

# URBANISATION

Towards an Energy Producing Built Environment  
using compact thermal energy storage

Technology development  
-  
status of compact storage systems

17-5-2018

dr. ir. Ruud Cuypers



# TNO: the Netherlands organization for Applied Scientific Research

**Founded by law in 1932, to enable business and government to apply knowledge.**



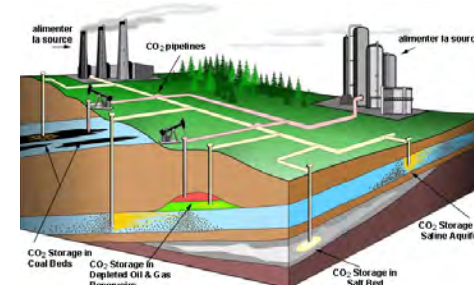
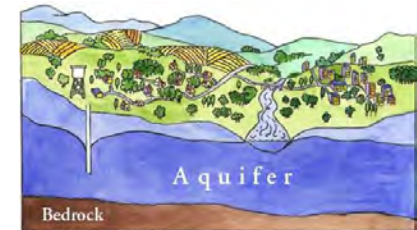
TNO connects **people** and **knowledge** to create **innovations** that boost the sustainable competitiveness of industry and well-being of society.

**As an organisation regulated by public law, we are independent:  
not part of any government, university or company.**



# Ways of energy storage

- › Electrochemical (batteries)
- › Gravitational (artificial lake)
- › Pressurized air (e.g. underground)
- › Bio-fuel (e.g. sugar cane)
- › Sensible heat (boiler, borehole)
- › Latent heat (PCM)
- › Thermochemical (e.g. silica gel, zeolite, salt hydrates)
- › ...





## Newly built vs. existing dwellings



- 70% of current dwellings will still be there by 2050
- Renovation → prime importance to reach targets → **COMPACT!**



## 1 year's worth of thermal energy per household (20 GJ; efficient building)

- › 0.6 m<sup>3</sup> crude oil (36 GJ/m<sup>3</sup>)
- › 0.9 m<sup>3</sup> (bio)ethanol (22 GJ/m<sup>3</sup>)
- › 1.0 m<sup>3</sup> coal (20.5 GJ/m<sup>3</sup>)
- › 2.5 m<sup>3</sup> redox active material (6-12 GJ/m<sup>3</sup>;  $\text{Cu} \leftrightarrow \text{CuO}_2$ )
- › 3.7 m<sup>3</sup> wood (5.4 GJ/m<sup>3</sup>,  $\text{RV}_{\text{wood}} = 20\%$ )
- › 6.5 m<sup>3</sup> Na<sub>2</sub>S (3.1 GJ/m<sup>3</sup>;  $9 \rightarrow 0\text{H}_2\text{O}$ )
- › 7.1 m<sup>3</sup> CaCl<sub>2</sub> (2.8 GJ /m<sup>3</sup>;  $6 \rightarrow 0\text{H}_2\text{O}$ )
- › 17 m<sup>3</sup> Ni-MH battery (1.2 GJ/m<sup>3</sup>)
- › 17 m<sup>3</sup> H<sub>2</sub>, 100 bar (1.2 GJ/m<sup>3</sup>)
- › 50 m<sup>3</sup> sodium-acetate tri-hydrate (PCM) (0.40 GJ/m<sup>3</sup>)
- › 56 m<sup>3</sup> lead-acid battery (0.36 GJ/m<sup>3</sup>)
- › 80 m<sup>3</sup> water with  $\Delta T = 60\text{ }^\circ\text{C}$  (0.25 GJ/m<sup>3</sup>)
- › 222 m<sup>3</sup> vanadium – redox battery (0.09 GJ/m<sup>3</sup>)
- › 571 m<sup>3</sup> methane (0.035 GJ/m<sup>3</sup>)
- › 800 m<sup>3</sup> groundwater with  $\Delta T = 6\text{ }^\circ\text{C}$  (0.025 GJ/m<sup>3</sup>)
- › 1667 m<sup>3</sup> H<sub>2</sub>, 1 bar (0.012 GJ/m<sup>3</sup>)

