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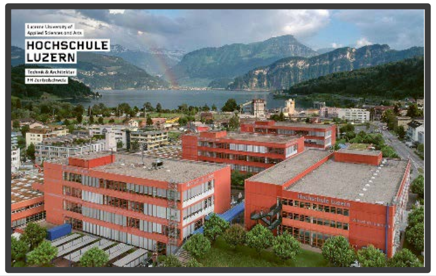


Hochschule Luzern
Technik & Architektur

What is the best thermal energy storage? A Guideline to find it out.

Thermal Energy Storage Workshop at SINTEF Energy
Trondheim 12.11.2021

Stefan Krimmel (s.Krimmel@gmx.com)
TU-Vienna, CCTES-Luzern, SINTEF Industry

Personal background

2015
Dipl.-Ing. Mechanical Engineering for Power Plants – RWTH Aachen, Germany

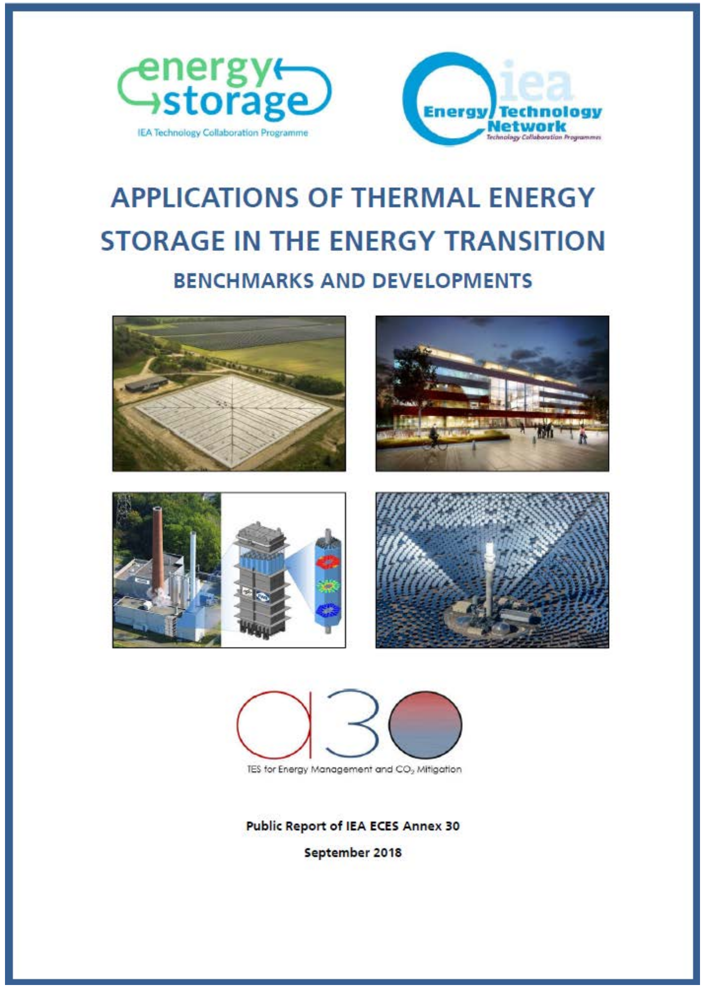
2015-2018
CC TEVT, University of supplied sciences in Lucerne, Switzerland
- sorption processes for energetic application
- drying processes

2018-2021
- CC TES, University of supplied sciences in Lucerne, Switzerland

2018-(2022)
Technical university of Vienna, Austria
- PhD student
    - Direct contact latent thermal energy storage

2021-2021
SINTEF Industry, Trondheim, Norway

Background for the next 10 minutes



http://iea-es.org/publications/final-report-annex-30/

applied sciences

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Article

Comparison of Heat Transfer Enhancement Techniques in Latent Heat Storage

William Delgado-Diaz, Anastasia Stamatiou *, Simon Maranda, Remo Waser and Jörg Worlitschek

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Abstract: Latent Heat Energy Storage (LHES) using Phase Change Materials (PCM) is considered a promising Thermal Energy Storage (TES) approach as it can allow for high levels of compactness, and execution of the charging and discharging processes at defined, constant temperature levels. These inherent characteristics make LHES particularly attractive for applications that profit from high energy density or precise temperature control. Many novel, promising heat exchanger designs and concepts have emerged as a way to circumvent heat transfer limitations of LHES. However, the extensive range of experimental conditions used to characterize these technologies in literature make it difficult to directly compare them as solutions for high thermal power applications. A methodology is presented that aims to enable the comparison of LHES designs with respect to their compactness and heat transfer performance even when largely disparate experimental data are available in literature. Thus, a pair of key performance indicators (KPI), Φ_{PCM} representing the compactness degree and NHTPC, the normalized heat transfer performance coefficient, are defined, which are minimally influenced by the utilized experimental conditions. The evaluation procedure is presented and applied on various LHES designs. The most promising designs are identified and discussed. The proposed evaluation method is expected to open new paths in the community of LHES research by allowing the leveled-ground contrast of technologies among different studies, and facilitating the evaluation and selection of the most suitable design for a specific application.

Keywords: heat transfer; high power; latent heat; energy storage; heat exchanger

1. Introduction

On the path to the integration of an ever-increasing share of variable renewable energy sources (VRES) into the current energy system, energy storage (ES) technologies play a fundamental role. Energy transformation and consumption globally account for more than 60% of the total green house gas emissions [1]. Additionally, in Switzerland and the European Union in general, over 50% of the total energy consumed is ultimately used as thermal energy for both industry and domestic applications [2,3]. Considering this, the development of thermal energy storage (TES) systems has become a priority for directly pure thermal applications and heat management systems, as well as combined electro-thermal storage initiatives, such as pumped thermal energy storage systems [4] and its potential for alternative use and flexibility for recovered waste heat from already existing sources at large scales [5].

Within the spectrum of TES technologies, Latent Heat Energy Storage (LHES) systems using Phase Change Materials (PCM) allow for thermal energy storage and release within narrow temperature differences with high energy density when compared to the sensible energy storage

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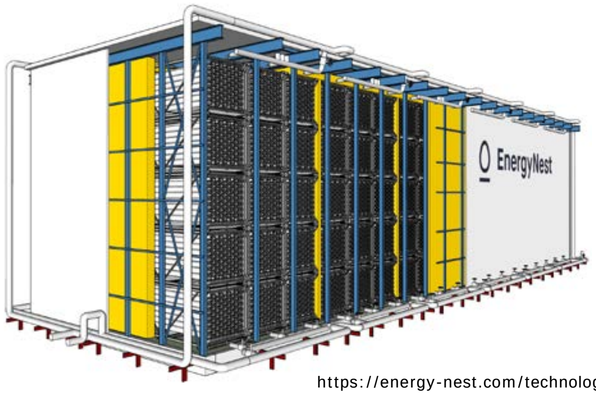
https://www.mdpi.com/2076-3417/10/16/5519

Variety of thermal energy storages


https://balkanenergy.net/product/water-heater-tesy-model-profi-line-volume-200l-free-standing-one-heat-exchanger-1



