“FLEXIBLE SECTOR COUPLING” – DEFINITIONS, ASSUMPTIONS AND CONCEPT

Andreas Hauer

Content

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- Energy Storage – Definitions
- Flexible Sector Coupling – Definitions & Assumptions
- Flexible Sector Coupling – Concept
- Flexible Sector Coupling – Further Structuring of Energy Storage Solutions
- Flexible Sector Coupling – Applications & Best Practice Examples
- Flexible Sector Coupling – Possible Benefits

Energy Storage – Definitions

Definitions „Energy Storage“

What is energy storage?
An energy storage system can take up energy and deliver it at a later point in time. The storage process itself consists of three stages: The charging, the storage and the discharging.

What is actually stored?
The form of energy (electricity, heat, cold, mechanical energy, chemical energy), which is taken up by an energy storage system, is usually the one, which is delivered. However, in many cases the charged type of energy has to be transformed for the storage (e.g. pumped hydro storage or batteries). It is re-transformed for the discharging. In some energy storage systems the transformed energy type is delivered (e.g. Power-to-Gas or Power-to-Heat).

Relation between energy storage systems and their applications
The technical and economical requirements for an energy storage system are determined by its actual application within the energy system. Therefore any evaluation and comparison of energy storage technologies is only possible with respect to this application. The application determines the technical requirements (e.g. type of energy, storage capacity, charging/discharging power,…) as well as the economical environment (e.g. expected pay-back time, price for delivered energy,…).

Difference between Power & Energy

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„Storage of Power“

e.g. Power Reserve

„Storage of Energy“

e.g. Peak Shaving / Dispatchable Load

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Energy Storage – Technologies

Overview of Energy Storage Technologies (non-exhaustive)

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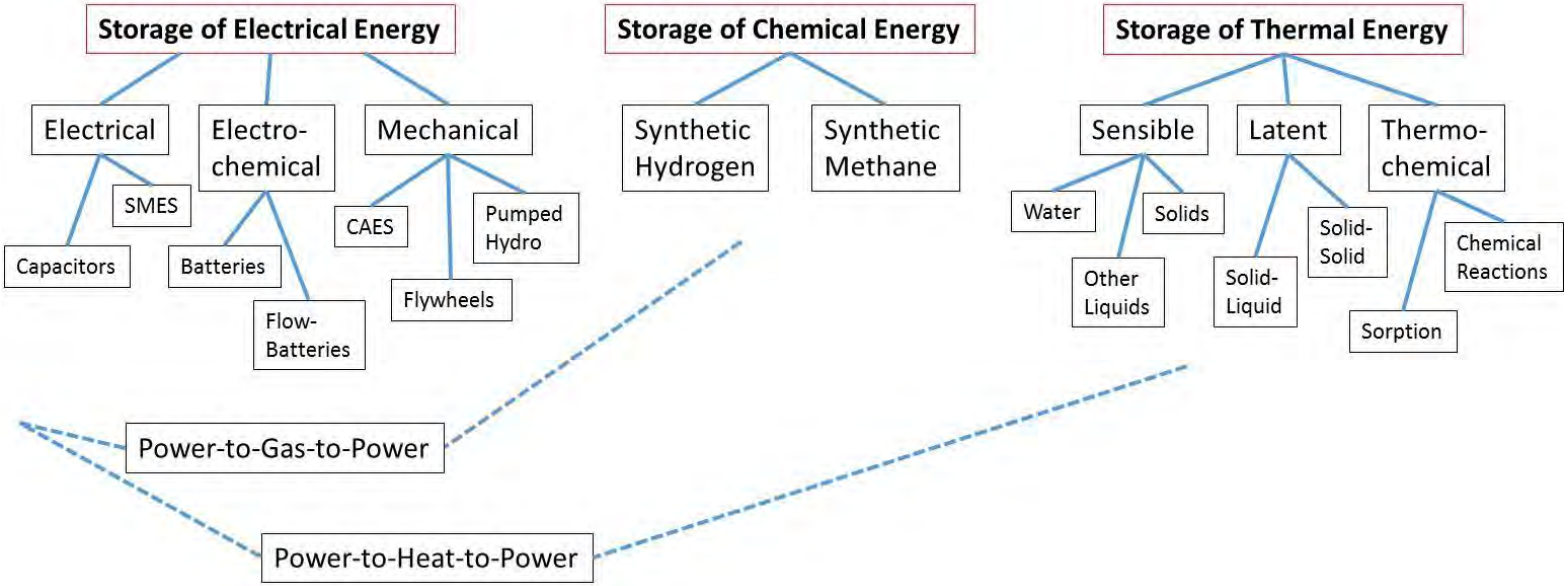
Structure of Energy Storage Technologies following the Physical Storage Effect
(not the relevance of the technologies!)



Electrical Storage Technologies

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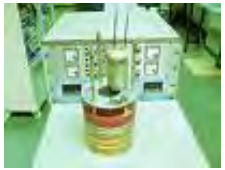
- **Storage as Electrical Energy**




- Super-conducting Magnetic Energy Storage (SMES)
- Super-Capacitor

- **Storage as Electro-chemical Energy**



- Lithium-Ion Battery
- Sodium-Sulfate Battery (NaS-Cells)
- Lead-Acid Battery
- Redox-Flow Battery

- **Storage as Mechanical Energy**



- Pumped Hydro Storage
- Compressed Air Energy Storage (CAES)
- Flywheel

Electrical Storage Technologies

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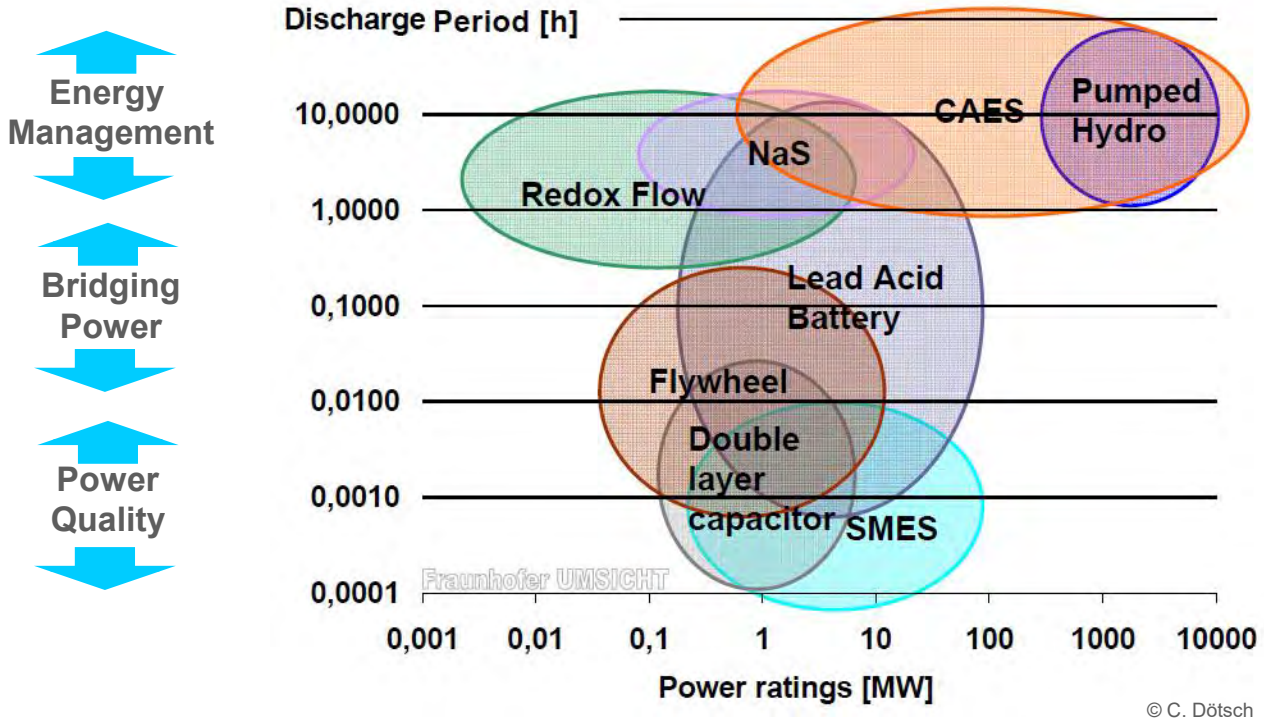
Storage Period and Discharging Power