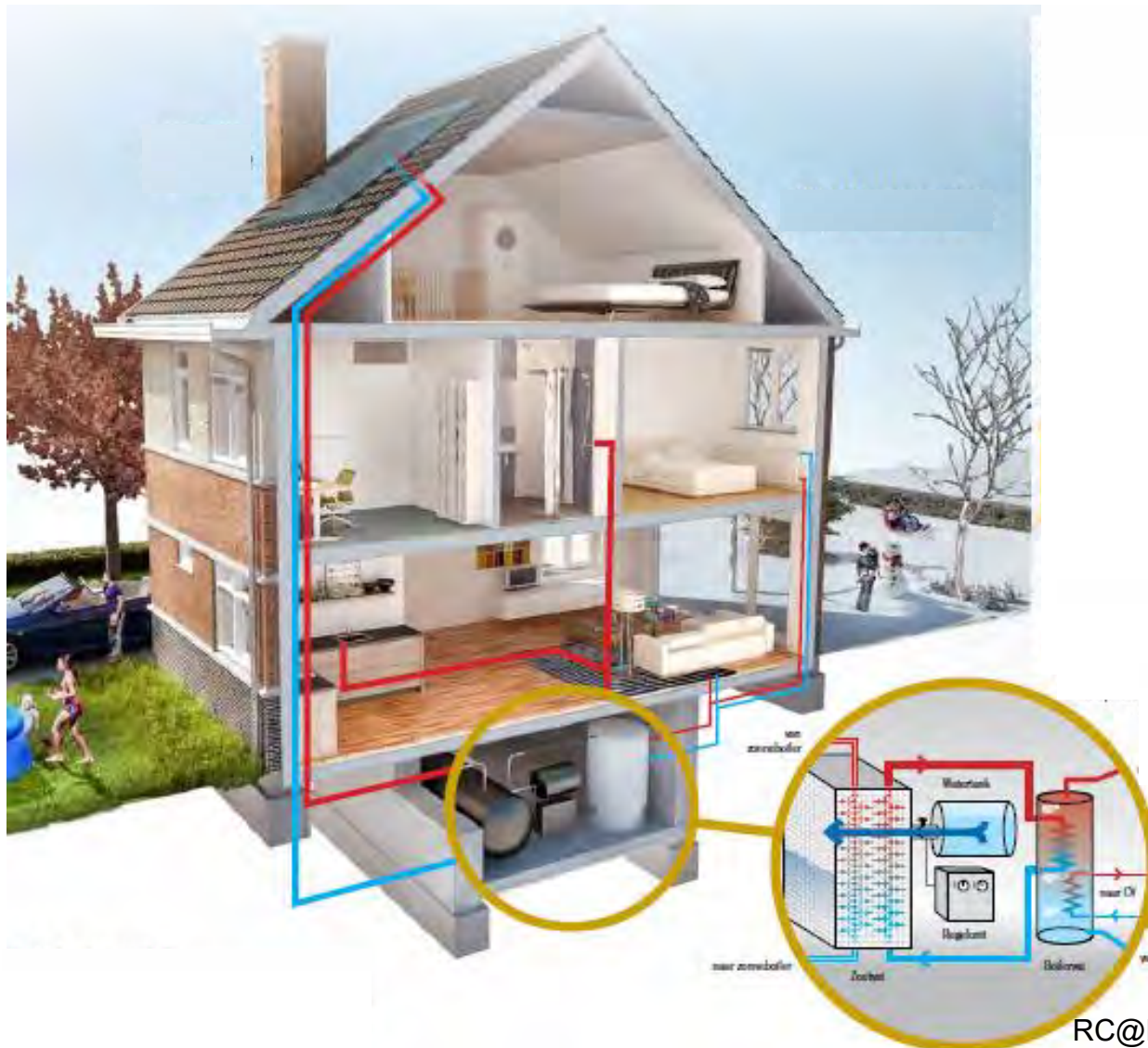


## 1 year's worth of thermal energy per household (20 GJ; efficient building)

- › 0.6 m<sup>3</sup> crude oil (36 GJ/m<sup>3</sup>)
- › 0.9 m<sup>3</sup> (bio)ethanol (22 GJ/m<sup>3</sup>)
- › 1.0 m<sup>3</sup> coal (20.5 GJ/m<sup>3</sup>)
- › 2.5 m<sup>3</sup> redox active material (6-12 GJ/m<sup>3</sup>;  $\text{Cu} \leftrightarrow \text{CuO}_2$ )
- › 3.7 m<sup>3</sup> wood (5.4 GJ/m<sup>3</sup>;  $\text{RV}_{\text{wood}} = 20\%$ )
- › **6.5 m<sup>3</sup> Na<sub>2</sub>S (3.1 GJ/m<sup>3</sup>;  $9 \rightarrow 0\text{H}_2\text{O}$ )**
- › **7.1 m<sup>3</sup> CaCl<sub>2</sub> (2.8 GJ /m<sup>3</sup>;  $6 \rightarrow 0\text{H}_2\text{O}$ )**
- › 17 m<sup>3</sup> Ni-MH battery (1.2 GJ/m<sup>3</sup>)
