Energy Storage Systems

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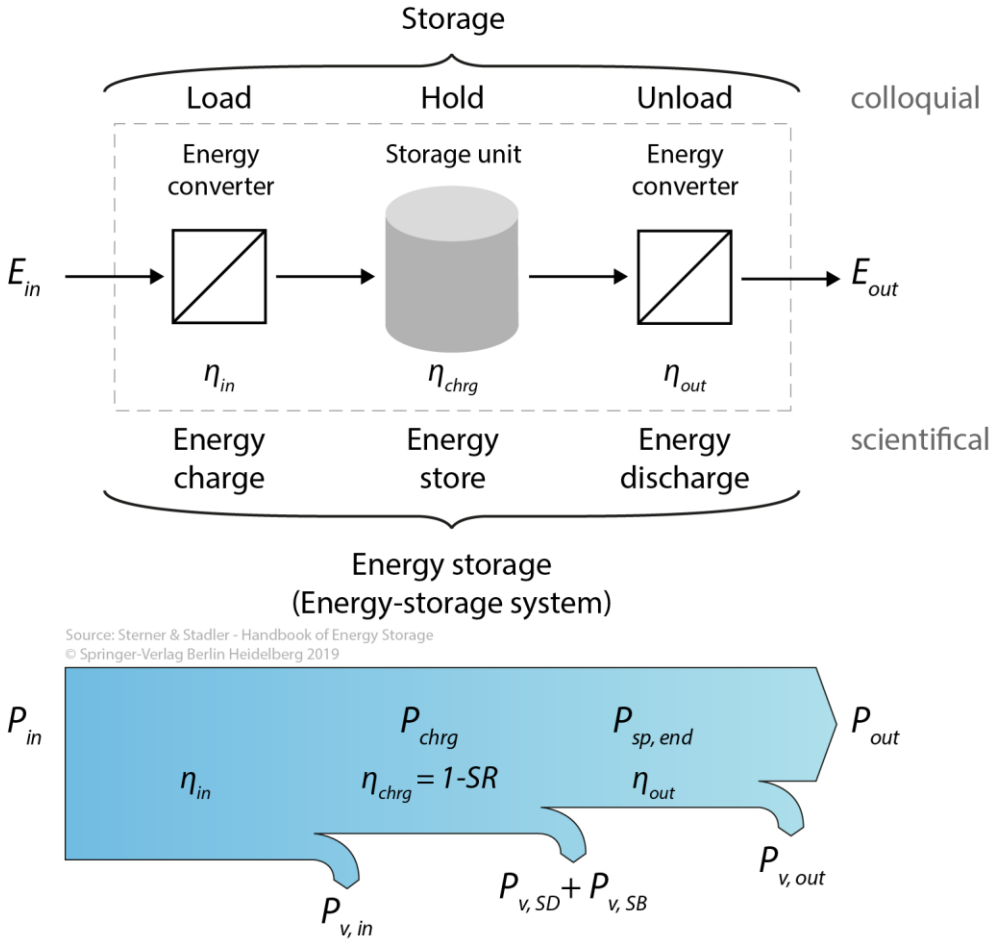
Energy storage

Energy storage systems: definition and operation



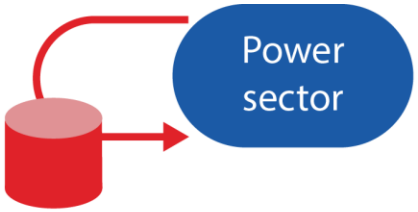
Round-trip efficiency: $\eta = \eta_{in} \times \eta_{chrg} \times \eta_{out}$

Sterner M., Bauer F. (2019) Definition and Classification of Energy Storage Systems. In: Sterner M., Stadler I. (eds) Handbook of Energy Storage. Springer, Berlin, Heidelberg.
DOI: 10.1007/978-3-66255504-0_2.

Main characteristics of energy storage systems

- Storage capacity C
- Rated power (charging and discharging) P
- Energy and power density E/V, P/V
- Round-trip efficiency η
- Rated discharge time $\tau = C/P$
- Response time t_r

Energy storage in different energy sectors



Power storage [S]

e.g., pumped hydro
batteries
supercaps

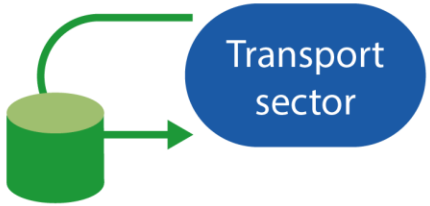
Charge: power-to-X
Store: X
Discharge: X-to-power

Gas storage [P, S]

Thermal storage [S]

e.g., solar thermal hot water storage, PCM, zeolites

Charge: heat-to-X
Store: X
Discharge: X-to-heat



Fuel storage [P, S]

e.g., oil tank, fuel tank

Charge: Crude oil/Biomass-to-X
Store: Tank, X
Discharge: X-to-shaft power

P Primary energy storage
S Secondary energy storage

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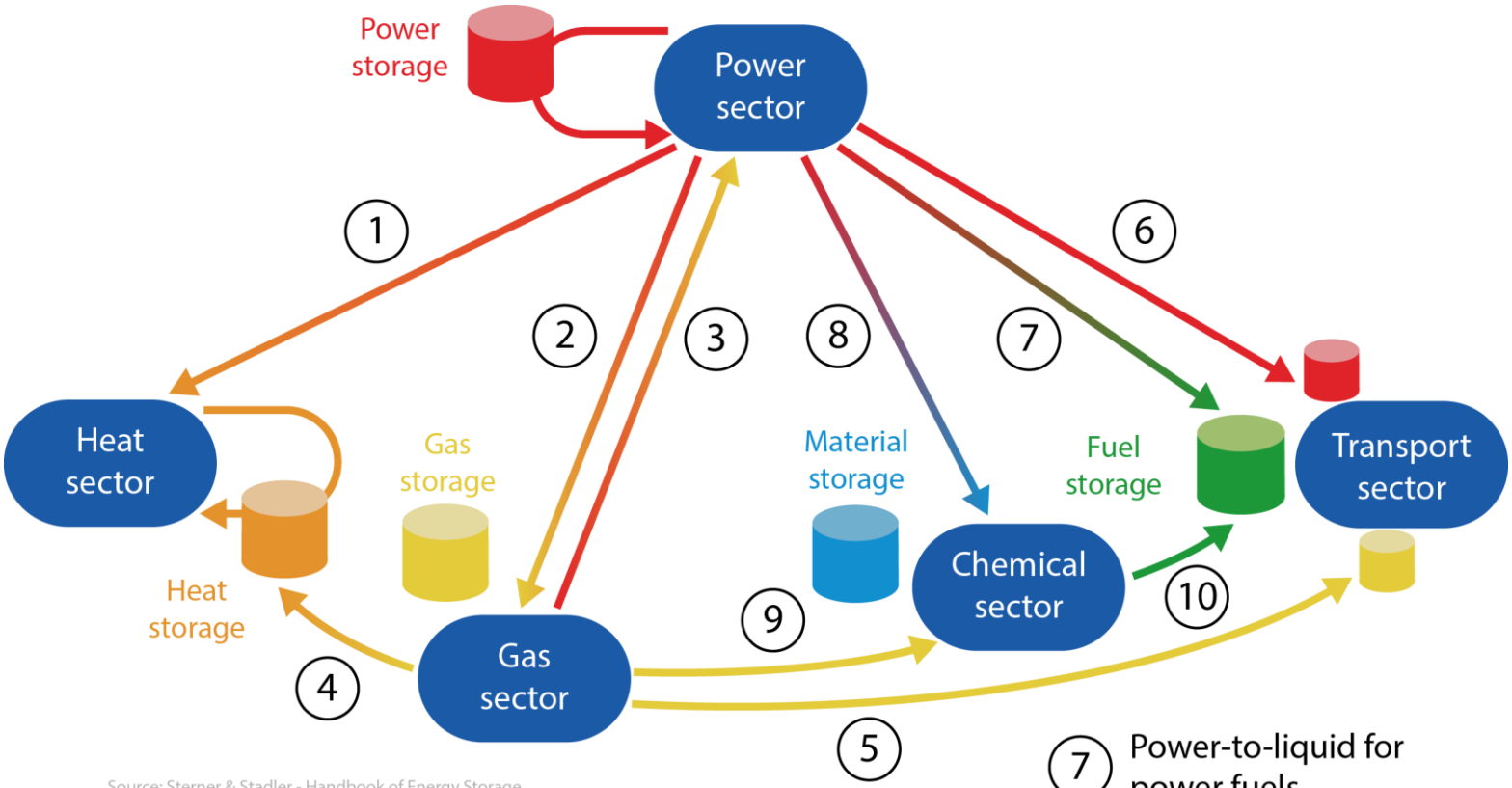
Interactions among different energy sectors through energy storage



