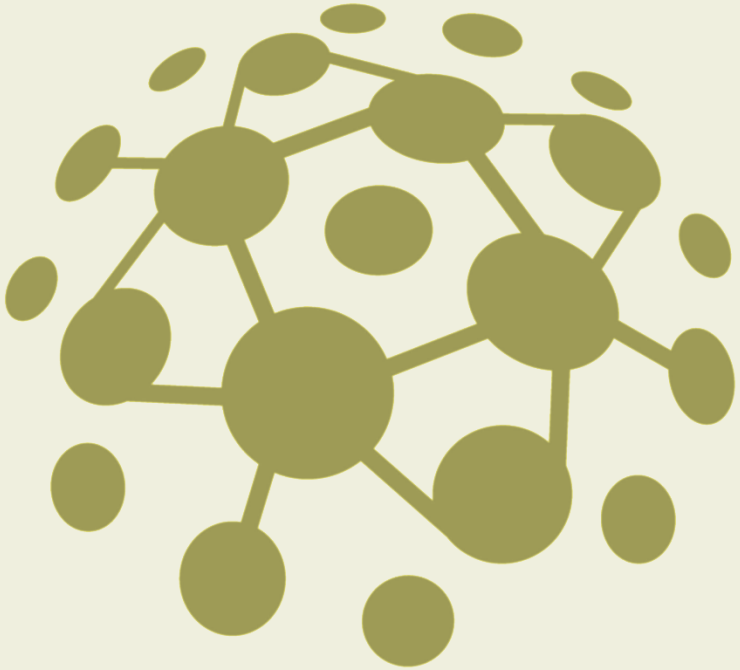

„Techno-economic assessment of seasonal heat storage in district heating with thermochemical materials“

Hans Böhm, Johannes Lindorfer

13th SDEWES Conference, 30.09. - 04.10.2018, Palermo

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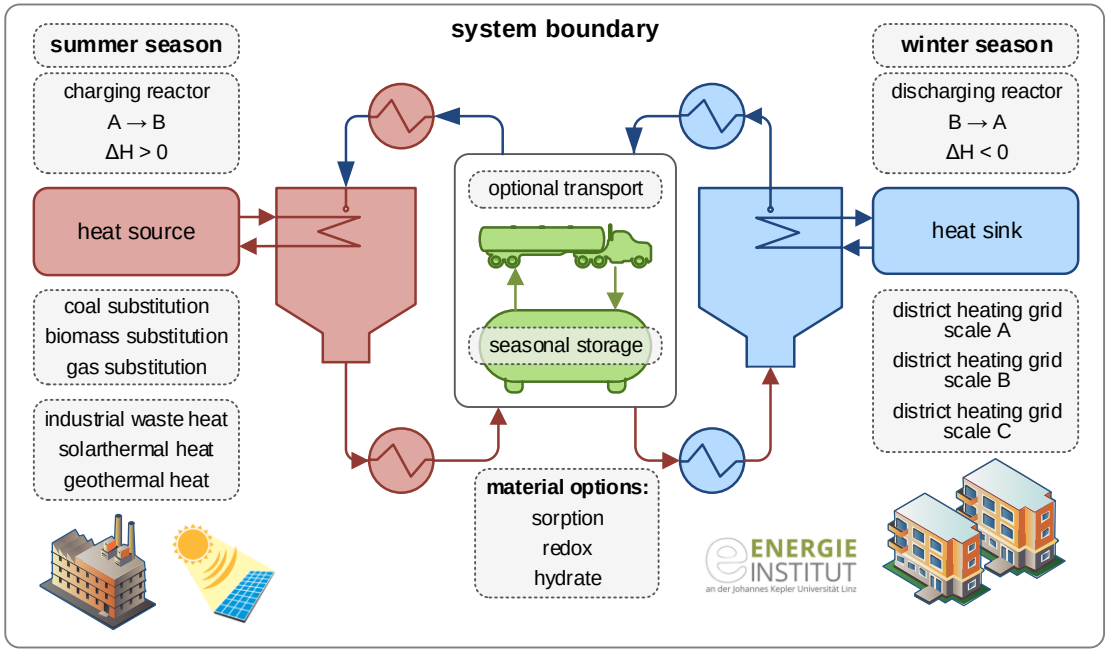
Subheadline