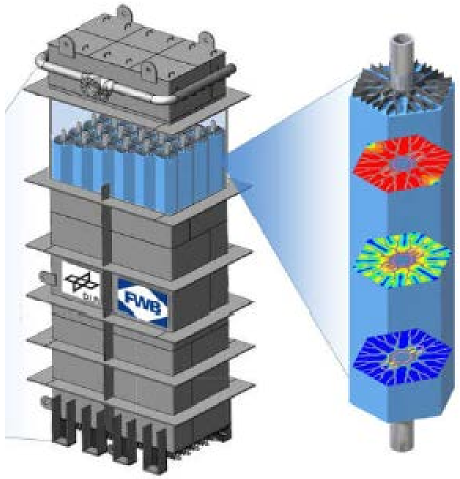
https://energy-nest.com/technology/


Seasonal snow storage, Sundsvall, Sweden

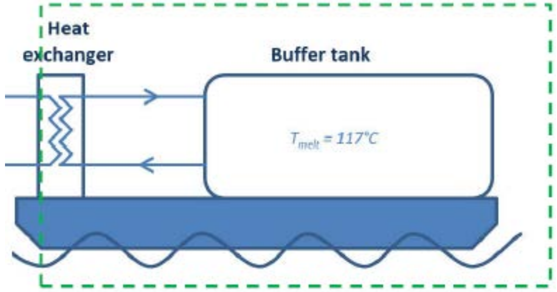

Lävemann, E. (2015). *Mobile Sorptionsspeicher zur industriellen Abwärmenutzung - Grundlagen und Demonstrationsanlage - MobS II*.
Truck with thermo chemical TES trailer, ZAE Bayern, Germany


Truck with direct contact latent TES trailer, Japan

https://cowa-ts.com/de#technology


Latent heat storage TESIN, DLR © FW Brökelmann


District heating, Ulm Germany



Sailing heat barge, study, Netherlands

Pictures out of (if not other mentioned): http://iea-es.org/publications/final-report-annex-30/

What is the storage for? - Integration goal

1. **Identification of THE problem** that could be solved/reduced by a thermal storage or **identification of THE value** that you could create by a thermal storage

   (a storage could decouple and/or levelized thermal demand and supply)

2. Identification of the benefit, if the problem is be solved/reduced (try to quantify)

3. Raw business model and concept for storage integration

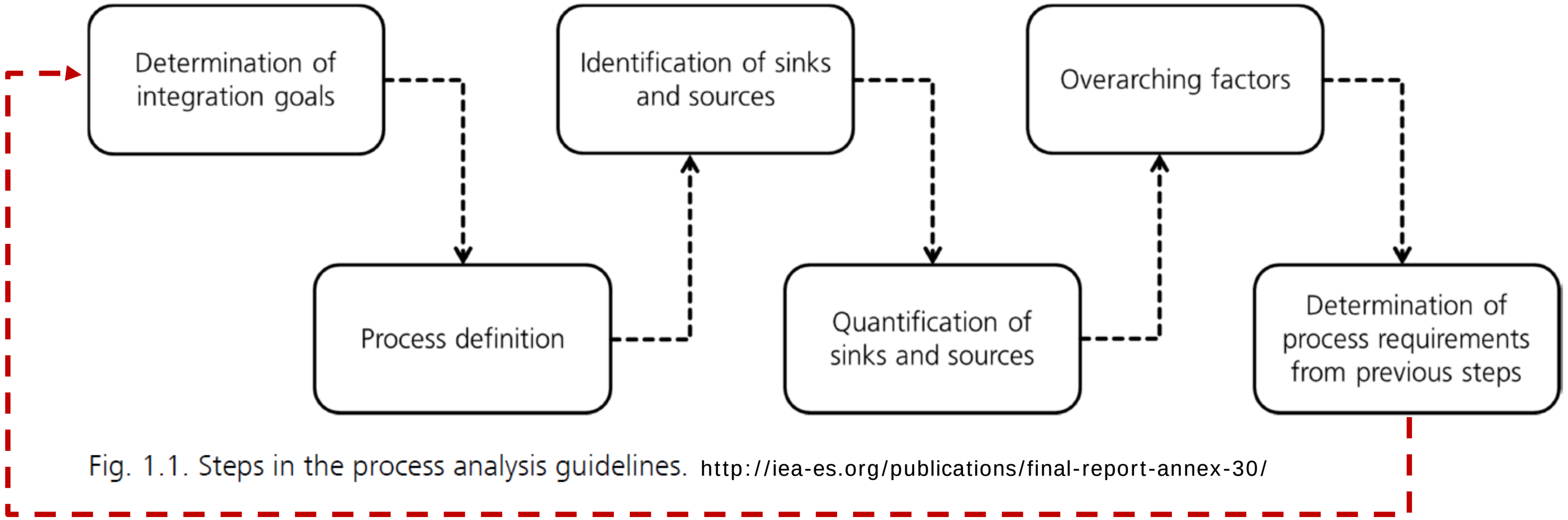
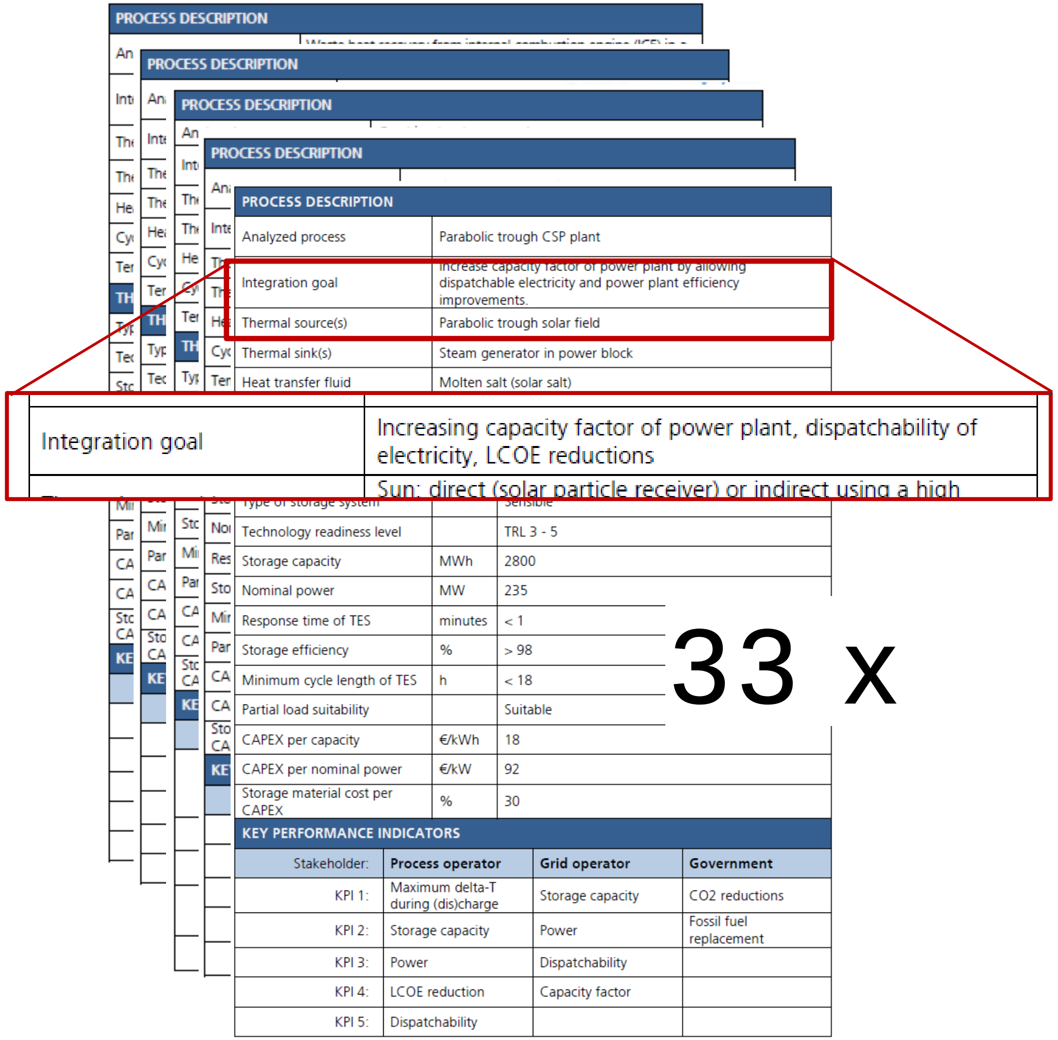


