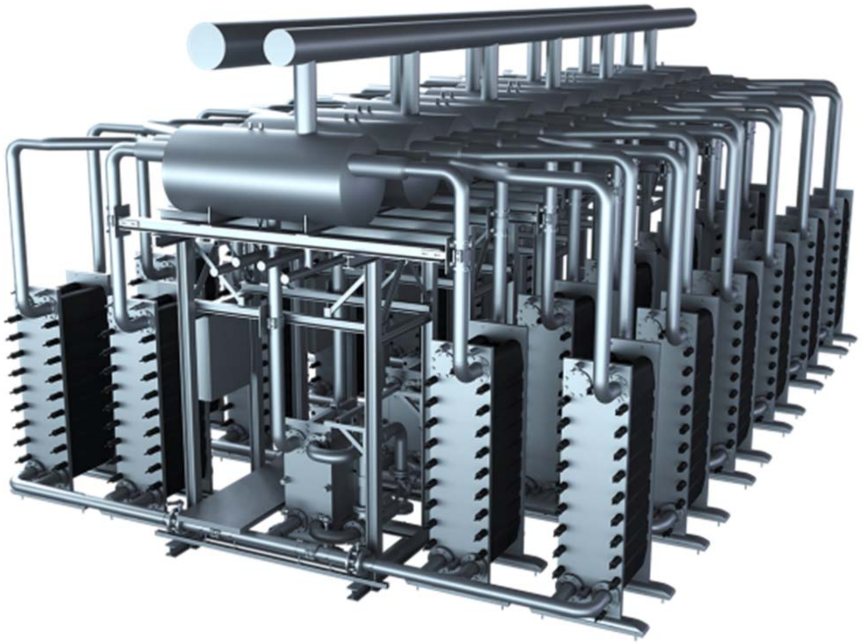
zero nitrogen

consumption during operation



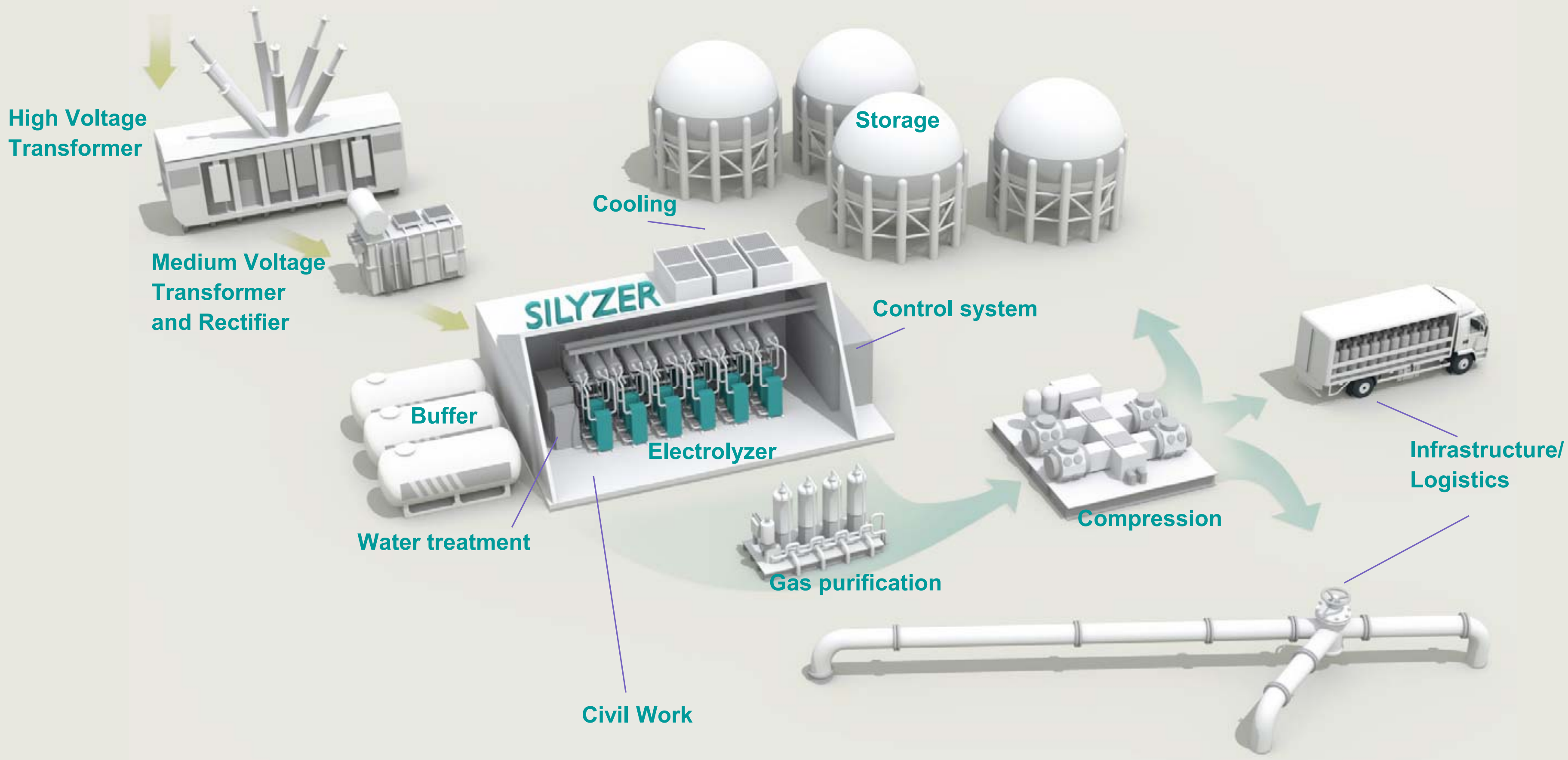
Silyzer 300
Fact Sheet

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]	99.999 %
Delivery pressure	customized

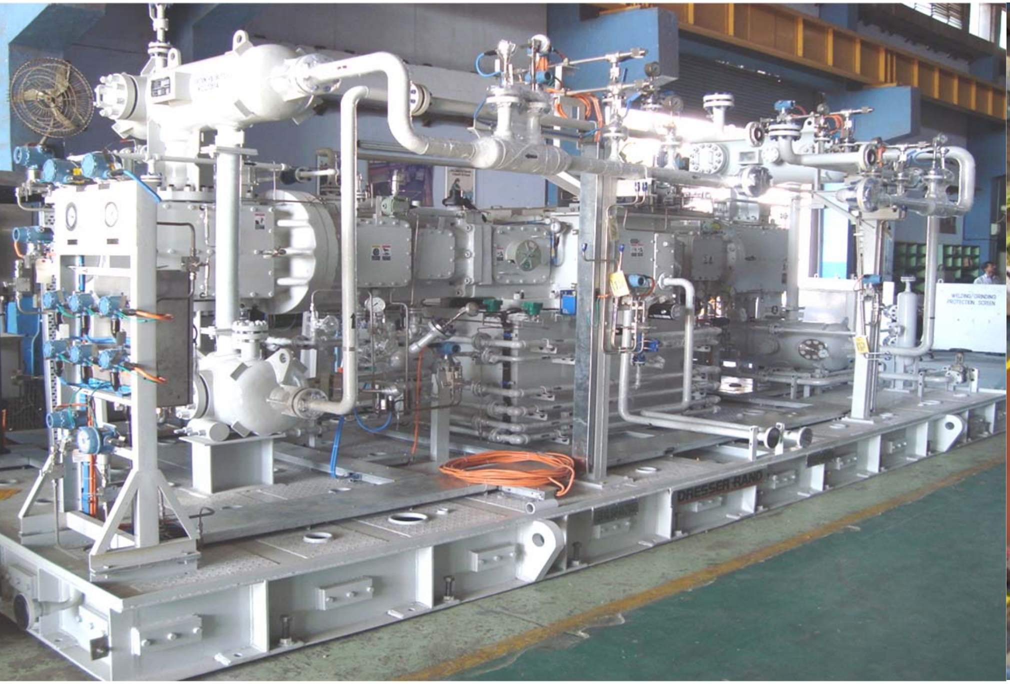


1) Plant efficiency includes rectifier, transformer, transformer cooling and gas cooling 2) Primary Frequency Response Service 3) w/ DeOxo

Hydrogen generation: more than just an electrolyzer



Compression
Highspeed & Lowspeed



H2FUTURE – a European Flagship project for generation and use of green hydrogen

H2FUTURE

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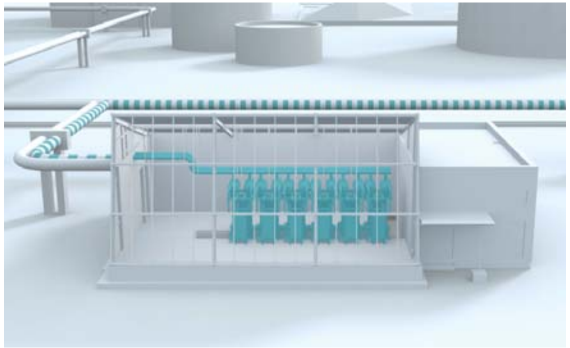

Project

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

Use cases

Hydrogen for the steel making process

Supply grid services

6 MW

Power demand based on Silyzer 300

1.200 cubic meters

of green hydrogen per hour

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 programme and Hydrogen Europe and NERGHY.