System Boundary

Definition



district heating grid	load	power (MW)	heat demand (GWh)	full load hours (h)
grid A: "large urban"	peak	70	28	400
	base	20	100	5.000
grid B: "small urban"	peak	20	7	350
	base	6	30	5.000
grid C: "rural"	peak	3	9	3.000
	base	1	5	5.000

Thermochemical Storage Materials

Key parameters

- Three basic material groups investigated
  - Redox materials
  - Hydrates & Hydroxides
  - Zeolites
- Criteria for material selection
  - Reaction enthalpy (energy density) **> 0.60 MJ/kg**
  - Specific material costs **< 0.10 €/MJ**
  - Availability **> 200 t per month**
  - **Hazard categories** allowing usage as storage material
  - Discharge reaction uses **oxygen** (air) or **water** (steam or moist air)
    → only one reactant has to be stored

Thermochemical Storage Materials

Selected materials

	reactant	product	energy density (MJ/kg)	material price[1)] (€/MJ)	availability (+ / ~ / -)	safety / hazard
zeolite	4A		0.65	0.484	+	classified as non-hazardous
	13X		0.86	0.834	+	classified as non-hazardous
hydrates & hydroxides	$MgCl_2$	$MgCl_2*6H_2O$	4.24	0.048[2)]	+	GHS07; irritant
	$MgCl_2$ $2H_2O$	$MgCl_2*6H_2O$	1.92	0.076[2)]	+	GHS07; irritant
	$MgSO_4$	$MgSO_4*7H_2O$	3.61	0.023[2)]	+	classified as non-hazardous
	$MgSO_4$ H_2O	$MgSO_4*7H_2O$	2.37	0.030[2)]	+	classified as non-hazardous
	$Al_2(SO_4)_3$	$Al_2(SO_4)_3*6H_2O$	1.79	0.084	+	GHS05; caustic
	CaO	$Ca(OH)_2$	1.86	0.080[2)]	+	GHS05, GHS07; caustic, irritant
	MgO	$Mg(OH)_2$	1.98	0.188	+	classified as non-hazardous
redox materials	Mg	MgO	24.75	0.025[2)]	+	GHS02; highly flammable
	Si	SiO_2	32.43	0.097	~	GHS02, GHS07; highly flammable, irritant
	Al	Al_2O_3	31.05	0.072	+	GHS02; highly flammable
	Ca	CaO	15.84	0.063	~	GHS02; highly flammable
	AlO	Al_2O_3	21.52	0.039	+	classified as non-hazardous

[1)] source: search on B2B platforms, e.g., Alibaba
[2)] Prices determined for product and mass converted to educt.

availability:
„-“: <200 t/month, „~“: <2,000 t/month, „+“: >2,000 t/month

Thermochemical Storage Materials

Restricting material properties

- **Phase change** of reactants during (dis)charge process, like liquefaction of $MgSO_4$ → difficult to handle in certain reactor concepts
- **Formation of hazardous substances** (toxic/caustic), like gaseous HCl from $MgCl_2$ at high temperatures
- **Risk of dust explosion** since TCS materials require large specific surface area for optimum use
- **Passivation** through uncontrolled oxidation or humidification when stored at ambient conditions
- Feasibility of purely thermal reduction due to **required temperature** levels

Storage operations

Charging the TCS

Energy Sources

- Solar heat
- Geothermal energy
- Industrial waste heat
- Electricity from renewables

Processes and Reactors

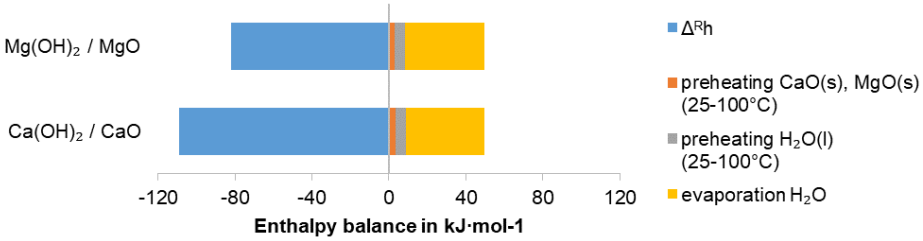
- **Drying** (zeolites, hydrates/hydroxides): circulation dryers, belt/roller dryers, fluidized bed reactors, rotary kilns, …
- **Reduction** (redox materials): electric arc furnace, electrolysis, blast furnace, smelting reduction furnace, …