Fig. 1.1. Steps in the process analysis guidelines. http://iea-es.org/publications/final-report-annex-30/

Examples of integration goals



24 decoupling demand from supply
- peak shaving
- decoupling load from supply
- flexibility
- energy balance market
- increase runtime of equipment

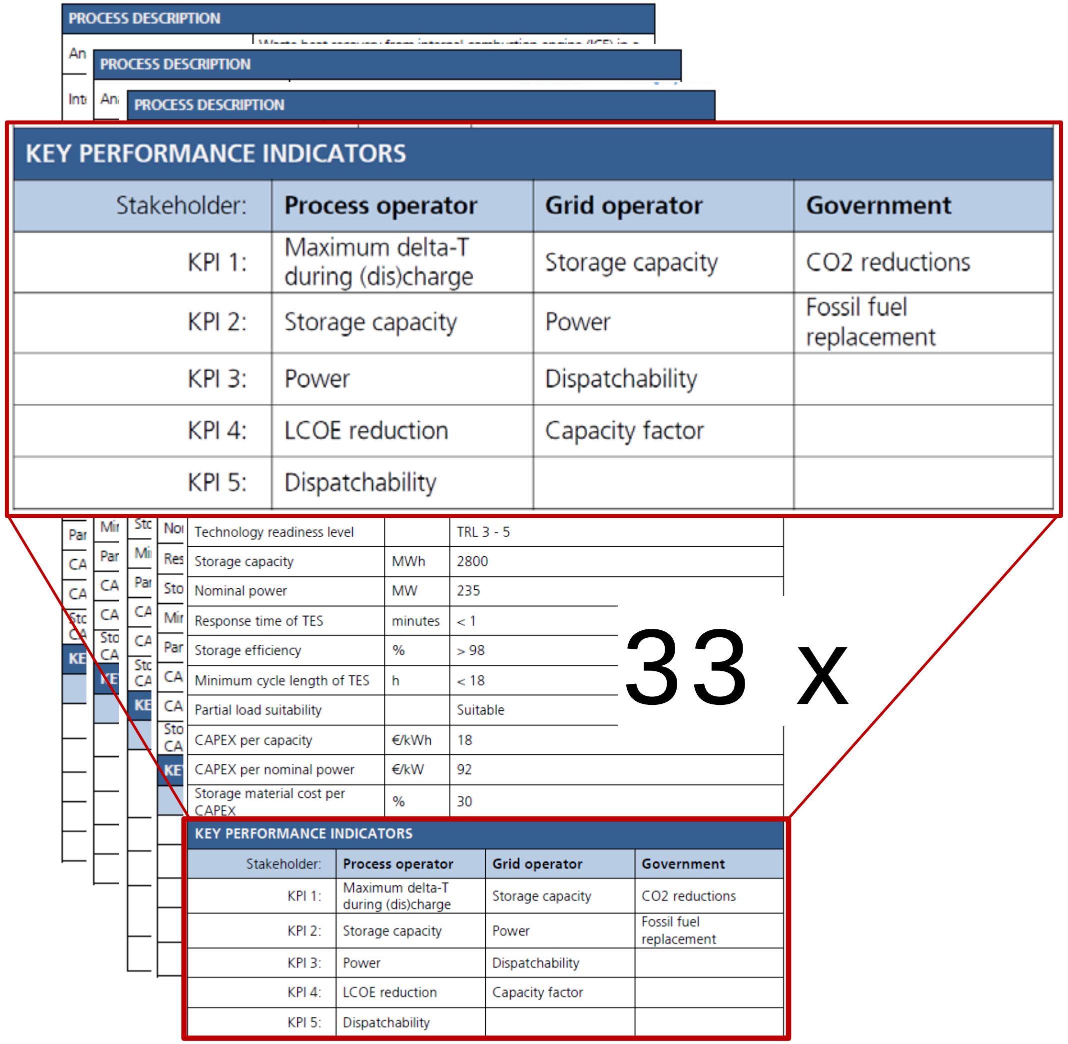
19 CO_2 reduction

7 waste heat utilization

7 heat quality

3 reduction of equipment size

Measure the quality of a storage



PROCESS DESCRIPTION

KEY PERFORMANCE INDICATORS

Stakeholder:	Process operator	Grid operator	Government
KPI 1:	Maximum delta-T during (dis)charge	Storage capacity	CO2 reductions
KPI 2:	Storage capacity	Power	Fossil fuel replacement
KPI 3:	Power	Dispatchability	
KPI 4:	LCOE reduction	Capacity factor	
KPI 5:	Dispatchability		

Technology readiness level		TRL 3 - 5
Storage capacity	MWh	2800
Nominal power	MW	235
Response time of TES	minutes	< 1
Storage efficiency	%	> 98
Minimum cycle length of TES	h	< 18
Partial load suitability		Suitable
CAPEX per capacity	€/kWh	18
CAPEX per nominal power	€/kW	92
Storage material cost per CAPEX	%	30

KEY PERFORMANCE INDICATORS

Stakeholder:	Process operator	Grid operator	Government
KPI 1:	Maximum delta-T during (dis)charge	Storage capacity	CO2 reductions
KPI 2:	Storage capacity	Power	Fossil fuel replacement
KPI 3:	Power	Dispatchability	
KPI 4:	LCOE reduction	Capacity factor	
KPI 5:	Dispatchability		

33 x

KPI 1 that includes Power Capacity Economic CO2

Thermal power
storage power
storage efficiency
storage density
Storage capacity
Storage capacity
Storage capacity
storage capacity
Storage capacity
storage capacity
storage capacity
Storage capacity

Storage capacity
recycling of heat (energy effiency)
partial load suitability

Net economic Benefit of TES for Building Owner

Net economic benefit (peak shaving, equipment downsizing)
Net economic Benefit

maximum delta-T during (dis)charge

Max/min temperatures
Max/min temperature

material storage density

economic incentive (control balance & day ahead energy markets, startup costs)
economic benefit (waste heat usage)
economic benefit (LCOE reduction)
Discharge time
cost saving caused by energy saving
(Dis)charge time

Thermal power
system durability
storage efficiency
storage density
storage density
Storage capacity
Storage capacity
storage capacity
Reliability
Process Flexibility
peak saving
outlet temperature

Net economic Benefit of TES for Utility
Net economic benefit (peak shaving, equipment downsizing)
Lifetime

Industrial process flexibility (grid balancing)

increase in startup time
improved grid stability

fewer fossil fuels burned

Energy efficiency improvement of product
efficiency

Dispatchable power

Dispatchability
discharge power
Difference between charging/discharging temperature

Cost of delivered heat
temperature level
storage efficiency
storage efficiency
solid material life cycle
Reduced fossil fuel use
peak saving
Heating cost
Heat price
fuel reduction
fleibility of energy system
Environmental benefit

Energy efficiency
efficiency
CO2 reduction
CO2 mitigation per ton of steel produced