- › 17 m<sup>3</sup> H<sub>2</sub>, 100 bar (1.2 GJ/m<sup>3</sup>)
- › **50 m<sup>3</sup> sodium-acetate tri-hydrate (PCM) (0.40 GJ/m<sup>3</sup>)**
- › 56 m<sup>3</sup> lead-acid battery (0.36 GJ/m<sup>3</sup>)
- › **80 m<sup>3</sup> water with  $\Delta T = 60\text{ }^\circ\text{C}$  (0.25 GJ/m<sup>3</sup>)**
- › 222 m<sup>3</sup> vanadium – redox battery (0.09 GJ/m<sup>3</sup>)
- › 571 m<sup>3</sup> methane (0.035 GJ/m<sup>3</sup>)
- › 800 m<sup>3</sup> groundwater with  $\Delta T = 6\text{ }^\circ\text{C}$  (0.025 GJ/m<sup>3</sup>)
- › 1667 m<sup>3</sup> H<sub>2</sub>, 1 bar (0.012 GJ/m<sup>3</sup>)

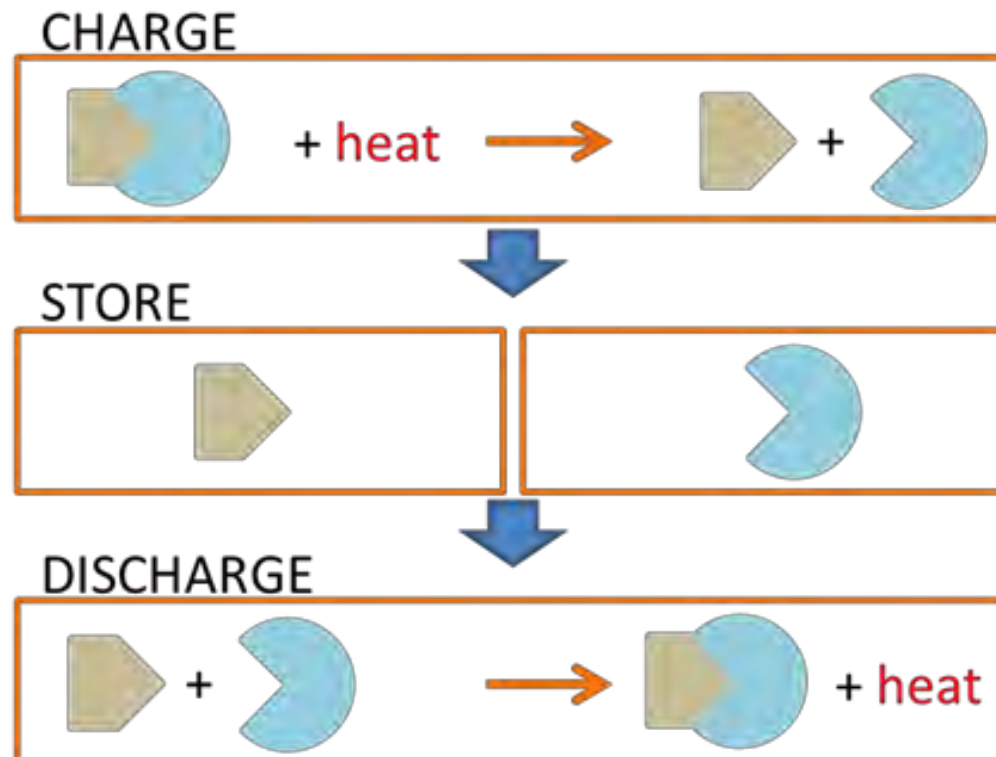


# Heat Battery





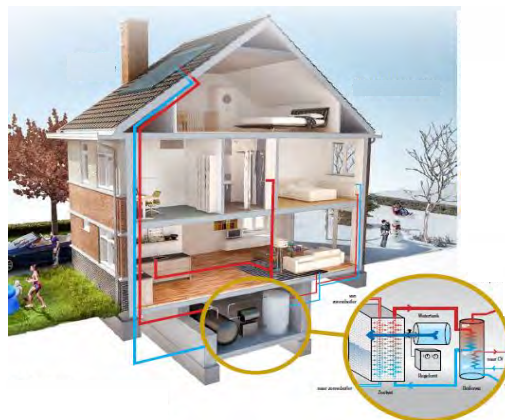
## What is thermo-chemical storage? (adsorption / absorption)