Storage operations

Discharging the TCS

Processes and Reactors

- **Humidification** (zeolites, hydrates/hydroxides):
  - Use of moist air was refused due to the high throughput required
  - Water vapour is preferred over liquid water to avoid decrease of net energy gained by heat of evaporation



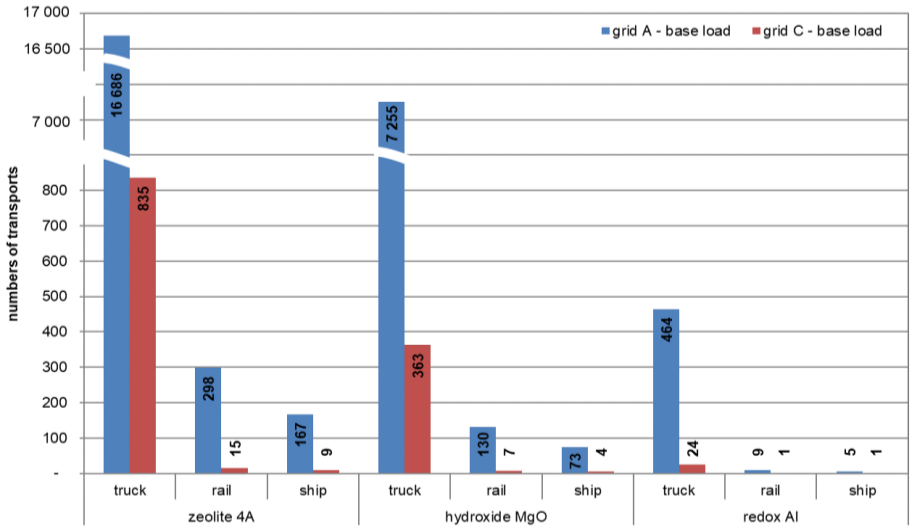
- **Reduction** (redox materials): materials are expected to be conventionally combusted by using air or oxygen

Both processes are presumed to be feasible in **well-established reactor concepts**, like fluidized bed reactors, dust firing or grate reactors

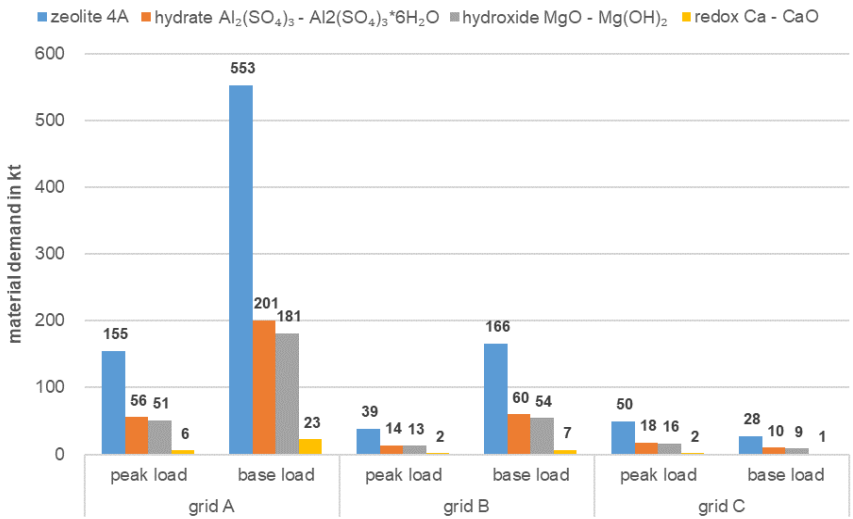
Storage operations

Transportation & Storage

- Required if charging and discharging **reactors are spatially separated**
- **Safety classification** of the material may increase transportation efforts and costs
- Usable transportation methods depend on **location and transport connection** of the reactor site



- According their properties and reactivity **materials must be contained** and not be exposed to environment
- Storage in **closed silos** was found to be a suitable method both on function and costs
- **Closed depots** were considered as an alternative in evaluations



Investigated Scenarios

Humidification

Scenario H1:

- Charging and discharging in the **same** fluidized bed **reactor**
- Charging with **solar thermal** energy, discharging with **steam not** available **for free**
- Transportation by **truck** (100 km total) and storage in **silos**

Scenario H2:

- Charging and discharging in the **same** fluidized bed **reactor**
- Charging with **industrial waste heat**, discharging with **steam** available **free of charge**
- **No transport** and storage in **closed depots**