Thermal Storage Technologies

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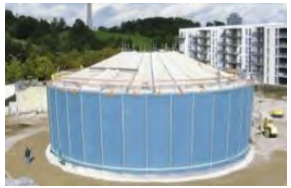
- **Thermal Energy can be stored as sensible heat**



  - Hot Water Tank
  - Underground Thermal Energy Storage (UTES)

- **Thermal Energy can be stored as latent heat**




  - Macro- / Micro-encapsulated Phase Change Materials (PCM)

- **Thermal Energy can be stored thermo-chemically**



  - Adsorption (Zeolite) and Absorption (LiCl) Storage
  - ThermoChemical Materials (TCM)

Thermal Storage Technologies

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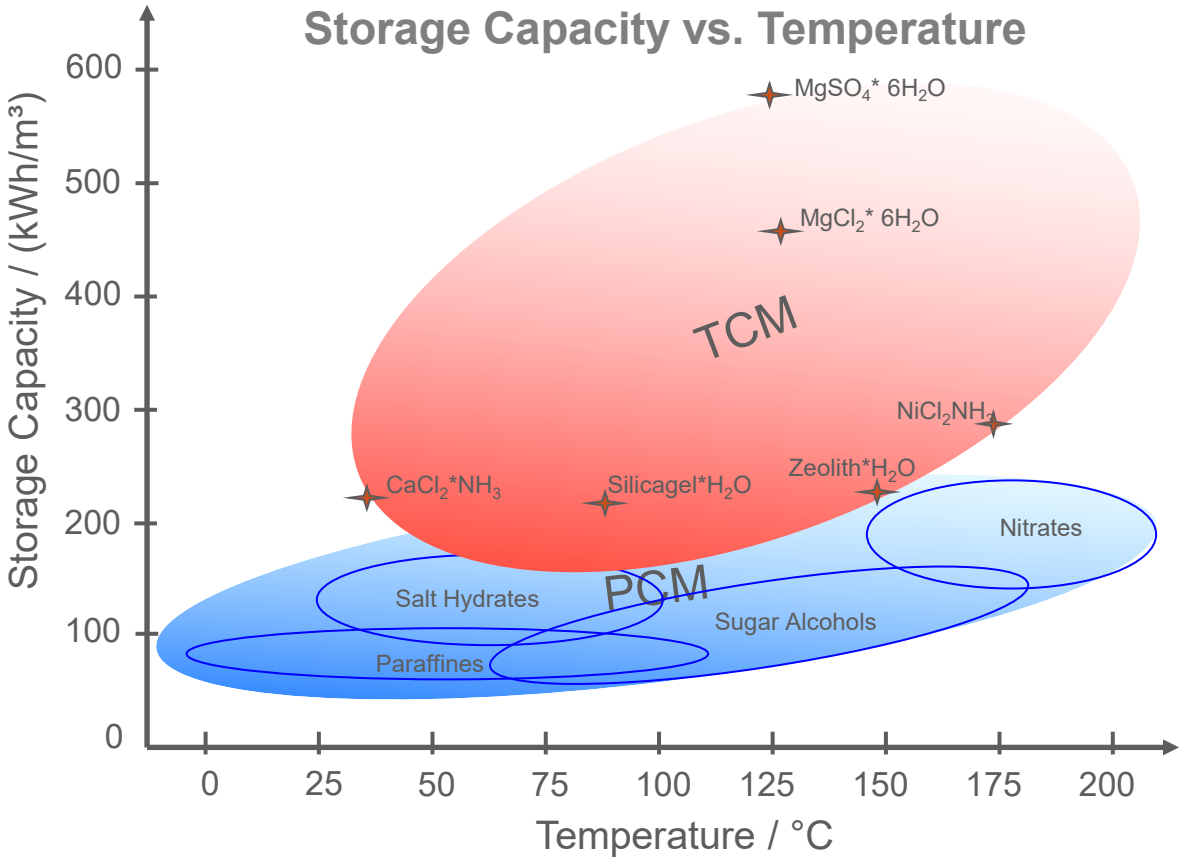

Chemical Energy Storage

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Energy Storage by Hydrogen Production and Storage

- Hydrogen is the **most powerful** fuel with regard to its mass
- Loss-free long-term storage possible
- Electricity production by fuel cells / H_2 turbines

Chemical Energy Storage

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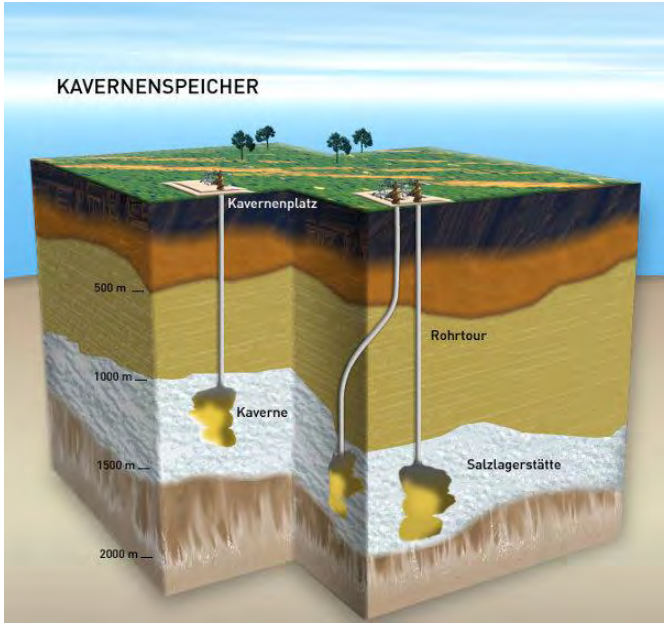
From Hydrogen a number of energy carriers can be developed, e.g. Methane



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Energy Storage by Methane Production and Storage

- Methane from Hydrogen (and CO_2)
- Efficiency > 80 % (Sabatier-Process)
- Existing Infrastructure (natural gas) can be used

