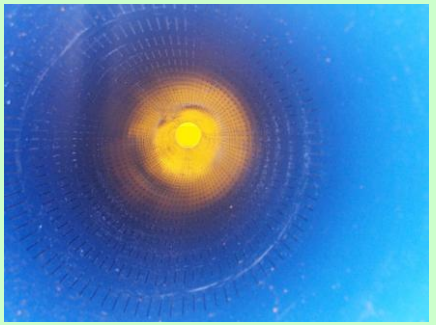
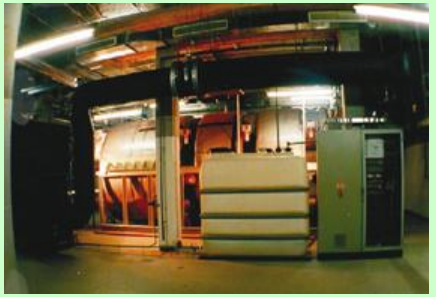
International Energy Agency

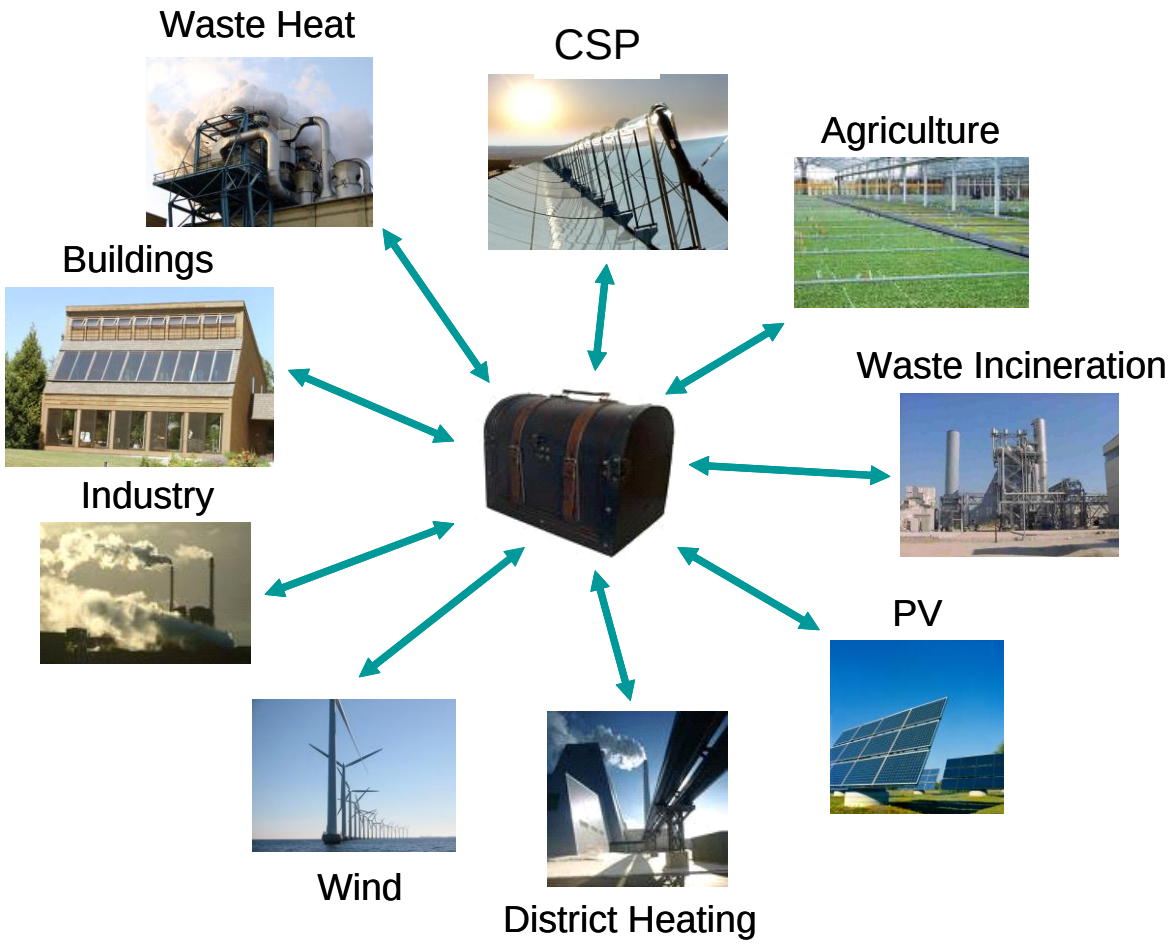




Energy Storage Technologies – Overview and Comparison

Energy Storage – Central Component

- Energy storages are central components of many energy systems.