Scenario H3:

- Charging and discharging **separate** fluidized bed **reactors**
- Charging with **deep geothermal** energy, discharging with **steam not** available **for free**
- Transportation by **rail freight** (400 km total) and storage in **closed depots**

Investigated Scenarios

Oxidation

Scenario O1:

- Charging by **electric arc furnace**, discharging in **fluidized bed reactor**
- Electricity from **renewable energy sources**
- Transportation by **truck** (100 km total) and storage in **silos**

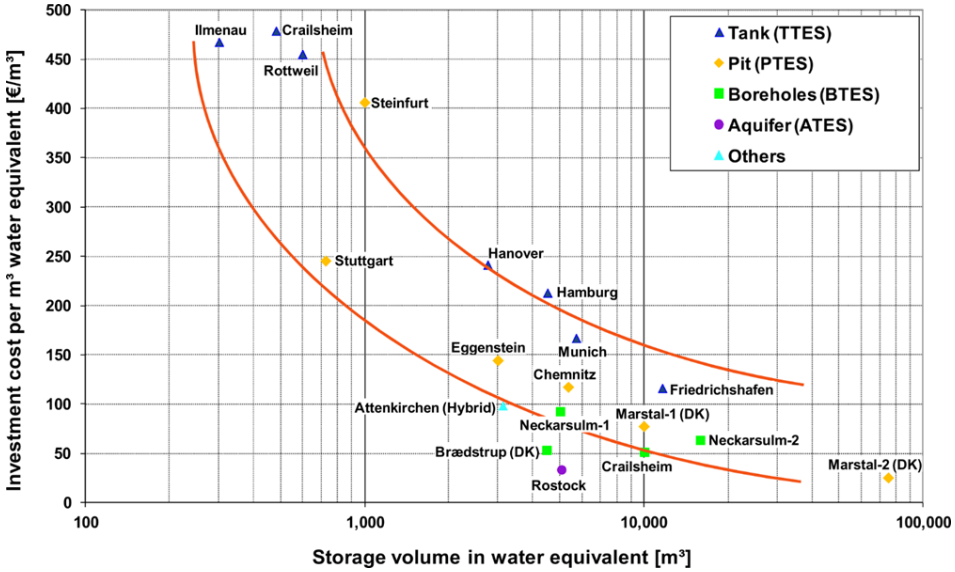
Scenario O2:

- Charging by **electric arc furnace**, discharging by **dust firing**
- Electricity from **renewable energy sources**
- No transportation and storage in **closed depots**

Benchmarks

Alternative storage technologies and conventional district heating

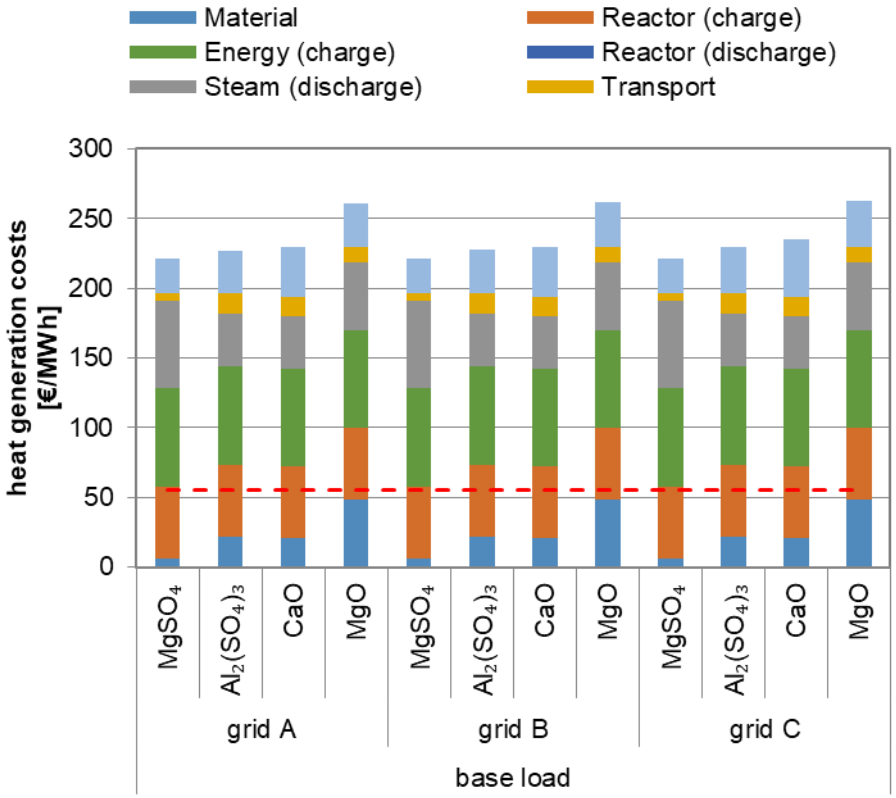
- Most common form of large-scale heat storage is the utilization of **sensible heat with hot water** with specific costs down to 35 €/m³ for **pit storages**
- **Average working price for district heating** in Austrian provincial capitals at approx. 55 €/MWh was applied as first guideline due to grid specific conditions and high bandwidth of generation costs

