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2018-06-07 Forum Energiewende Vortragsabend 4:

Wasserstoff – Verlässlicher Energieträger der Zukunkft

Vortragsabend 4:
Wasserstoff – Verlässlicher Energieträger der Zukunft!

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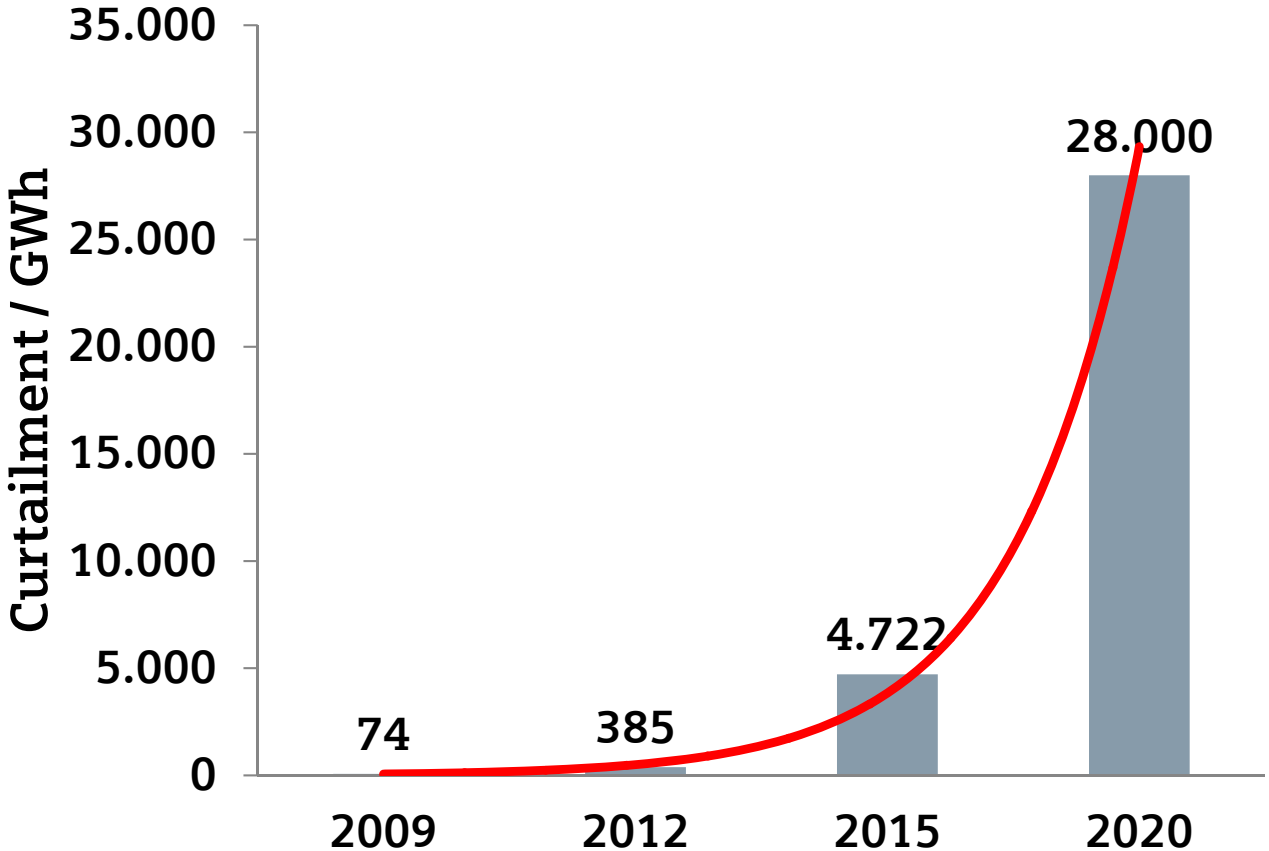
Nachhaltige Energiesysteme der Zukunft werden geprägt sein von häufigen Zeiten mit einem **massiven Überangebot von Energie** aus Windkraft- und Solarenergie-Anlagen. Andererseits wird es **saisonal** Zeiten geben, in denen **über einige Wochen hinweg nicht ausreichend Energie** aus diesen Anlagen für die Versorgung Deutschlands zur Verfügung steht. Wasserstoff kommt nach Meinung vieler Experten eine zentrale Rolle für den saisonalen Ausgleich zu. Mittels **Elektrolyse** gewonnen und bei hohem Druck von 200 bar in unterirdischen **Kavernen** gepresst, ließen sich so bis zu 130 **Terawattstunden elektrische Energie in Form von Wasserstoff speichern**, was fast einem Viertel des deutschen Stromverbrauchs pro Jahr entspricht. Aber auch durch den direkten Einsatz von **Wasserstoff in** speziellen **Gasturbinen** lässt sich Wasserstoff schon heute zur kurzfristigen Stabilisierung des Stromnetzes nutzen. Der Referent Erik Wolf wird über den aktuellen Stand der Technik, realisierte Projekte und Szenarien für unser zukünftiges Energiesystems berichten.

...massiven Überangebot von Energie...