Chemical Energy Storage

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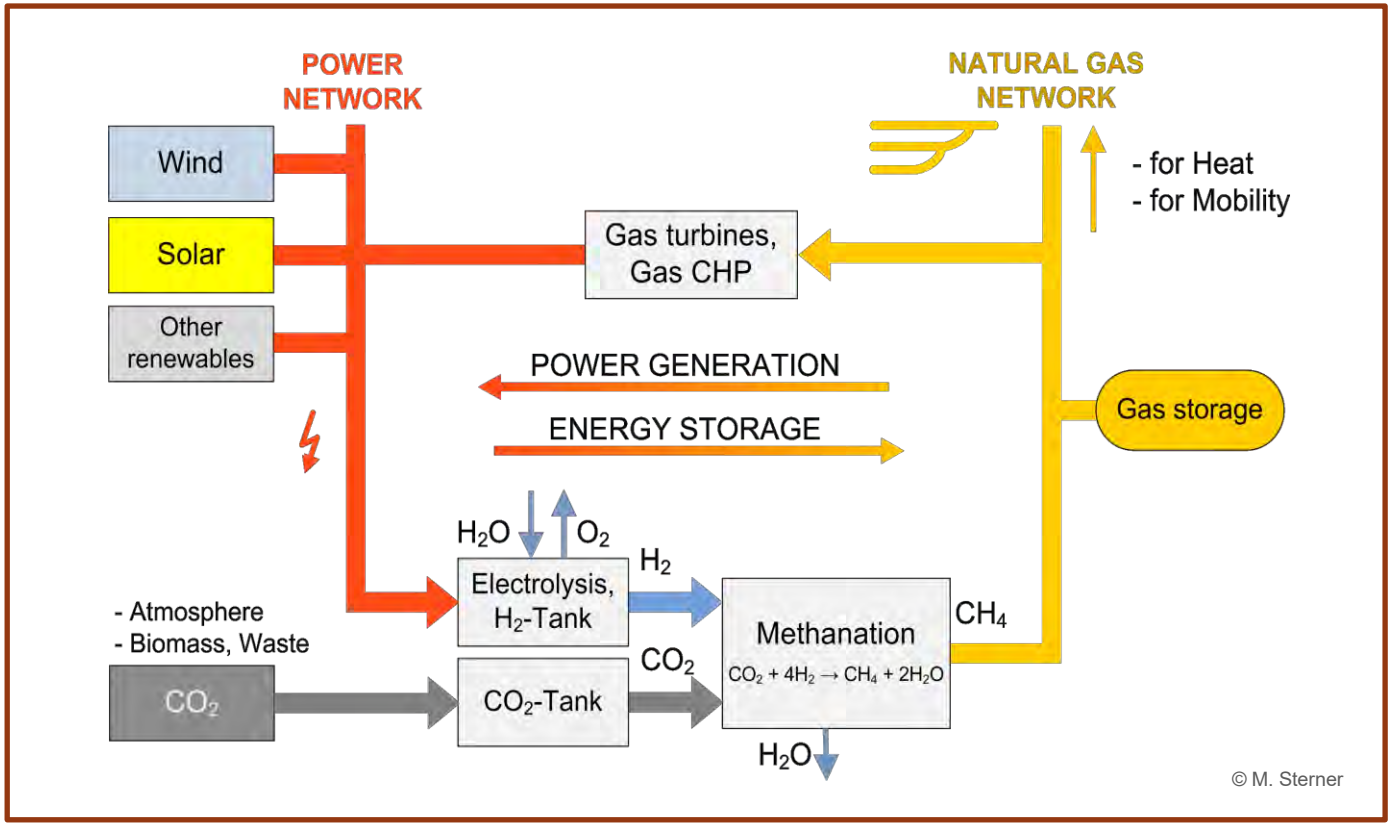

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Energy Storage – Applications

Energy Storage Applications

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Renewable Energies

Integration of Renewable Electricity

- Grid Stability
  - Frequency regulation
  - Voltage support
  - T&D congestion relief
  - Black start
- Grid balancing
  - Fast power reserve
  - Peak shaving
  - Self-consumption, Off-grid
- Demand Side Integration
  - Dispatchable Load
  - Power-to-Gas
  - Power-to-Heat

Integration of Renewable Thermal Energy

- Concentrated Solar Power
- Solar-thermal Process Heat
- Solar-thermal Heating & Cooling

Energy Efficiency

Industrial Processes

- Waste Heat Utlization
- Recuperation of Mech. Energy

Buildings

- Heating & Cooling
  - Day/Night-Balancing
  - Summer/Winter-Balancing

Electricity Production

- Fossil Thermal Power Plants
- Heat Utilization of CHP
- …

Transport

- Propulsion
- Heating / Air Conditioning

Energy Storage Applications

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Renewable Energies

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Electricity Production

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- Heat Utilization of CHP
- …

Transport

- Propulsion
- Heating / Air Conditioning

EES – Electrical Energy Storage

TES – Thermal Energy Storage

CES – Chemical Energy storage

EES/TES/CES – All Storage Technologies

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„Flexible Sector Coupling“ – Definitions and Assumptions

Definitions of Energy Sectors

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In this context **Sectors = Demand Sectors**

„The energy form needed“ → **Electricity**, **Transport**, **Thermal**

Electricity-Sector: (= electric energy)
- „Everything that consumes electricity“
- Obvious = lighting, ICT, controlling,…but also electric motors in industry, appliances in householdes etc.

Transport-Sector: (= kinetic energy)
- Transportation of goods and people in general
- Vehicles: cars, buses, trucks, trains, ships, planes,…

Thermal-Sector: (= thermal energy)
- Heating & cooling in buildings and industry
- Process heat &cold, space heating, Domestic Hot Water,…

Example Germany: Energy Demand Sectors and CO2 Emissions

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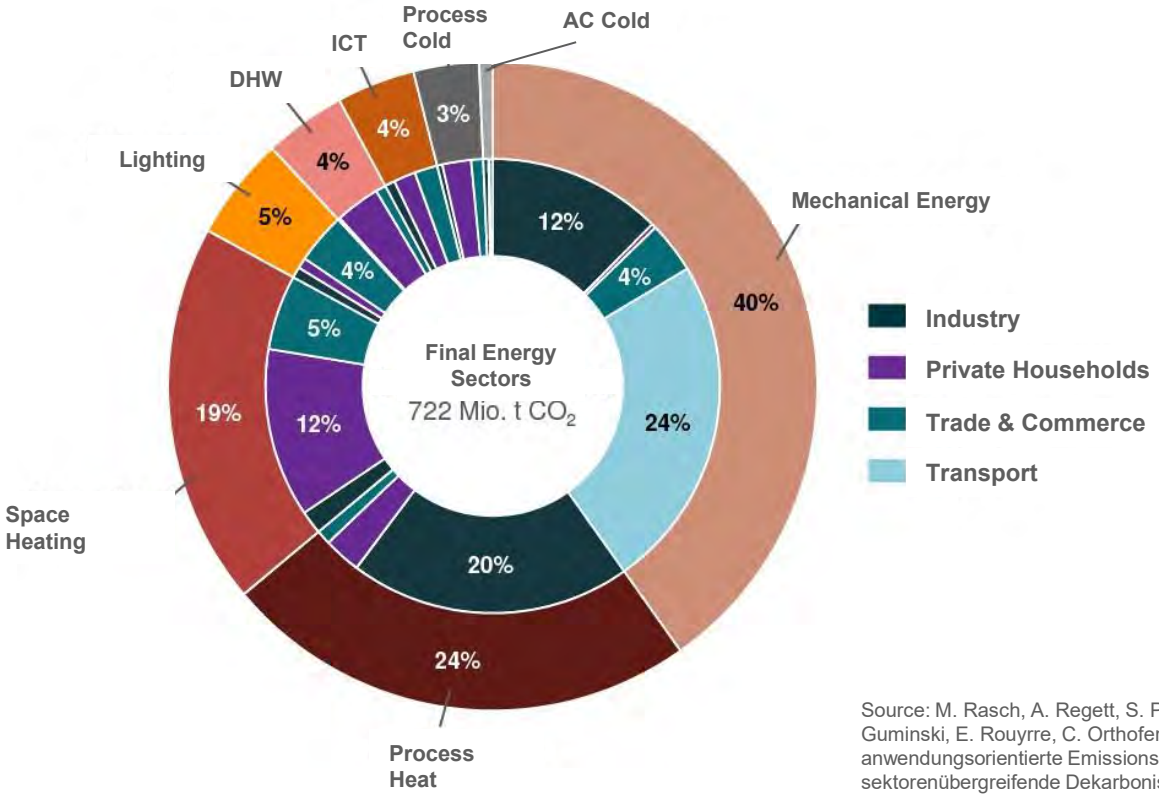
Final energy demand in Germany about 2,600 TWh per year