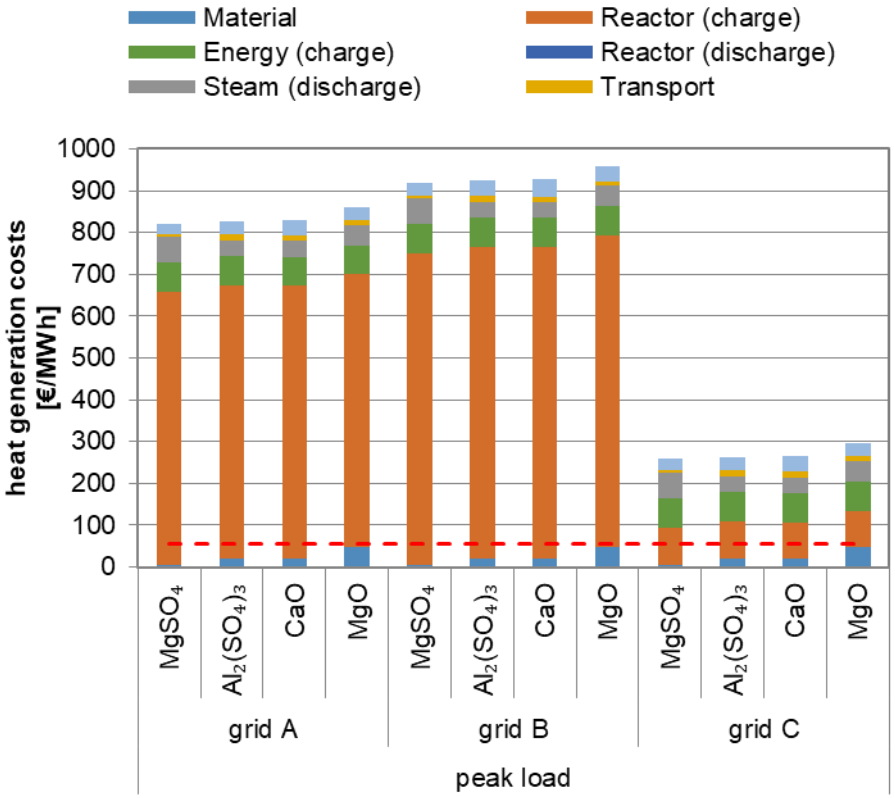


Economic evaluation of the scenarios

Results – Humidification

Scenario H1

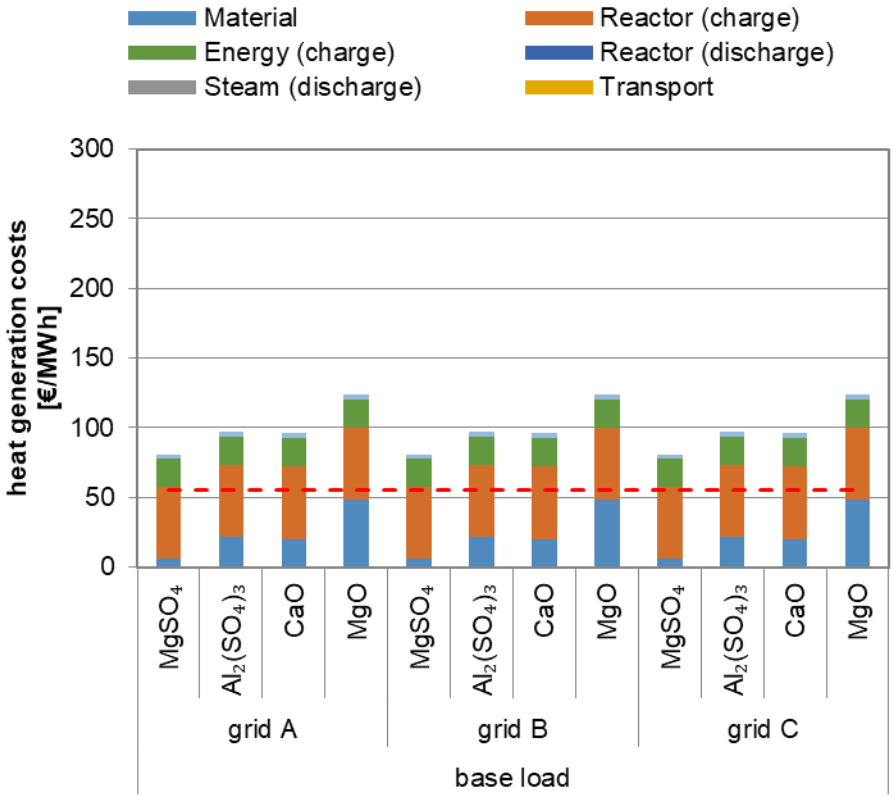




