Sweden Gasdagarna | 16. May 2019

Role of Gas in Future Sustainable Energy Systems

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Future sustainable energy landscape will be more manifold rather than pure electrification

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<u>Common statements:</u>

- 100% renewable energy systems by 2050, realistic?
- Renewables in combination with battery storage capable to secure security of supply?
- Gas power plants only bridge technology?
- Synthetic fuels not applicable due to high cost and low efficiency?

… but current markets already indicate development in a more manifold direction!

Gas in power will expand globally even in decarbonization case, for EU it will be stable or shrinking depending on decarbonization level

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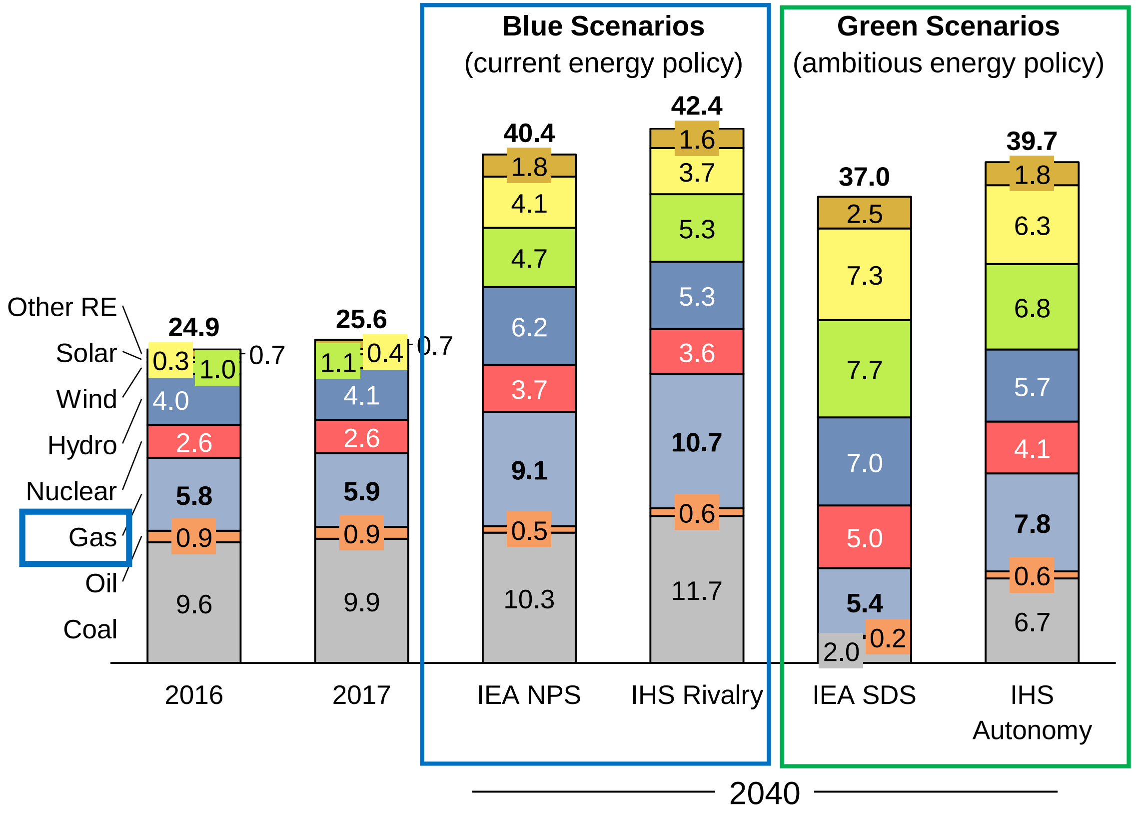
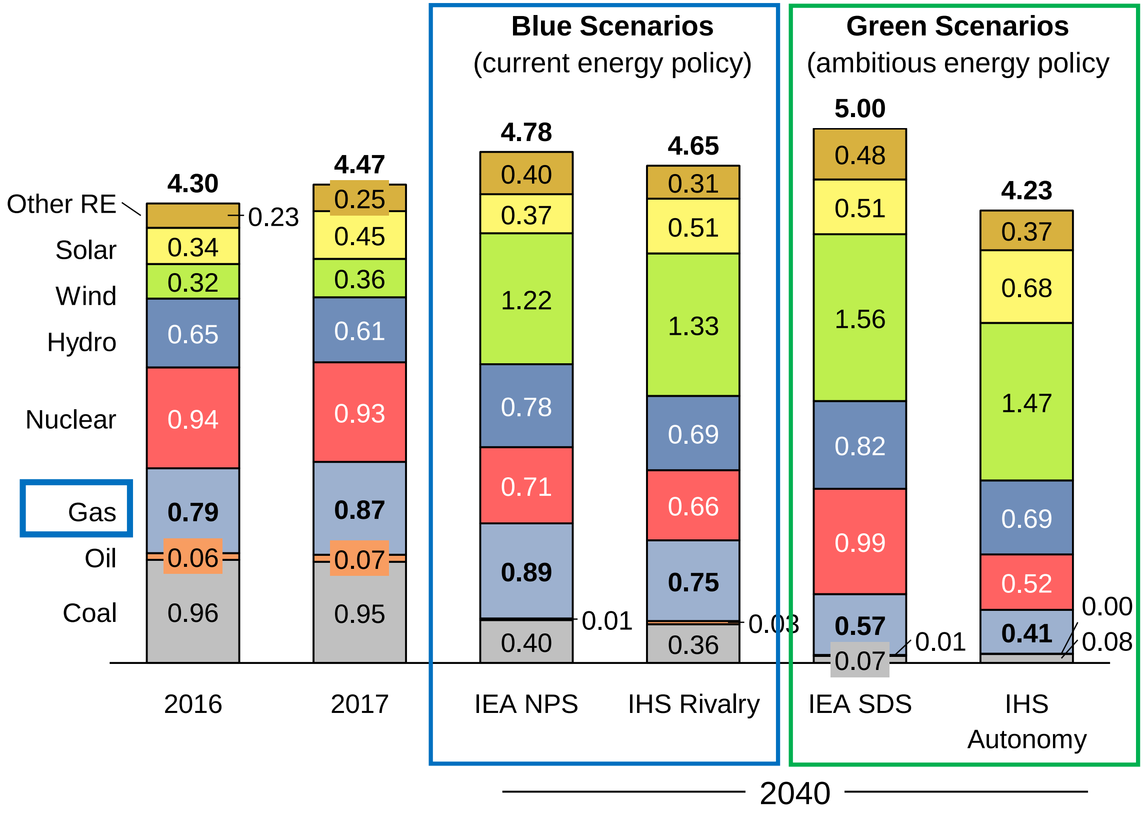
World: power generation (1,000 TWh)



