Wuppertal Institute
for Climate, Environment
and Energy

Christine Krüger

Improvements of Electric and Thermal Energy Storage

LCS R Net 6th Annual Meeting
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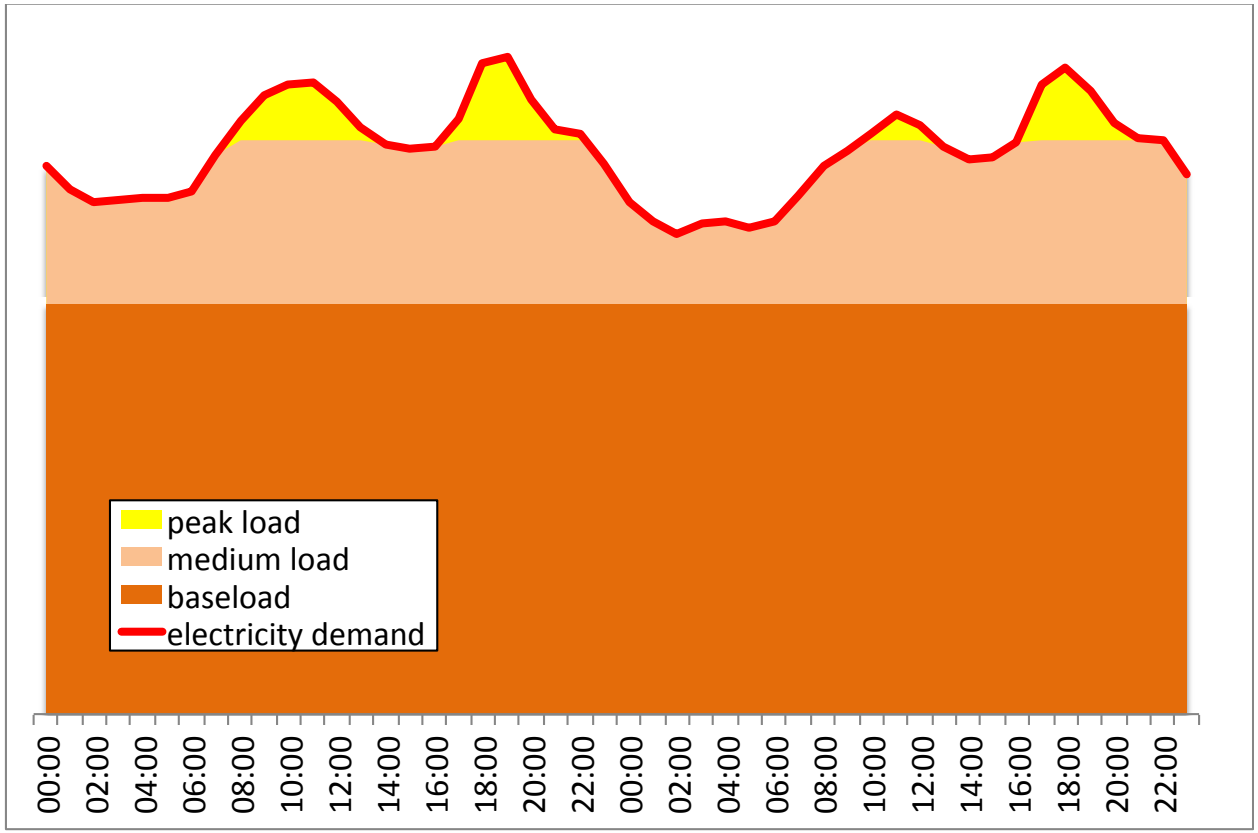
Introduction

