PCM-STORAGE: Enabling the efficient and flexible supply of process heat from renewable energies

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DLR

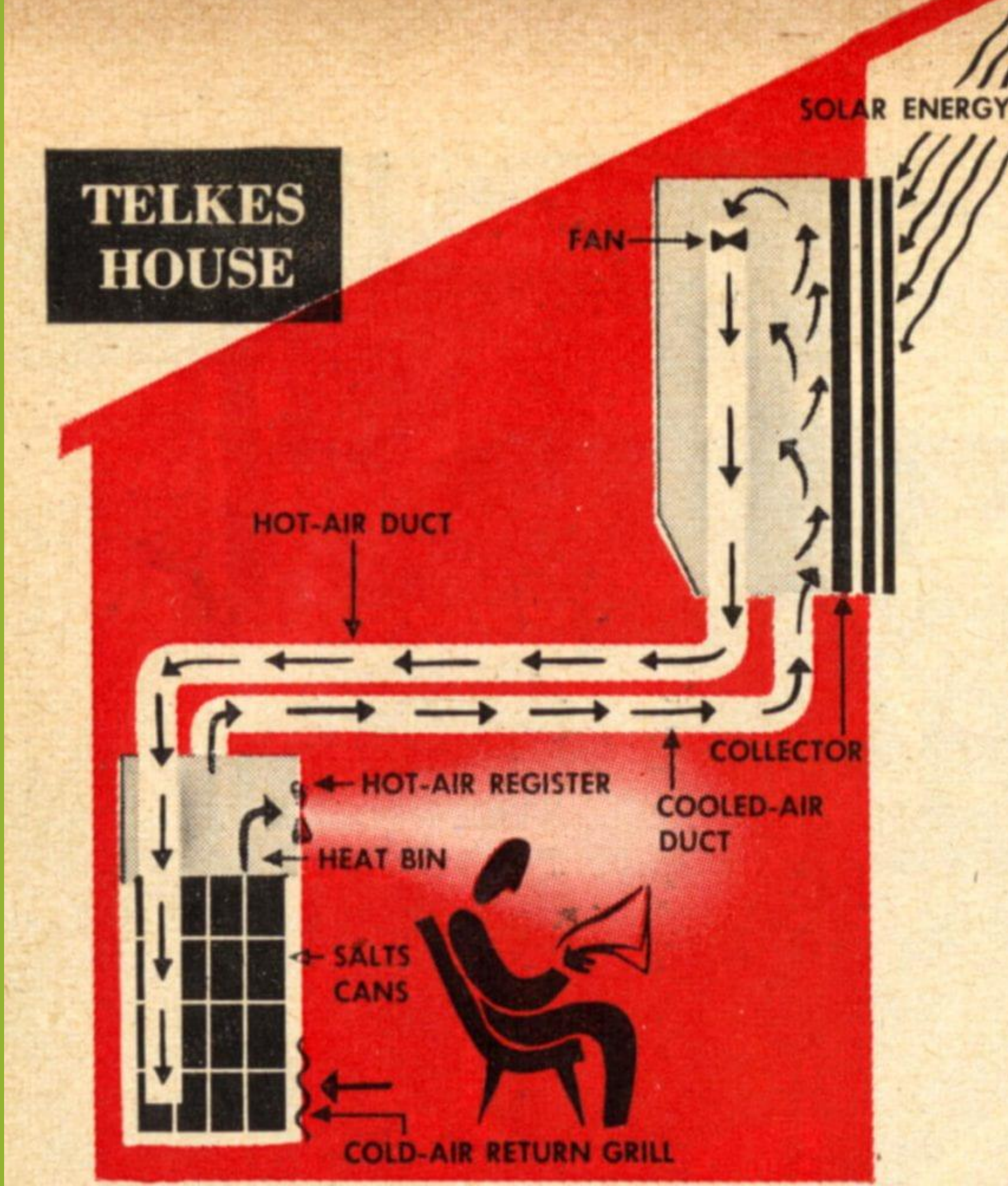
Bridging the gaps:

*How can we support the Energy Transition **today** and in the **Future**?...*

…let's have a look at the past

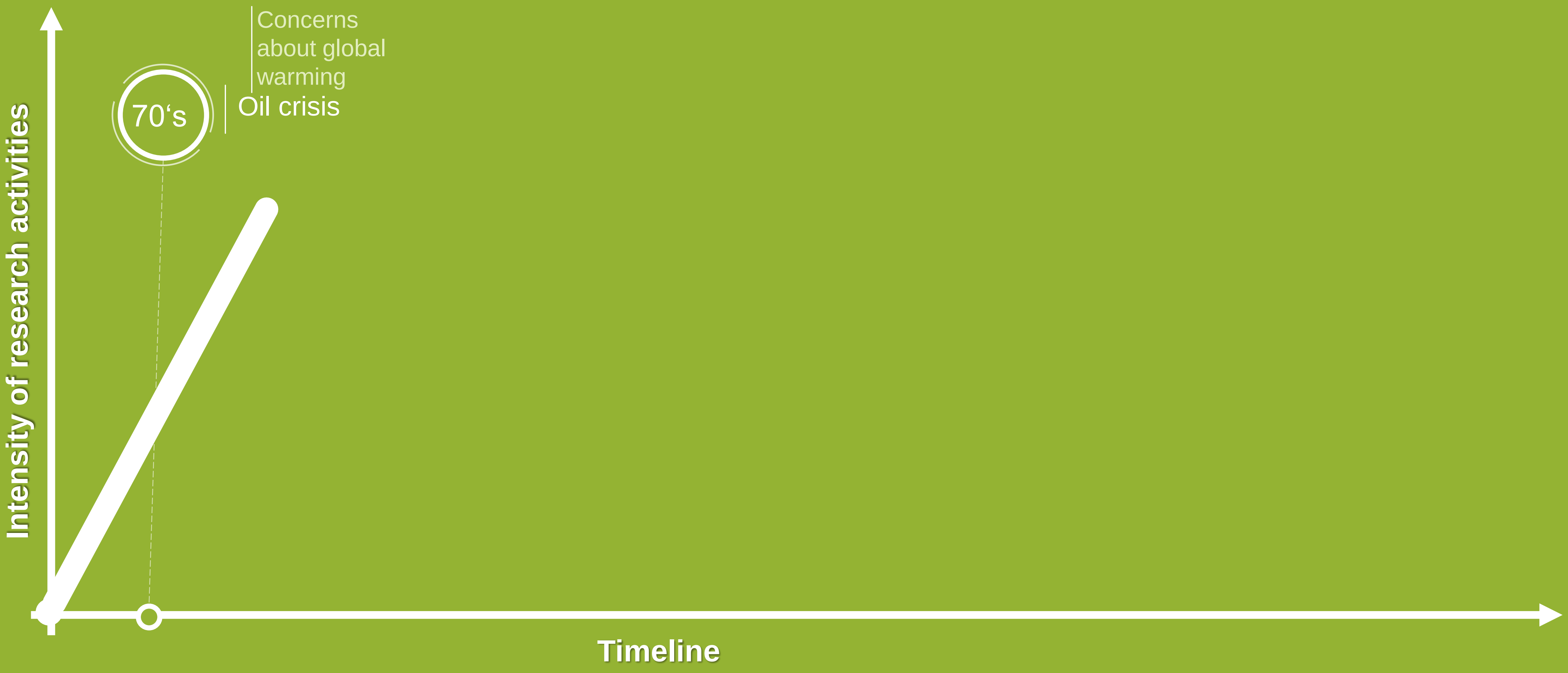
1948
the Peabody
Sun House

Maria Telkes
MIT Engineer - researcher (left)
Eleanor Raymond
Boston University Architect (right)



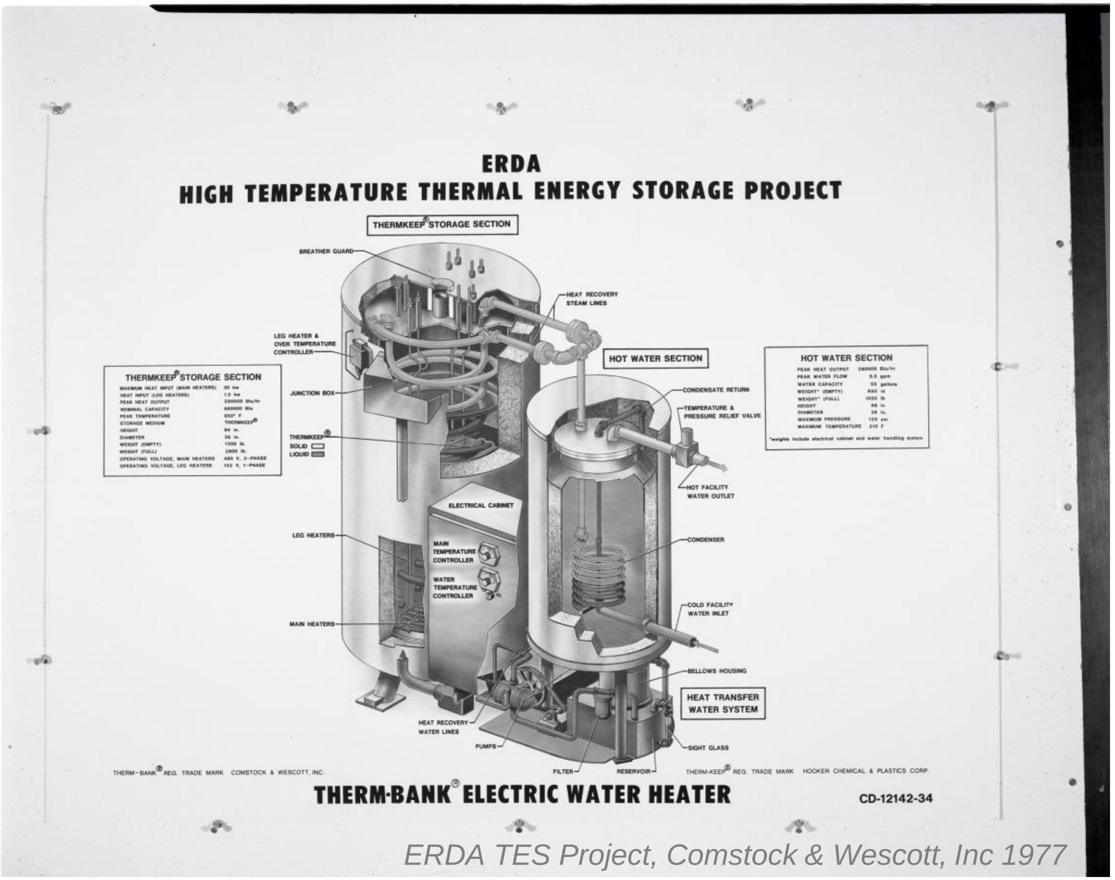
Source: https://energyhistory.yale.edu/

Development of (Latent Heat) TES technologies
… influenced by external factors



PCM Storage development
1977 Therm-bank electric water heater (TEWH)

- Developed by
  Comstock and Wescott Inc (USA)
- PCM-Module (NaOH-NaNO3-MgO2)
- Melting range (234-293°C)
- Stores off-peak electricity for domestic hot water