Energy Storage

Technologies

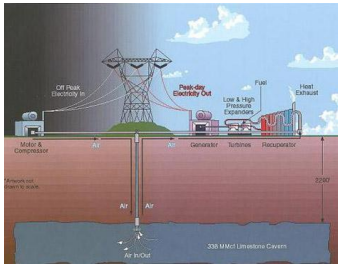
Energy Storage – Electricity

- Electrical Energy can be stored directly

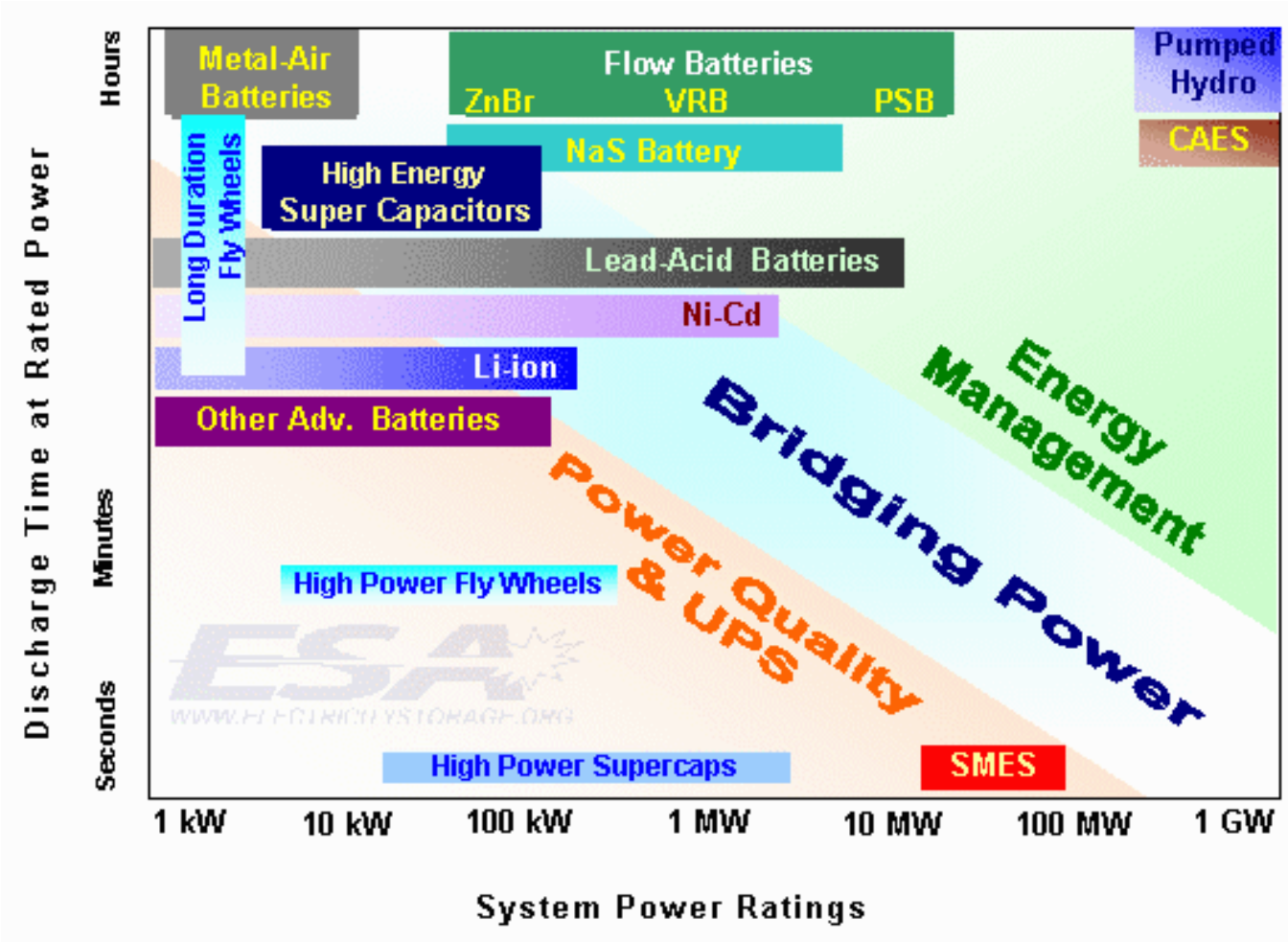

- Electrical Energy can be stored as chemical energy



- Electrical Energy can be stored as mechanical energy

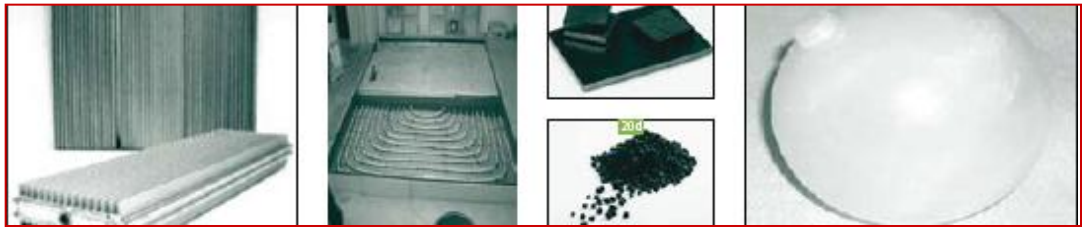
Energy Storage – Electricity



Energy Storage – Thermal Energy

- Thermal Energy can be stored as sensible heat

- Thermal Energy can be stored as latent heat



- Thermal Energy can be stored thermo-chemically

Energy Storage – Thermal Energy

Different Thermal Energy Storage (TES) Technologies:

- Sensible TES (Heating/cooling Storage medium)

  Storage Capacity ≈ 100 MJ/m³
  Storage Volume ≈ 10 m³

- Latent TES (Phase Change Materials PCM)

  Storage Capacity ≈ 300 - 500 MJ/m³
  Storage Volume ≈ 2,5 m³

- Thermochemical Reactions (e.g. Sorption storages)

  Storage Capacity ≈ 1000 MJ/m³
  Storage Volume ≈ 1 m³

Energy Storage – more?

- Hydrogen Storage!

  Over-all Efficiency < 45-50 %, fuel cells

- Methane from Renewable Electricity!

  Over-all Efficiency >60 %, storage capacity (Germany) = 200 TWh

- Synthetic Liquid Fuels!

  Mobility!

- No Losses → long-term storage
- Distribution possible + existing infrastructure

Energy Storage

Properties

Energy Storage – Properties

- **General Properties of an energy Storage System:**
  - Storage capacity (kWh/kg, kWh/m³)

    Phys. / chem. effect, storage materials
  - Charging/discharging power (W/kg, W/m³)

    Transfer phenomena, storage construction
  - Storage Efficiency

    Losses due to time or energy transformation
  - Storage period (time)

    From seconds to years
  - Price (€/kWh, €/W)