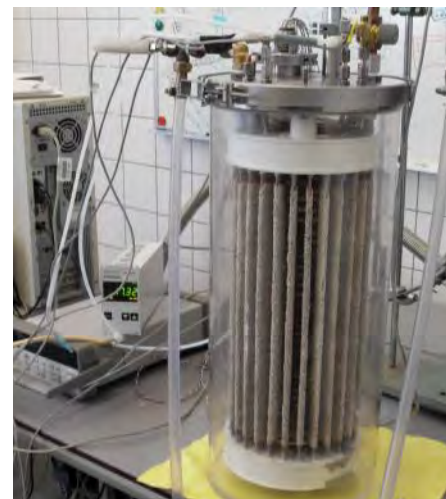
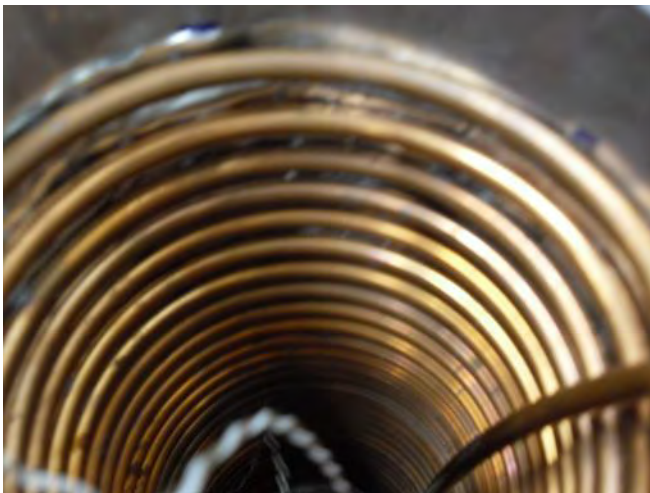
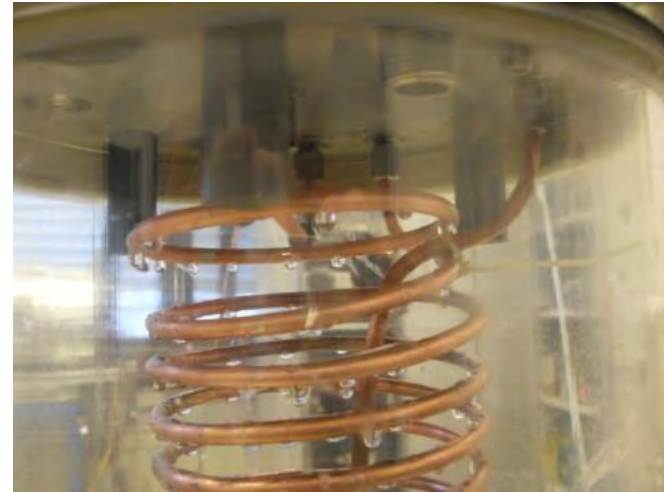
## TCS: project overview (next slides)

E-Hub (EU FP7)	: <a href="http://www.e-hub.org/">http://www.e-hub.org/</a>
EINSTEIN (EU FP7)	: <a href="http://www.einstein-project.eu/">http://www.einstein-project.eu/</a>
ICOON (prov. NH, NL)	: <a href="http://www.icoonwoning.nl/warmtekoude.html">http://www.icoonwoning.nl/warmtekoude.html</a>
MJP-CCO (NL TKI)	: <a href="http://www.tki-energo.nl/files/MJPCCO.pdf">http://www.tki-energo.nl/files/MJPCCO.pdf</a>
MERITS (EU FP7)	: <a href="http://www.merits.eu/">http://www.merits.eu/</a>
CREATE (EU H2020)	: <a href="http://www.createproject.eu/">http://www.createproject.eu/</a>
COMPAS-2 (NL TKI)	: <a href="https://projecten.topsectorenergie.nl/">https://projecten.topsectorenergie.nl/</a>



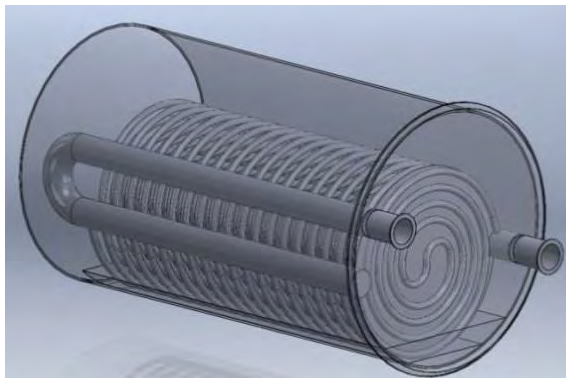
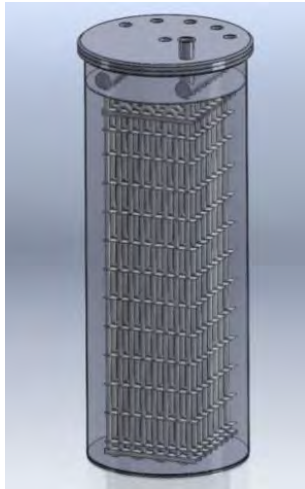