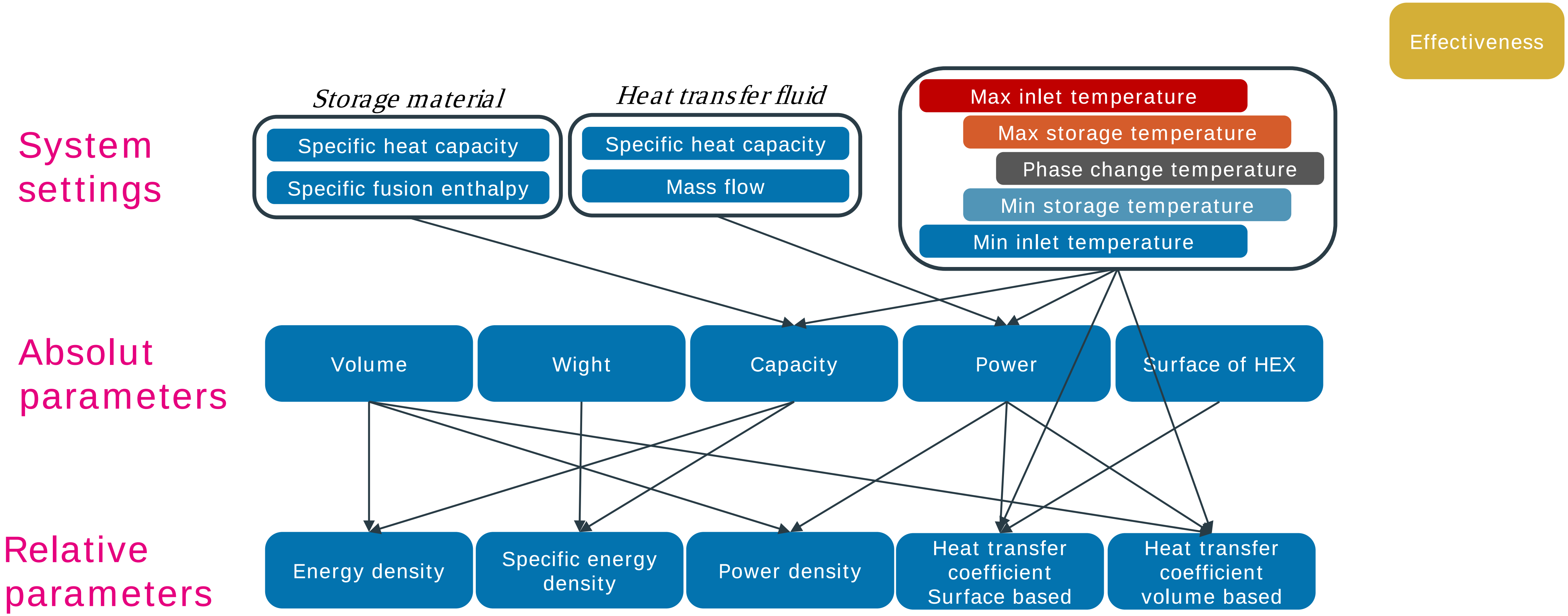
CO2 mitigation
CO2 mitigation

CO2 mitigation

CO2 emissions reductions
CO2 emissions reductions
average power during discharging

(Dis)charge time

Complexity of key performance indicators – be careful by interpretation and comparisons



$\Delta t_{0-100} = f(track, tyres, weather, wight, \ldots)$

Values deviate by about 30%

Comparison only under „exact similar" conditions
(human factor)

Comparison of key performance indicators

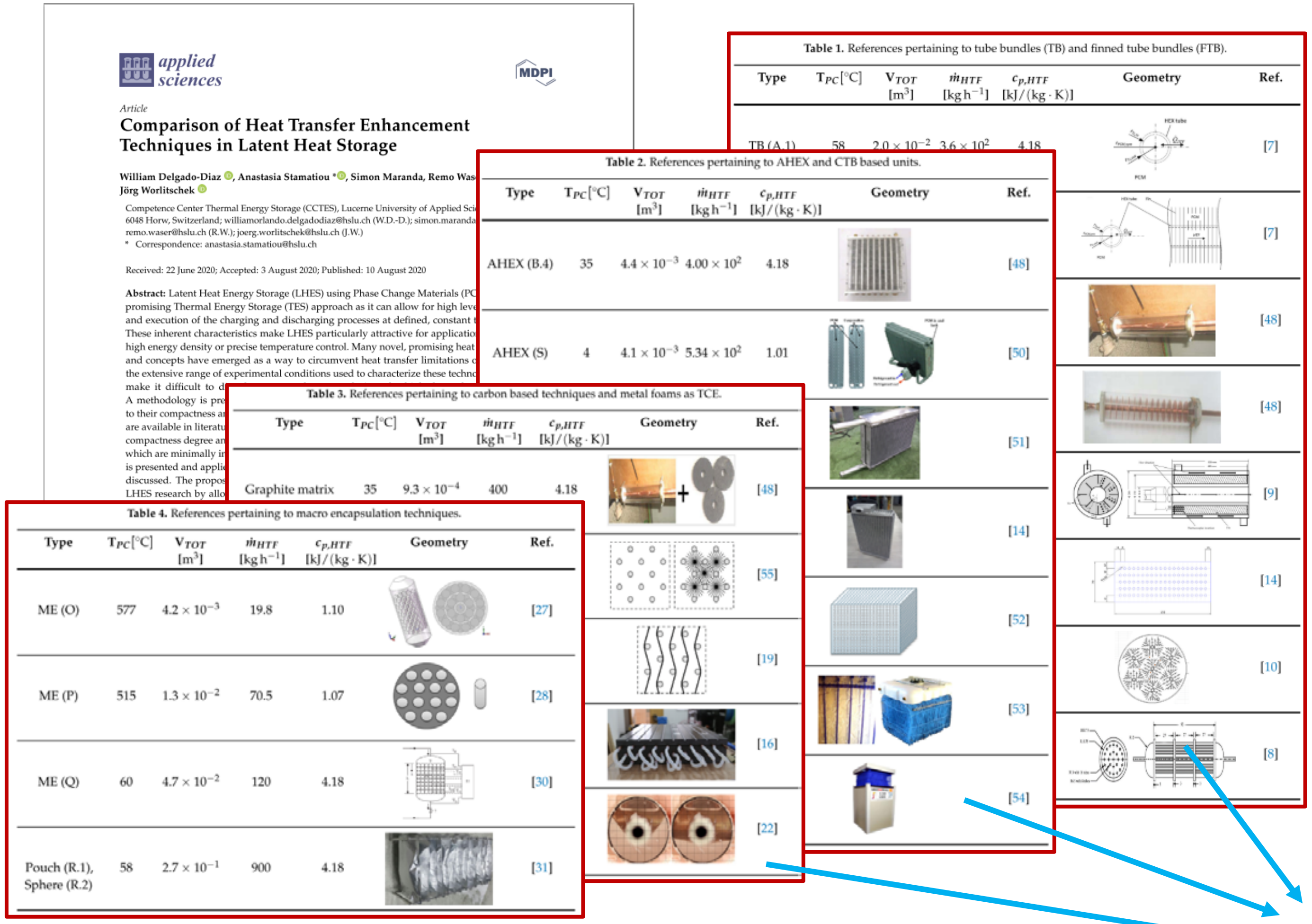


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Table 1. References pertaining to tube bundles (TB) and finned tube bundles (FTB).

Type	T_{PC}[°C]	V_{TOT} [m³]	$\dot{m}_{HTF}$ [kg h⁻¹]	$c_{p,HTF}$ [kJ/(kg·K)]	Geometry	Ref.
TB (A.1)	58	2.0×10^{-2}	3.6×10^{2}	4.18		[7]
						[7]
						[48]
						[48]
						[9]
						[14]
						[10]
						[8]

Table 2. References pertaining to AHEX and CTB based units.