ERDA TES Project, Comstock & Wescott, Inc 1977

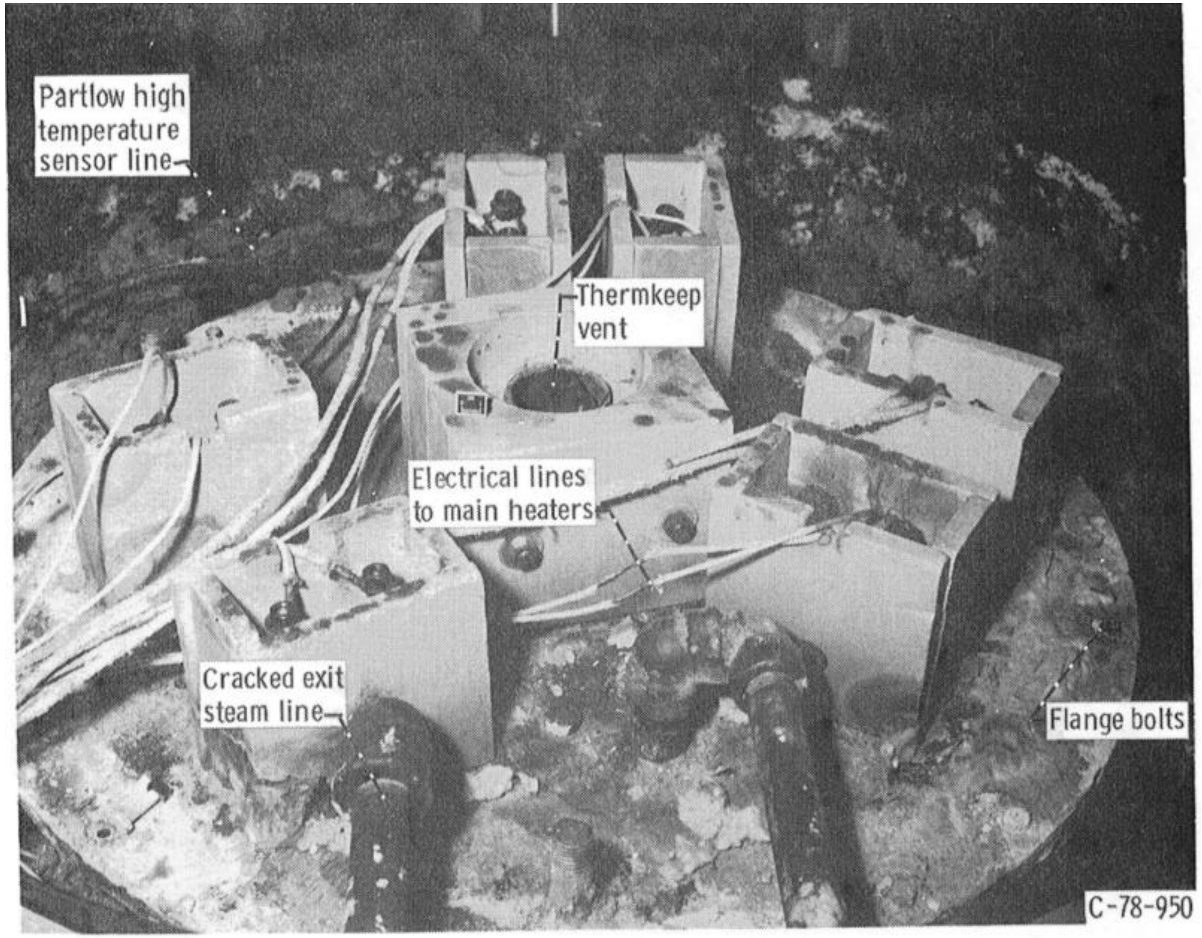
PCM Storage development
1977 Therm-bank electric water heater (TEWH)

Tested succesfully:

- 88% effiency (Therm./Electr.)
- Hot water supplied at 70 °C; 28 l/min

But:

- After 3600 h operation
  internal leackage of molten NaOH
- Corrosion of instrumentation
  and malfunction of HX



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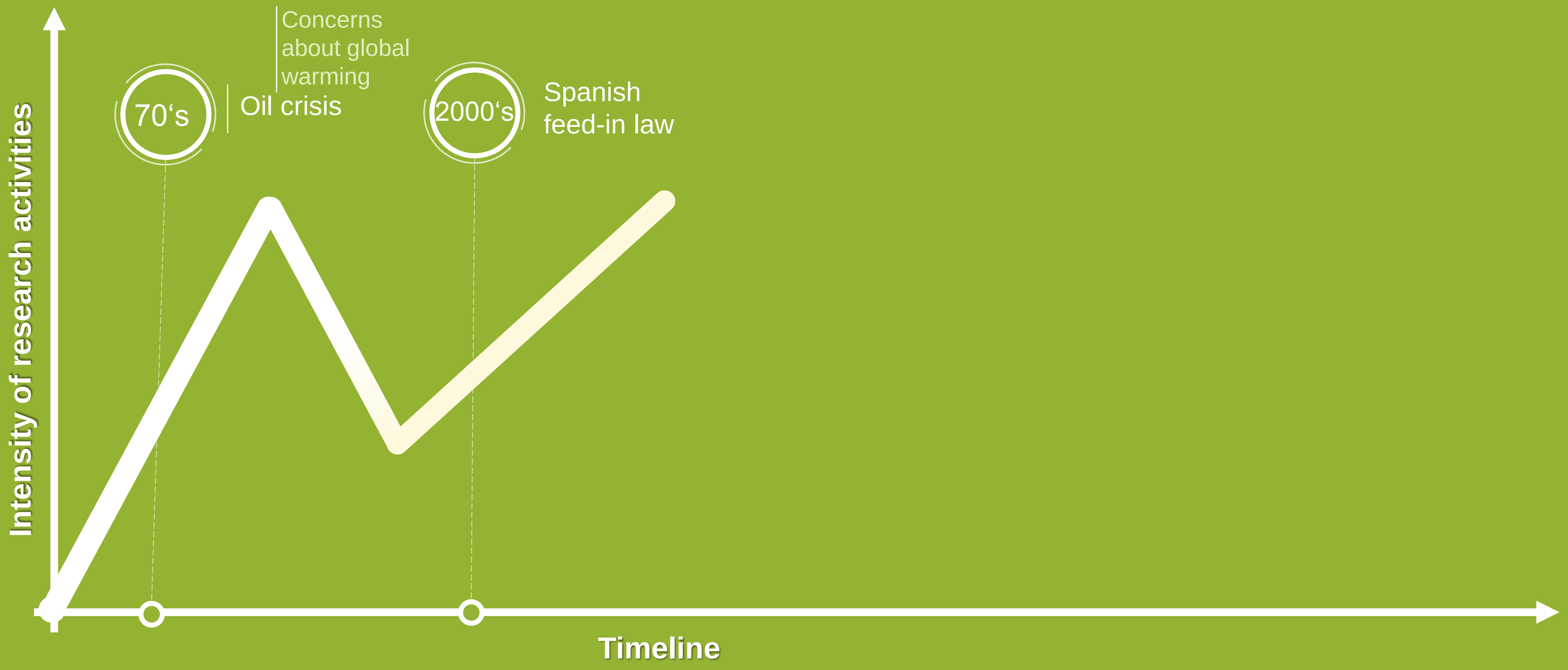
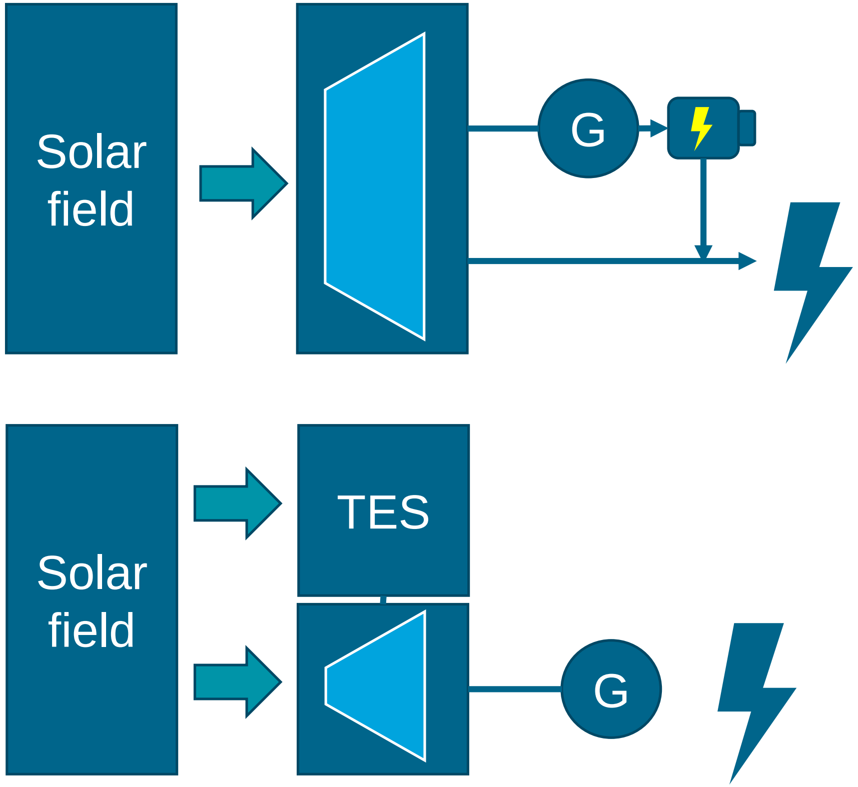


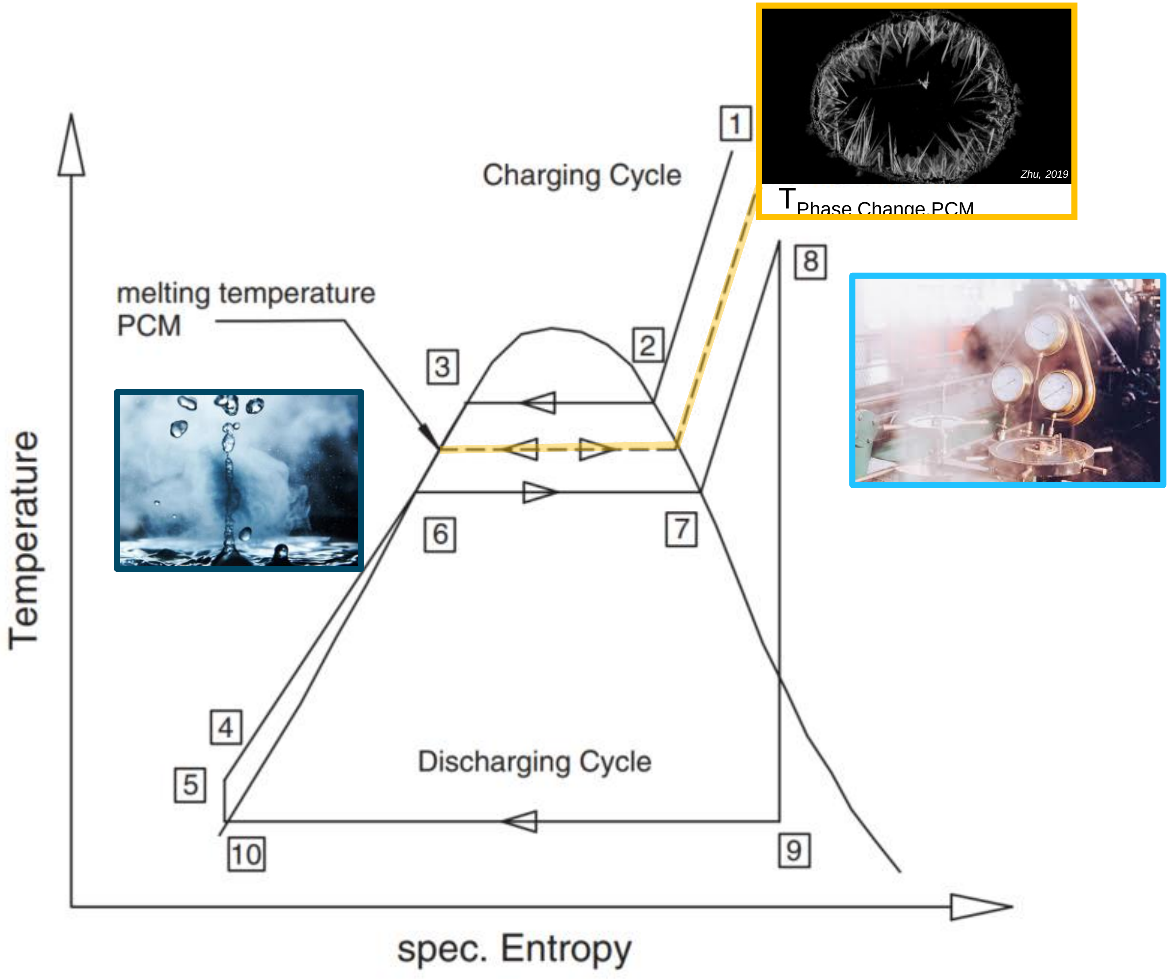
TES & CSP
Made for each other



Nach der Photovoltaik wächst in Spanien die nächste Boombranche heran: solarthermische Kraftwerke

