Thermal High Perfomance Storages for vehicle applications

2. ETA - Tagung

Energie- und Thermomanagement, Klimatisierung, Abwärmenutzung

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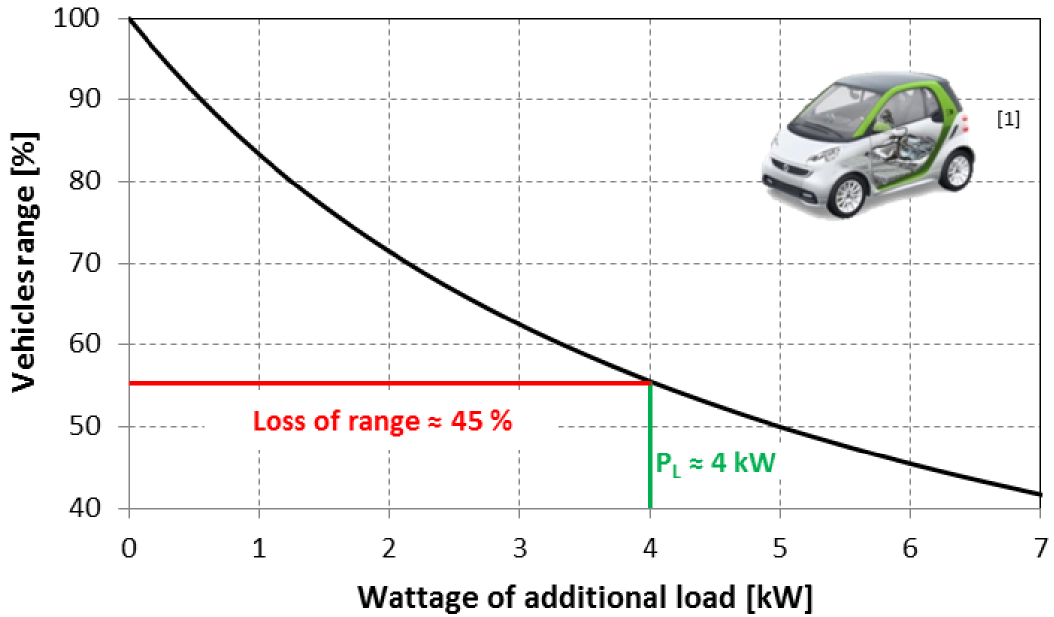
Content

Motivation and approach

Motivation and approach
Thermal management in battery electric vehicles

- High heating capacity for vehicles interior at low ambient temperatures
- High efficiency of drive train, little waste heat
- Use of electric heaters for interior heating

→ Essential **loss of range**



Smart fortow electric drive: Driving Cycle: ST-LA (freeway)			Ref.
Distance	92	km	[2]
Duration	2	h	[2]
Battery Capacity	17,6	kWh	[3]
Required Energy (without additional load)	10	kWh	[2]

[1] "Smart Fortwo Electric Drive," [Online]. Available: http://www.alleelektroautos.de/smart-fortwo-electric-drive.html. [Last access on 29th of August 2017].
[2] B. Mayer and M. Hubner, "Thermal properties of a special commuter vehicle concept," in *EVER Conference – EVER'15 Final Program*, Monaco, 2015.
[3] "smart fortwo electric drive und smart BRABUS electric drive," [Online]. Available: https://www.smart.com/content/dam/smart/DE/PDF/Preisliste_smart_fortwo_electric_drive.pdf. [Last access on 29th of August 2017].

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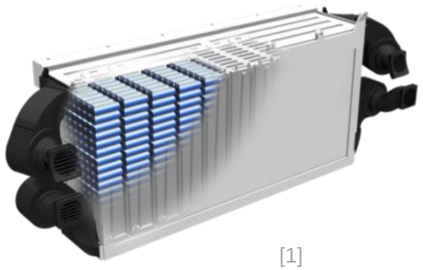
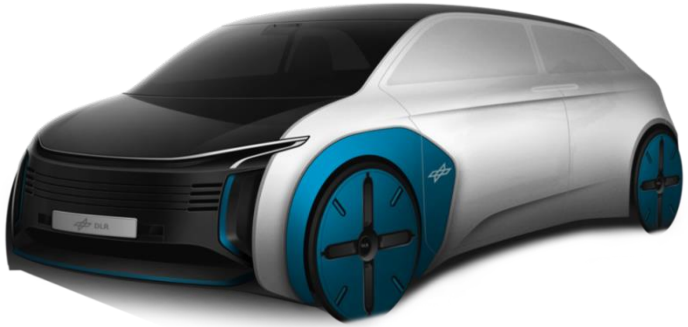
Motivation and approach
Use of Thermal Energy Storage for Heating

