Life cycle analysis of PCM-enhanced domestic hot water storage

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THERMAL ENERGY STORAGE

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Background: Swiss Energy Landscape

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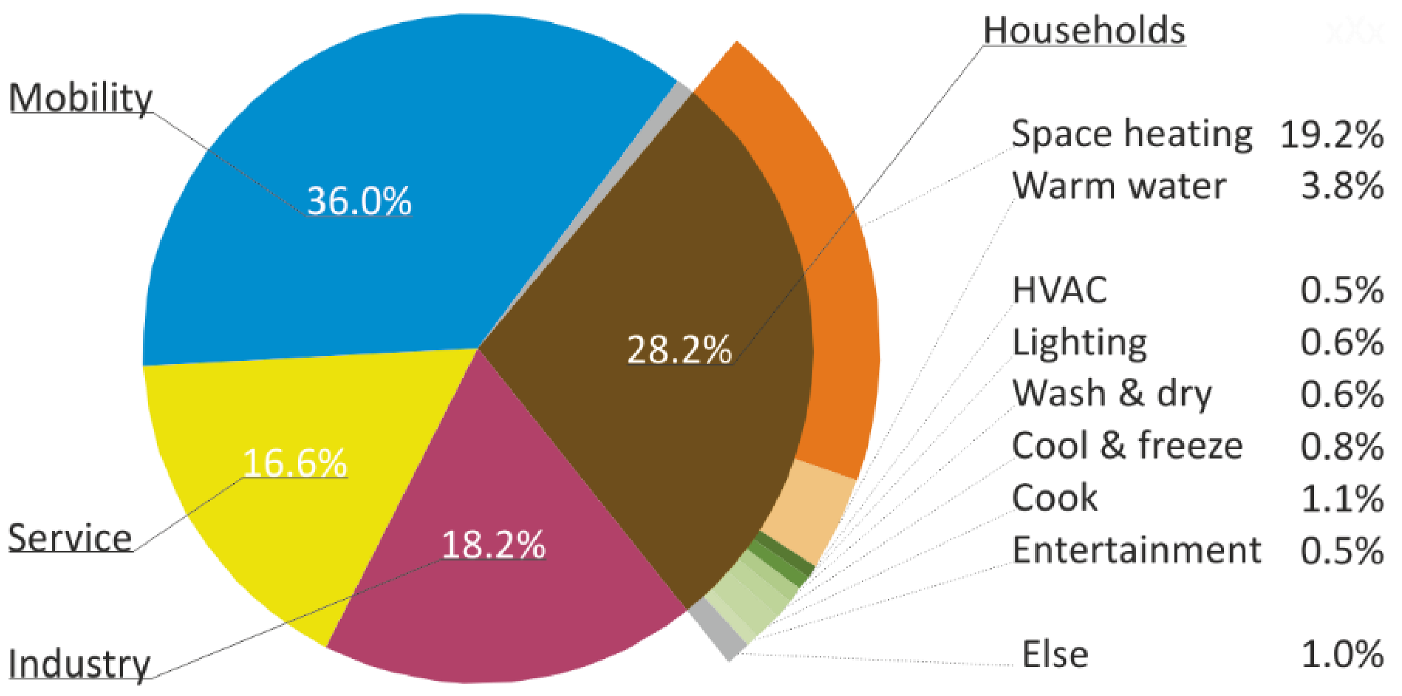
Breakdown of energy use by sectors, with focus on households, for Switzerland in 2016, as share of total.



Source: Berger, M., Worlitschek, J. Energy (2018) 159: pp. 294-301.

Thermal storage principles

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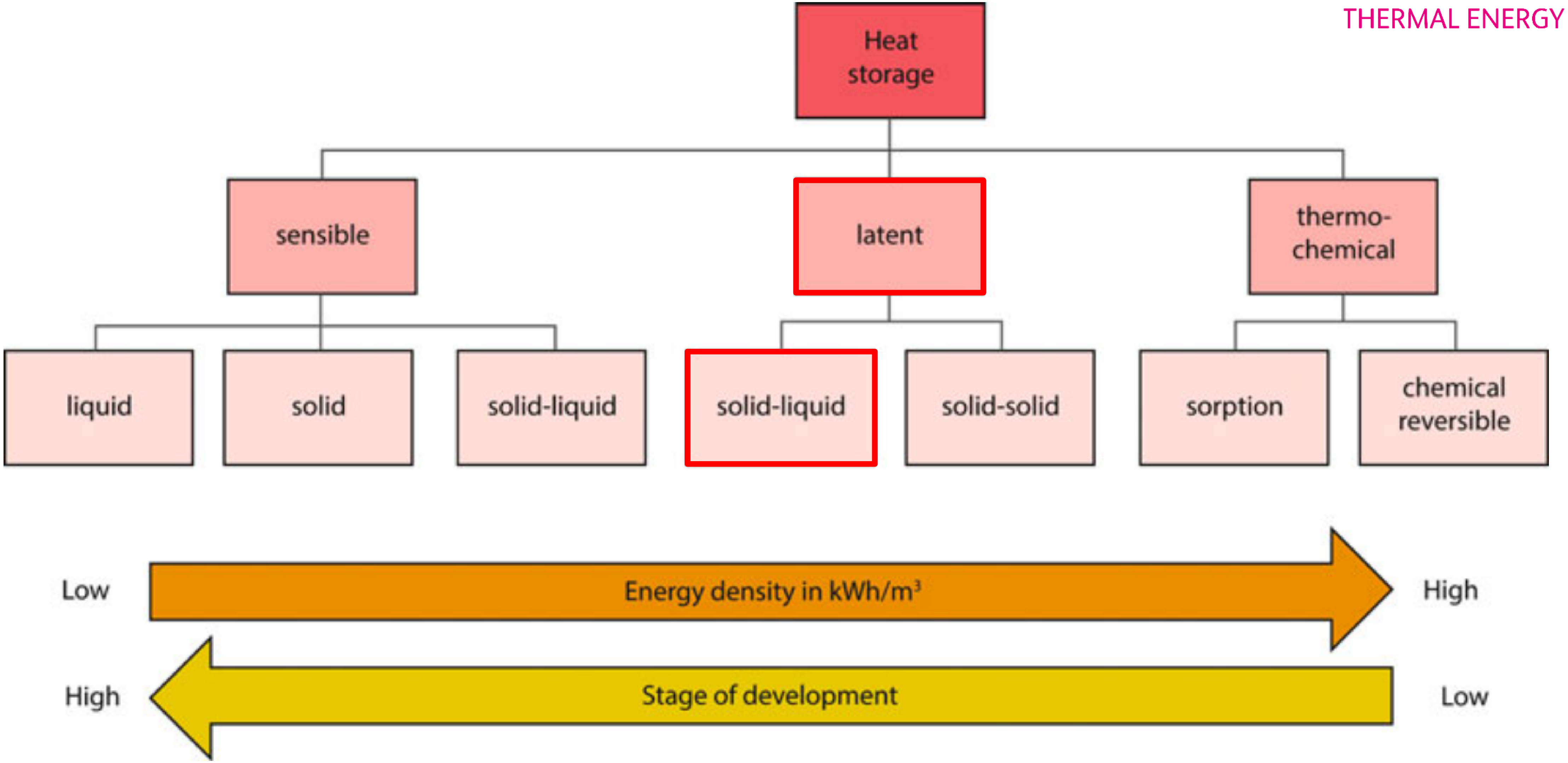