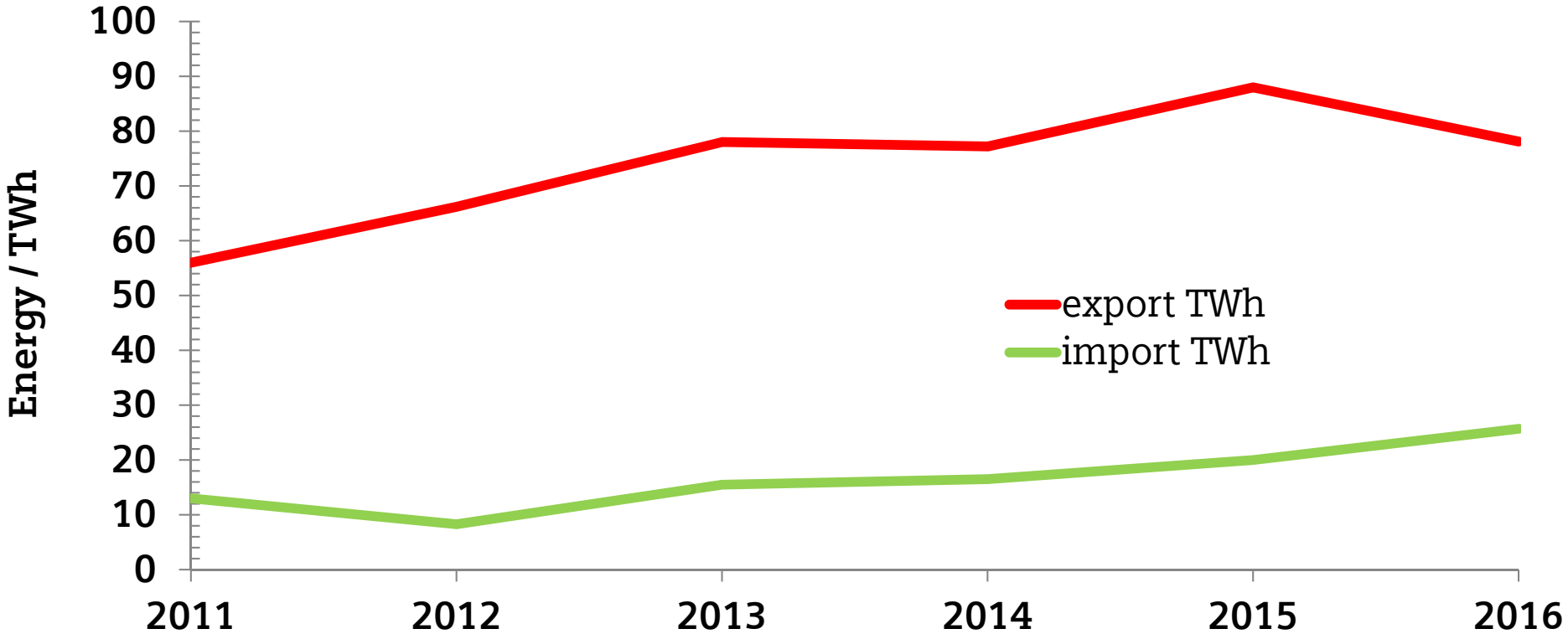
Curtailment of renewable energy

Germany ~ 6TWh

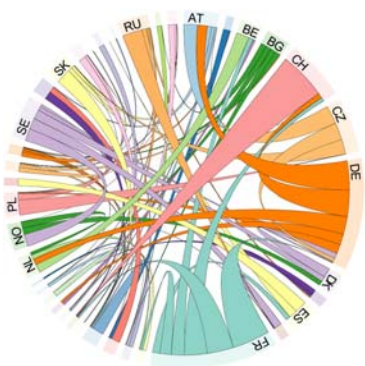


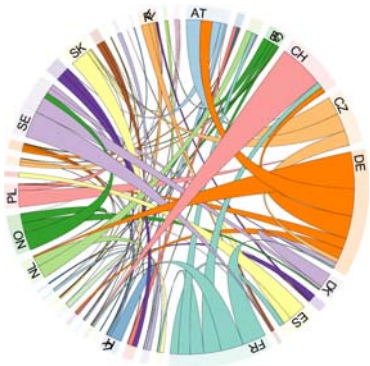
Biggest exporter of energy in Europe

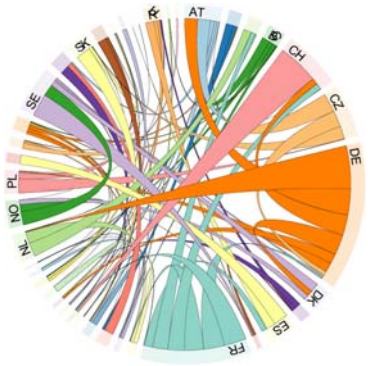
Germany ~ 60TWh

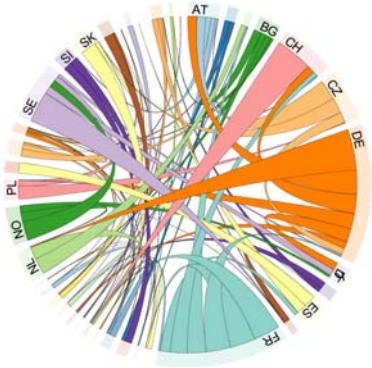


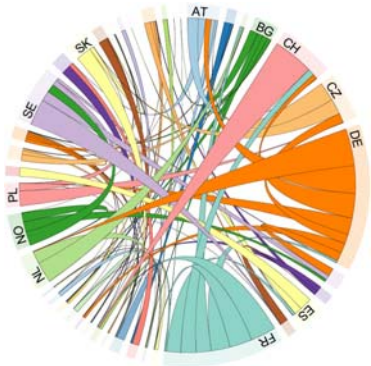
Source ENTSO-E

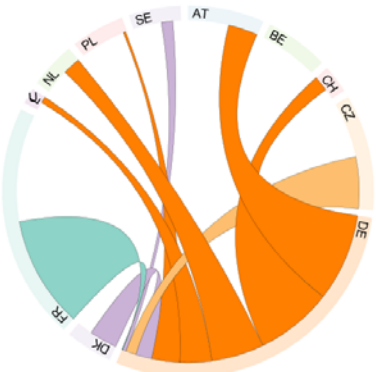


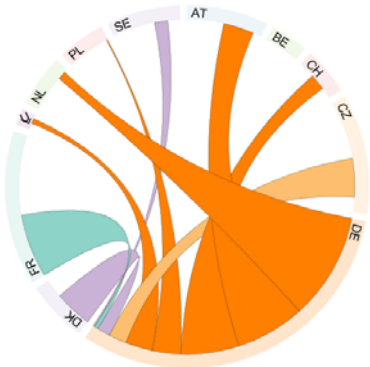


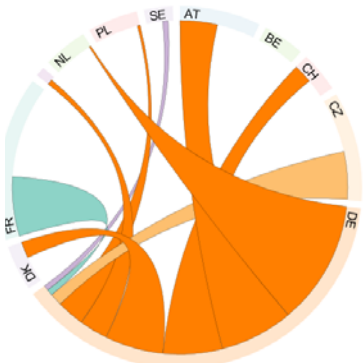


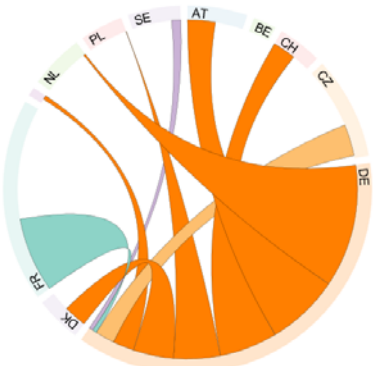


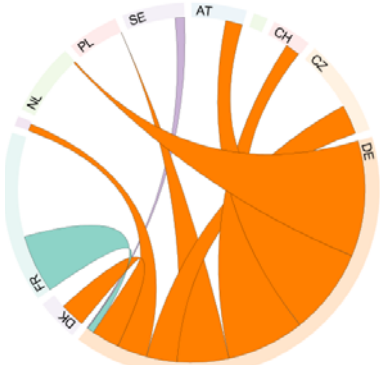












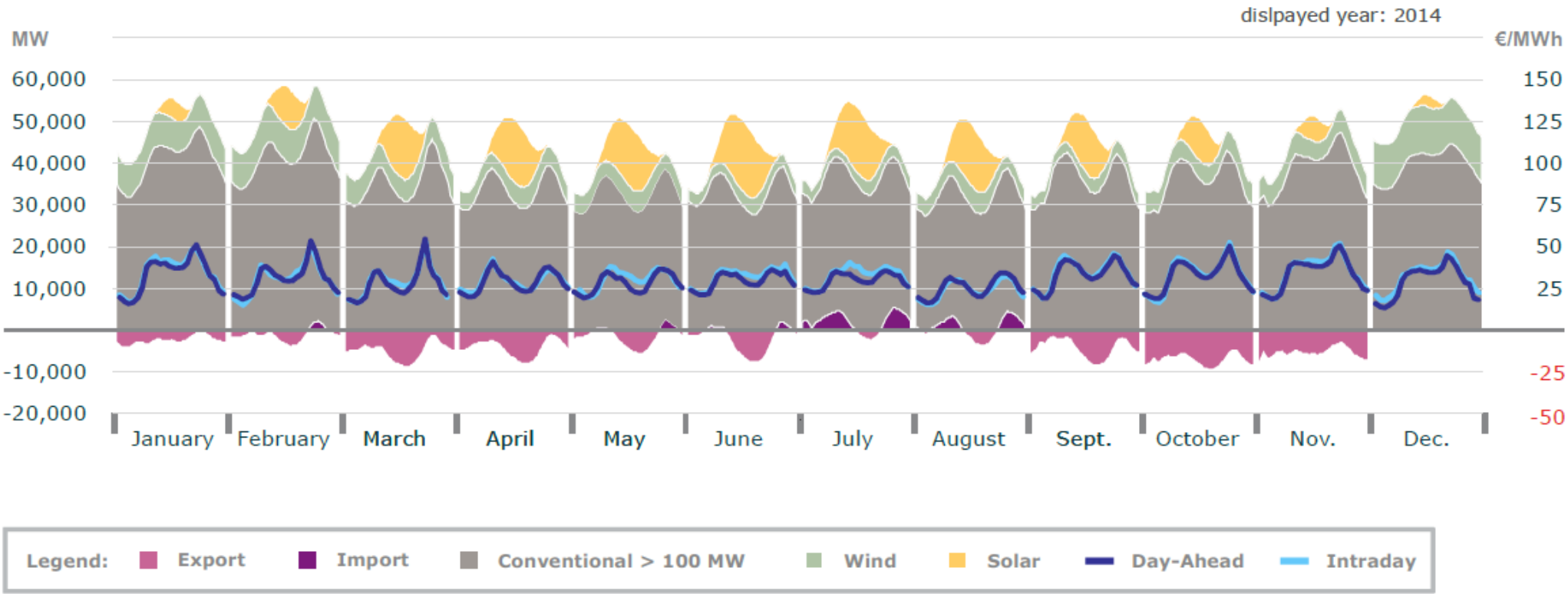
Germany is by far the largest exporter of energy in the EU

Energy Charts

2011	2012	2013	2014	2015
56TWh exp.	**66,2**TWh exp.	**78** TWh exp.	**77,2**TWh exp.	**88**TWh exp.
13TWh imp.	**8,3**TWh imp.	**15,5**TWh imp.	**16,5**TWh imp.	**20**TWh imp.

