Energy Storage Options for a Renewable Power Supply System

SEI Seminar Series – Toronto, March 12th, 2013

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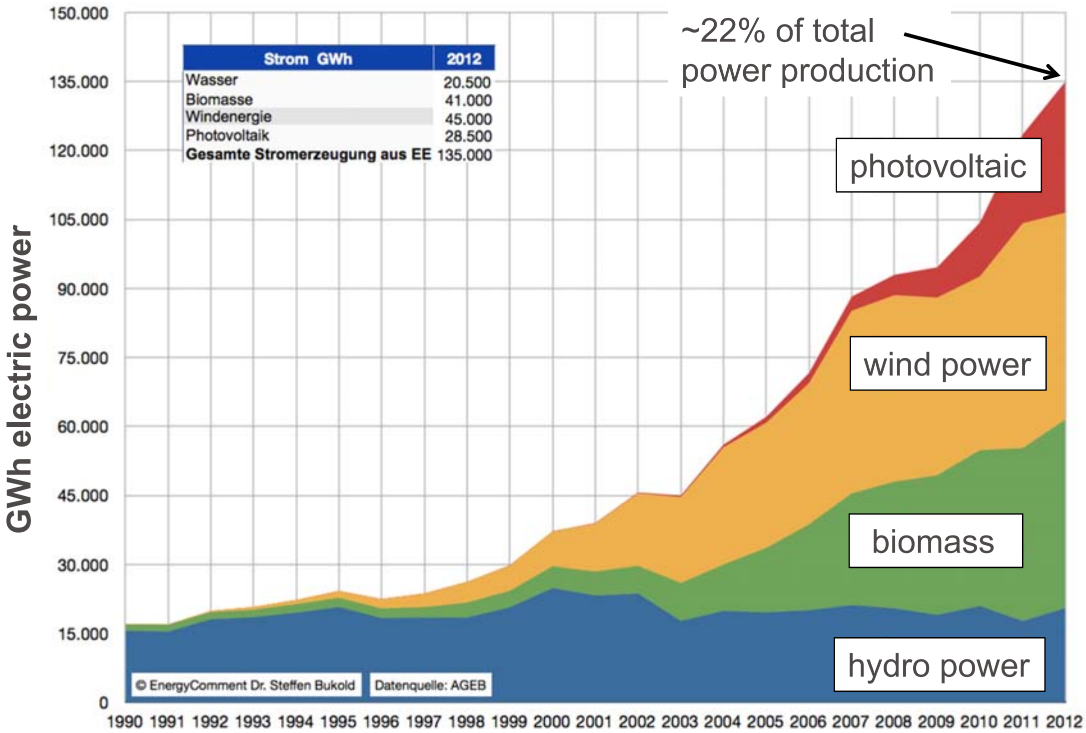
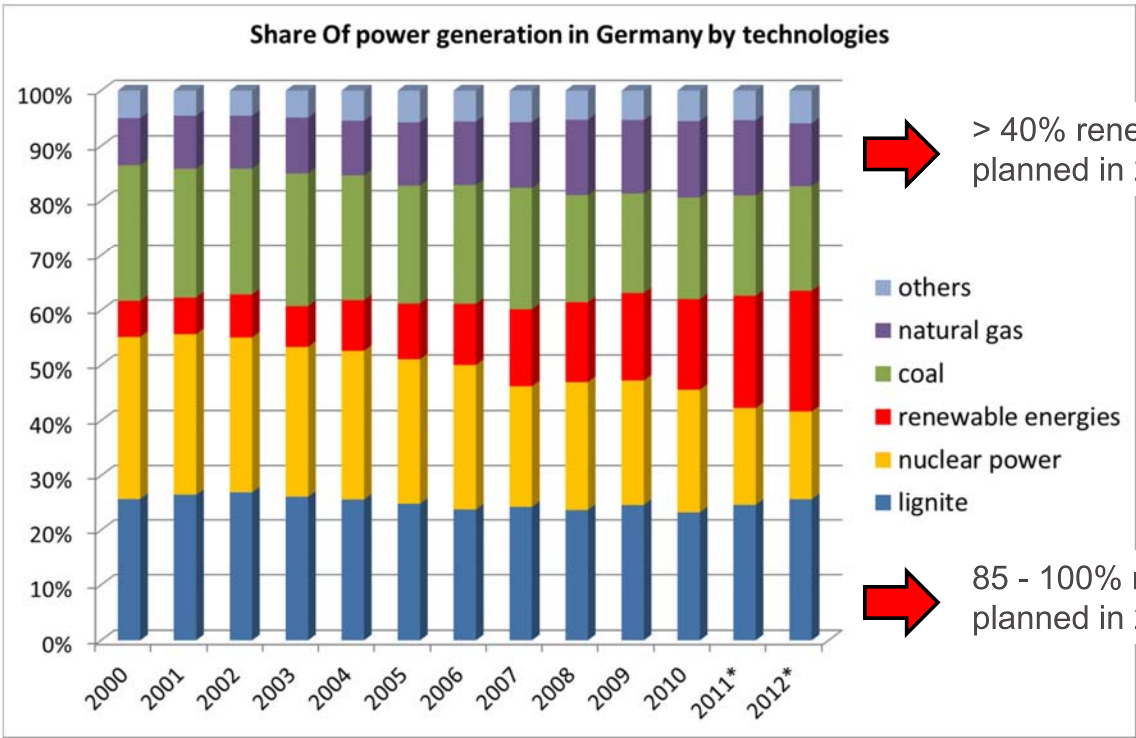
Electricity production from renewable energies by technology in Germany



Share of power generation technologies



> 40% renewables planned in 2020

85 - 100% renewables planned in 2050

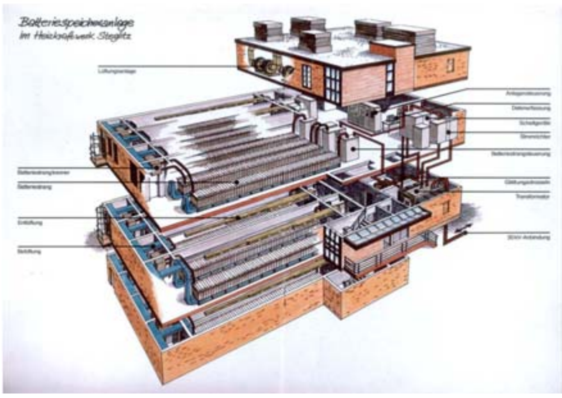
Storage demand for power supply for Germany for 100% renewables

“Daily storage”

- 30 – 50 GW
- 2 – 4 hours energy

“Long-term storage”

- 40 – 60 GW (discharge)
- Up to a maximum of 3 weeks



- Rough estimation based on different studies, only for estimation of storage demands

Example for size of battery storage systems

- 20 foot container with 1 MWh / 1 MW
- Offer of Hannover Fair 2012 for about 600,000 € (incl. power electronics, no medium voltage connection)
- 600 containers of such type deliver the full primar control power for Germany

Example for size of battery storage systems

- Latest class of conatiner ships offer space for 15.000 Container (area about 400 m x 56 m)

Example for size of battery storage systems

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- Filled with operational battery containers this is equivalent with 15 GWh / 15 GW
- German pumped hydro systems together have 40 GWh / 6 GW

≡
energy

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≡
power

Example for size of hydrogen storage system

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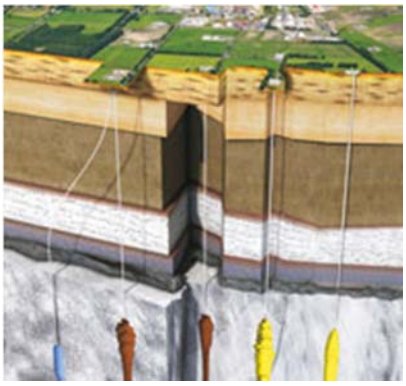
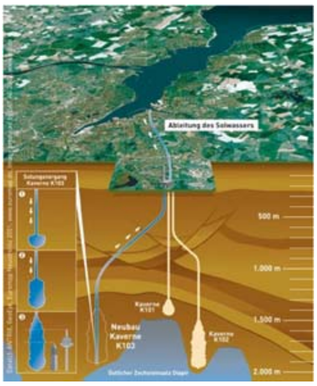
- Today existing cavern capacity in Germany for natural gas (methane): approx. 20 billion Nm^3
- Filled with hydrogen allows to serve Germany for 3 weeks with power
(reconversion with 60% efficiency)





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The problem about storage technologies is cost, not space or technology !

There is no need for creating new storage technologies, there is a need for life cycle cost reductions.

There is need for improving the technology for lowering the life cycle cost (including increasing the efficiency).

100% Renewables needs flexibility in power supply and power consumption.

Storage technologies is one out of several technologies to serve this flexibility.

Classification of flexibility options: **Duration of supply**

- **“seconds to minutes“ – short-term energy storage**
- **“daily storage“ – medium-term energy storage**
- **“weekly to monthly storage“ – long-term energy storage**

Reactive power	➔ „seconds to minutes“
Primary (frequency) control power	➔ „seconds to minutes“
Secondary control power	➔ „daily storage“
Minute reserve	➔ „daily storage“
Spread in energy trading	➔ „daily storage“
Power plant scheduling	➔ „weeks to month“

Possible technologies for long-term storage

Possible technologies:

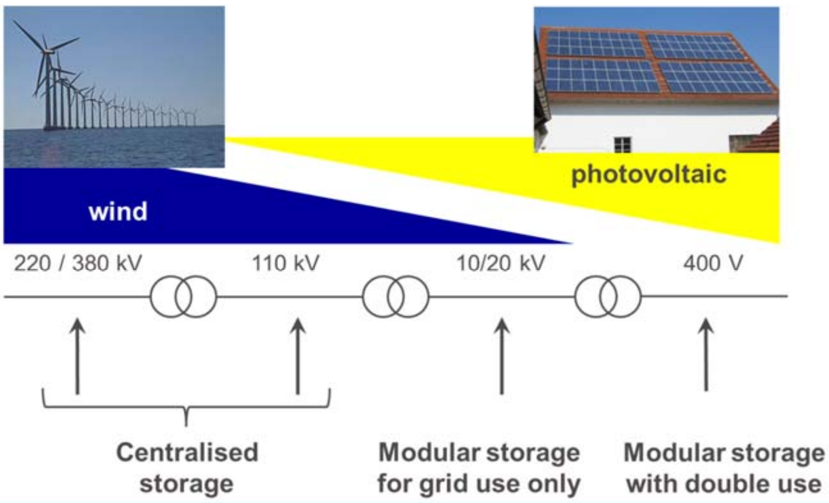
- Hydro storage systems and pumped hydro storage systems (limited sites e.g. in Scandinavia)
- Hydrogen storage systems (and maybe its derivatives such as CH_4 – known as “power to gas” – or methanol)

hydrogen or CH_4 (“power to gas”)

hydro storage

Classification of flexibility options: **Location of storage system**

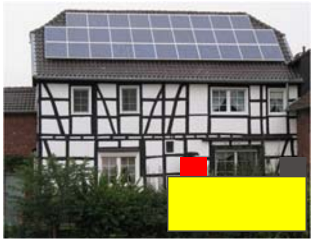
- **“Centralised storage technologies“**
- **“Modular storage technologies for grid use only“**
- **“Modular storage systems with double use“**



Modular storage system with double use will rule the “short-term” and “daily” market

- Storage systems are purchased for another primary reason
- Grid services offer additional income
- Very high potential

Vehicle to grid



Self consumption
in PV systems

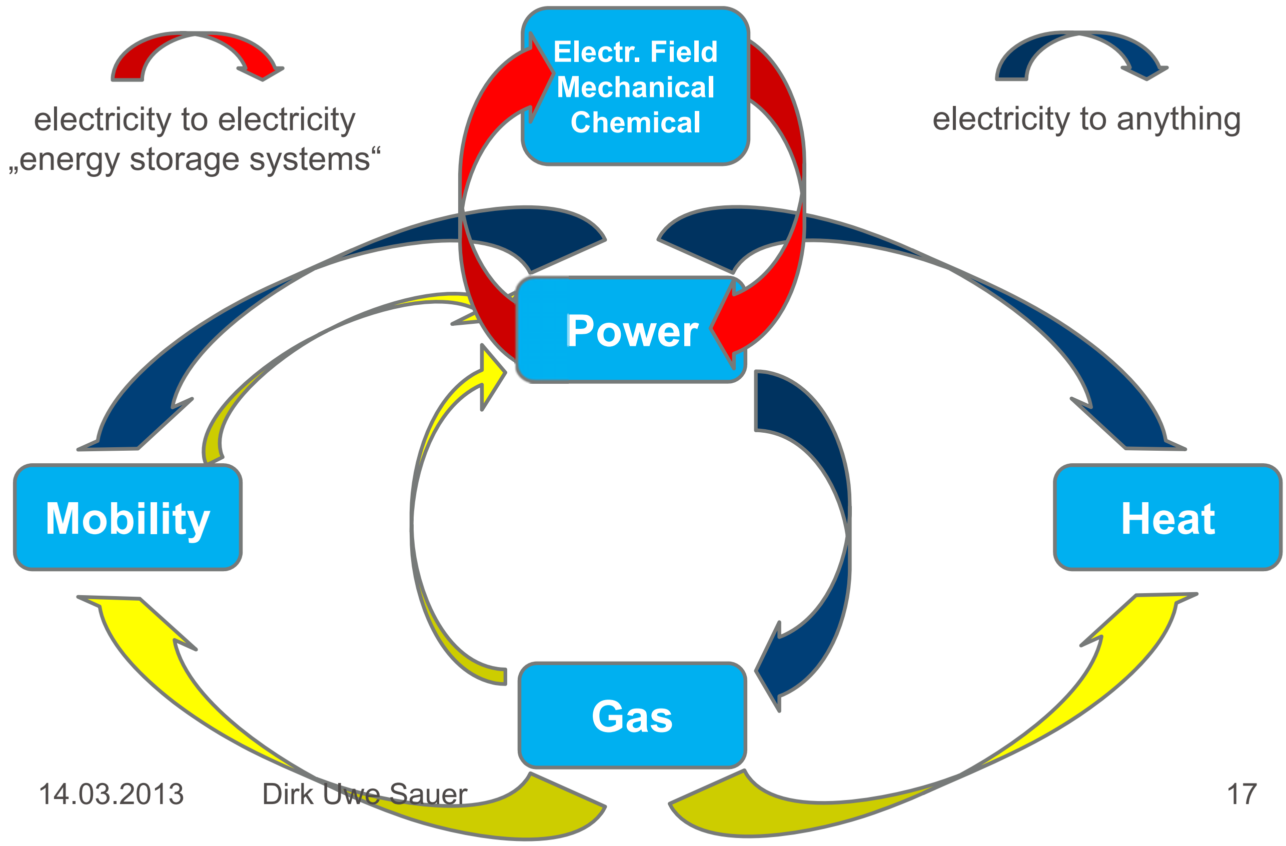
Demand side
management
(e.g. space heating)

- Newly build centralized storage systems (e.g. pumped hydro, compressed air) will have difficulties to compete

Classification of flexibility options:
Quality of supply

- **“Electricity to Electricity“ – positive and negative control power**
  - **Storage system takes electricity from the grid and supplies electricity back into the grid**
- **“Anything to electricity“ – positive control power**
  - **Generation of electricity from any type of stored energy carrier or by shutting down power consumers**
- **“Electricity to anything“ – negative control power**
  - **Electricity is converted into a energy carriers with lower exergy or it is wasted**

Interconnected energy systems and energy storage options



Careful definition required

"power to gas"

Electrical power is converted into hydrogen (or methan or methanol or cabazol or …) **for the use outside the electrical power sector** (e.g. mobility, heat, chemical industry).

"gas storage system" (analog to e.g. "compressed air storage system CAES)

Electrical energy is converted into hydrogen gas, hydrogen is stored (e.g. in underground caverns) **and it is reconverted into electrical energy**.

Functions

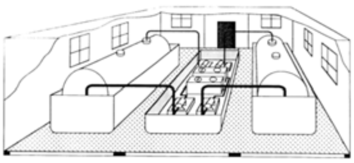
<u>"power to gas"</u>

- Delivers negative control power
- Components: Electrolyser, maybe H_2 → CH_4 converter, gas pipelines and storage
- Transfers CO_2-free in non-electrical energy sectors (today 2/3 of total energy consumption)

<u>"gas storage system"</u>

- Delivers positive and negative control power
- Components: Electrolyser, gas storage, fuel cell or gas turbine
- Is used as long-term storage
- Serves reliable power and replaces conventional back-up power plants

Technologies for electricity storage systems


Redox-Flow batteries


hydrogen

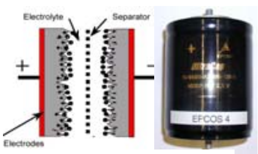

Pumped hydro


Supra-conducting coils


Electro mobility


Self-consumption in PV systems


flywheel

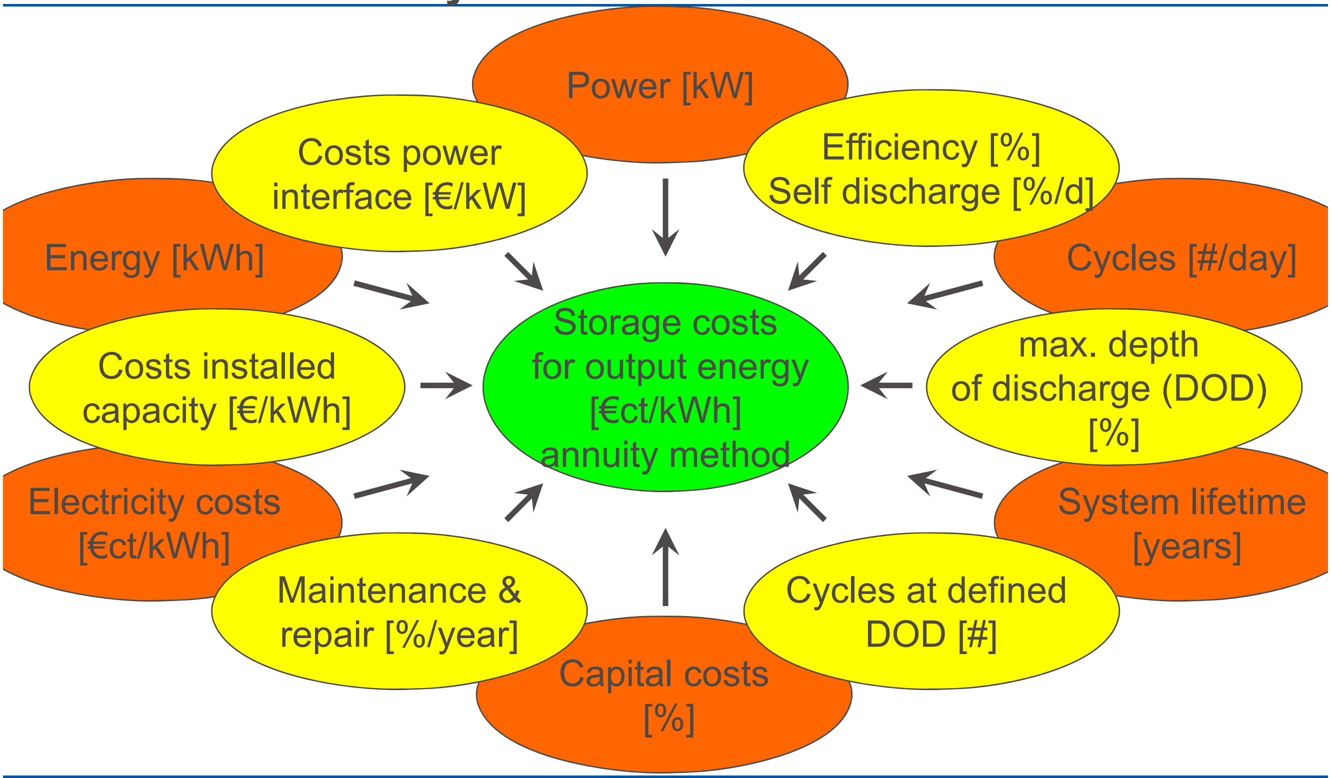


SuperCaps


batteries - lead, lithium, NaS, ...