Battery
- High - value electric energy for traction
- High cost (≈ 200 €/kWh)
- High mass and volume
  (≈ 100 – 150 Wh/kg, 150 – 250 Wh/l)
- Use of critical materials (Li, Co)
- Limited recyclability



[1]



Thermal Energy Storage
- Needed form of energy
- Potentially lower cost (≈ 50 €/kWh)
- Potentially lower mass and volume
  (≈ 200 – 230 Wh/kg, 300 – 350 Wh/l @ T_{max} ≈ 600 °C)
- No use of critical materials
- High recyclability

[1] “Traction battery” [Online]. Available: http://www.eenewsautomotive.com/sites/default/files/images/01-edit-photo-uploads/2014/2014-06-june/akku.png [Last access on 29th of August 2017].

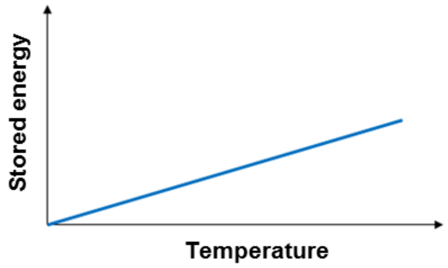
Metallic Phase Change Materials (mPCM)

Metallic Phase Change Materials
Basic principles heat storage

Sensible heat storage

Change of the temperature

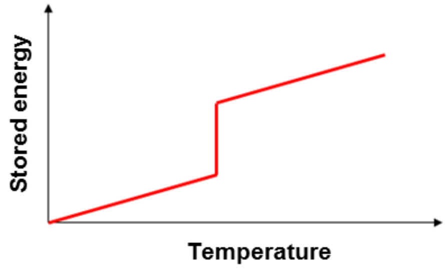
$$Q = c_p * m * (\vartheta_1 - \vartheta_2)$$



Latente heat storage

Change of the aggregate state

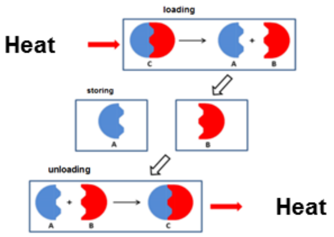
$$Q = c_p * m * (\vartheta_1 - \vartheta_2) + m * h_f$$



Thermochemical heat storage

Reaction enthalpy of a chemical process

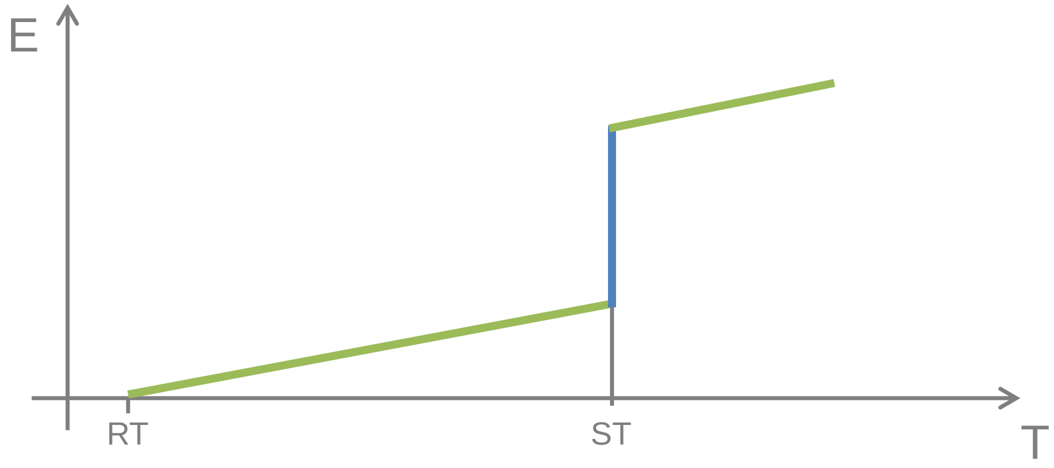
$$Q = \Delta H_R$$



[1]