Latent vs. sensible storage

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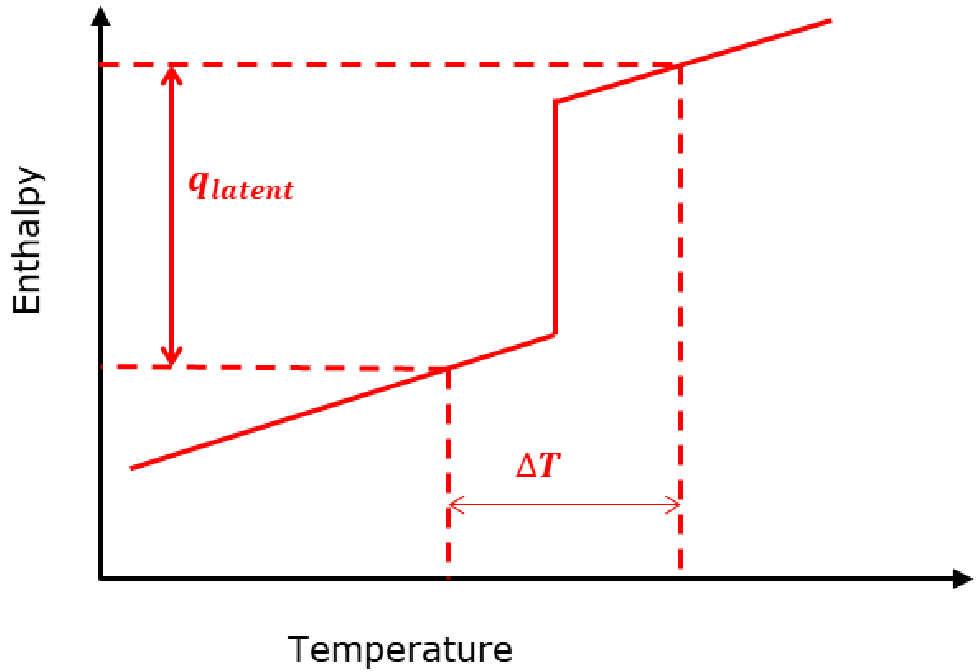
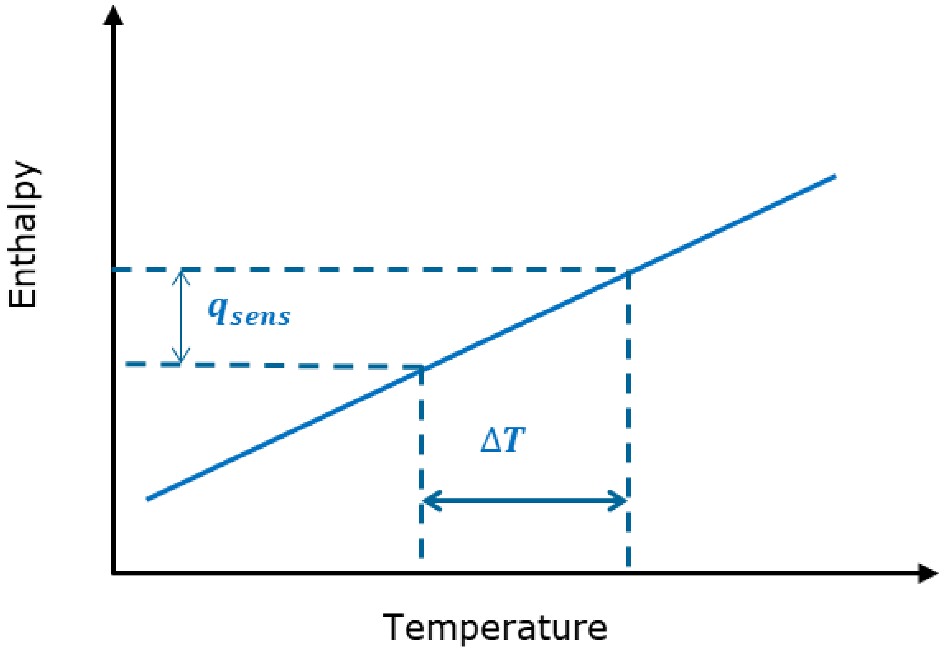
Latent Storage

$$q_{latent} = c_p \Delta T + h_{PC} \text{ (kWh/m}^3\text{)}$$



Sensible Storage



Relevant applications:

- Need compact storage solutions
- Need for temperature stability (both in storage and thermal management applications)

PCM: technical applications

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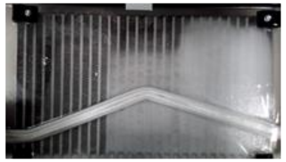
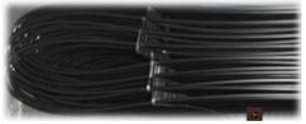
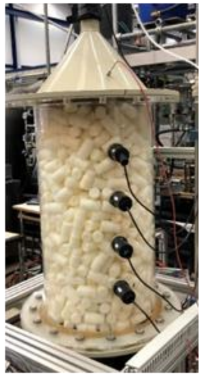
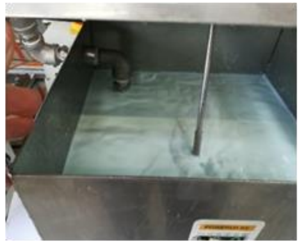
Finned HEX



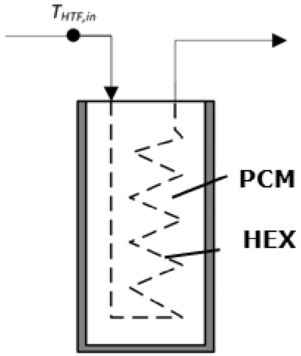
Tube bundle HEX

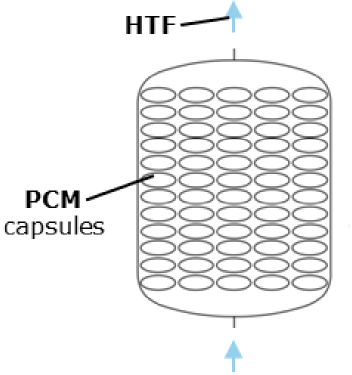


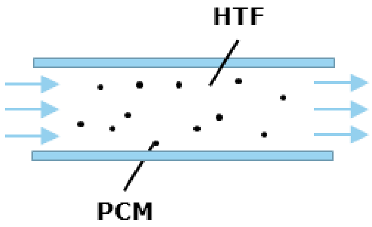


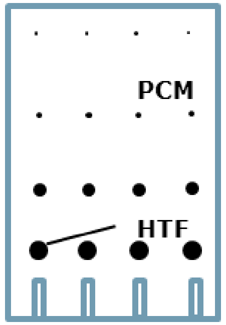


HEX immersed in PCM | **Macro Encapsulated PCM** | **Phase Change Dispersions** | **Direct Contact**

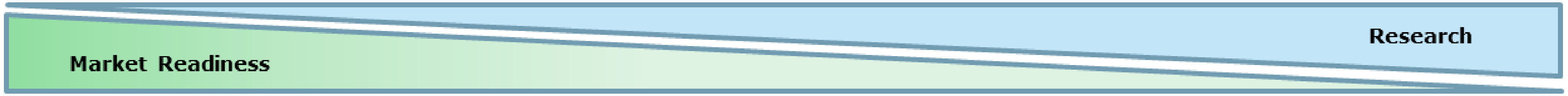








PCM: Phase Change Material; **HTF**: Heat Transfer Fluid; **HEX**: Heat exchanger



