Key technologies for a hydrogen-based energy system

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Nov. 4th 2019

www.siemens.com/silyzer

To decarbonize the global economy by 2100 we need to take more than one measure

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Politics force worldwide decarbonization

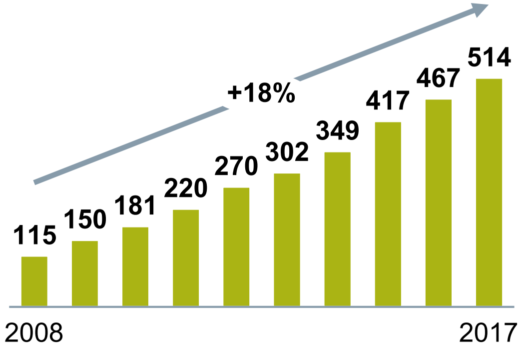
G7 summit, 2015:
Decarbonization of the global economy by 2100: Greenhouse gas emissions reductions of 40% to 70% by 2050 (baseline: 2010)

COP21, 2015:
195 countries adopt the first universal climate agreement: Keep a global temperature rise this century well below 2°C

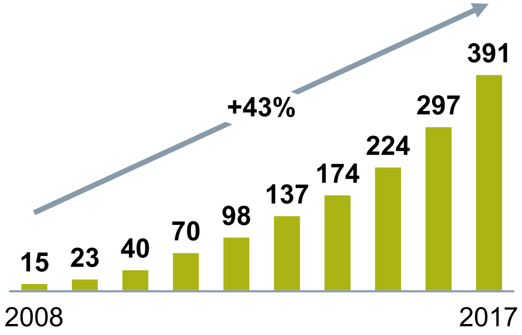
COP23, 2017:
The 197 Parties discussed how and how far they can implement decarbonization measures

Renewables installation increase

Global Wind Installations (GW)[1]

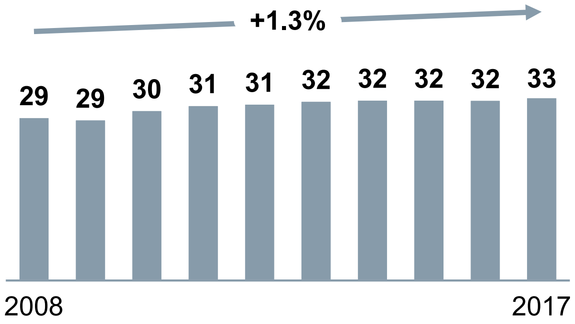


Global Solar PV Installations (GW)[1]