Type	T_{PC}[°C]	V_{TOT} [m³]	$\dot{m}_{HTF}$ [kg h⁻¹]	$c_{p,HTF}$ [kJ/(kg·K)]	Geometry	Ref.
AHEX (B.4)	35	4.4×10^{-3}	4.00×10^{2}	4.18		[48]
AHEX (S)	4	4.1×10^{-3}	5.34×10^{2}	1.01		[50]
						[51]
						[14]
						[52]
						[53]
						[54]

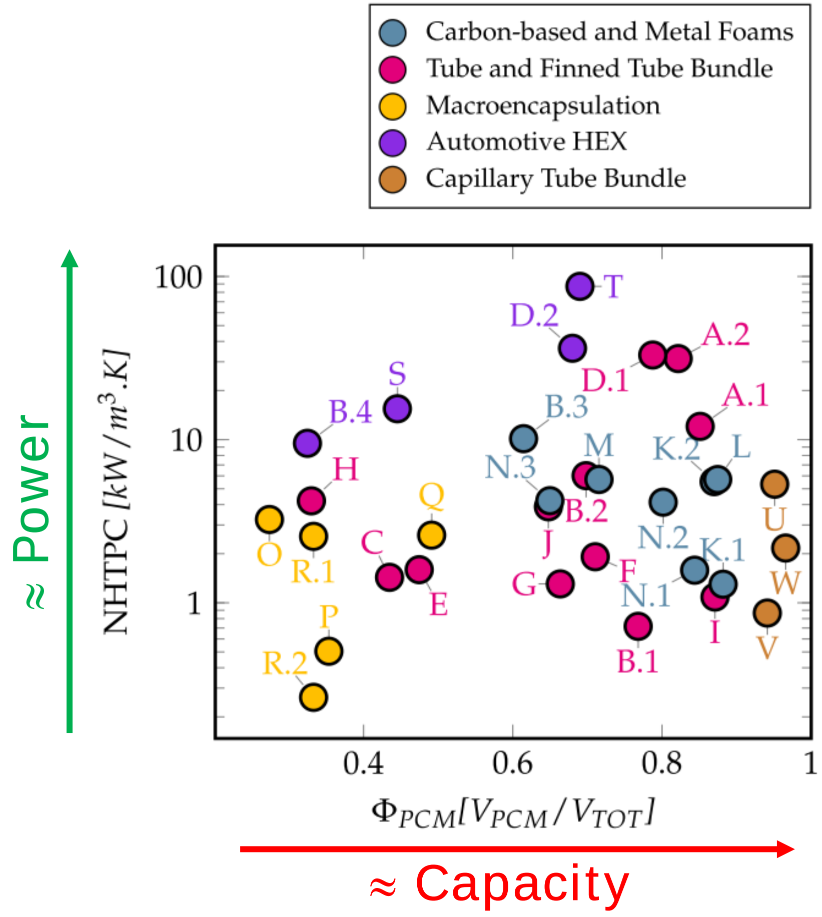
Table 3. References pertaining to carbon based techniques and metal foams as TCE.

Type	T_{PC}[°C]	V_{TOT} [m³]	$\dot{m}_{HTF}$ [kg h⁻¹]	$c_{p,HTF}$ [kJ/(kg·K)]	Geometry	Ref.
Graphite matrix	35	9.3×10^{-4}	400	4.18		[48]
						[55]
						[19]
						[16]
						[22]

Table 4. References pertaining to macro encapsulation techniques.

Type	T_{PC}[°C]	V_{TOT} [m³]	$\dot{m}_{HTF}$ [kg h⁻¹]	$c_{p,HTF}$ [kJ/(kg·K)]	Geometry	Ref.
ME (O)	577	4.2×10^{-3}	19.8	1.10		[27]
ME (P)	515	1.3×10^{-2}	70.5	1.07		[28]
ME (Q)	60	4.7×10^{-2}	120	4.18		[30]
Pouch (R.1), Sphere (R.2)	58	2.7×10^{-1}	900	4.18		[31]

https://www.mdpi.com/2076-3417/10/16/5519



Economic

Conclusion

What is the best thermal energy storage?

The best storage can be at maximum as good as the concept.

The best concept do not need a storage.

If you need a storage, be sure that you know the benefit/value of the storage.

Quantify the benefit/value of the storage.

Who is paying for this benefit/value? (Business model)

Key performance parameters could help to identify a storage technology but must be interpretated carefully.

Thank you for your attention

Direct contact promise to: high power, capacity and economic

Motivation

High power for low cost

Technical principal

No physical heat exchanger

Heat transfer fluid and storage material are not soluble in each other

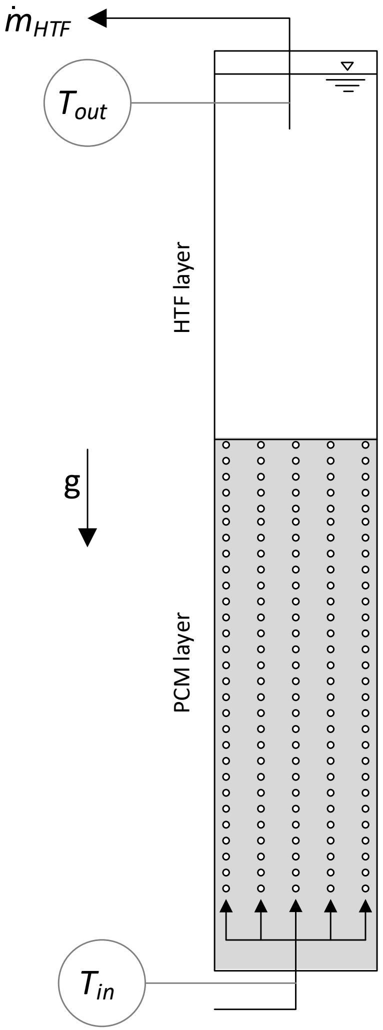
Droplet swarm by density difference

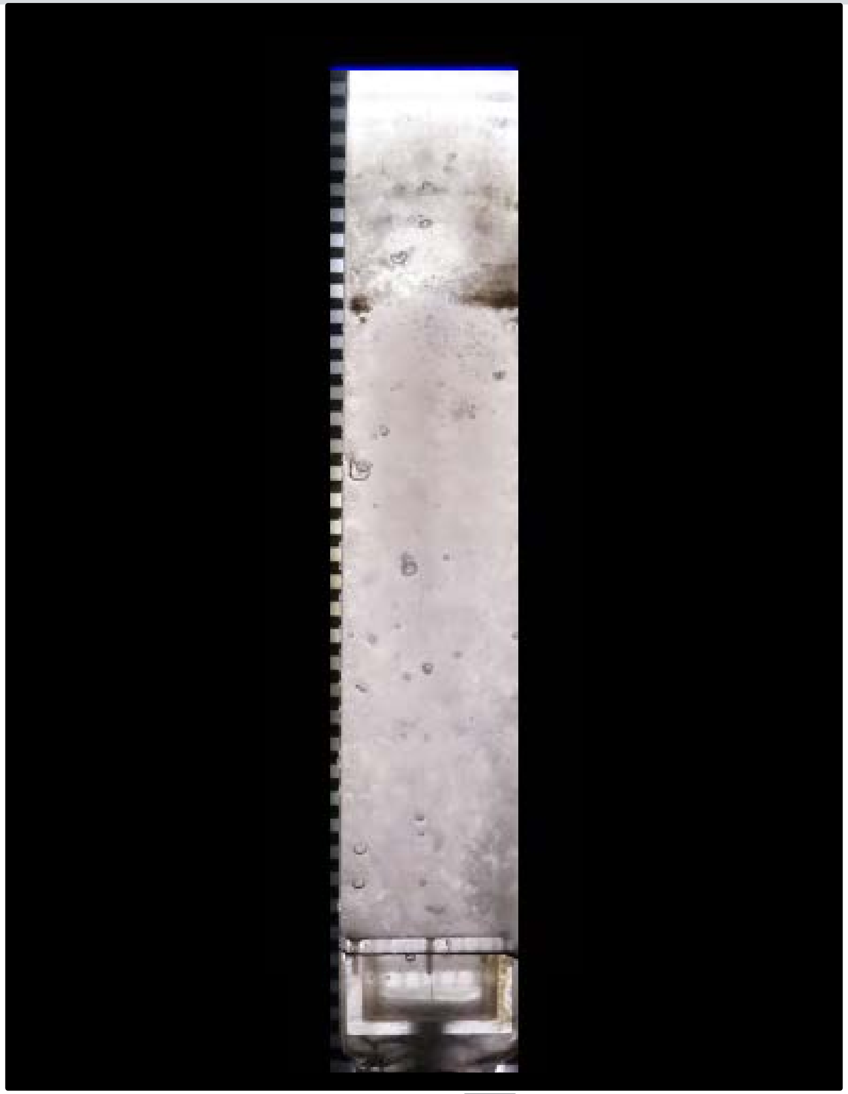
Research Questions

Performance evaluation: “direct contact”