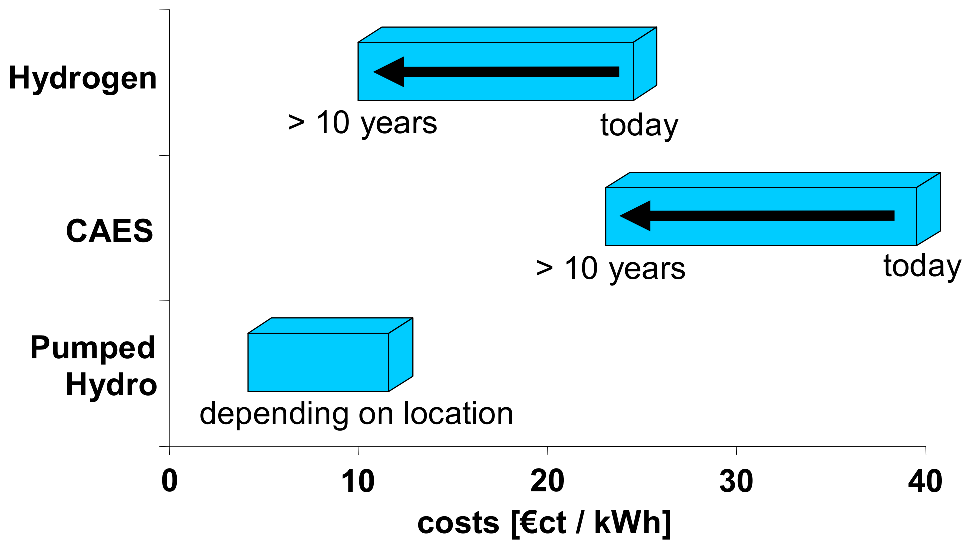

compressed air

Calculation of life-cycle costs



Long term storage system

- 500 MW, 100 GWh, 200 h full load, ~1.5 cycle per month
  (optimistic cycle number, simulations show 1 – 2 cycles/year for three week storage systems)



Quelle: **ENERGY STORAGE FOR IMPROVED OPERATION OF FUTURE ENERGY SUPPLY SYSTEMS**, M. Kleimaier, et.al., CIGRE 2008

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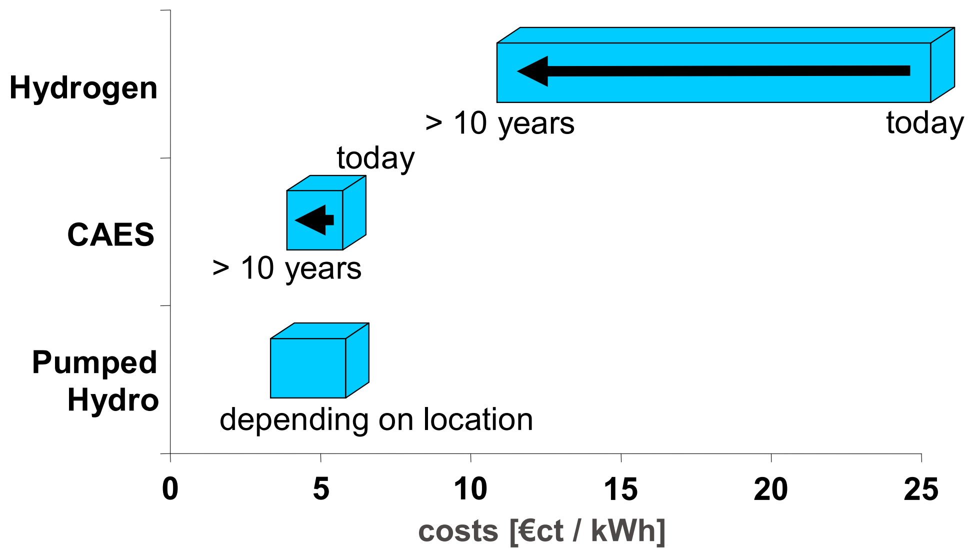
Load-Levelling

- 1 GW, 8 GWh, 8 h full load, 1 cycle per day



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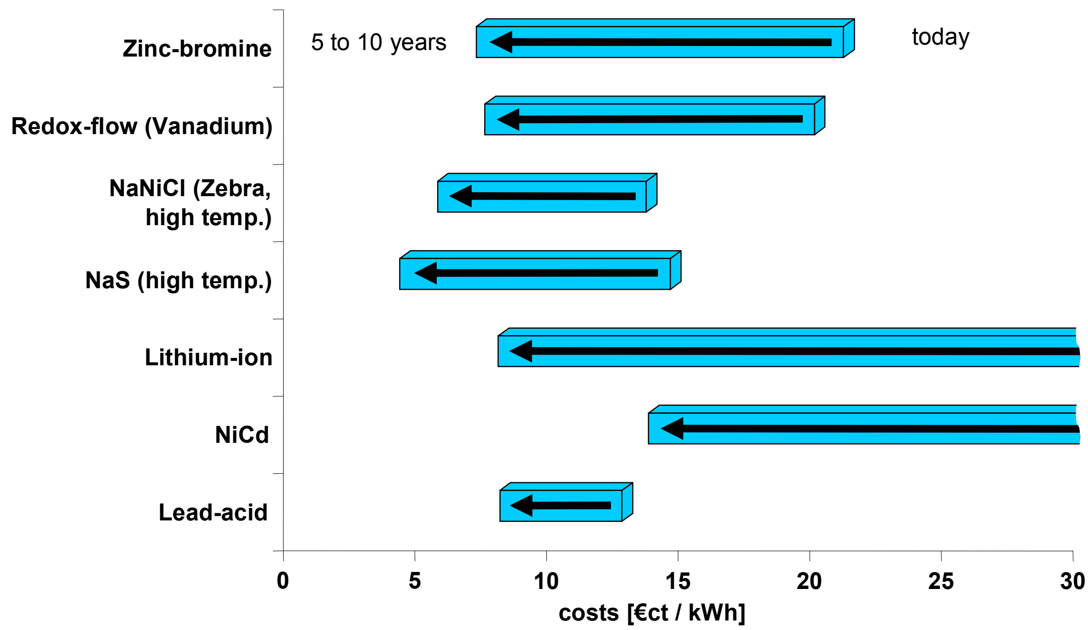
Peak-Shaving at distribution level

- 10 MW, 40 MWh, 4 h full load, 2 cycles per day



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Is there a need for a discussion “storage systems vs. grids” ?

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General

Grids allow a **shift** of energy **in space**.

Storage systems allow a **shift** of energy **in time**.

Transport grid

No storage system is cheap enough to justify not to build a transmission line if an energy consumer can be found in the point of time somewhere in space.

Distribution grid

Things are more complex, between extensions in the distribution grid result in three to five time higher specific costs compared with the transport grid.

Storage classification: “electricity to electricity“

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"Electricity to Electricity" storage systems only		"seconds to minutes" storage systems	"daily" storage systems	"weekly to monthly" storage systems
	E2P ratio	< 0.25 h	1 - 10 h	50 - 500 h
	typical power			
modular storage systems with double use	1 kW - 1 MW			
modular storage technologies for grid control only	1 kW - 100 MW			
centralised storage technologies	100 MW - 1 GW			

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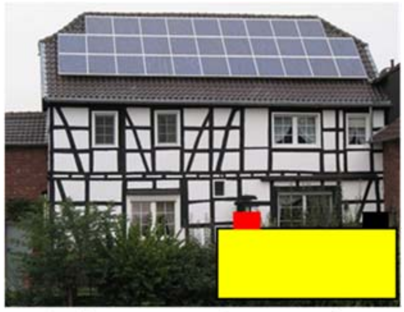
Elektromobilität



Eigenverbrauch in PV-Anlagen

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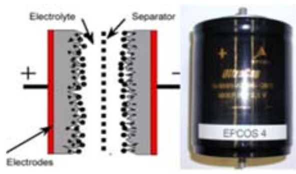
NiCd / NiMH

Lithium-Ionen-Batterien



Doppelschicht-kondensatoren

Schwungrad

Storage classification: “electricity to electricity“

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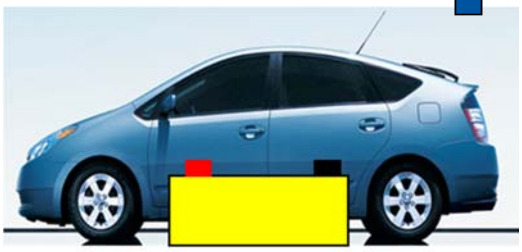
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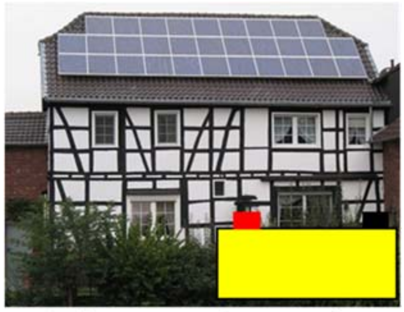
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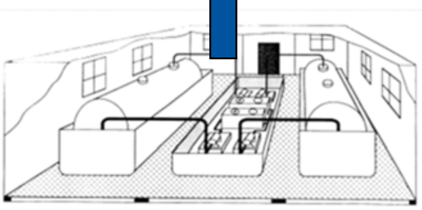
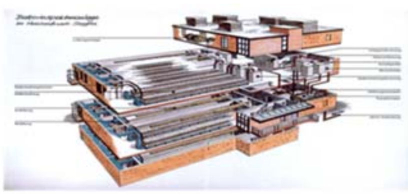

Redox-Flow Batterien


Blei-Batterien, NaS-Batterien

Lithium-Ionen-Batterien

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Druckluft


Pumpspeicher

Storage classification: “electricity to electricity“

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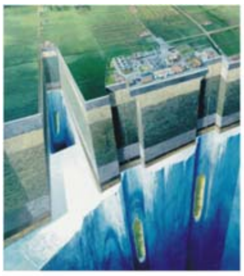

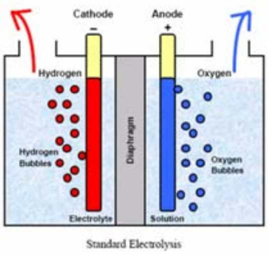

Wasserstoffspeichersystem


sehr große Pumpspeicher

Competition of different storage technologies

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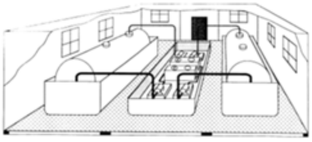
Direct competition

Elektromobilität

Eigenverbrauch in PV-Anlagen



Redox-Flow Batterien

Blei-Batterien, NaS-Batterien

Druckluft

Pumpspeicher

Comparison of flexibility options for "daily" storage systems

E.ON Energy Research Center

"Daily" storage systems		Electricity to Electricity storage systems only	"Anything to electricity" positive control power	"Electricity to Anything" negative control power
	typical power	Direct competition		
modular storage systems with double use	1 k 1 M	electric and plug-in hybrid vehicles with bi-directional charger - grid-connected PV-battery systems	- CHP units with thermal storage - Demand side manag. (DSM) of electrical loads (shut down) - Electric vehicles and PHEV (stop charging)	- electric domestic house heating or cooling incl. heat pumps - demand side management (household & industry) - cooling devices - electric vehicles & PHEV (uni-directional charger)
modular storage technologies for grid control only	1 k 100	- lead-acid batteries - lithium-Ion batteries - NaS batteries - redox-flow batteries - zinc-bromine flow batteries	- bio-gas power plants	- hydrogen for direct use (e.g. in the traffic secor) - methan or methanol made from CO2 and hydrogen - shut down of renewables (wind, PV)
centralised storage technologies	100 M 1	- pumped hydro - compressed air (diabatic or adiabatic)	- gas power plants - coal power plants - hydro storage - solar thermal power plants with heat storage	- hydrogen for direct use (e.g. in the traffic secor) - methan or methanol made from CO2 and hydrogen

Direct competition

Storage Technologies - Overview

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Electricity Storage Systems

Electrical

- Super-Capacitor
- Superconductive Magnetic Coil

Short *Medium* *Long*

Time Scale

Overview

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Electricity Storage Systems

Electrical

- Super-Capacitor
- Superconductive Magnetic Coil

Mechanical

- Pumped Hydro Power
- Compressed Air Energy Storage System
- Flywheels

Thermal

- Thermoelectric Storage

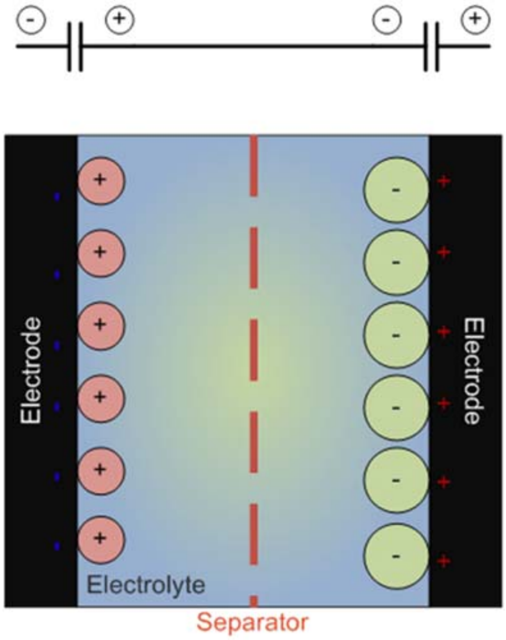
Chemical

- Lithium-Ion Battery
- Lead-Acid Battery
- High Temperature Batteries
- Flow Batteries
- Hydrogen Storage
- Natural Gas Storage System

Short *Medium* *Long*

Time Scale

Supercapacitors



- Electrical energy stored in static electric field between electrodes and ions in the electrolyte
- Ion movement to the electrodes during charging
- Power and energy density between classical capacitors and batteries
- High cycle lifetime

Supercapacitors

Applications

- Short-term and high power storage systems
- Hybrid storage systems in combination with batteries (to reduce dynamics on battery)
- Voltage stabilization in cars and trains

Development

- Lithium-ion supercaps
- Increases energy density by a factor of 2 to 3
- High power density and cycle lifetime

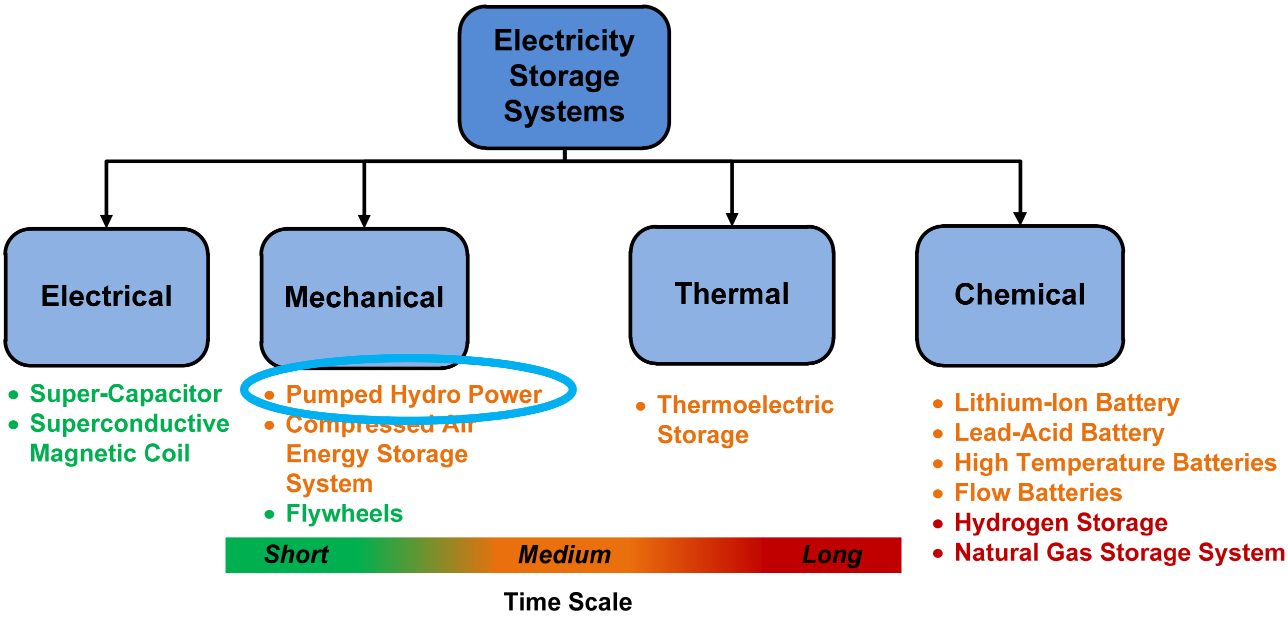
Supercapacitors – Parameters

Parameters for Super-Capacitors	All numbers are indications and my vary significantly among different products and installations	
	Today	2030
Round-trip efficiency	90 % to 94 %	No numbers available
Energy density	2 Wh/ l to 10 Wh/ l	
Power density	up to 15 kW/ l	
Cycle life	up to one million	
Calendar Life	15 years	
Depth of discharge	75 %	
Self-discharge	up to 25% in the first 48 hours, afterwards very low	
Power installation cost	10 €/ kW to 20 €/ kW	
Energy installation cost	10,000 €/ kWh to 20,000 €/ kWh	
Deployment time	< 10 ms	
Site requirements	None	
Main applications	Primary frequency control, voltage control, Peak shaving, UPS	

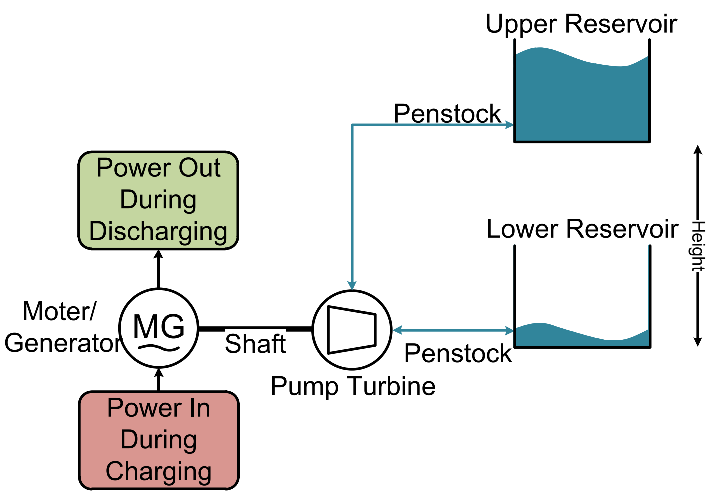
Supercapacitors – SWOT

Supercapacitors	Strengths	Weaknesses
Internal	• High efficiency • High power capability • Long cycle lifetime	• Low energy density • High costs per installed energy
	Opportunities	**Threats**
External	• Applications with very high power demand and cycle load	• High power applications might be served by high power lithium-ion batteries

Overview



Pumped Hydro

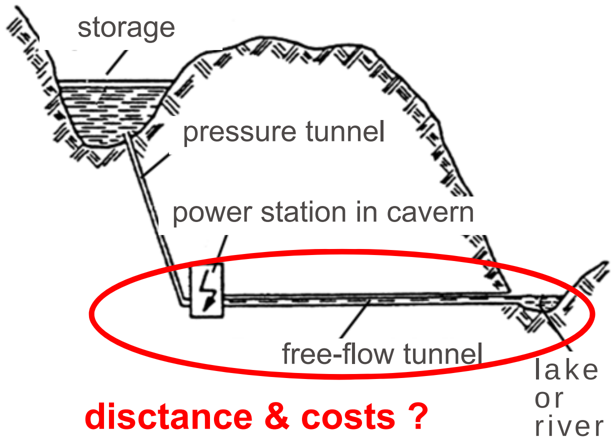


- Two water reservoirs at different heights
- Charging: pumping water from lower to upper reservoir
- Discharging: turbine is powered by falling water from upper to lower reservoir
- Amount of stored energy proportional to height difference and water volume
- Major storage technology with more than 127 GW installed worldwide

„Retrofit " of existing hydro power plants with a pumping system

- Huge capacity in existing water reservoirs
- Retrofit with pumps
- Evaluation of potential is needed – critical point is the connection to sufficient base reservoir

Artificial lake with natural feeders



disctance & costs ?