But CO_2 emissions stagnate

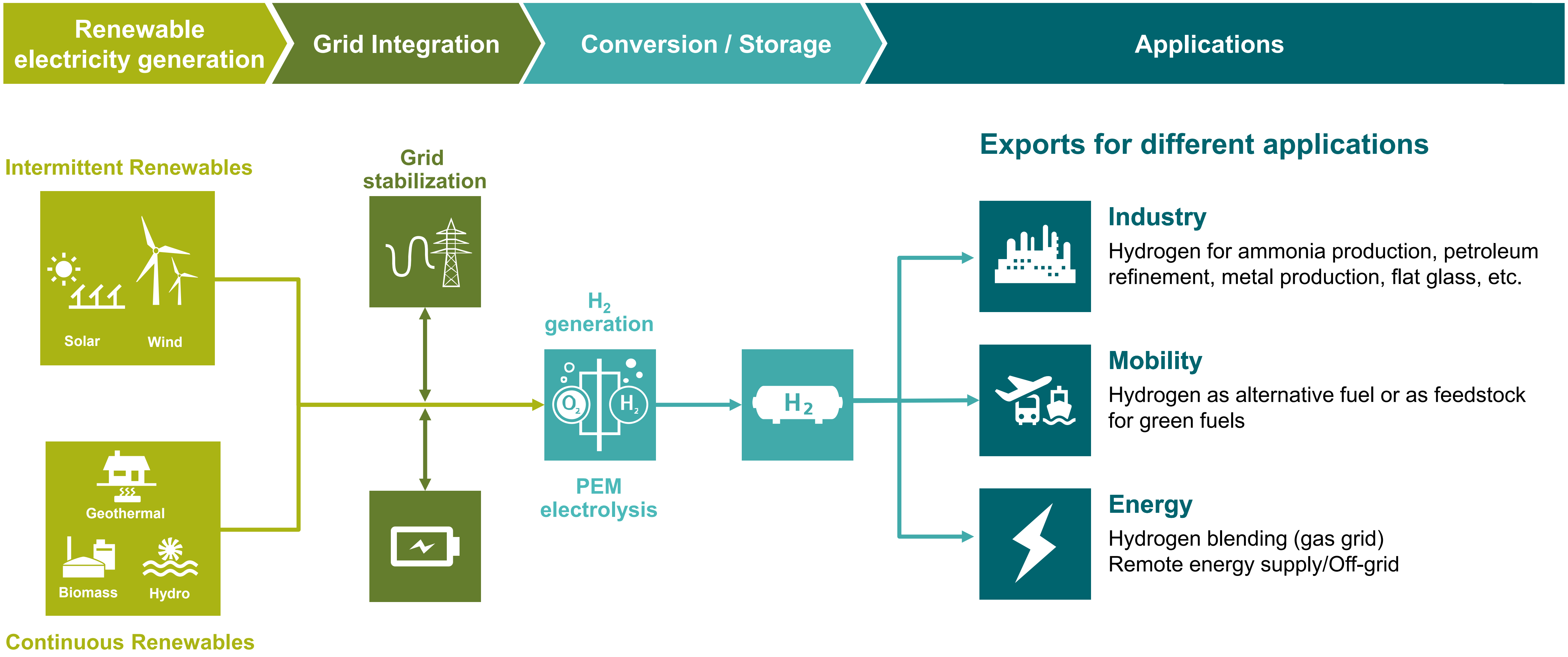
Global CO_2 Emissions (Gt)[2]



! Renewables integration; Decarbonization of every industry; Changes in legislation

Sources: [1] IRENA, Renewable Capacity Statistics 2018; [2] IEA

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



There are three considerable technologies of water electrolysis

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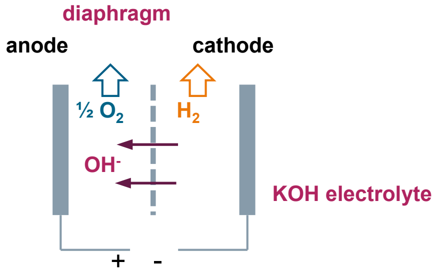
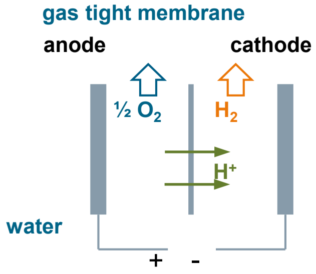
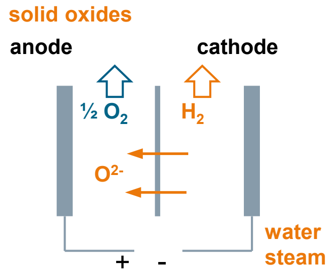
Alkaline Electrolysis



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 ºC	RT[4] - 80 ºC	700 - 900 ºC
Technical maturity[1]	Industrially mature	Commercially available	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

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

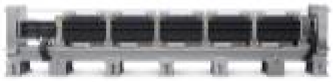
2011

Silyzer 100
Lab-scale demo
~4.500 OH[1],
~150k Nm^3 of H_2

1 MW

2015

Silyzer 200
~86.500 op.h
~7.3 mio Nm^3 of H_2

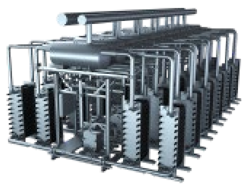


World's largest Power-to-Gas plants with PEM electrolyzers in 2015 and 2017 built by Siemens!