50 MW Power to Methane reference plant
One plant – multiple values

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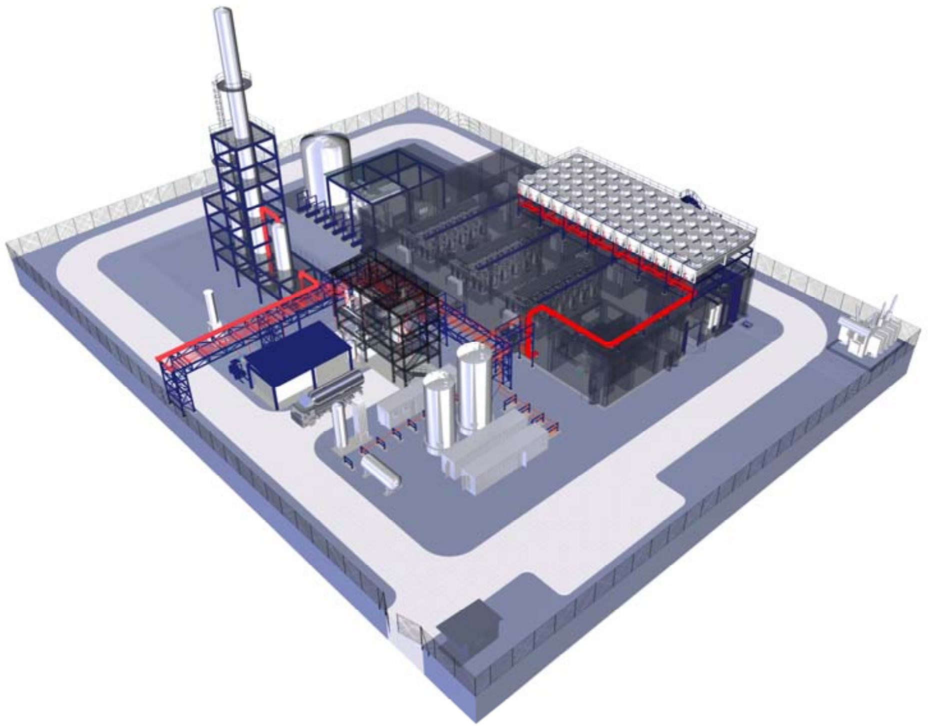
Technology	
Electrolysis type	PEM
Methanation type	Catalytic
CO_2 separation	Amine gas treating
Footprint	
Plant space requirements	85 x 100 m
Input	
el. Power @ electrolysis:	55 MW
Carbon Dioxide (CO_2) [1]	5.1 t/h
Water (m^3H_2O/m^3CH_4)	4
Output	
Methane (CH_4) [2]	1.8 t/h (@ 80 bar)
Hydrogen (H2)	11100 Nm³/h
Oxygen (O_2) [3]	7.3 t/h
Saturated Steam @ 270°C, 55barg	5 t/h



[1] @ CO_2 >95%, H_2O <5%, SO_2 ≤0,01 ppm; [2] @ CH_4 >95%, H_2 + CO_2 <5%; [3] @ 99.95% purity