Europe: power generation (1,000 TWh)



- **Increase of power generation by gas by 80% in ‘blue scenarios’**
- **At least stable or increase in gas demand by 35% in ‘green scenarios ‘**

- **Stable power generation by gas in ‘blue scenarios’**
- **Decrease in power generation by gas by 35-50% in ‘green scenarios‘**

Gas power plant capacity is expected to grow by 40-60% globally in all scenarios, also for Europe capacity will increase but more moderate

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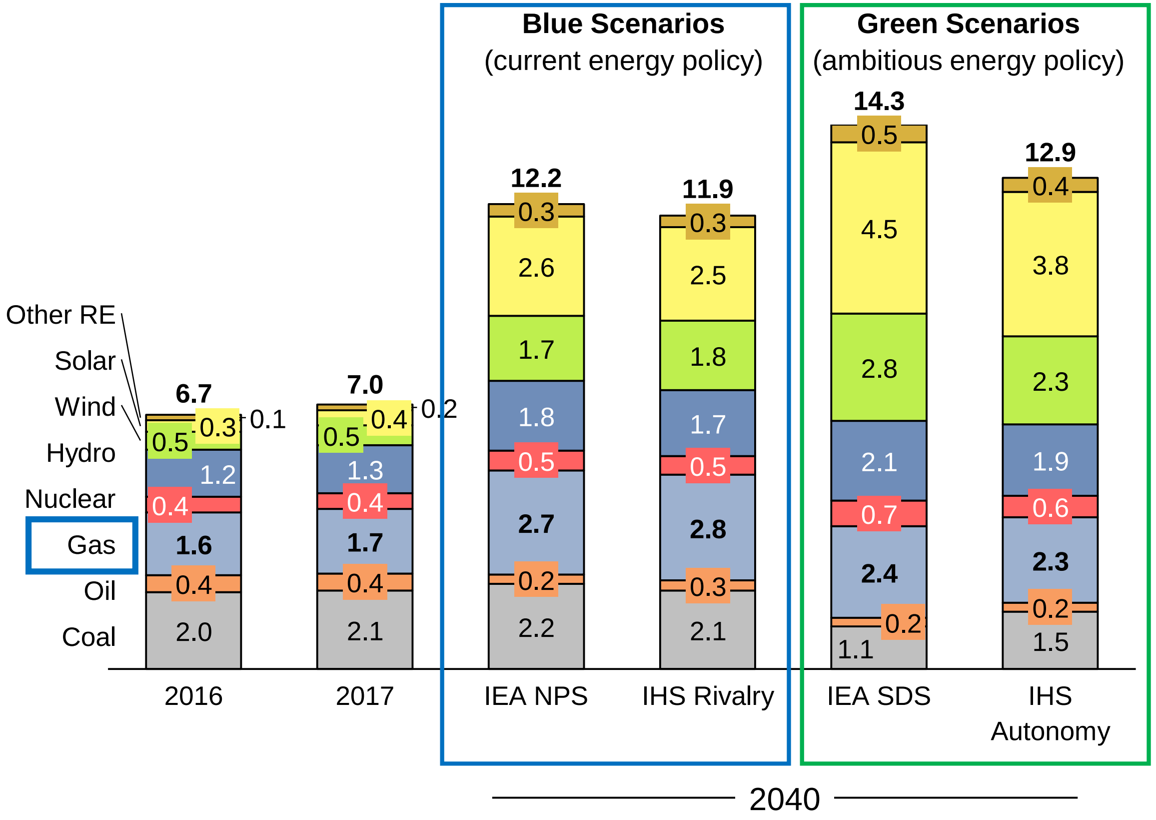
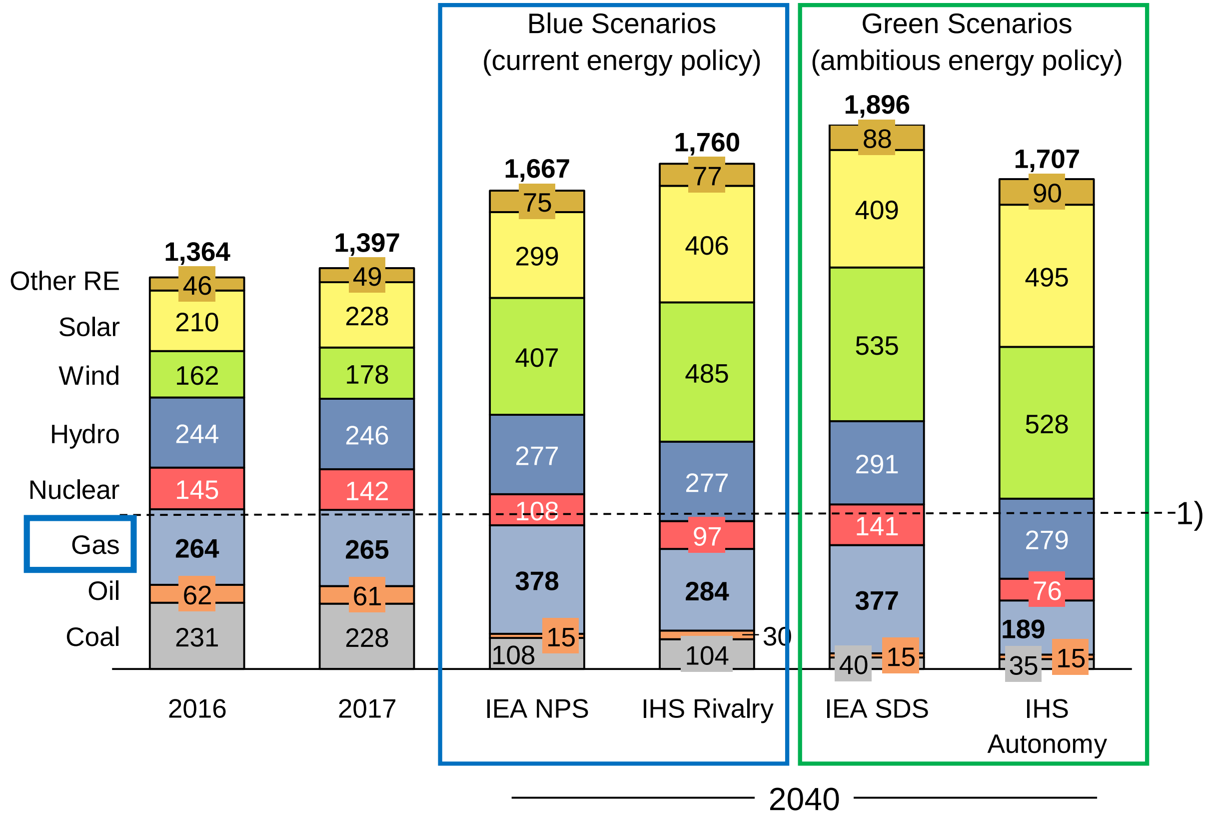
World: power generation capacity (1,000 GW)