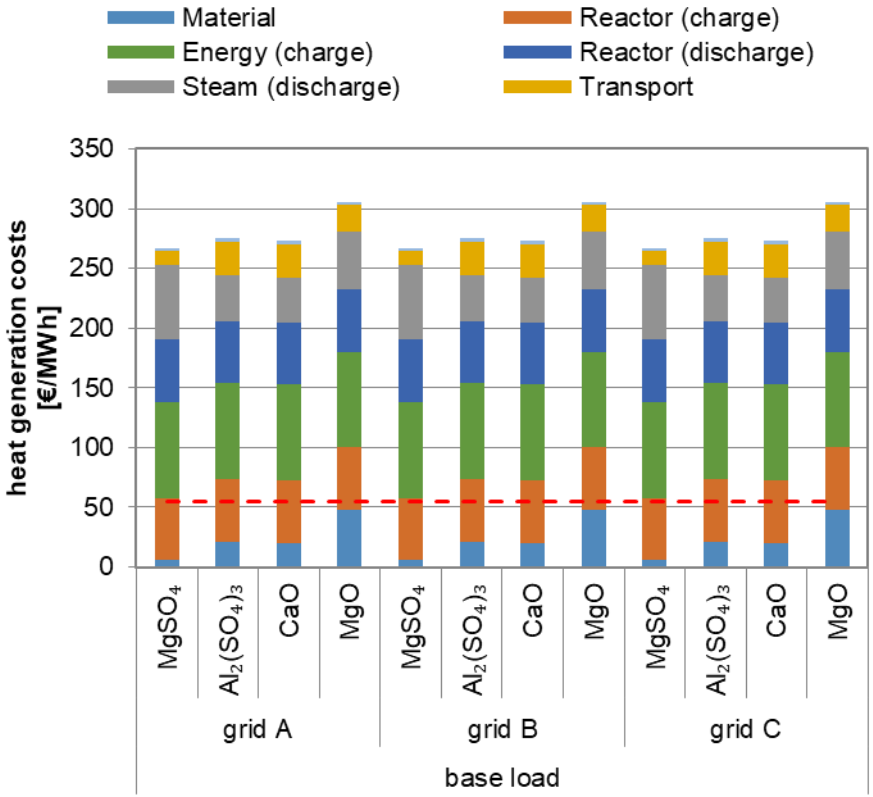
Economic evaluation of the scenarios

Results – Humidification

Scenario H2



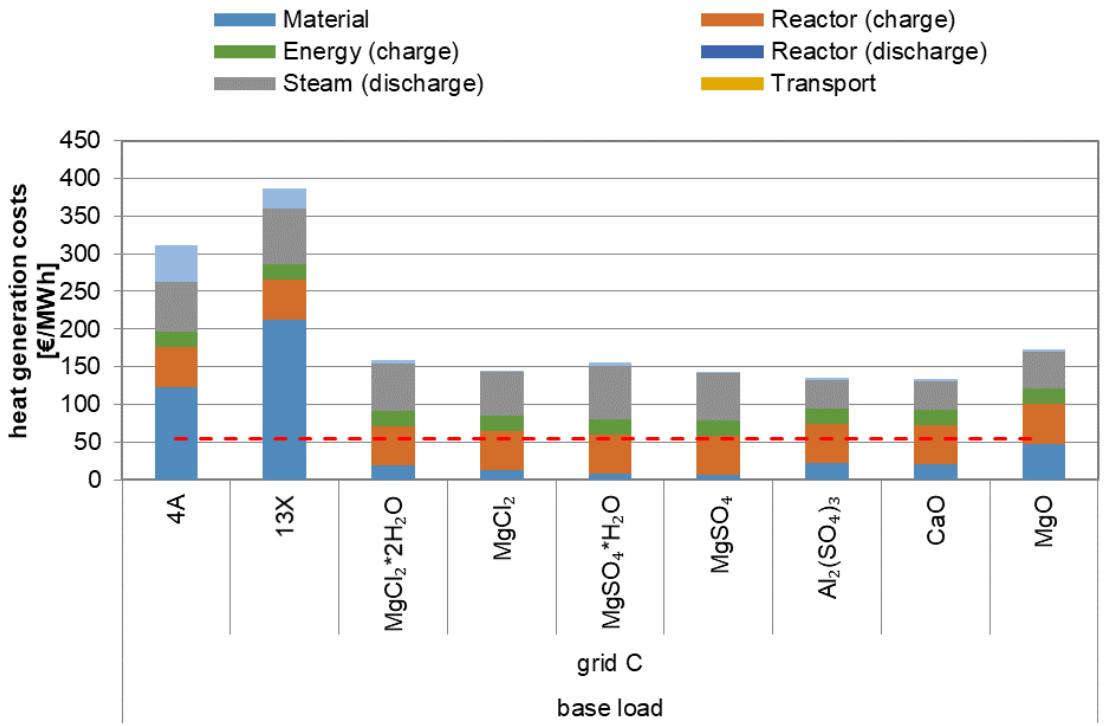
