LIMTECH Alliance
HEMCP:Helmholtz Energy Materials Characterization Platform

High Temperature Direct Energy Conversion for Concentrated Solar Power

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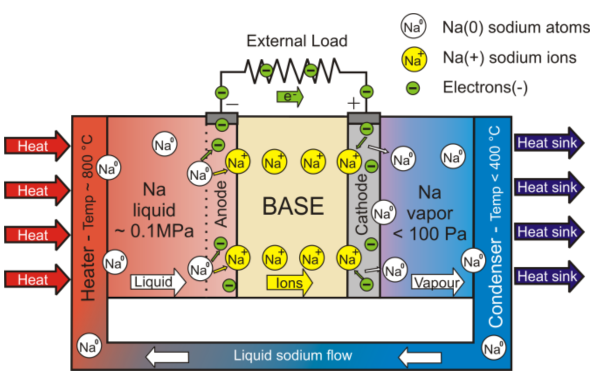
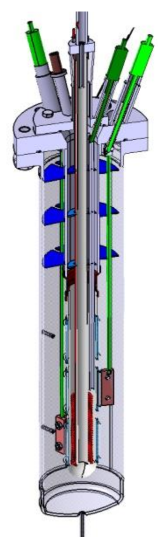
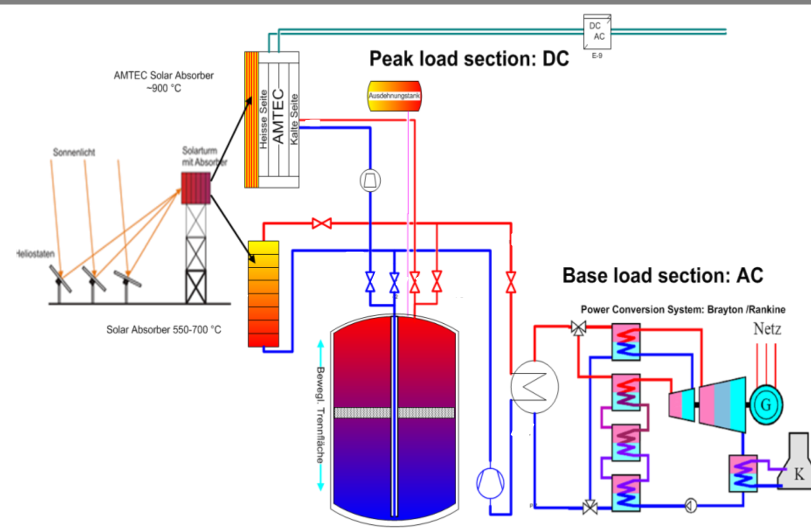
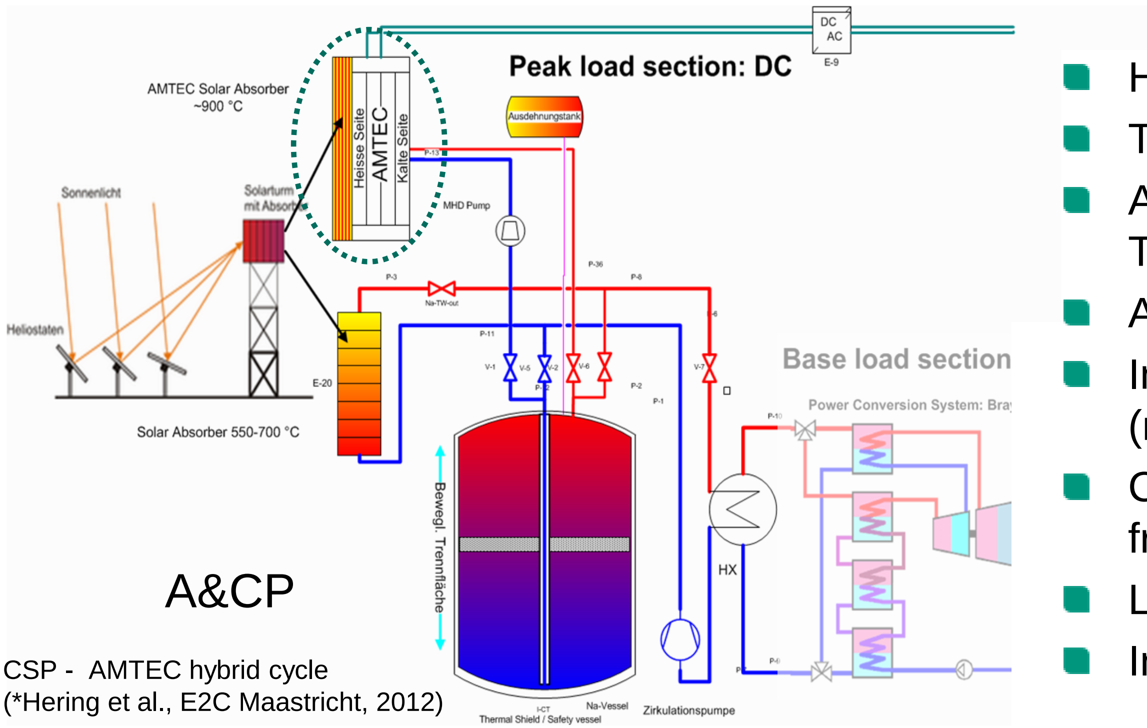
Karlsruhe Institute of Technology (KIT) – Institute for Neutron Physics and Reactor Technology (INR)