Design rules of a direct contact latent energy storage

Technical challenges and bottle necks of the concept





Key parameters to describe TES

Conflict:
Transient behavior vs. single (constant) key parameter

Subsequent:
It could not exist a single independent key parameter

Effect:
Key parameter depends to additional parameters

Analog Example: Acceleration @ cars: value vs. races

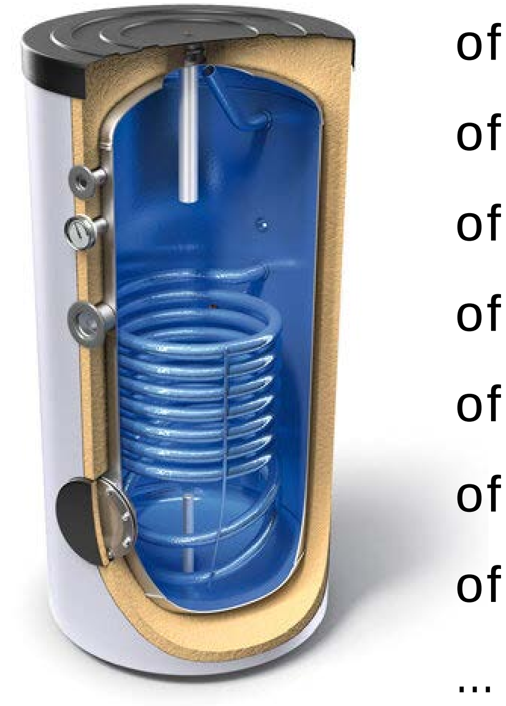
$$\Delta t_{0-100} = f(track, tyres, weather, wight, \ldots)$$

Values deviate by about 30%

Comparison only under „exact similar“ conditions *(human factor)*

Definition of physical boundaries

Volume | Wight



of storage material

of heat transfer fluid

of all fluids .... 206 l / 206 kg

of tank

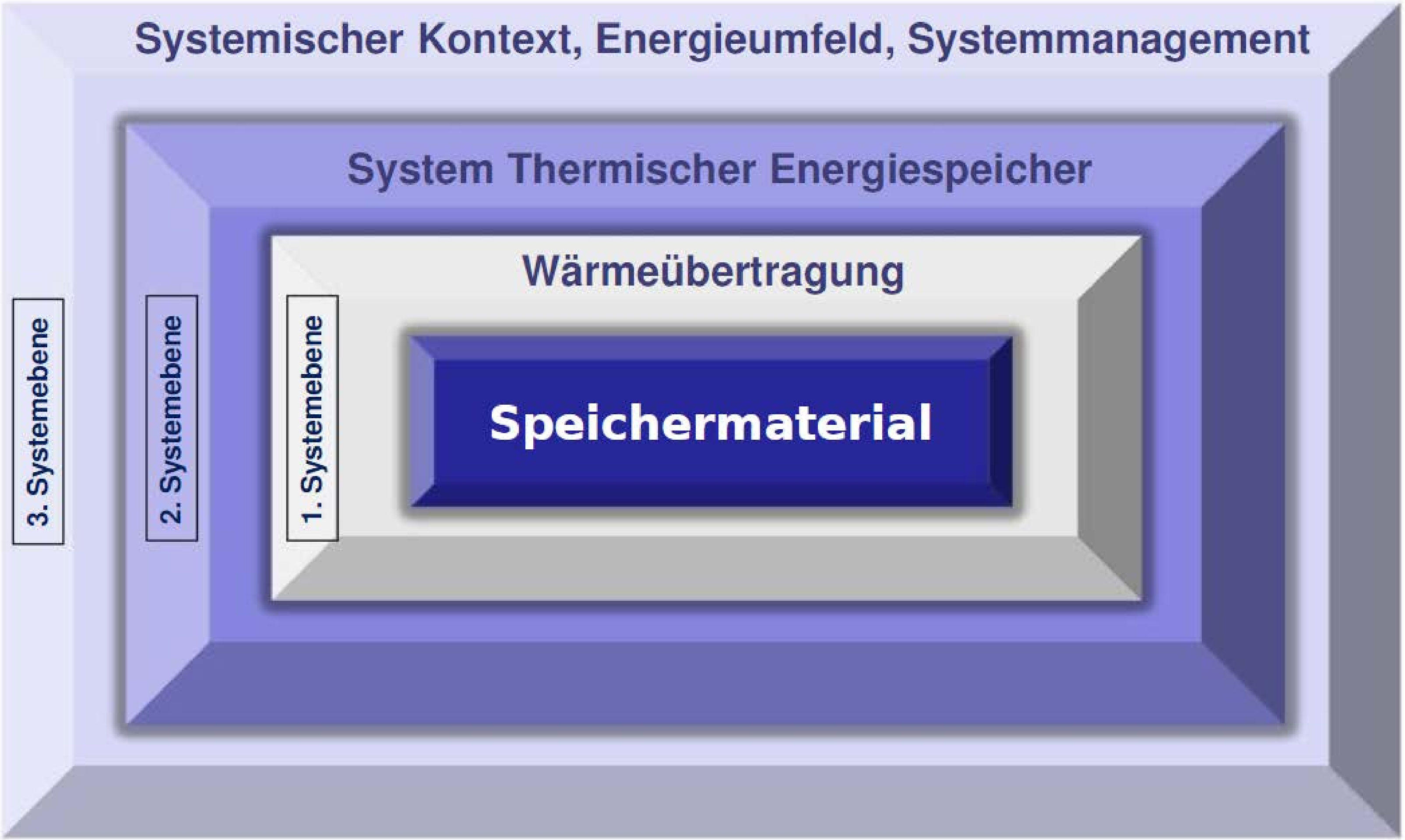
of heat exchanger

of tank, insulation and heat exchanger +70 % / +33% 340 l / 271 kg

of tank, insulation, heat exchanger and all fluids

...

https://balkanenergy.net/product/water-heater-tesy-model-profi-line-volume-200l-free-standing-one-heat-exchanger-1