Scenario H3



Economic evaluation of the scenarios

Results – Humidification

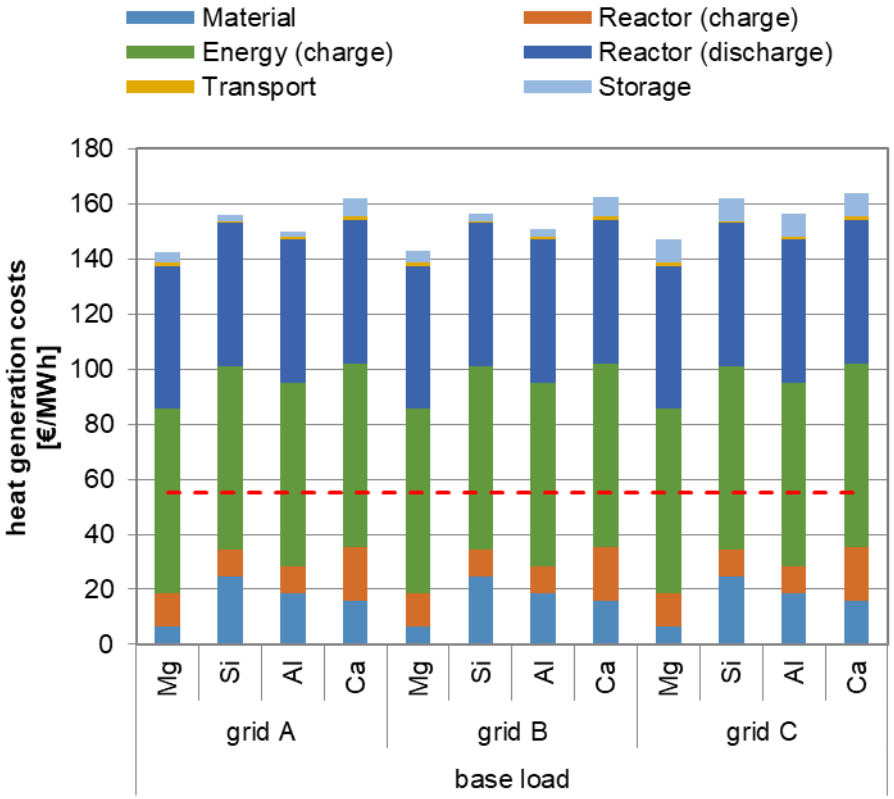
Comparison to zeolites and other hydrates