10 MW

2018

Silyzer 300

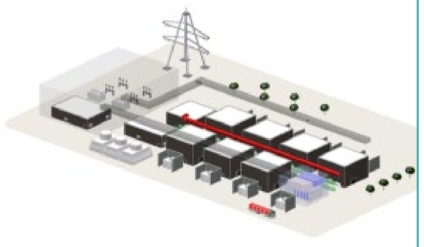


Biggest PEM cell in the world built by Siemens!

100 MW

2023+

Next generation
Under development



1000 MW

2030+

First investigations in cooperation with chemical industry

[1] Operating Hours; Data OH & Nm^3 as of July 2019

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 300 –
the next paradigm in PEM electrolysis

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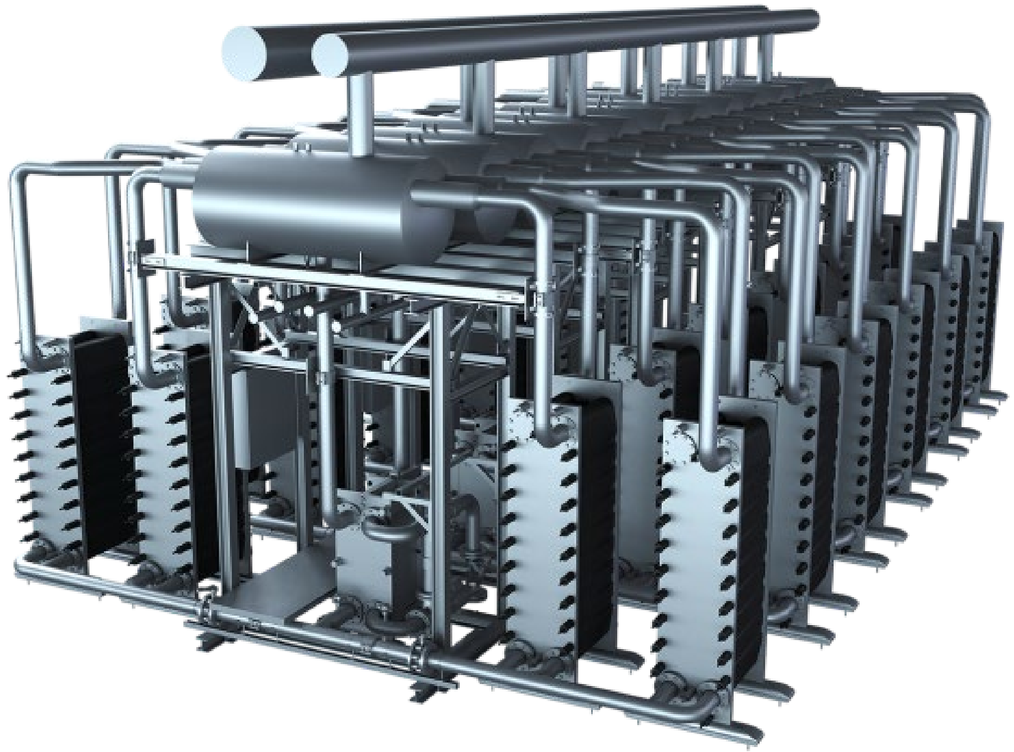
17.5 MW	Power demand per full Module Array (24 modules)
75 %	System efficiency (higher heating value)
24 modules	to build a full Module Array
340 kg	hydrogen per hour per full Module Array (24 modules)



Silyzer 300 – Module Array (24 modules)

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

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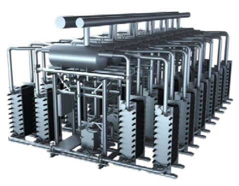
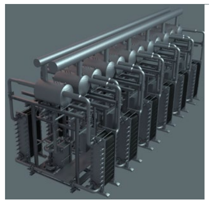
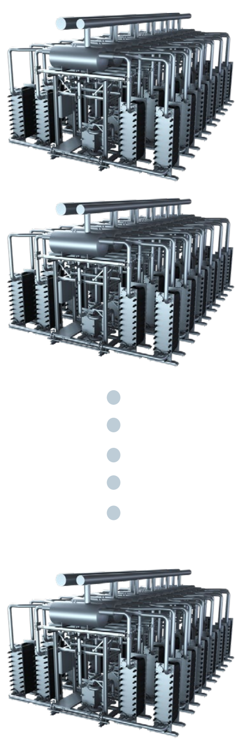
Module	Module array	n+1 Customized solution	Plant