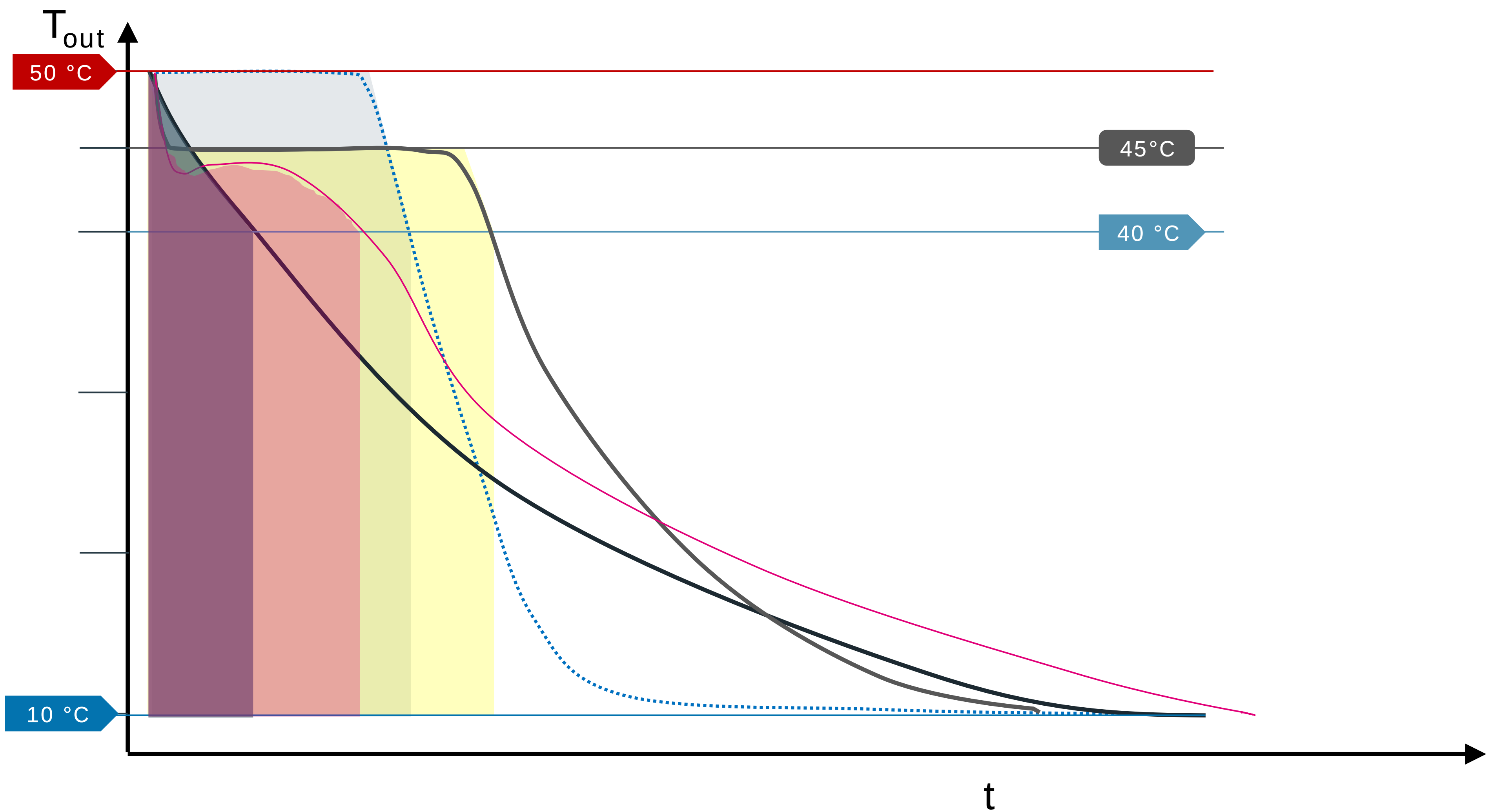


Systemischer Kontext, Energieumfeld, Systemmanagement
System Thermischer Energiespeicher
Wärmeübertragung
Speichermaterial
3. Systemebene
2. Systemebene
1. Systemebene

- The best storage is no storage
  - Each storage need an invest of:
    - capital
    - CO_2-Emission
    - material resources
    - construction time

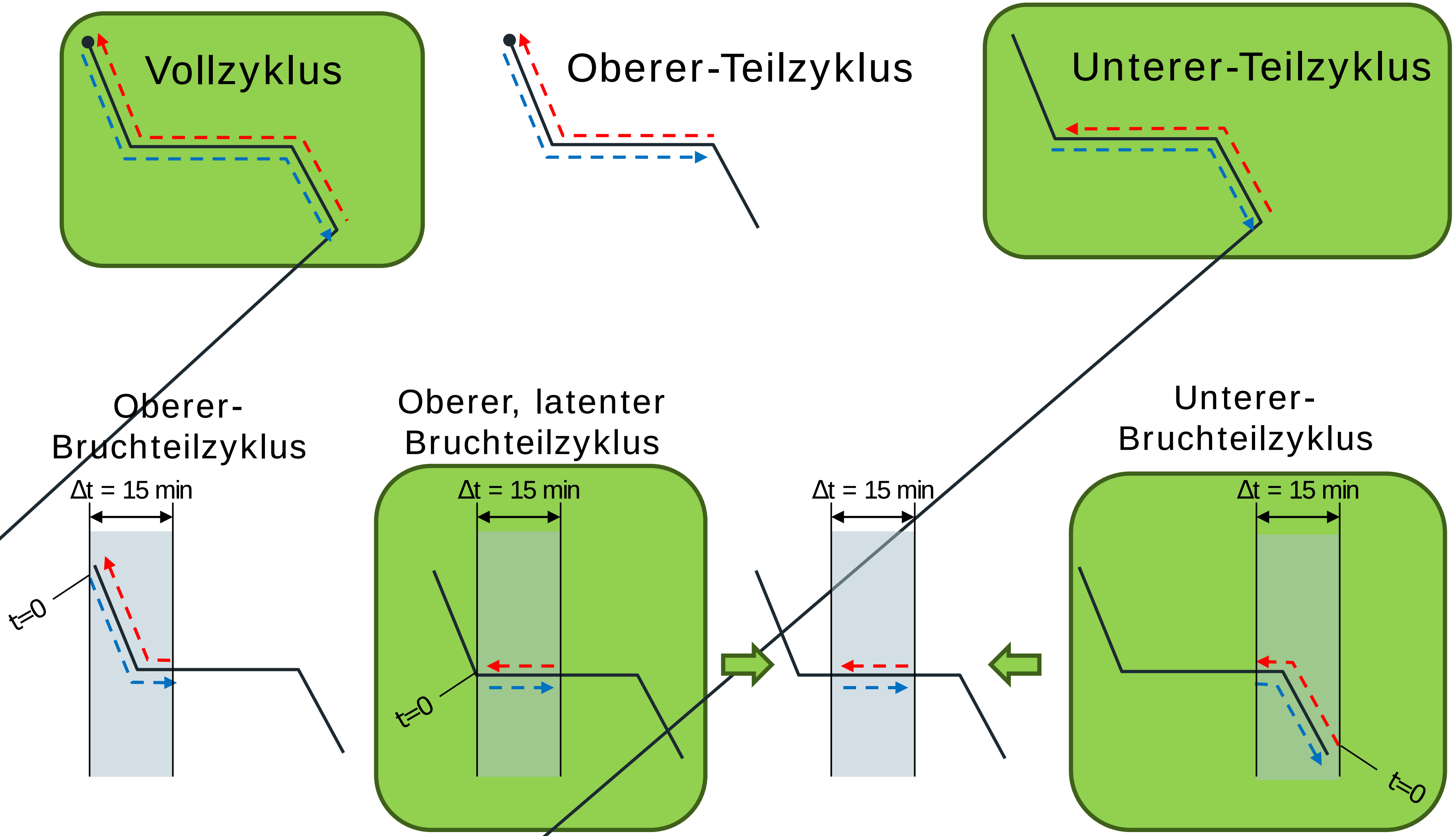
- Remind the goal of project!
  - Reducing CO2-Emissions (System boundary)
  - Increase quality of heat/cold supply

- Formulate as minimum two concepts to reach the goal
  - Use virtual optimal storages
  - Give them technical