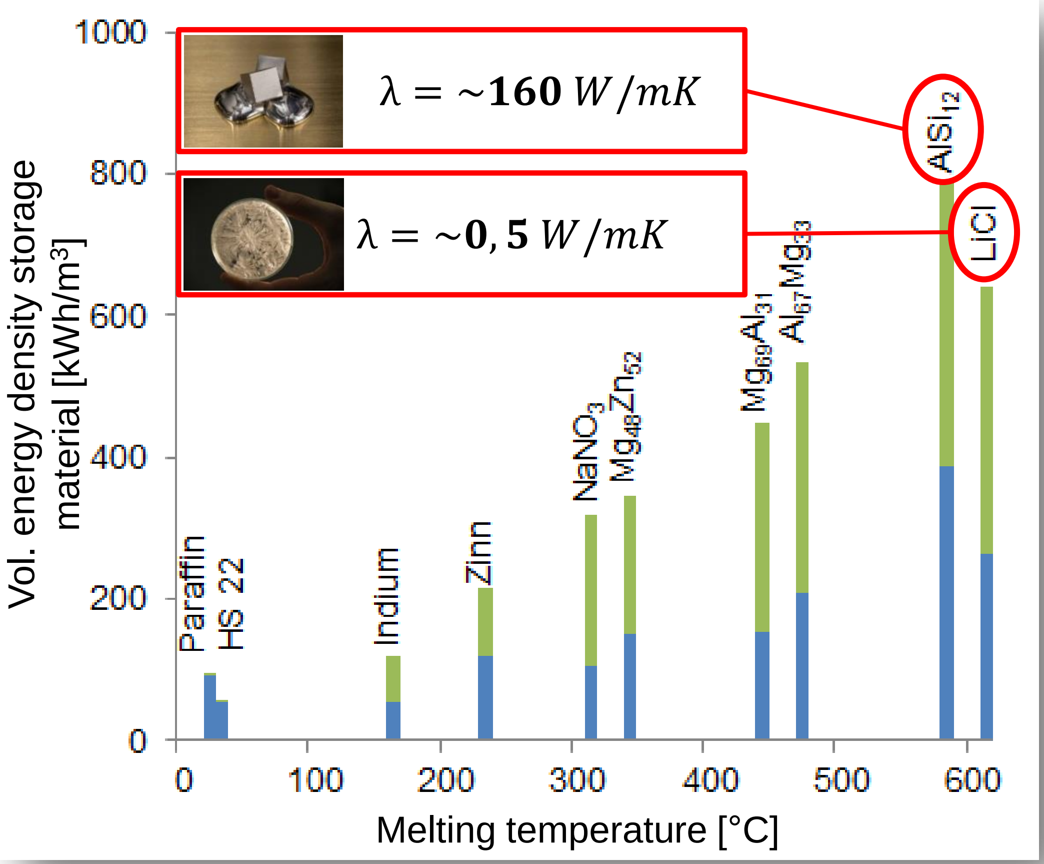
[1] “Wärme auf kleinstem Raum speichern”[Online]. Available: http://forschung-energiespeicher.info [Last access on 23rd of October 2018].

Metallic Phase Change Materials
Sensible + Latent heat storage



Sensible heat
- ➢ Use of sensible heat in solid and liquid state
- ➢ Used temperature range approx. 100 °C to 600 °C

Latent heat



Metallic Phase Change Materials

Beneficial properties

High thermal conductivity	→	High thermal output ✓
Eutectic alloys	→	High cycling stability ✓ High long - term stability
High maximum temperature level	→	High energy density ✓ Low mass Low volume

Metallic Phase Change Materials
Challenges

Potential reactivity in liquid state → Suitable housing material 

[1]

Volume expansion → Compensation method 

Unique for vehicle application (TRL 4) → Demonstration in real vehicle 

[1] http://www.pago-computer.de/ [Last access on 23rd of October 2018].