50 MW Power to Methane reference plant
One plant for an entire value chain – how to earn money!

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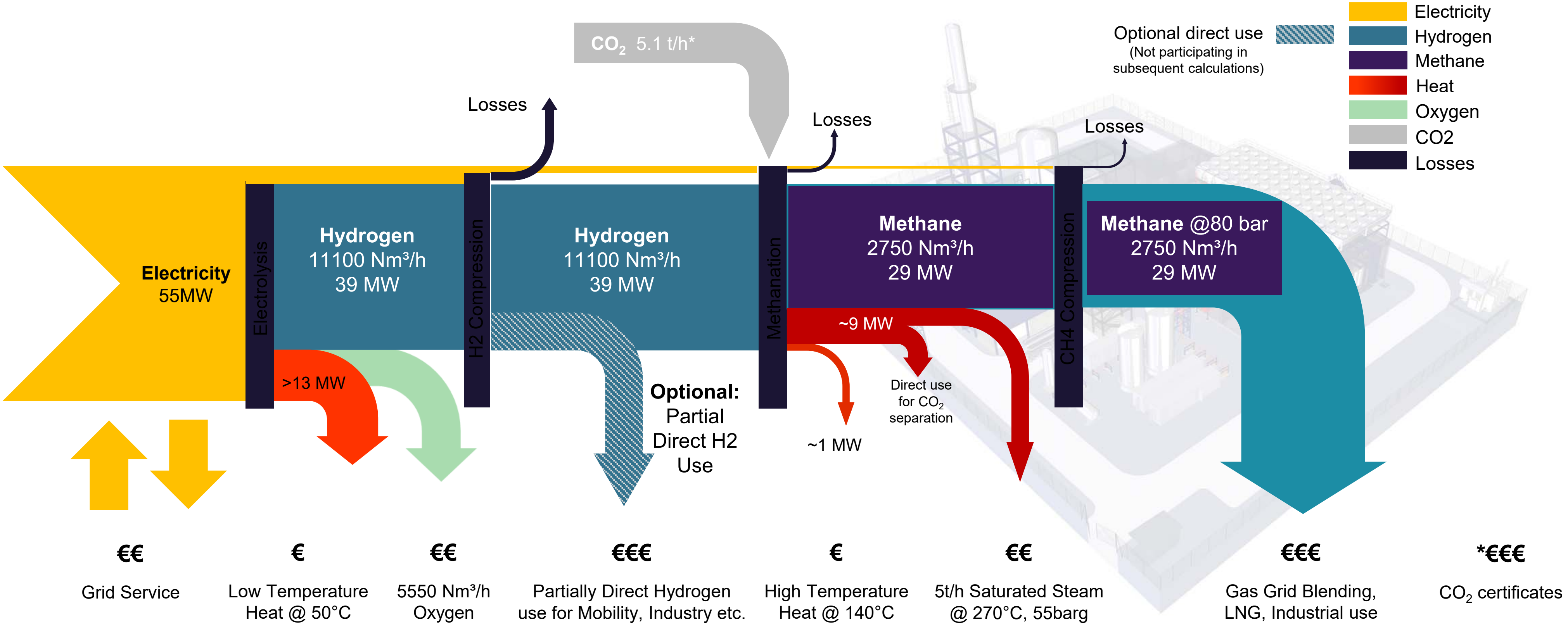


€ = Qualitative value in EU zone. Does not stand for a concrete value and is regionally very different.

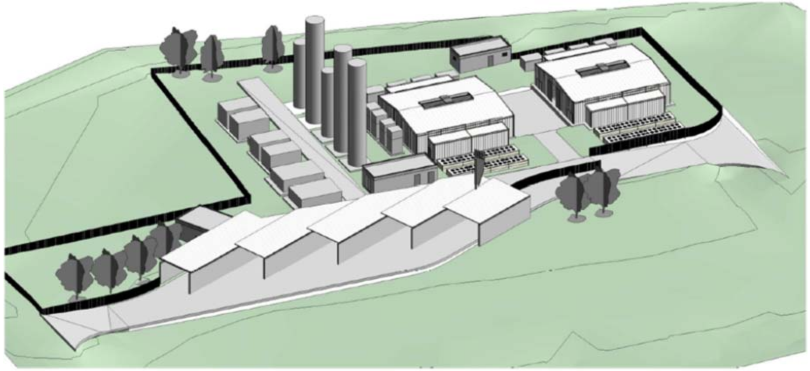
We have references for our Silyzer portfolio in all applications

Year	Country	Project	Customer	Power demand	Product offering
Silyzer 200 Reference					
2015	Germany	Energiepark Mainz	Municipality of Mainz	3.8 MW / 6 MW (peak)	Pilot Silyzer 200
2016	Germany	Wind Gas Haßfurt	Municipality of Haßfurt Greenpeace Energy	1.25 MW	Silyzer 200
2017	Germany	H&R	H&R Ölwerke Schindler GmbH	5 MW	Silyzer 200
2020	UAE	DEWA Expo 2020	Dubai Electricity and Water Authority (DEWA)	1.25 MW	Silyzer 200
2019	Australia	Hydrogen Park SA (HyP SA)	Australian Gas Infrastructure Group (AGIG)	1.25 MW	Silyzer 200
2019	Sweden	Food & Beverage	Food & Beverage Company	2.5 MW	Silyzer 200
Silyzer 300 Reference					
2019	Austria	H2Future[1]	voestalpine, Verbund, Austrian Power Grid (APG)	6 MW	Pilot Silyzer 300

[1] 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 innovative programme and Hydrogen Europe and NERGHY.