Europe: power generation capacity (GW)



1) Typical peak load level in Europe 530 GW

Beside RE expansion significant new build of gas power plants required for global energy transition

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World: gas power generation capacity in detail

2018-2040	NPS / Rivalry Blue Scenarios (current energy policy)	SDS / Autonomy Green Scenarios (ambitious energy policy)
Retirements	600-650 GW	
Capacity additions	**1700 GW**	**1350 GW**
Installed Capacity	+1050-1100 GW	+700-750 GW

Europe: gas power generation capacity in detail

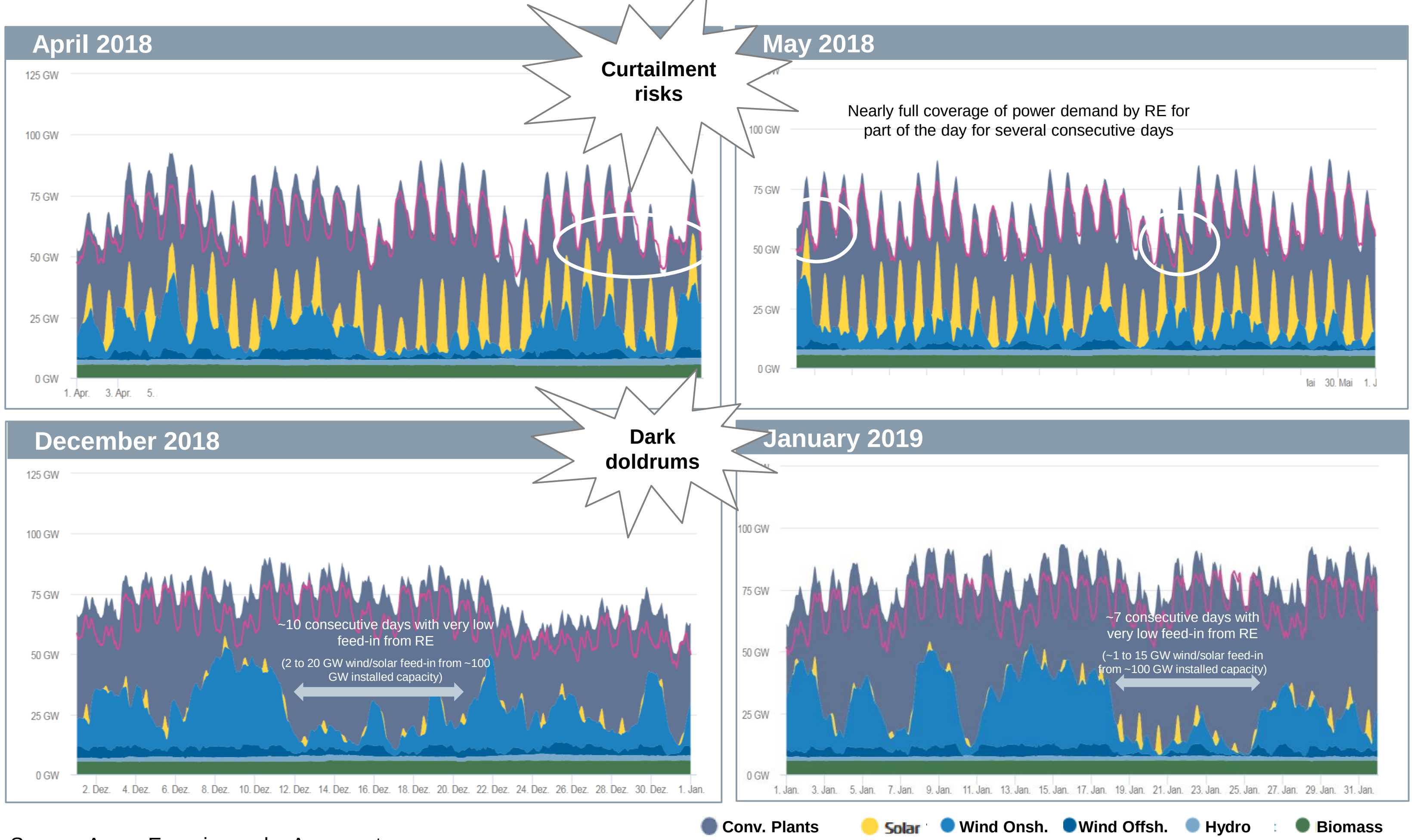
2018-2040	NPS / Rivalry Blue Scenarios (current energy policy)	SDS / Autonomy Green Scenarios (ambitious energy policy)
Retirements	100-150 GW	
Capacity additions	**150-260 GW**	**60-260 GW**
Installed Capacity	+50-110 GW	-40..+110 GW