    Coupled to the number of storage cyles

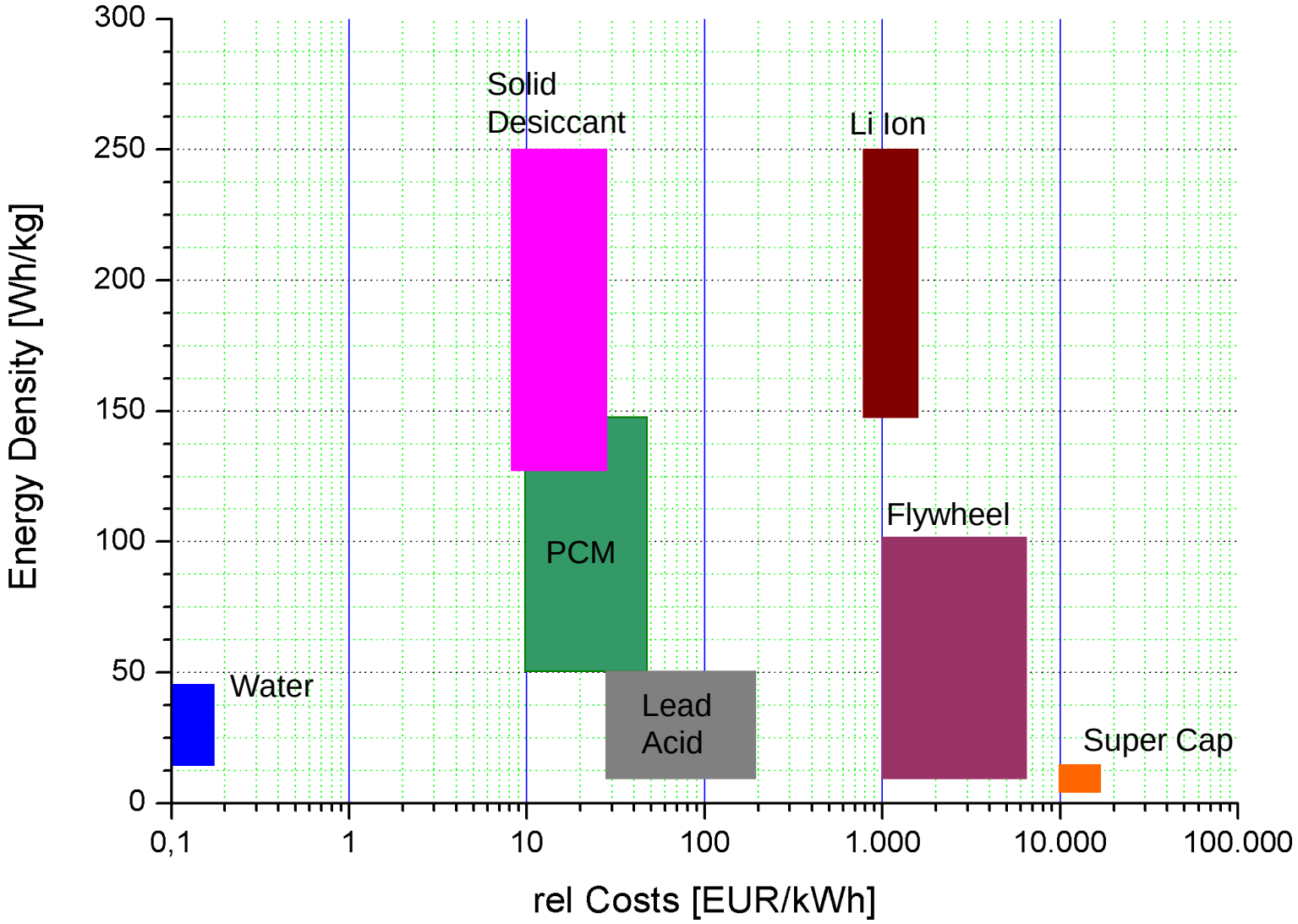
Mechanical, Electrical and Thermal Energy Storage Technologies

Storage Technologies	Capacity kWh/t	Power MW	Efficiency	Storage Time	Cost €/kWh
Pumped Hydro	1	1-500	80%	day - month	50
Flywheel	5-100	1-100	90%	hour	3000-5000
CAES	2 kWh/m³	300	40-70%	day	400-800
Lead-Acid	40		85%	day - month	200
Li-ion bat.	130	0.02 - ??	90%	day - month	1000
NaS bat.	110	0.05 - 50	85%	day	300
Redox-Flow bat.	25	0.01-10	75%	day - month	500
SMES	3	10	95%	hour - day	100000
Supercaps	5	0.001 - 1	95%	hour - day	100000
Hot Water	10-50	0.001 - 10	50-90%	day - year	0.1
PCM	50-150	0.001 - 1	75-90%	hour - week	10-50
Chemical Reactions	120-250	0.01 - 1	100%	hour - day	8-40
Hydrogen	30000	0.001 - 1	25-50%	day - year	1000 €/kW