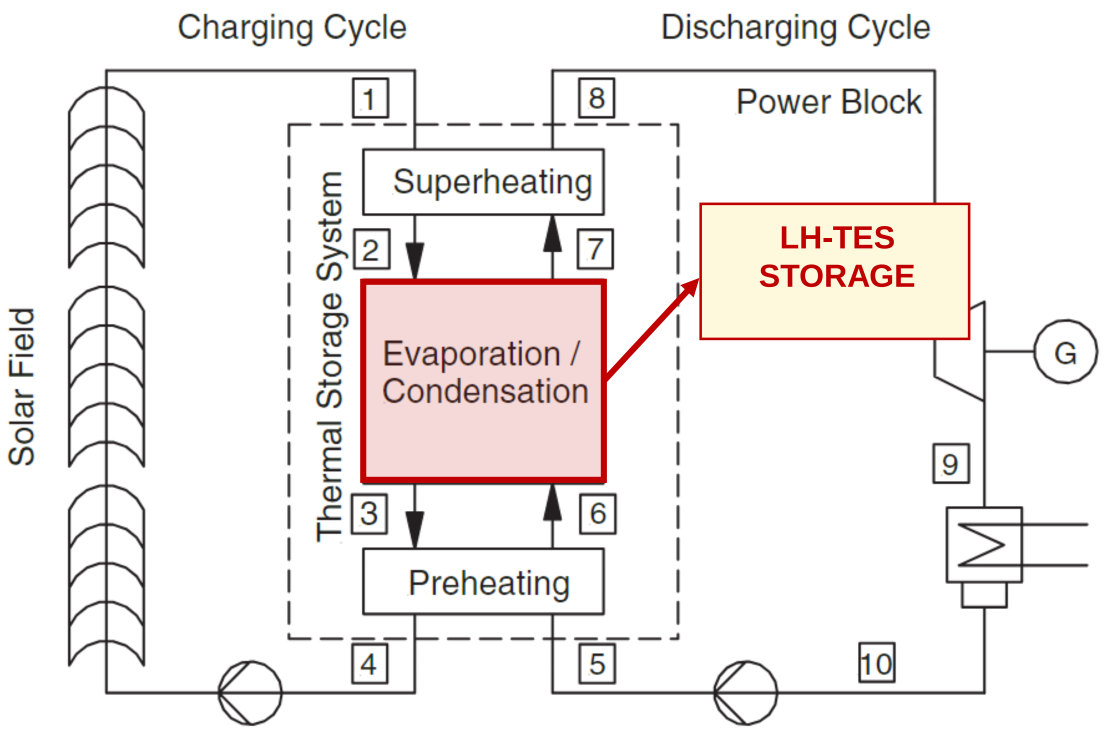
CSP: Operating limitations of thermal oil for sensible storage lead to the development of PCM-Storage systems

- Thermal oil T_{max} = 400 °C
- 2 Tanks molten salt systems
  ➔ Storage range temperatures 282 – 386 °C
- Solar Salt as storage medium
- Energy storage density ~75 kWh_{th}/m^3



DSG – The Initial Motivation for PCM Development

Integration of energy storage in a simplified parabolic trough power plant with direct steam generation



- **Steam cycle at about 100 bar (311 °C)**
- **Discharging over multiple hours**
- Concrete sensible heat preheating & superheating
- LH-TES – condensor/evaporator
  - Charging 105.6 bar (315 °C)
  - discharging 80 bar (295 °C) ~ **700 kW**

Tamme, R., Bauer, T., Buschle, J., Laing, D., Mueller-Steinhagen, H., & Steinmann, W.-D. (2008). Latent heat storage above 120 C for applications in the industrial process heat sector and solar power generation. Journal of energy Research, 032736017(July 2007), 264-271. doi:10.1002/er

High thermal conductivity structures in LH – TES
Development and testing at lab scale

Solar Salt ($NaNO_3$-$KNO_{3,(EU)}$) – $T_{PCM,melting}$: 225 °C – 1kW

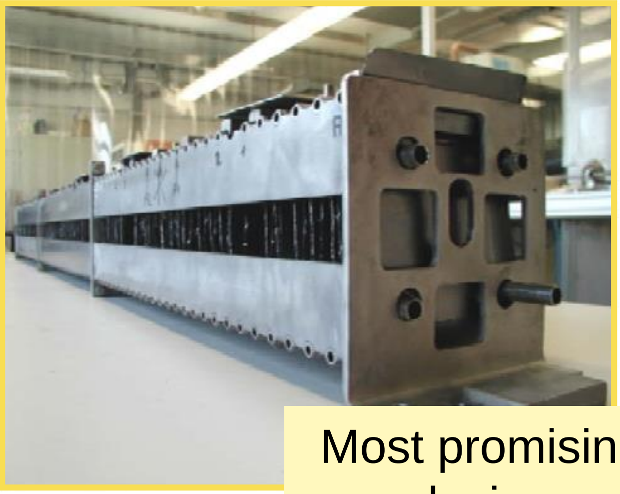
Objective

- increase the **heat transfer area**
- Increase **the effective thermal conductivity**

Macro-encapsulation of PCM

Composite PCM - EG

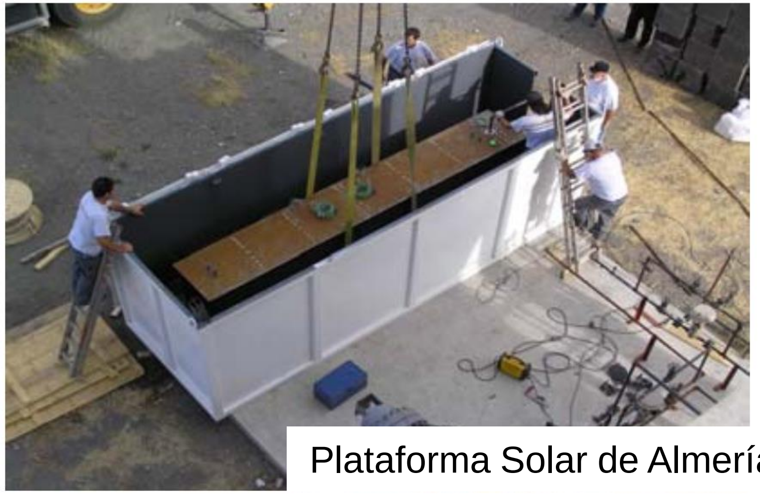
Sandwich Design Graphite foil as fins



Most promising design

High thermal conductivity structures in LH – TES
Testing at large scale

100kW Demonstrator fed with steam from CSP Plant



Plataforma Solar de Almería

- 2 tonne, $NaNO_3$-$KNO_{3,(EU)}$ - **$T_{melting}$: 225 °C**
- Design steam pressure: 25 bar

Main results

Max. $power_{CHARGING}$: 150 kW_{th}
Avg. $power_{CHARGING}$: 90 kW_{th}

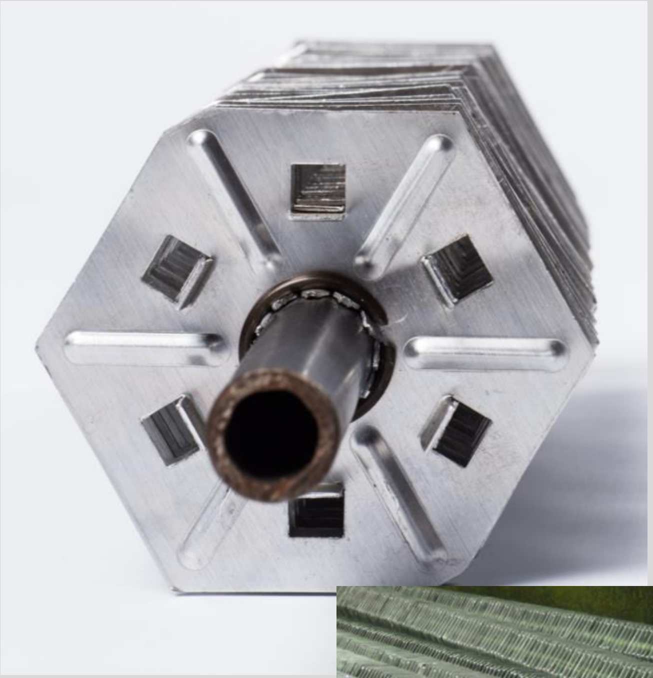
Max. $power_{DISCHARGING}$: 90 kW_{th}
Avg. $power_{DISCHARGING}$: 35 kW_{th} for 1 h

Storage Capacity **~ 40 kWh**

From graphite to aluminium fins

Commercially available Alu-fins

After numerical optimization & 4000h testing



Factors studied → Influence of

- fin geometry
- fin thickness
- a gap between fin and tube
- a fin with a collar

SES6-CT-2004-503526, DISTOR: Energy Storage for Direct Steam Solar Power Plants – EU – Project
ITES - Entwicklung und Integration Thermischer Energiespeicher in Rinnenkraftwerken mit Solarer Direktverdamfung -
16UM0064 – 65

LH-TES developed in the frame of ITES Project (2006-2012)
Direct steam generation – 700kWh Demonstrator

Highlights of the LH-TES development during the project:

- $NaNO_3$ (305°C) identified and characterized as PCM for steam generation up to 350 °C
- Proof of technical feasibility through design, construction and testing of PCM-Storage

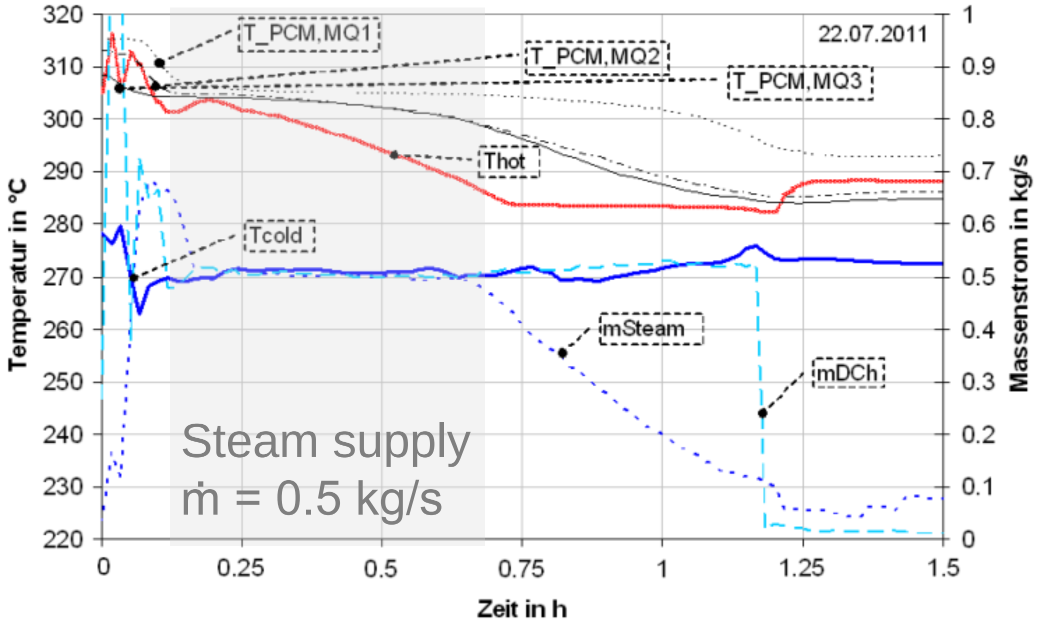
PCM Module Evaporator & condenser

- 3 t PCM ($NaNO_3$) @305 °C - 700 kWh
- Steam cycle @ 100 bar (311°C)
- > 3000h in different operating modes