Storage concept

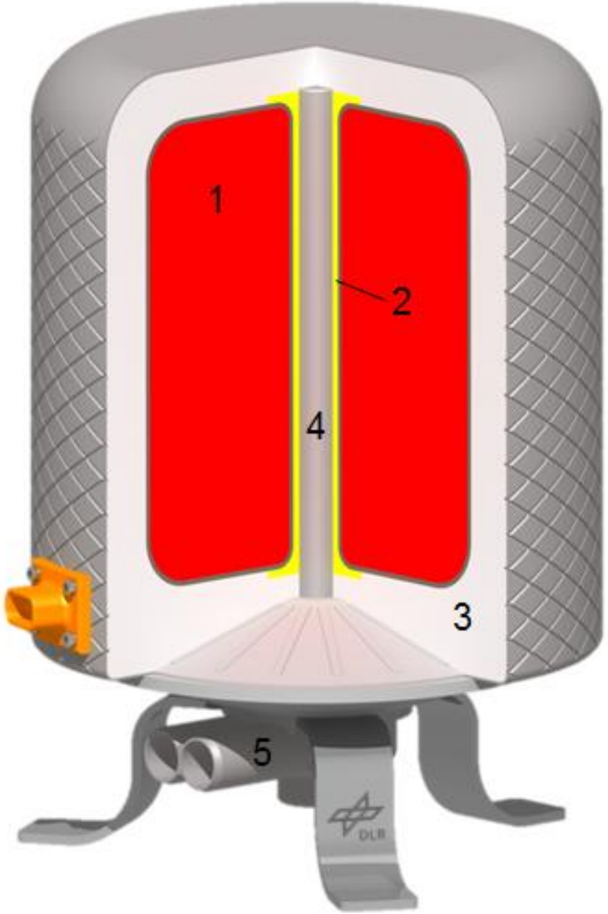
Storage concept
MonoTherm – High Performance Thermal Energy Storage

MonoTherm

- ✓ small
- ✓ lightweight
- ✓ powerful

Technologie
metallic Phase Change Material (mPCM)

Charging:	Electric resistance heater
Discharging:	Indirectly on cooling fluid (evaporation of working fluid, e.g. water, alcohol)
Working temperature:	ca. 100 °C – 600 °C



1 Heat storage material
2 Electric heater
3 Thermal insulation
4 Heat transport system
5 Coolant system

Reference scenario

Reference scenario
Basic setting

- Design of MonoTherm Storage for winter term conditions -10 °C and -20 °C
- Realistic long range driving scenario (e.g. Skiing Holidays, Christmas Travelling, etc.)

	ca. 4 h	variable	ca. 0,5 h	ca. 2,3 h
	Phase 1	2	3	4
Vehicle	Charging Battery (11 kW)	-	PreCon Interior (by THS)	Driving Maximum Range Motorway
THS	-	Charging (11 kW)	Charging (11 kW)	Discharging for Interior Heating

Time

[1]

[2]

1: Charging of the battery

2: Charging of the Thermal Energy Storage

3: Pre-Conditioning of the interior

4: Driving maximum Range (motorway cycle)

[1] https://deavita.com/dekoration/weihnachtsdeko-ideen/weihnachtsbaum-festlich-schmucken-spas-fur-die-ganze-familie.html [Last access on 23rd of October 2018].

[2] https://www.hotelaustria.com/[Last access on 23rd of October 2018].

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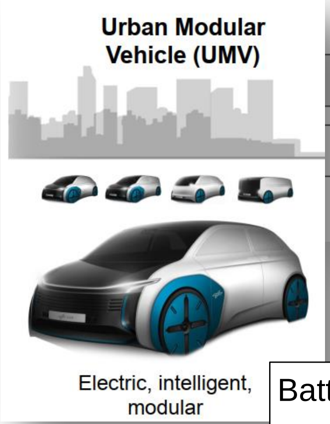
Reference scenario
Procedure