Source: https://www.energy-charts.de

Electricity Production and Spot-Prices: Diurnal Courses



 Source: https://www.energy-charts.de

EPEX Spot Market-Price 24h-Day Ahead

Surplus of Supplies erodes Market Price

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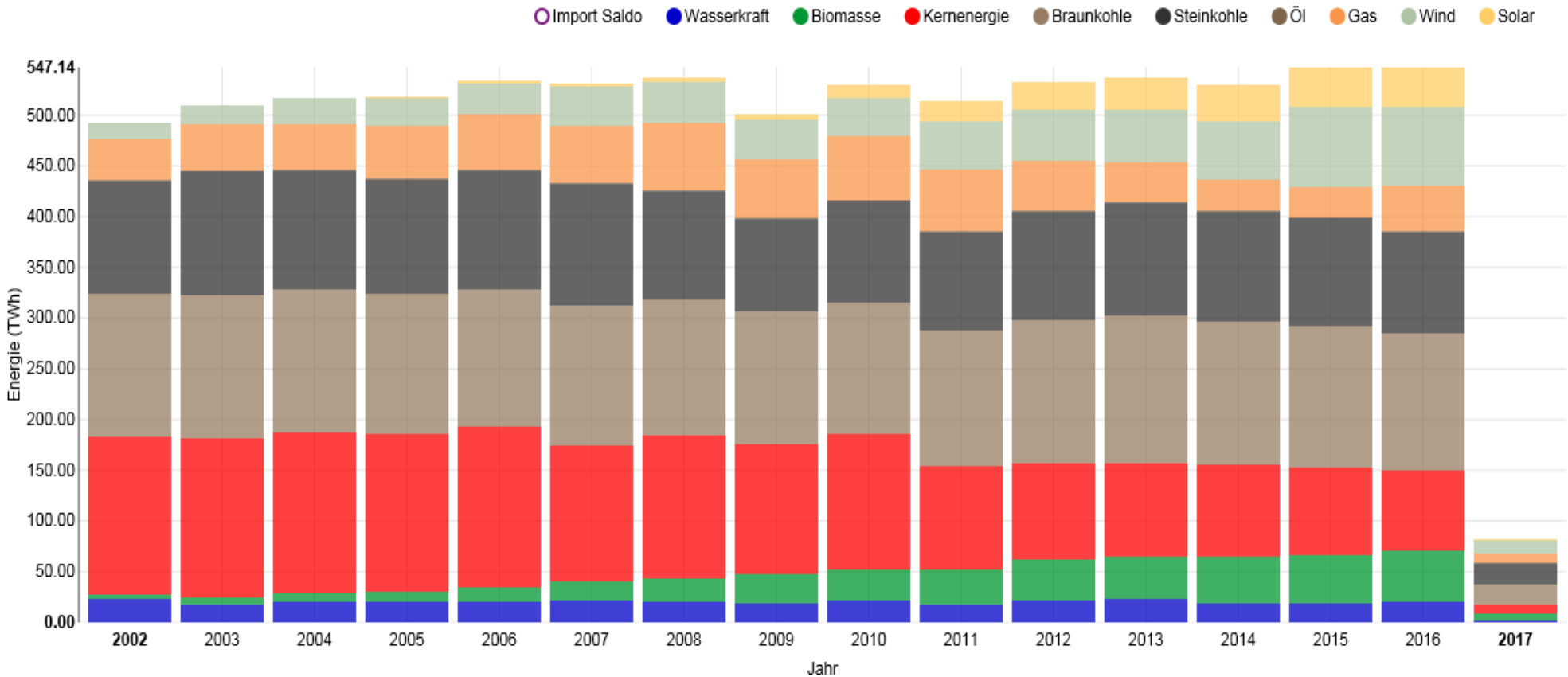
 Source: https://www.energy-charts.de

Power Generation Germany
Coal is the back bone, ~300TWh



Source: https://www.energy-charts.de

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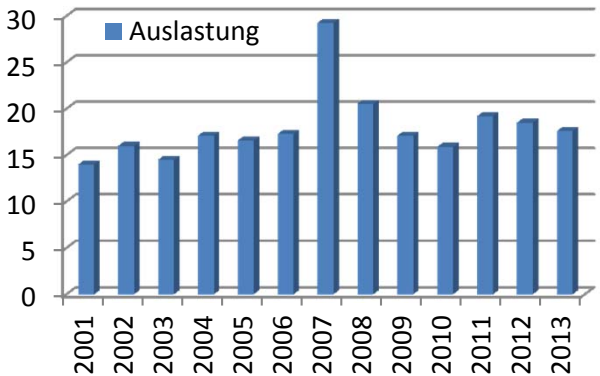
... saisonal Zeiten geben, in denen **über einige Wochen hinweg nicht ausreichend Energie ...**

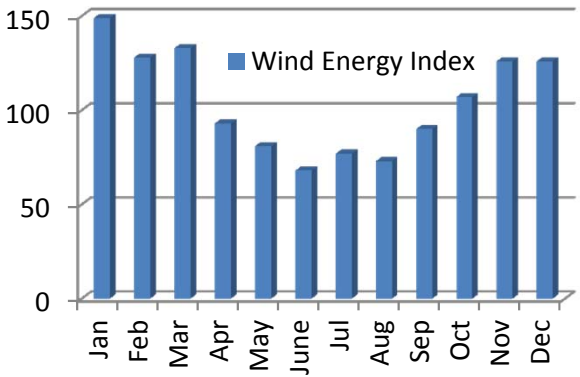
Characteristics of Wind Power

13 Jahre

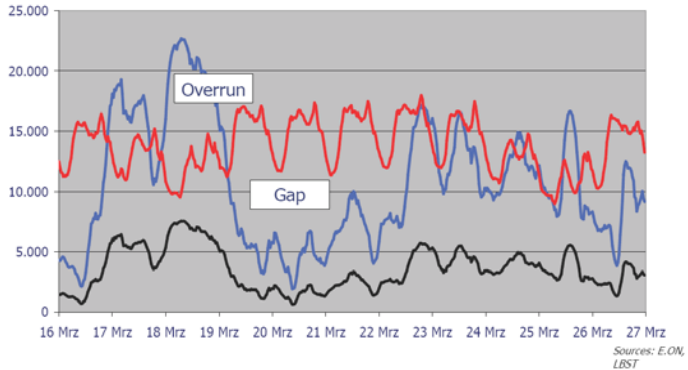


Quelle: https://de.wikipedia.org/wiki/Windenergie#Stromerzeugung_durch_Windenergie

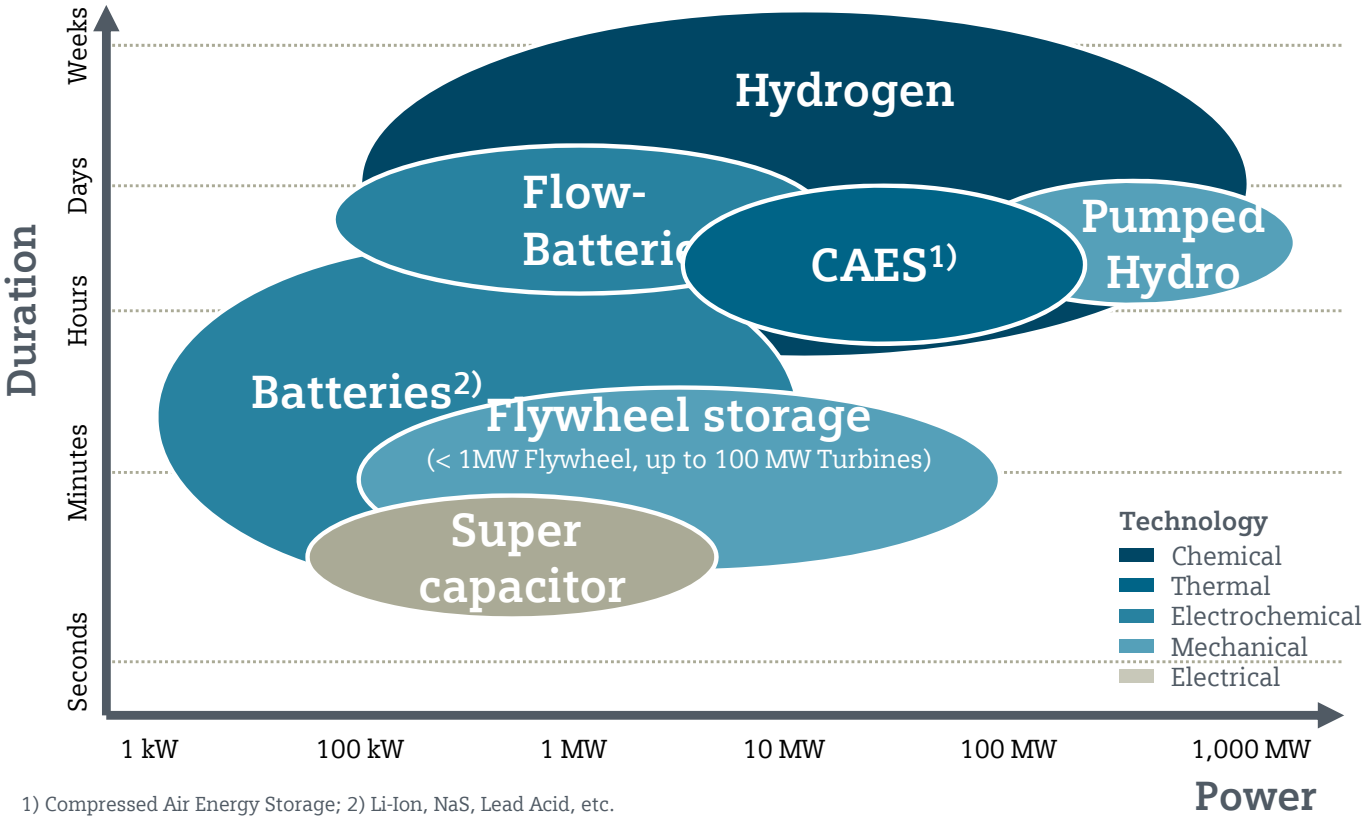
12 Monate



11 Tage



Ragone Diagram



Hydrogen can be stored cost-effectively and in large scale.