THE CHALLENGE

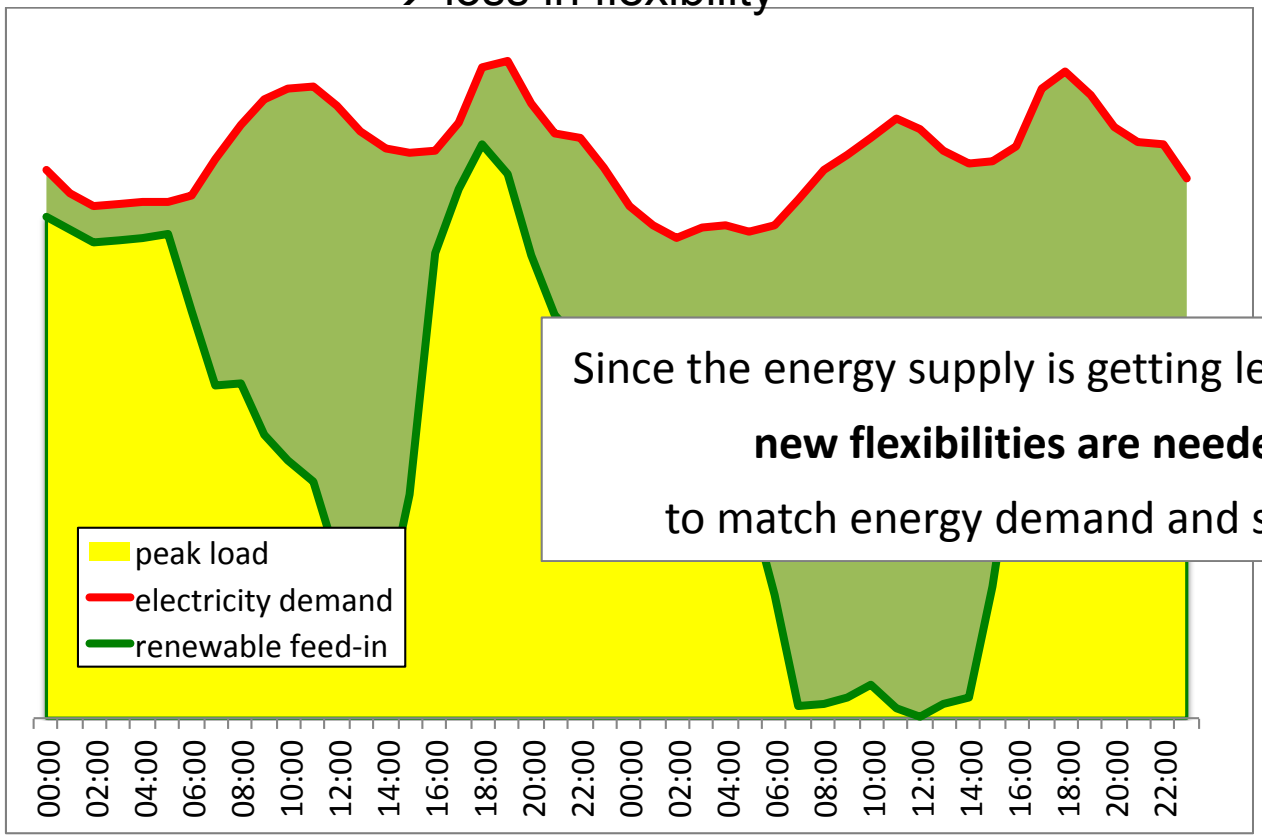
The Challenge

In a fossil based energy system:
energy production follows demand



The Challenge

A rising share of renewable energy coming into the system:
energy supply is weather-dependent
→ loss in flexibility



Since the energy supply is getting less flexible,
new flexibilities are needed
to match energy demand and supply

New flexibilities needed
Electric flexibility options

- Extension of the electricity grid
- Demand Side Management
- **Electricity-to-Electricity-Storage**
- **Electricity-to-x (virtual Storage)**
- Over-installation and curtailment of renewable surpluses
- …

➢ **Electricity storage is just one among many balancing options**

New flexibilities needed
Thermal flexibility options

Same problem: renewable energy supply is less flexible, doesn't follow demand

- balancing is needed for thermal appliances, too

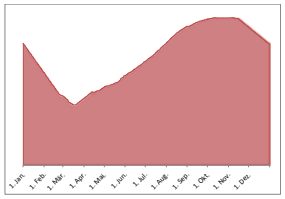
In contrast to electricity, heat and cold are rather hard to transport, but easy to store

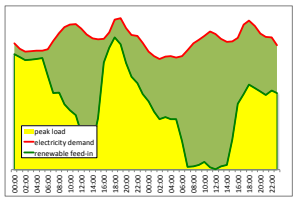
Highly decentralised installations, no spatial balancing possible

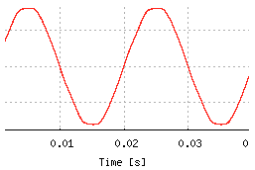
- Renewable heat & cold supply can only work with storage or fossil back-up