Pumped **hydro storage in federal waterways** – using small differences in water levels

View of ship lift Lüneburg

Pumped Hydro

Applications

- Medium-term storage with 2 to 8 hours discharge time
- Long-term storage (several weeks) with hydro storage in Norway
  - Pumping option and lower reservoir have to be added

Development

- No big improvements in efficiency and costs (established technology)
- Limited sites available in Central Europe
- Retrofitting of existing plants with higher power

Pumped Hydro – SWOT

	Pumped Hydro Power	
	Strengths	**Weaknesses**
Internal	• Established technology • Very long life-time • Low self-discharge • Good efficiency	• Low energy density • Geographical restriction • High investment costs and long return of investment (> 30 years)
	Opportunities	**Threats**
External	• Very large additional potential in Norway and Sweden, some smaller potential elsewhere • Storage costs are very competitive compared with other storage technologies	• Lengthy approval processes, high environmental standards • Increasing competition from decentralized storage systems • High power requires connection to the transmission grid and therefore cannot solve problems in the distribution grid • Pumped Hydro in Norway: Public and political acceptance critical due to the impact of trading on electricity prices.

Compressed Air Energy Storage (CAES)

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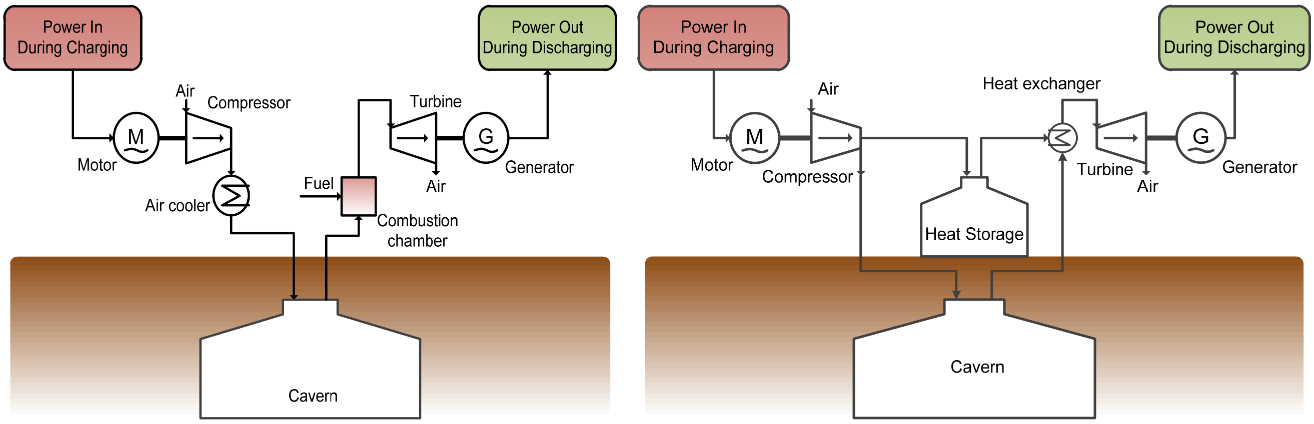


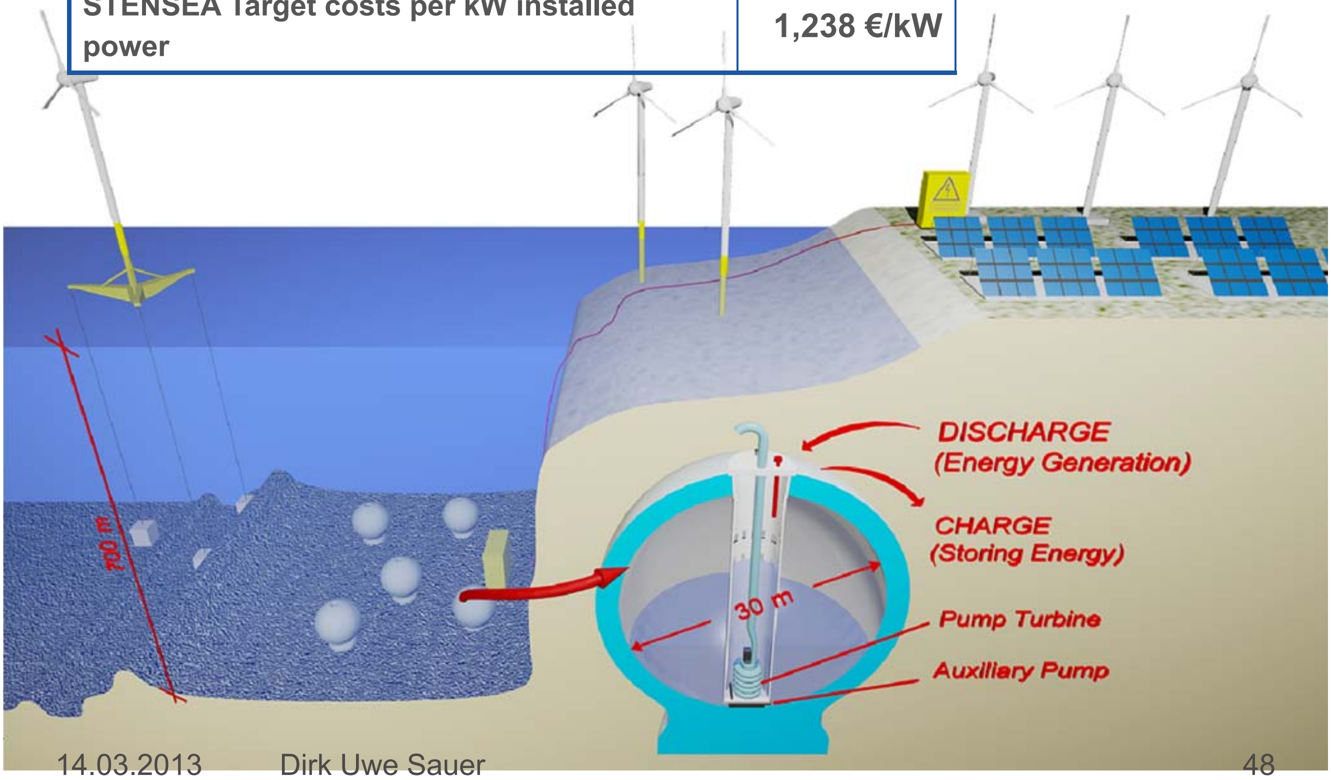
diabatic CAES

adiabatic CAES (with heat storage)

Underwater pumped hydro system

HOCHTIEF SOLUTIONS AG

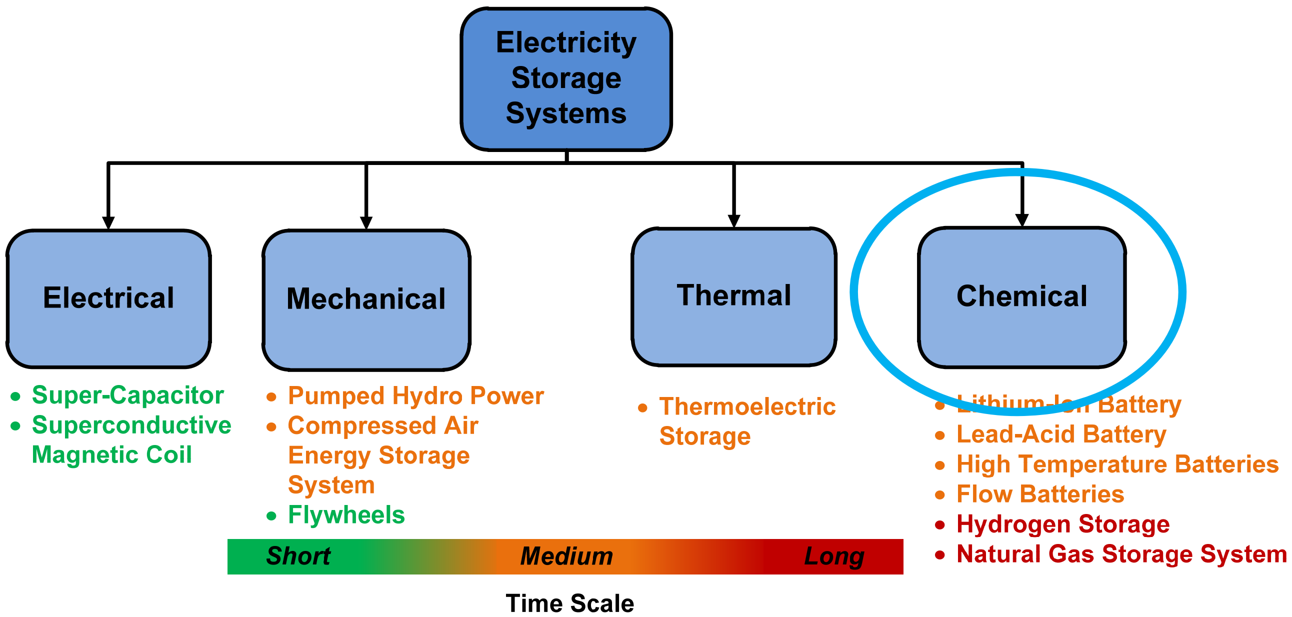
STENSEA Target costs per kW installed power	**1,238 €/kW**



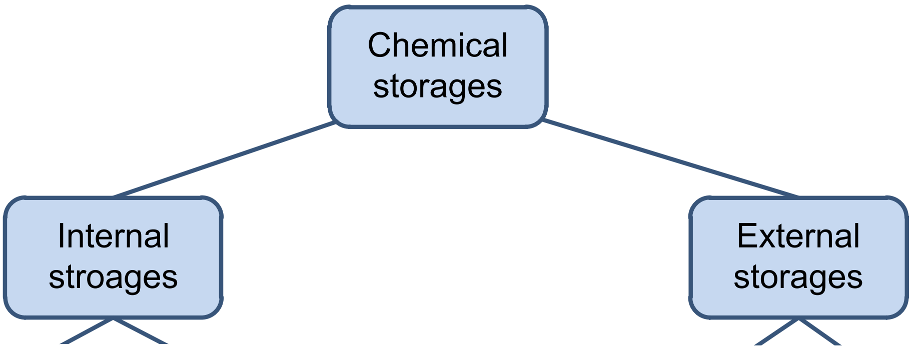
Compressed Air Energy Storage – SWOT

	Compressed Air Energy Storage System	
	Strengths	**Weaknesses**
Internal	• Relatively low cost for the energy storage (caverns) • Small footprint on surface due to underground storage • Long life of the air reservoir (cavern) and the power systems (compressors, turbine) • Low self-discharge of compressed air	• Certain geological restrictions necessary (pressure-tight cavern) • High investment costs • Only two (and old) diabatic pilot plants, no adiabatic power plants available yet • Thermal storage for adiabatic CAES not yet demonstrated in full scale • High self-discharge of the thermal storage • Low efficiency for diabatic CAES (< 55%) • Long return of investment (> 30 years) • Only large units connected to the transmission grid are economical
	Opportunities	**Threats**
External	• Successful demonstration of the technology could help a short time-to-market • Good regional correlation between caverns and high wind areas in Germany	• Limited number of suitable sites for caverns • Competition in the use of caverns (e.g. gas or oil storage) • Increasing competition from decentralized storage systems • Limited number of locations outside Germany • High power requires connection to the transmission grid and therefore cannot solve problems in the distribution grid

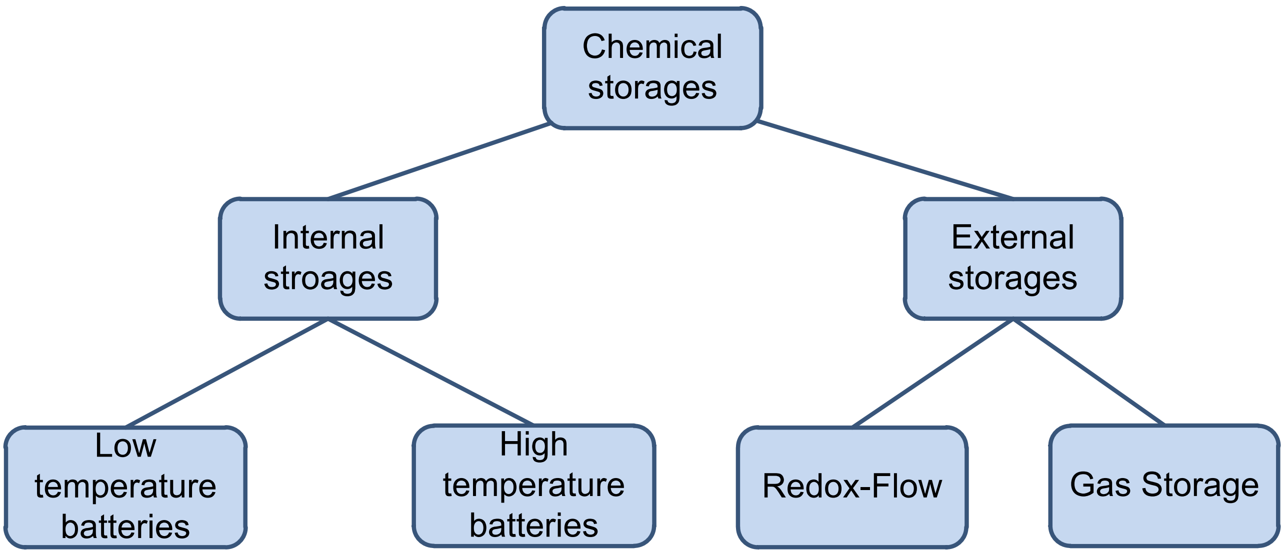
Overview



Chemical storage systems



Chemical storage systems



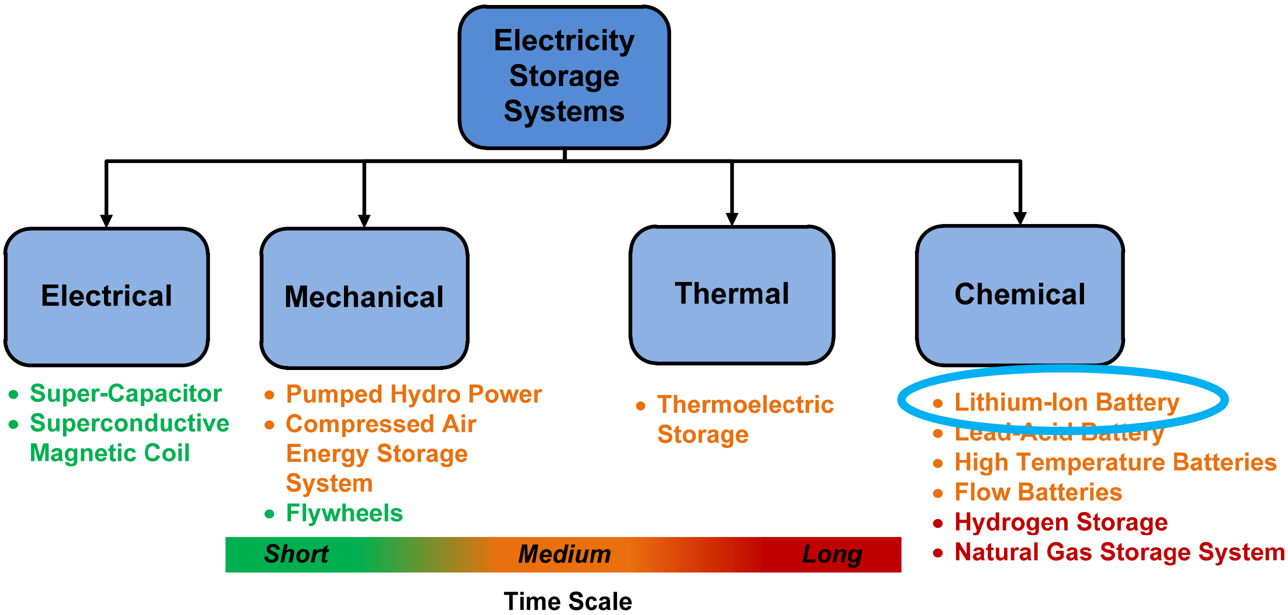
- Lithium-Ion
- Lead-Acid
- Nickel-Cadmium

- Sodium-Nickel-Chloride ($NaNiCl_2$)
- Sodium-Sulphur (NaS)

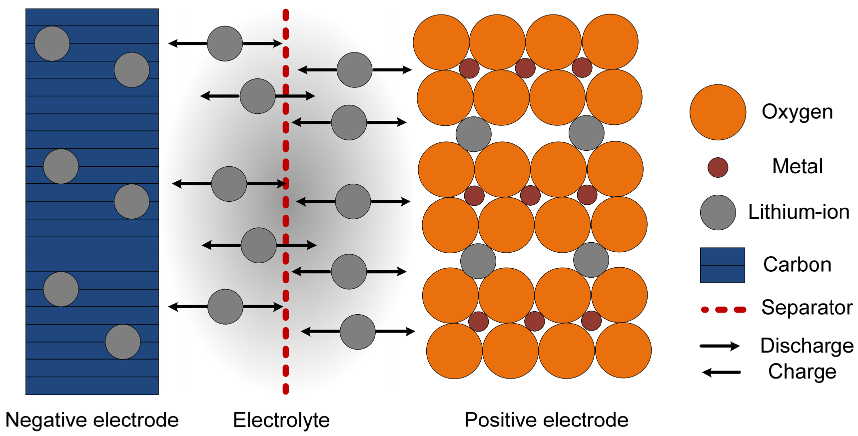
- Vanadium
- Zinc-Bromine

- Hydrogen
- Methanation

Overview



Lithium-ion Batteries



- Charging and discharging is an intercalation/deintercalation process of lithium-ions
- Electrolyte and electrodes are no reacting agents
- High energy and power density
- Long lifetime (compared to lead-acid batteries)

Lithium-ion Batteries

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Applications

- Short- and medium-term storage
- Portable applications (mobile phones, laptops etc.)
- Electric Vehicles

- More and more in stationary applications (MW battery containers, PV-home-systems)

Development

- Large variety of electrolytes and combinations of electrodes exist
  - Different characteristics
  - Different costs

- Main development paths
  - Cost reduction (life cycle costs)
  - Safety

Lithium-ion Batteries – SWOT

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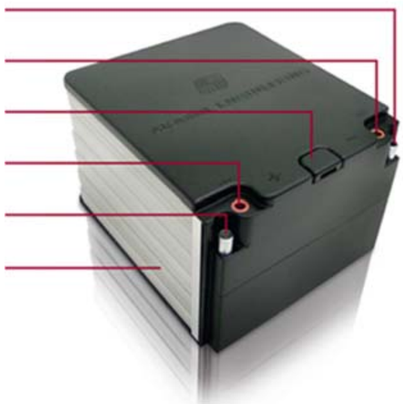
	Lithium-Ion-Battery	
Internal	**Strengths** • High energy density • Long lifetime • High performance	**Weaknesses** • No inherent security (thermal runaway) • Sophisticated battery management system required (single cell monitoring) • Packaging and cooling costly depending on the cell shape • High costs
External	**Opportunities** • High number of items in the automotive industry lead to faster cost reduction • No special requirements for storage location (no gassing)	**Threats** • Social acceptance problems due to lithium mining in problematic countries possible • Lithium resources limited to only few countries • High energy and power densities represent a low added value in most stationary applications