1) Compressed Air Energy Storage; 2) Li-Ion, NaS, Lead Acid, etc.

Today's challenges to integrate RE

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Grid stability

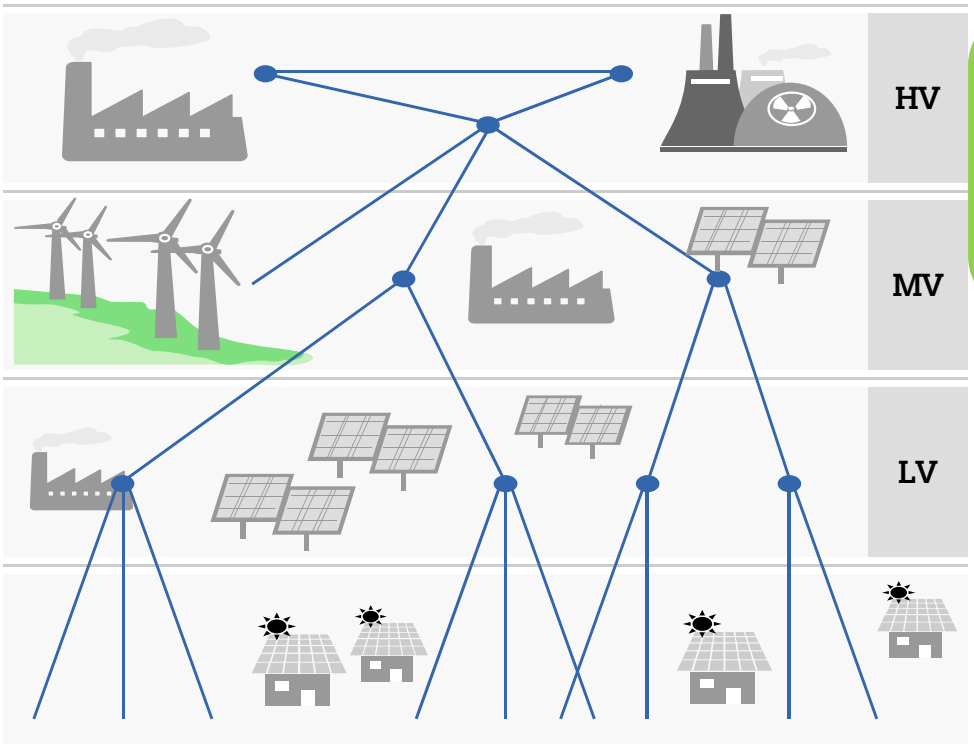
The increase in power electronic based energy feed-in impacts grid stability which is mainly ensured by synchronous generators today.

Control power reserve

As weather changes on short notice, so does in return the power generated by RE. Compensation is still provided by conventional generation units, so called must run capacity.

Electrical System of today

Grid stability mainly provided by the high voltage level



	S/S_K	df/dt	$Q_{Ü/U}$	J	dU/dt	dP/dt	BS	ER*)
HV	+	+	+	+	+	+	+	+
MV	0	0	+	0	0	+	0	+
LV	-	-	0	-	+	+	-	0
	-	-	-	-	0	0	-	0

*) Energy Reserve **+** . . . High impact **0** . . . Medium impact **-** . . . No impact

Electrical System of tomorrow
Power electronic based feed-in impact

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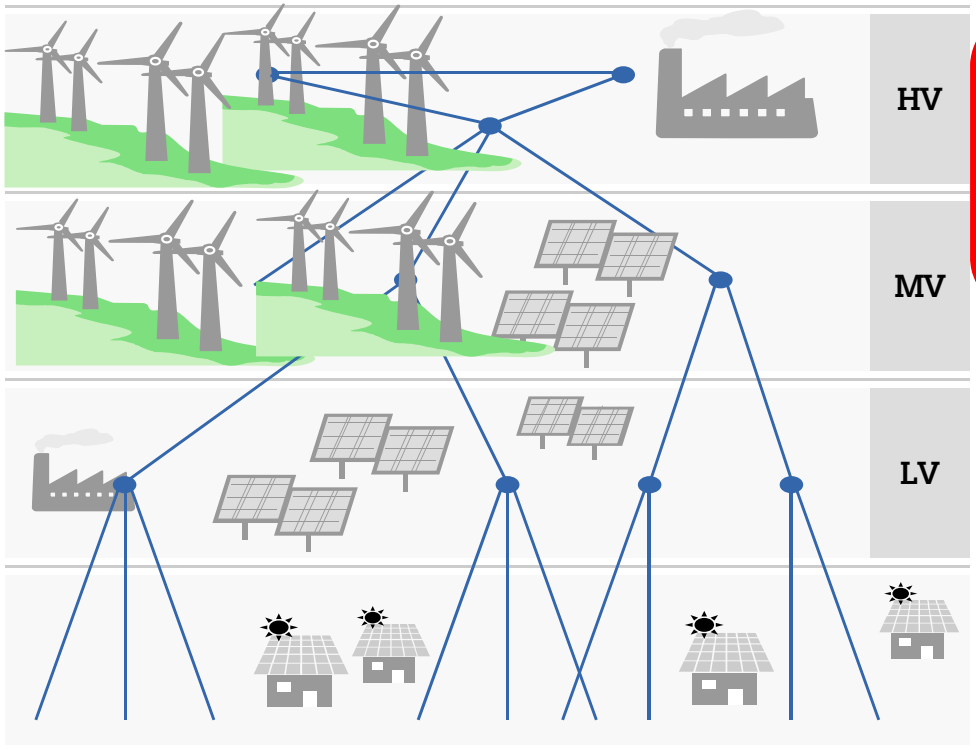

	S/S_K	df/dt	$Q_{Ü/U}$	J	dU/dt	dP/dt	BS	ER*)
HV	0	0	0	0	0	0	0	0
MV	0	0	0	0	0	0	0	0
LV	-	-	0	-	+	+	-	0
	-	-	-	-	0	0	-	0

*) Energy Reserve **+** . . . High impact **0** . . . Medium impact **-** . . . No impact

Electrical System of tomorrow
Grid stability ensured by EES System

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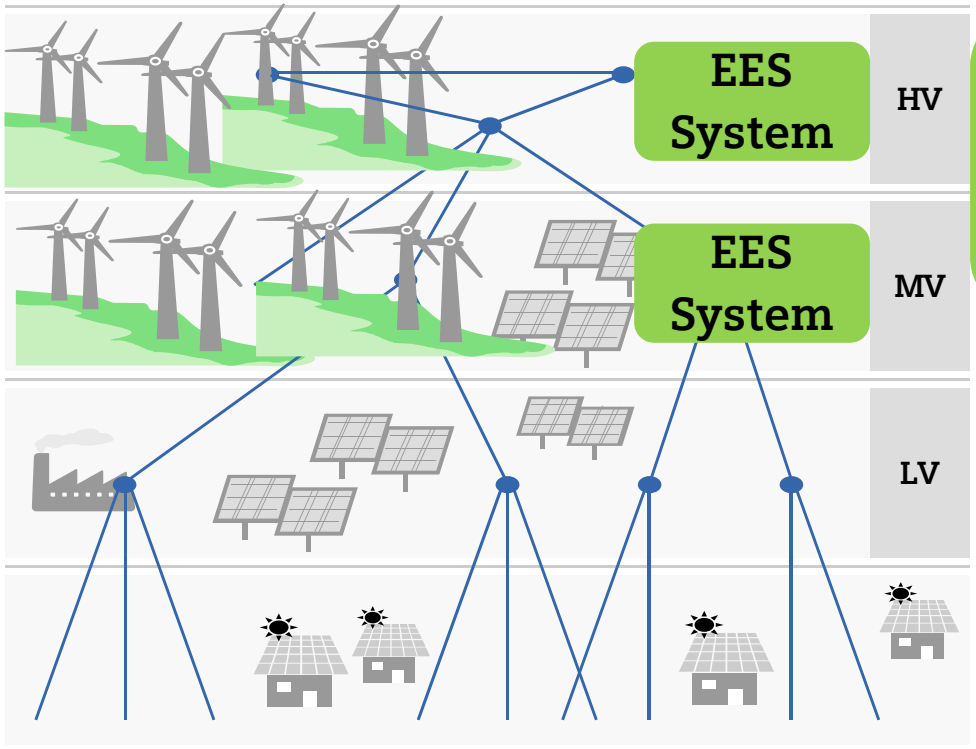

	S/S_K	df/dt	$Q_{Ü/U}$	J	dU/dt	dP/dt	BS	ER*)
HV	+	+	+	+	+	+	+	+
MV	0	0	+	0	0	+	0	+
LV	-	-	0	-	+	+	-	0
	-	-	-	-	0	0	-	0

*) Energy Reserve **+** . . . High impact **0** . . . Medium impact **-** . . . No impact

Today's challenges to integrate RE

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Grid stability

The increase in power electronic based energy feed-in impacts grid stability which is mainly ensured by synchronous generators today.