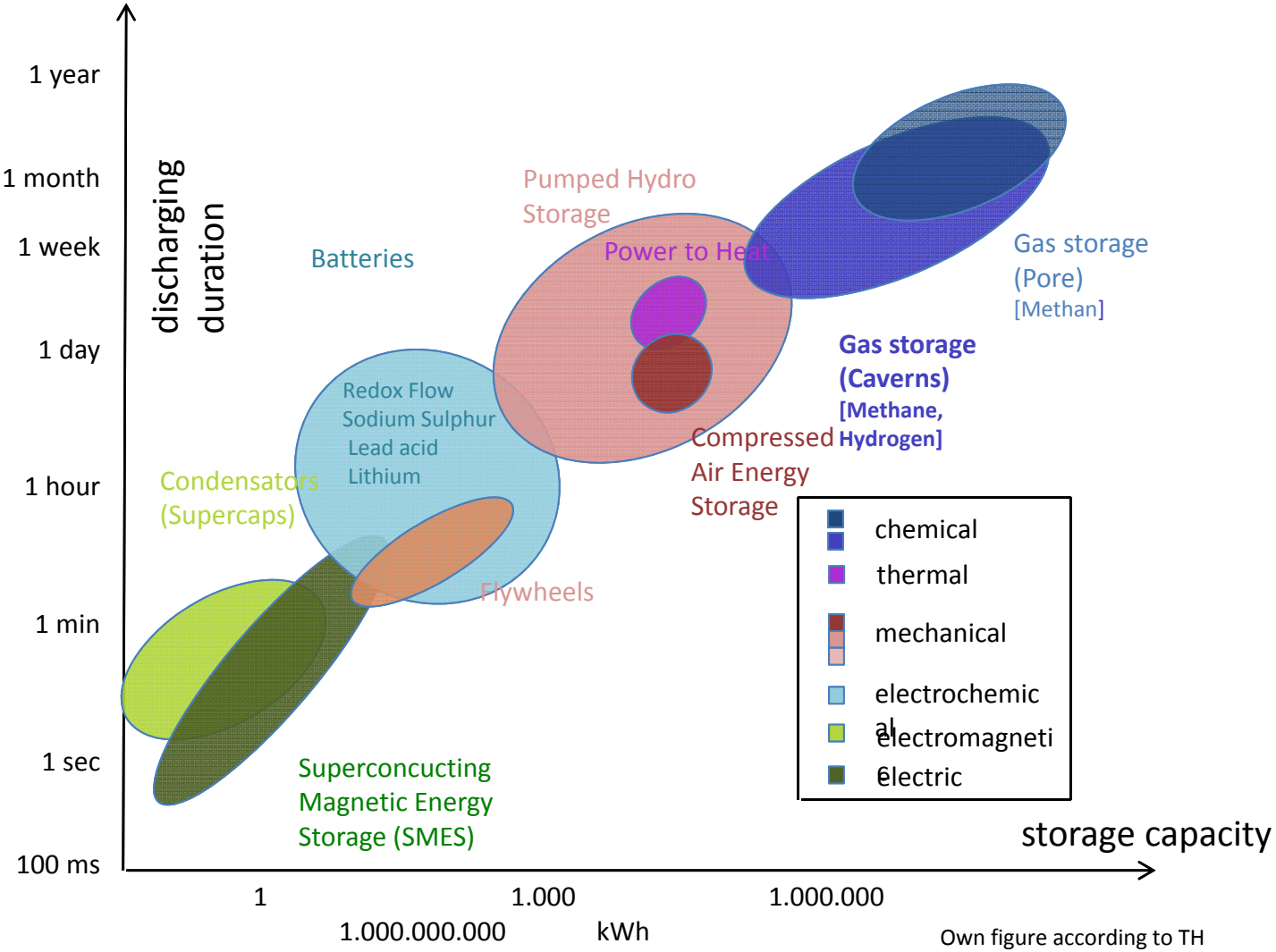
ELECTRIC STORAGE

Electric Storages
Overview







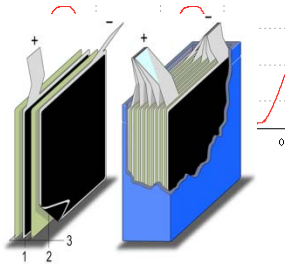


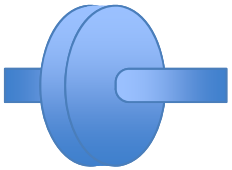
Own figure according to TH Regensburg FENES, 2013

Electric Storages

Short term storages

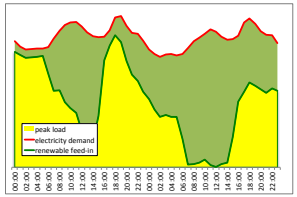
- Short term storages are needed for **power** quality → need to be quick responding
- suited technologies:
  - Supercaps
  - Superconducting magnetic energy storages (SMES)
  - Flywheels
  - Batteries
  - Pumped Hydro





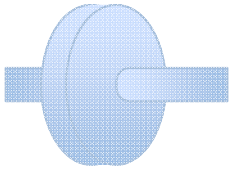
Pictures: Flywheels © WIKUE; Supercaps © Wikipedia User Tosaka; SMES ©KIT-ITEP; Batteries © Younicos; Pumped Hydro © dena

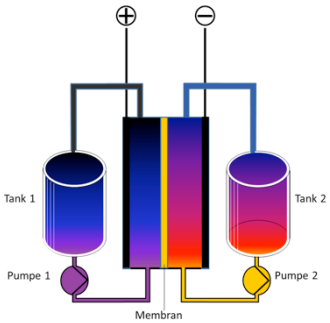
Electric Storages
Medium term storages

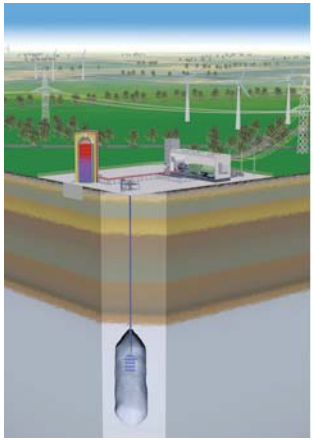


- Medium term storages: balancing **energy**, shifting it minutes up to days

- suited technologies:
  - (Flywheels)
  - Batteries
  - Pumped Hydro
  - Compressed Air