We have references for our Silyzer portfolio in all applications - update -

Year	Country	Project	Customer	Power demand	Product offering
Silyzer 200 Reference					
2020	PR China	Near Beijing	Utility	1,25MW	Silyzer 200
2020	Germany	Wunsiedel	Municipality	6(18) MW	Silyzer 300



https://press.siemens.com/global/en/pressrelease/siemens-build-large-co2-free-hydrogen-production-plant-bavaria

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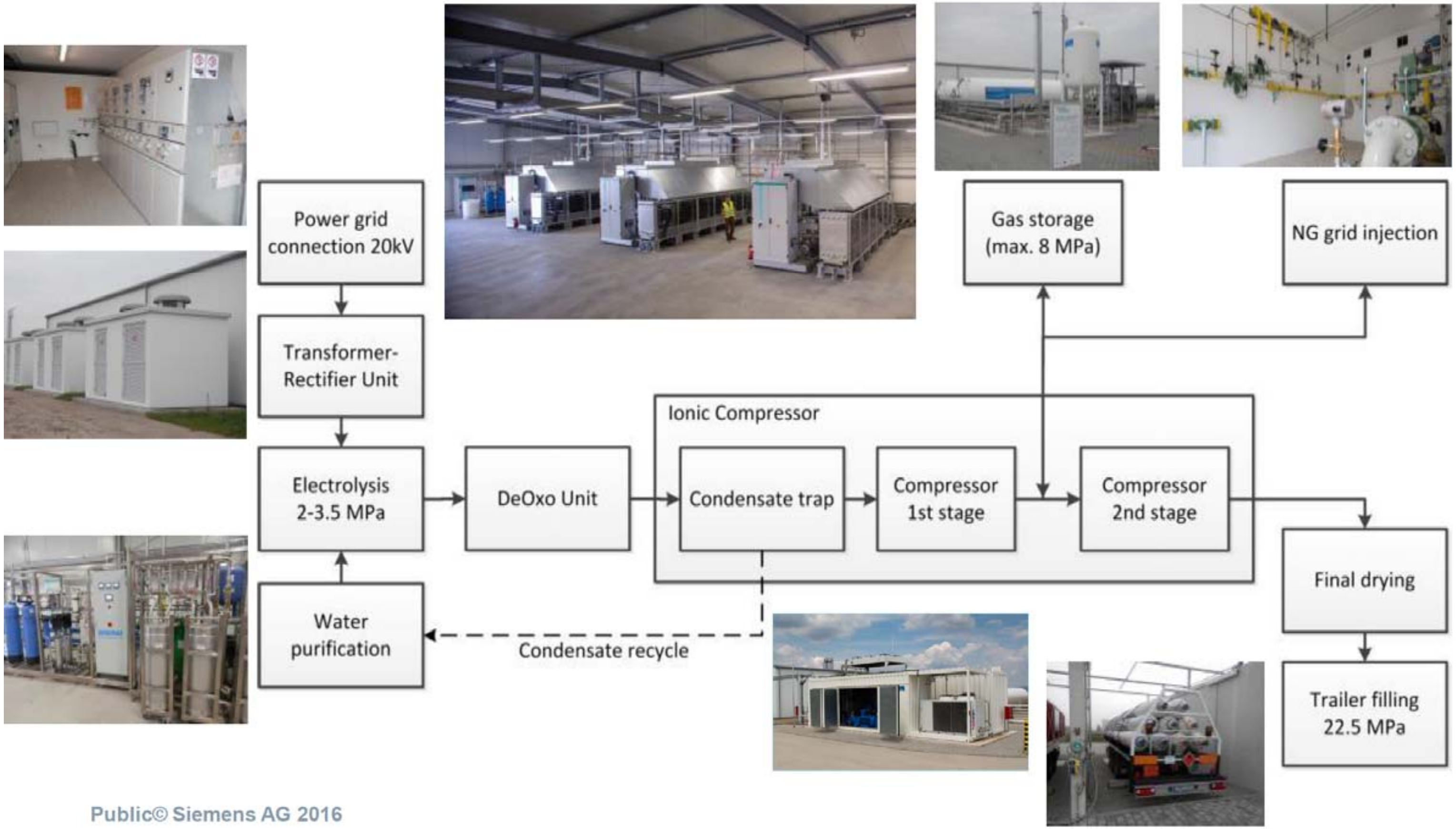
Back-up