1. Power-to-heat, heat pump, flexible CHP
2. Charge technology power-to-gas
3. Power-to-gas for power storage
4. Power-to-gas for heat storage
5. Power-to-Gas for power fuels
6. Electromobility
7. Power-to-liquid for power fuels
8. Charge technology power-to-chemicals
9. Power-to-gas for material storage
10. Power-to-chemicals for fuel storage

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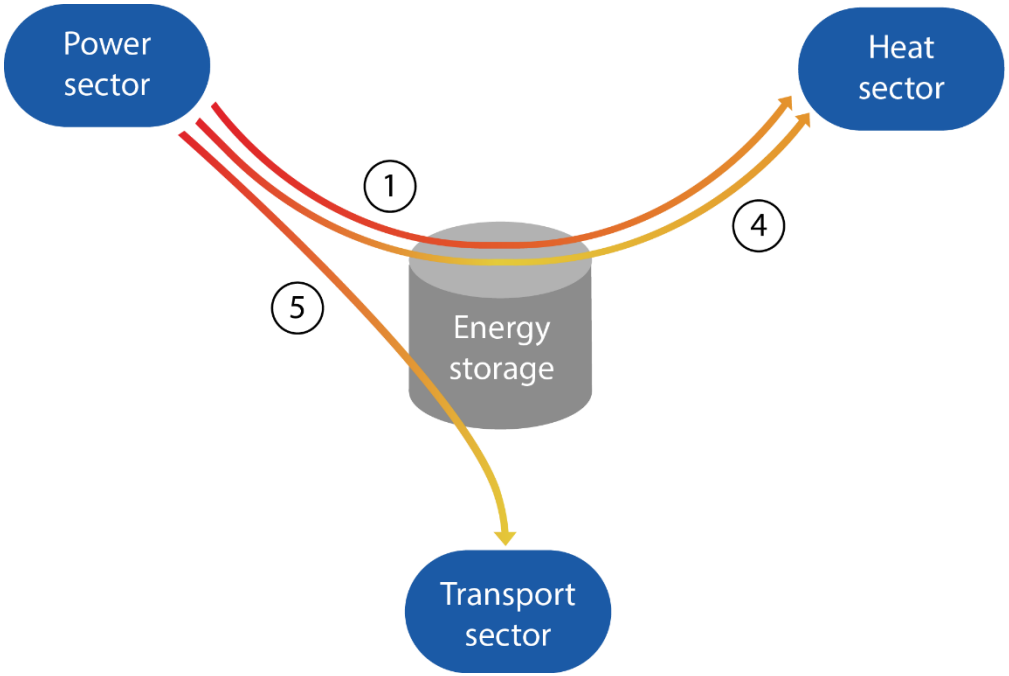
Interactions among power, heat and transport sectors through energy storage



1	Charge:	Heating rod, heat pump
	Store:	Tank, water, district heating
	Discharge:	Heat exchanger
4	Charge:	Power-to-gas
	Store:	Gas grid, gas storage
	Discharge:	Gas boiler
5	Charge:	Power-to-gas
	Store:	Gas grid, gas storage
	Discharge:	Vehicle

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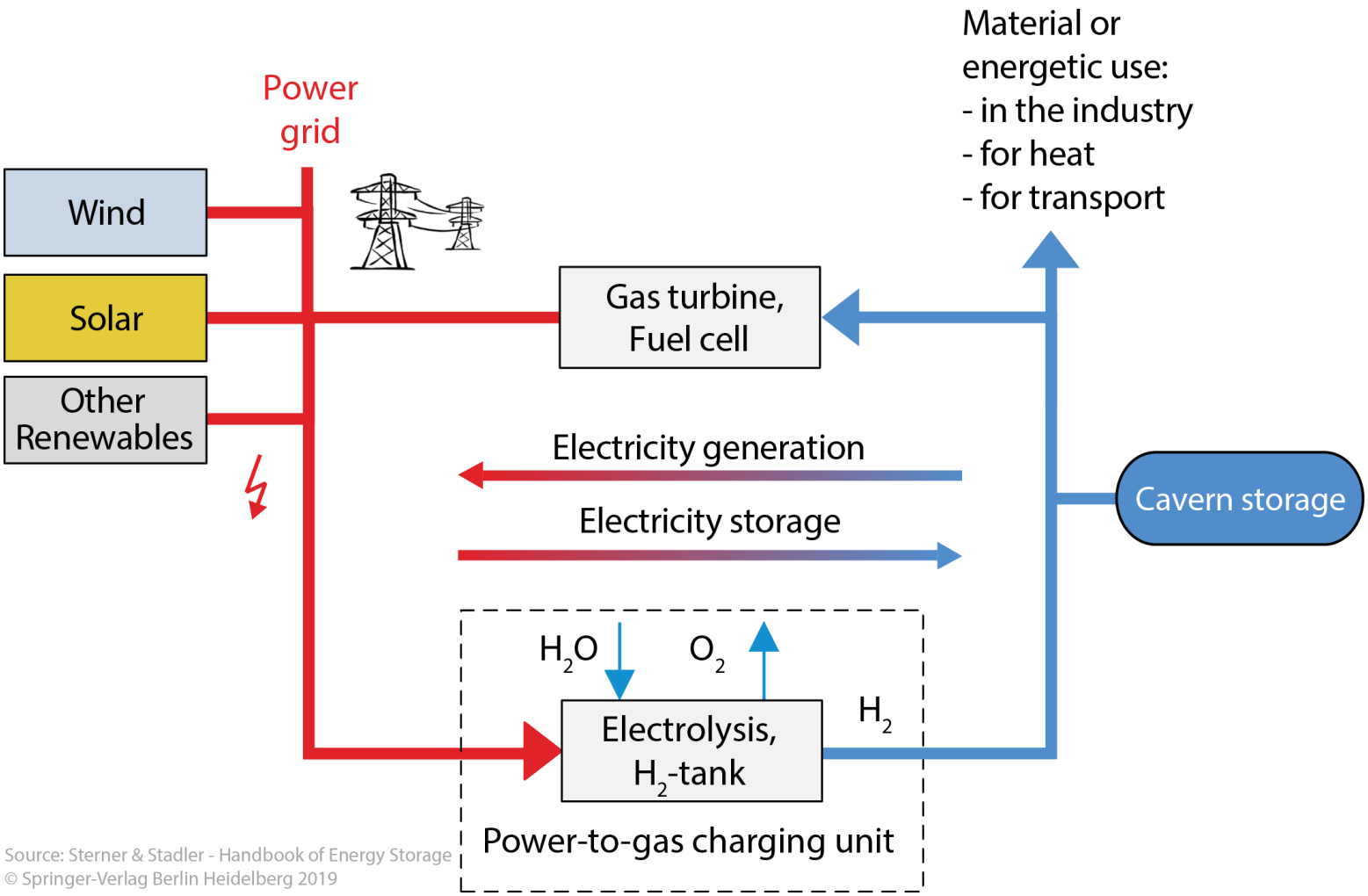
Power-to-Gas using hydrogen in a hydrogen-only infrastructure