New build of gas power plants driven by:

- **Replacement of coal and nuclear power plants** (Coal-to-Gas shift)
- **Accompanying expansion of fluctuating renewables** (firm, dispatchable capacity)
- **Ageing of existing gas power plants**
- **Split of new builds into CHP, CCPP and peaker plants** (GTPP)

Wind and Solar power are the dedicated pillars of a decarbonized energy system, but fluctuation is challenging

Germany: Daily power generation profiles for Renewables and Conventional Power Plants



Source: Agora Energiewende, Agorameter

Showcase Germany

Installed Wind/Solar Capacity:

Status December 2016:

Wind Power	**59 GW**
Solar PV	**46 GW**

Projections for 2050:

Wind Power	190-210 GW
Solar PV	110-180 GW

Contribution of Wind/Solar to firm capacity at time of peak load:

- **Wind Power typically <5 GW for periods of 8-10 consecutive days several times a year**
- **Solar PV always 0 GW at time of peak load (7 p.m.) every winter day**

Phase-out of coal in power generation is targeted in numerous countries in Europe, in some for nuclear power as well

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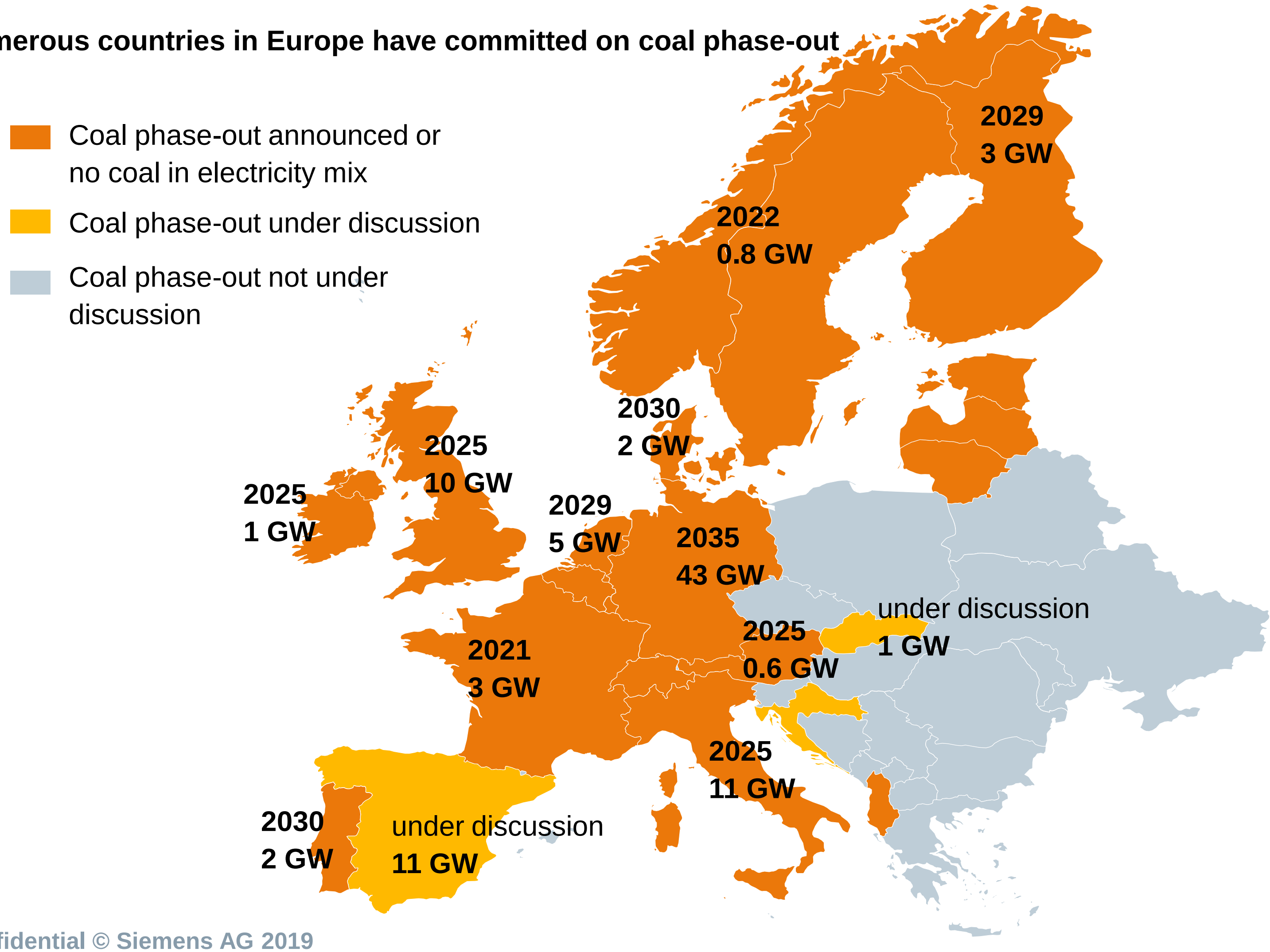
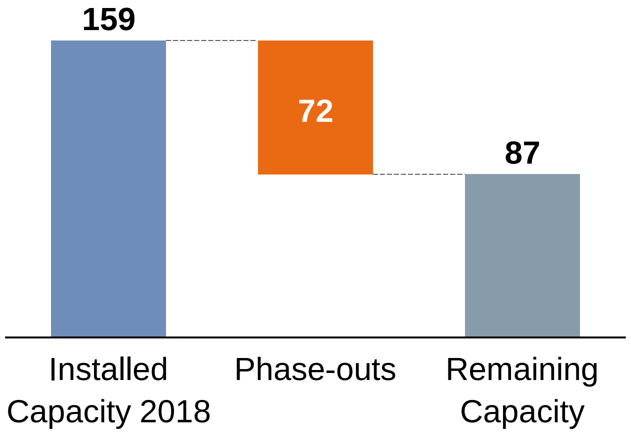
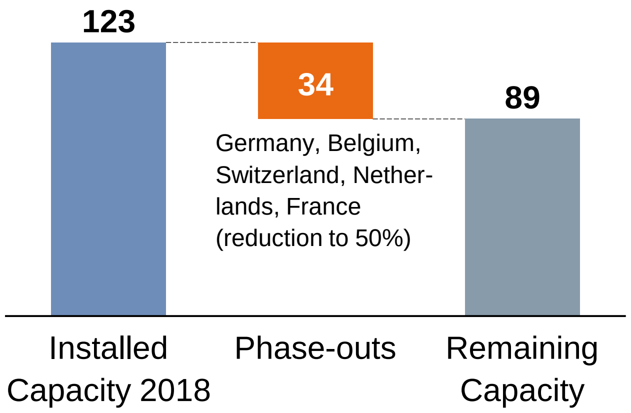
Numerous countries in Europe have committed on coal phase-out