Boundary Conditions

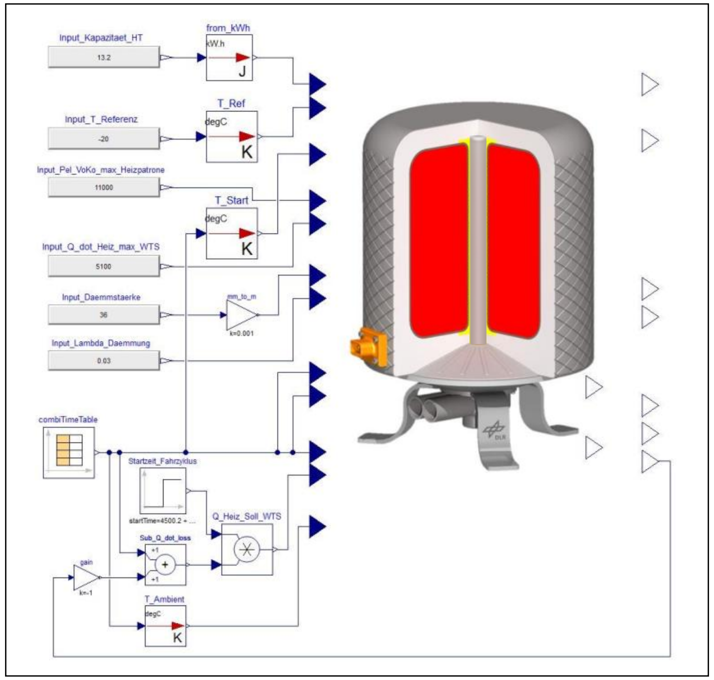


	ca. 4 h Phase ①	variable ②	ca. 0,5 h ③	ca. 2,3 h ④
Vehicle	Charging Battery (11 kW)	-	PreCon Interior (by THS)	Driving Maximum Range Motorway
THS	-	Charging (11 kW)	Charging (11 kW)	Discharging for Interior Heating

Time

Battery Capacity:	45 kWh
Heating demand:	3,4 kW (@ -10 °C) 5,1 kW (@ -20 °C)
Energy usage:	19,3 kWh / 100 km (Motorway)
Charging power:	11 kW

Designing Tool



Results

Volume

Mass

Dimensions

Range

SOC

…

Reference scenario
Results

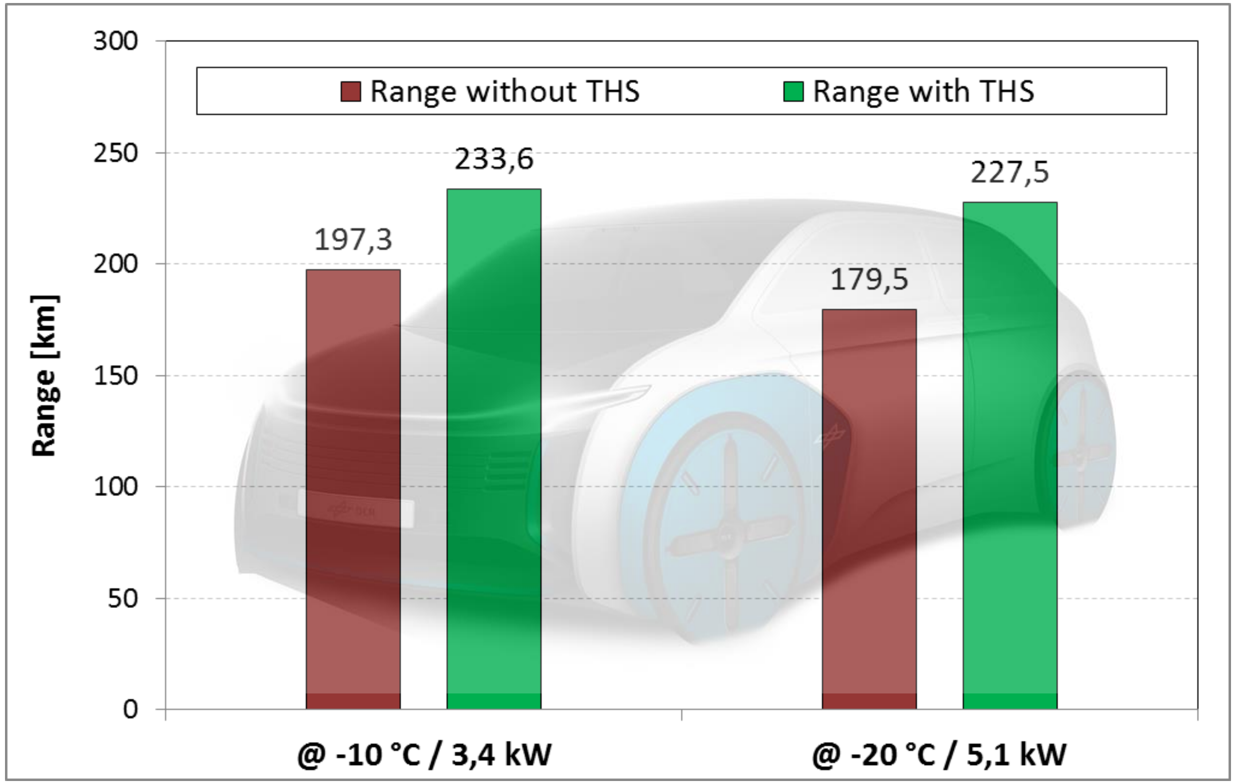
MonoTherm Storage (@ -10 °C / @ -20 °C)