Source: M. Rasch, A. Regett, S. Pichlmair, J. Conrad, S. Greif, A. Guminski, E. Rouyrre, C. Orthofer and T. Zipperle, Eine anwendungsorientierte Emissionsbilanz – Kosteneffiziente und sektorenübergreifende Dekarbonisierung des Energiesystems, Forschungsstelle für Energiewirtschaft FfE, bwk, Ausgabe 03/2017

Example Germany: Energy Demand Sectors and CO2 Emissions

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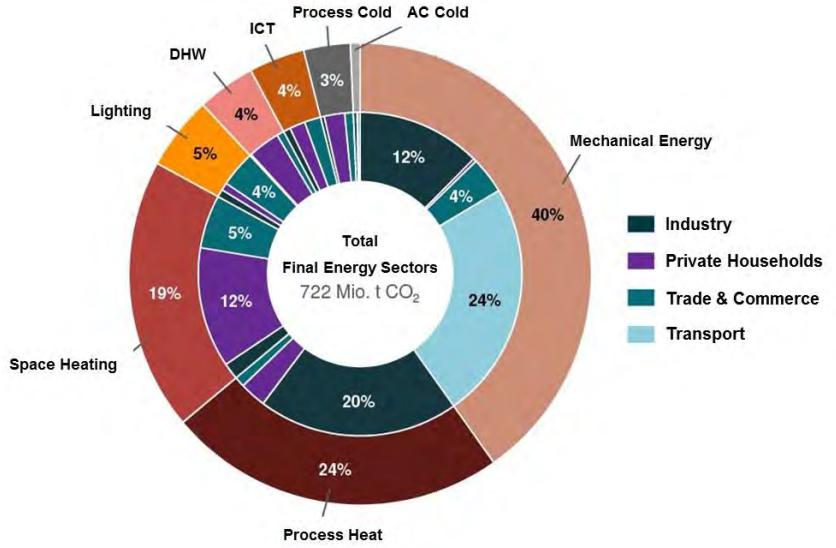
Distribution of CO_2 emissions among the „Sectors“:

- **Electricity** **24%**
  - Lighting 5 %
  - ICT 4 %
  - Mech. Energy in Ind./T&C 16 %
- **Thermal** **> 50 %**
  - DHW 4 %
  - Process Cold 3 %
  - Process Heat 24 %
  - Space Heating 19 %
  - AC <1 %
- **Transport** **24 %**



The thermal and the transport sector cause about 75 % CO_2 emissions in developed countries!

Assumptions for Sector Coupling

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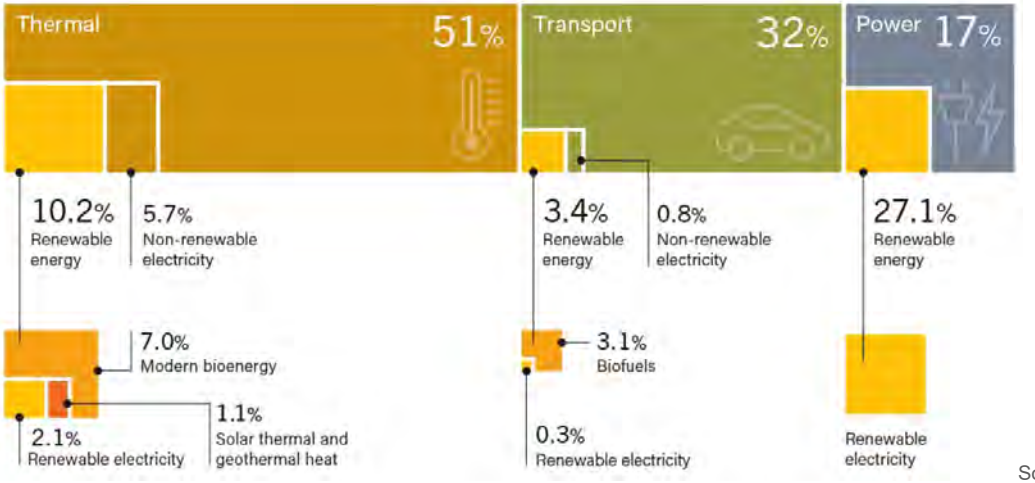
1. Main energy source in the future has to be **Renewable Energy**
2. Renewable Energy will come (mainly) from **Wind and PV = input to the electricity sector**
3. The **relevance of the sectors** (concerning final energy demand and CO_2 emissions) = Electricity ≈ 25 %, Transport ≈ 25 %, Thermal ≈ 50 % in developed countries, globally as per figure below
4. **Share of Renewable Energy** already integrated in the different sectors = highest in the electricity sector but low in transport and heat sectors



Source: REN21 Global Status Report 2021

Sector Coupling is key to decarbonization of all sectors!

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„Flexible Sector Coupling“ – Concept

First Conclusions

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1. **Decarbonizing the transport and thermal sector** is crucial = intergration of renewable electricity by **sector coupling**
2. Higher shares of renewable energy only possible by **matching supply and demand in time** = **flexibility** of fluctuating sources (Wind and PV)
3. This **flexibility** can be delivered by the implementation of **energy storage**
4. The **installed storage capacity** can provide the **final energy needed** e.g. heat/cold, green fuels,…
5. Higher shares of renewables = **Higher degree of utilization of** (already) **installed renewable sources! = Economic benefits!**

This leads to the concept of

→ **„Flexible Sector Coupling“**

Flexible Sector Coupling (FSC) Concept Development

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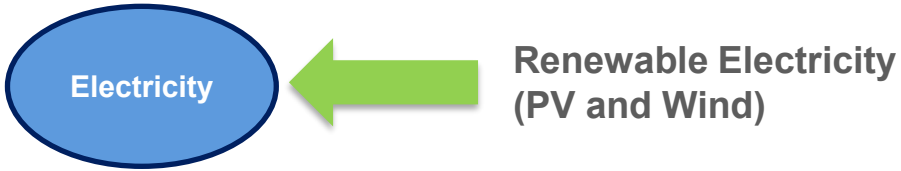

Carrier / Storage

All Carrier = 100 % energy to store and to provide (thermal, electrical, chemical)

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Flexible Sector Coupling (FSC) Concept Development