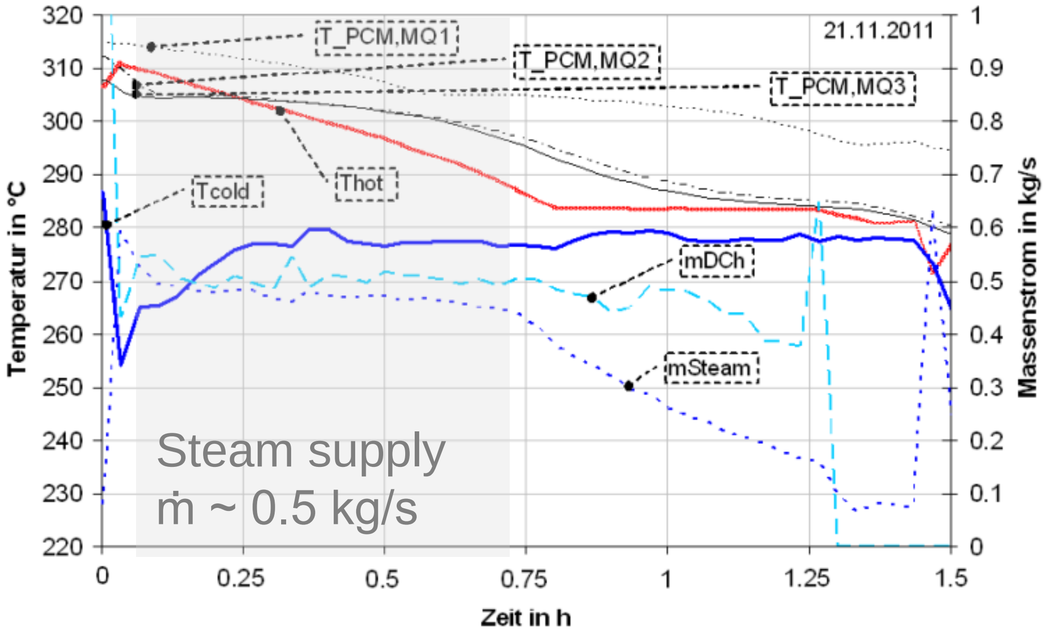
LH-TES developed in the frame of ITES Project

Direct steam generation – results

Forced circulation



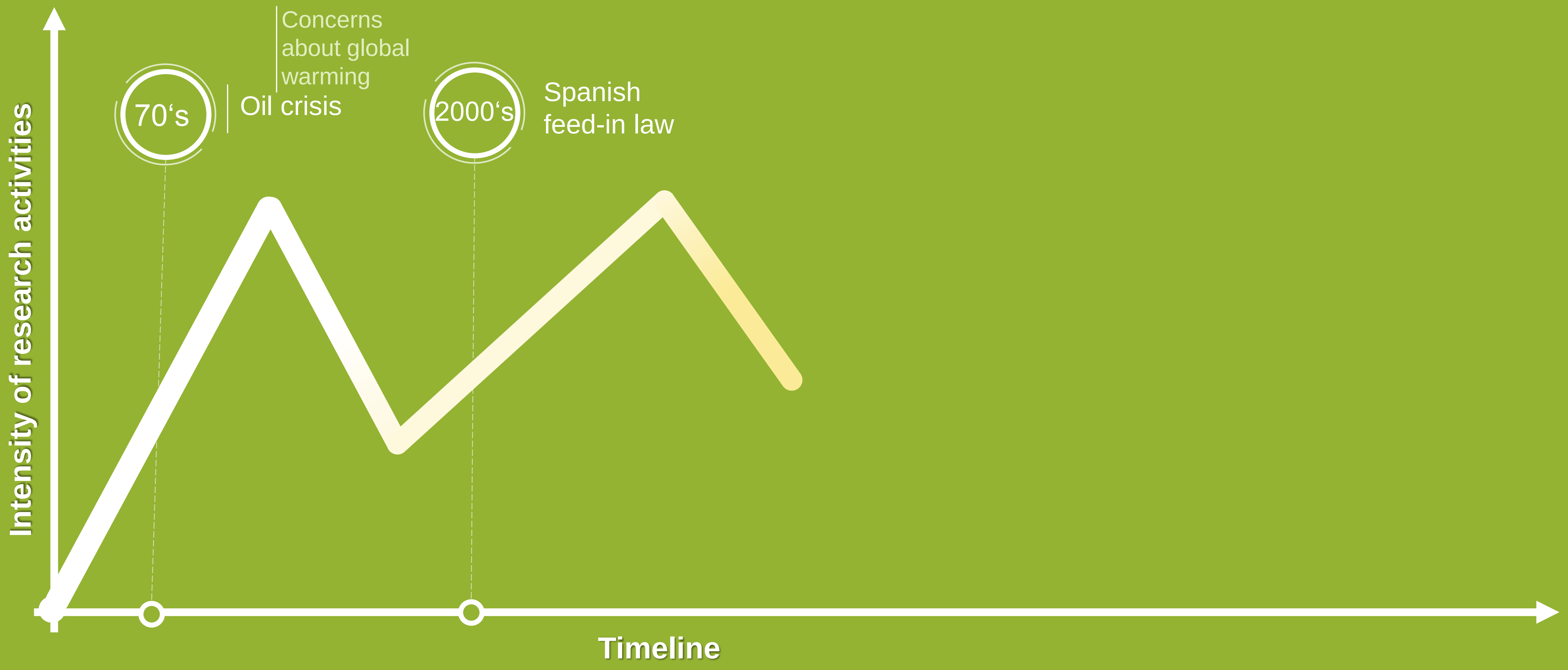
Once-through concept



Fixed steam pressure 69 bar & mass flow 0.5 kg/s (corresponds to 750 kW_{th})

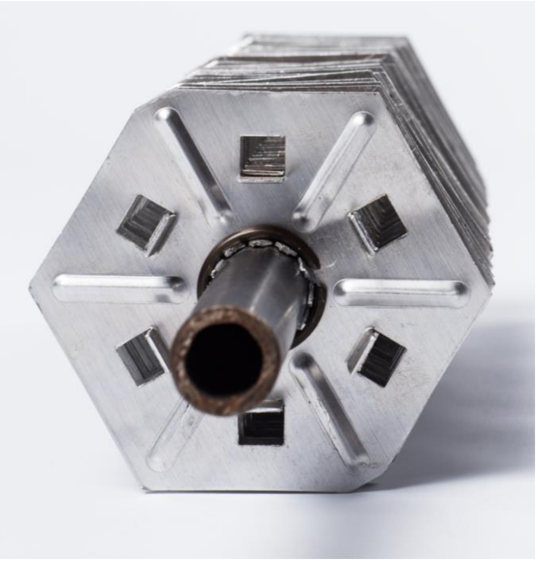
→ **Technical requirements met, estimated cost of 200 €/kWh**

Development of (Latent Heat) TES technologies … influenced by external factors

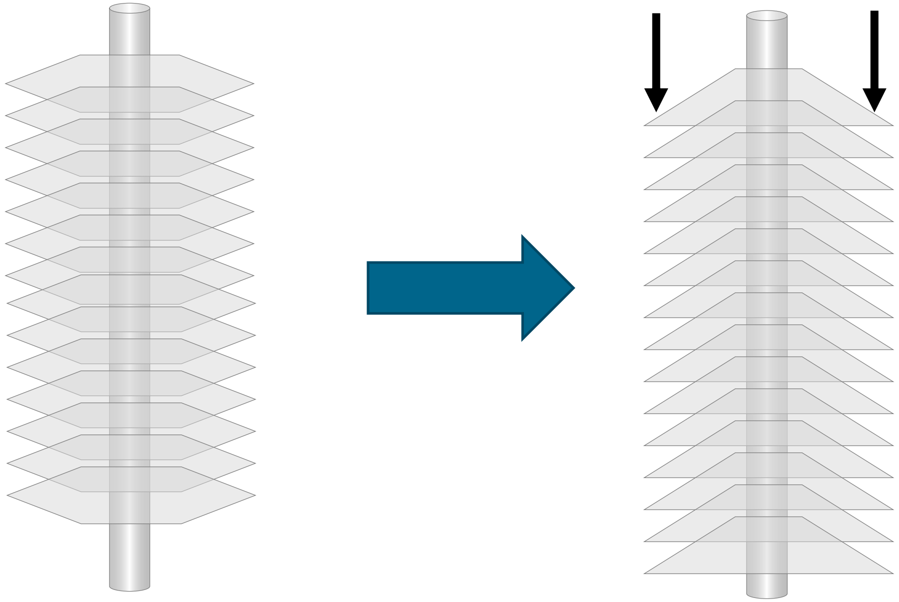


Cost reduction through larger tube pitch and fins
A challenging endaveour

- Larger diameter of aluminium **radial fins** in vertical position of the tube-and-shell heat exchanger

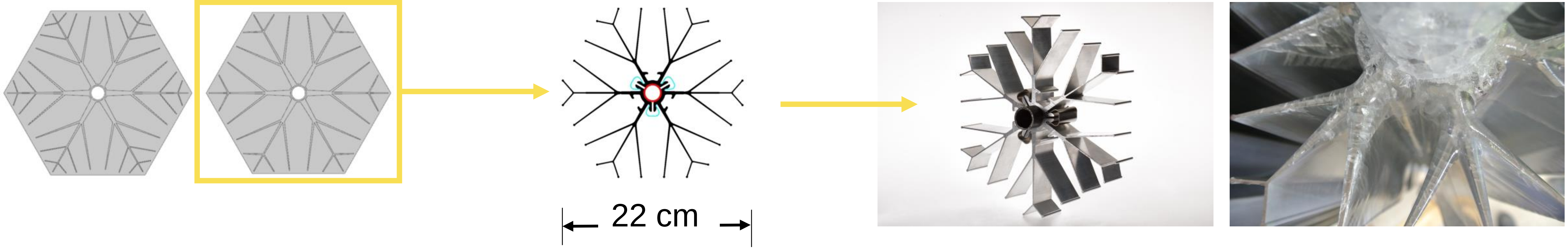


The aluminum loses its hardness with temperature and the radial fins get a Christmas tree-like shape