Innovative products

Li-ion battery module



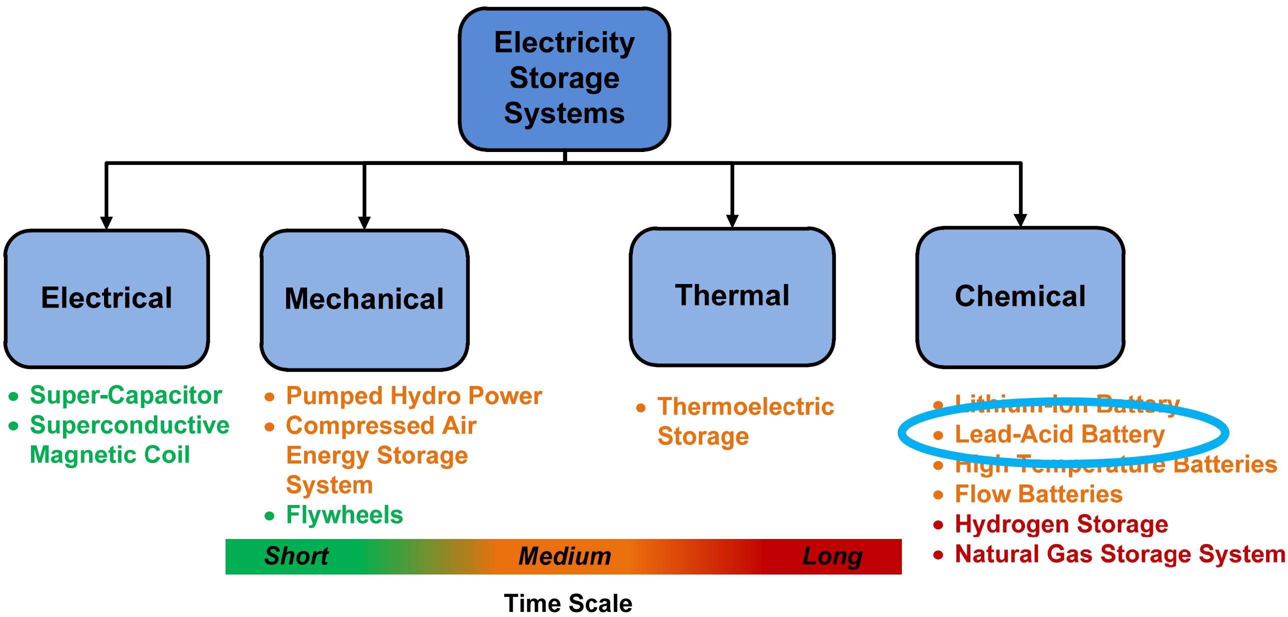
Björn Eberleh, Akasol Engineering

Standardized battery packs for Smart Homes

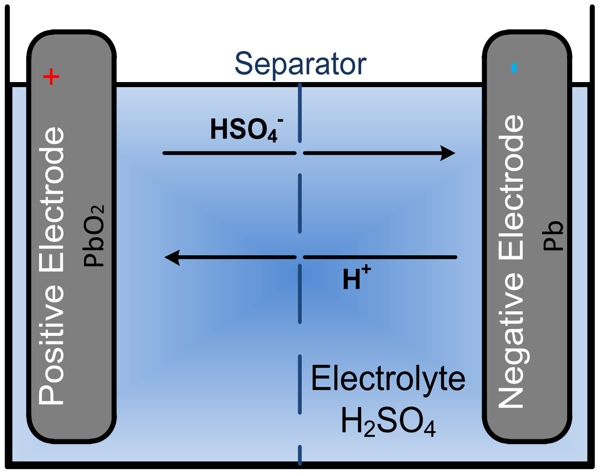
Andrew Kwon, Samsung SDI

- **Carry-over parts from the automotive industry allow for significant cost reductions**
- **Standard units including power electronics lower costs**

Overview



Lead-acid Batteries



- Only lead and sulfuric acid as active materials
- Electrolyte is part of the reaction

- Low energy density
- Low cycle lifetime (at high depths of discharge)

- Important technology for the near and mid-term future due to relatively low life cycle costs
- Major battery technology in stationary applications

Lead-acid Batteries

Applications

- Short- and medium-term storage
  - Frequency control
  - Peak shaving
  - Load leveling
  - Island grids
  - Residential storage systems
  - Uninterruptible power supply
- 17 MW / 14 MWh storage system was operated by BEWAG in Berlin until 1986 (frequency control)

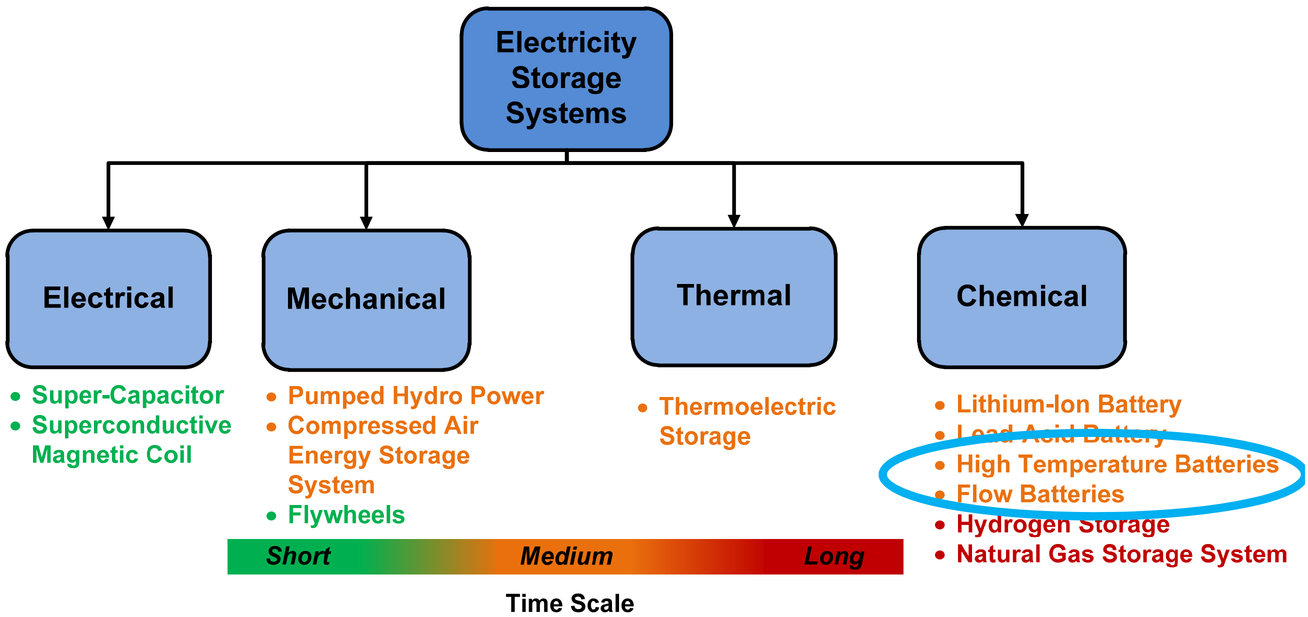
Development

- Cells and batteries for stationary applications not produced in large quantities (still high cost reduction potential)
- Lifetime improvement possible by optimizing cell design

Lead-acid Batteries – SWOT

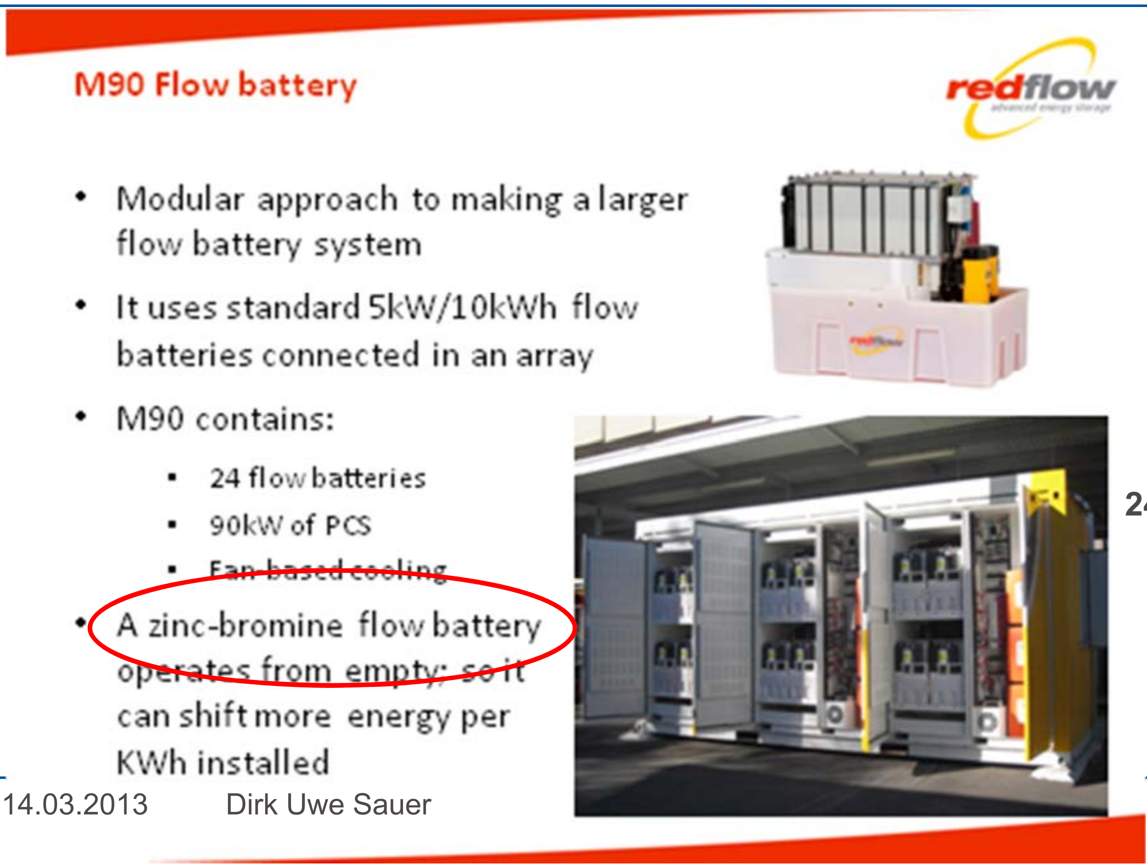
	Lead-Acid-Battery	
	Strengths	**Weaknesses**
Internal	• Today already high number of items • Acceptable energy and power density for stationary applications • Inherent safety by controlled overcharge reaction • Experience with large storage • Short amortization period and relatively low initial investment	• Charging and discharging ability are not symmetrical • Ventilation requirement • Limited cycle life • Industrial batteries are still not built with fully automatic systems
	Opportunities	**Threats**
External	• Significant cost savings through fully automated mass production possible • Location independence • Large number of manufacturers around the world	• Prohibition of the use of the heavy metal lead • Very strong cost reduction with lithium-ion batteries (the same application segment) • Limitations of the lead deposits • Insufficient R&D capabilities and experienced personal available

Overview



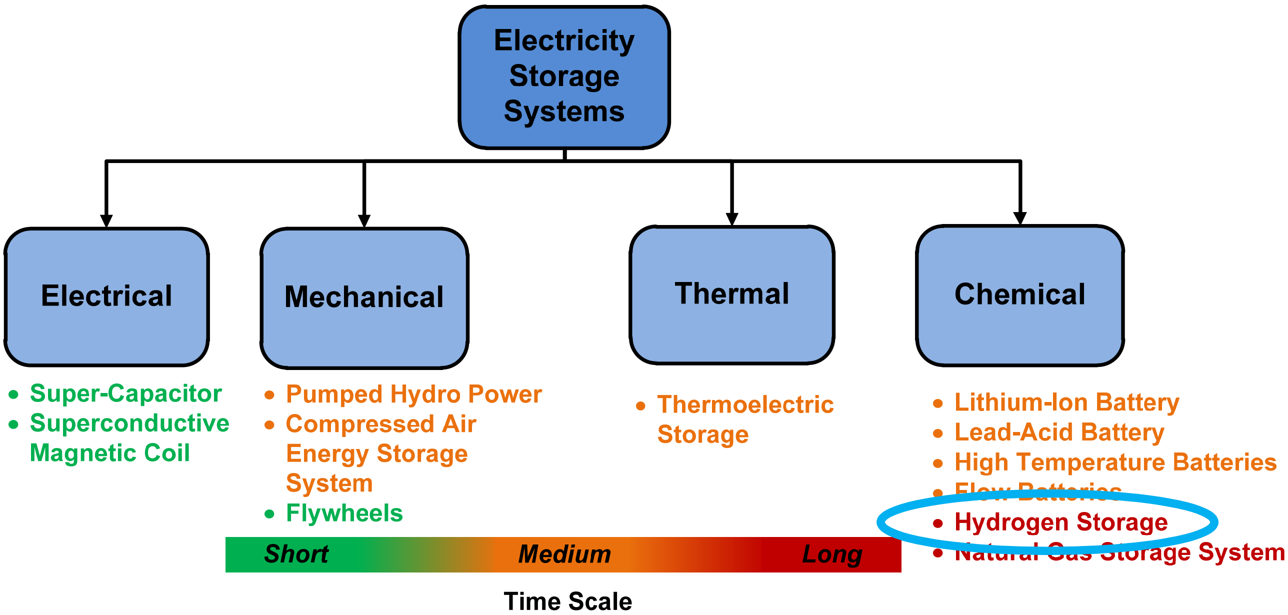
Sodium Nickel batteries storage applications

Field results of a flow-battery supported an equiv-alent unsupported 340 kWp PV array - Chris Winter



240 kWh

Overview



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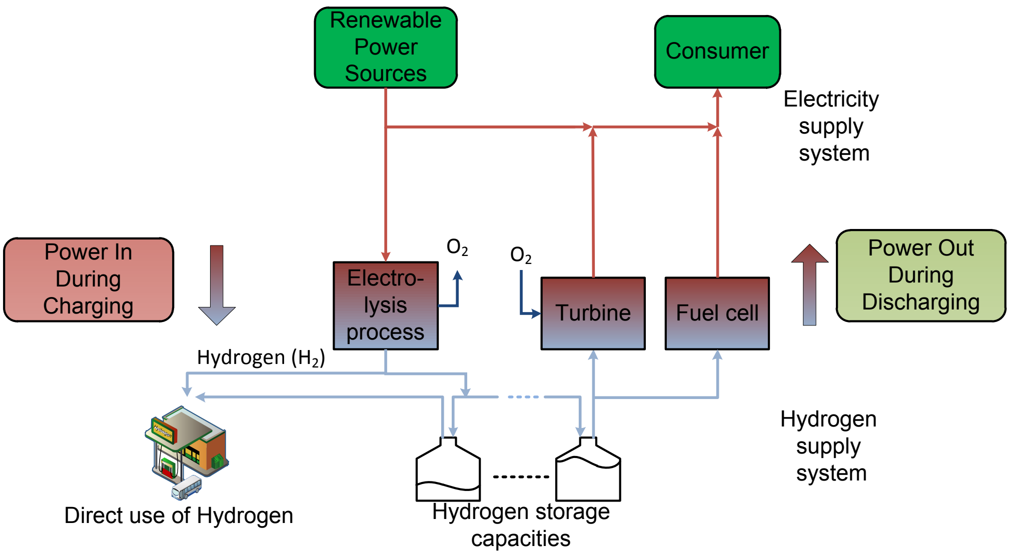
Hydrogen Storage



- Electrolyzer produces hydrogen which is compressed and stored in caverns
- Back-conversion to electricity with turbines and fuel cells
- Efficiency only around 40%

Hydrogen Storage

Applications

- Specific costs of storage volume are low
- Long-term storage („dark calm" periods, around 3 weeks)
- Needed in electricity systems with high shares of renewables
- Island grids

Development

- No large scale plants in operation
- Electrolyzer well known from chemical industry
  - Increasing efficiency
  - Decreasing cost
  - Increasing flexibility
- Technology for hydrogen turbines is available
- Fuel-cells would improve overall efficiency

Hydrogen Storage – SWOT

	Hydrogen Storage System	
	Strengths	**Weaknesses**
Internal	• Low footprint, because of underground storage • Sufficient experience with hydrogen storage in caverns • Very large amounts of energy can be stored • Water in unlimited quantities available	• High costs for electrolyzers • Low efficiency (less relevant for long-term storage) • Storage density is about one-third lower than for methane • Hydrogen turbines for the reconversion is not yet available
	Opportunities	**Threats**
External	• The only realistic option for long term storage of electricity • Progress in the field of high-pressure electrolyzers is expected • Synergies with the development of new power plant processes which use hydrogen-rich gas • Hydrogen can also be used in other energy sectors	• Competition from long-term storage of energy in Norwegian pumped storage power plants • Competition in the use of suitable caverns • Operating costs strongly depend on price of the purchasing power due to low efficiency

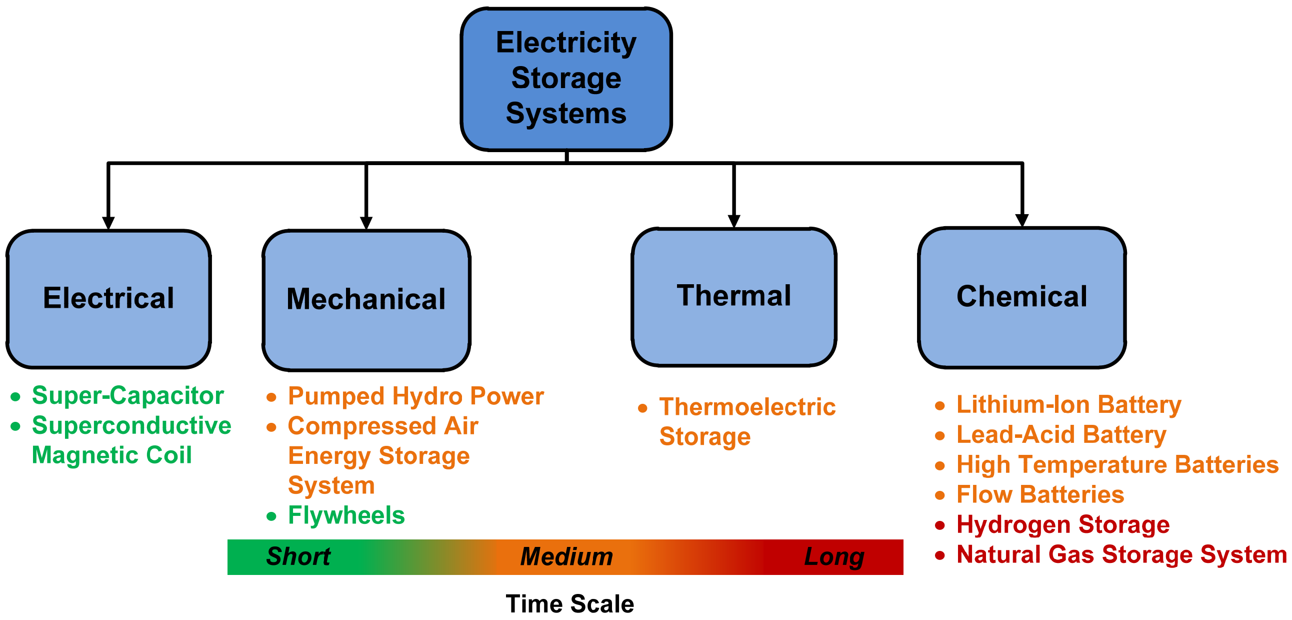
Methanation

- Hydrogen is converted to methane
  - External CO_2-source is needed
  - Heat is produced
  - Overall efficiency only 35%