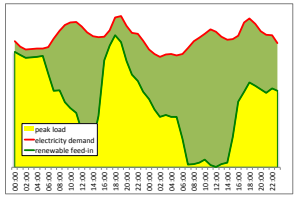




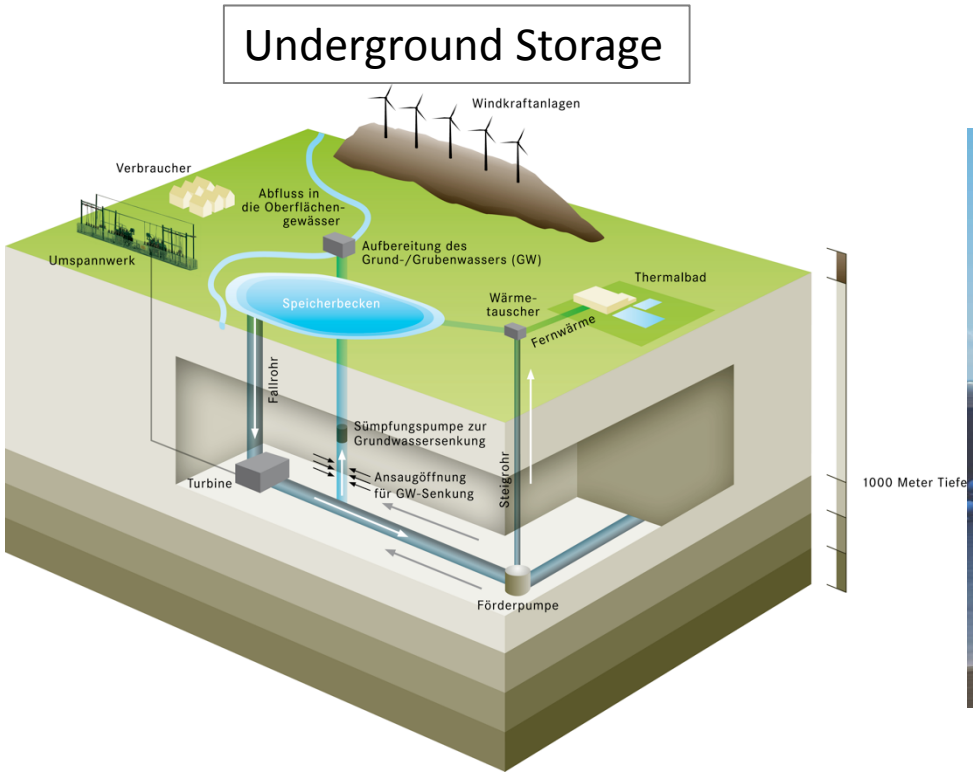
Pictures: Flywheels © WIKUE; NaS-Batteries © Younicos; Redox-Flow-Batteries © Wikipedia User Nick B. ; Pumped Hydro © dena; A-CAES © RWE

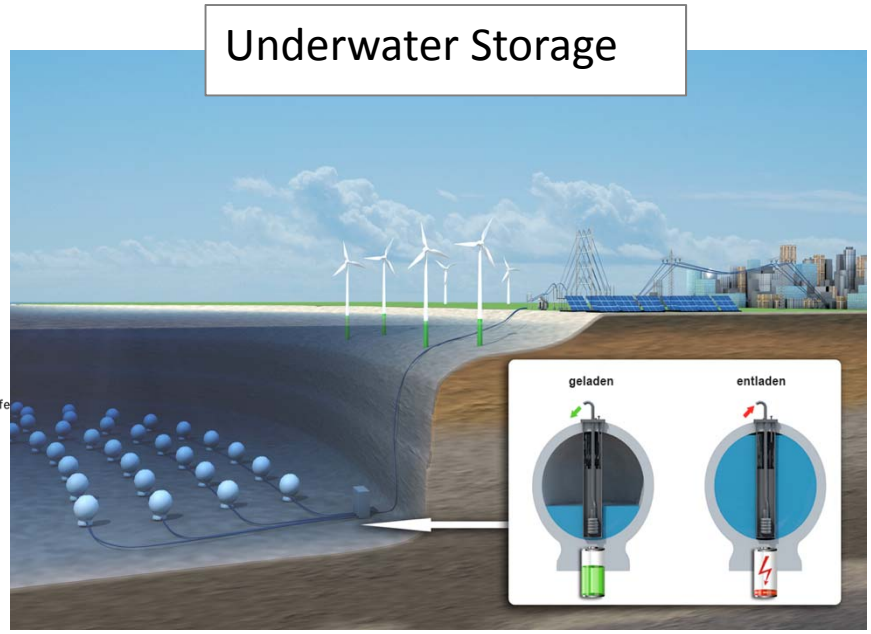
Electric Storages

Medium term storages – “Pumped Hydro” Storage



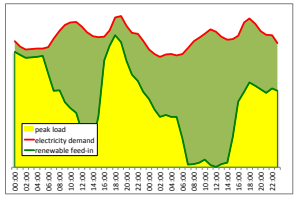
New concepts coming up:





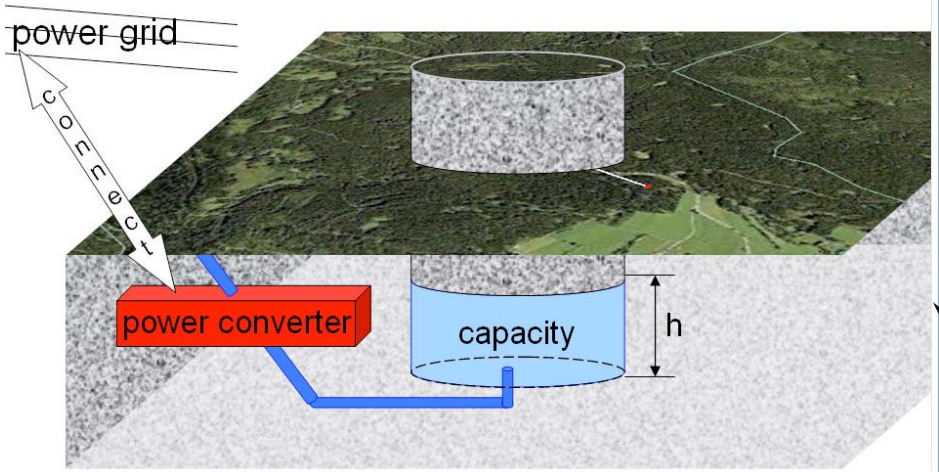
Pictures: Underground Storage © Universität Duisburg Essen; Underwater Storage © HOCHTIEF AG