Energy Storage

Crossing Borders

Comparison of Technologies



„Between“ the Technologies: Existing Examples

- CAES:

  Electrical Energy → mechanical Energy → Storage → mechanical Energy → Electrical Energy

  Efficency: about 40 %

thermal Energy → Storage → thermal Energy

Electrical Energy → mechanical Energy → Storage → mechanical Energy → Electrical Energy

Efficency: about 70 %

„Between“ the Technologies: Existing Examples

- Concentrated Solar Power (CSP)

  Thermal Energy → Storage → thermal Energy → electrical Energy

Sensible TES (R&D on latent TES)

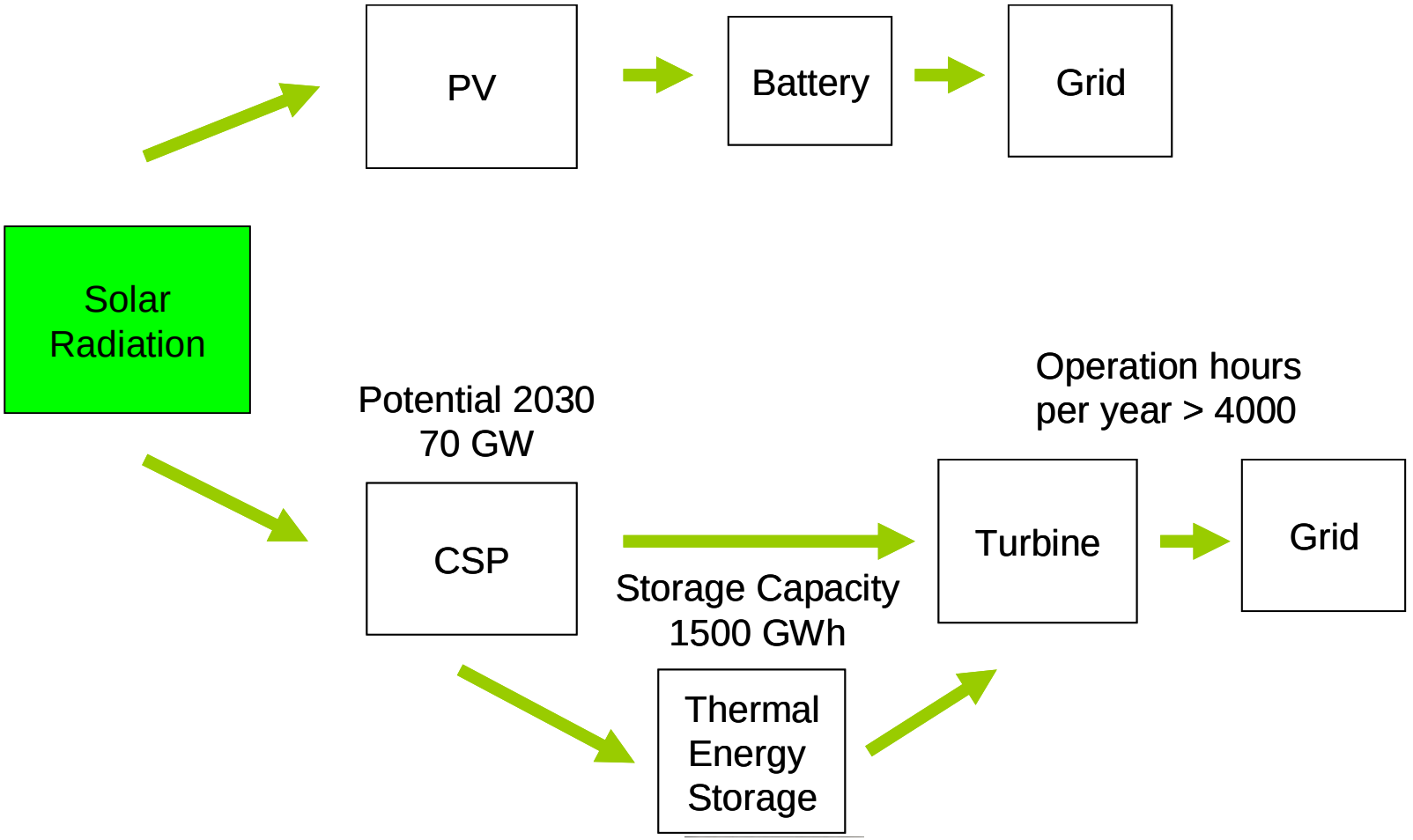
Storage medium: Molten Salt, concrete, sand,…