- Estimated costs of 71 to 86 €/kWh possible

Extruded Axial fins
Optimized high thermal conductivity structures



Design for high storage capacity & optimal manufacturing

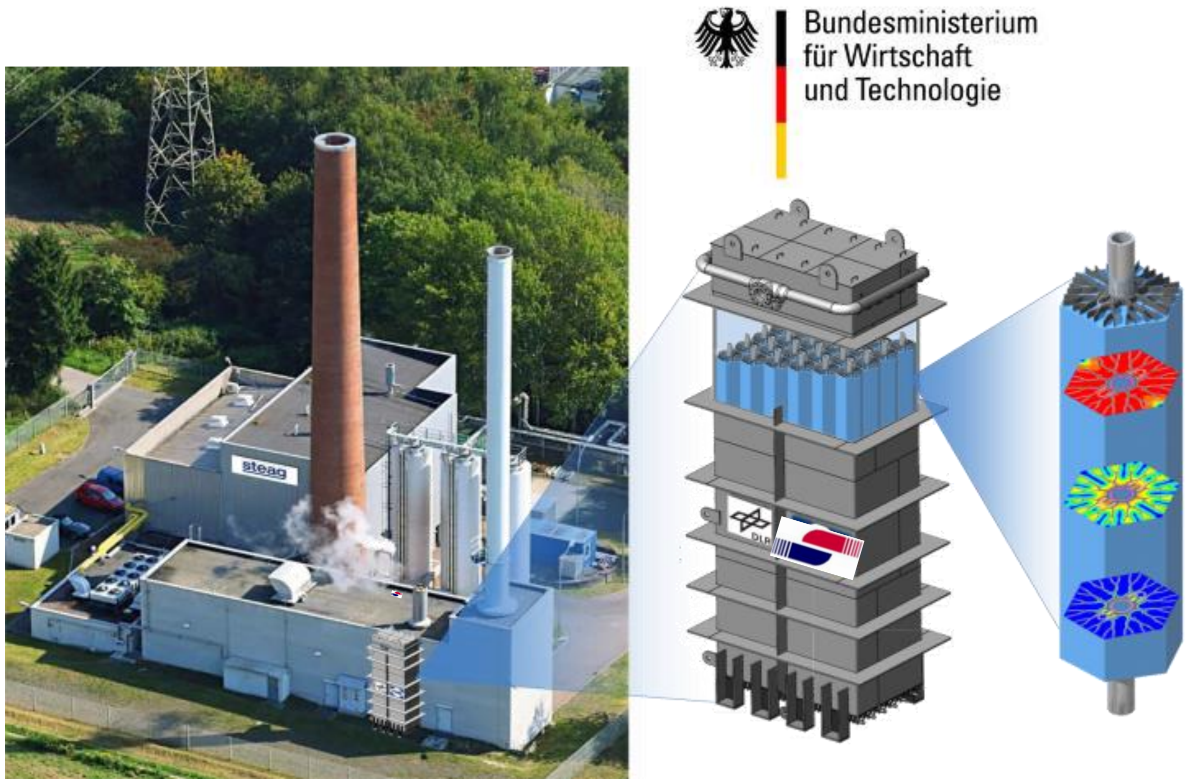
PCM:	$NaNO_3$
Melting Temperature:	306 °C
Total PCM mass:	ca. 3.3 t
Active PCM mass:	ca. 1.3 t
Latent heat, active:	70 kWh

Projekt DSGstore

THE LINDE GROUP

Linde

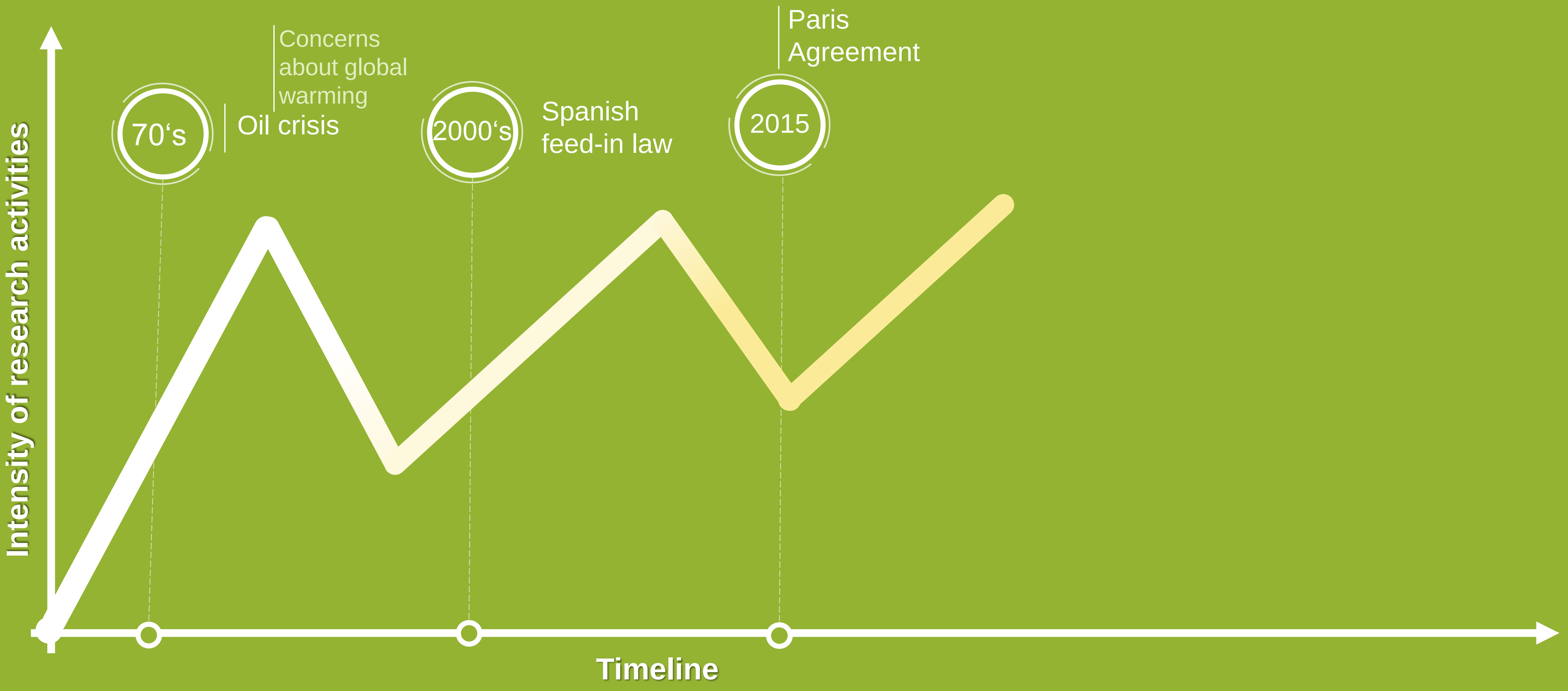
The TESIN Project was born



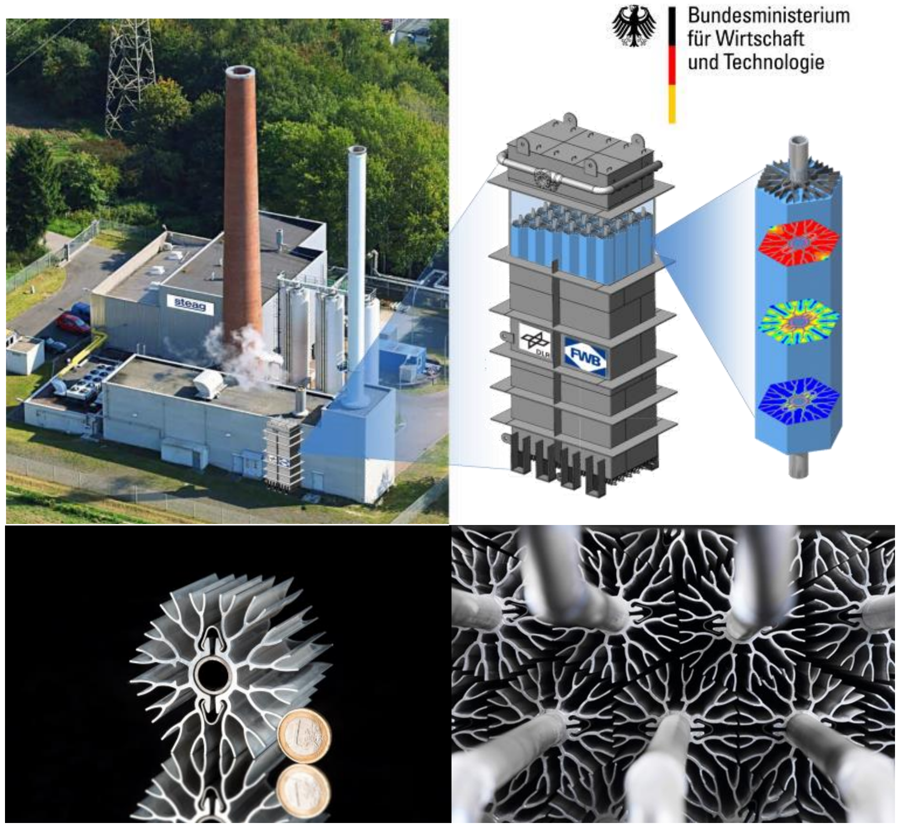
Very ambitous goals :

- Complete integration in the power plant
- Generate superheated steam in the MW power rate

Development of (Latent Heat) TES technologies
… influenced by external factors



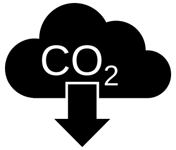
Project TESIN – 1,5 MWh Demonstrator
Stand-by LH-TES integrated in a co-generation plant



- **Technical parameters required by the user**
  - Direct superheated steam
  - @ 300 °C, 26 bar, 8 t/h, 15min

- **Large scale PCM-Storage unit**
  - → thermally charged/discharged
  - → **6 MW power rate for at least 15 min**
  - →1.5 MWh storage capacity
  - →32 t PCM ($NaNO_3$)

- **Expected annual reduction in the fuel requirements: 5 000 MWh**
  - CO2 savings Approx. 2 200 t/a
  - 66 000 €/a savings in CO2 taxes*
  - fuel costs saving of 75 000 €/a.

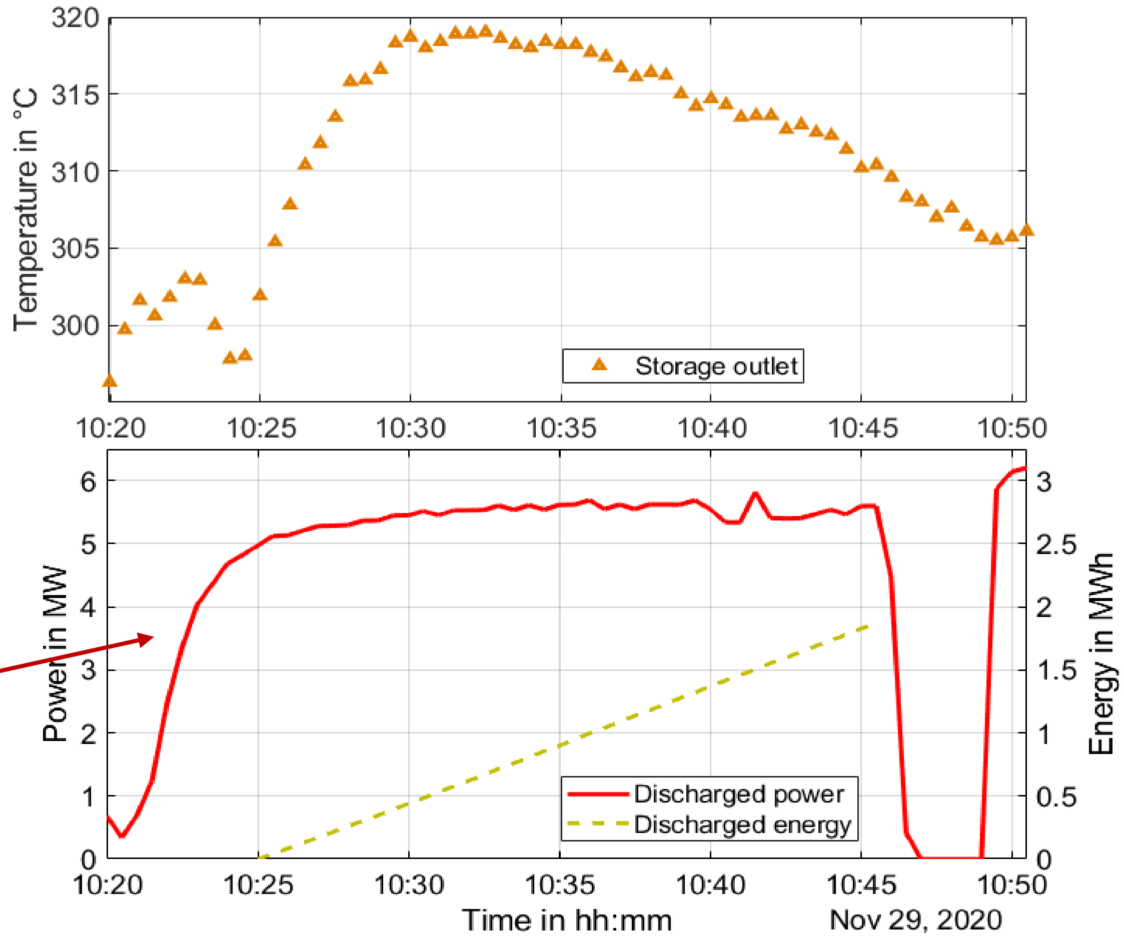


**Based on the CO2 taxes prices (30 €/t) in 2023 in Germany*

German Project TESIN
Experimental results

- Superheated steam supply demonstrated
- First operational integration of a latent heat steam generator
- Demand of the co-generation plant was met