- Methanation makes sense, if energy should be removed from the electricity system and used for e.g. transportation

- Back-conversion of methane to electricity not favored due to additional losses compared to hydrogen

Overview



Summary

- Many different electricity storage systems exist, only a selection could be presented
- Each technology has its specific and application-sensitive advantages and disadvantages
- There is no generally superior electricity storage technology
- For a given application, the storage technology with the lowest life cycle costs should be selected
  - Careful analysis of application is necessary
  - Deep understanding of storage technology is necessary (e.g. lifetime)

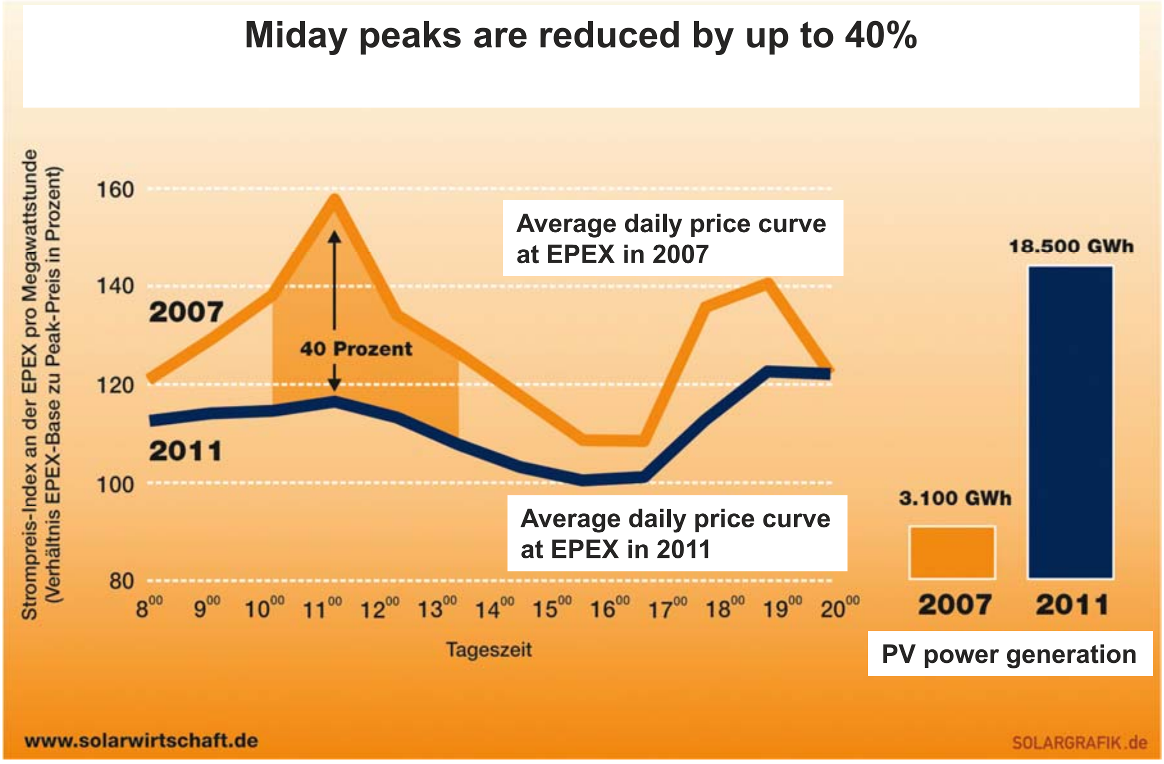
Policy strategies for advancing the widespread of storage technologies

- 1st step: Enlarging of research activity
  - Improving the technology basis
  - Increasing the number of skilled scientist and engineers
- 2nd step: Supporting demonstration programs
  - Learning from doing
  - Giving potential operators and investor the opportunity to see system operating
- 3rd step: Market introduction programs by subsidizing systems for users
  - Supporting technologies for markets which may become commercial in few years
  - Fostering development and manufacturing of mature systems for operation under real-world operation conditions
  - Reducing costs and prices by enlarging the production numbers

Policy strategies for advancing the widespread of storage technologies

- 4th step: Changing legislations, standards and design rules (parallel to step 3)
  - Adapting existing standards and laws to allow a widespread market introduction of storage technologies
  - Removing barriers which may protect old technologies and players
  - Assuring independent storage system operators to take part in the market
- 5th step: Adapting market designs to the new needs and requirements
  - Assuring investors a return of invest
  - Profiting from all savings and efficiency gains in the complete power supply systems cause by the storage systems
  - Defining rules which assure a good balance between economically needed and existing storage technologies

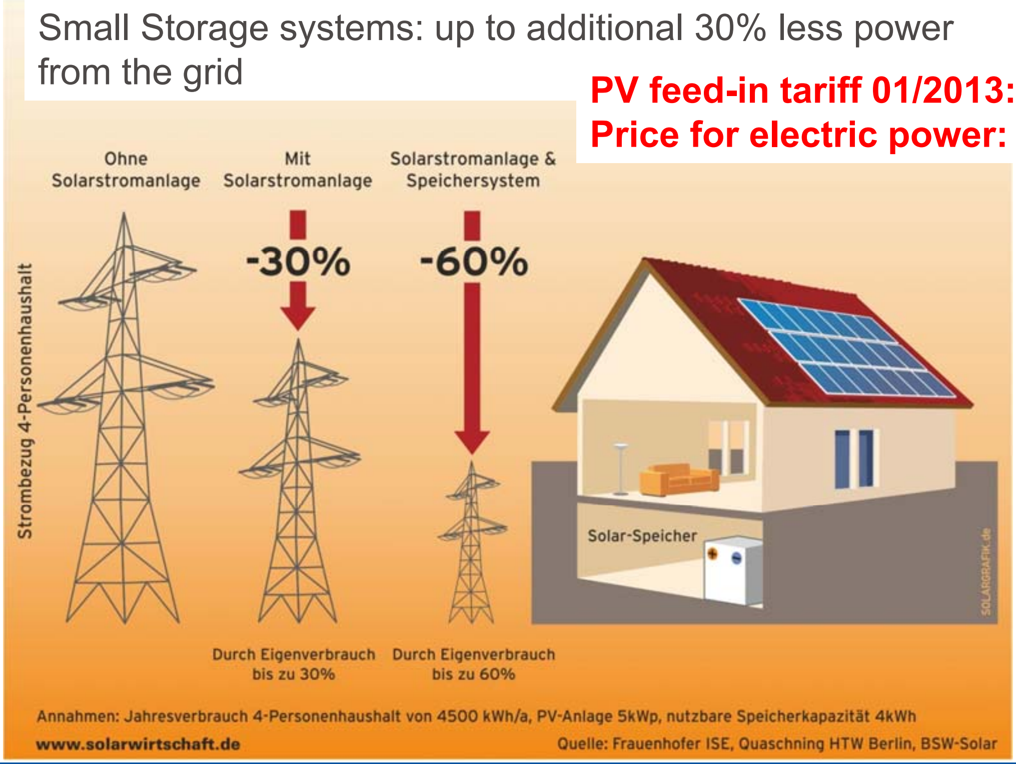
Designing the markets is very complex: PV reduces prices at power exchange



Market introduction program for batteries in PV systems in Germany

Small Storage systems: up to additional 30% less power from the grid

PV feed-in tariff 01/2013: 17 ct/kWh
Price for electric power: 25 – 28 ct/kWh



Grid connected PV battery systems

Aleksandra Sasa Bulvic-Schäfer – SMA Armin Schmiegel, voltwerk electronics

- **Several manufacturers offer system solution**
- **Roll-out starts**

Grid connected PV battery systems

Andreas Piepenbrink – E3/DC

Udo Möhrstedt, IBC Solar

- **Lead-acid batteries and lithium-ion batteries are technologies of choice – definitely an open race**
- **Products for the international market**

Summary

- There are technologies and there is space for sufficient storage systems for 100% renewable scenarios
- Different energy market will get linked to each other significantly
- "Power to gas" links the electricity market with other markets (e.g. mobility, space heating, etc.)
- Both is needed: Storage systems and grid extension
- Decentralised "double use" storage systems will dominate the "short-term" and the "daily" storage market
- Pumped hydro (where applicable) and gas storage systems are the options for the long-term storage market
- **Cost is the main issue !!**
- **Without political willingness, not much will happen**

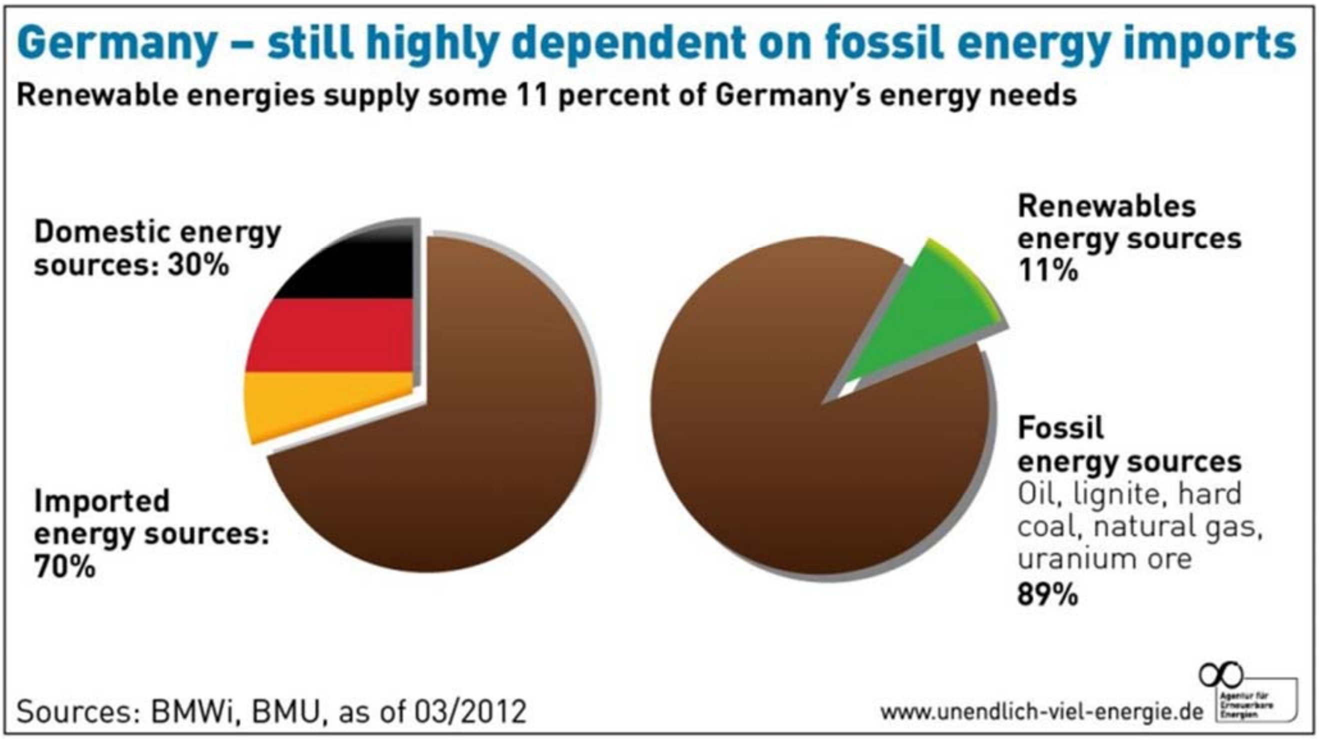
Energy Storage Options for a Renewable Power Supply System

SEI Seminar Series – Toronto, March 12th, 2013

Dirk Uwe Sauer
email: sr@isea.rwth-aachen.de

Chair for Electrochemical Energy Conversion and Storage Systems

Institute for Power Electronics and Electrical Drives (ISEA) &
Institute for Power Generation and Storage Systems @ E.ON ERC
RWTH Aachen University



Germany is exceeding (a little bit) its climate protection aims

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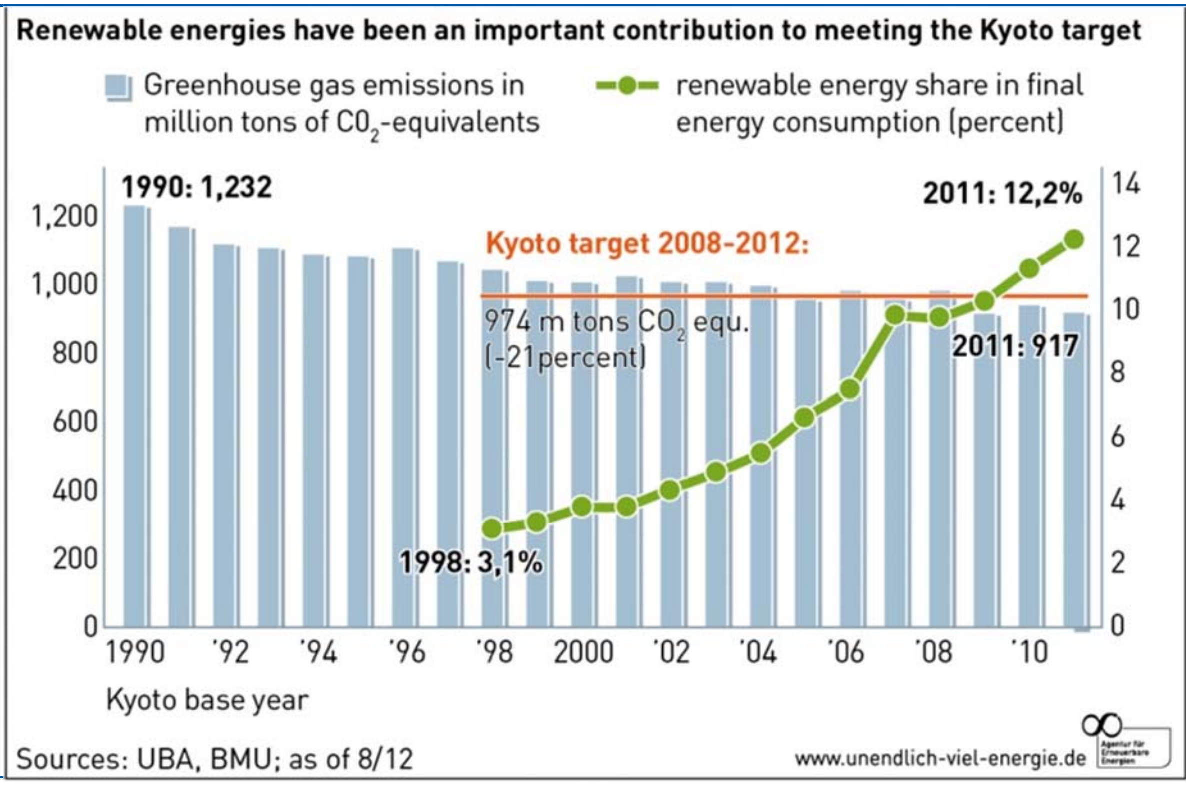

The German “Energiewende” – history I

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- German population is critical concerning nuclear power approx. since mid of 1970ies
- Since the Tschernobyl accident the German government started to invest significantly in renewable energies
- Several research institutes and university research including demonstration and market introduction programs for renewable energies were started
- Focus for Germany in the electricity sector is on wind power and photovoltaics, solar thermal systems for residential buildings and some solar thermal power generation for the use outside Germany
- All governments, independent from the political party, supported the programs continuously
- Most important instrument is the feed-in tariff.

Feed-in tariff for accelerated market introduction of renewables

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- The feed-in tariff guarantees every operator of a renewable power plant a full repayment of the investment incl. O&M costs and capital costs by paying a fixed fee per kWh delivered to the grid.
- Payment only for delivered kWhs, no upfront investment subsidy.
- Responsibility for keeping the system running stays with the operator.
- Renewable energies have priority in the power market.
- Shut-down is allowed only in case of grid problems.
- Extra costs are distributed to (almost) all users of electricity in Germany.
- Annual reduction of the feed-in tariffs for newly installed systems assures cost pressure on manufacturers.
- For photovoltaics the feed-in tariff is meanwhile adjusted monthly to limit the newly installed capacity.

Solar settlement »Auf dem Kruge« in Bremen

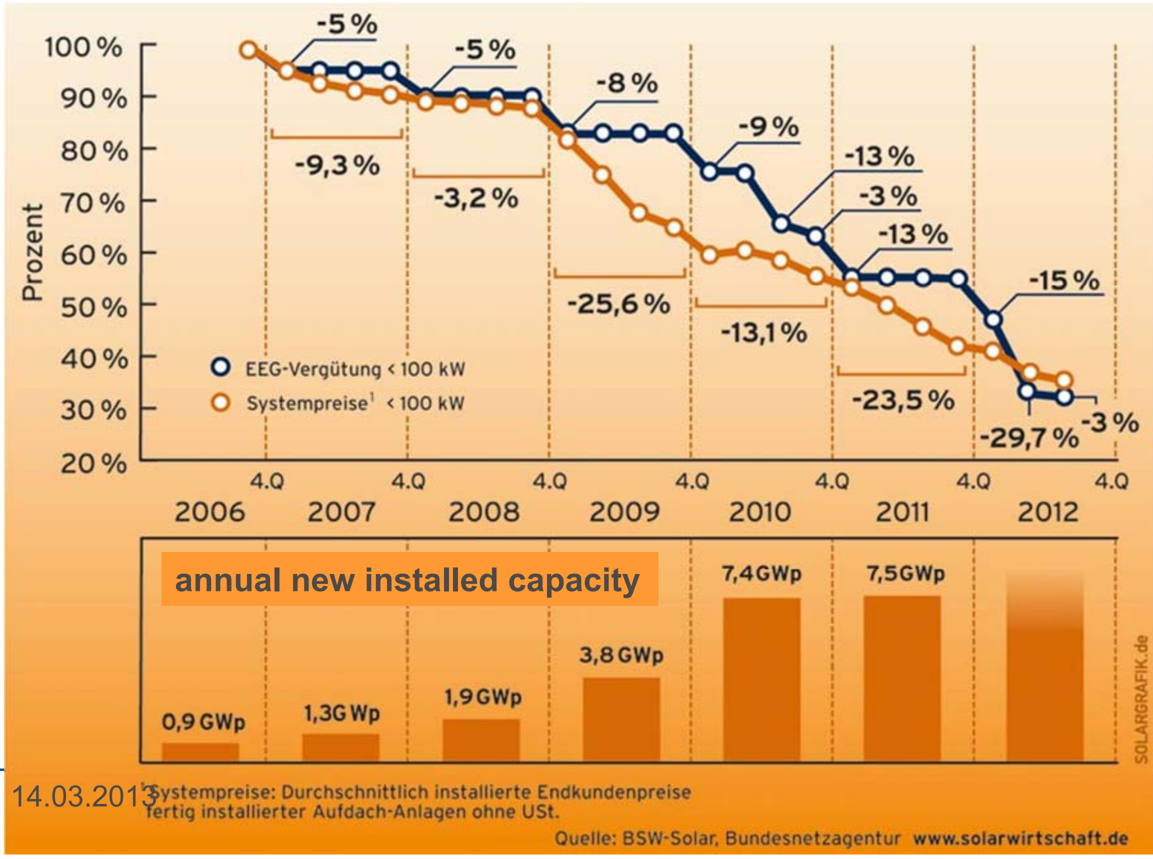
Solarpark Gut Erlasee Karlsruhe garbage dump