Source: Sterner & Stadler - Handbook of Energy Storage

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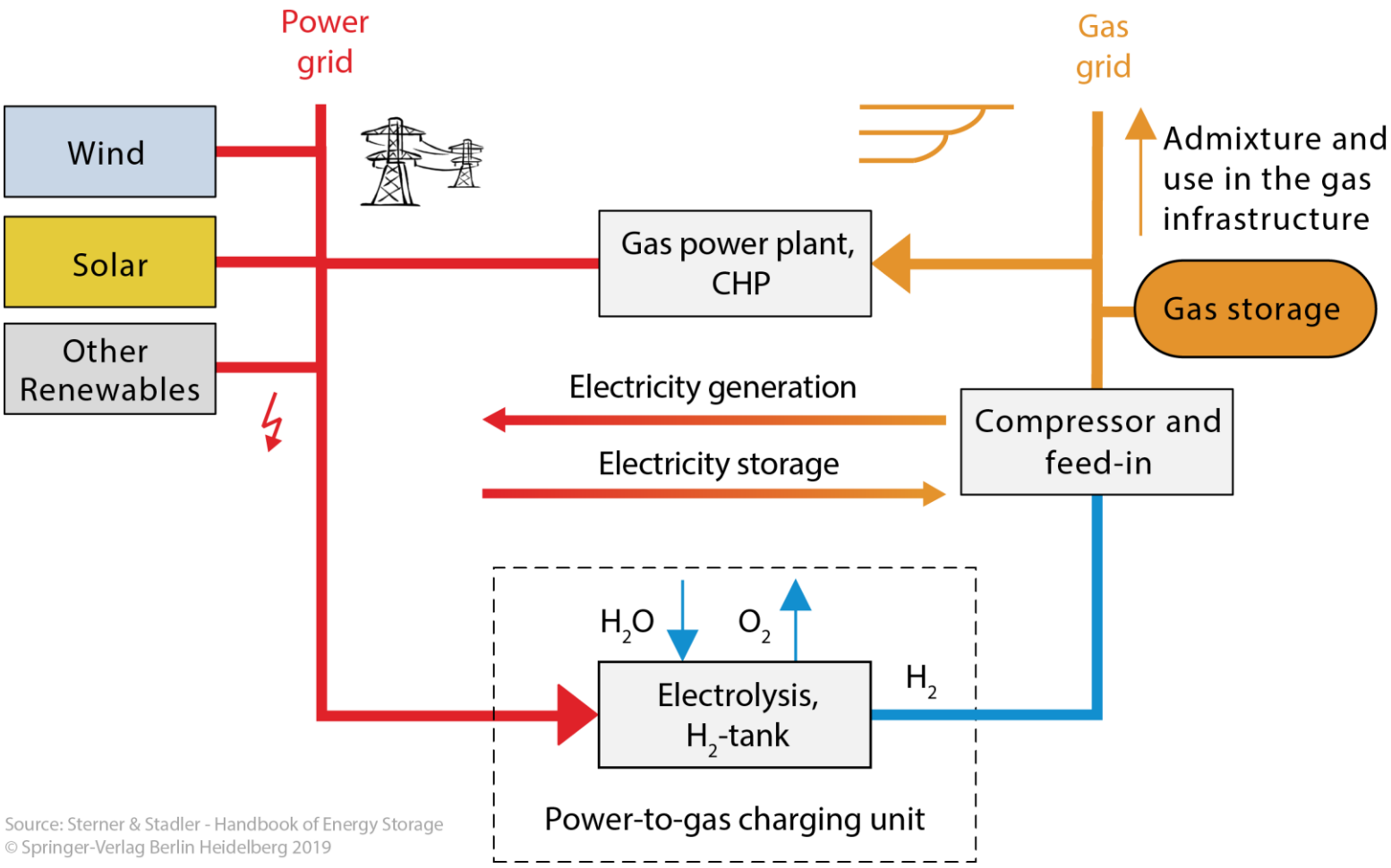
Power-to-Gas using hydrogen in the existing gas infrastructure



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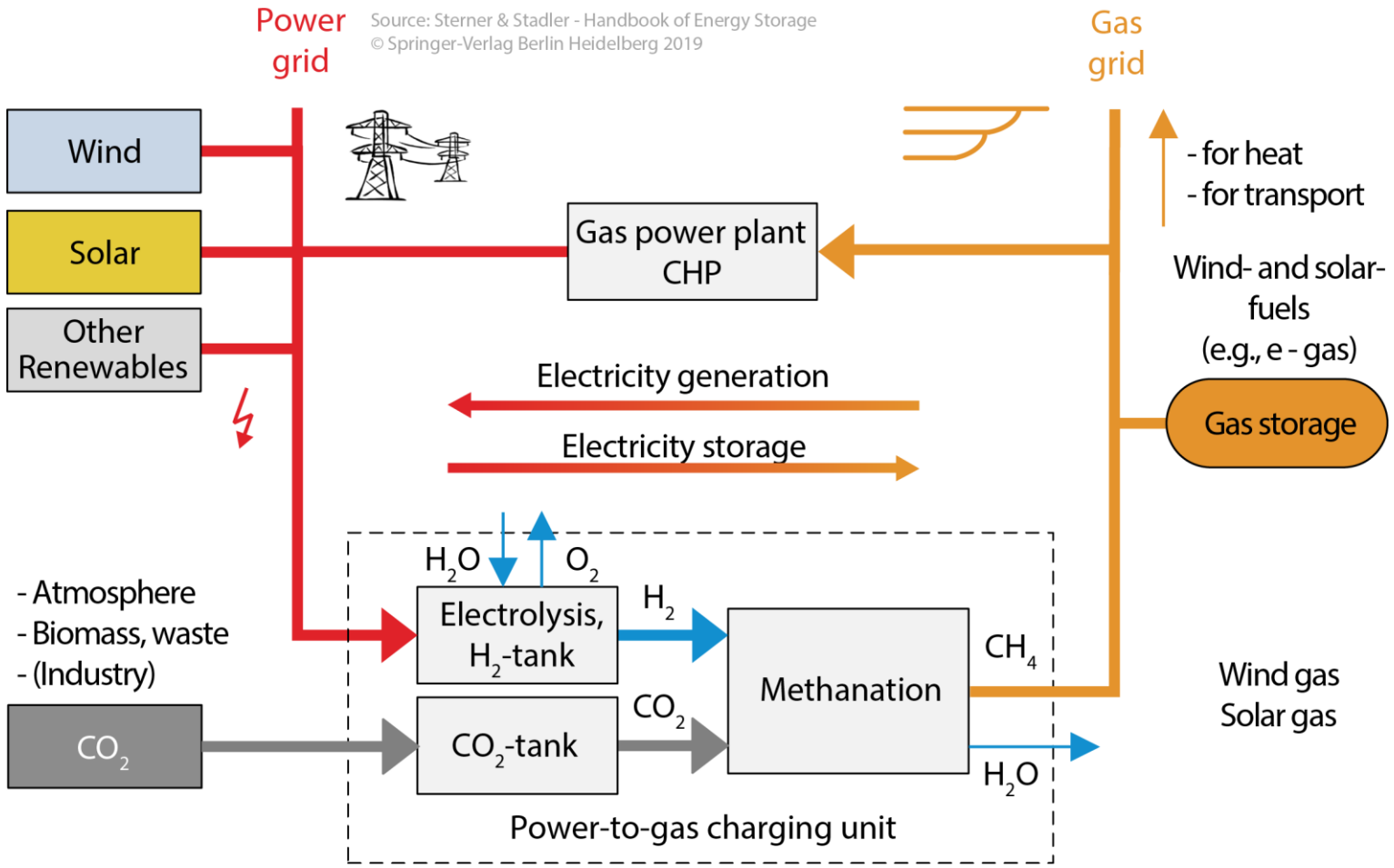
Power-to-Gas using methane