Storage Material: $AlSi_{12}$

Capacity: 8,9 kWh / 13,2 kWh
Mass: 35 kg / 50 kg
Volume: 25 l / 36 l
Heigth (=Diameter): 317 mm / 359 mm

Effect. grav. energy density: **222 / 227 Wh/kg**
Effect. vol. energy density: **311 / 325 Wh/l**

Working Temperature: 110 °C – 610 °C
Thermal output: 3,4 kW / 5,1 kW
Installed el. charging power: 11 kW



- Increase of range: **36,3 km** resp. **18,4 %** @ **-10 °C**
- Increase of range: **48 km** resp. **26,7 %** @ **-20 °C**

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Reference scenario
Comparison

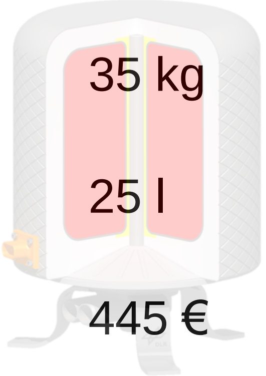
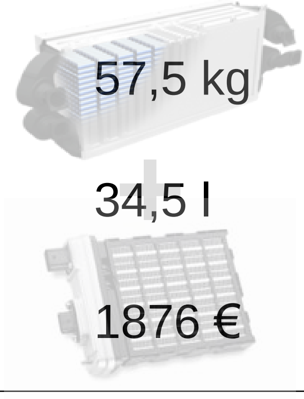
Battery + PTC - Heater

Grav. energy density:	150 Wh/kg
Vol. energy density:	250 Wh/kg
Overall efficiency:	90 %
Specific cost battery:	200 €/kWh
Cost PTC - Heater:	150 €

[1]

- ➢ Battery capacity to enable same range increase as MonoTherm Storage

MonoTherm vs. Battery + PTC – Heater (@ -10 °C)

	MonoTherm	Battery + PTC – Heater
Mass:	35 kg	57,5 kg
Volume:	25 l	34,5 l
Estimated Cost:	445 €	1876 €