Energy Park Mainz
Overview



Energy Park Mainz
Hydrogen Electrolysis

SIEMENS
Ingenuity for life

Energy Park Mainz

H2 Storage 700kg / 23MWh$_{(th)}$

- 2x gas storage at 80 bar
- ~700kg H2

Silyzer 300
Latest & most powerful product line in the double-digit MW-class

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High performance

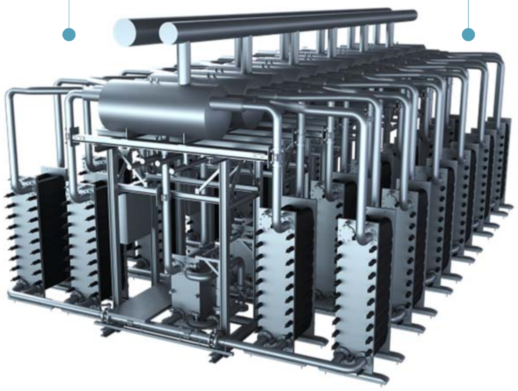
High efficiency: system >75%
Modular: H_2 production range 100-2,000 kg/h

High availability

Advanced design for low degradation
Robust industrial design

Maintenance friendly

Maintenance free module 80,000 op.h[1]
Easy exchange of modules
No cleaning effort
World wide service coverage



Flexible operation

Fast start-up and shut-down
High dynamics
High Gas purity
No Ex-zone within PEM Array
No hazardous chemicals
Power factor compensation
No permanent operating personnel required

Digitally enabled

Active Single Cell Voltage Monitoring
Remote monitoring
SIMATIC PCS7
Mindsphere

[1] op.h.: operating hours

The modular design of Silyzer 300 can be easily scaled to your demands

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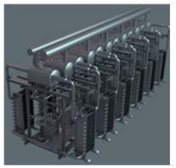
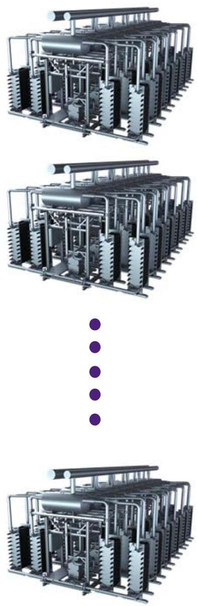
Module	Module array	n+1 Customized solution	Plant