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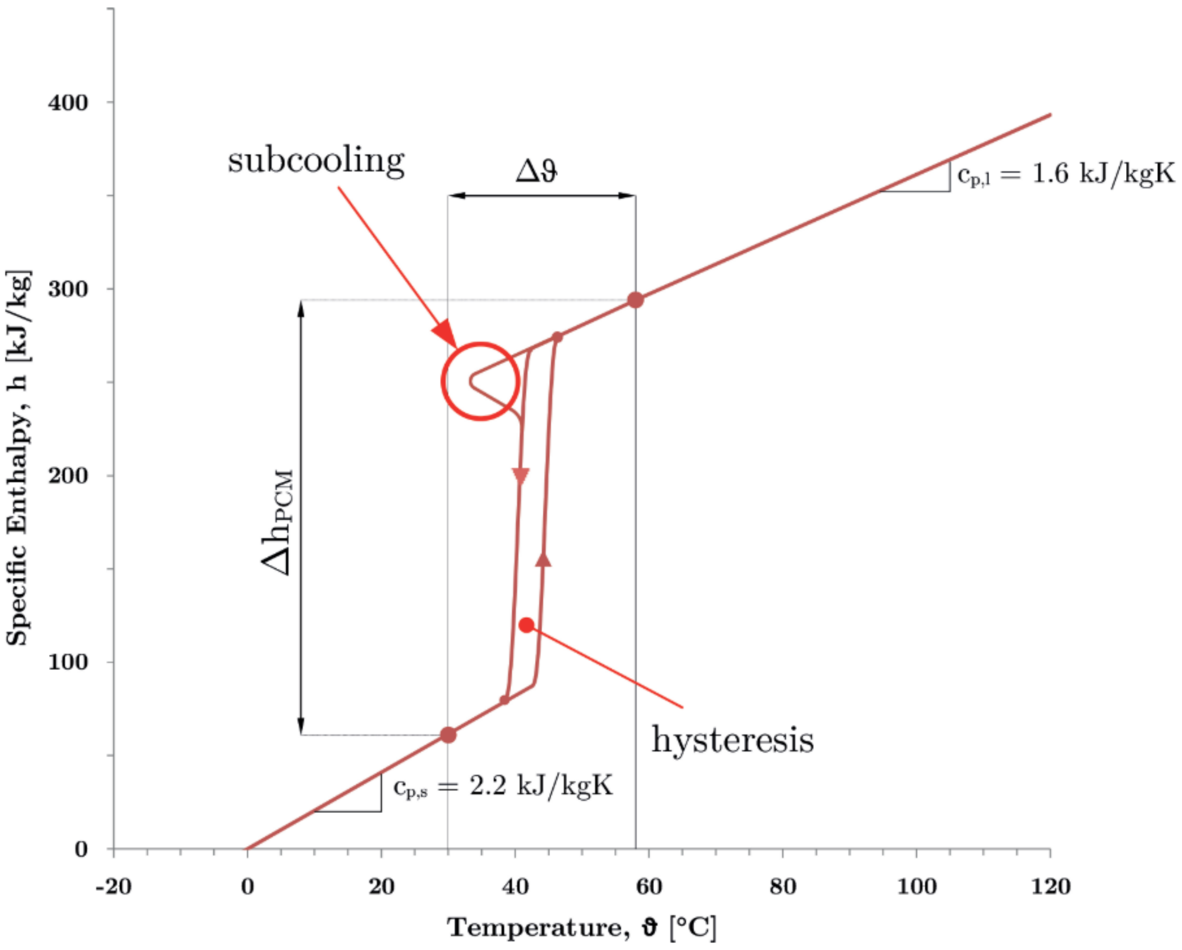
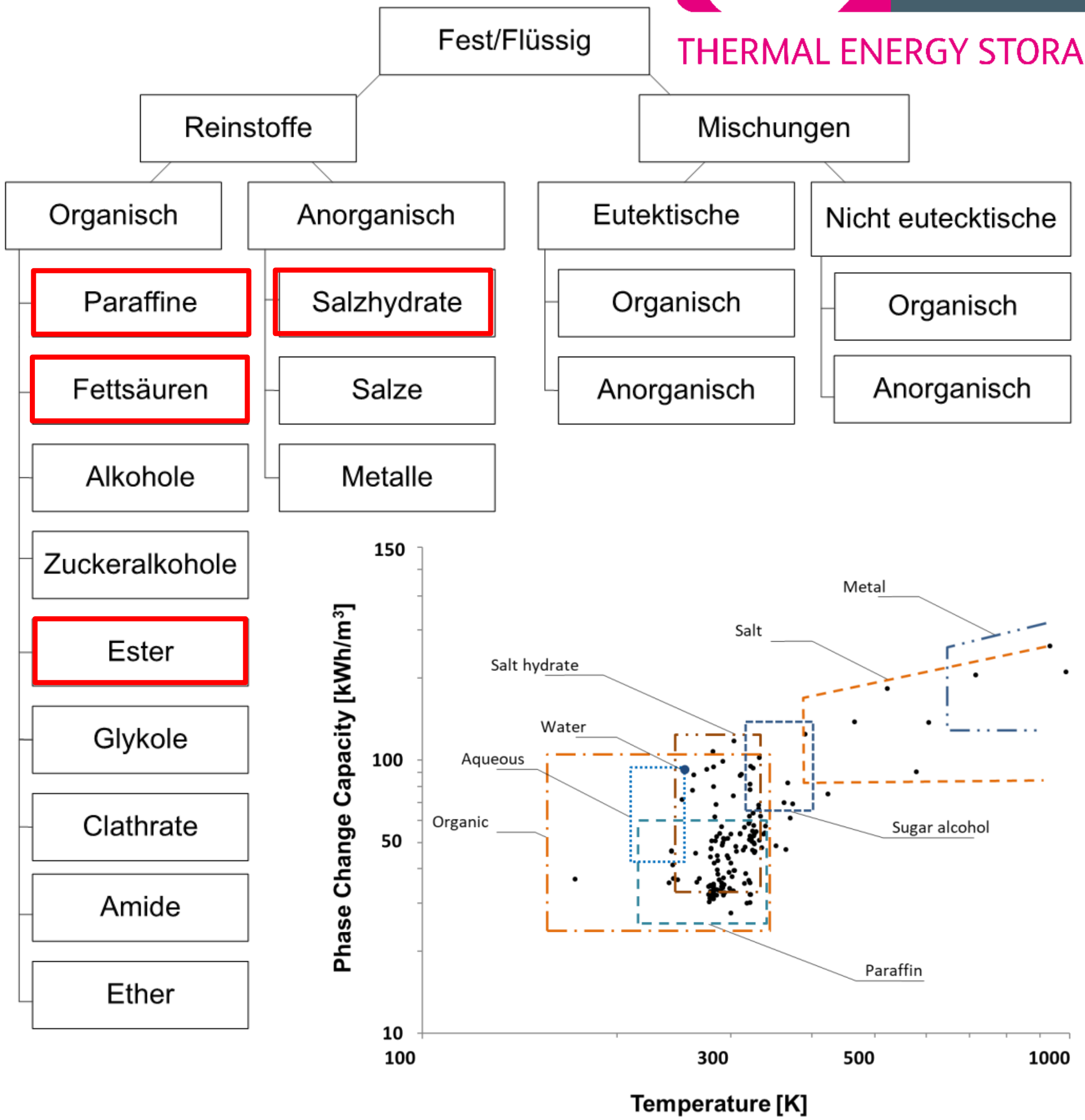
PCM: challenges & opportunities