Additional potential benefits MonoTherm

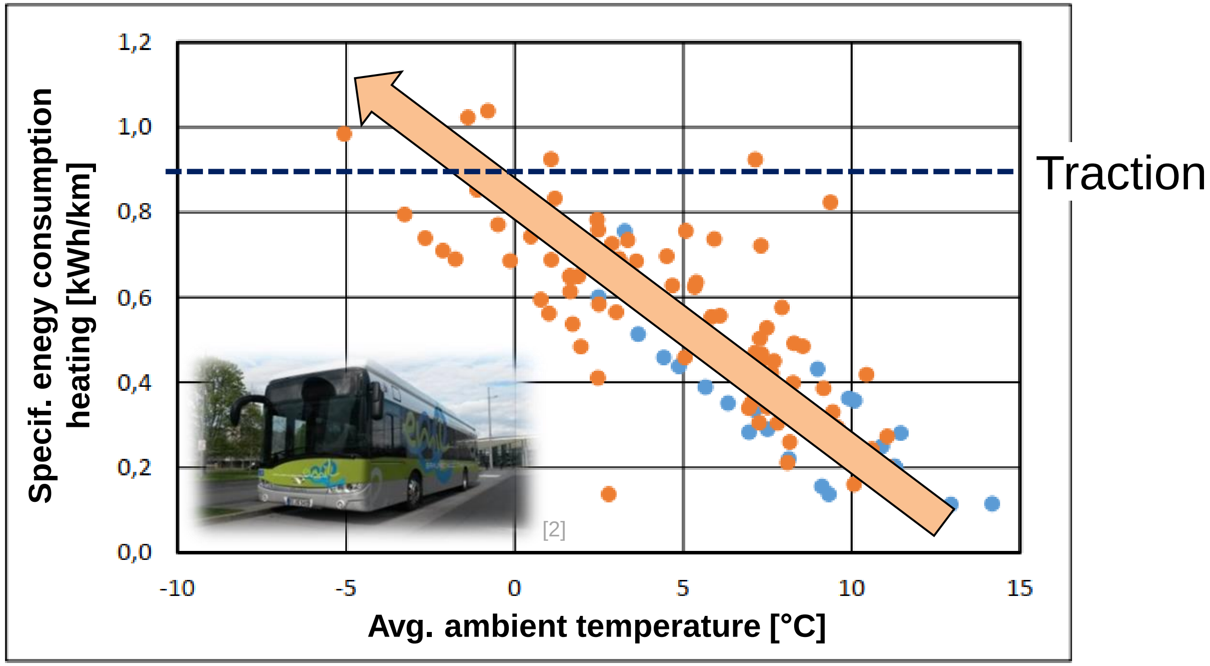
- ➢ No use of critical raw materials (e.g. Lithium, Cobalt)
- ➢ Use of recycled raw materials (e.g. $AlSi_{12}$)
- ➢ High recyclability
- ➢ Lower energy effort for manufacturing
- ➢ Long term stability

[1] https://www.eberspaecher.com[Last access on 23rd of October 2018].

Thermal High Performance Storages (THS) in electric buses

THS in electric buses

Boundary Conditions



[1]

State of the art

[3]

- Fuel heaters using Diesel
  - ➢ Local emissions
  - ➢ Already ban of Diesel driven cars from cities
- Heat pump with R134a or CO_2
  - ➢ Additional electric heater for low temperatures necessary
  - ➢ Loss of range at low temperatures not solved
  - ➢ Battery prices > 500 €/kWh

⇨ **Necessity for alternative heating solutions even more relevant !**

[1] Fraunhofer IVI, Thoralf Knote : „Ansätze zur Standardisierung und Zielkosten für Elektrobusse“, Dresden, 2017
[2] [Online] https://de.wikipedia.org/wiki/Solaris_Urbino_12_electric#/media/File:BSVAG_Solaris_Urbino_12_electric_%22EMIL%22_Hauptbahnhof.jpg [Last access on 23rd of October 2018].
[3] [Online] https://www.eberspaecher.com/produkte/fuel-operated-heaters/produktportfolio/wasserheizungen/produkte.html [Last access on 23rd of October 2018].

THS in electric buses
Potentials and Challenges

Challenges

Long operating times → Long term stability

Various defined scenarios → Modular storage design

High amount of mPCM → Questions regarding safety

Potentials

High prices for batteries → THS even more economic

High energy demand → Positive scaling effects

Defined scenarios → Custom design possible

[1]

[1] [Online] https://de.123rf.com/lizenzfreie-bilder/erlangen.html?sti=lwdgns9ucgh215eaw4|&mediapopup=17855419[Last access on 23rd of October 2018].

THS in electric buses
Current project

Thermal High Performance Storage for airport bus

DLR Deutsches Zentrum für Luft- und Raumfahrt

STUTTGART AIRPORT

[1]

KONVEKTA
Technical leadership starts with ideas.

Baden-Württemberg
MINISTERIUM FÜR WIRTSCHAFT, ARBEIT UND WOHNUNGSBAU

[1] [Online] https://vm.baden-wuerttemberg.de/de/verkehrspolitik/elektromobilitaet/ [Last access on 23rd of October 2018].

MonoTherm

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