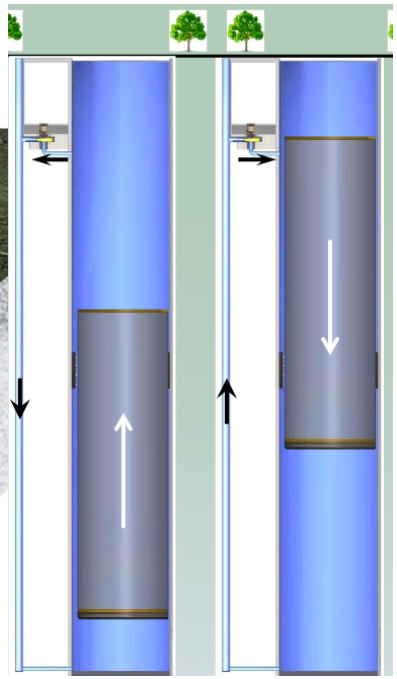
Medium term storages – Pumped Hydro Storage



New concepts coming up:

Stroke Storages

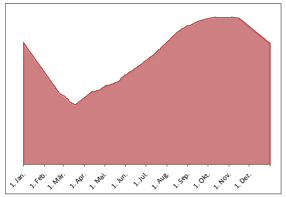




and more…

Pictures: left Picture© Gravity Power GmbH; right Picture © Eduard Heindl

Electric Storages
Long term storages



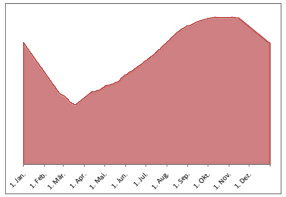
Long term storages will be needed in an electricity system with RE-Shares near 100%

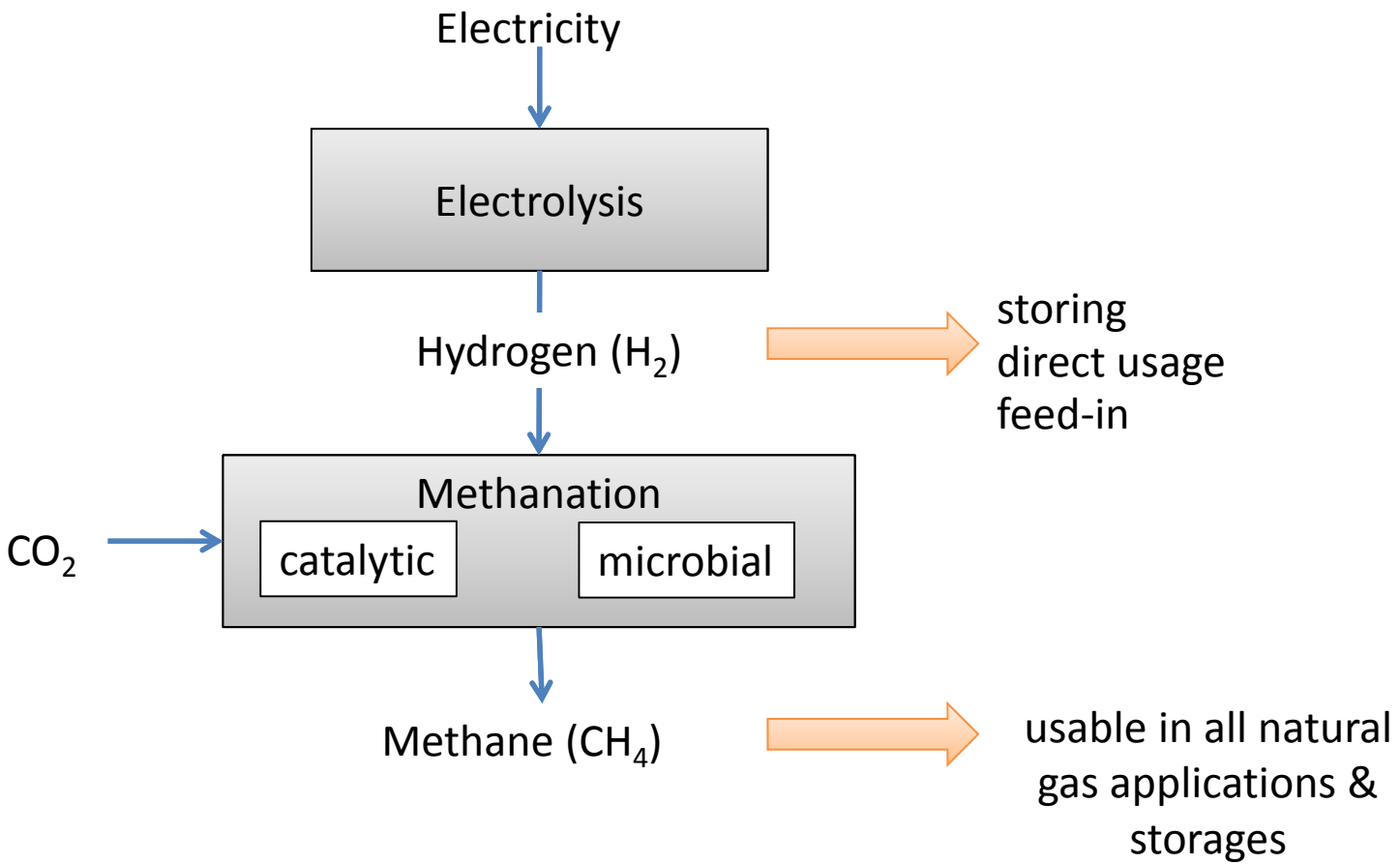
Possible technologies:

- pumped Hydro with large reservoirs (e.g. Scandinavia, Alps)
- conversion of electric power to gas with gas storage (Power-to-Gas, P2G)

Electric Storages

Long term storages – Power-to-Gas





CROSS-SECTORAL STORAGE

New potentials: Linking the sectors

- When electricity and other energy appliances are linked, new potentials arise:

- Electricity and Heating
  - Combined heat and power (CHP) plants with thermal storages can be used to compensate feed-in fluctuations
  - Heatpumps and other electric heating devices with thermal storages can be used in times of surplus energy (“Power-to-Heat”)
  - (Methane or Hydrogen from electricity can be used for heating)

New potentials: Linking the sectors

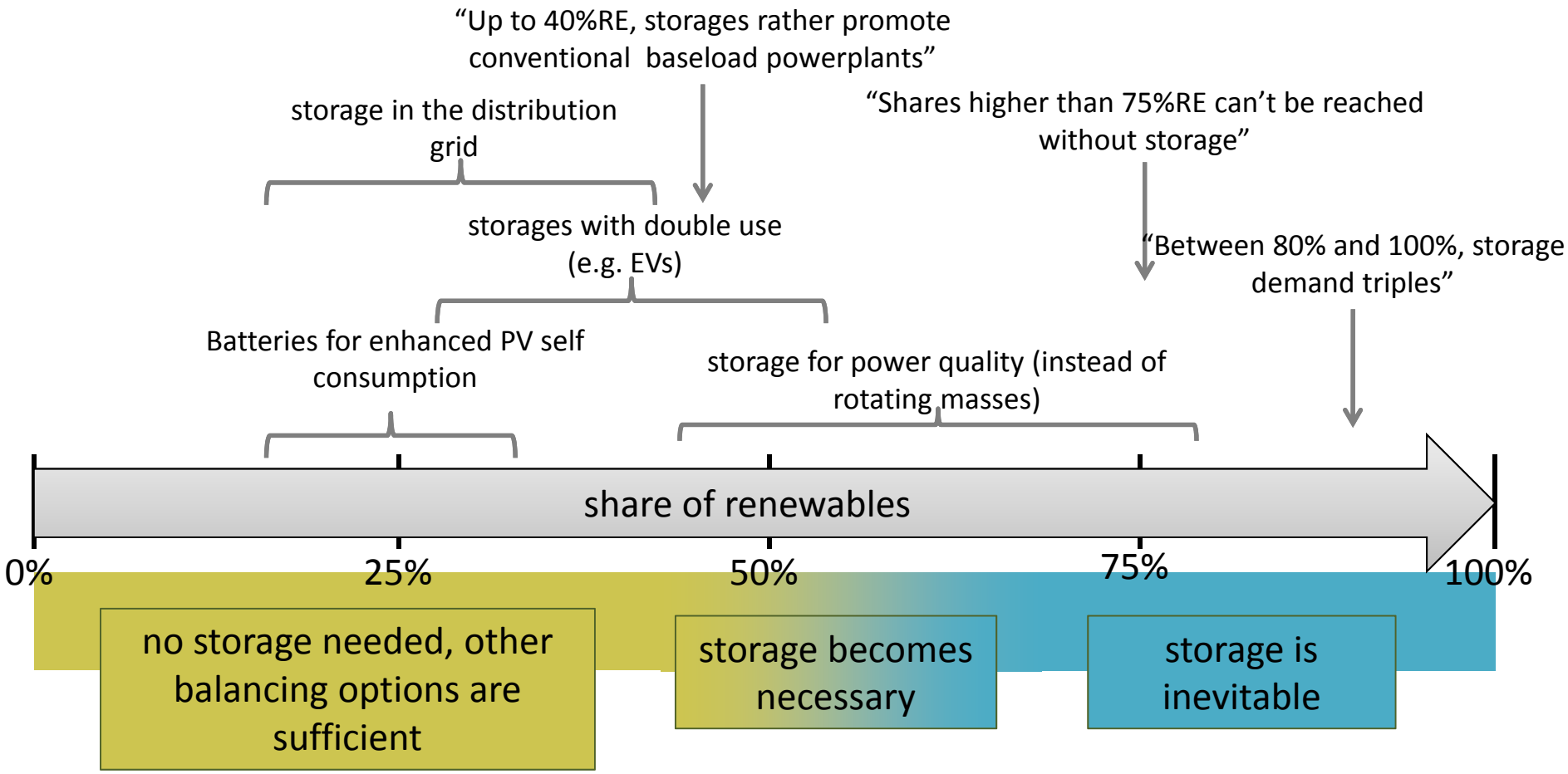
- Electricity and Transport
  - Electric vehicles' batteries can be charged (and discharged) in suited times
  - Hydrogen production for fuel cell vehicles in times of excess energy