Reduction in Coal power capacity in Europe (GW)



Reduction in Nuclear power capacity in Europe (GW)



Sweden: retirement of thermal power plants causes decrease in dispatchable capacity despite renewable installations

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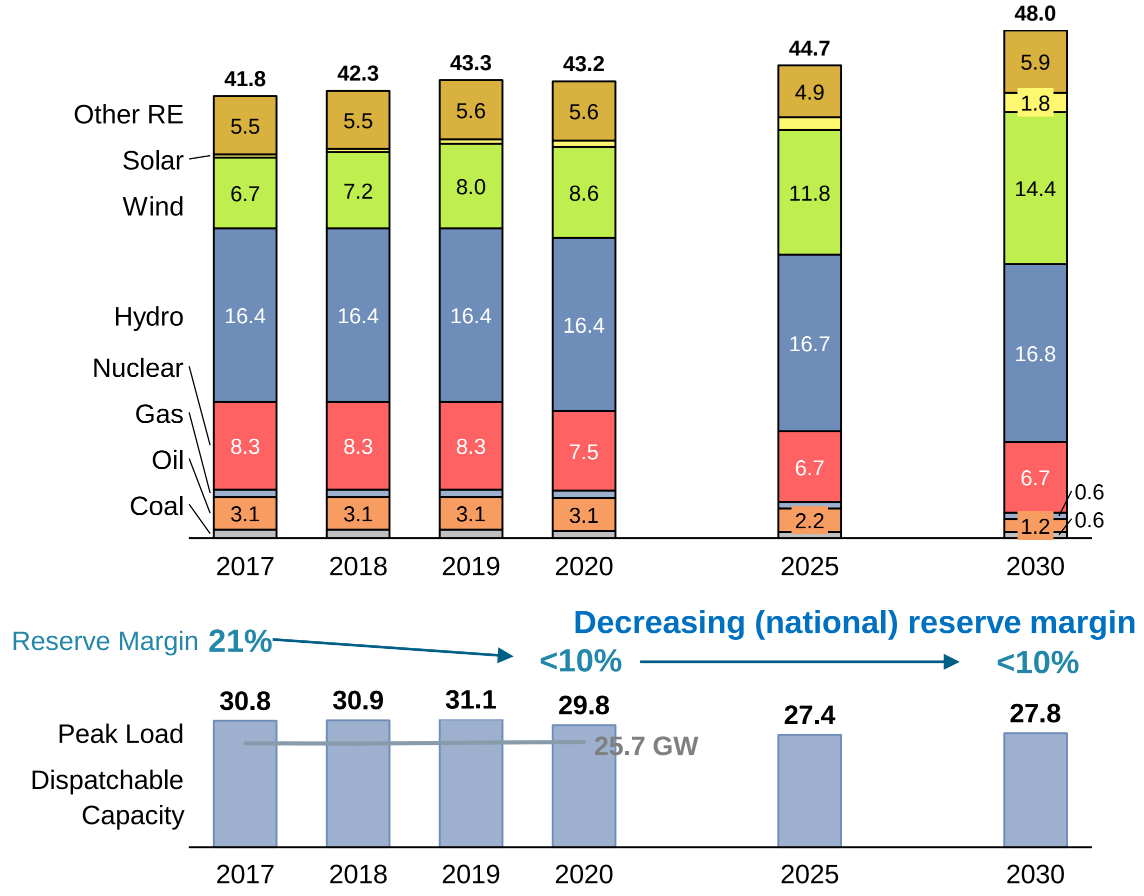
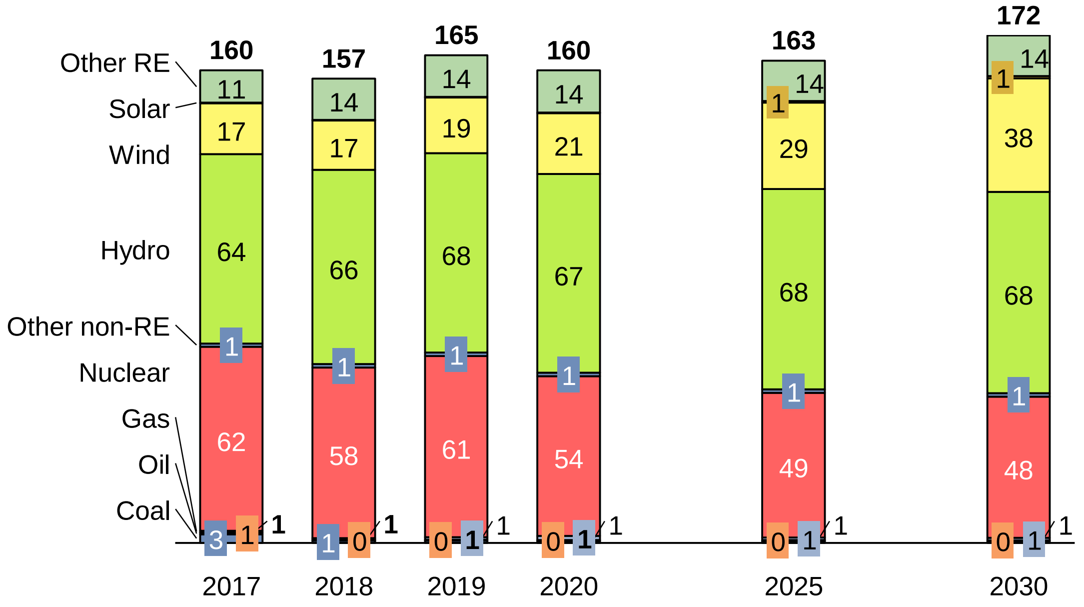
Sweden: power generation capacity (GW)



Source: IHS Markit, July 2018

Sweden: power generation (TWh)



Power plant load factors:

	2017		2030
Nuclear	6,300	→	7,200
Gas	900		1,600

Increasing load factors for conventional power plants (Nuclear, Gas) foreseen

Power-to-Hydrogen as a basis for sector coupling – Convert electricity in chemical form as energy carrier and feedstock