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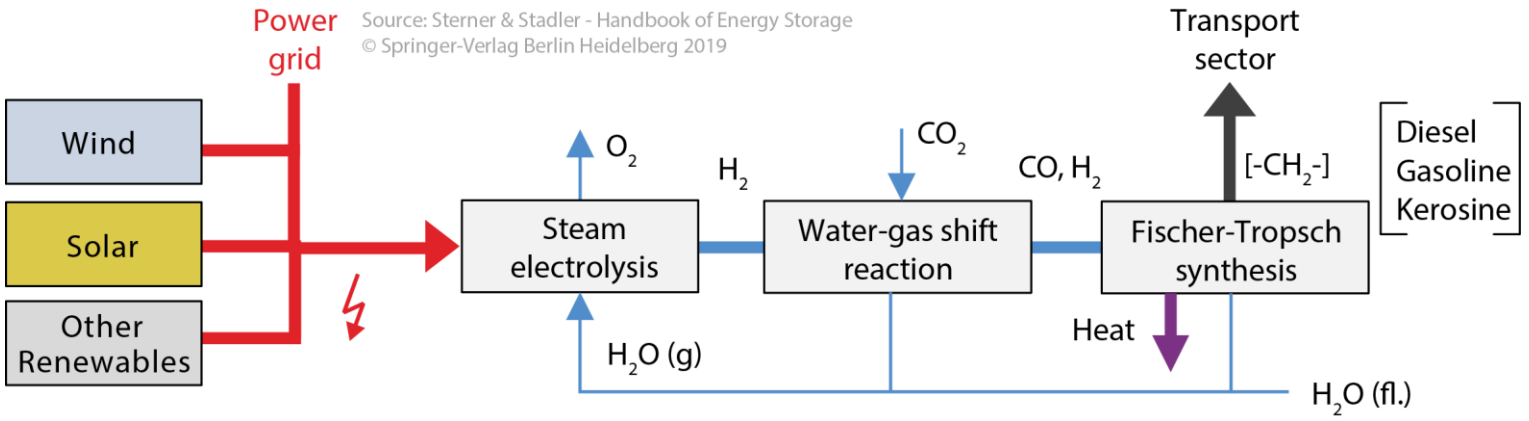
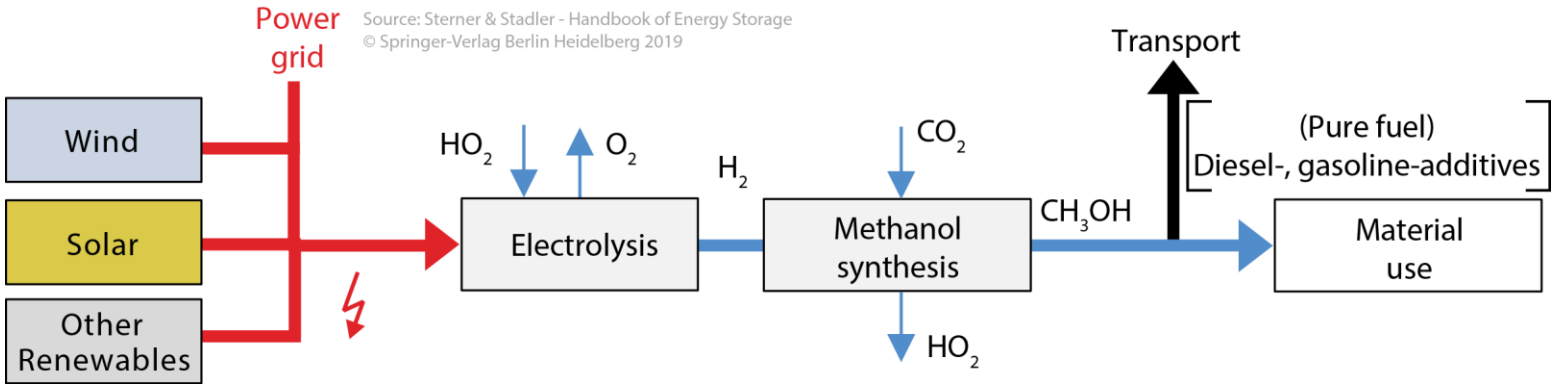
Power-to-Liquid





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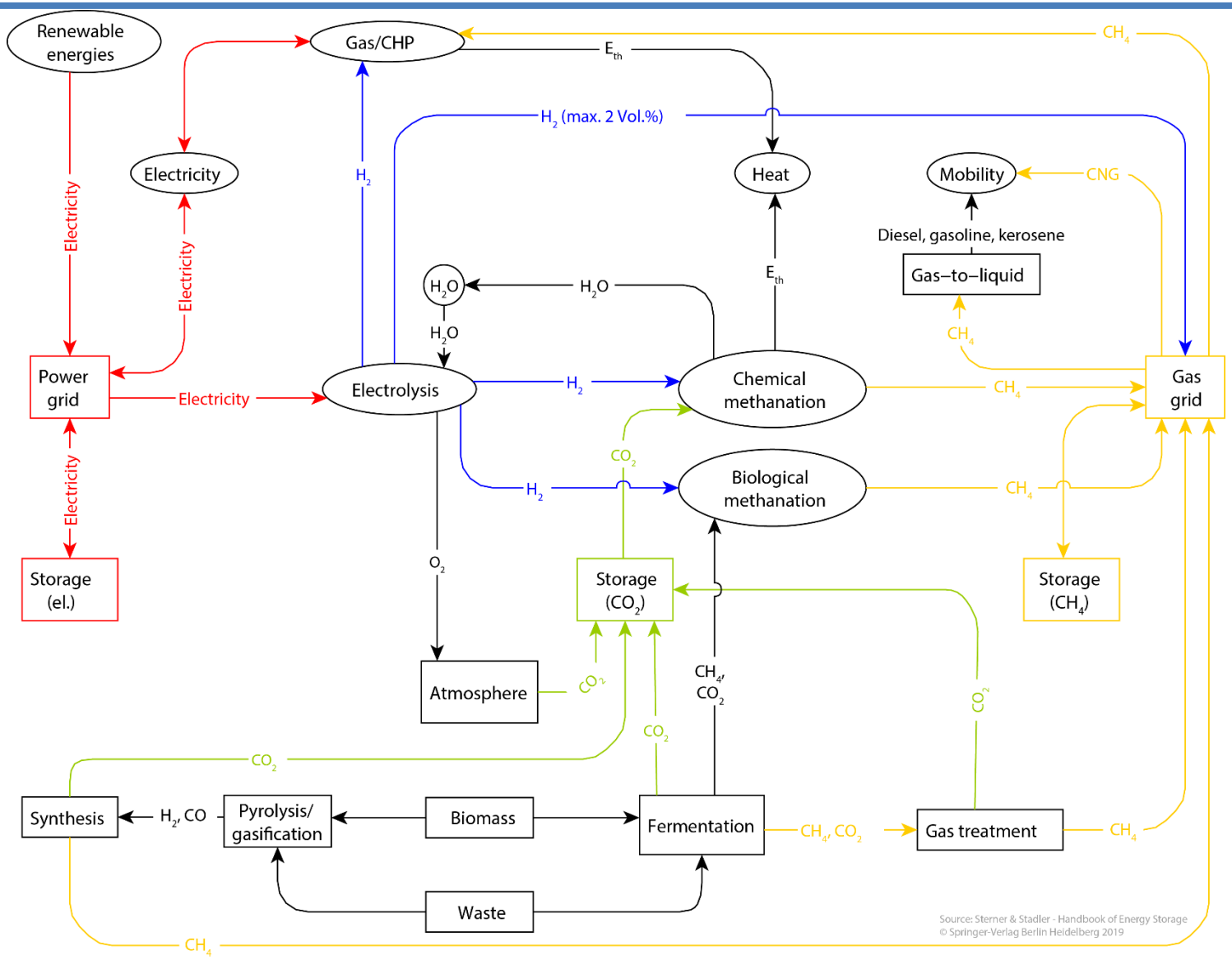
Sector coupling (electricity, heat, transport) through P2G/P2L