Control power reserve

As weather changes on short notice, so does in return the power generated by RE. Compensation is still provided by conventional generation units, so called must run capacity.

Demand for balancing power 2012

...it further increases

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		Gradienten der VNL je Zeitbereich						Max. VNL
		1 min	5 min	15 min	1 h	2 h	8 h	
Amprion	negativ	-260	-500	-800	-2.190	-3.650	-7.470	20.800
	positiv	250	530	1.330	3.360	5.560	8.560	
TenneT	negativ	-270	-410	-1.130	-3.230	-4.710	-10.650	18.200
	positiv	240	470	1.270	3.210	5.370	9.710	
50Hz	negativ	-290	-420	-770	-2.080	-3.140	-7.080	9.800
	positiv	220	420	1.070	2.120	3.360	7.360	
TNG	negativ	-150	-280	-360	-950	-1.490	-3.460	8.600
	positiv	160	-270	630	1.500	2.340	3.980	
4 ÜNB	negativ	-400	-950	-1.900	-6.000	-11.200	-26.470	54.900
	positiv	500	1.220	3.630	9.520	15.180	27.190	

Source: Studie zur Ermittlung der technischen Mindestlistung des konventionellen Kraftwerksparktes zur Gewährleistung der Systemstabilität in den deutschen Übertragungsnetzen bei hoher Einspeisung aus erneuerbaren Energien

Balancing power (Regelenergiereserve)
...results in power feed-in

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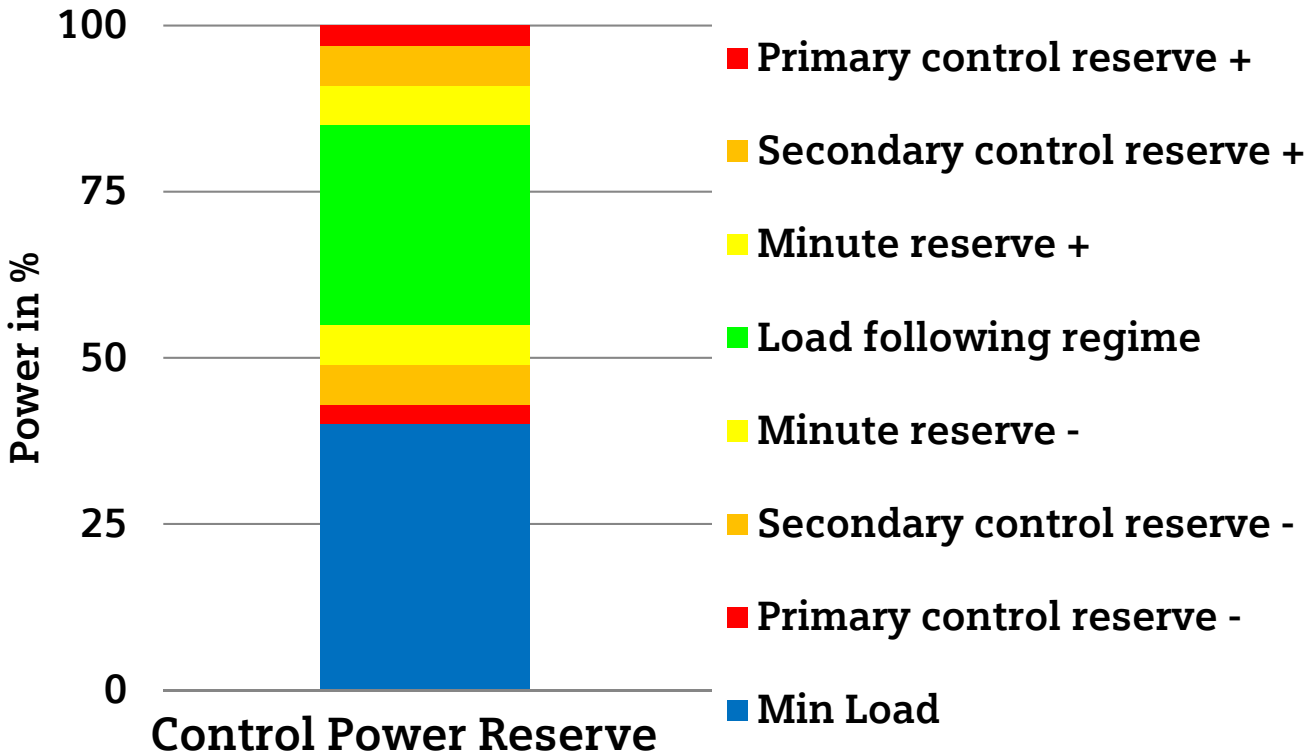
Must run power depends on grid load and RE-feed-in

Low load & high RE-feed-in ~20GW

High load & high RE-feed-in ~ 40GW



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CO_2 Reduction Goals w/o Storage not achievable

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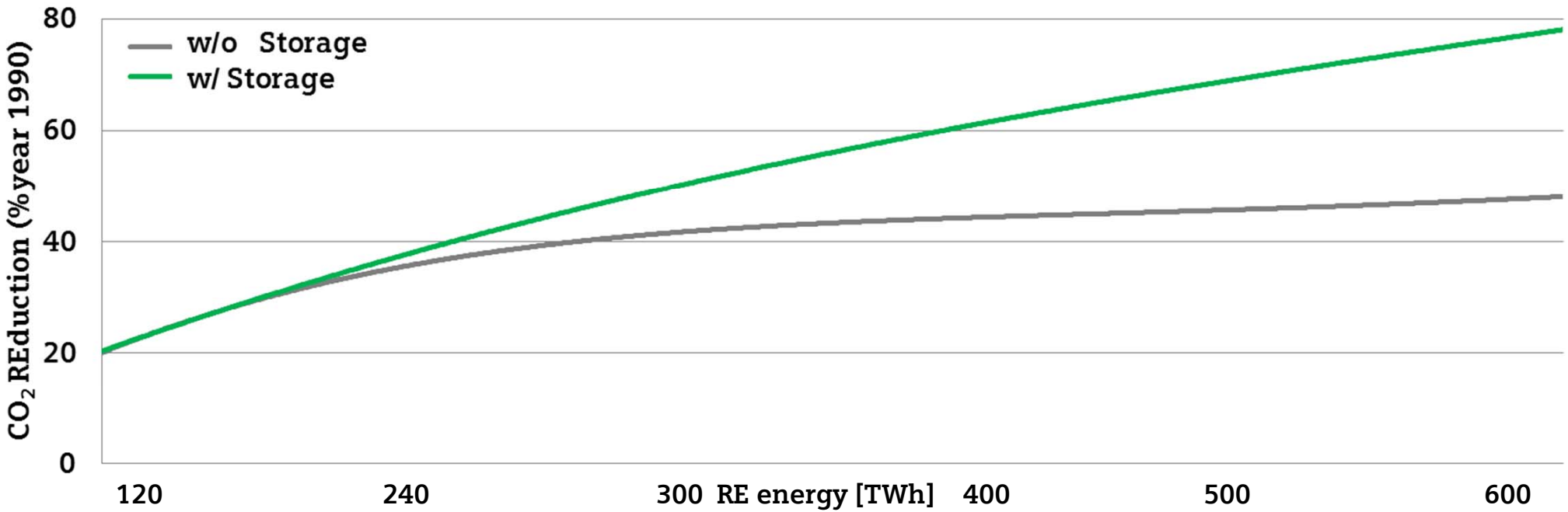
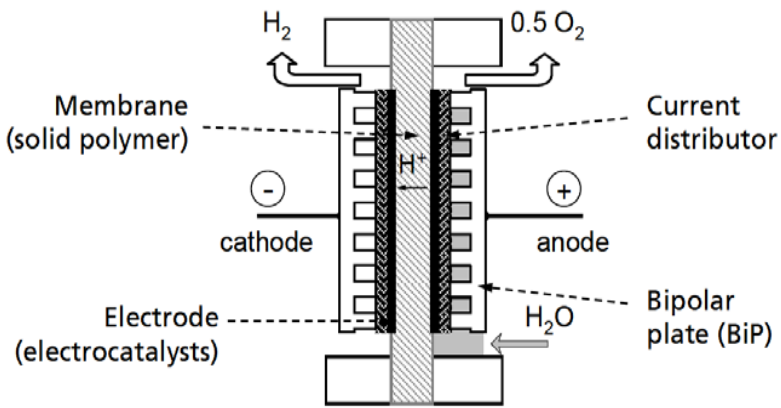
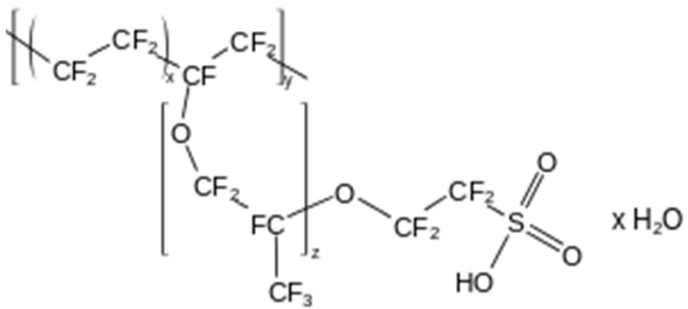
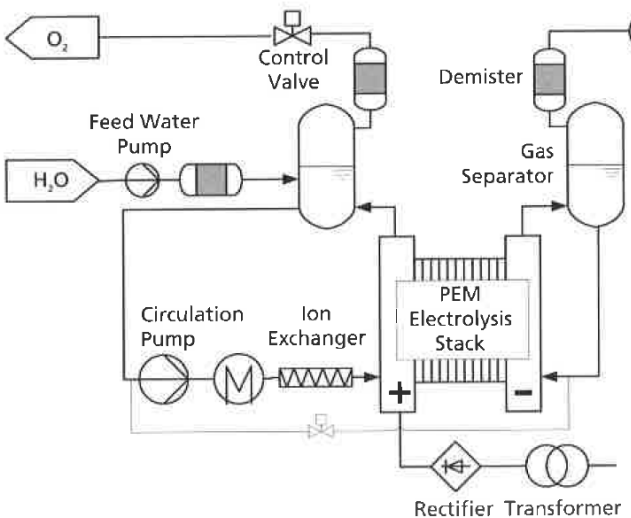