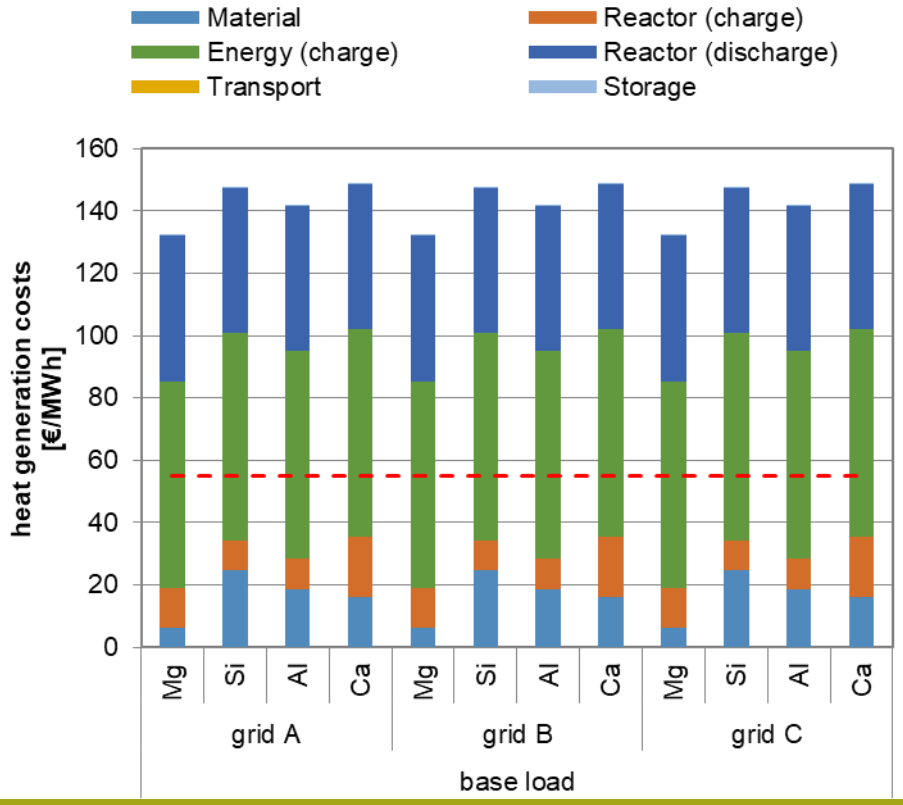
Economic evaluation of the scenarios

Results – Oxidation

Scenario O1



Scenario O2



Economic evaluation of the scenarios

Results – Oxidation

- Ecological reasonability for redox materials is highly dependent on the use of low emission reduction procresses

TCS-material	CO_2 equivalent[1] [kg_{CO2}/kg_{educt}]	spec. CO_2 emissions[1] [kg_{CO2}/GJ]	
RedOx Al - Al_2O_3	3,82	**123.02**	Hall-Héroult process
RedOx Ca - CaO	1,71	**108.24**	Aluminum from Hall-Héroult
RedOx Si - SiO_2	3,13	**96.63**	acc. to gross reaction
RedOx Mg - MgO	1,81	**73.16**	Silicium acc. to gross reaction

minimal CO_2 emissions from reduction;
does not include emissions from required energy (electricity), transportation, etc.

Comparison to fossil fuels	
brown coal	**110.9**
natural gas	**55.9**

[1] calculations for stoichiometric reactions

Conclusions

- Choice of the **heating grid has major influence** on the potential use cases for TCS
  → grids with **low power demand** and **high number of full load hours** to be preferred
- **Location** of charging energy sources and **distance to the heating grid** should be kept low to save reactor and transportation costs
  - **hydration-based materials** show lowest costs when processed **near industry**
  - **redox** are preferable **for long distances** due to low transportation efforts
- **Operating materials** for reduction processes have not been considered and **are expected to increase costs**
- **Use of inorganic salts** (Bischofite, …) instead of pure/synthetic materials could significantly decrease costs despite lower conversion efficiency and performance
- **Zeolites** are **not suitable for large-scale applications** due to low storage densities and high material price
- Considering expectable conversion rates, it will be **hard for TCS to compete with hot water storages** in larger grids. Therefore, future research should focus on optimization of materials, conversion technologies and storages for specific applications.

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