Between 12 and 24 modules





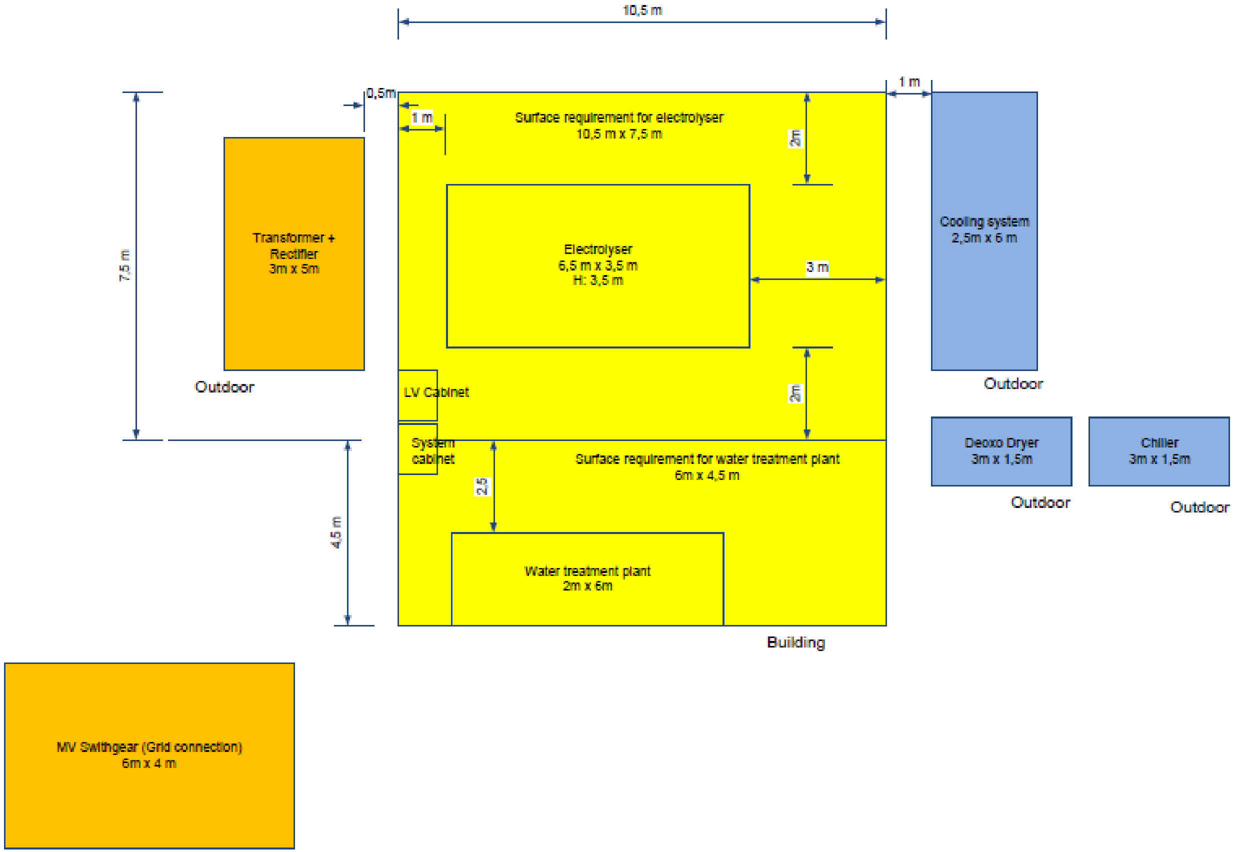
Scale up to the necessary demand

Control system · Water refinement · Transformer · Rectifier · LV supply

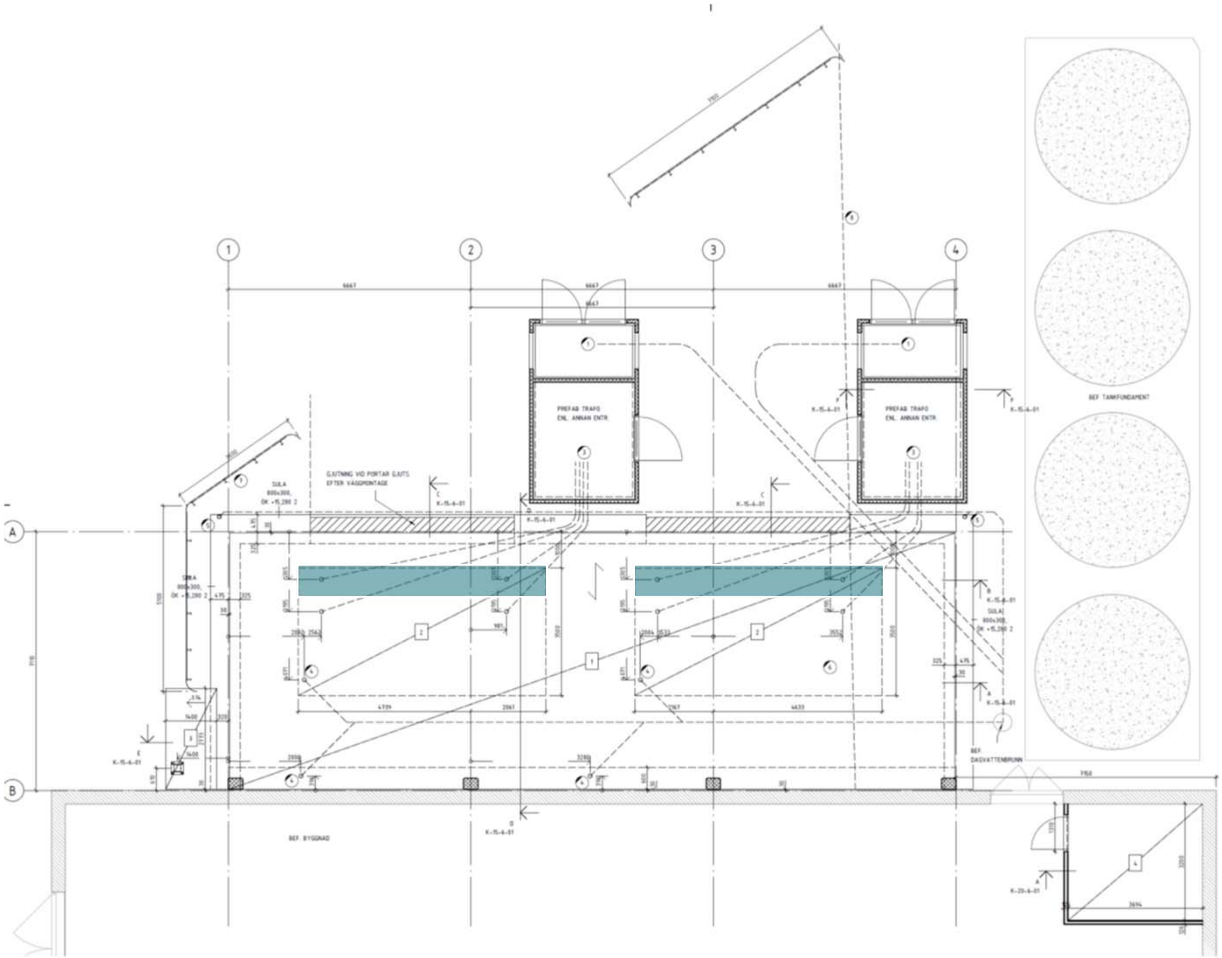
! Modular concept to cover wide production rate