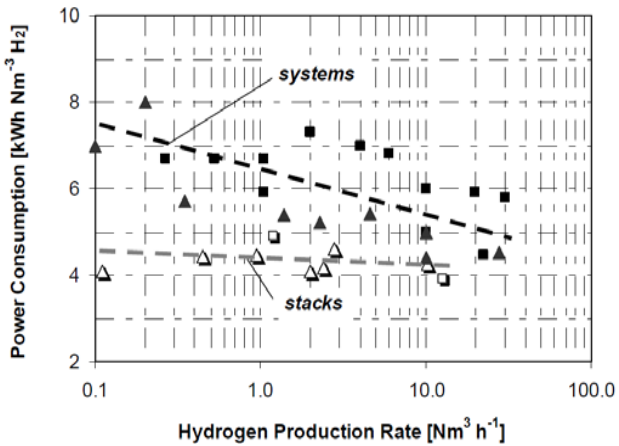
… Elektrolyse …

Hydrogen Electrolyzer
Proton Exchange Membrane









Quelle: Hydrogen Energy 2010, ISBN: 978-3-527-32711-9

Evolution of Siemens' PEM Electrolyzer Technology

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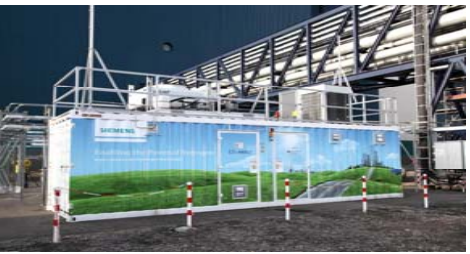

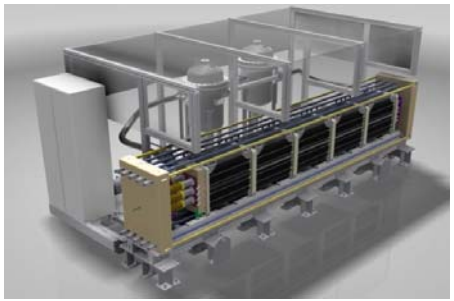

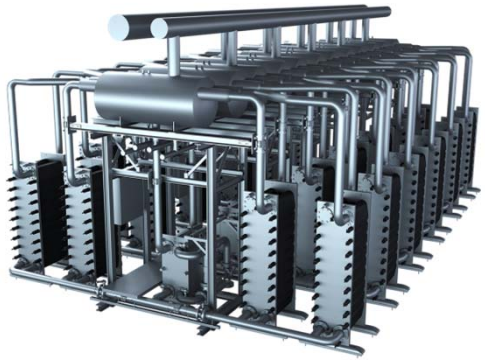

Silyzer 100
100/300kW
2012

Development
Silyzer 200
1,250kW
2013

6,000kW Energy
Park Mainz
2015

Development
Silyzer 300
2015

6,000kW
Silyzer 300
2018

300MW
Silyzer 300
2020

… elektrische Energie in Form von Wasserstoff speichern …

Hydrogen generation
General process chart and use cases

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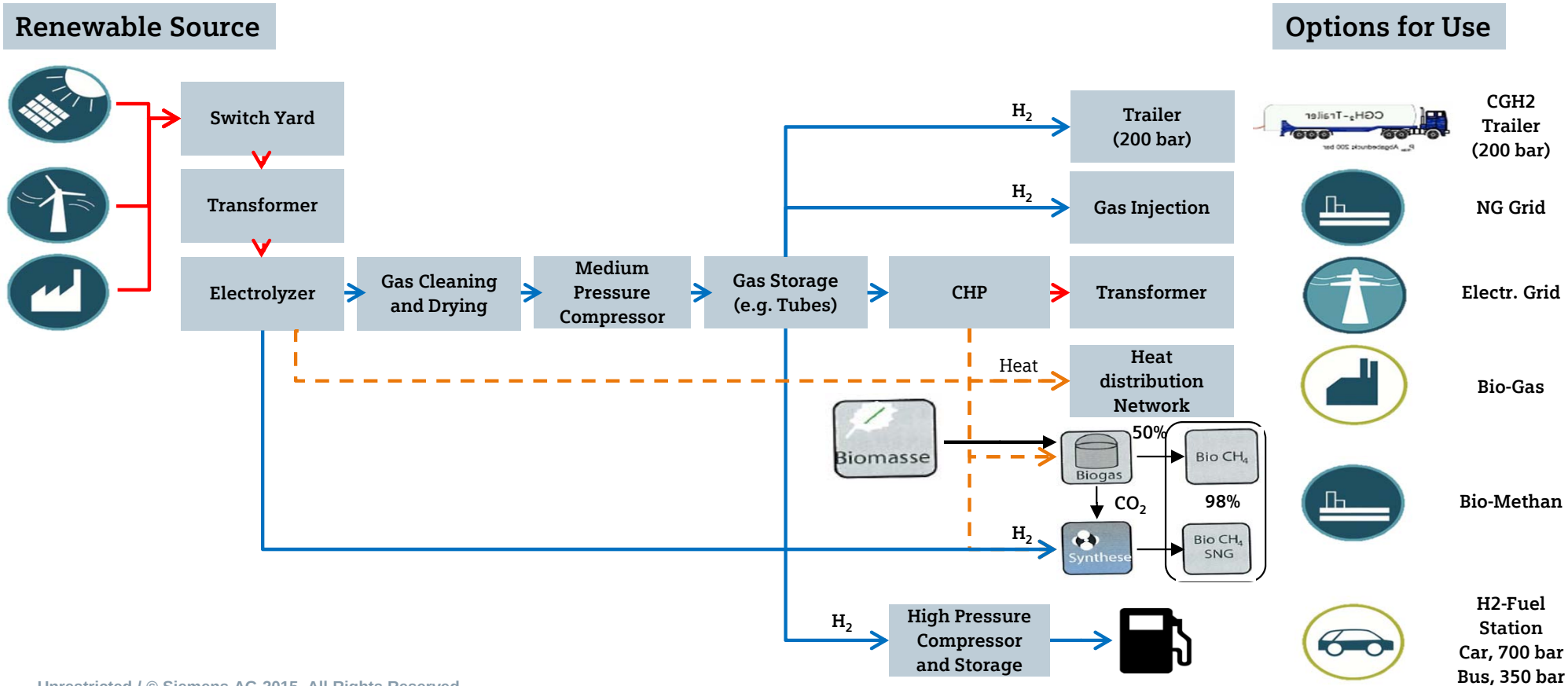

Power to Gas (Hydrogen), how it looks like

Gas Storage (price estimates per $kWh_{(th)}$)