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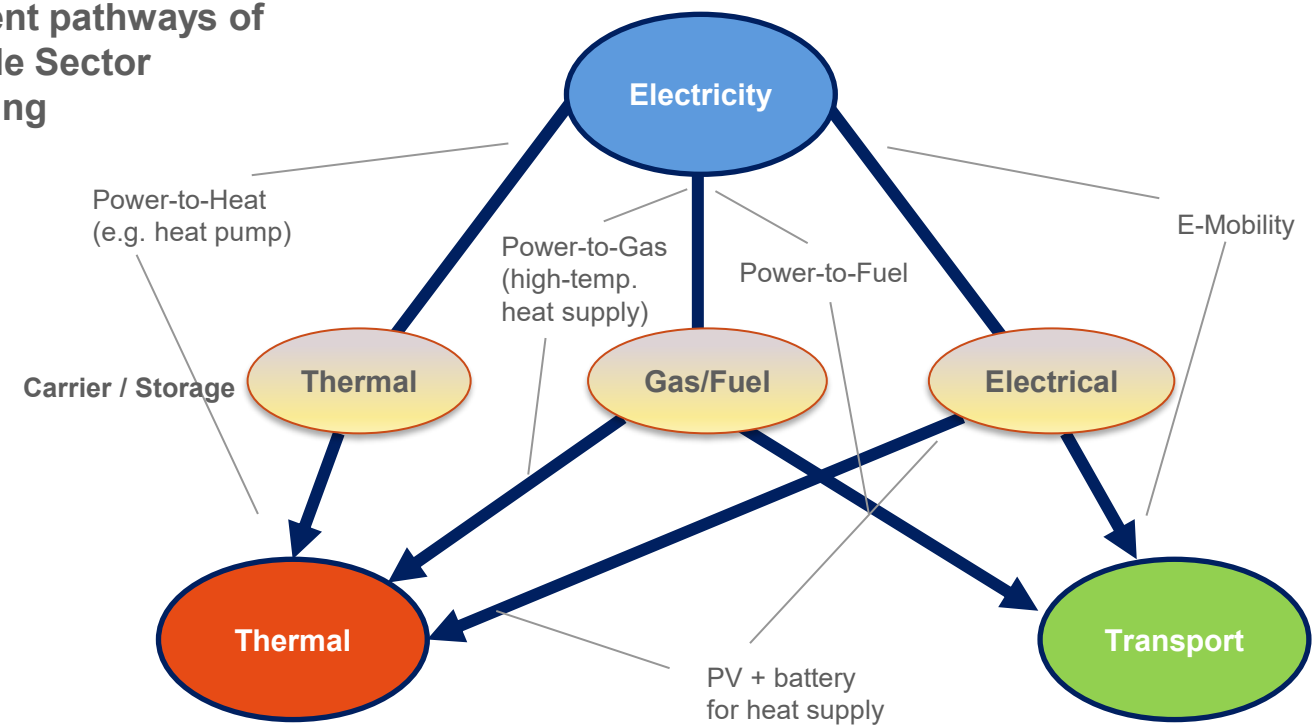
Different pathways of Flexible Sector Coupling



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…better keep it simple!

BVES
BUNDESVERBAND
ENERGIESPEICHER

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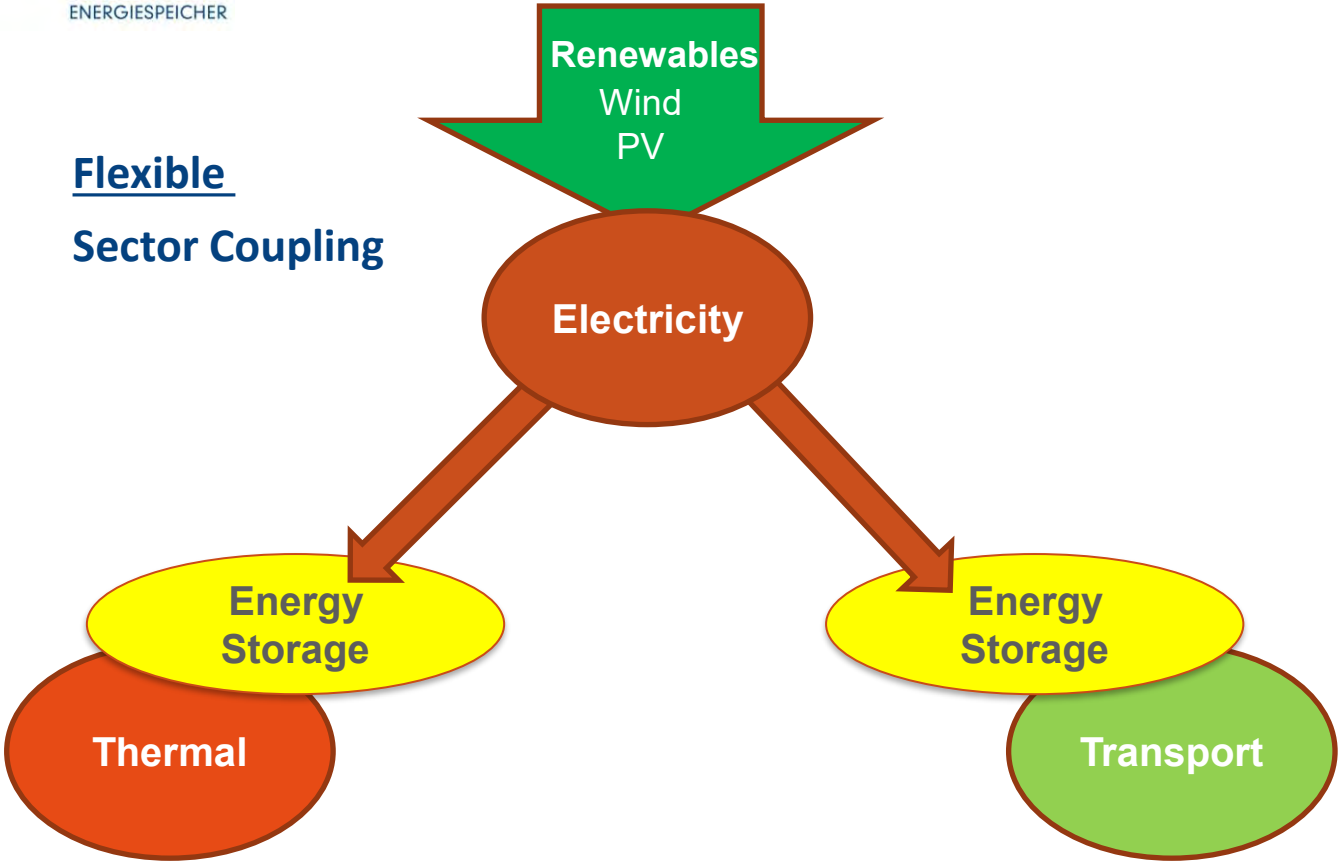
Flexible