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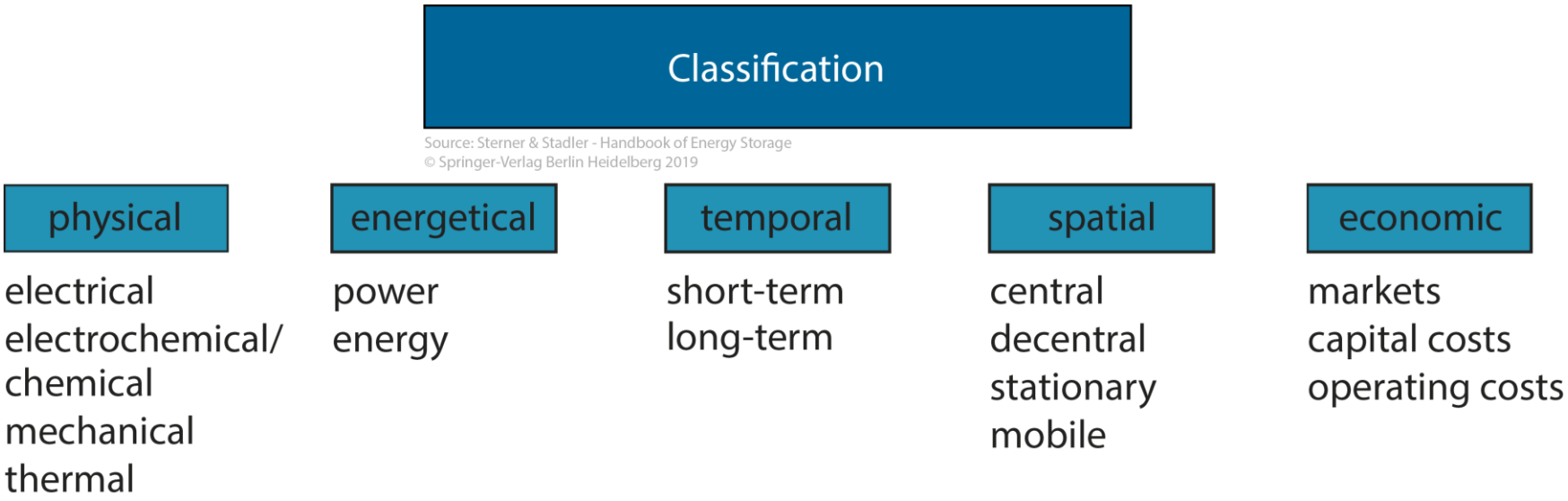
Efficiency, capacity rating and rated discharge time of selected energy storage technologies

Technology	Efficiency	Capacity rating MW	Time scale
Pumped hydro storage	70–85 %	1–5,000	Hours—months
Li-Ion battery pack	80–90 %	0.1–50	Minutes—days
Lead acid battery	70–80 %	0.05–40	Minutes—days
Power-to-Gas[a]	30–75 %	0.01–1,000	Minutes—months
Compressed air	70–75 %	50–300	Hours—months
Vanadium redox battery	65–85 %	0.2–10	Hours—months
Sodium sulfur (NaS) battery	75–85 %	0.05–34	Seconds—hours
Nickel cadmium (NiCd) battery	65–75 %	45	Minutes—days
Flywheel	85–95 %	0.1–20	Seconds—minutes

M. Lehner, R. Tichler, H. Steinmüller, and M. Koppe, *Power-to-Gas: Technology and Business Models*, 1st ed. Cham: Springer International Publishing, 2014.

Classification of energy storage systems



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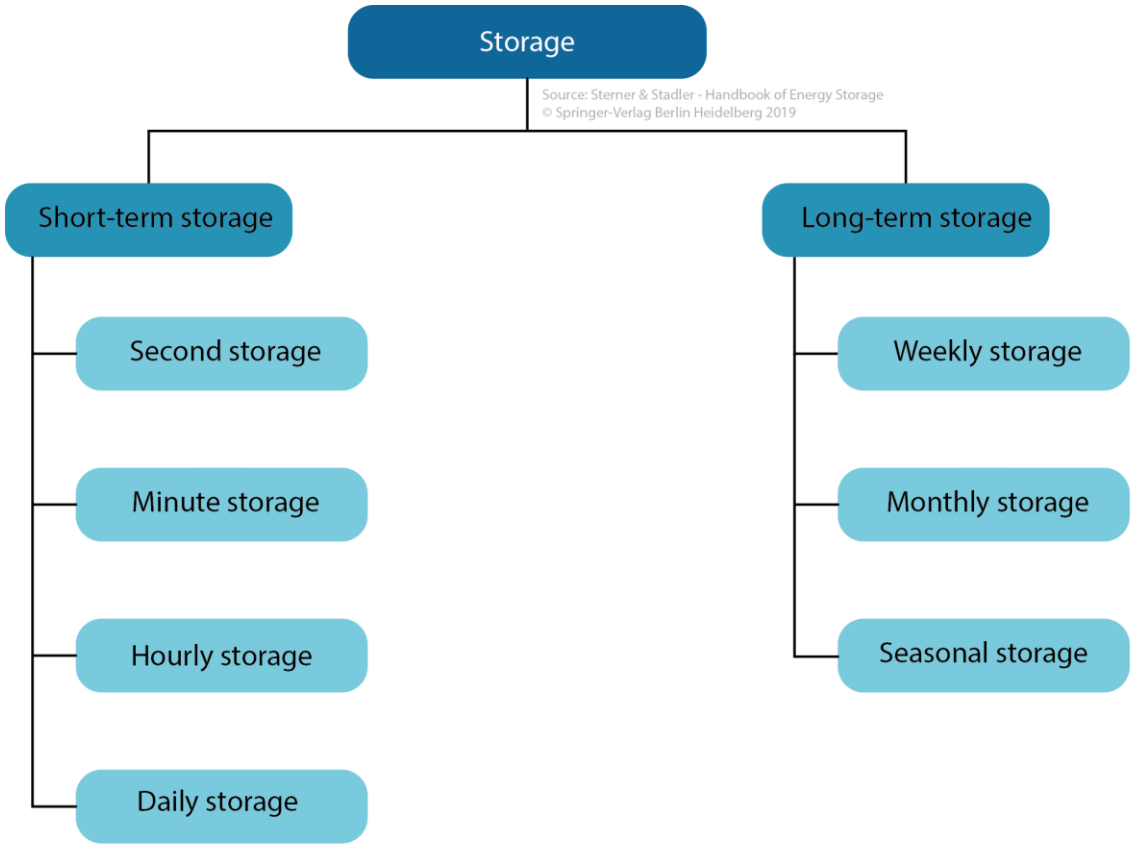

Examples:

Batteries
Capacitors, Coils
Flywheel-energy storage
Sensible and latent-heat storage

Sensible and latent-heat storage
Compressed-air storage
Pumped-hydro storage
Gas storage
Fuels

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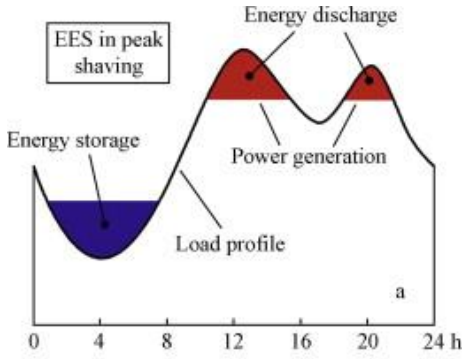
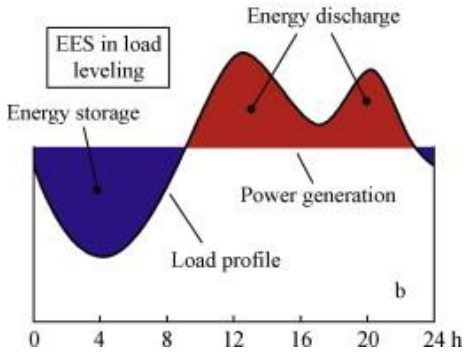
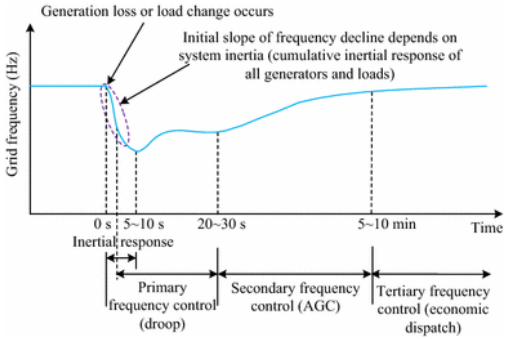
Energy storage systems: stationary applications