Low pressure vessel	**150MWh** 15€ - 60€
High pressure vessel	**2.250MWh** 13€ - 50€
High pressure tube	**4.300MWh** 5€ - 30€
Cavern	**240.000 MWh** 0,12€ - 0,3€

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… Kavernen …
… Terawattstunden…

Back-up
Underground Storage in General

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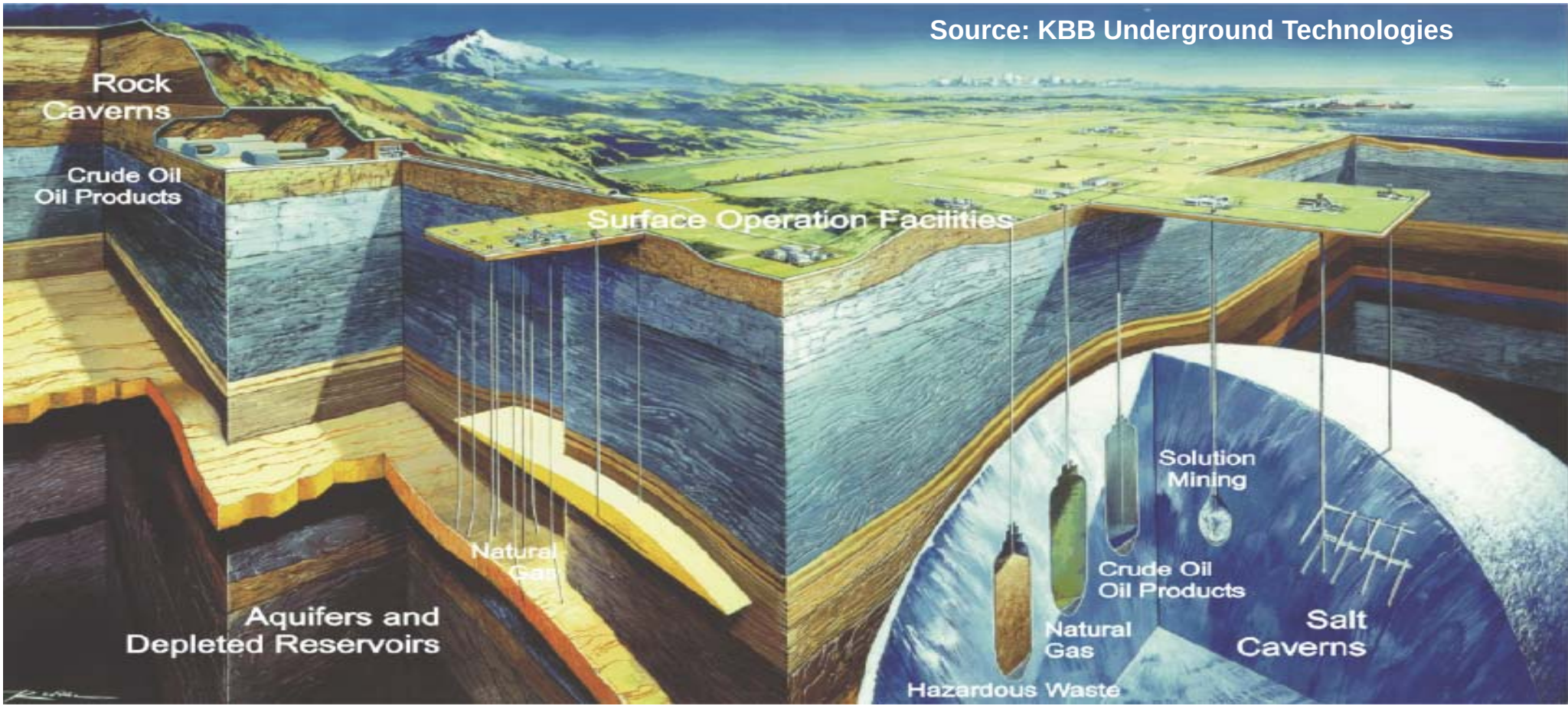

Power to Gas (Hydrogen), how it looks like

Reconversion of H_2 to electricity & heat, kW to MW

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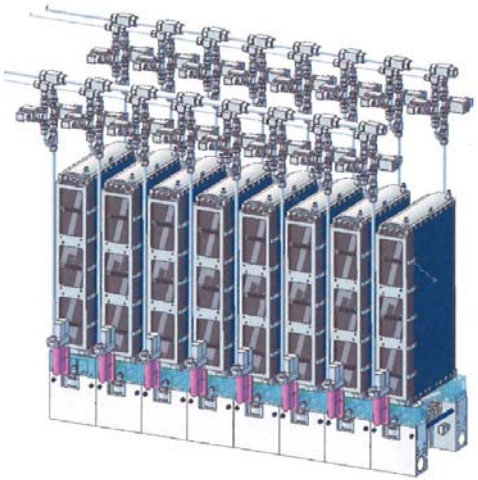
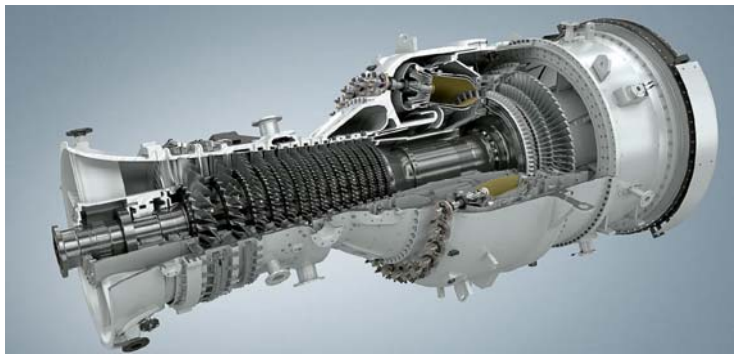


		Cyl	Displac.	Power (kW)
SFGLD	240	8L	24	250
SFGLD	480	16V	48	500



Fuel Cell
kW – MW, η≈ 58%

Gas Motor
kW – MW, η≈ 35%

Gas Turbine
25 – 50 MW, η≈ 35% - 57%

Grid Integration

Wide Range of Power, Decentral to Central Applications

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Application cases by location of storage

Central	Decentral
Large Utilities	Small utilities, municipalities, industry – prosumer

Pumped storage

Power to Power

Grid balancing and stability

H2

Electricity | H2/ Methane | Heat

FC Mobility

Power to Gas

Power to Power

Power to Heat

Battery

Power to Power

Grid stability and self-supply

Thermal

Heat

Power-to-Heat

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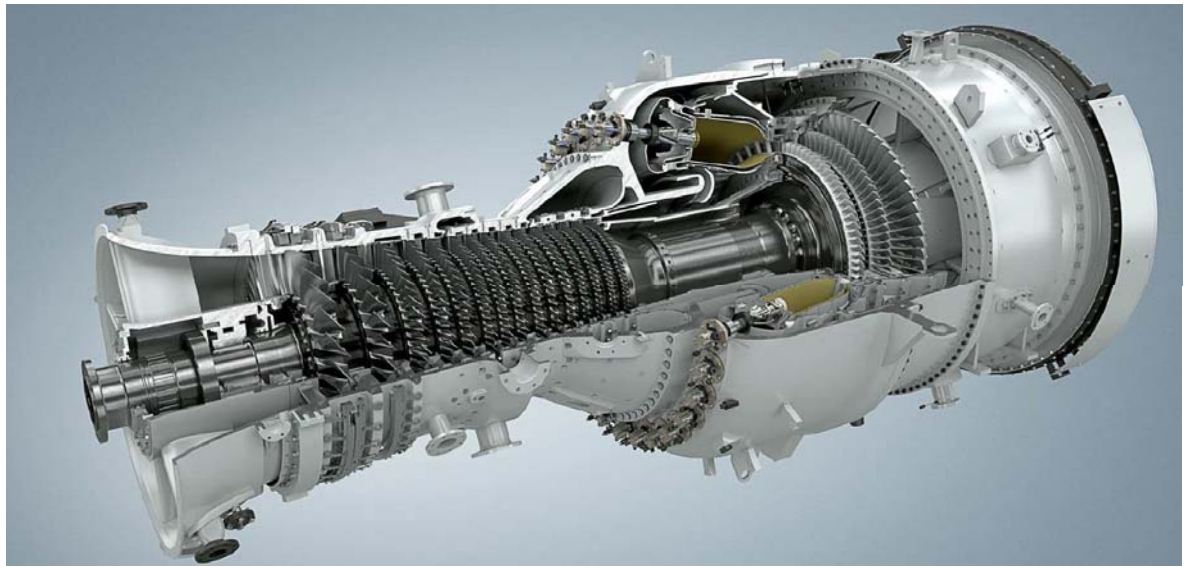
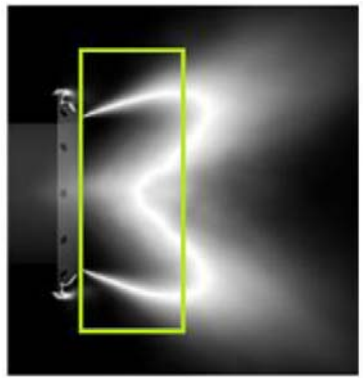
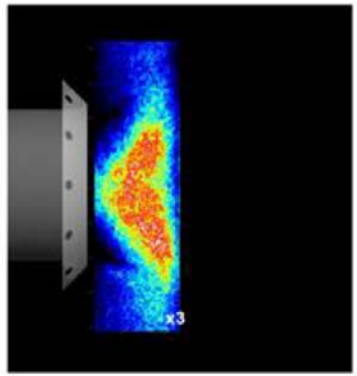
… Wasserstoff in speziellen Gasturbinen …