Solarpark Lieberose

Former training area of the army

Total installed power: 53 MW
Annual yield: approx. 53 Mio. kWh

Costs and feed-in tariffs for PV have been reduced by 60% since 2006



Electricity production from renewable energies by technology in Germany

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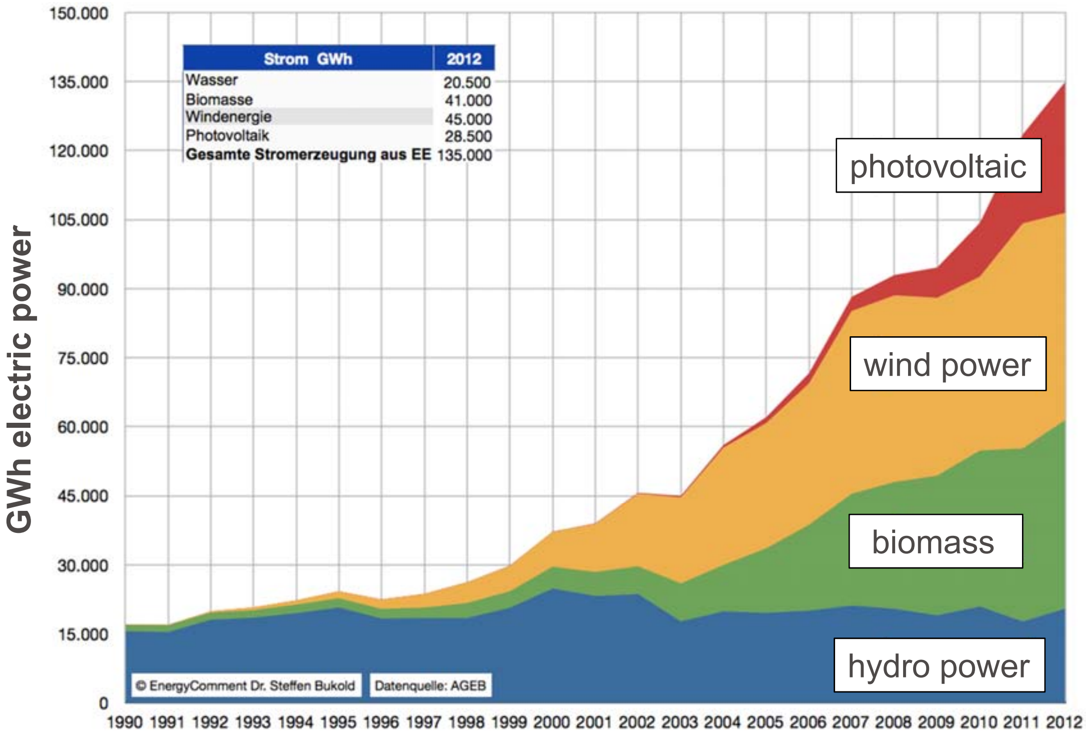

Investment in heating systems in Germany

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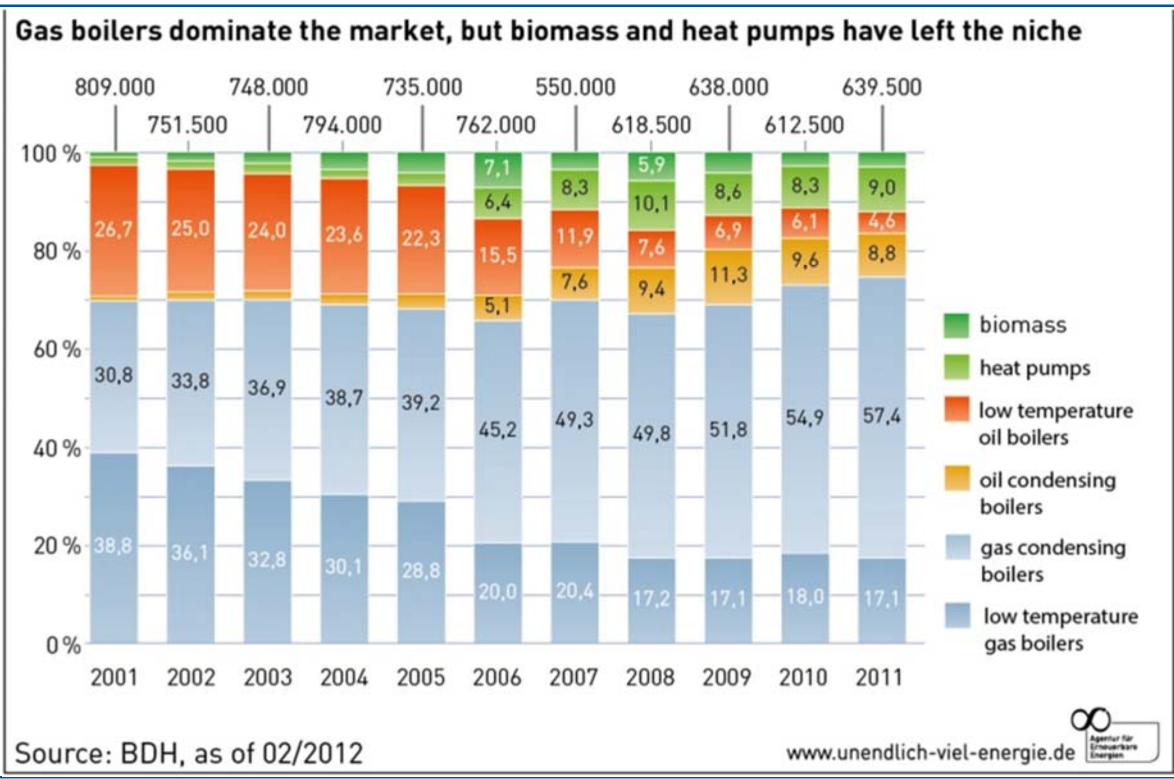


Feed-in tariff extremely successful

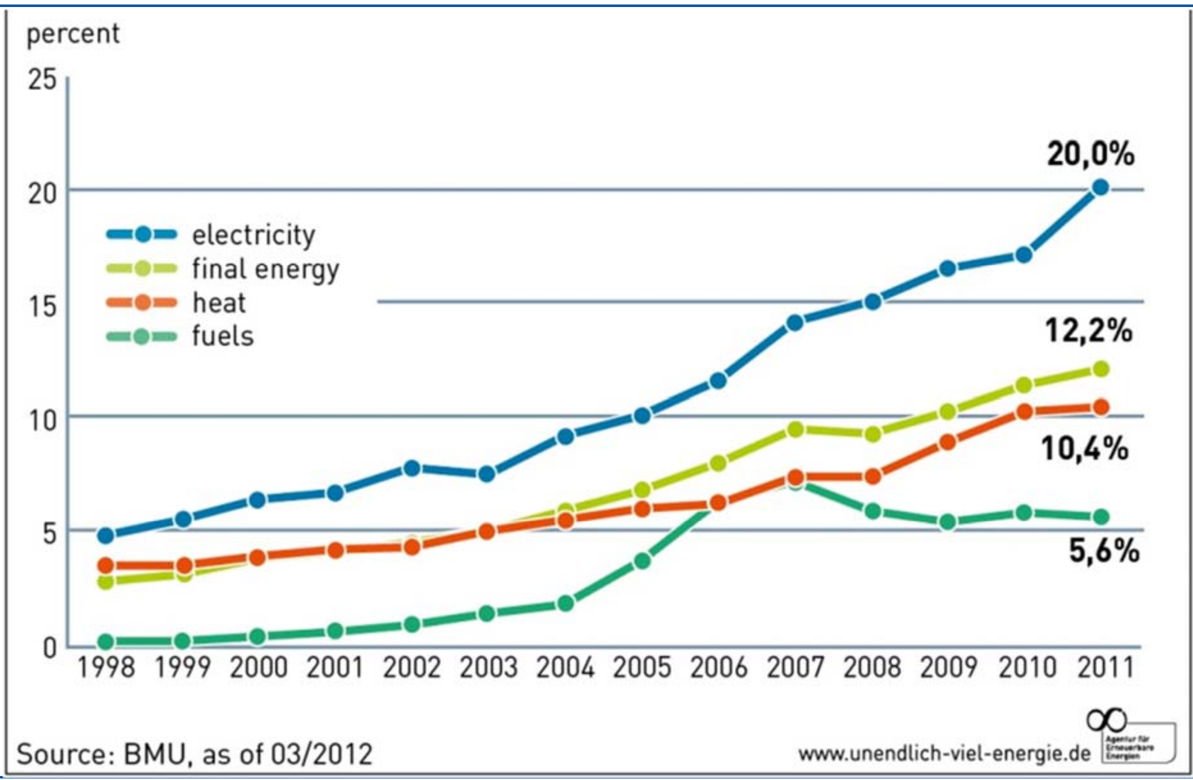
- Mass production resulted in a significant reduction in prices for PV systems.
- Roof-top PV systems have production costs around 15 to 16 €ct/kWh
- Last year the first free-field PV system showed costs below 10 €ct/kWh

- Both at around 1000 kWh/m²/year solar radiation

➔ Southern Europe has 1500 to 1800 kWh/m²/year resulting in 10 €ct/kWh (roof-top) to 6 €ct/kWh (free field) – today!

➔ North Africa has 2000 and more kWh/m²/year resulting in 8 €ct/kWh (roof-top) to 5 €ct/kWh (free field) – today!

Share of renewable energies in Germany's energy market



The German "Energiewende" – history II

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- In 2001 the national government made a contract with the power plant operators to fade out nuclear power plants until approx. 2022 (social democratic party and green party in power)
- Independent from this the German government has committed itself to reduce green house gas emissions by 2050 by 85% or more
- In autumn 2010 the national government (conservative party and liberal party) increased the maximum operation time by 14 years on average for the nuclear power plants. The CO_2 reduction goal remained unchanged.
- This was highly criticized by a majority of the population and the industry which prepared itself for the fade out, e.g. by building localized co-generation power plants.
- In April 2011 after Fukushima an immediate shut down of approx. half of the nuclear power plants and a fade out until 2021 of the remaining plants was decided by the same government, called "Energiewende"

Share of renewable energies in Germany's energy market

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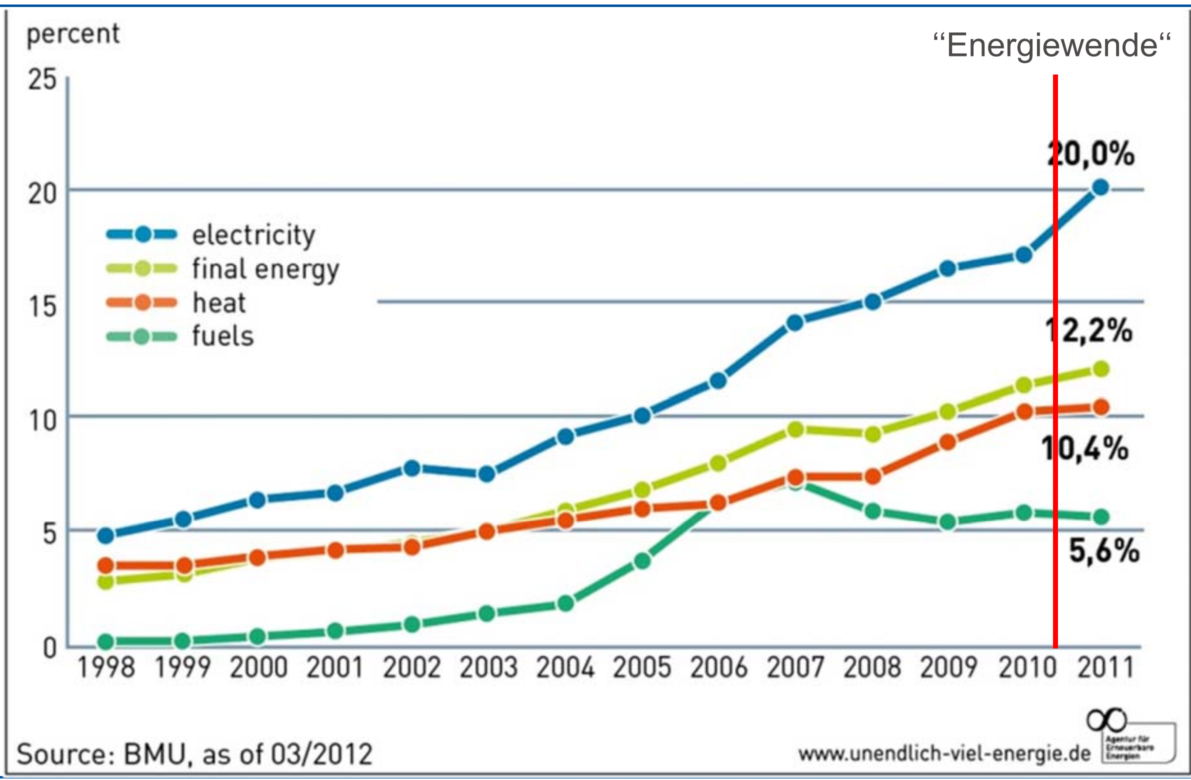

Canges in fossil and nuclear electricity production until 2020

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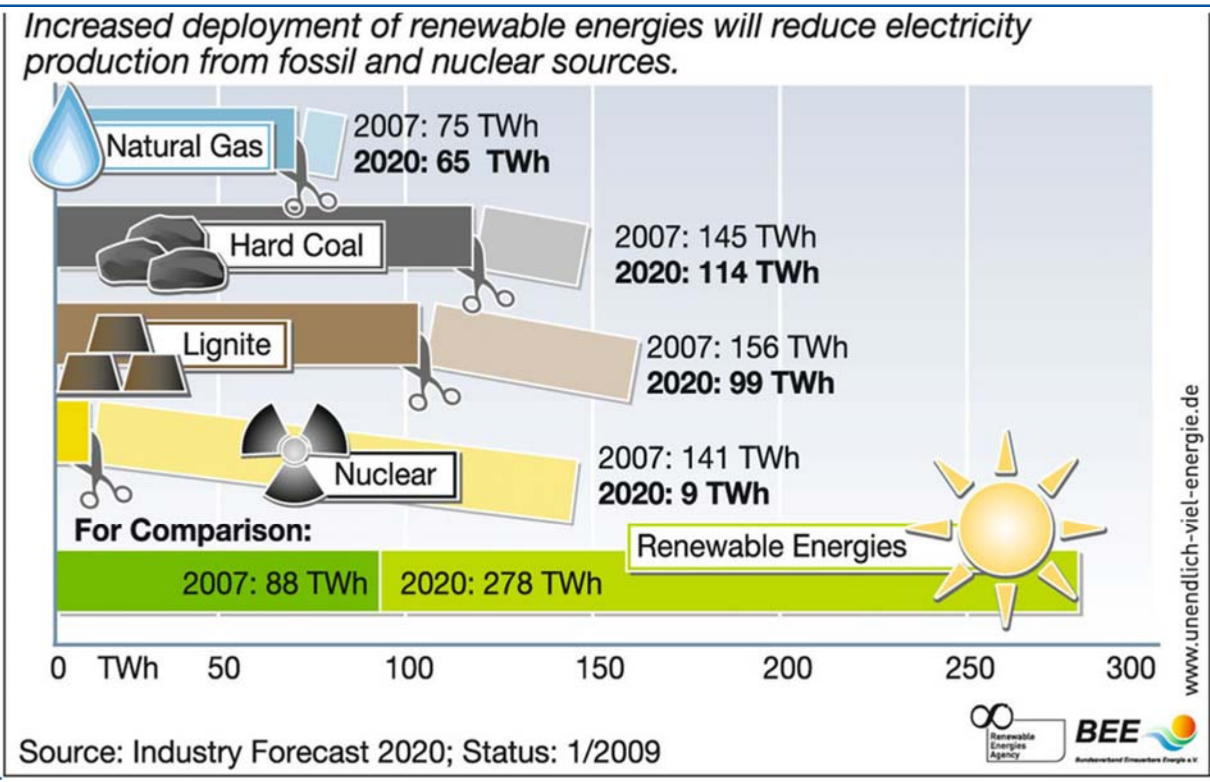

Development of electricity production from renewables and CO_2-emissions until 2020

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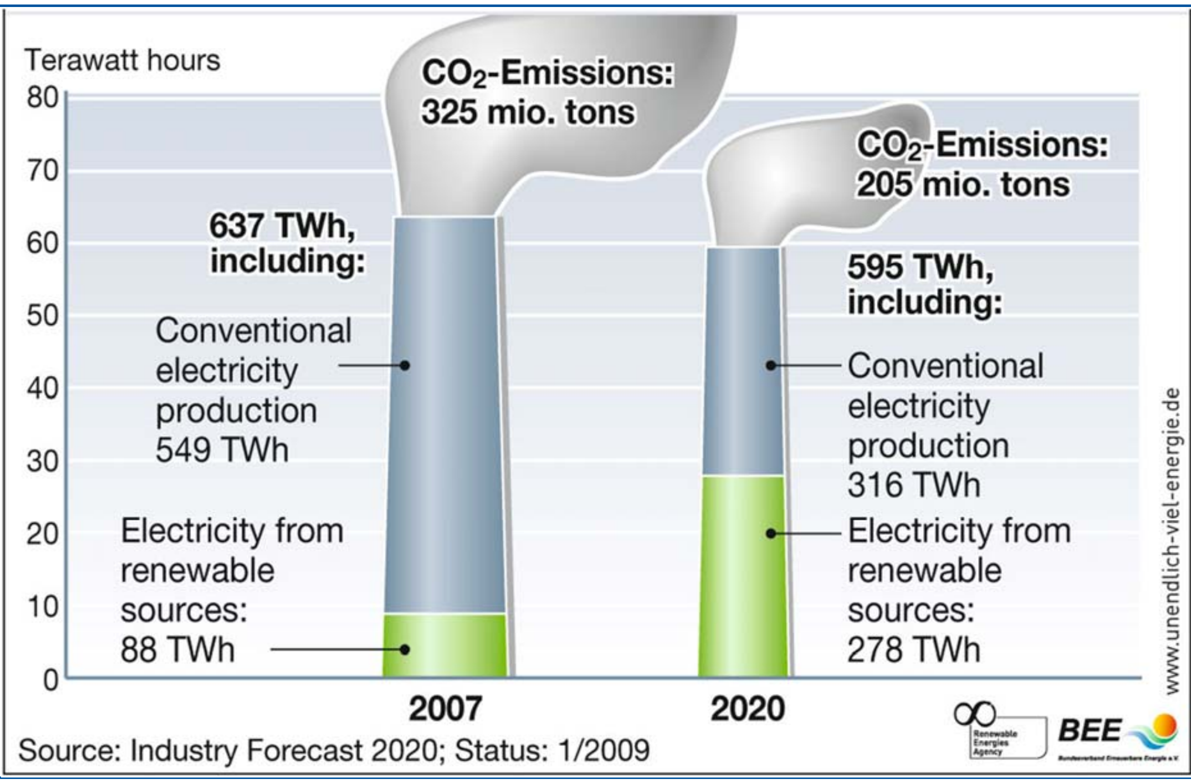