## Experimental reactor (E-hub)





## Up-scaled experimental reactor (E-hub / EINSTEIN)





## Up-scaled experimental reactor (E-hub / EINSTEIN)





## From components & reactor development towards applications → demonstrators

- › Single-family house, zeolite-based
- › iCOON Demonstration – Stad van de Zon (Heerhugowaard, NL)





## iCOON demonstration – iCOON-woning (NL)



- › Storage system
  - › Vacuumreactor with zeolite
  - › In a real dwelling
  - › Translucent reactorvolume
- › Separate cylinders for ad/desorption & evaporation/condensation
- › Principle demonstrated



## TKI EnerGO MJP CCO:

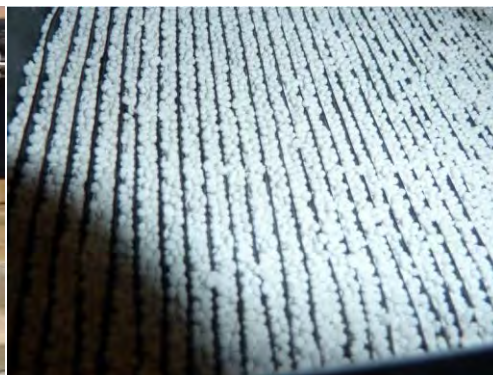
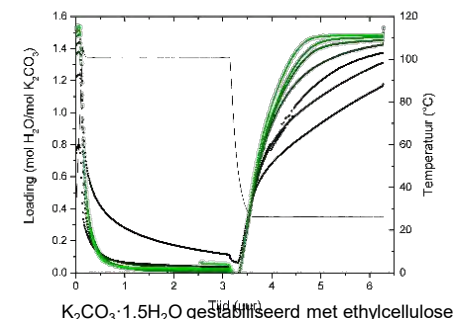
### “meerjarenprogramma Compact Conversion & Storage”

- › The problem: efficient existing housing ← efficient conversion & storage of thermal energy for energetic & economic system optimization
- › The solution: the second heating revolution
- › Goal:
  - › **Enhancing development of compact storage and conversion techniques for available heat & cold**
  - › **Introduction in the built environment**
- › Method: 4 WPs – Roadmap, Applied research, Development, Integration
- › Results: direct contribution to energy transition and long-term chances – commercial applications & long term research agenda



## MJP CCO – main Results

- › Programmatic approach: Technology roadmaps for TCS, PCM and MCHP, for specific use-cases
  - Roadmaps adapted for implementation by TKI UE
- › Prototype TCM reactor built and validated
- › Tested active PCM materials
- › Tested active TCM materials, with  $K_2CO_3$  as main material
- › Tested prototype TCM reactor with  $K_2CO_3$  as storage material
- › Modeling results of MCHP

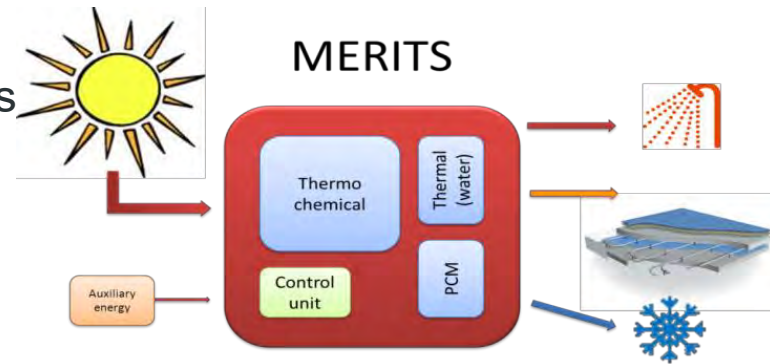

Vacuum Chamber reactor setup (left) and  $K_2CO_3 \cdot 1.5H_2O$  inside a HX (right [RTB, 2018])

TKI UE Roadmap TCS (2016)