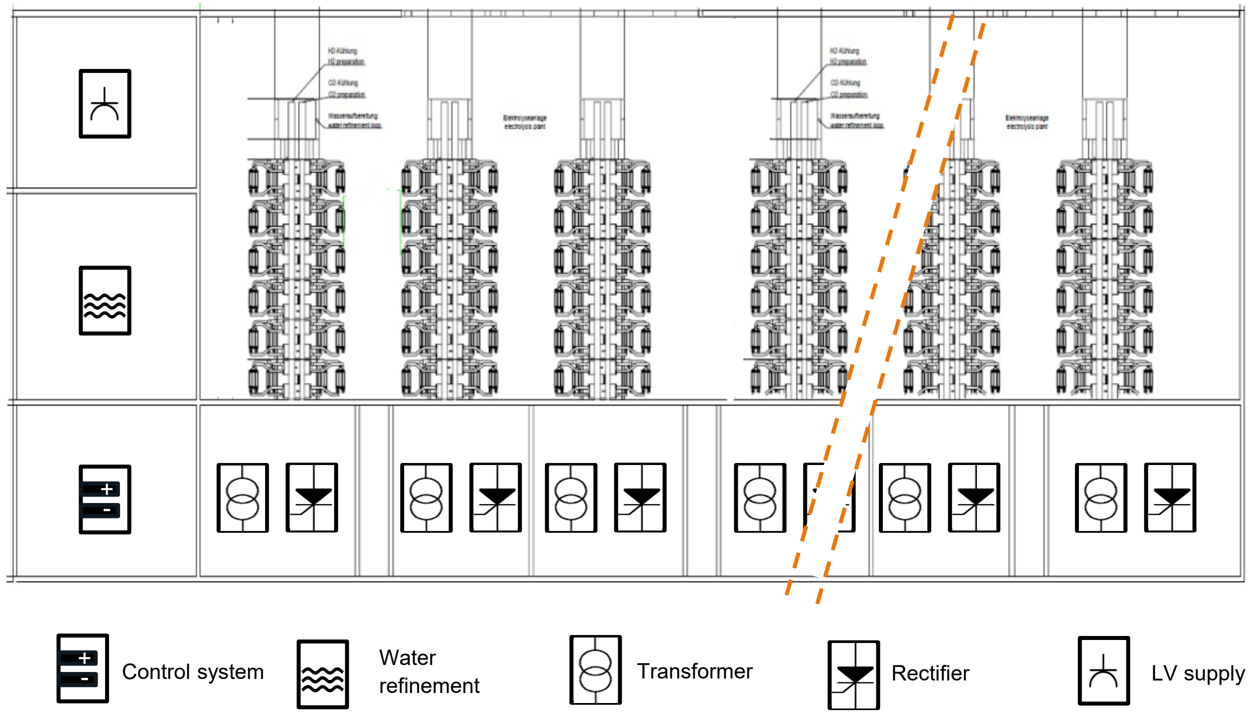


Between 12 and 24 modules





Scale up to the necessary demand



! Modular concept to cover wide production rate

Hydrogen production cost depends on site and technology specific drivers

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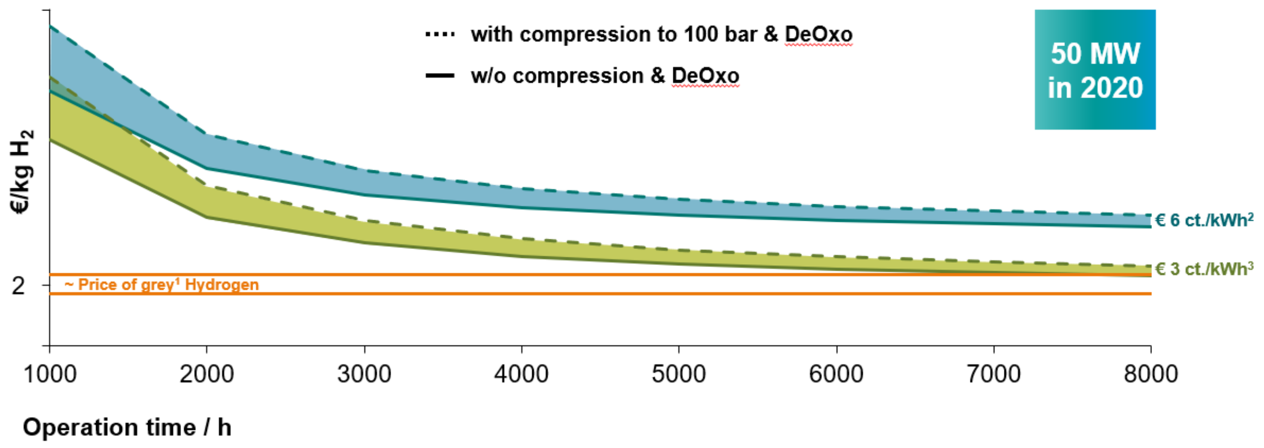
Site specific drivers

Electricity price

Operation time



Technology specific drivers

Efficiency

CAPEX

Maintenance cost

[1] Grey H2 : Hydrogen produced by conventional methods as steam methane reforming; [2] € 6 ct./kWh: e.g. on shore wind (4-6ct./kWh) or PV in Germany; [3] € 3 ct./kWh: Reachable in renewable intense regions like Nordics (Hydro Power), Patagonia (Wind), UAE (PV)