Power generation mix in Germany in 2012

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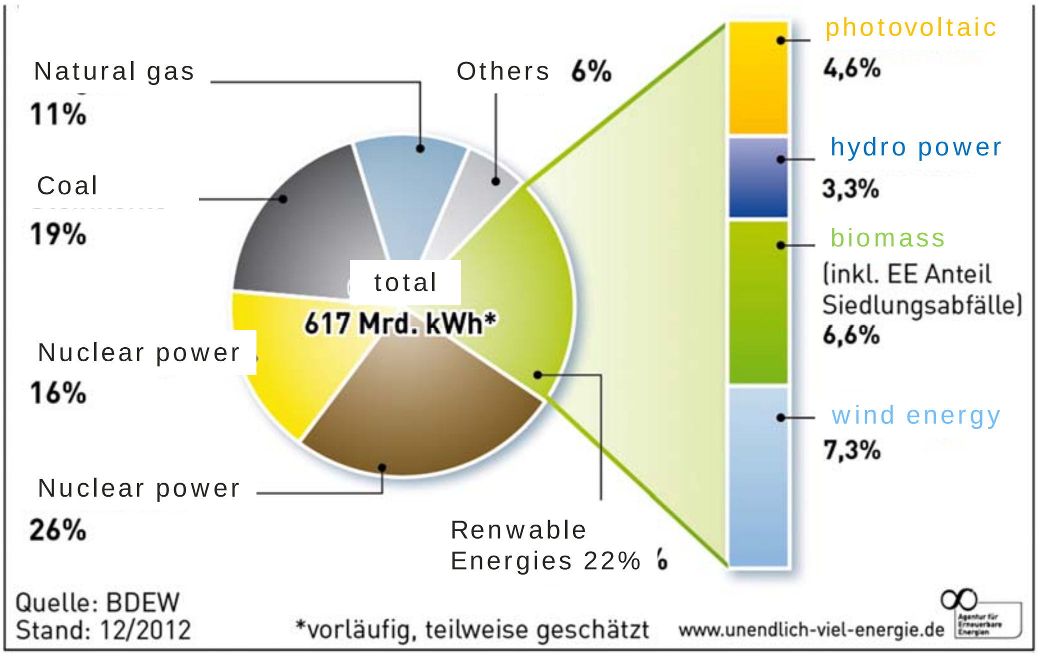

Share of power generation technologies

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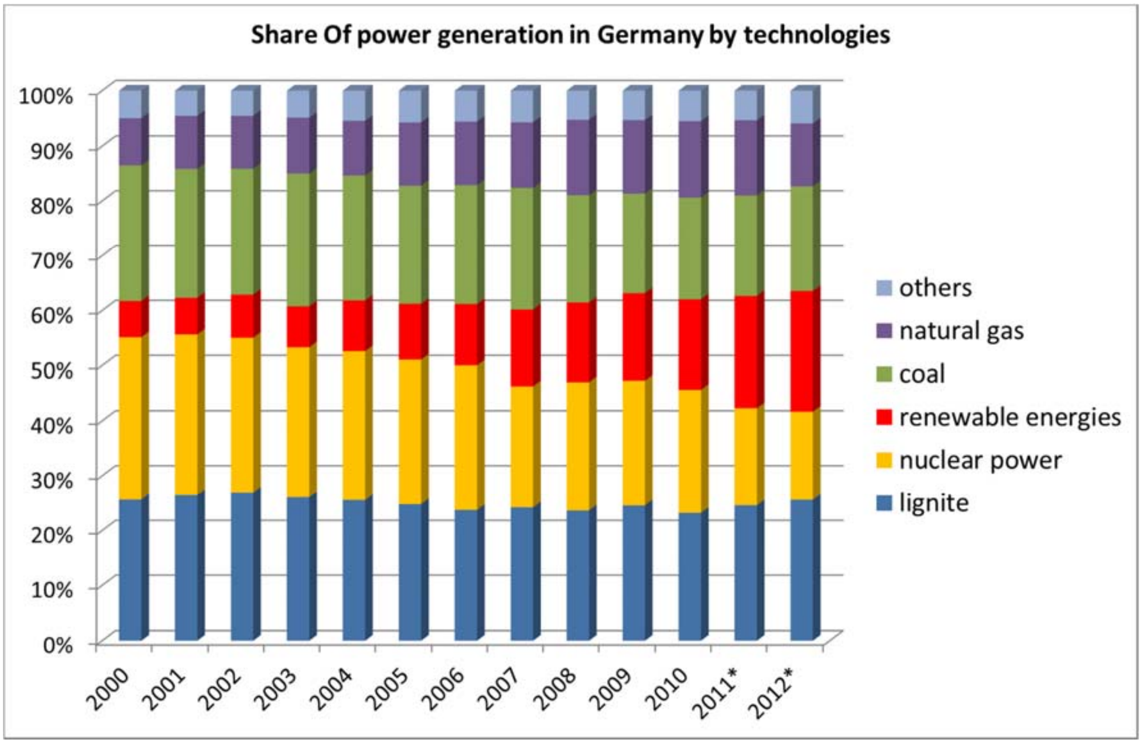
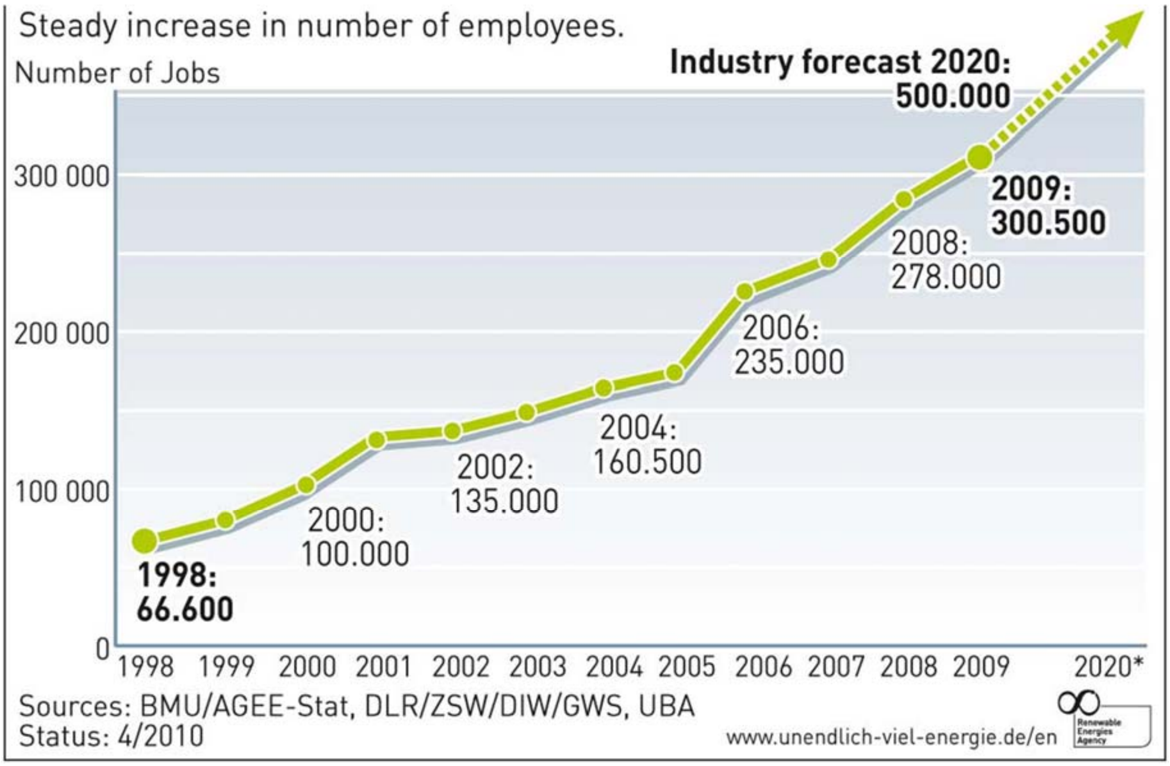


Development of jobs in the renewable energy sector in Germany



Renewable Energy in Germany: 300,000 jobs in 2009

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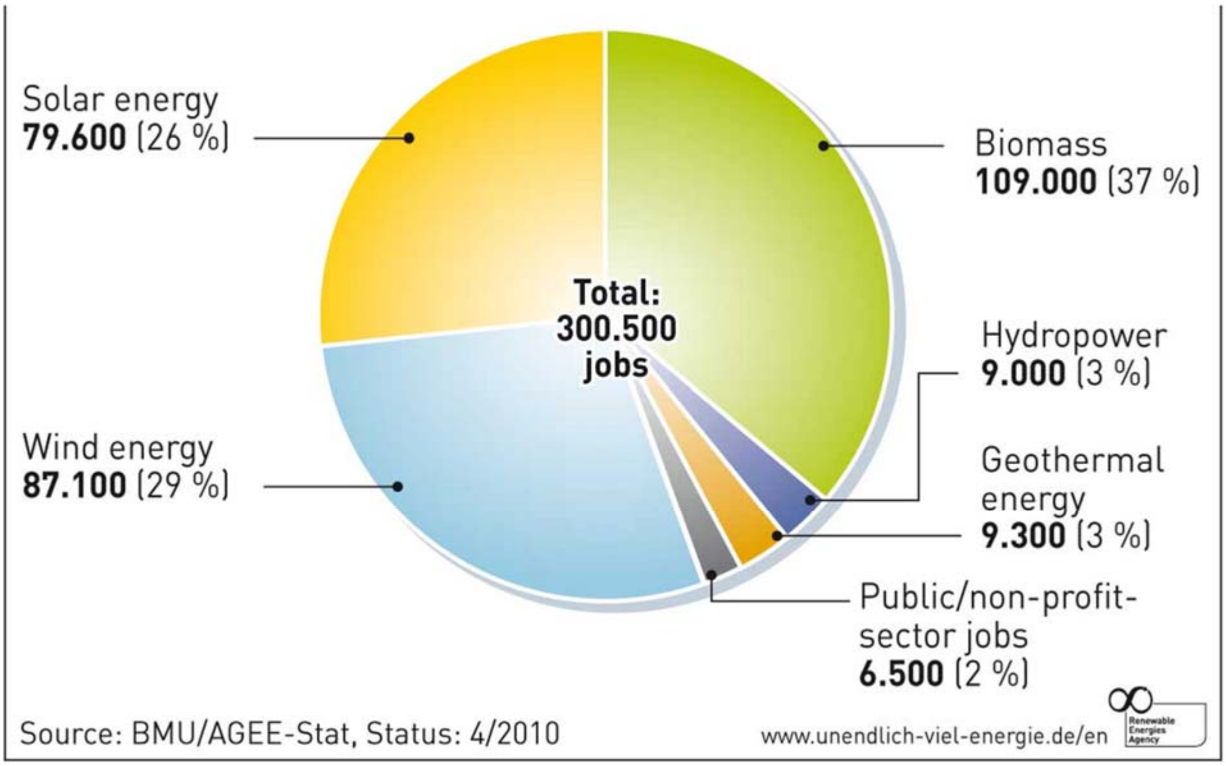

Renewable energies – an economic stimulus

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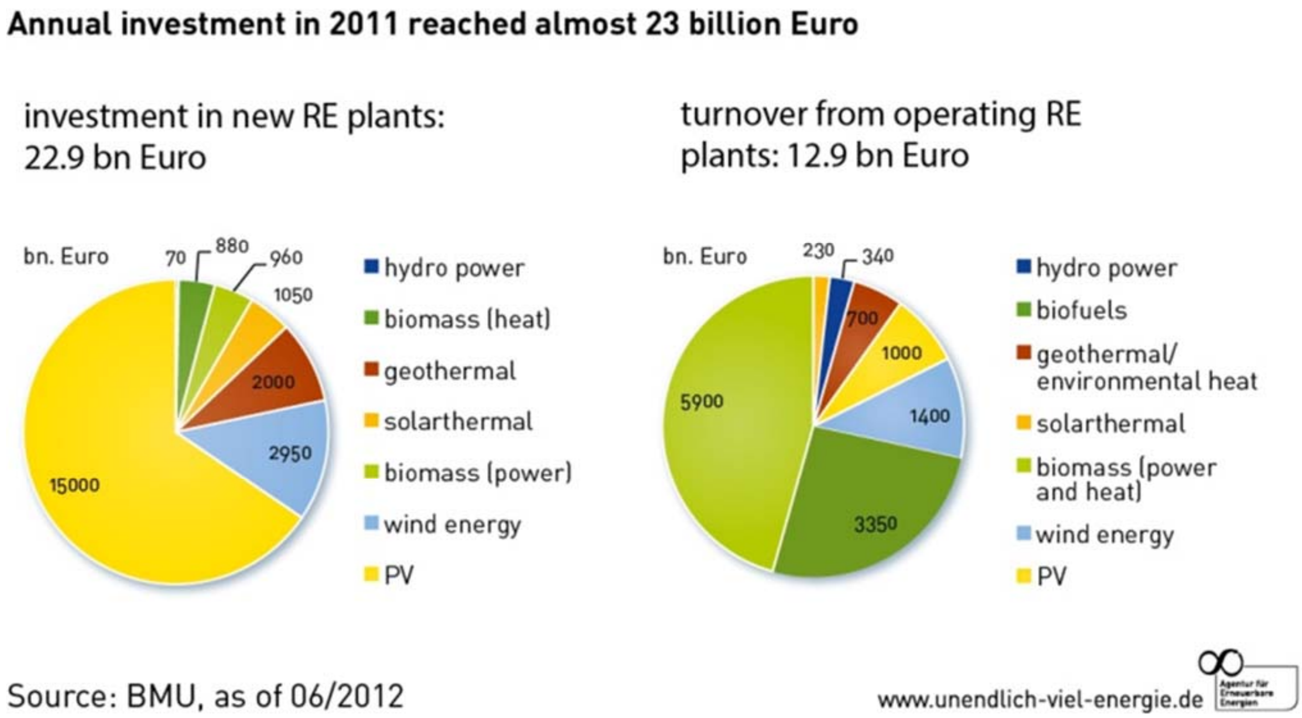
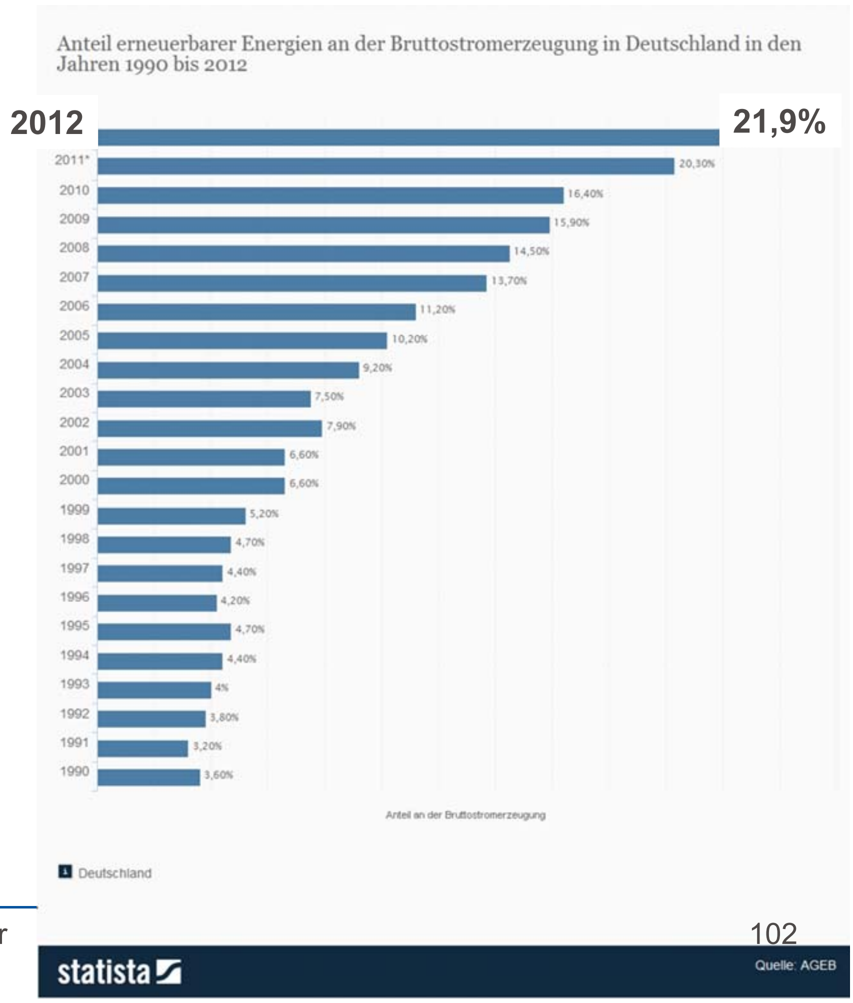
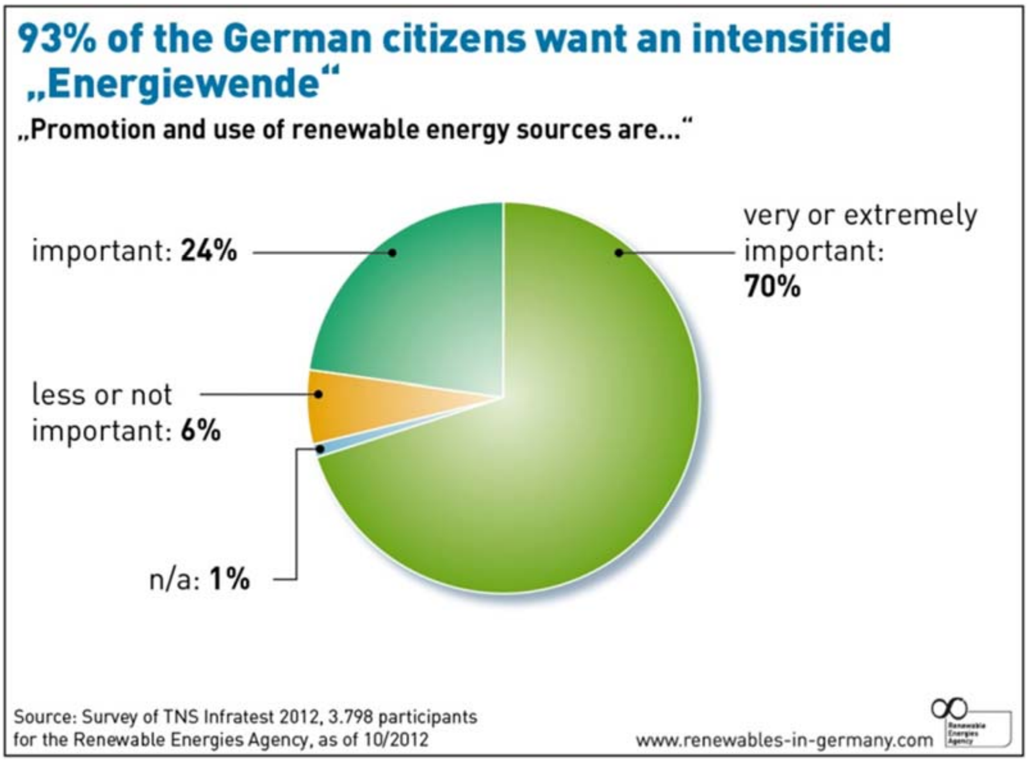