## MERITS (EU FP7; [www.merits.eu](http://www.merits.eu))

- › The international MERITS consortium is working on a new solution for
  - › improved use of renewable sources
  - › for heating, cooling & DHW applications
  - › in individual dwellings (new & existing)
- › for all three European climate zones

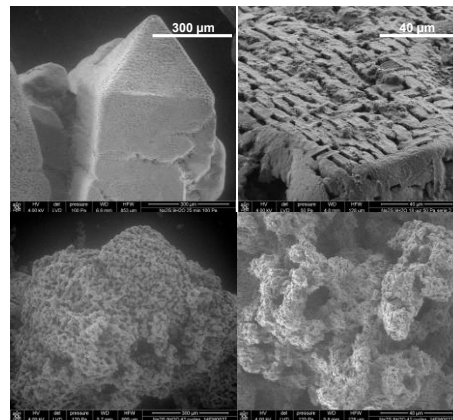
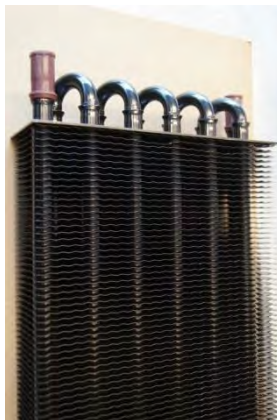
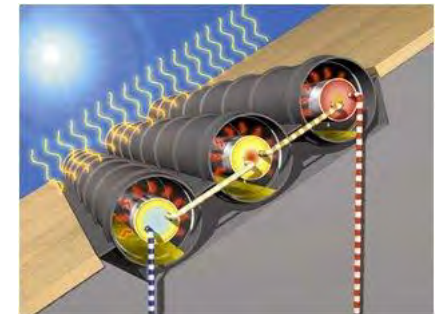
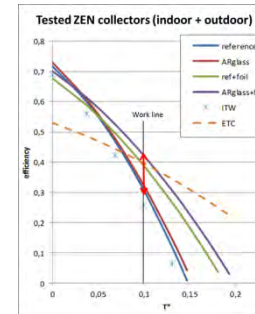


- › The aim was
  - › to build a prototype of a fully functioning compact rechargeable thermal battery
  - › that would fit in for example a cellar or underground a garden
  - › including business models & market strategies to foster market take-up <2020



## Achievements (highlights)

- › Renewable Energy Supply: Solar collectors + integration of storage



- › Energy storage: Enhanced materials, reactor + components

- › Energy delivery: System integration and control strategies





## MERITS end-of-project

### Seasonal thermal battery

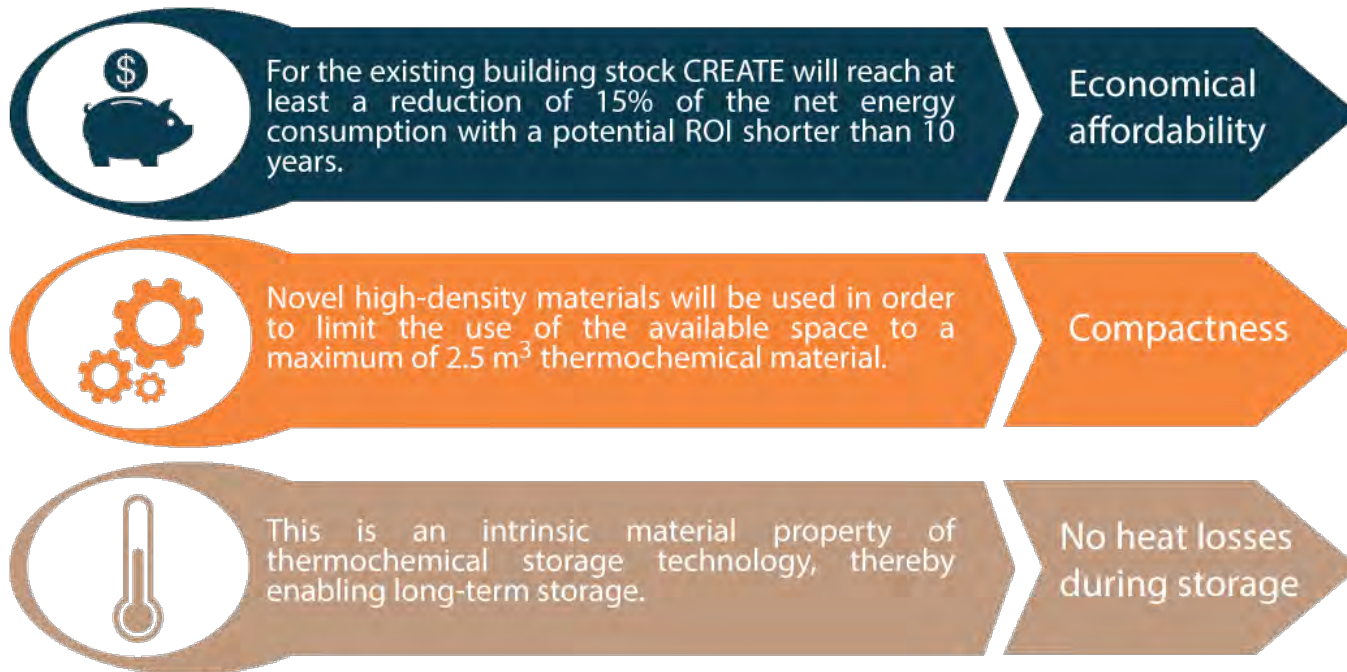
- Capacity demo:  $\sim 0.1 \text{ GJ/m}^3$   
(outlook for future:  $\sim 1 \text{ GJ/m}^3$ )
- Modular: 8 modules
- Fixed bed, vacuum system
- TCM material:  $\text{Na}_2\text{S}$