We have references for our Silyzer portfolio in all applications

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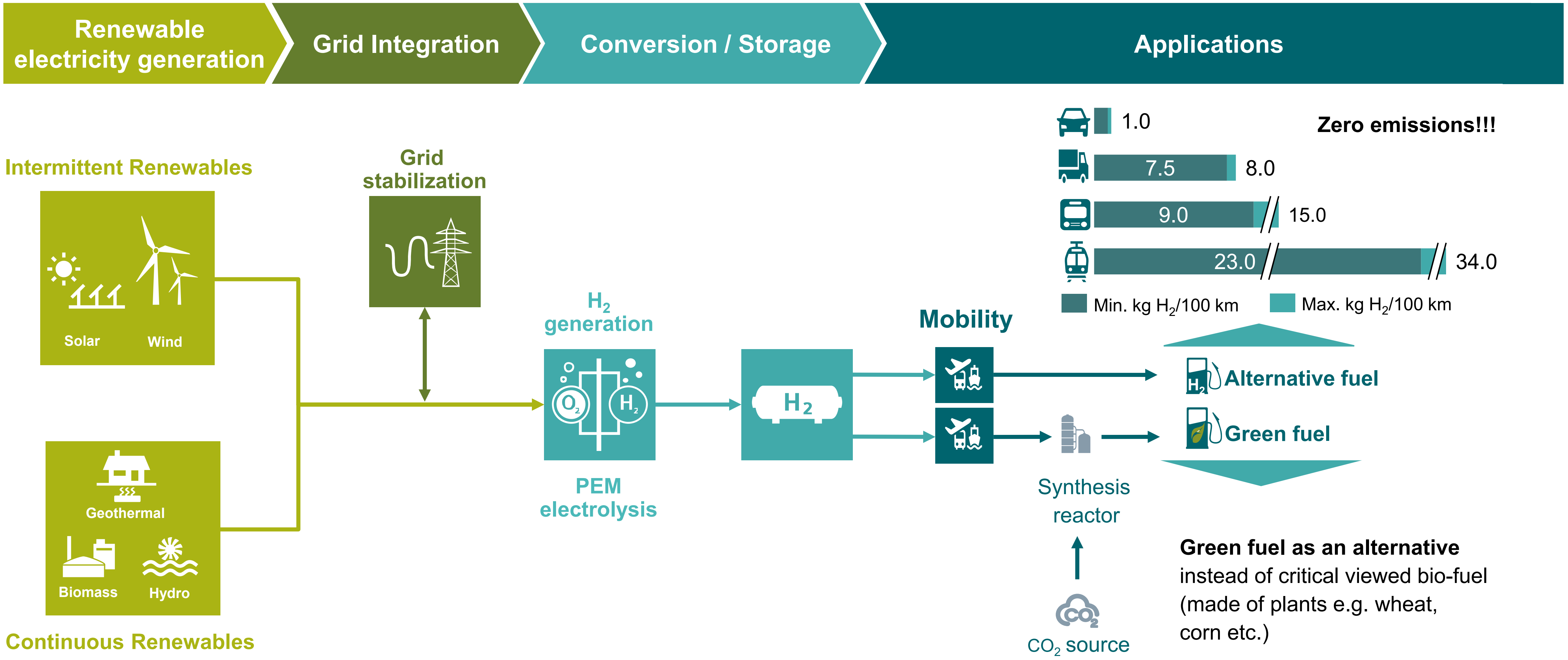
Year	Country	Project	Customer	Power demand	Product offering
Silyzer 200 Reference					
2015	Germany	Energiepark Mainz	Municipality of Mainz	3.8 MW / 6 MW (peak)	Pilot Silyzer 200
2016	Germany	Wind Gas Haßfurt	Municipality of Haßfurt Greenpeace Energy	1.25 MW	Silyzer 200
2017	Germany	H&R	H&R Ölwerke Schindler 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 research and innovative programme and Hydrogen Europe and NERGHY.