Share of renewable power generation

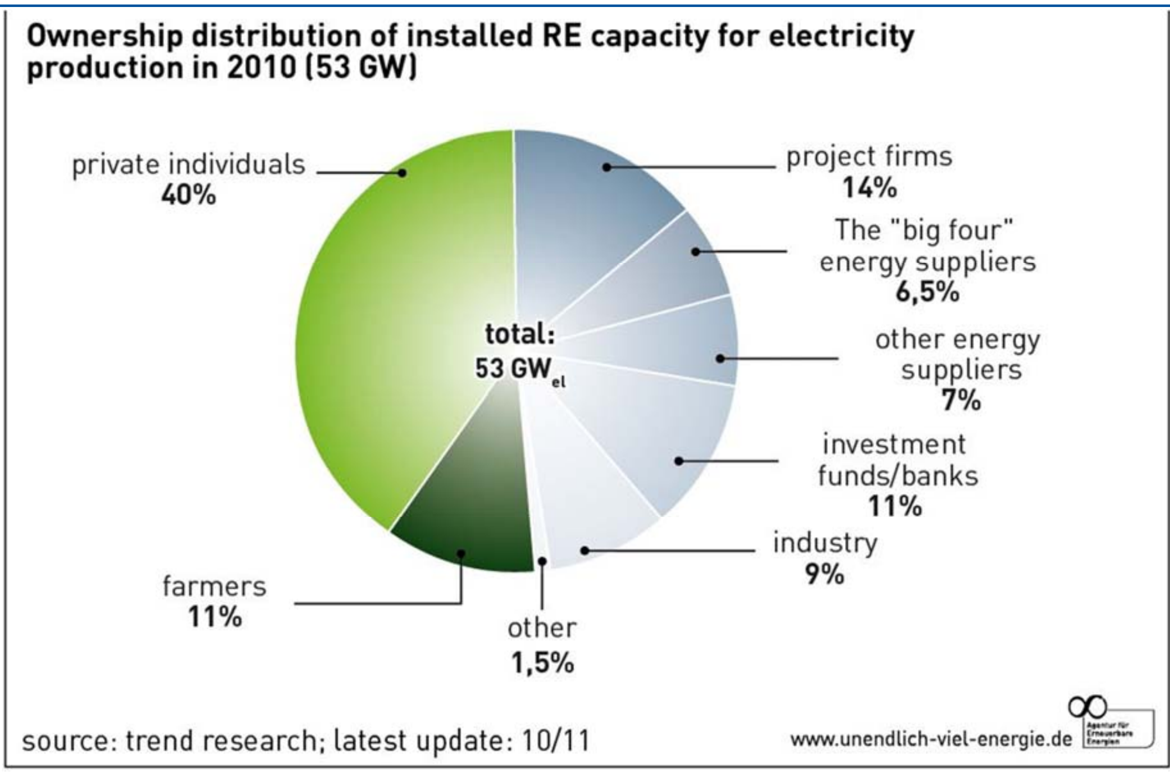
- Years 1990 - 2012
- Germany



German citizens want the "Energiewende"



Renewable energies in the hands of the people



Share of renewable energies in Germany's electricity consumption until 2020

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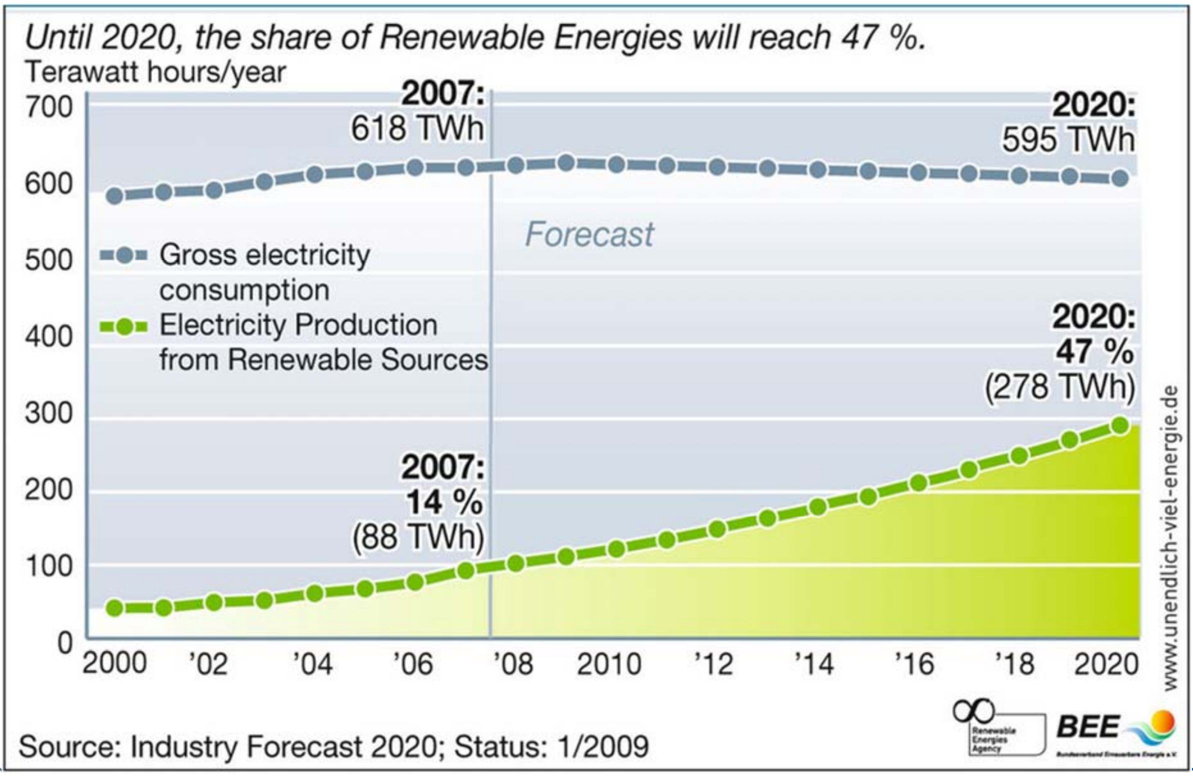

Problems

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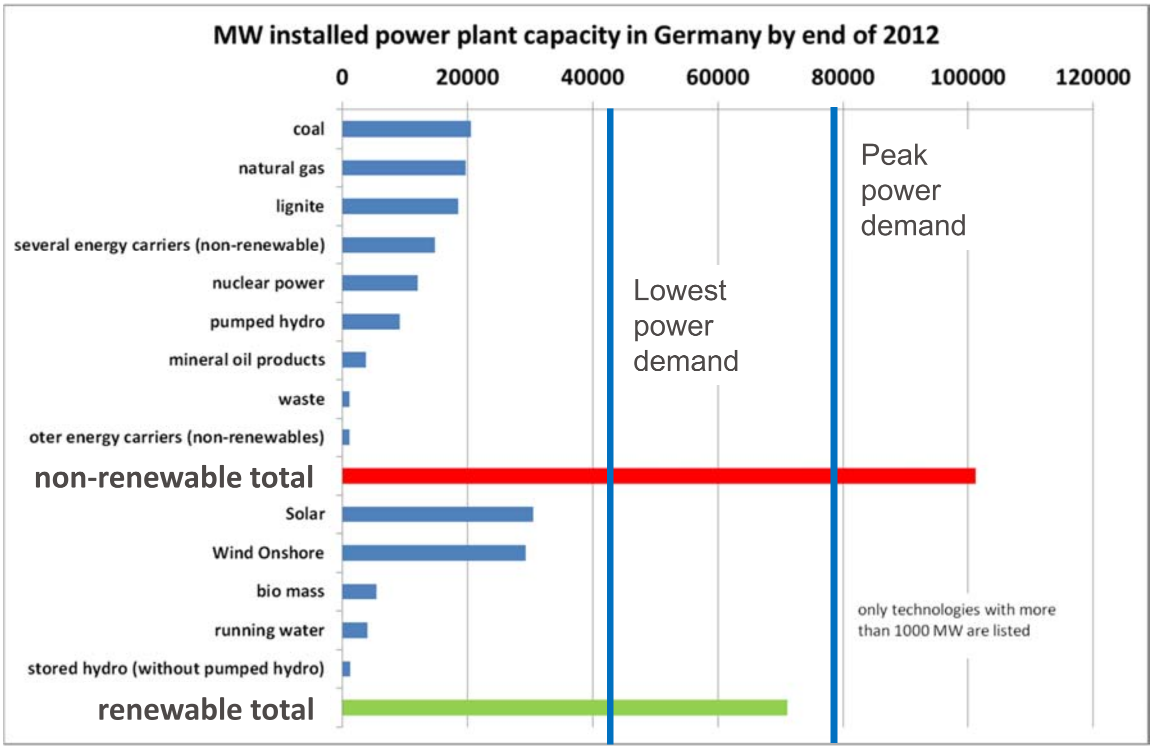
- In the past 25 years emphasis was put mainly on the development and market introduction of renewable power generators.
- Finally the increase in installed renewable capacity was much faster even compared with the most optimistic outlooks.

- This resulted more or less suddenly in several problems:
  - **Merit order** process for price-building on the power exchange is not working well anymore due to the large amount of power generation at differential costs near zero.

    ➔ Prices and price spreads at the power exchange decrease and make it difficult for conventional power plants & pumped hydro plants to earn money
  - **Grids** are not prepared for the additional power flows
  - Additional **storage systems** are not available

Installed power plant capacities in Germany by the end of 2012



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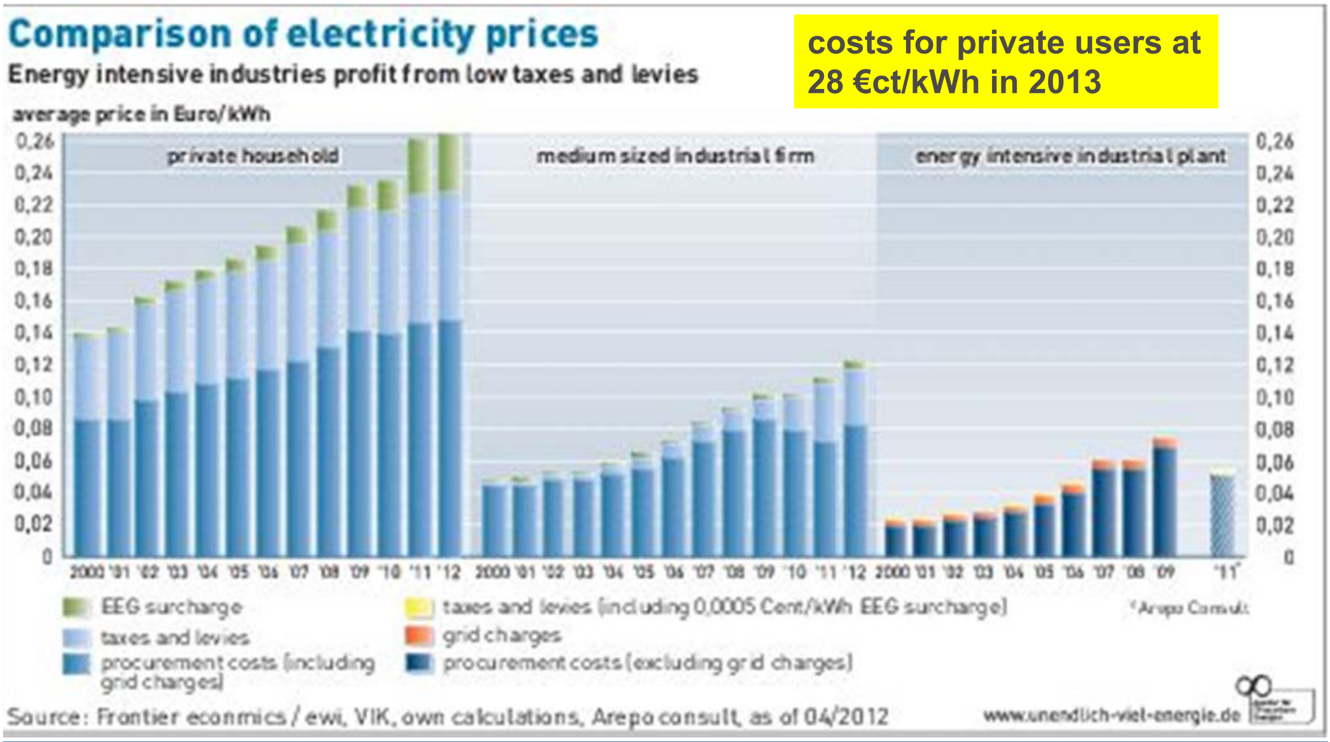
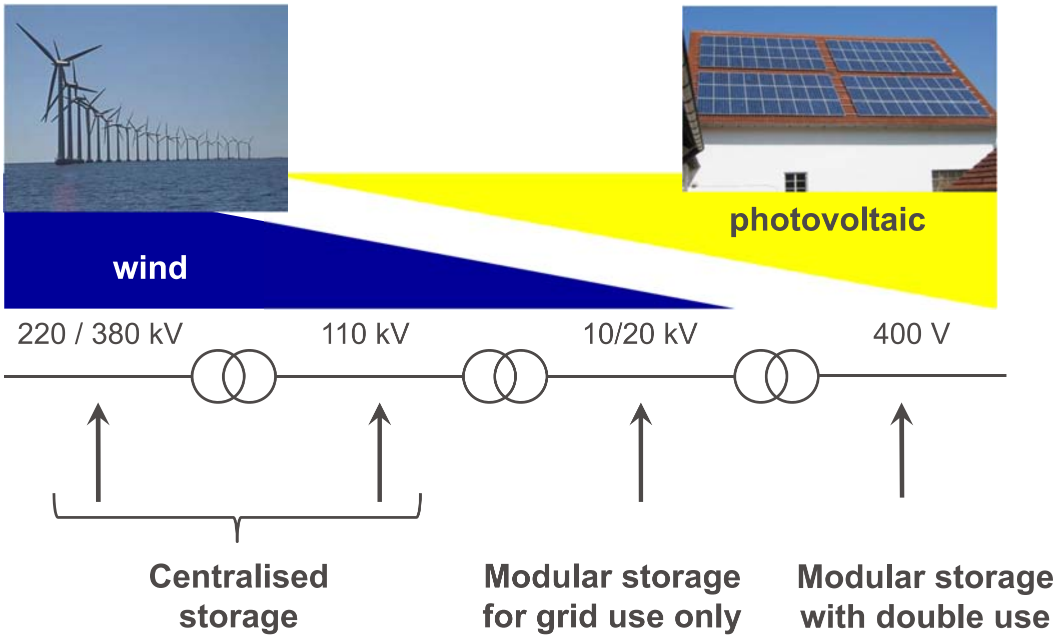
End-user electricity costs in Germany



Grid structure and grid restrictions for power flows



Prediction of needed storage capacities is difficult, because it is very sensible to ...

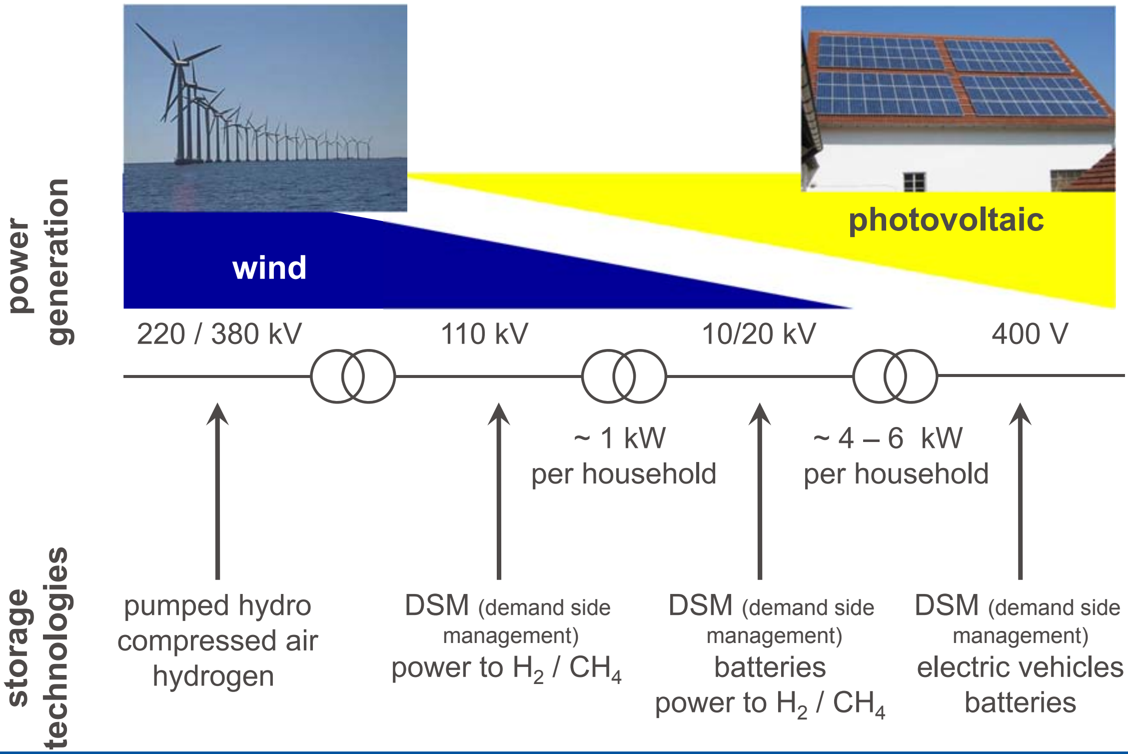
… power plant mix (share of fluctuating and non-fluctuating renewable energies, conventional power plants, e.g. gas turbines w/o CCS)

… grid expansion, especially trans-national grid expansion

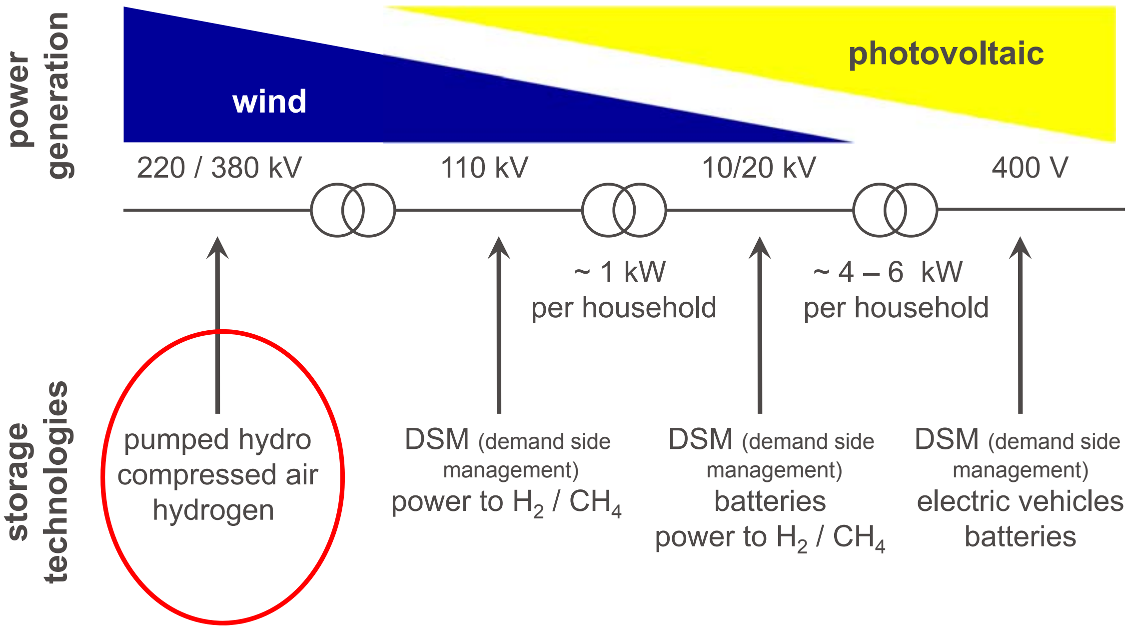
… costs of storage technologies

… capacity of storage systems with double use

Grid structure and grid restrictions for power flows



Grid structure and grid restrictions for power flows



Can not solve any problems in the distribution grid

Scenario 20xx – 100% renewables

- **No conventional power plants available anymore**
  (assumption: no carbon capture and storage technology in operation)

➔ **Storage needs in transport grids**

- Primary reserve
- Secondary / minute reserve
- **Reserve capacities for extended periods without renewable power generation in the range of a days to weeks**

➔ **Storage needs in distribution grids**

- Local congestions in the grid due to high penetration of decentralised power generators (mainly PV)
- Optimisation of self-consumption of PV systems