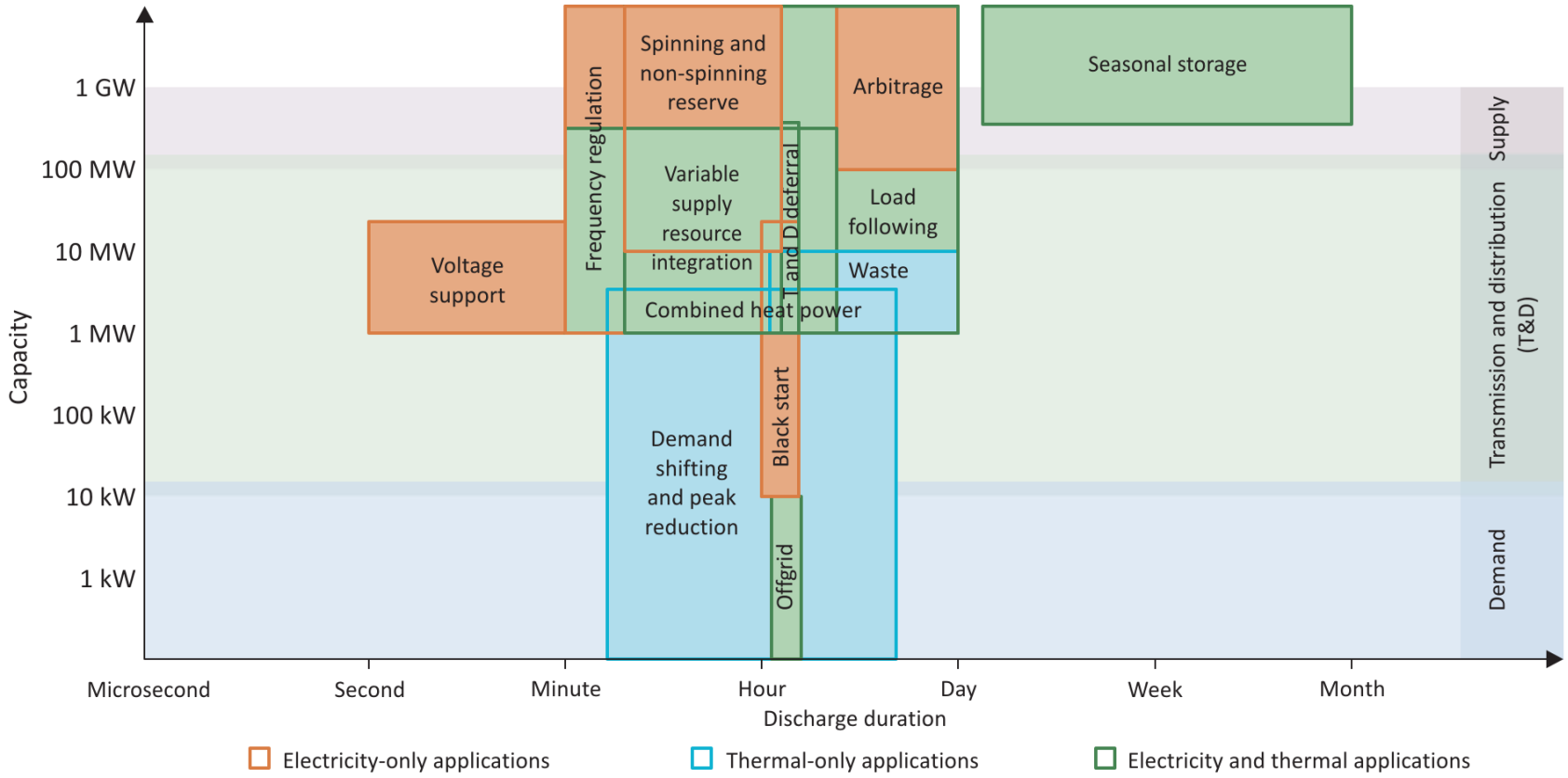
- **Time-shift** or **energy arbitrage** (*energy applications*)
  - peak shaving
  - load levelling
  - seasonal storage
- Transmission and distribution grid **investment deferral**
- Integration of non-dispatchable renewable energy sources
- Grid **ancillary services** (*power applications*)
  - frequency control (primary, secondary, tertiary)
  - power quality control
  - black start
  - contingency reserve



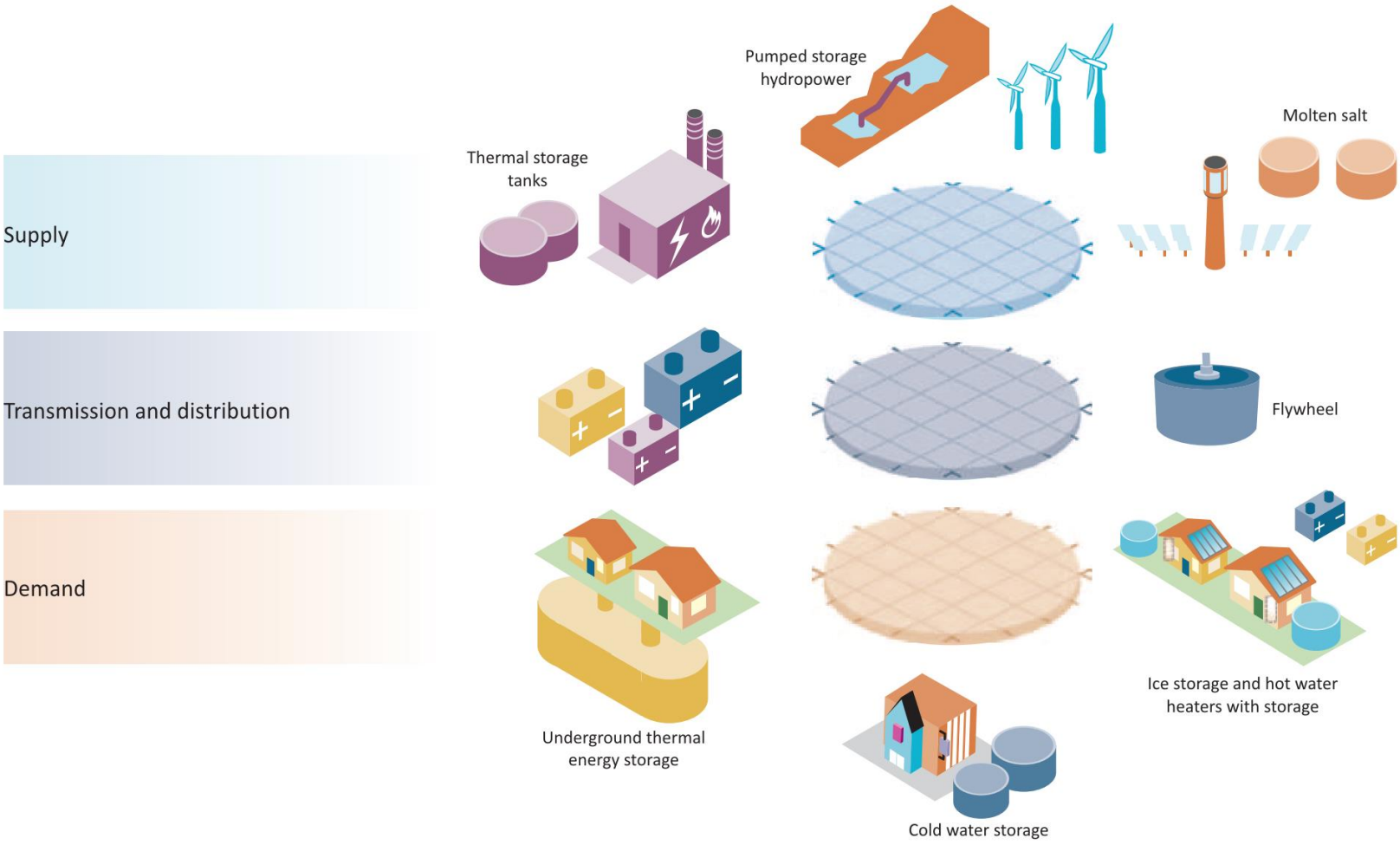




Power requirement versus discharge duration for some applications in today's energy system