Long time perspective (motivation)
Hybrid system **CSP + AMTEC** (toping system)



CSP - AMTEC hybrid cycle
(*Hering et al., E2C Maastricht, 2012)

- HTF + storage fluid: Na
- $T_{receiver}$ ~ 550 – 700 °C
- AMTEC as topping system
  T ~ 900 °C
- AMTEC excess energy reused in TS
- Increase system efficiency*
  (η ~ 25 %)
- Compensation of fluctuations
  from source
- Longer and more flexible operation
- Increase lifetime of PCS

Research projects (milestones)

- ➢ AMTEC prototype
- ➢ Material characterization in Na
- ➢ High temperature thermal storage device
- ➢ A&CP → integration of small prototype in Karlsruhe Sodium Laboratory

Liquid metals as HTF for CSP

Heat transfer fluid (HTF)	Therminol VP-1	Solar Salt (60% NaN03/ 40% KNO3)	Steam@ 10bar	Liquid Sodium	
Boiling Point	400 °C	~ 585 °C	-	873 °C	✓
Therm. Cond. 600 °C	0.0956 W/mK	≥ 0.58 W/mK	0.09 W/mK	60 W/mK	✓
Melting Point	12 °C	228 °C	-	97.7 °C	✓
Density 600 °C	696 kg/m³	1867 kg/m³	2.5 kg/m³	810 kg/m³	✓
Spec. Heat 600 °C	~ 2,5 kJ/kgK	1,5 kJ/kgK	2.2 kJ/kgK	1,25 kJ/kgK	✓

- Comparison of HTFs *:
  Na identified as the best HTF for CSP-TS

→ Sodium good candidate as a HTF in CSP systems

Disadvantage of Na

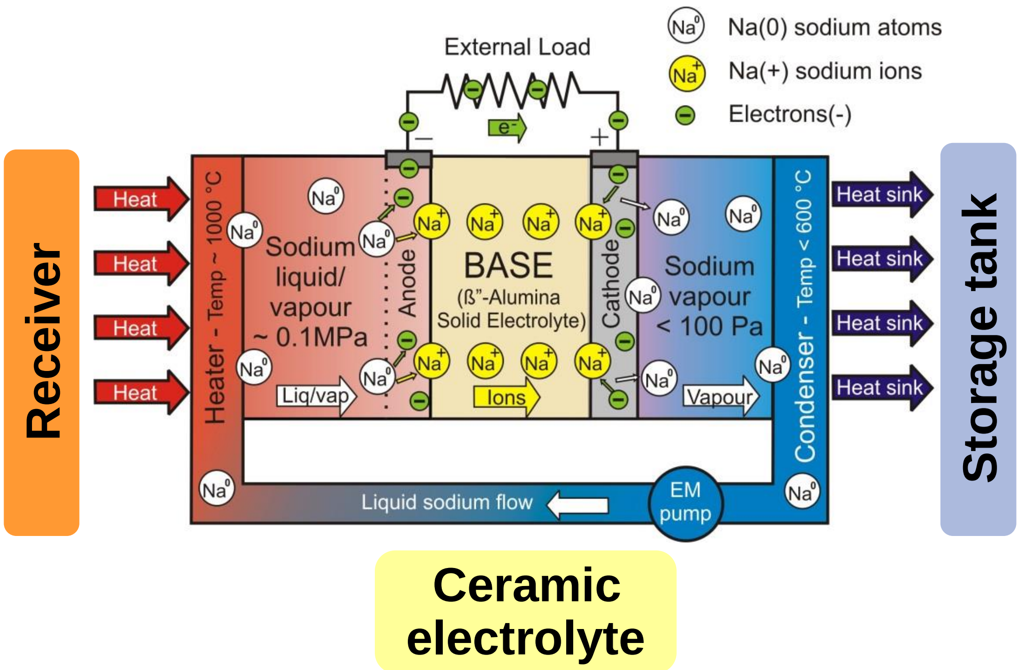
- Reactive with air and water

→ Safety oriented design and maintenance

* Liu et al. SE 101, 220-231, 2014

AMTEC – direct heat to electricity conversion

Alkali Metal Thermal to Electric Converter



- Key component:
  β''-Alumina Solid Electrolyte (BASE)
- Key process: Na-ionization
  ΔP across BASE → Δ(sodium activity)

$$Na \rightarrow Na^+ + e^-$$

Main advantages

- High theoretical efficiency (40 %)
- Flexible regarding the heat source
- Suitable for modular design
- No moving components