Hydrogen from renewables enabling the decarbonization of the mobility sector



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

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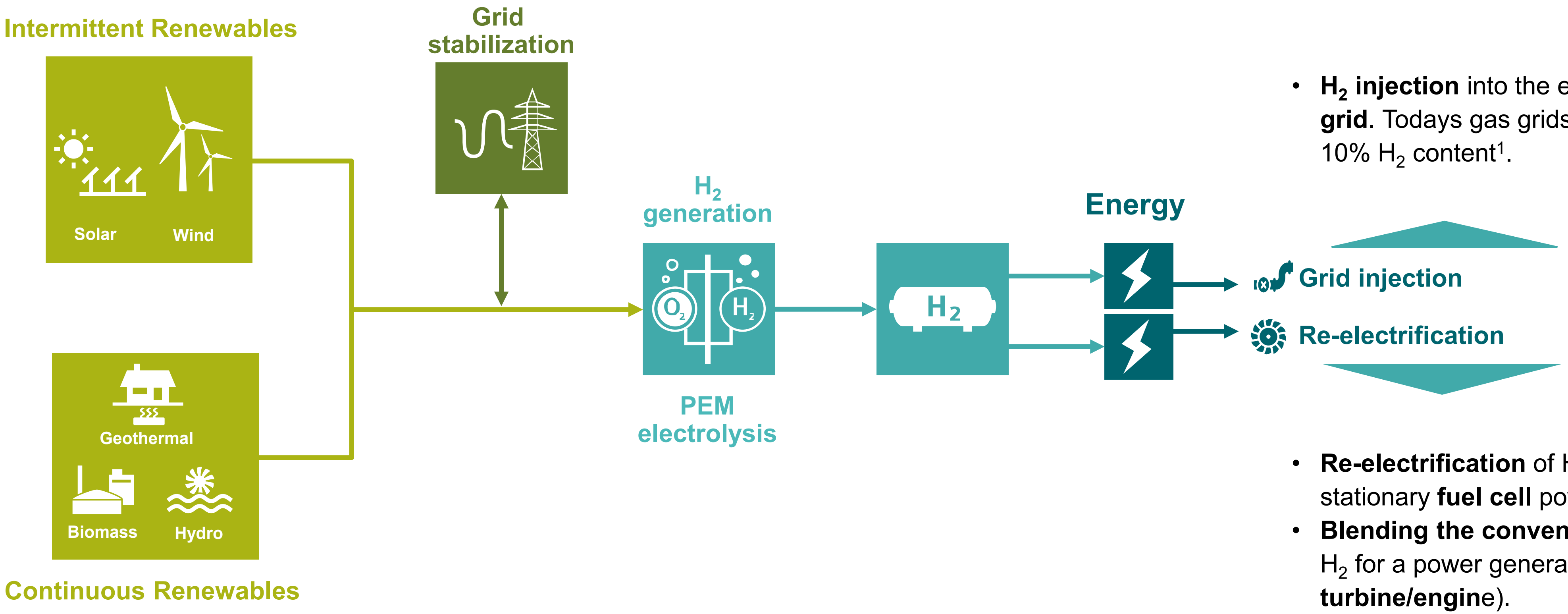
Renewable electricity generation	Grid Integration	Conversion / Storage	Applications



- **H_2 injection** into the existing **natural gas grid**. Todays gas grids can manage up to 10% H_2 content[1].