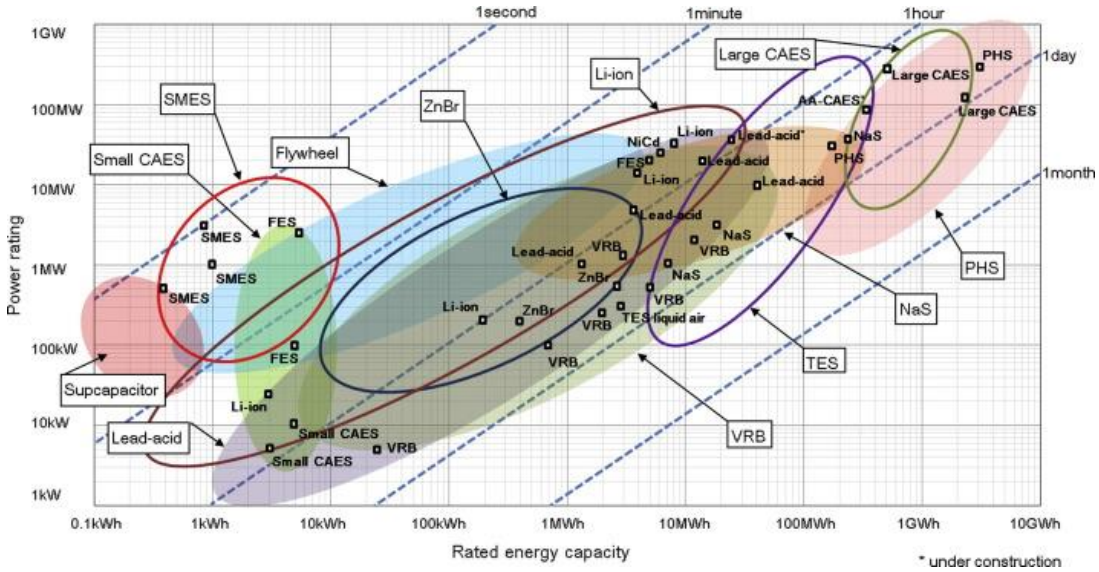


Hypothetical deployment of storage assets across an electric power system



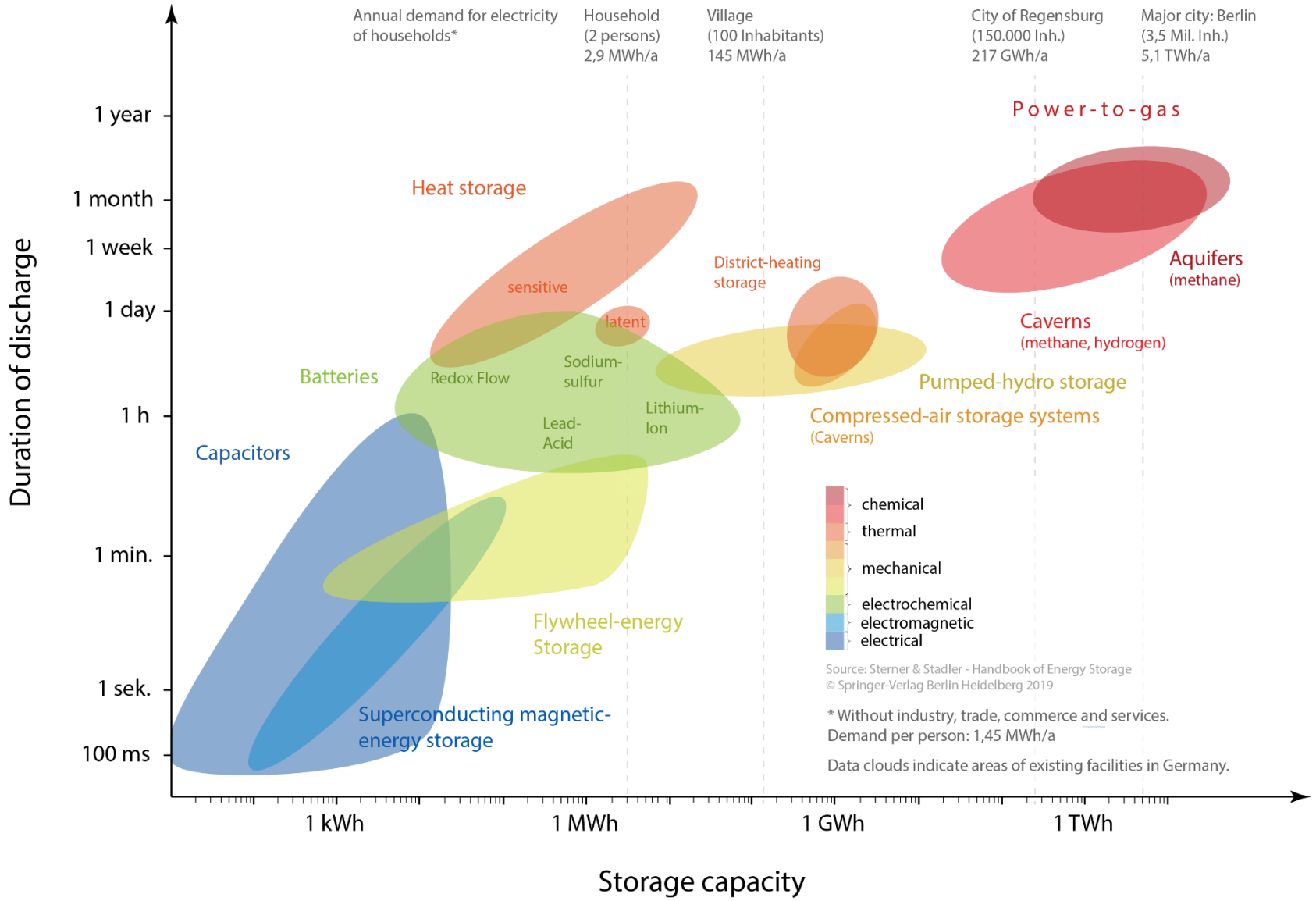
Classification of electrical energy storage systems

- **Mechanical**
  - Pumped Hydro (PHS)
  - Compressed Air (CAES)
  - Flywheel (FES)
- **Electrical**
  - Capacitor, supercapacitor
  - Superconducting Magnets (SMES)
- **Electrochemical**
  - Batteries (BES)
  - Flow batteries (FBES)
- **Chemical**
  - Hydrogen (+ fuel cells)
- **Pumped Thermal (Pumped Heat)**
  - low-temperature, cryogenic (LAES)
  - high-temperature



Graphs taken from: Luo X, Wang J, Dooner M, Clarke J, *Overview of current development in electrical energy storage technologies and the application potential in power system operation*, Applied Energy 2015;137:511–536. DOI: 10.1016/J.APENERGY.2014.09.081.