PCM: COWA’s storage

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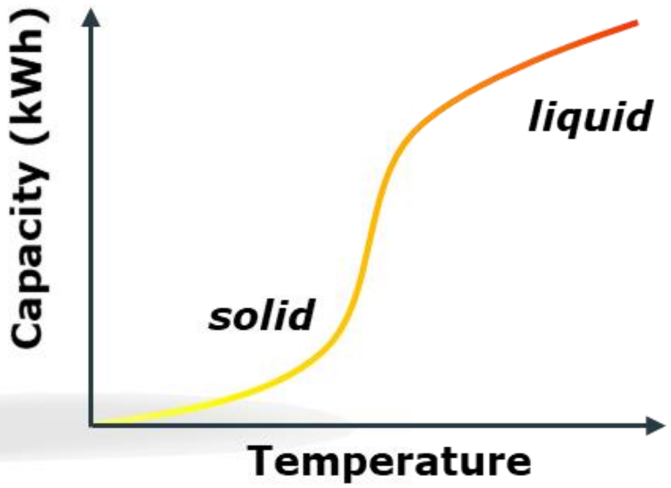

- **Large Capacity (50-70 kWh/m3)**
- **Simple insertion into hot water tanks**
- **Stability > 10’000 Cycles**
- **Non toxic, non flammable, recyclable**

PCM: residential heating

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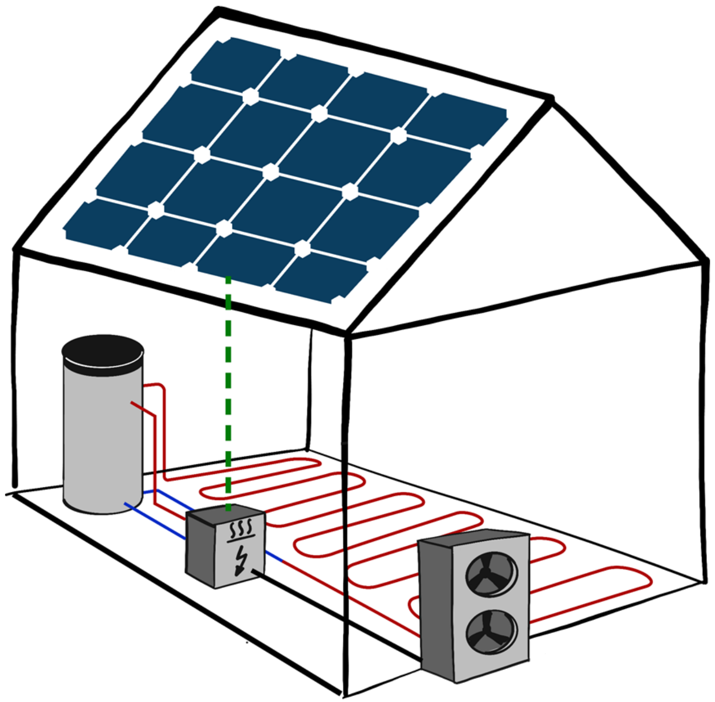
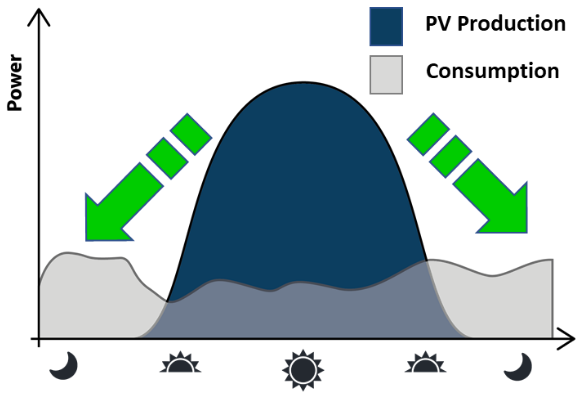
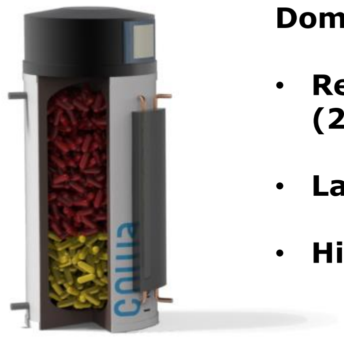




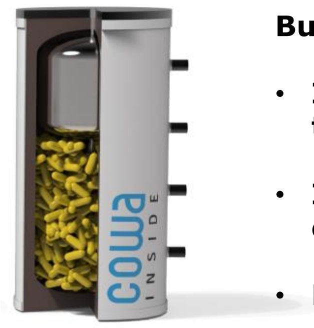
Self-Consumption with Storage

70%



Domestic Hot Water

- Reduction of neededed space (2 times smaller)
- Large market for DHF + HP
- High Power = High costs



Buffer Storage

- Increase capacity of existing thermal storages
- Increase self sufficiency of PV or Solar Thermal
- Low Power = Low costs

Research question

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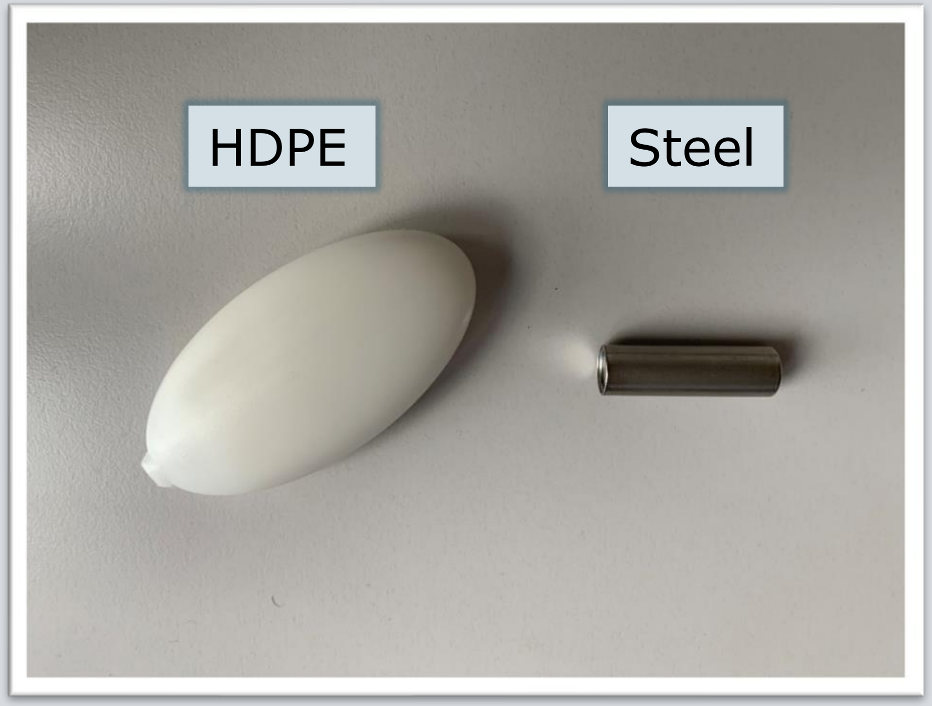
Hypotheses:

- PCM-enhanced thermal storages have been proven to be technically & economically feasible
- Storages can only reduce the overall CO_2-footprint if they increase the usage of a low-carbon RES

Research questions:

- What is the global warming potential of COWA capsules (two different designs)?
- What is the CO_2-payback time of a domestic hot water storage with COWA capsules?