# CREATE: project objectives

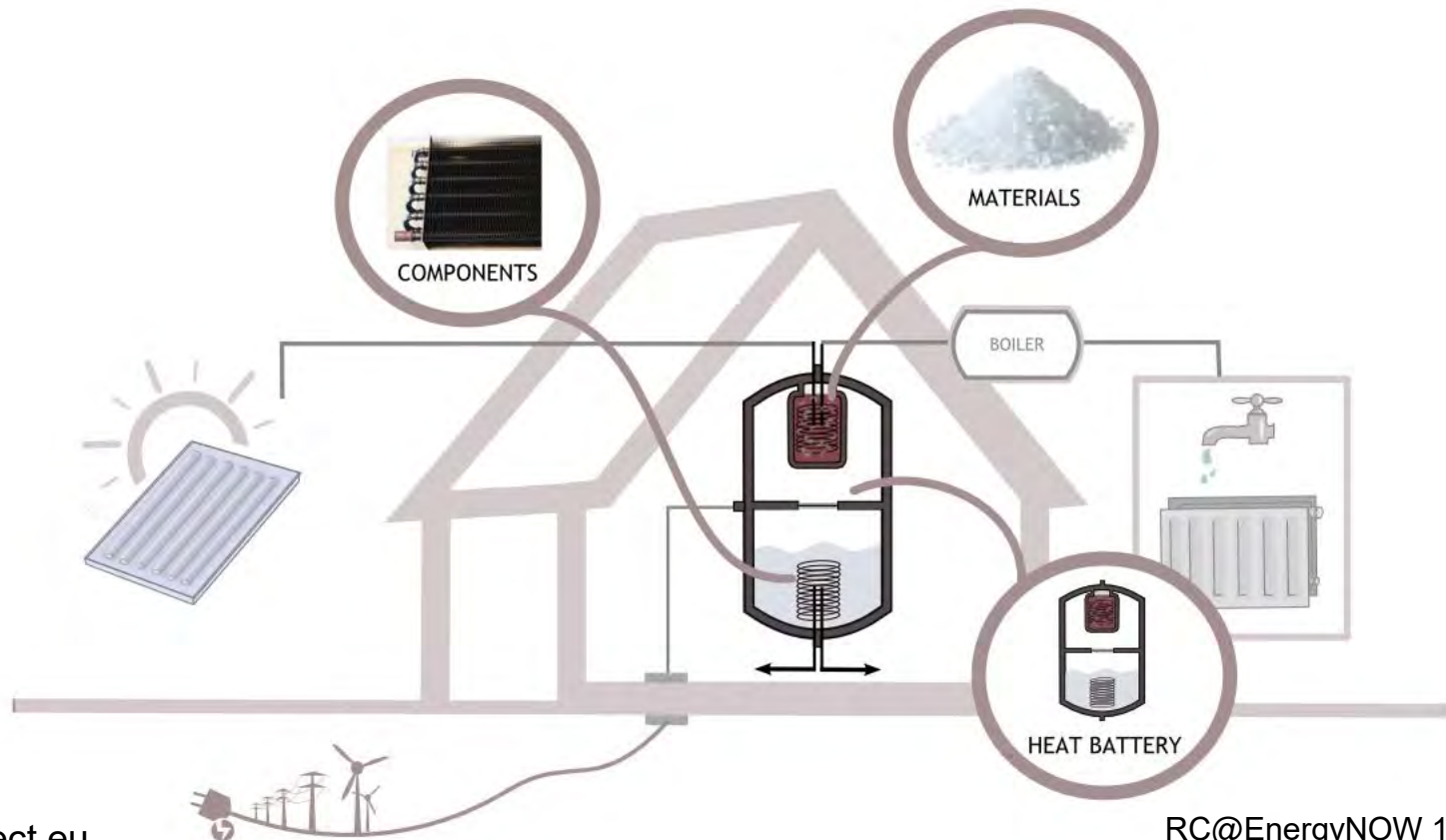
- › To develop and demonstrate a **heat battery**, i.e. an advanced thermal storage system based on Thermo-Chemical Materials (TCMs), that enables:





## CREATE concept

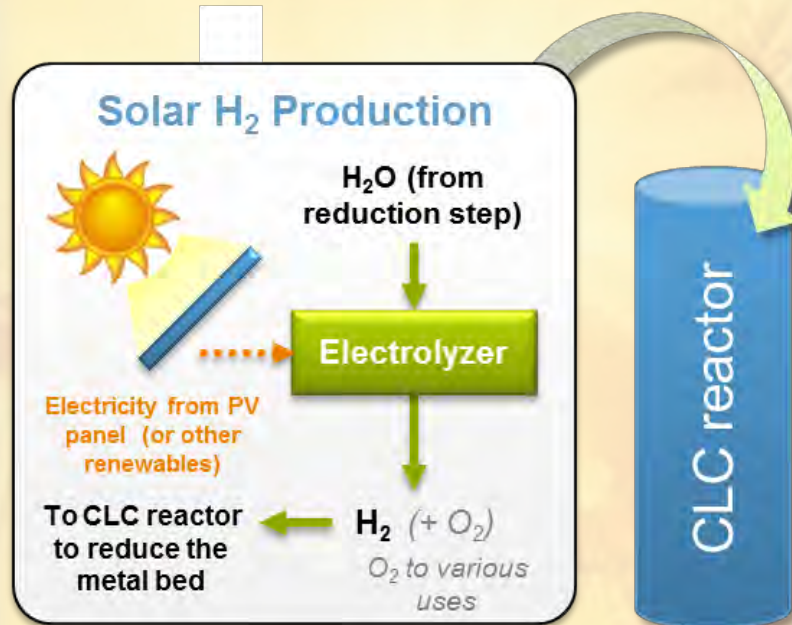
- The heart of the system is the heat storage module, i.e. the heat battery.
- Different sources for heat supply exist (heat generated by solar collectors on the building or heat-pumps fed by excess electricity from the grid).





# COMPAS: concept

## Energy storage



**Bed reduction:** Solar energy from summer is stored as chemical energy, without losses, until the heat is needed

## Heat supply

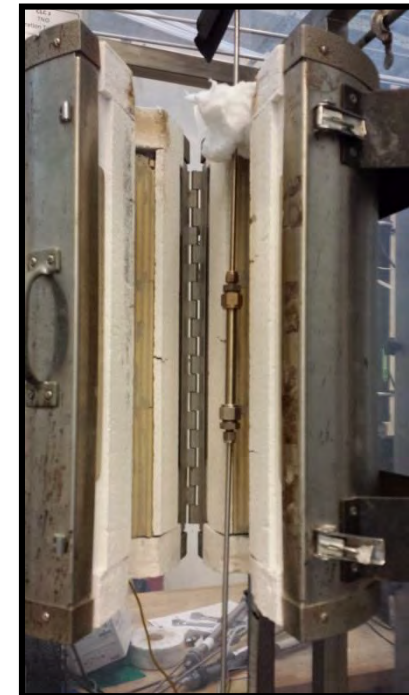


**Bed oxidation:** Running air through the reactor oxidizes the bed and provides heat all winter long



## COMPAS 2 (ongoing)

- › Build upon the results from the first phase of the technology development → scale up the technology to an integrated prototype system
  - › Startup- and heat-management strategies
  - › Build upon a reactor and system model → control strategy.
  - › Investigate alternative way of producing hydrogen
  - › Techno-economical assessment & business cases
- › Next phase:
  - › Cooperation with OEMs
  - › Ready for scale-up & mass-production



# URBANISATION

Towards an Energy Producing Built Environment  
using compact thermal energy storage

dr. ir. Ruud Cuypers – 17-5-2018  
TNO Sustainable Process & Energy Systems (SPES)  
Leeghwaterstraat 44  
2628 CA Delft  
088-8662472  
[ruud.cuypers@tno.nl](mailto:ruud.cuypers@tno.nl)