Energy storage systems: discharge time vs. storage capacity



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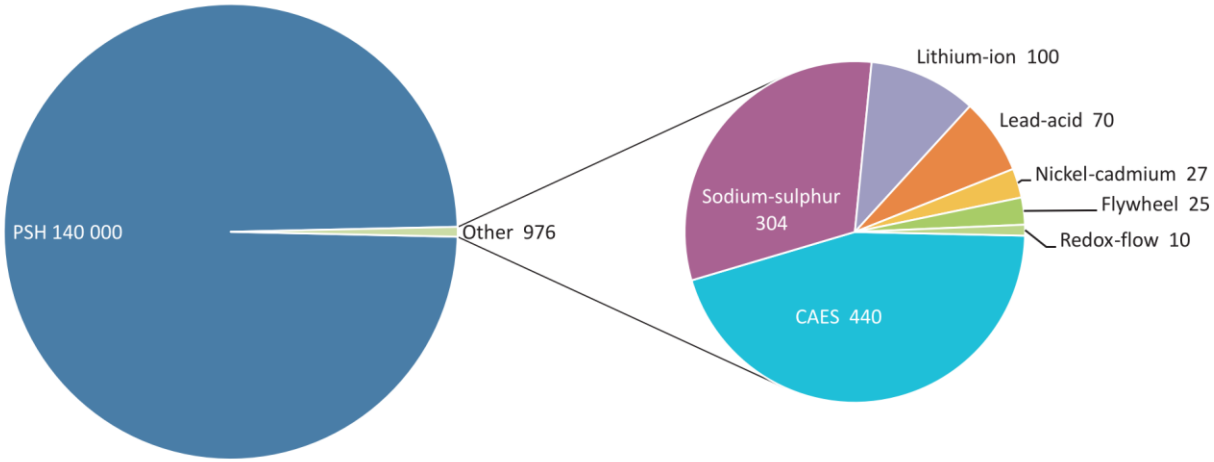
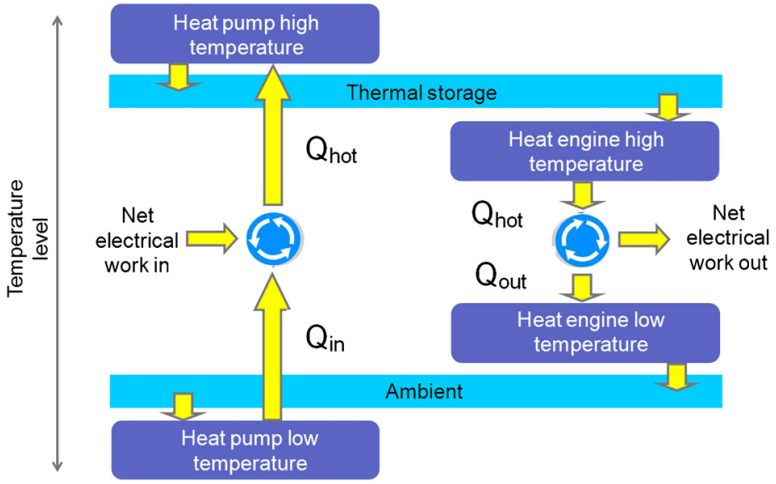
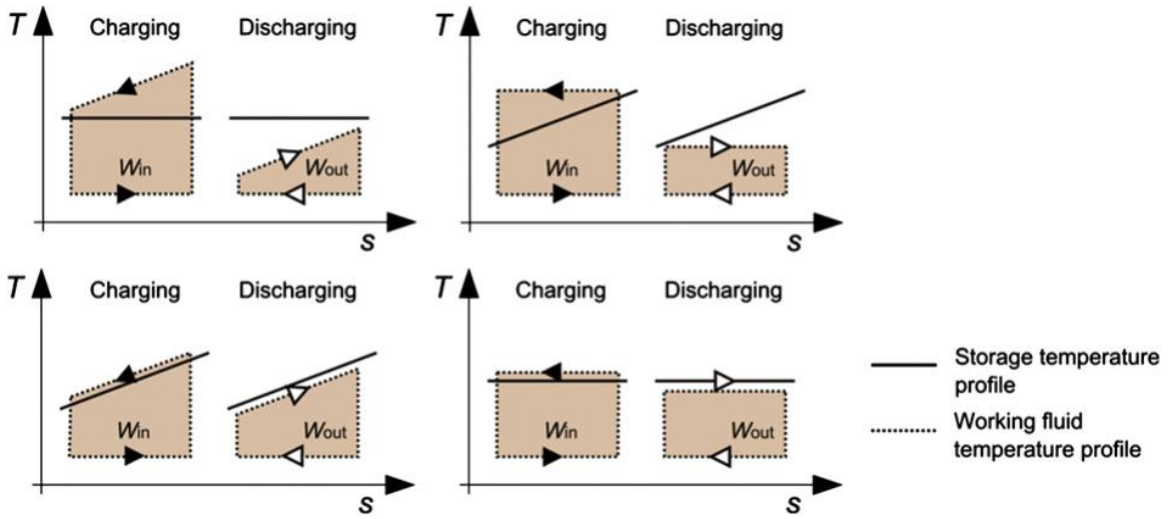
Current global installed grid-connected electricity storage capacity (MW)



Pumped Heat Energy Storage (PHES)





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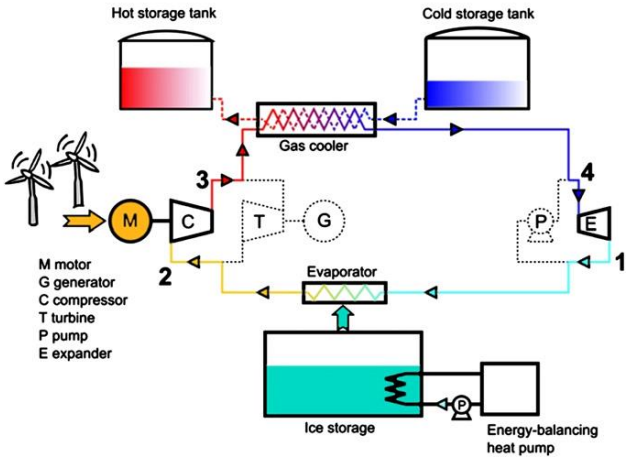
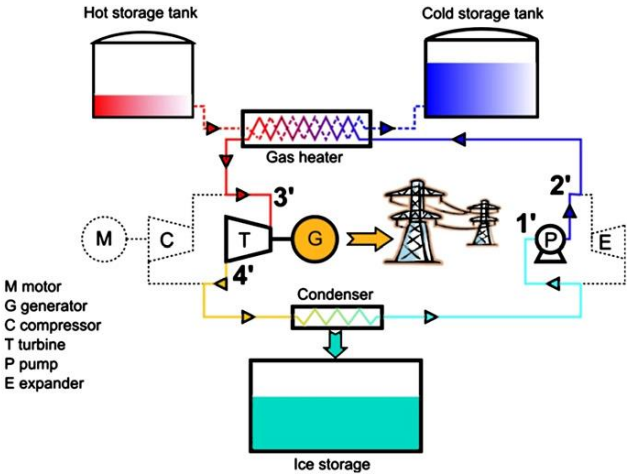
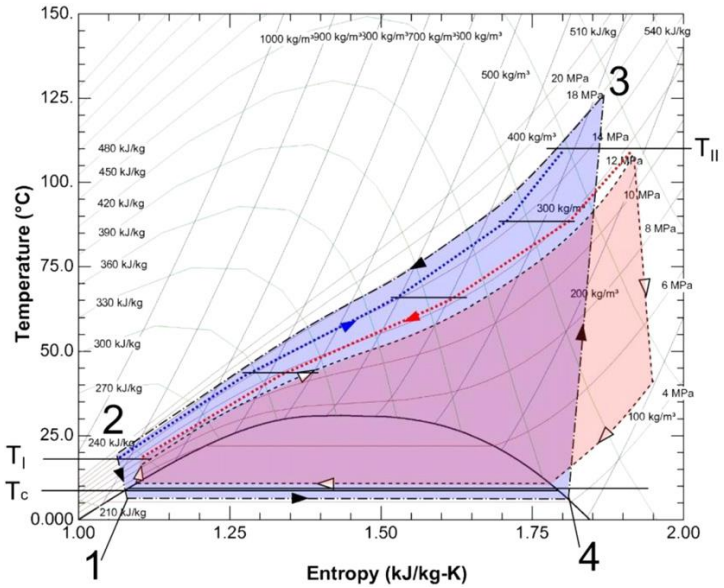
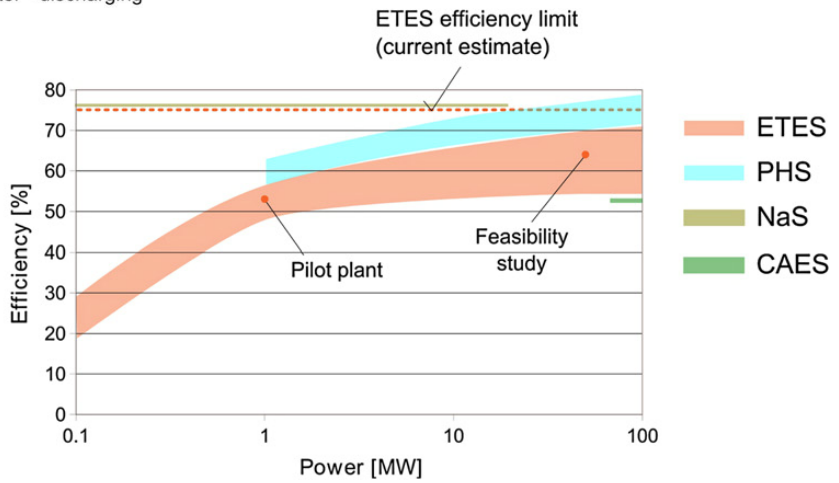
Pumped Heat Energy Storage with transcritical CO_2 cycles









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