Capsules: PCM 58°C with HDPE & Steel



Database:	Ecoinvent 3.7
Model:	APOS
Method:	EF 2.0 midpoint ($CO_{2\ eq}$)

BMS system

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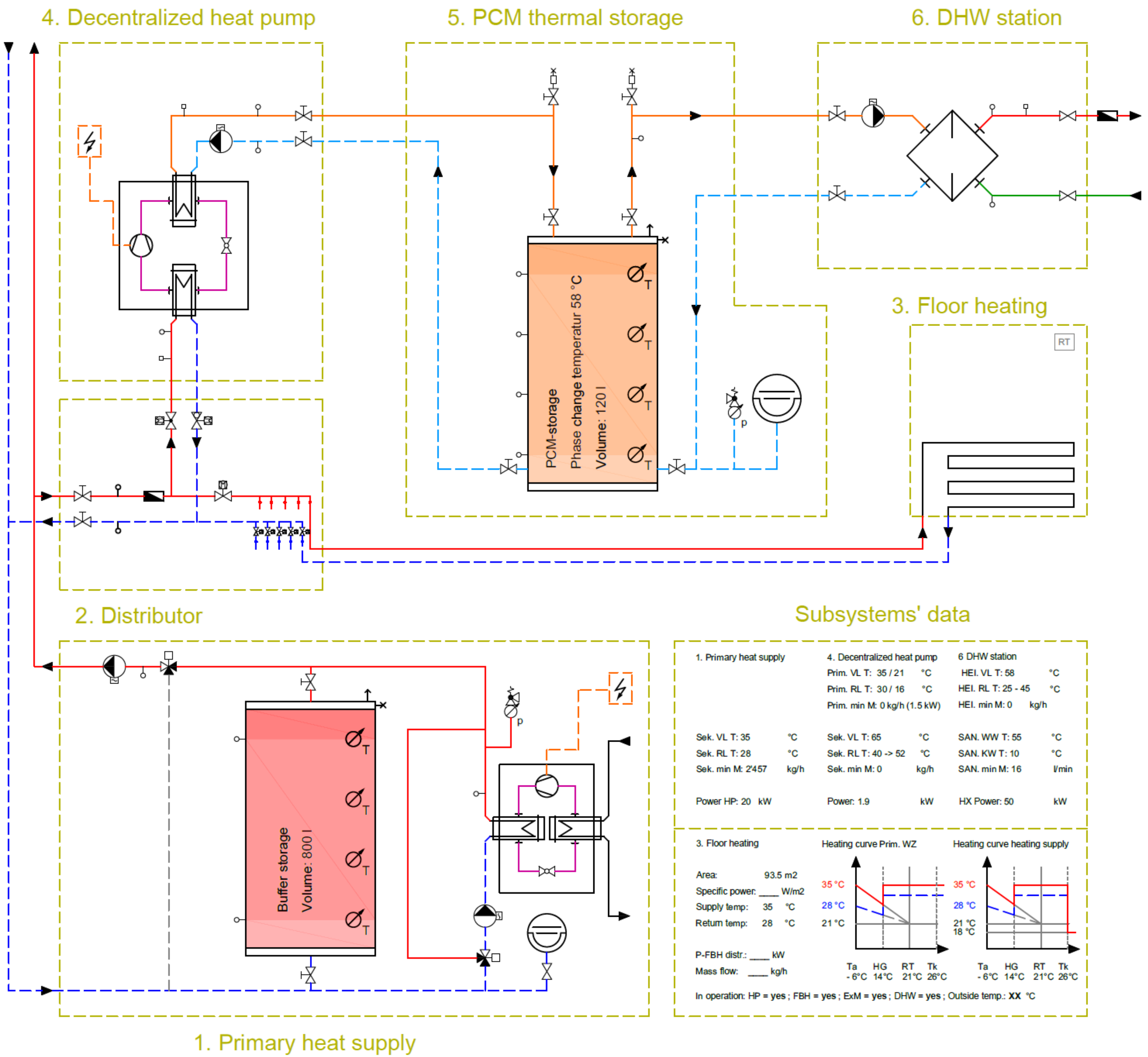
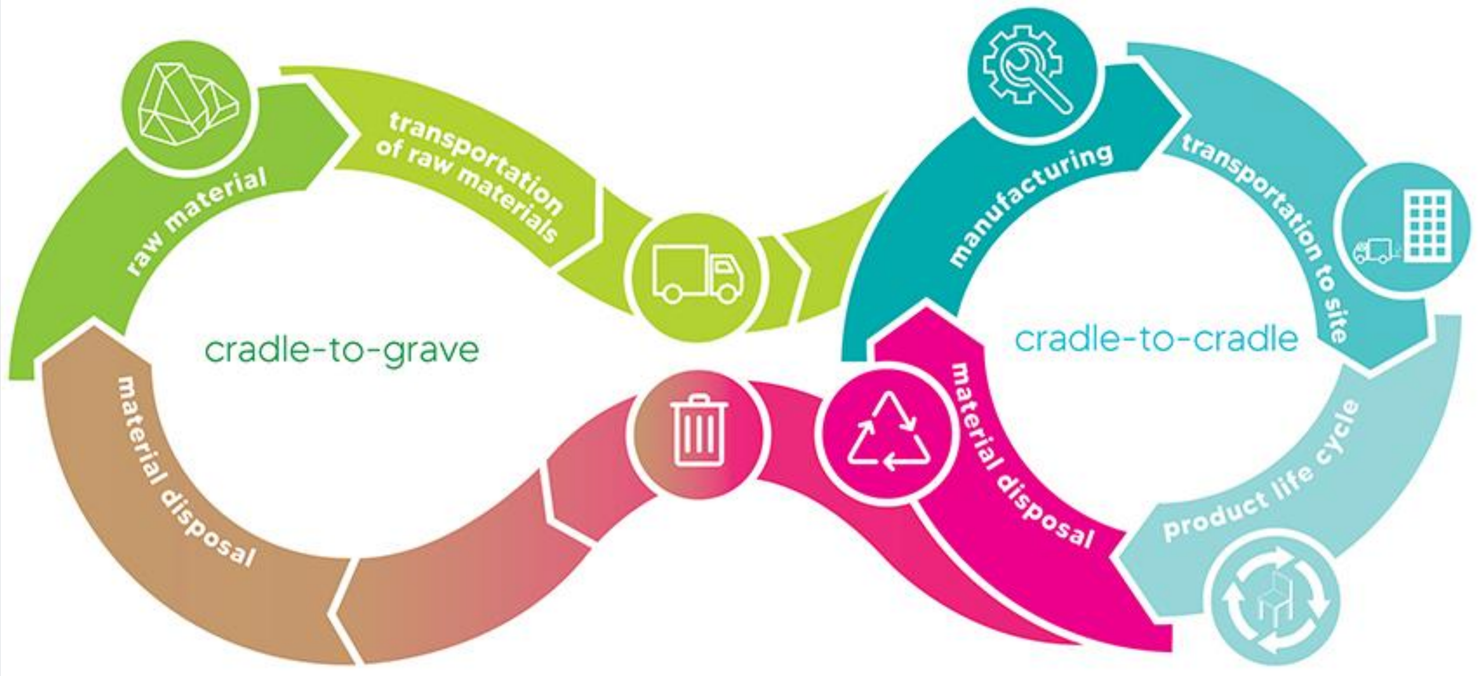
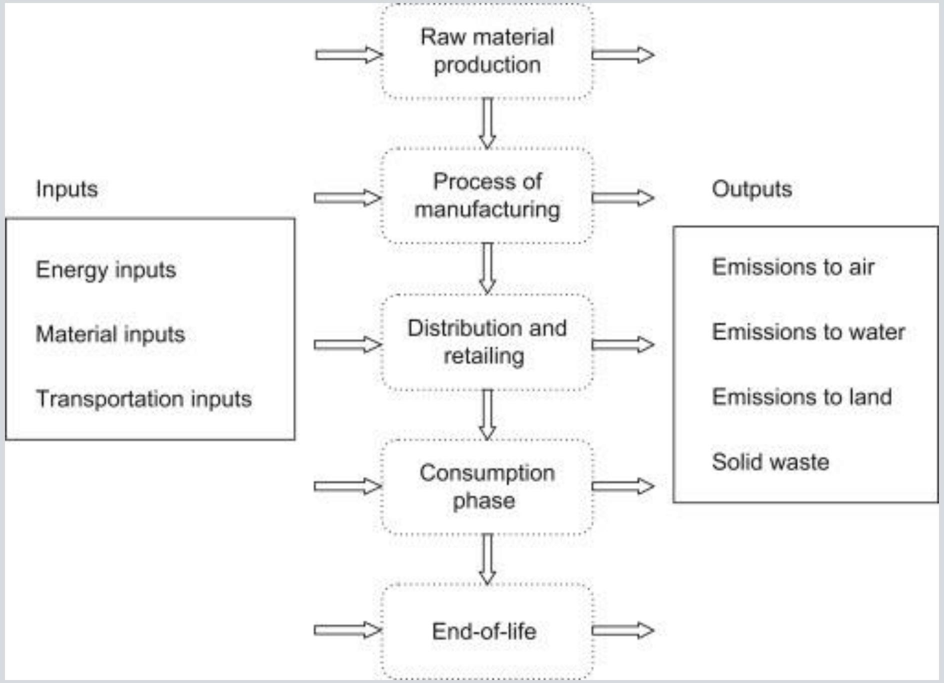