Layout examples Silyzer 200

Indoor 1,25MW
1 x Silyzer 200 (10m x 10m)



Indoor 2,5MW
2 x Silyzer 200, (14m x 20m)



Indoor 3,75MW / 6MW
3 x Silyzer 200

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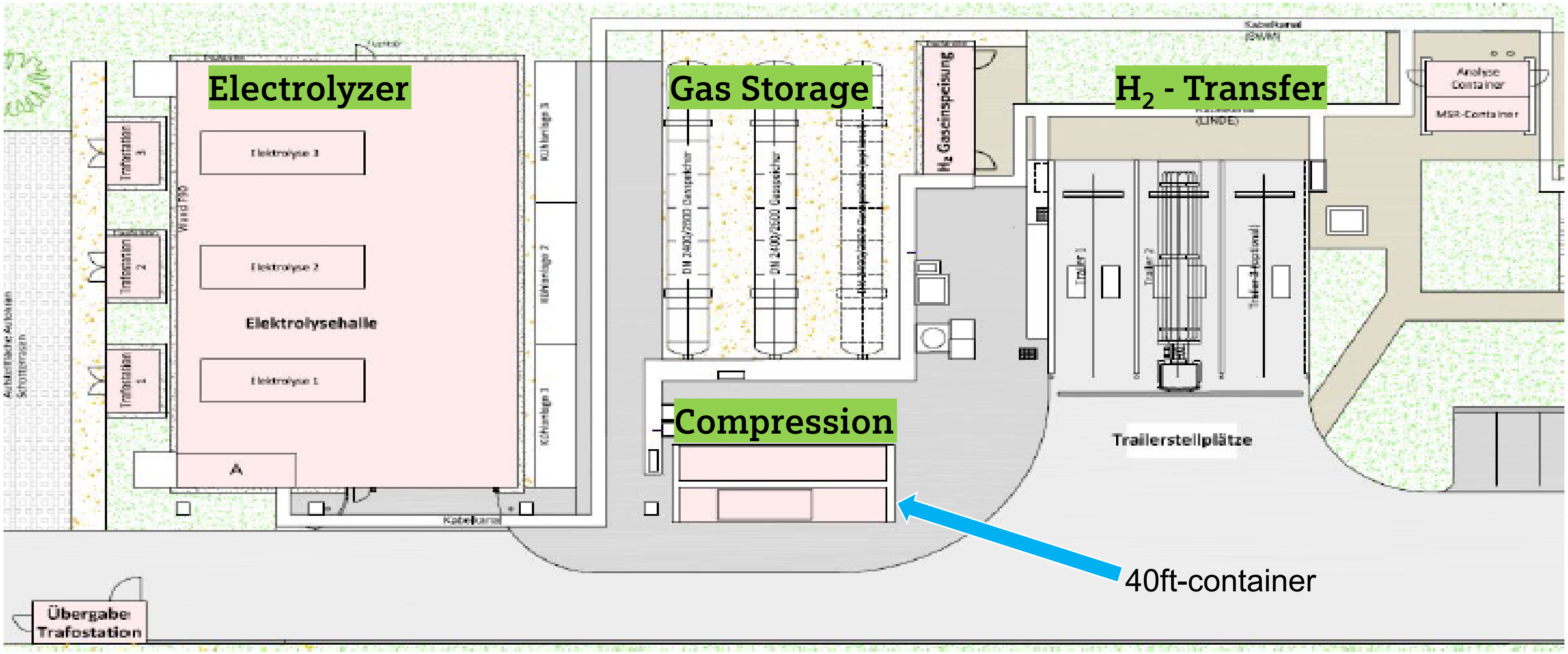
Planning of infrastructure and civil engineering



Ein Forschungsprojekt von STADTWERKE MAINZ AG, Hochschule RheinMain University of Applied Sciences Wiesbaden Rüsselsheim Geisenheim, Linde, SIEMENS

Gefördert durch Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages

ENERGIESPEICHER Forschungsinitiative der Bundesregierung

Indoor 5MW
4 x Silyzer 200 (40m x 10m)