- **Re-electrification** of H_2 with a stationary **fuel cell** power plant
- **Blending the conventional fuel** with H_2 for a power generator (**gas turbine/engin**e).

Source: [1] https://www.dvgw.de/medien/dvgw/leistungen/forschung/berichte/1510nitschke.pdf p. 24

Hydrogen from renewables enables large scale long term storage and can be re-electrified

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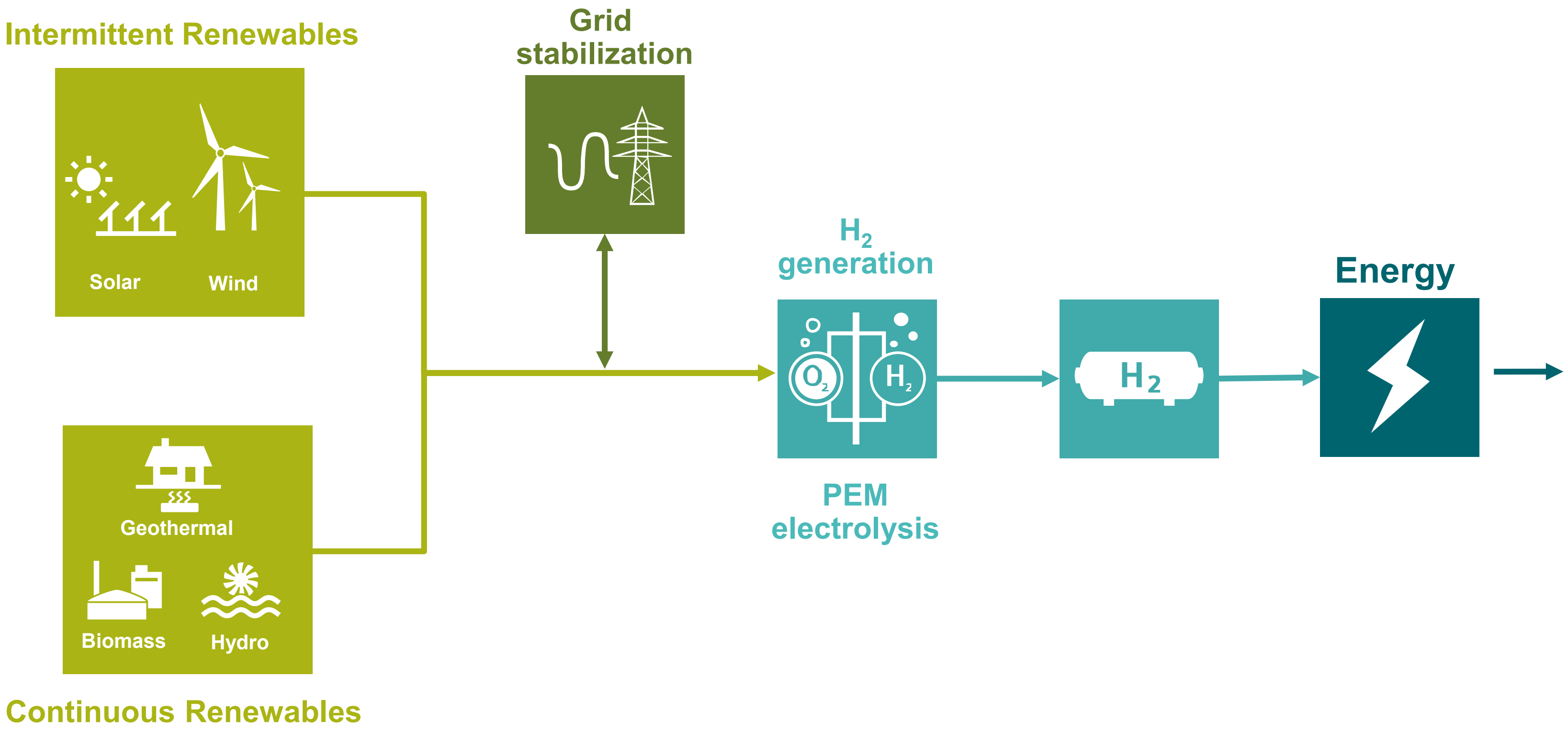
Renewable electricity generation	Grid Integration	Conversion / Storage	Applications