Life cycle assessment

In the life cycle inventory analysis (LCIA), the life cycle is drawn up and all energy and material requirements; emissions to air, water and soil; and other environmental releases are quantified.





LCA on COWA capsules

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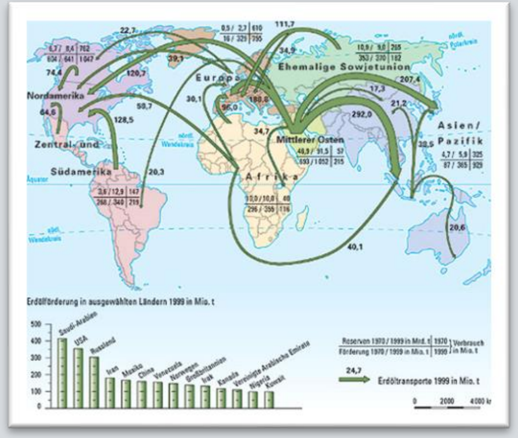
Inventory

Transport

Processing

Disposal / Recycling

PCM 58
Salt hydrate
Additive #1
Additive #2
HDPE / Steel



econvent

Assumptions for LCA

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- Global warming potential for all phases
- Relative results
  - per capsule
  - per m^3 of storage
  - per kWh (capacity)
  - per kWh (life time)
  - CO2 payback time

Parameter	HDPE	Metal
Volume PCM [cm^3]	58	6.08
Volume outside [cm^3]	75.33	7.47
Mass [g]	20	5.16

Parameter	Value	Unit
COP heat pump	2.6	
Latent heat PCM	264	kJ / kg
Sensible heat PCM (ΔT=10K)	28	kJ/kg
GWP grid CH	128	g $CO_{2\ eq}$ / kWh
GWP grid DE	408	g $CO_{2\ eq}$ / kWh
GWP grid AT	100	g $CO_{2\ eq}$ / kWh
GWP solar CH	40	g $CO_{2\ eq}$ / kWh
Liftime of capsule	10000	cycles
Lifetime of battery	1850	cycles
Packing density HDPE	65	%
Packing density metal	58	%
Shipping distance PCM	14000	km
Shipping distance additives	14000	km
Lorry & train distance	1500	km
Ratio lorry vs. train	40	%
Energy input for HDPE filling	35	MJ / 1000 capsules
Energy input for metal filling	3.67	MJ / 1000 capsules

Results I

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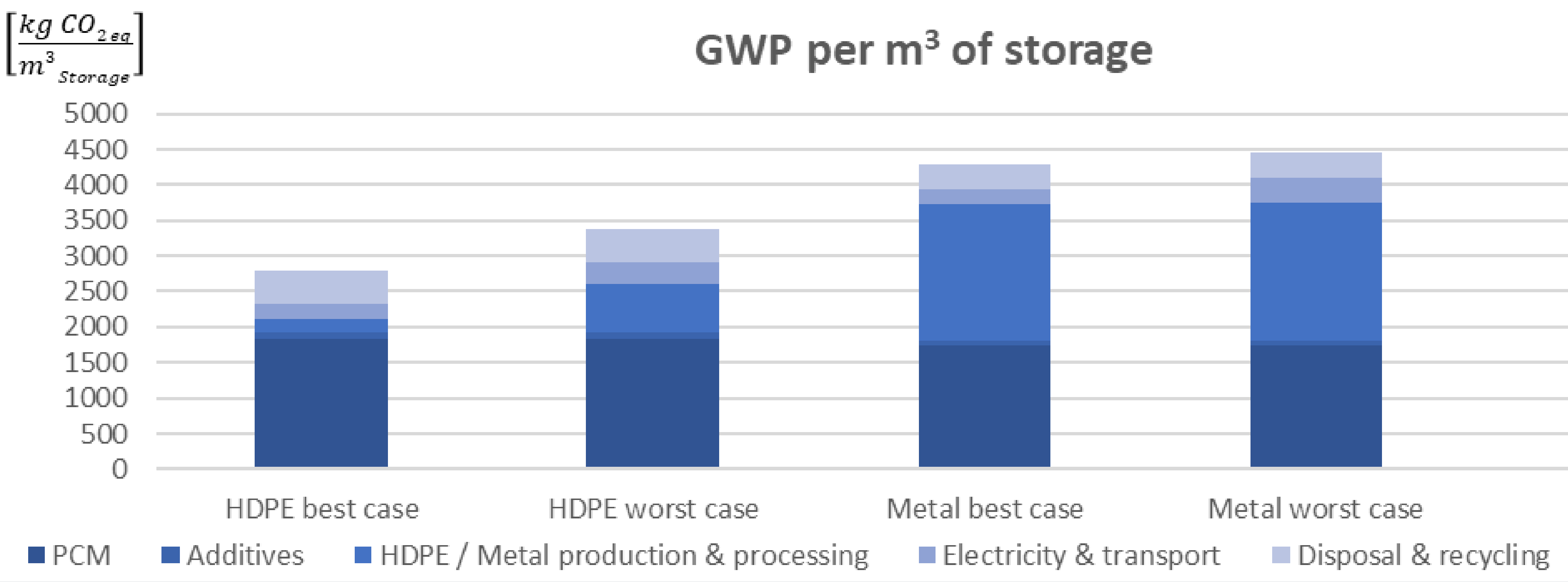