5.46 MW for 20 minutes at quasi-nominal conditions



Source: Johnson, M., Fiss, M. Superheated steam production from a large-scale latent heat storage system within a cogeneration plant. Commun Eng 2, 68 (2023). https://doi.org/10.1038/s44172-023-00120-0

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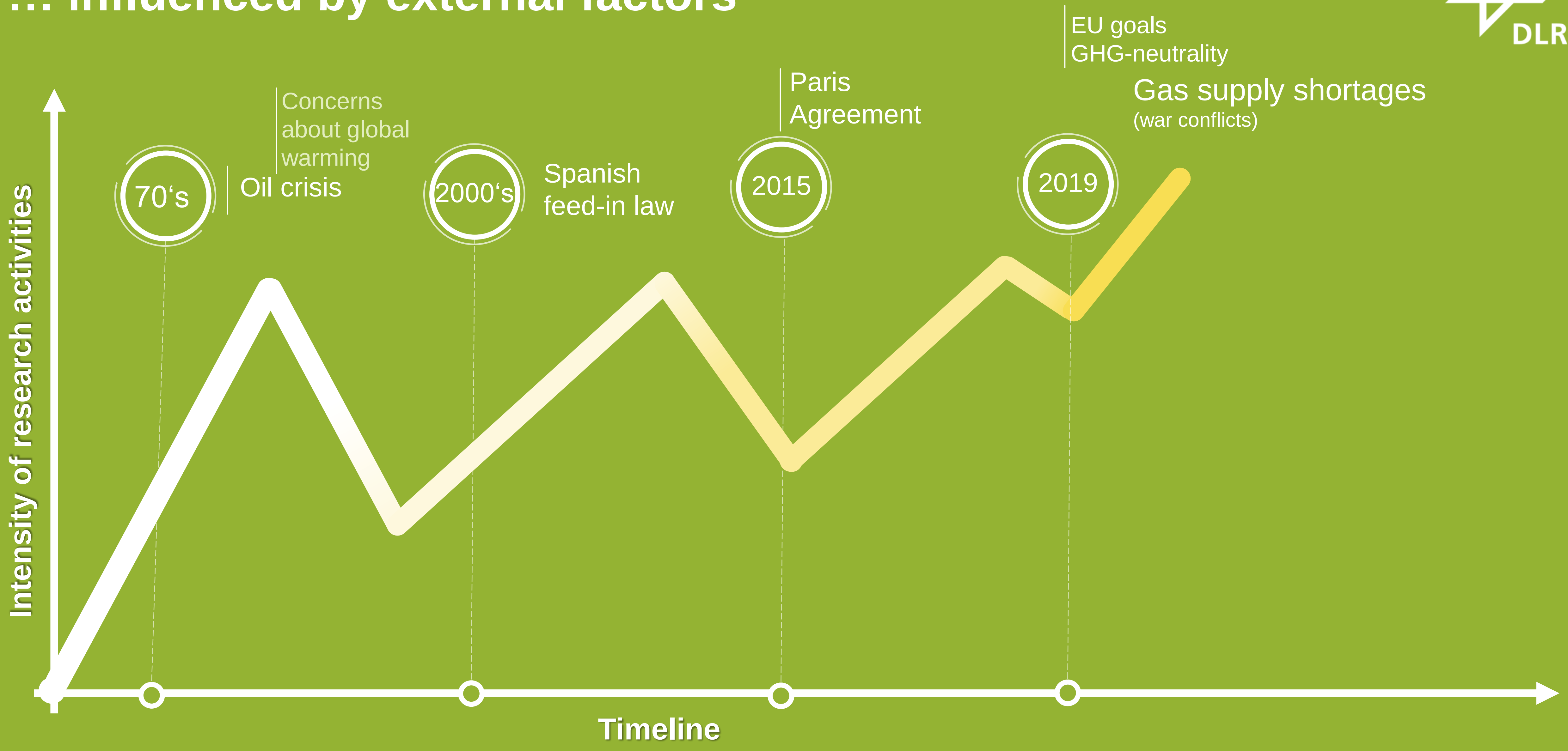
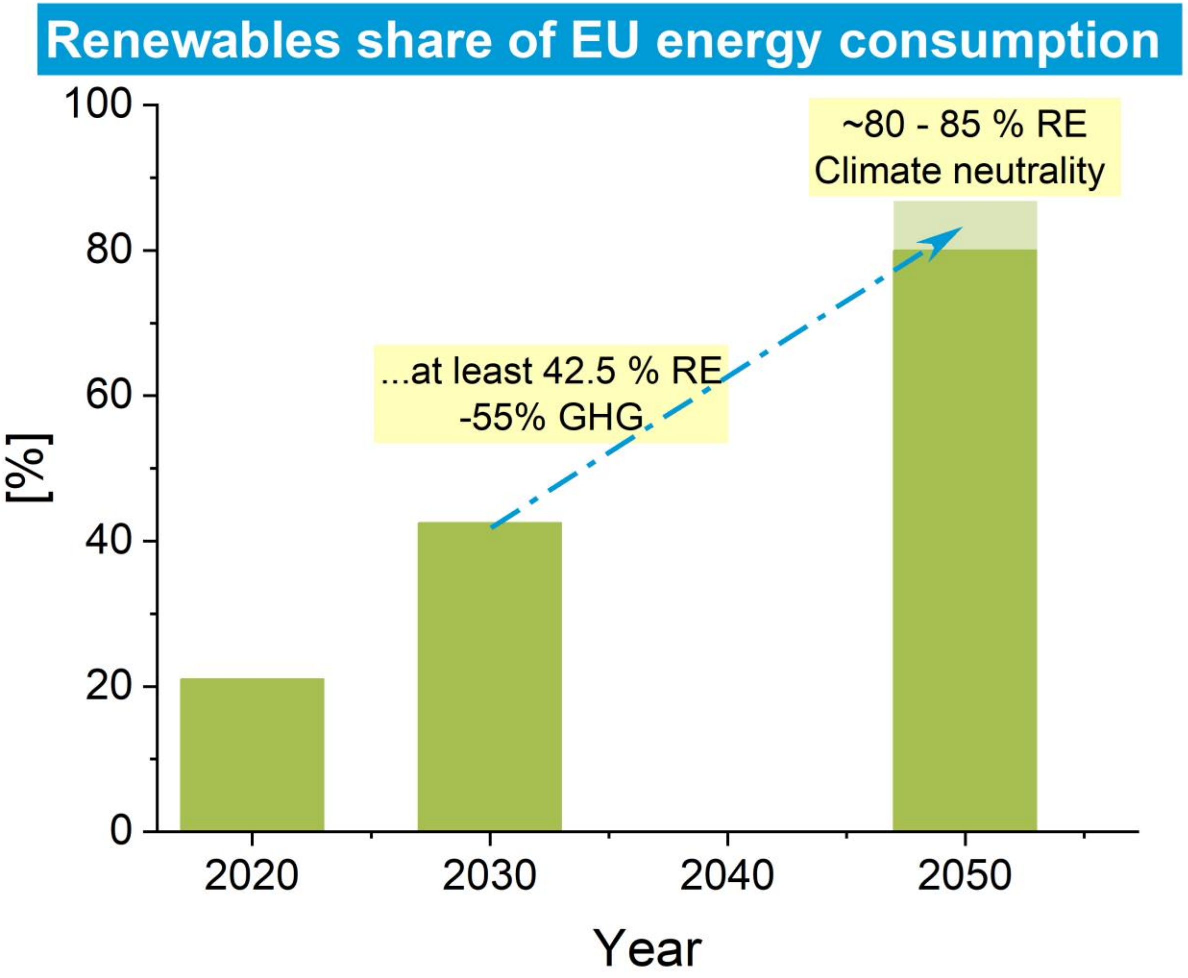