Re-electrification

- **Fuel cell ~0,3 MW_{el}**
  - ~20 kg/h H_2 demand

- **Gas engine ~0,28 MW_{el}**
- 100% H_2
  - ~20 kg/h H_2 demand

- **Gas turbine ~5 MW_{el}**
- Natural gas with H_2 blending of 26 vol%
  - ~20 kg/h H_2 demand

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

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Gas turbine category	Frequency	Gas turbine model	Power Output[1]	H_2 capabilities in vol. % – DLE burner	H_2 capabilities in vol. % – WLE burner	H_2 capabilities in vol. % – Diffusion burner with unabated NOx emissions
Heavy-duty gas turbines	50Hz	SGT5-9000HL	593 MW	30		
Heavy-duty gas turbines	50Hz	SGT5-8000H	450 MW	30		
Heavy-duty gas turbines	50Hz	SGT5-4000F	329 MW	30		
Heavy-duty gas turbines	50Hz	SGT5-2000E	187 MW	30		
Heavy-duty gas turbines	60Hz	SGT6-9000HL	405 MW	30		
Heavy-duty gas turbines	60Hz	SGT6-8000H	310 MW	30		
Heavy-duty gas turbines	60Hz	SGT6-5000F	215 to 260 MW	30		
Heavy-duty gas turbines	60Hz	SGT6-2000E	117 MW	30		
Aeroderivative gas turbines	50Hz or 60Hz	SGT-A65	60 to 71/58 to 62 MW	15	100	
Industrial gas turbines	50Hz or 60Hz	SGT-800	48 to 57 MW	50		
Aeroderivative gas turbines	50Hz or 60Hz	SGT-A45	41 to 44 MW		100	
Industrial gas turbines	50Hz or 60Hz	SGT-750	40/34 to 41 MW	40		
Industrial gas turbines	50Hz or 60Hz	SGT-700	33/34 MW	55		
Aeroderivative gas turbines	50Hz or 60Hz	SGT-A35	27 to 37/28 to 38 MW	15	100	
Industrial gas turbines	50Hz or 60Hz	SGT-600	24/25 MW	60		
Industrial gas turbines	50Hz or 60Hz	SGT-400	10 to 14/11 to 15 MW	10		65
Industrial gas turbines	50Hz or 60Hz	SGT-300	8/8 to 9 MW	30		
Industrial gas turbines	50Hz or 60Hz	SGT-100	5/6 MW	30		65
Aeroderivative gas turbines	50Hz or 60Hz	SGT-A05	4 to 6 MW	2	15	

DLE burner | WLE burner | Diffusion burner with unabated NOx emissions

Values shown are indicative for new unit applications and depend on local conditions and requirements. Some operating restrictions/special hardware and package modifications may apply.

Higher H_2 contents to be discussed on a project specific basis

1 ISO, Base Load, Natural Gas
Version 2.0, March 2019

Future of Energy is about decarbonization through “Sector-Coupling” with the key component electrolyzer

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Cornerstones of a Future Energy System

- PEM Electrolyzer are one of the key component of a hydrogen based economy
- Sector Coupling” is the key lever for decarbonization of all end-user sectors
- Hydrogen production costs with electrolysis are already competitive
- Siemens gas turbines are ready to support a hydrogen-based energy world
- Regulatory Framework: Set decarbonization targets, technology-open, the end of the energy-only market

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