Temperatures: 300- 600 C

Examples from Background Document

„Between“ the Technologies: Existing Examples

- Solar Power



„Between“ the Technologies: Existing Examples

- PV has two bottlenecks: Costs for PV itself and for the storage system

  Central Question: Increase of efficiency for PV and decrease costs for balancing the net

  Who is addressed: PV sector, Storage Technologies, Energy Distribution

- Thermal energy storage is able to provide a longer operation time for the turbine

  Central Question: Identification of a suitable high temperature (> 400 °C) storage material

  Who is addressed: Solar power sector, storage technologies

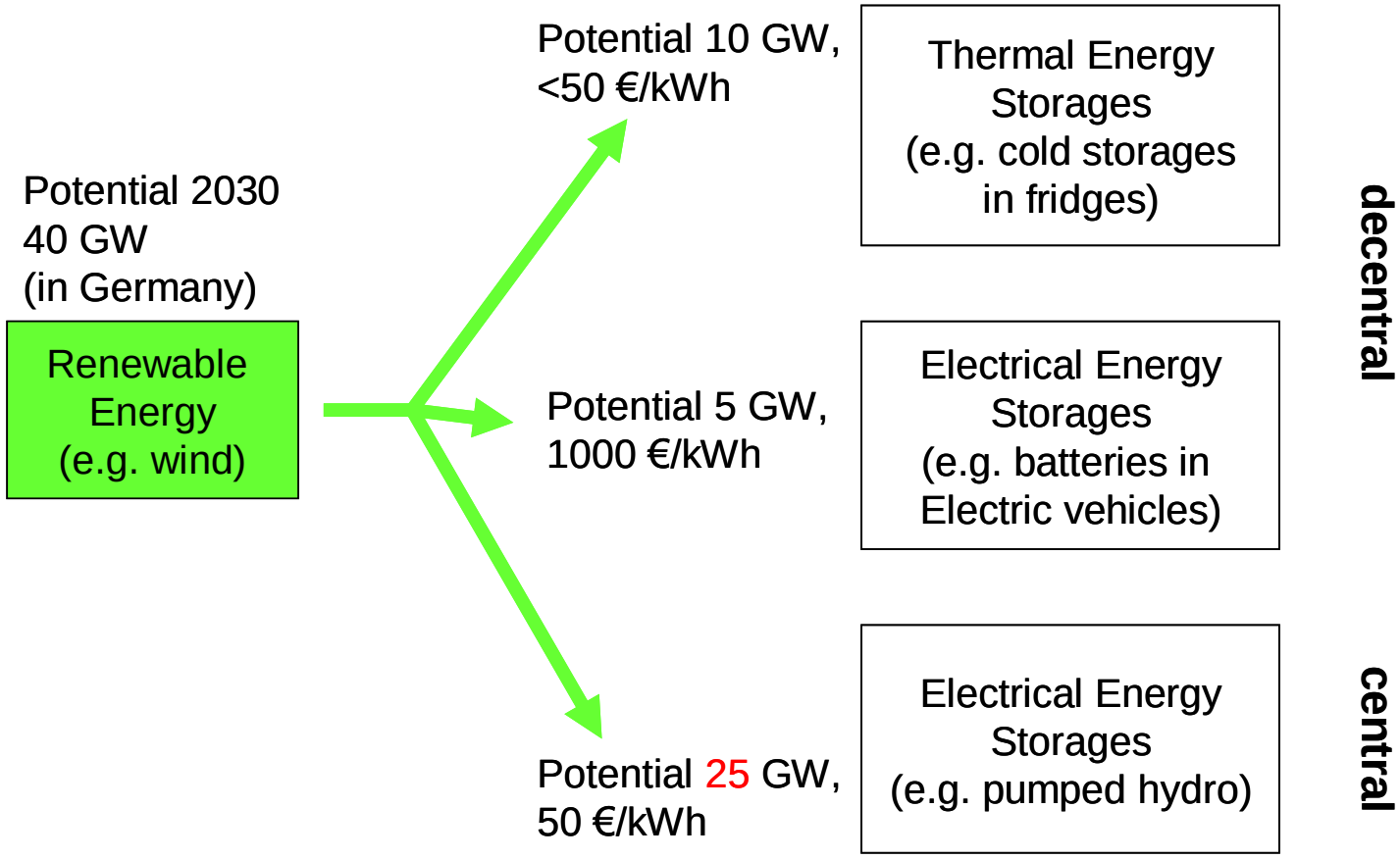
- Storage enables CSP to cover the electricity production base load