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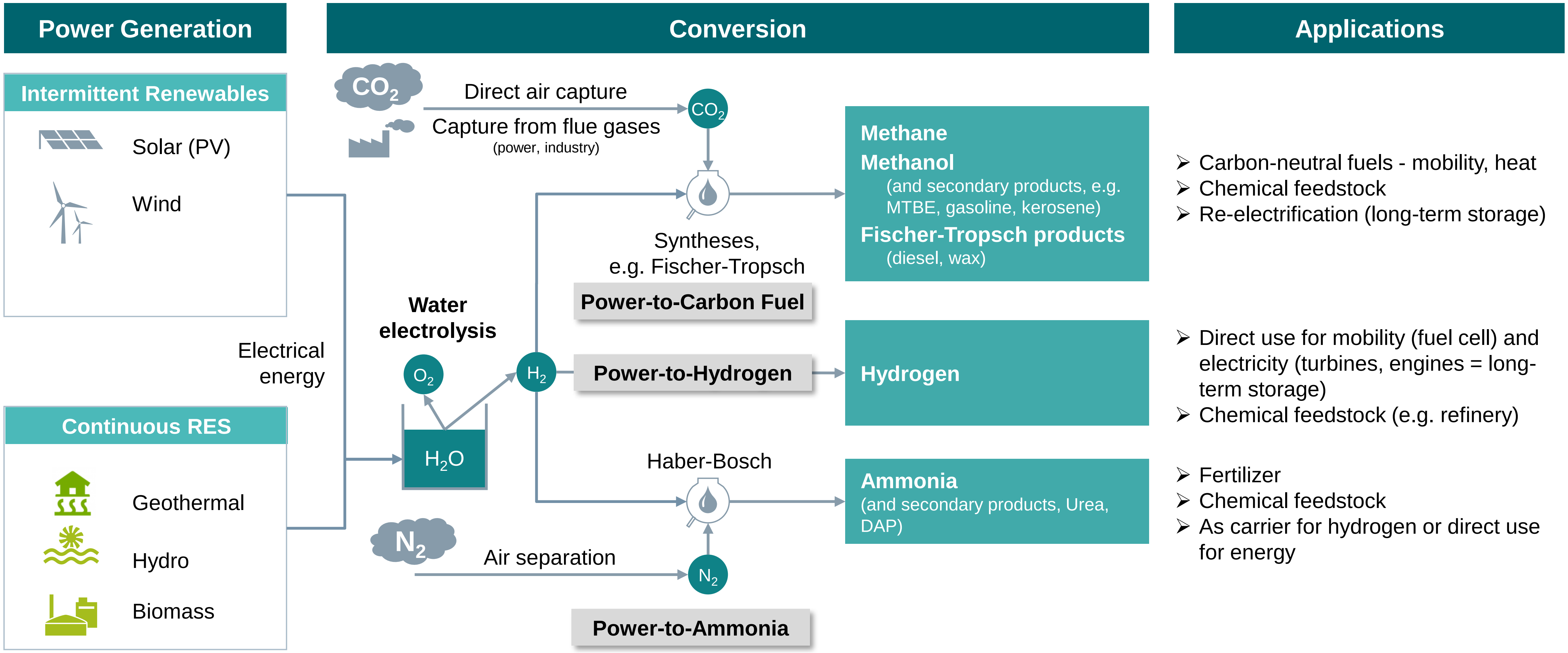

Siemens Hydrogen Gas Turbines for our sustainable future – The mission is to burn 100% hydrogen

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

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. Any project >25% requires dedicated engineering for package certification.

Higher H_2 contents to be discussed on a project specific basis

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

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

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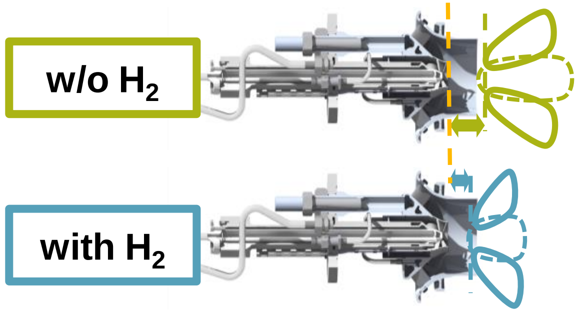
Differences of using hydrogen and natural gas as fuel in gas turbines

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



flame location closer to the burner

Resulting effects to be managed

- **Increased creation of NOx** for high amounts of H_2
- **Risk of flashbacks** for high amounts of H_2
- 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% H_2)

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
~86.500 op.h
~7.3 mio Nm³ of H_2

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

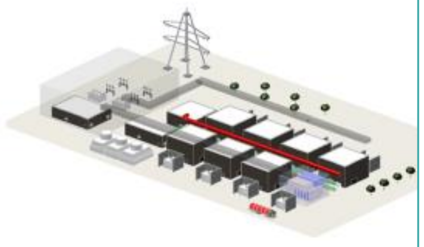
2018

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; Data op.h & Nm³ as of Jan. 2019