The first carbon neutral continent by 2050



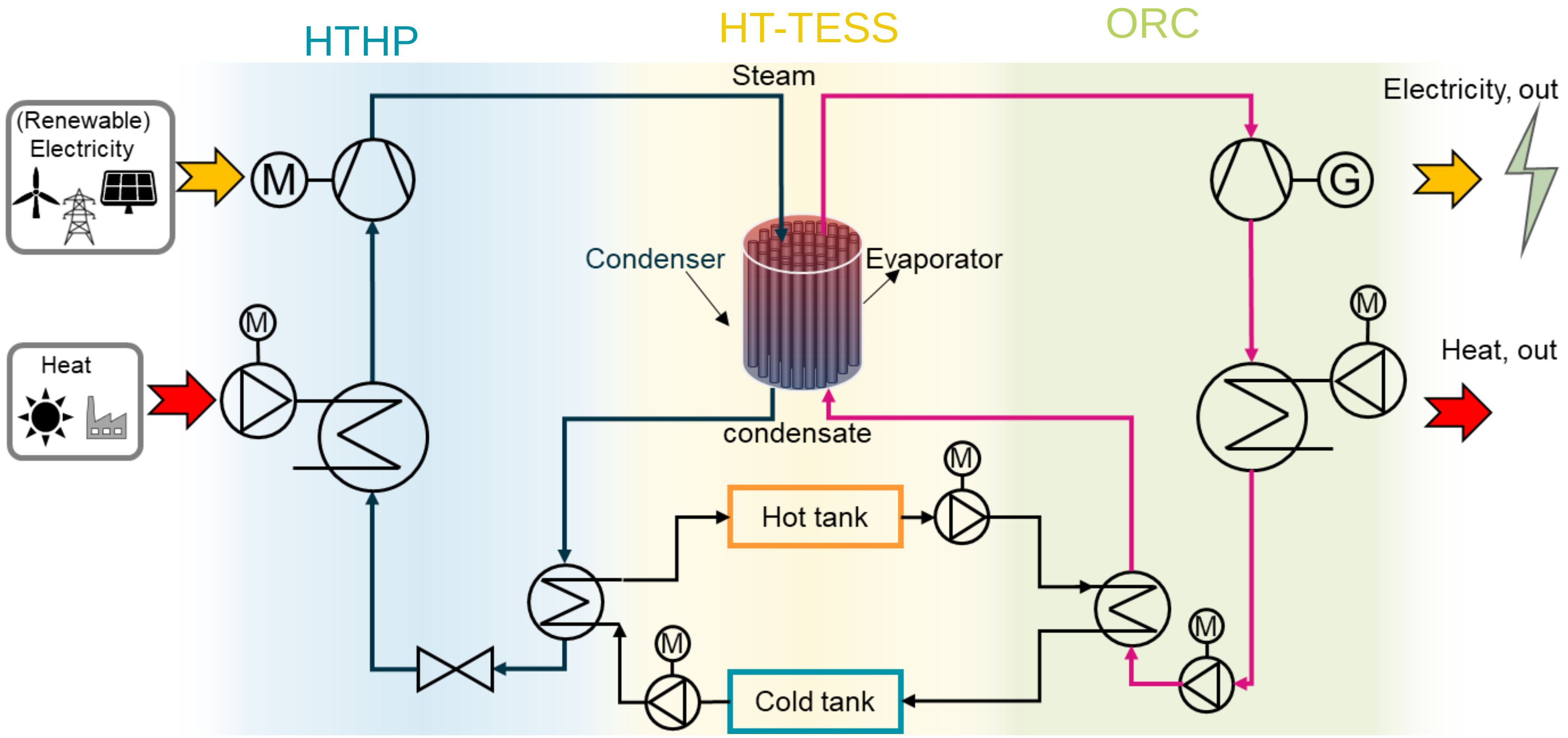
Based on two main strategies

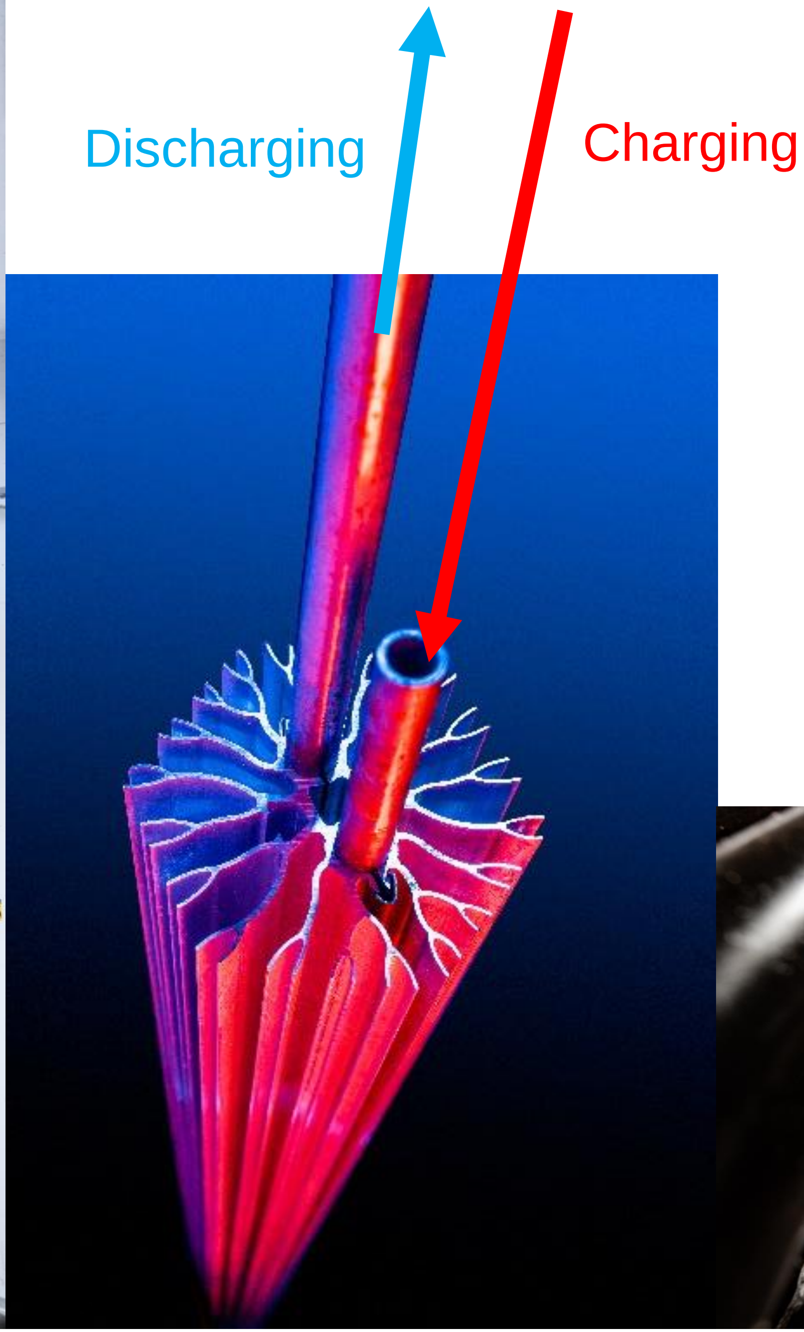
1. **Increase the efficiency of energy use**, hence reduce the total energy consumption

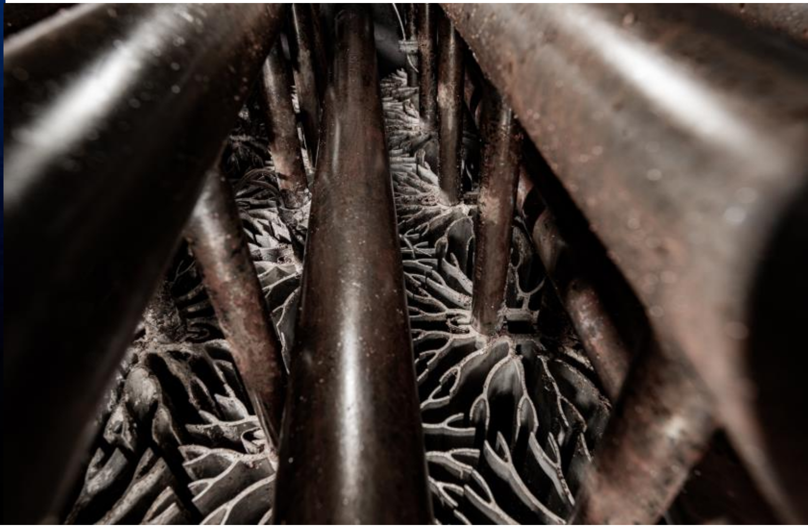
2. **Expansion of renewable electricity capacity**
   592 GW Solar PV and
   510 GW Wind by 2030

Solution to balance the grid are urgently required …

Rankine based Carnot Battery ➔ EU Project CHESTER







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CHESTER
Compressed Heat Energy Storage for Energy from Renewable sources

Solutions to integrate RE in the energy grid
Sector coupling

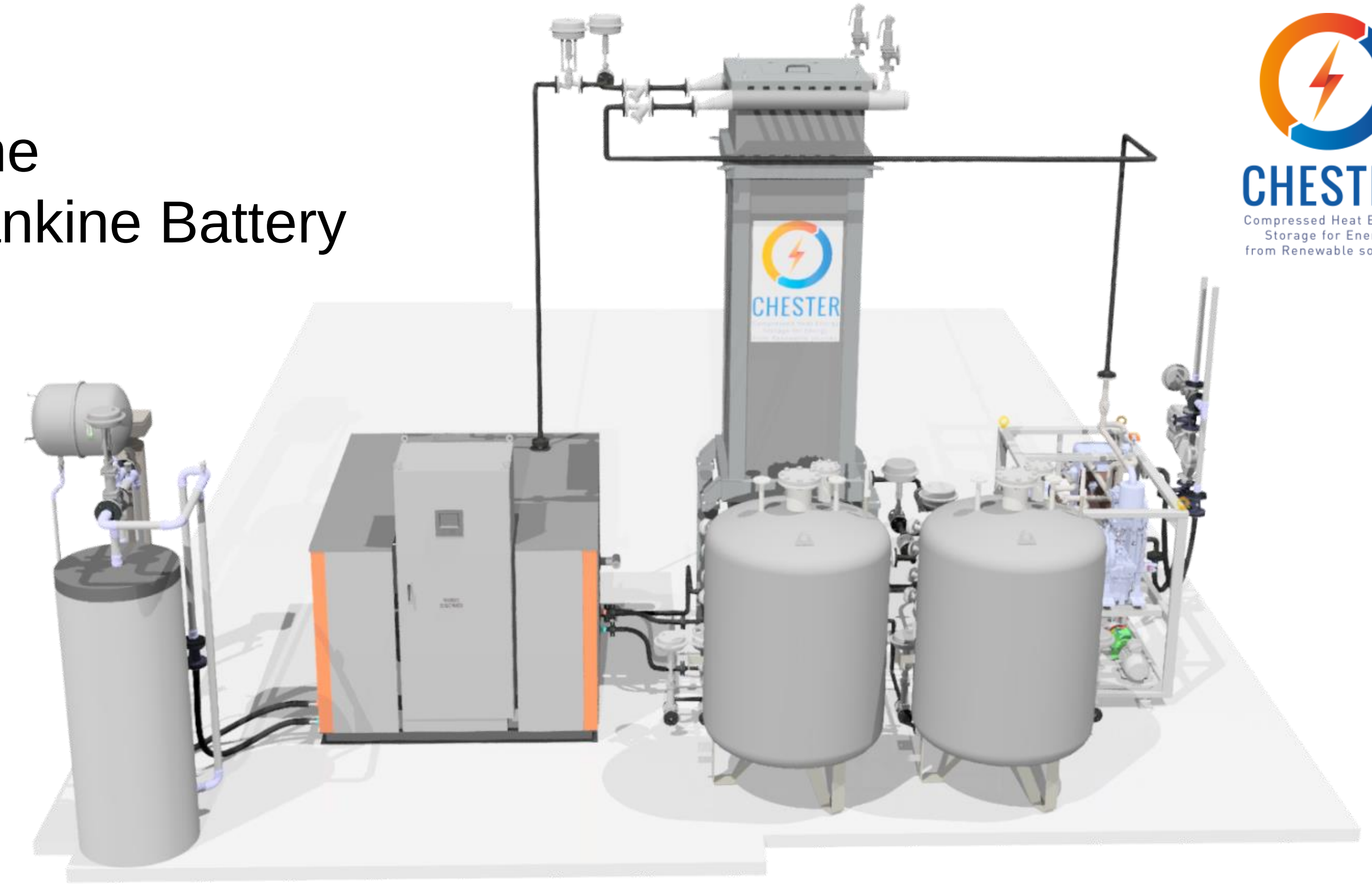
DLR

CHESTER
Compressed Heat Energy
Storage for Energy
from Renewable sources

- CHESTER – Operation of the first of its kind - 10 kW_{el} - Rankine Battery
- Organic working fluids

<u>LH-TES Unit</u>

- Vertical shell-and-tube HX
- Dual-tubes with axial aluminum fins
- Two refrigerant cycles
- Storage capacity: 160 kWh @ 133 ºC
- 45 kW_{th} Charging (avg.)
- 60 kW_{th} Discharging (avg.)