  Central Question: Influence on the cost calculation for the solar electricity integration

  Who is addressed: Energy distribution, power sector, storage technologies, renewable energies

„Between“ the Technologies: Planned Examples

- Integration of renewable Electricity



„Between“ the Technologies: Planned Examples

- Decentral solutions based on storages may offer both: The potential of balancing the grid and decreasing energy consumption.

  Central question: Identifying further applications and evaluating economic potential

  Who is addressed: Building sector, storage technologies, home appliances

- Costs for decentral and central solutions with and without storages have to be compared concerning costs and energy efficiency / energy consumption

  Central questions: Calculating the costs for further control demand, distribution, increasing electrification of demand side, etc.

  Calculating the costs for surplus Renewable installation (as the electricity demand has to be fulfilled even in times with less supply)

  Who is addressed: Energy distribution, power sector, storage technologies, Renewable energies

„Between“ the Technologies: Planned Examples

- Decentral Latent TES for Electricity Storage:

Electrical Energy → Thermal Energy → Storage → Thermal Energy

Example: Decentral TES for „Electricity Storage“

Refrigerators as a moveable electrical load!

- **Boundaries:**
  - 40 Million households in Germany with a refrigerator
- **Assumptions:**
  - COP of refrigeration cycle is 1.2
  - Every frige has 120 l cooling capacity and a 17 l **** freezing compartment
  - Every fridge has a A++ efficiency and an engery consumption of 124 kWh per year
  - Use of 20 Billion fridges as moveable load
  - Storage capacity for 12 hours
  - 175 kJ/kg spec. Heat of fusion capacity for PCM
  - Cost for PCM 3 EUR/kg and 5 EUR for the complete component

.