Global warming potential in kg $CO2_{eq}$ per cubic meter of storage

Results II

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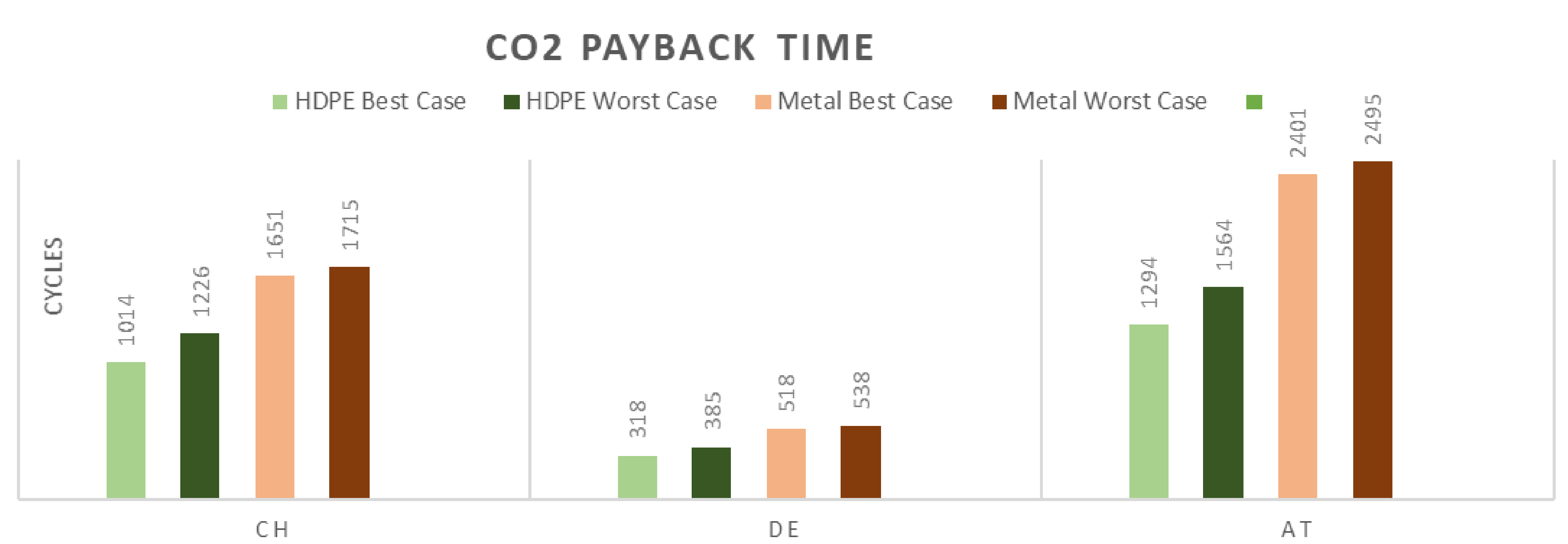
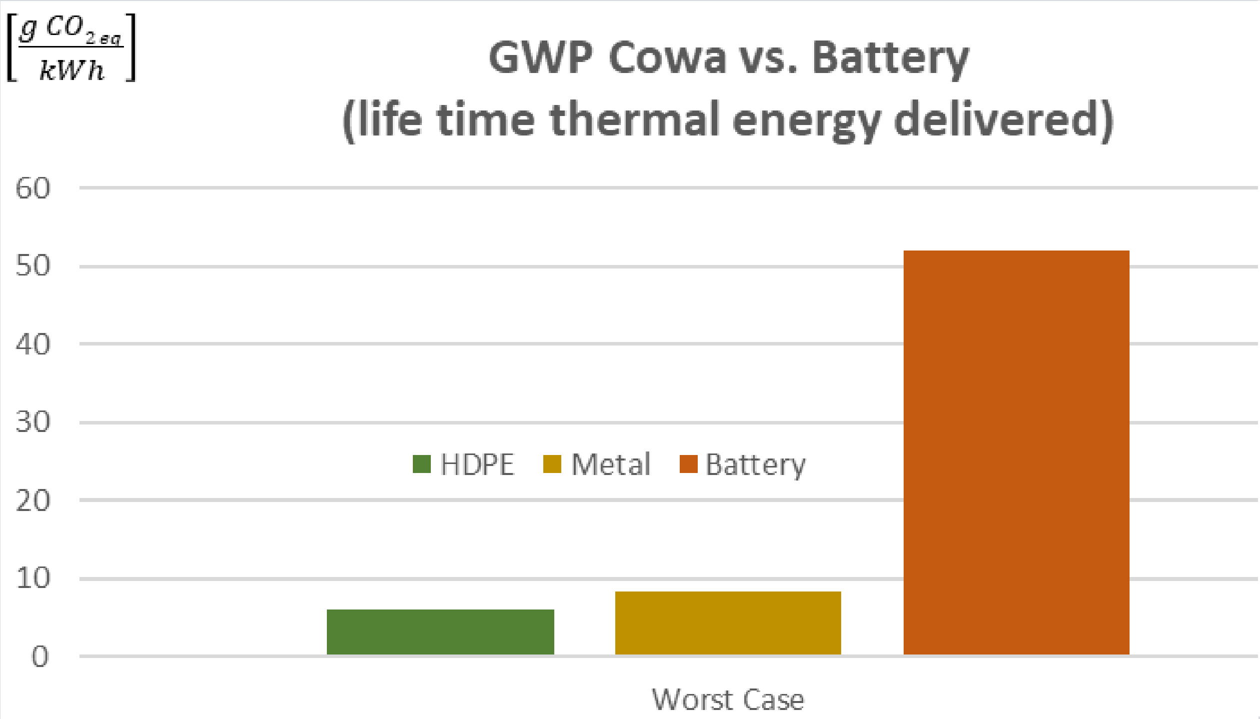
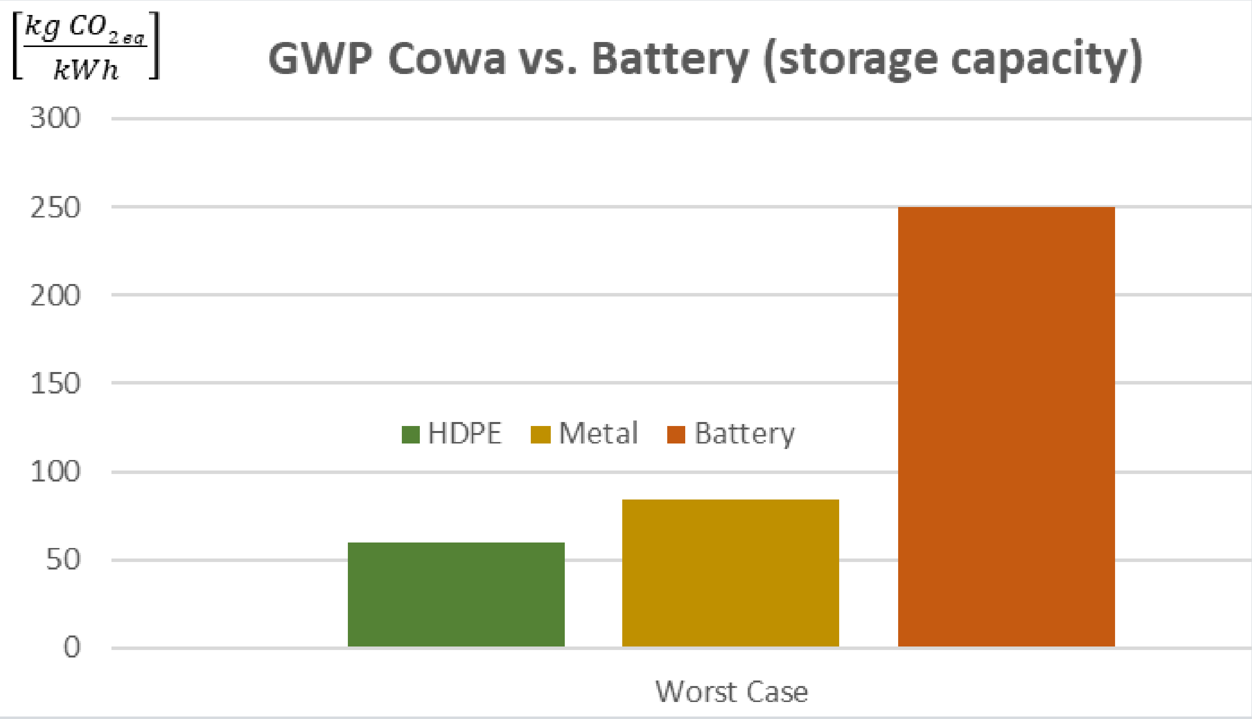


Comparison of CO2 payback time of HDPE and metal capsules for Switzerland, Germany and Austria.