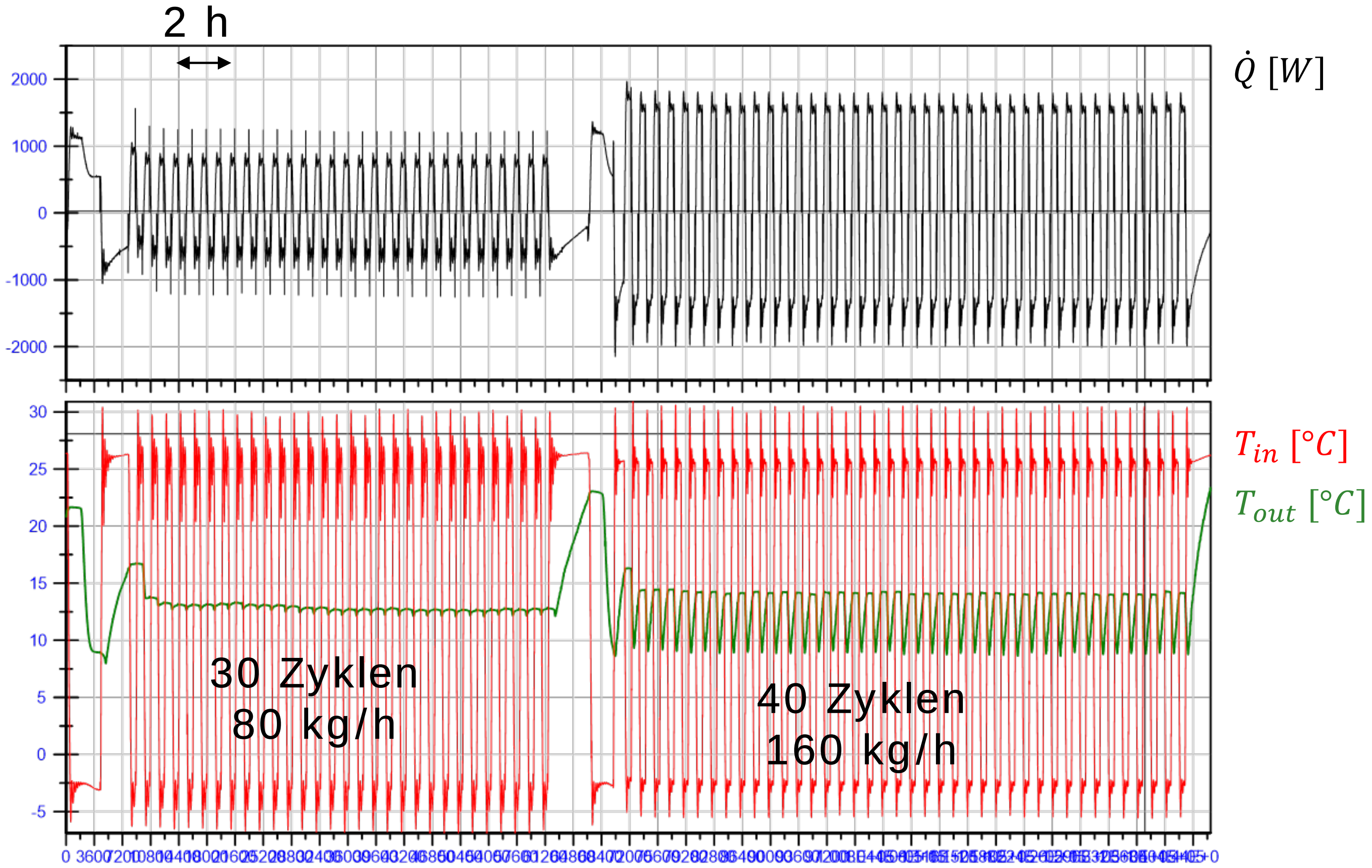
Tout
50 °C
45°C
40 °C
10 °C
t

Methodik

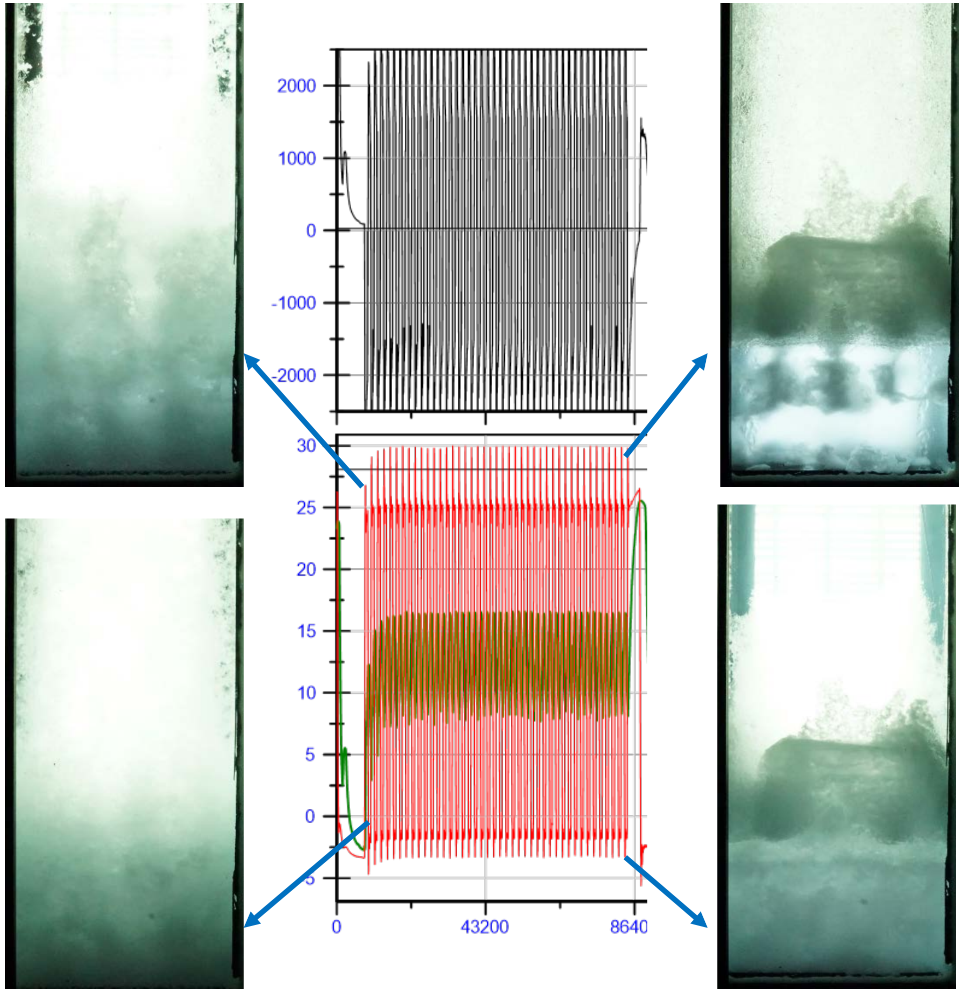


Vollzyklus
Oberer-Teilzyklus
Unterer-Teilzyklus
Oberer-
Bruchteilzyklus
Oberer, latenter
Bruchteilzyklus
Unterer-
Bruchteilzyklus
Δt = 15 min
Δt = 15 min
Δt = 15 min
Δt = 15 min
t=0
t=0
t=0

Oberer, latenter Bruchteilzyklus: ΔT = 15K $\dot{m}$ = 80 & 160 kg/h (DC03-D026)



Unterer Bruchteilzyklus: Erstarrungsbild nach 47 Zyklen ΔT = 15K $\dot{m}$ = 240 kg/h (DC03-D028)




Nach 37 Zyklen ΔT = 5K $\dot{m}$ = 80 kg/h