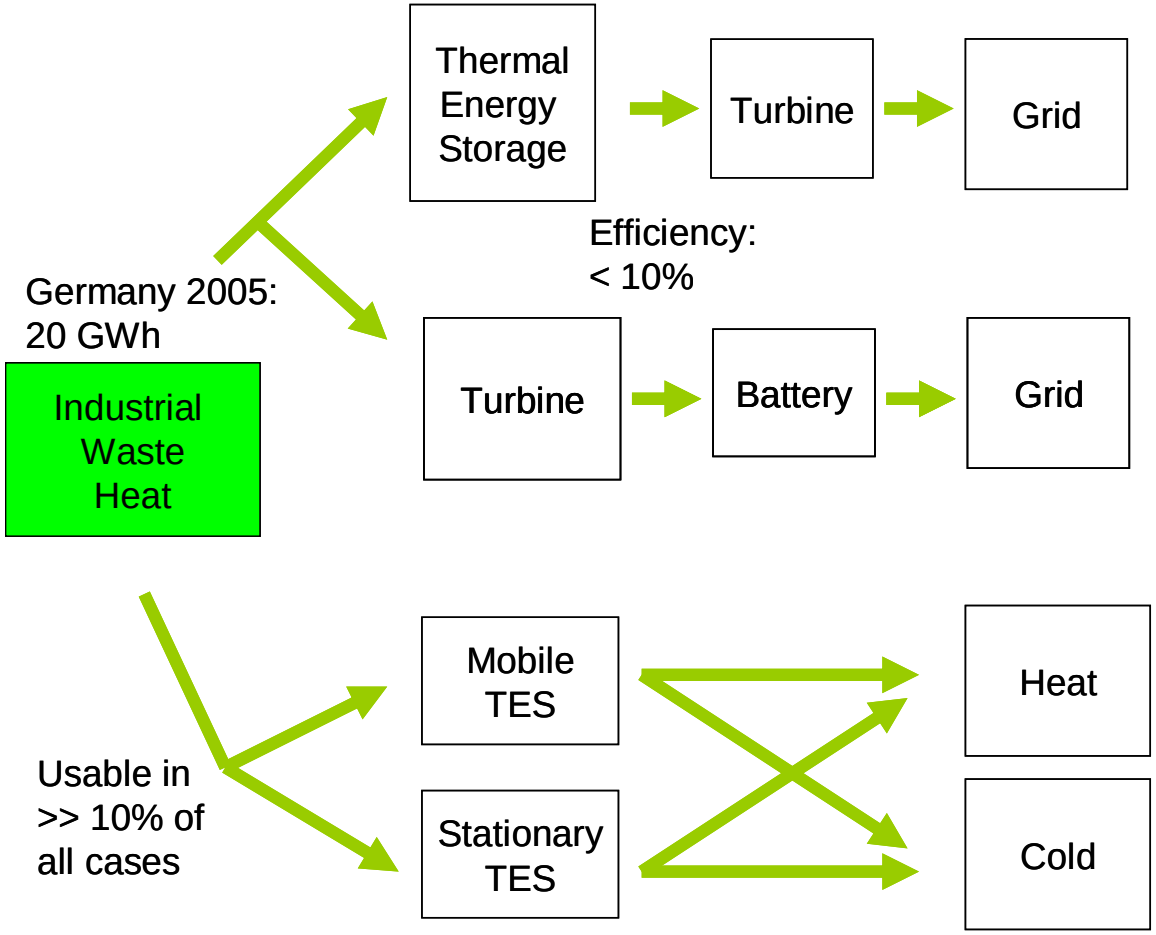
Example: Decentral TES for „Electricity Storage“

Results:

- An electrical load of 1.15 GW can be generated
- An electrical storage capacity for 3.4 GWh can be generated
- Charching time for PCM storage is 2.9 hours
- The costs of the PCM storage can be coverd with 120 cycles per year with a price difference between high and low electrical tariff of 0,08 EUR/kWh within the lifetime of 15 years.

„Between“ the Technologies: Planned Examples

- Industrial Waste Utilization



„Between“ the Technologies: Planned Examples

- Thermal Energy Storage may be the most cost-efficient way to optimize the energy efficiency of industrial processes

  Central question: Characterisation of industrial processes with regard to the potential of the increase of energy efficiency and costs using thermal energy storages

  Who is addressed: Industrial sector, storage technologies

- Using even low-temperature waste heat for generating electricity may decrease need for conventional power plants

  Central questions: Compare costs and primary energy consumption with other measures to increase energy efficiency in the industrial processes

  Compare cost and primary energy consumption with other measures to reduce need for conventional power plants

  Who is addressed: Industrial sector, energy distribution, power sector, storage technologies

Conclusions

- The general aspects of energy storage integration in a system are a relevant topic for all
- The possibilities of energy transformation open (new) possibilities in energy storage
- Exchange and collaboration will be valuable for R&D and the further development of energy storage technologies

Thank you very much for your attention!

Is that all you saved from last summer? Energy Storage helps to conserve Energy and to protect the environment!