H_2 in Combustion Turbines

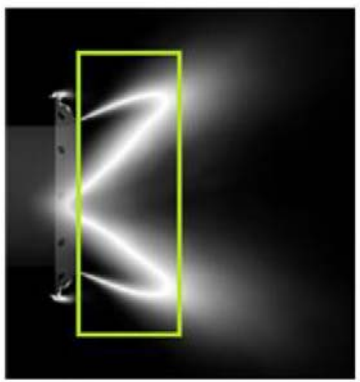




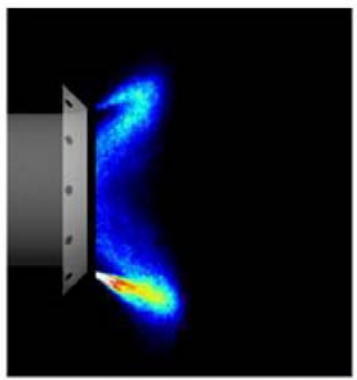
a) 0% H_2 numerical



b) 0% H_2 measured radicals

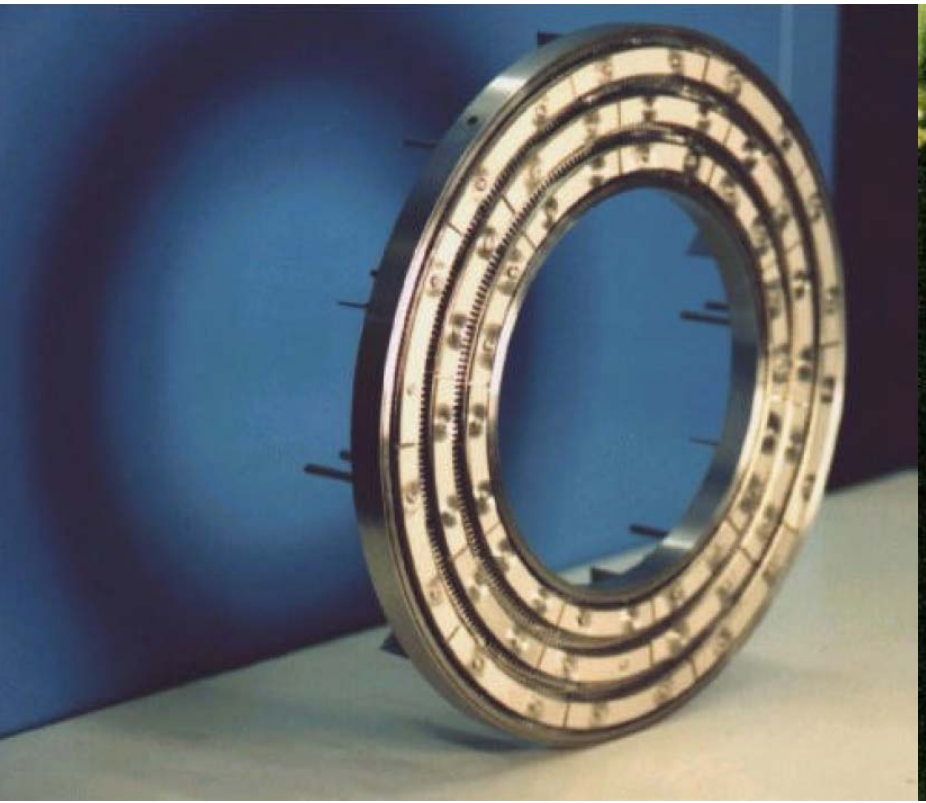


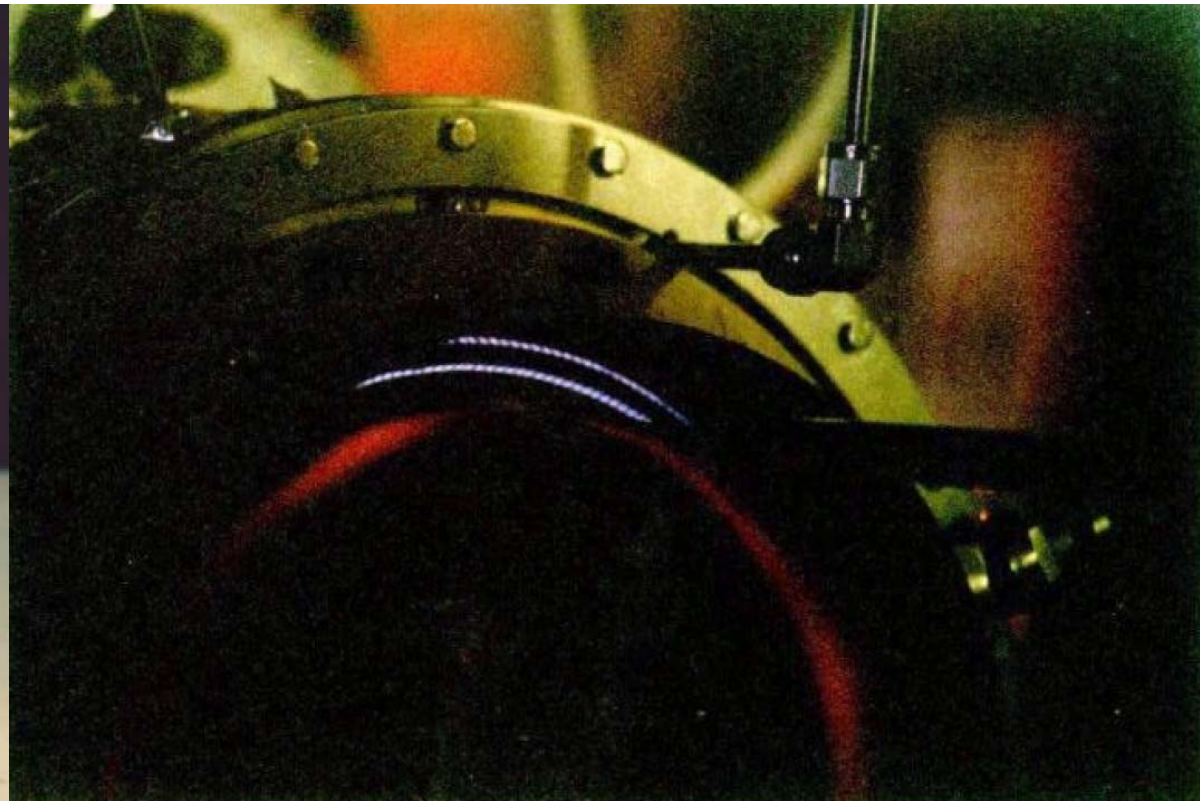
c) 80% H_2 numerical



d) 80% H_2 measured radicals

Evolution in H_2-Combustion

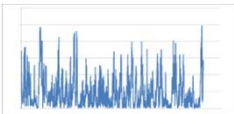




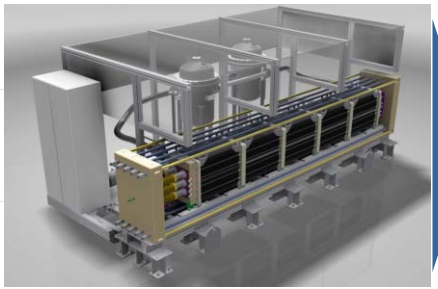
Hydrogen Energy Storage

SIEMENS

Generation



Conversion

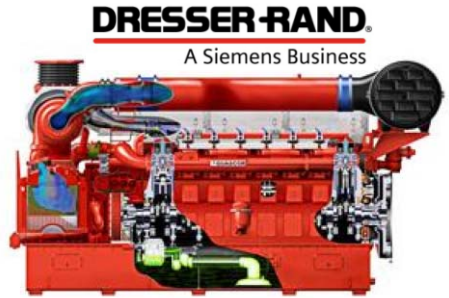


Power input [MVA]

Storage & Compression

Energy [MWh]

Generation



Power output [MVA]