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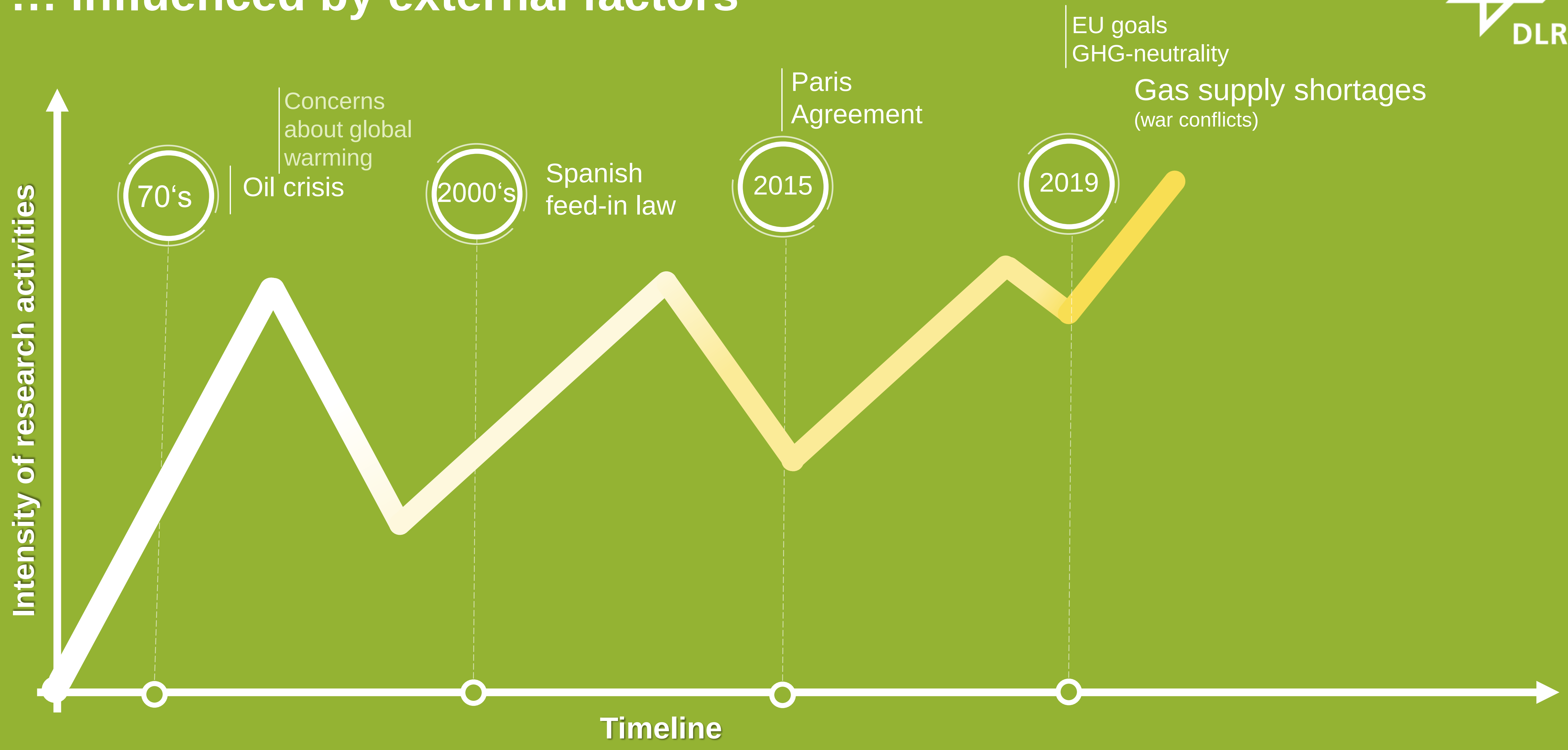


Kick-Off PCM-Grid
Electricity-powered steam generators with storage capability

Gefördert durch:

Bundesministerium für Wirtschaft und Klimaschutz

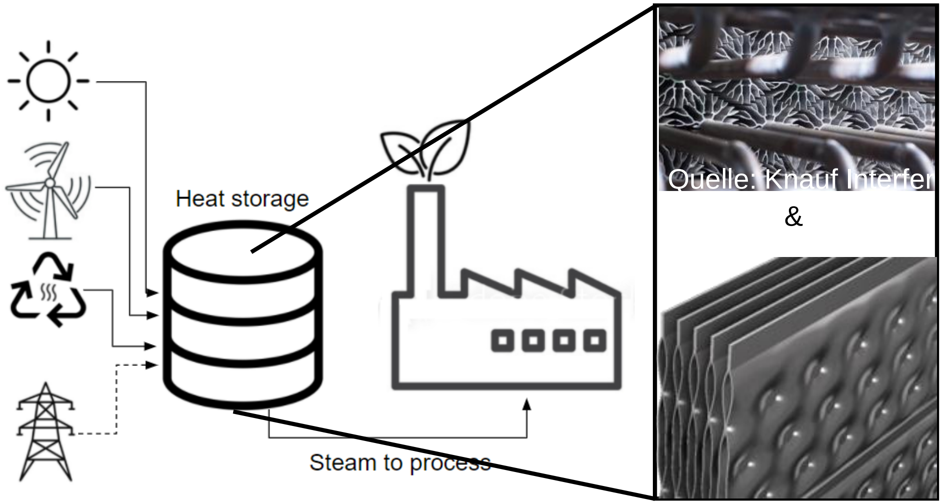
aufgrund eines Beschlusses des Deutschen Bundestages

Motivation:

- Electrify industrial heat flexibly and reliably by integrating PCM storage systems

Objective:

- Development of an electrically powered steam generator with storage function and testing in real operation
- **Consortium**
  - DLR e. V.
  - Viessmann Industriekessel Mittenwalde GmbH,
  - RuLa-BRW GmbH
  - Fraunhofer IFAM.
  - Progroup AG (Ass.)
  - Knauf Interfer (Ass.)



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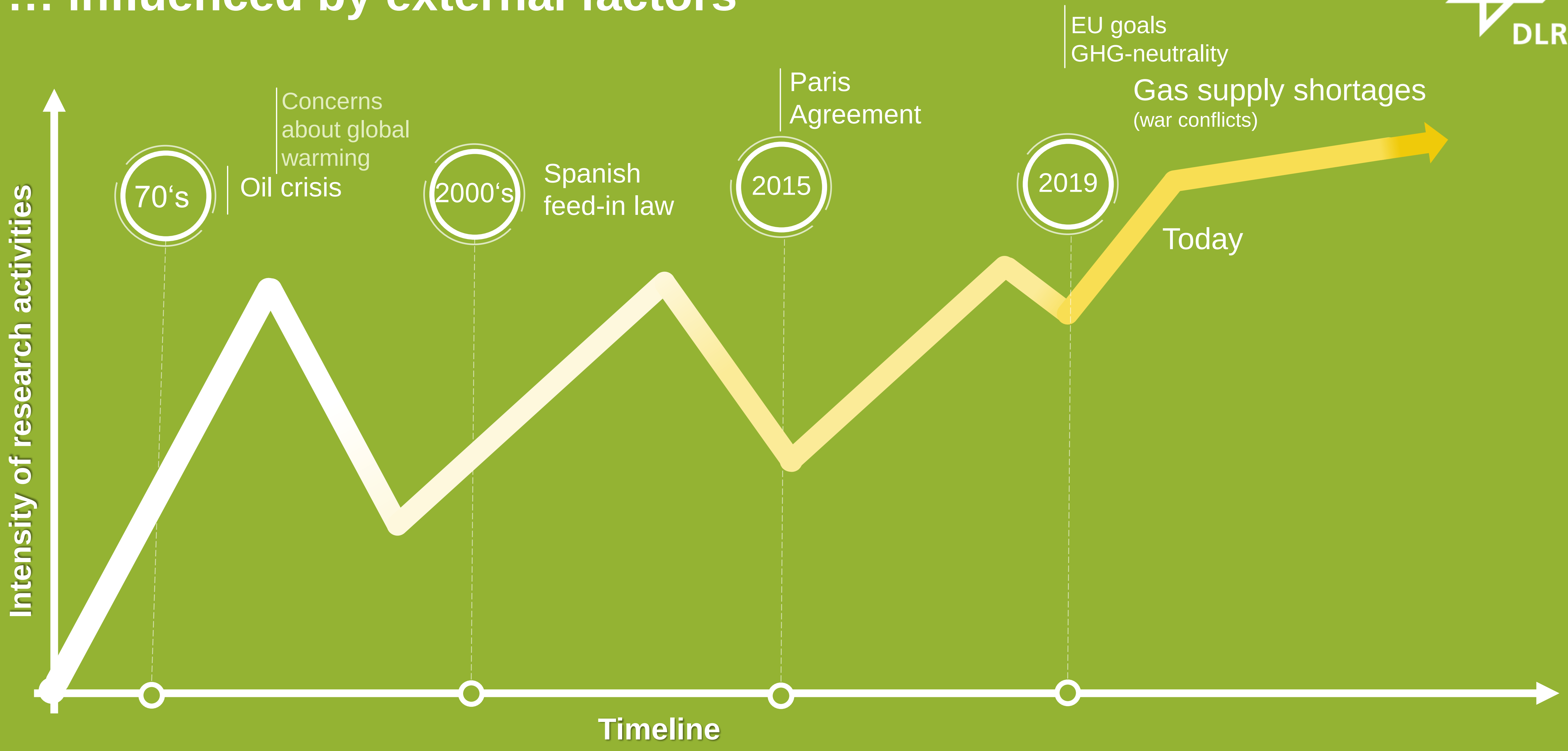

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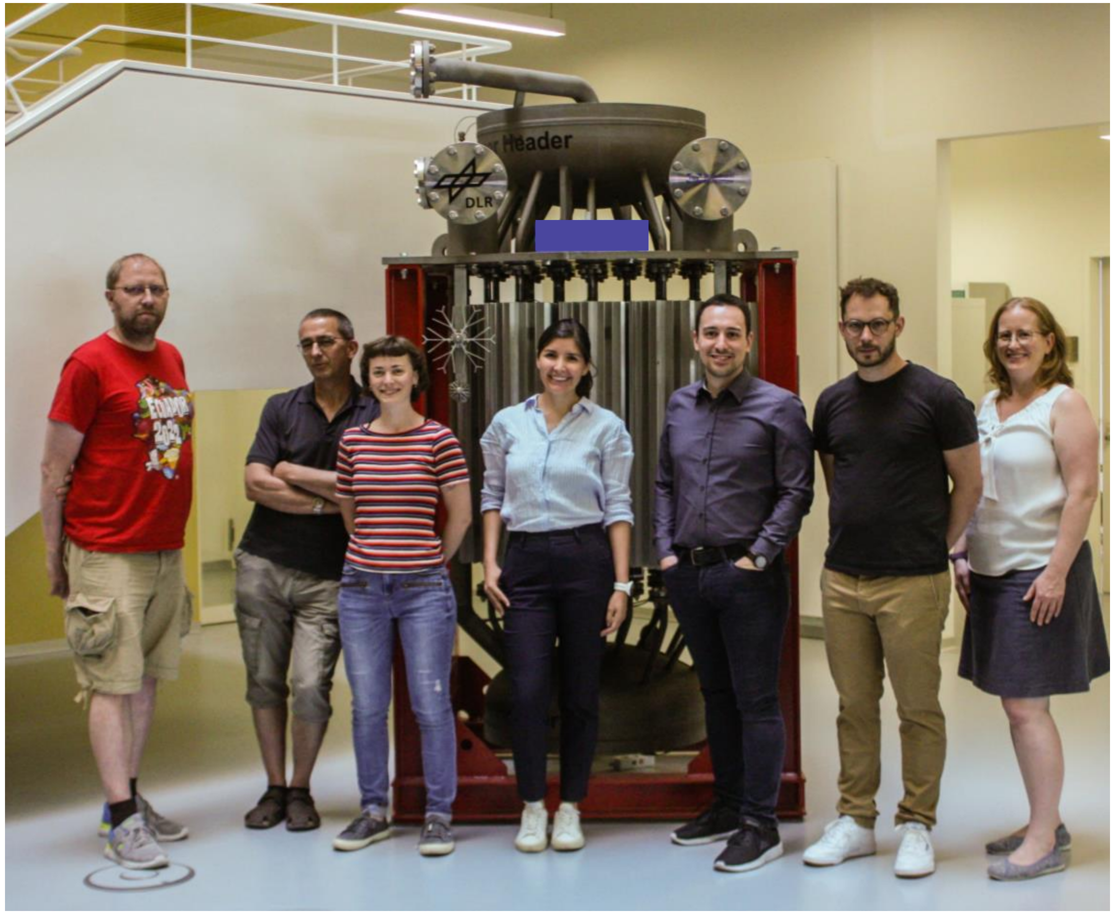

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