Sector Coupling



BVES
BUNDESVERBAND
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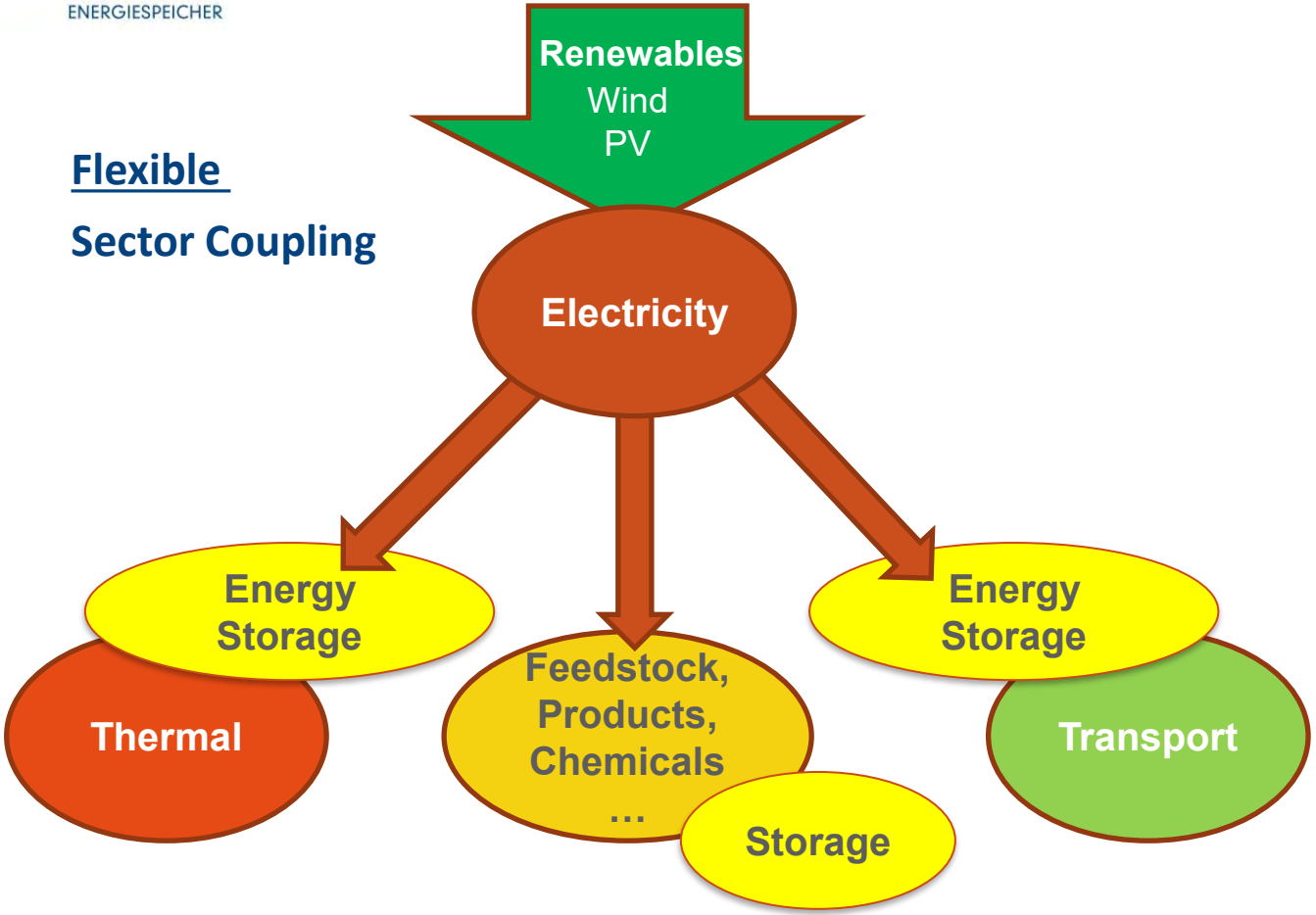
Flexible

Sector Coupling



BVES
BUNDESVERBAND
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Flexible Sector Coupling - Further Structuring of Energy Storage Solutions

Energy Storage Configuration: Source - Storage - Consumer

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- Assumption: The energy source is renewable energy, which mainly comes from PV and Wind
- In Flexible Sector Coupling the Consumer side is represented by Heating/Cooling and Mobility
- Energy Storage Configurations can be found on different system sizes:
  - Autarcic systems / island solutions
  - Rural structures (or villages)/districts/mini grids
  - Central structures/cities/(national) grid

Configuration Related Storage Technology Specifications

Energy storage solutions have to be adapted to their actual application!

	Autarcic Systems/ Island Solutions	Rural Structures/ Districts/Mini Grids	Central Structures/ Cities/Grid
Renewable Energy Source	PV / Wind Biomass Solarthermal	PV / Wind CSP / Biomass Solarthermal Geothermal	PV / Wind CSP / Geothermal
Energy Storage Technologies	EES / TES P2G P2F	EES / TES P2G P2F	EES
Demand/ Energy Consumption	Heating/ Cooling Mobility	Heating/ Cooling Mobility	All (supply from grid)

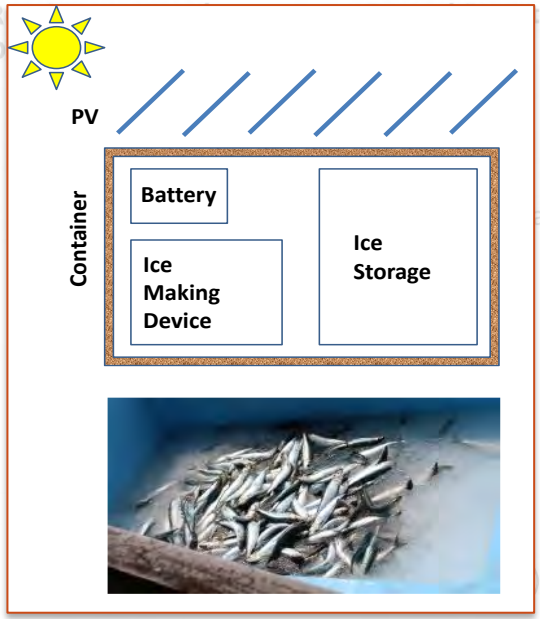
EES = Electrical Energy Storage, TES = Thermal Energy Storage, P2G = Power-to-Gas; P2F = Power-to-Fuel, CSP = Concentrated Solar Power

Configuration Related Storage Technology Specifications

Example: Ice production and storage for fishermen by PV: Power-to-Cold application.

Autarcic Systems/ Island Solutions

Renewable Energy Source	PV / Wind Biomass Solarthermal
Energy Storage Technologies	EES / TES P2G P2F
Demand/ Energy Consumption	Heating/ Cooling Mobility

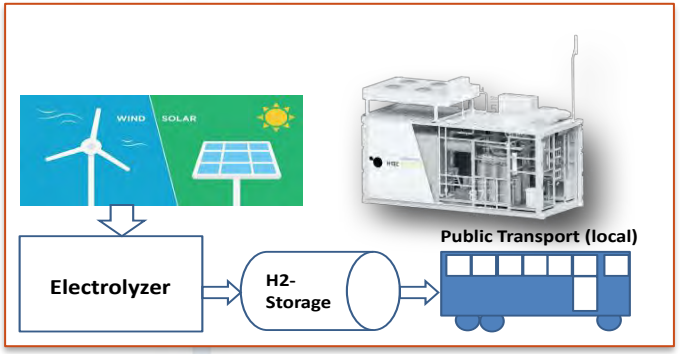


EES = Electrical Energy Storage, TES = Thermal Energy Storage, P2G = Power-to-Gas; P2F = Power-to-Fuel, CSP = Concentrated Solar Power

Configuration Related Storage Technology Specifications

Example: Public transportation in a rural village by local hydrogen production: Power-to-Mobility application.

	Autarcic Systems/ Island Solutions	**Rural Structures/ Districts/Mini Grids**	Central Structures/ Cities/Grid
Renewable Energy Source	PV / Wind Biomass Solarthermal	PV / Wind CSP / Biomass Solarthermal Geothermal	
Energy Storage Technologies	EES / TES P2G P2F	EES / TES P2G P2F	
Demand/ Energy Consumption	Heating/ Cooling Mobility	Heating/ Cooling Mobility	All (supply from grid)



EES = Electrical Energy Storage, TES = Thermal Energy Storage, P2G = Power-to-Gas; P2F = Power-to-Fuel, CSP = Concentrated Solar Power

Configuration Related Storage Technology Specifications

Example: Large scale hydrogen production and export by concentrated solar powerplant and electrolysis: Power-to-Fuel application.