Results III





LCA comparison of HDPE and metal capsules with batteries. GWP relative to lifetime thermal energy delivered (left) and relative to storage capacity (right).

Comparison

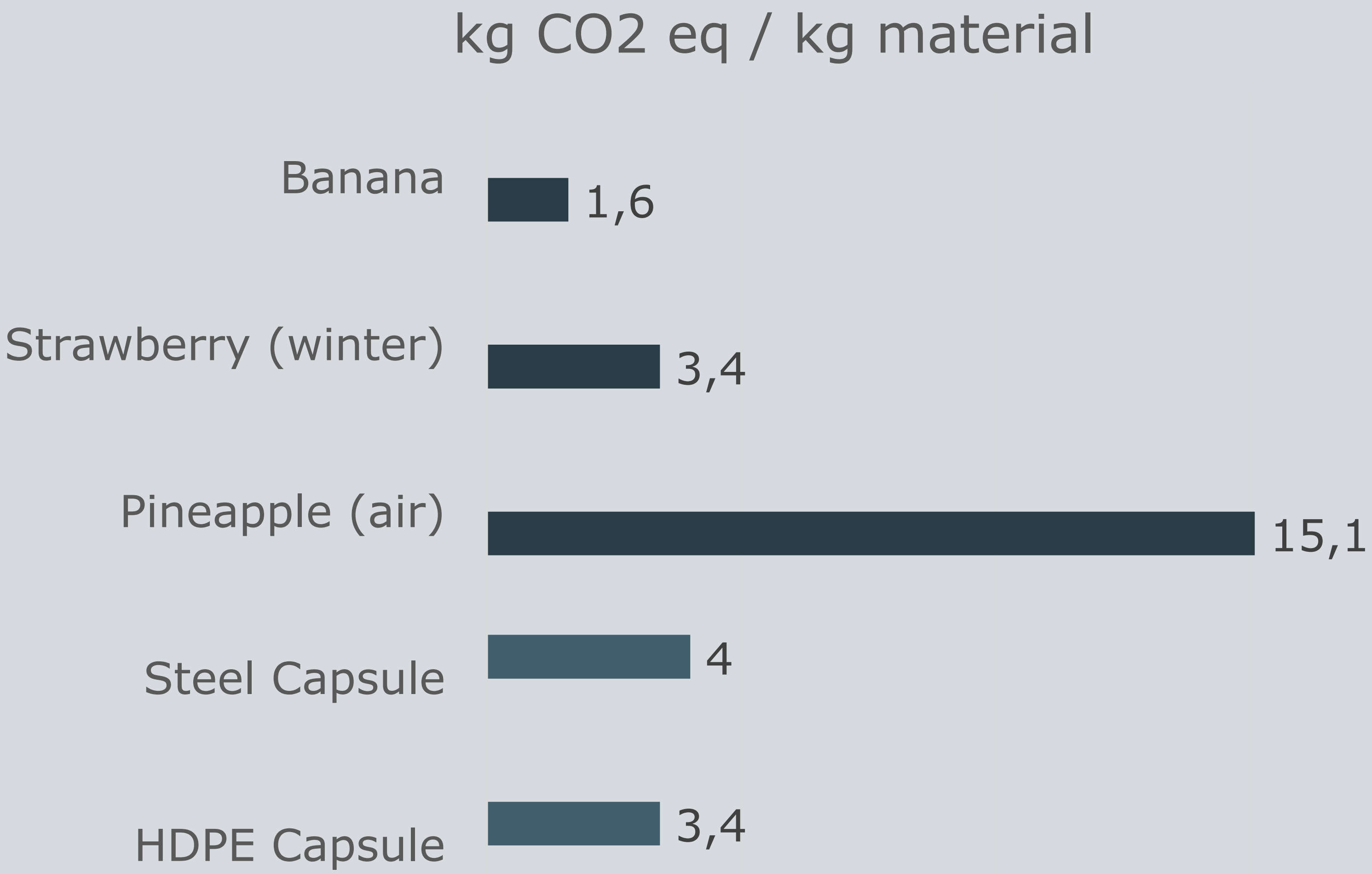

kg CO2 eq / kg material
Banana
1,6
Strawberry (winter)
3,4
Pineapple (air)
15,1
Steel Capsule
4
HDPE Capsule
3,4

Table 3: LCIA for PCM 58. GLO: Global, RER: Rest of Europe, RoW: Rest of World

		HDPE capsule		Metal capsule		Origin	
Material		best case [g CO2 eq]	worst case [g CO2 eq]	best case [g CO2 eq]	worst case [g CO2 eq]	best case	worst case
PCM & additives		222.69	222.69	23.35	23.35	CN & GLO	
HDPE production & blow moulding		23.06	79.22	–	–	CH & RER	RoW
Metal production & deep drawing		–	–	24.49	25.04	RER	RoW
Electricity & transport		22.75	34.15	2.71	4.31	–	–
Electricity [MJ/1000 Capsules]		0.98	9.10	0.10	0.95	CH	CN
Transport [kg*km]	Vessel	10.46	13.74	1.10	1.84	Global	
	Train	5.58	5.58	0.75	0.75	DE	
	Lorry	5.73	5.73	0.77	0.77	RER	
Disposal & recycling		55.01	55.01	4.68	4.68	–	–
Waste treatment	*PCM*	44.45	44.45	4.66	4.66	CH	
	HDPE	10.56	10.56	–	–	CH	
	Metal	–	–	0.02	0.02	CH	
Total		323.51	391.08	55.23	57.38	–	–

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Table 4: Meta calculations and results

Parameter	Formula	HDPE	Metal	Unit
Heat storage capacity of one capsule per cycle	Q_{CAP}	23.29	2.446	$\left[\frac{kJ}{capsule * cycle}\right]$
Electrical energy needed to produce this heat	$\frac{Q_{CAP}}{COP_{HP}}$	8.973	0.941	$\left[\frac{kJ}{capsule * cycle}\right]$
GHG mitigation by using PV electricity instead of CH grid (PV has zero impact)	$\frac{Q_{CAP}}{COP_{HP}} * \frac{GWP_{grid\ CH}}{3600}$	0.319	0.033	$\left[\frac{g\ CO_2\ eq}{capsule * cycle}\right]$
GHG mitigation by using PV electricity instead of DE grid (PV has zero impact)	$\frac{Q_{CAP}}{COP_{HP}} * \frac{GWP_{grid\ DE}}{3600}$	1.017	0.107	$\left[\frac{g\ CO_2\ eq}{capsule * cycle}\right]$
GHG mitigation by using PV electricity instead of AT grid (PV has zero impact)	$\frac{Q_{CAP}}{COP_{HP}} * \frac{GWP_{grid\ AT}}{3600}$	0.250	0.026	$\left[\frac{g\ CO_2\ eq}{capsule * cycle}\right]$
GHG mitigation by using PV electricity instead of CH grid (PV has impact)	$\frac{Q_{CAP}}{COP_{HP}} * \frac{GWP_{Solar}}{3600}$	0.219	0.023	$\left[\frac{g\ CO_2\ eq}{capsule * cycle}\right]$
Heat storage capacity in Wh of one capsule per cycle	$Q_{CAP,\ kWh}$	6.48	0.68	$\left[\frac{Wh}{capsule * cycle}\right]$
Number of Capsules in 1 m³ storage	–	8'629	77'696	–