- Electricity and the Industrial Sector
  - Electrify suited processes
  - Hydrogen production in times of excess energy for use in the chemical industry or further processing of synthesis gas

SYSTEMIC QUESTIONS

Systemic Research Questions

When will we need storages?



Sources: H.P. Beck et al: "Eignung von Speichertechnologien zum Erhalt der Systemsicherheit", EFZN, 2013; D. Fürstenwerth et al. "Stromspeicher in der Energiewende" Agora Energiewende 2014; ETG "Energiespeicher für die Energiewende", VDE, 2012

Systemic Research Questions
How to finance storage?

Storage and markets:

- Historically, storages used price spreads at the energy market
  - these spreads decrease due to rising PV-share
- By now, first storage projects business models are implemented that aim at the control power market

- But:
  - Energy market can’t offer incentives for needed capacity
  - Control power market is to small to finance sufficient storage

RECOMMENDATIONS

Energy Storage
Recommendations

Regulatory Issues:

- The role of storages in an unbundled energy system needs to be clarified
- New energy market design should give long-time security regarding conditions for storage

The Overall System:

- Mechanisms are needed that anticipatorily ensure sufficient system flexibility
- Efficient system balancing needs spacious energy markets (e.g. European)
- To determine the balancing demand, research programs are needed to investigate the complex interactions in large energy systems
- storages must never be considered without the alternative balancing options

Energy Storage
Recommendations

Preparing storage for the future:

- prepare suited conditions for market introduction
- develop business models for storages with different primary uses (e.g. PV batteries, electric vehicles, thermal storage) to participate in load balancing
- research is needed to decrease cost at all storage levels
- demonstrational projects need to be funded for new storage technologies
- enhance acceptance of large infrastructure projects by participation in early stages of planning

RÉSUMÉ

Résumé

Important to know about storage

- With rising share of renewables, new flexibilities are needed to match energy demand and supply
- Energy storage is just one among many balancing options
- There's no urgent need for large scale storage implementation in the next two decades, but that time will be needed to prepare
- In a near system near 100% renewable share, storage will be indispensable
- There already are storage technologies for all needs existing or under development
- Systematic problem: today's conditions and market designs do not give sufficient incentives for storages

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Thank you for your kind attention!

short overview

THERMAL STORAGE

Thermal Storage
Technologies and Applications

Three different principles:

- sensible thermal storage → storage medium heats up
  - hot water storage (from some litres up to several thousand cubic metres)
  - gravel-water heat storage
  - aquifer seat / cold storage
- latent thermal storage → storage medium changes state of aggregation
- thermochemical storage → thermal energy stored in chemical reaction

Applications:

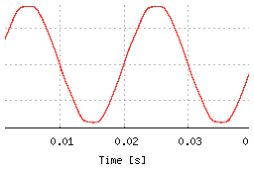
- support renewable heat / cold supply
- latent / thermochemical storage: transport of heat / cold

Thermal Storage
Current Research

Some examples for current research questions:

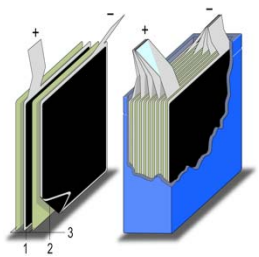
- materials for latent storages
- Applications for latent heat storages
- Materials and storage media for high-temperature storage
- building integration of thermal storages
- cost reduction
- …

Short term storages - Supercaps



Supercaps (electrochemical double layer capacitors – EDLC):

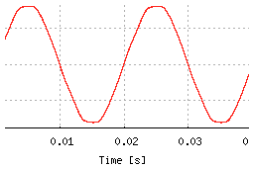
- capacitors with high energy density
- used for appliances with frequent cycling
  - high efficiency (no conversion of electrical energy)
  - high stability
- used for voltage quality
- used for mobile applications (recuperation of breaking energy)
- current research: reaching higher energy densities by using materials with large surfaces (e.g. porous carbon, nanomaterial)



Sources: Agentur für Erneuerbare Energien “Hintergrundinformation Strom speichern”, 2009; Picture: © Wikipedia User Tosaka

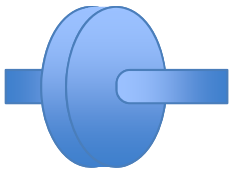
Electric Storages

Short term storages - Flywheels



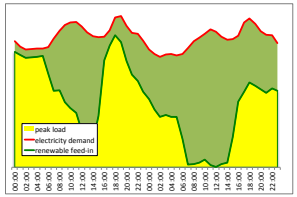
Flywheels:

- have been used in machinery for a long time for storing mechanical energy
- can react during milliseconds and are therefore used for voltage quality applications
- for electricity storage application, high speeds are needed
  - ➢ research on new materials with high stability (up to 100.000 rpm achieved)
  - ➢ research on materials and coting of bearings and magnetic contact-free bearings
- can also be used for mobile applications (recuperation of breaking energy)

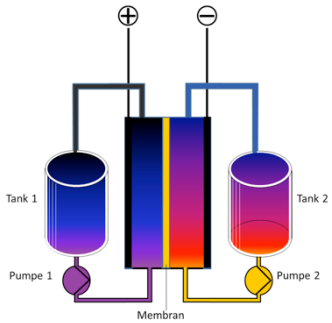


Sources: bine Informationsdienst: Projektinfo 11/03 “Kinetische Speicherung von Elektrizität”;
Agentur für Erneuerbare Energien “Hintergrundinformation Strom speichern”, 2009

Electric Storages
Medium term storages - Batteries

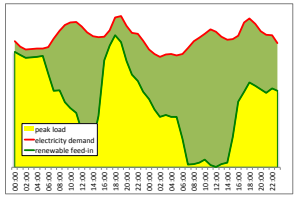


- Large stationary batteries are currently used for
  - industrial load management → established
  - PV-Home-Systems → rising number of installations
  - regional load balancing, e.g.
  - balancing wind power feed in (demo projects)
  - balancing insulated grids (historical, e.g. West Berlin, demonstrational, e.g. Island of Graciosa)
  - primary/secondary control power (demo projects)



Pictures: NaS-Batteries © Younicos; Redox-Flow-Batteries © Wikipedia User Nick B.

Electric Storages
Medium term storages – Battery technologies

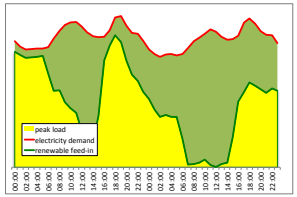


- Lead-Acid Batteries:
  - mature technology
  - research on gradual improvements

- Lithium Batteries:
  - different material combinations possible
  - high energy density → interesting for mobile applications
  - storage sizes up to some MW
  - very high research activity (2011: 5'000 patents), e.g. on new materials, enhancement of production,..

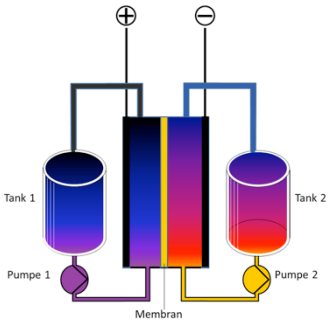
Source: S. Müller et al. "Monitoring innovation in electrochemical energy storage technologies: A patent-based approach", Applied Energy, 2014

Medium term storages – Battery technologies



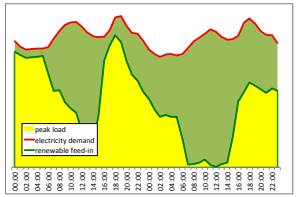
- Sodium-Sulfur Batteries:
  - high working temperature (≈300 ° C) → idling decreases efficiency
  - for stationary applications

- Redox-Flow Batteries:
  - external electrolyte tanks allow scaling of storage capacity
  - old idea (1970s) coming back
  - growing research interest (90 patents in 2009, 200 patents in 2011)



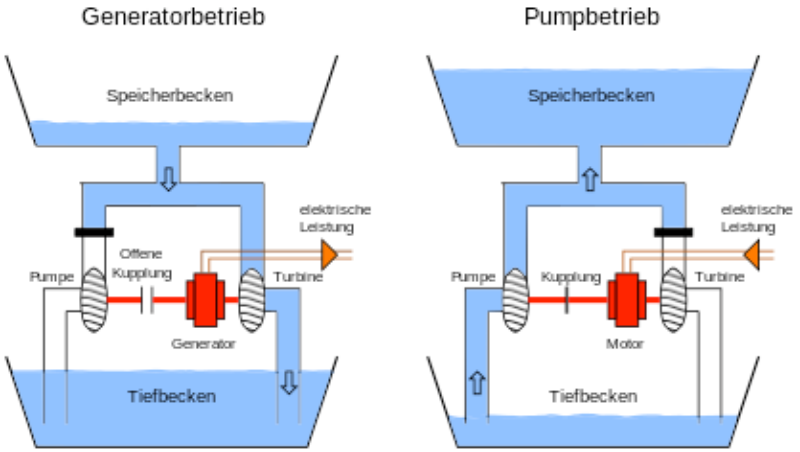
Source: S. Müller et al. "Monitoring innovation in electrochemical energy storage technologies: A patent-based approach", Applied Energy, 2014
Picture: Redox-Flow-Battery © Wikipedia User Nick B

Electric Storages
Medium term storages – Pumped Hydro Storage



Pumped Hydro Storage is the most established electricity storage technology

- ca. 350 existing plants, ca. 150 GW
- ca. 250 projects, ca. 170 GW (ca. 30 projects under construction)



Source: ecoprog “Der Weltmarkt für Pumpspeicherkraftwerke”, 2013
Pictures: Scheme © Wikipedia User wdwd; Photo © dena