	Autarcic Systems/ Island Solutions		Central Structures/ Cities/Grid
Renewable Energy Source	PV / Wind Biomass Solarthermal	**Concentrated Solar Power** 	PV / Wind CSP / Geothermal
Energy Storage Technologies	EES / TES P2G P2F	**Power -to- Fuel** **Synthetic Fuel Storage**	EES
Demand/ Energy Consumption	Heating/ Cooling Mobility	**Synthetic („Green") Fuel Export** 	All (supply from grid)

EES = Electrical Energy Storage, TES = Thermal Energy Storage, P2G = Power-to-Gas; P2F = Power-to-Fuel, CSP = Concentrated Solar Power

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„Flexible Sector Coupling“ – Applications and Best Practice Examples

Flexible Sector Coupling (FSC) Best Practice Examples

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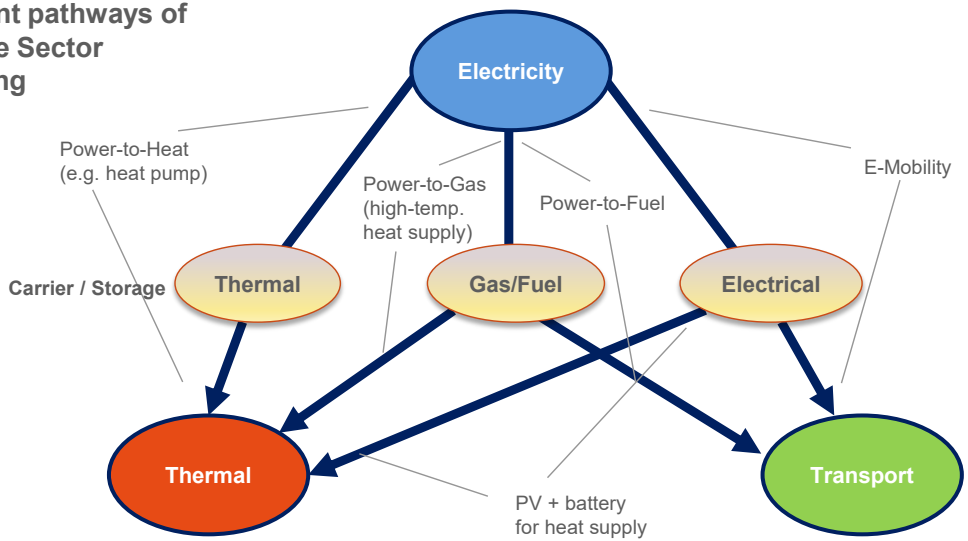
The examples represent possible pathways from the Electricity sector to the Thermal and Mobility sector

Different pathways of Flexible Sector Coupling



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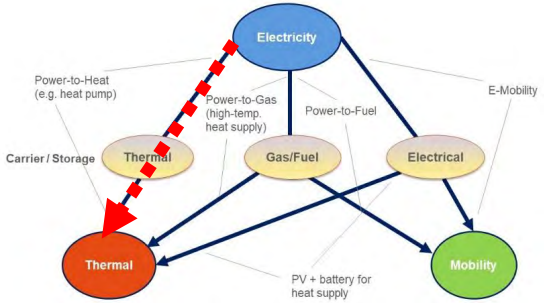
Collection of FSC examples



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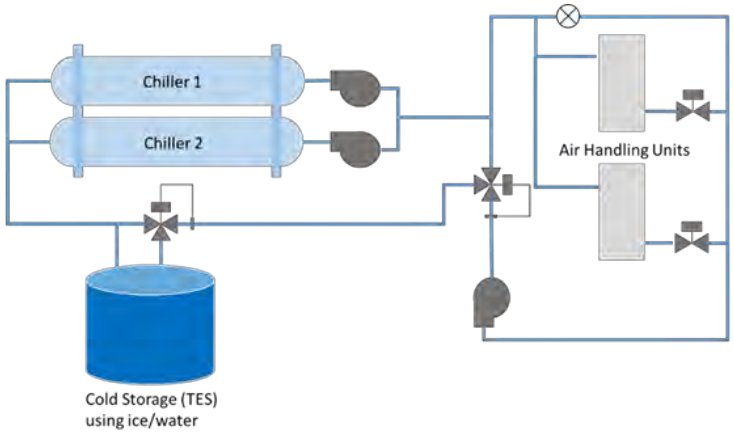
Flexible Power-to-Cold Application at CSIR in South Africa

- Chillers running on PV (Power-to-Cold)
- Cold storage installation for continuous cold supply



Collection of FSC examples

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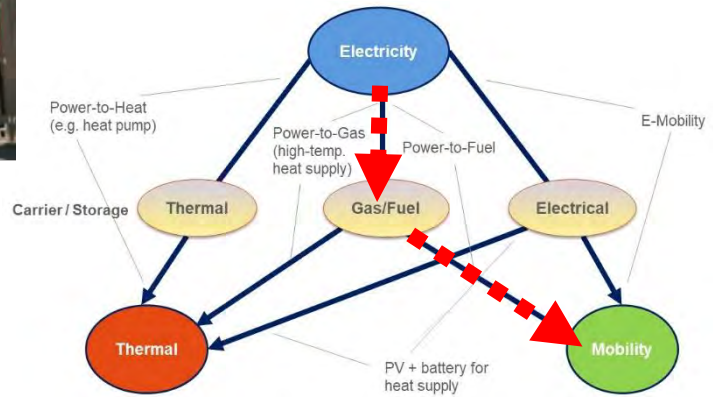
Power-via hydrogen storage-to transport Application

- Electrolyzers running on Wind power for hydrogen production for local public transportation
- Project “eFarm“, north of Germany: Electrolysers, hydrogen filling stations, fuel cell buses and cars



Collection of FSC examples

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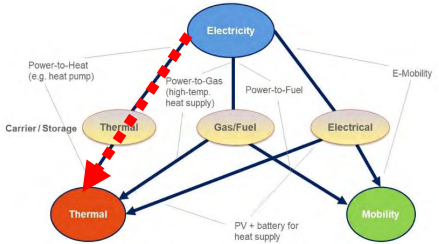
Power-to-Heat Application

1.Giga_Tes

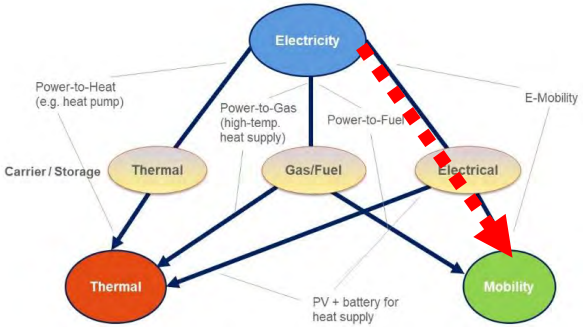
AEE, Austria

TRL	*4-5*
Storage tech.	*Pit storage*
Capacity	*70.000 MWh*
Power	*70 MW*
Storage Period	*Seasonal*
Sector	*Heat*
Application	*Building*



Description:
In this project, a pit store for seasonal energy storage is used for sector-coupling. Excess heat and electricity in combination with heat pumps is used to heat up the pit storage and deliver heat to the district heating system. Due to high land prices, the surface should be kept as low as possible, to ensure cost efficiency and therefore new construction methods and materials are investigated.

Collection of FSC examples



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Renewable Electricity (PV/Wind) for Batteries in Fast Charging Infrastucture:

- **Batteries can replace grid upgrade**
- **Batteries can enable „Mobile Charging“ (e.g. for events like festivals)**

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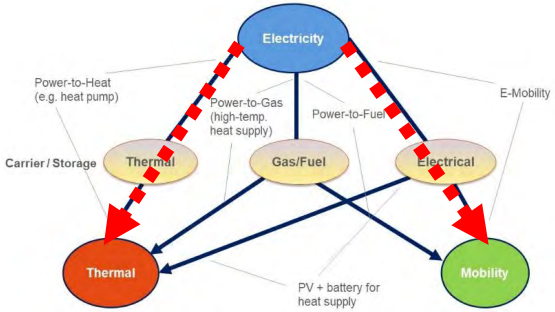
Power-to-Heat Application

1. Scores

AEE, Austria

TRL	4-9
Storage tech.	Chemical/LiIon
Capacity	240/62 kWh
Power	30 kW
Storage Period	Daily/Seasonal
Sector	Heat
Application	Building

Description:
The SCORES concept is based on a hybrid system combining heat and electrical storage solutions to increase the self-consumption of locally produced PV electricity by providing electricity and heat to the building. The storage technologies used are: a sensible buffer storage in combination with a heat pump (short term), second-life Li-Ion Batteries (short term), and a chemical heat storage (long term).



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„Flexible Sector Coupling“ – Possible Benefits

On the way to carbon neutrality: Separation of final demand sectors

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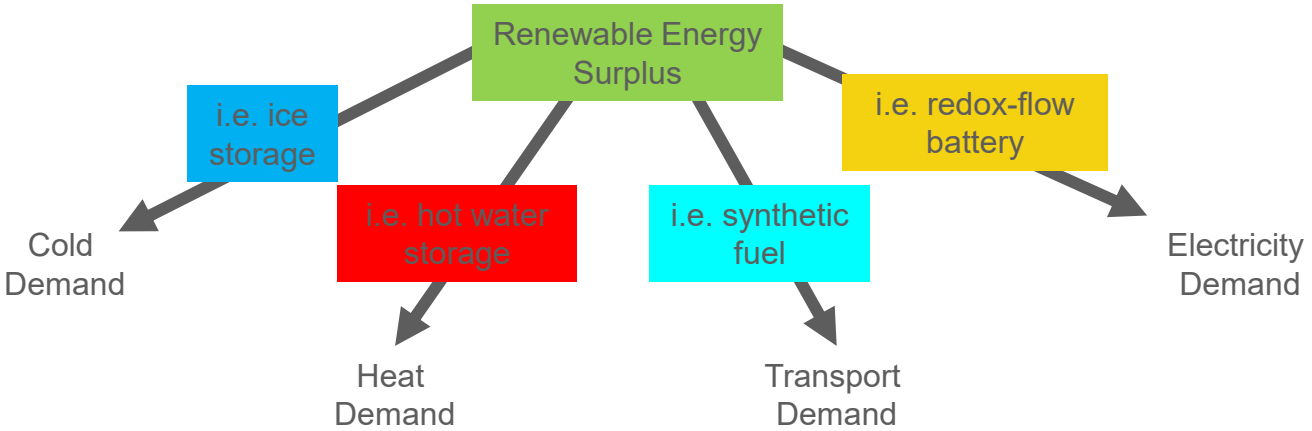
Flexible Sector Coupling unlocks possibilities to cover the required storage capacity on different pathways ➡ P2C, P2H, P2T and P2Electricity



- Utilization of Renewable energy surplus by different storage technologies
- Large storage cost differences could provide economic benefits

Cold Storage can be by a factor of >100 less expensive than battery solution!

On the way to carbon neutrality: Separation of final demand sectors

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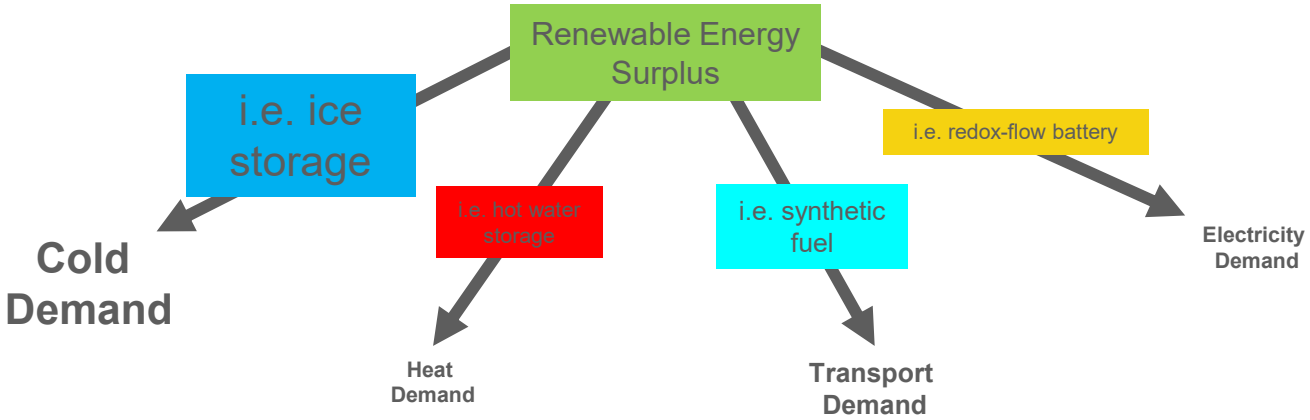
Concept development and storage capacity sizing starts from actual final energy demand!



Example: Electricity demand peak caused by AC

Increasing Awareness – Reference Projects

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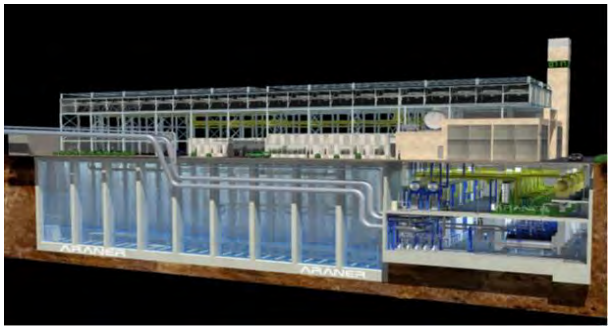
Demonstration / pilot projects are key to increasing awareness of Flexible Sector Coupling

- Projects on power-to-cold including cold storage in test beds (Morocco, India and South Africa)
- Decentral small scale pilot projects, private public partnerships

Rooftop solar system with ice-storage - Morocco



PV electricity for district cooling with cold storage - Jordan

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Conclusions

Conclusions

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- The electricity sector will have the highest share of renewable energy input
- Thermal and the transport sector are responsible for 75 % of CO_2 emissions
- Sector coupling is crucial for decarbonizing all sectors
- Only „Flexible Sector Coupling“ allows to match supply and demand!
- A number of energy storage technologies is available to address this approach

Thank you very much for your attention!

Dr. Andreas Hauer
Walther-Meissner-Str. 6
85748 Garching
Germany
T +49 89 329442-16
andreas.hauer@zae-bayern.de

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FVEE ForschungsVerbund Erneuerbare Energien
Renewable Energy Research Association

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