Issues

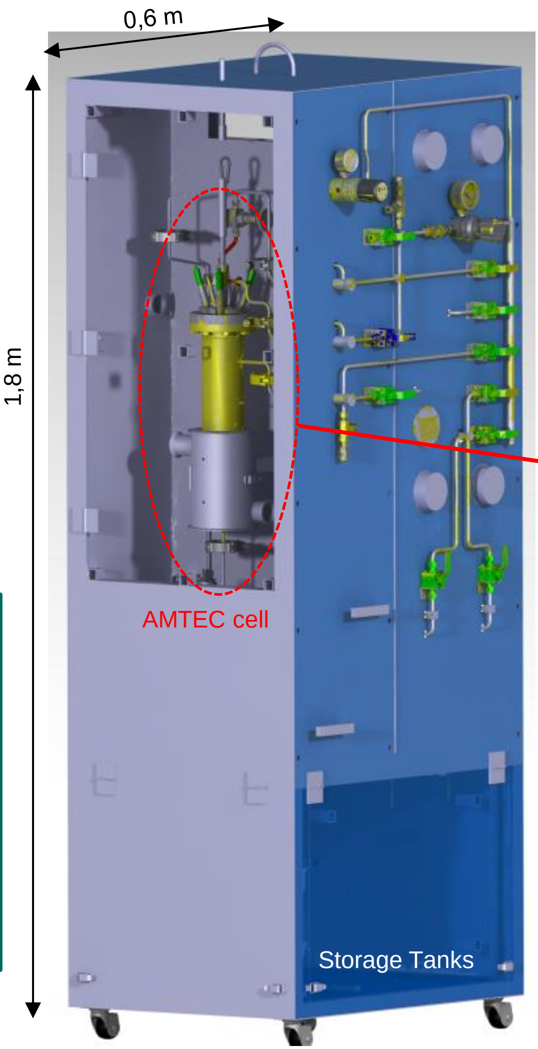
- Real efficiency of 20 %
  - Heat losses (10 – 15 %)
  - Electrical losses (12 – 15 %)
- Power degradation over time
  - Degradation of BASE
  - Electrode sintering (grain growth)

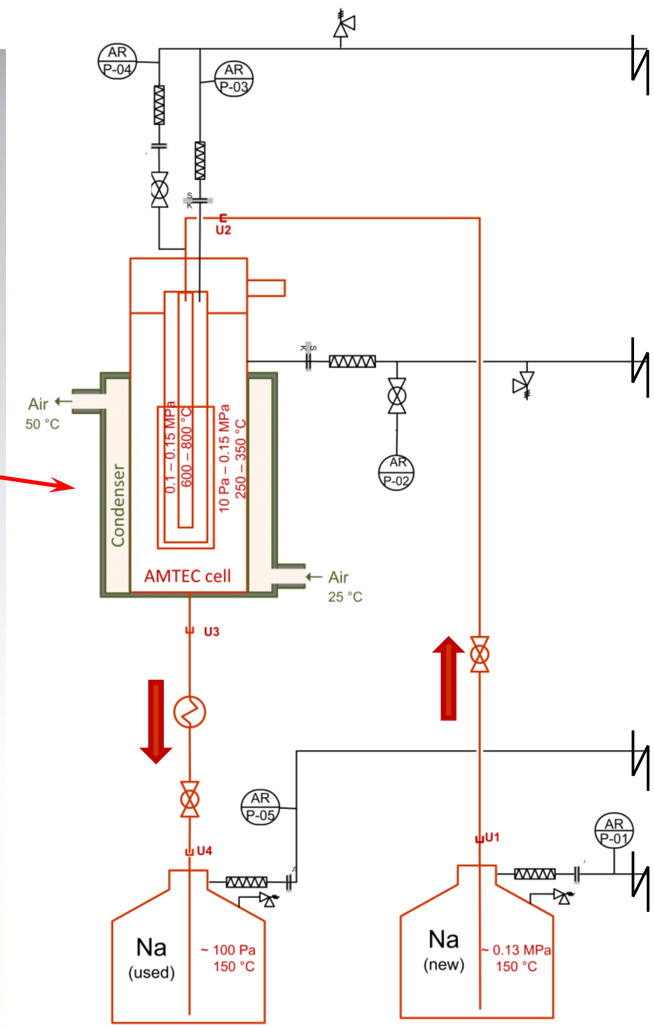
AMTEC TEst FAcility (ATEFA)

- **Na-side** includes:
  - Two storage tanks (~ 4,5 l)
  - AMTEC test cell
    T_{Na} = 600 – 800 °C
  - Air-cooled condenser
    T_{Na} ~ 300 °C
  - Heating trace, T_{Na} ~ 150 °C
- **Ar-side** controls Na-flow and pressure in cell and tank

Safe design

✓ Enclosed in a metallic box
✓ Possibility to float with Ar
✓ Small Vol_{Na} ~ 0.4 l in cell
✓ Max. p = 1.5 bar





AMTEC test cell

- Single BASE tube
  (D=3 cm, L=22 cm, wall thickness 1 mm)
- Na-liquid anode
- Sputtered cathodes (~ 5 µm)

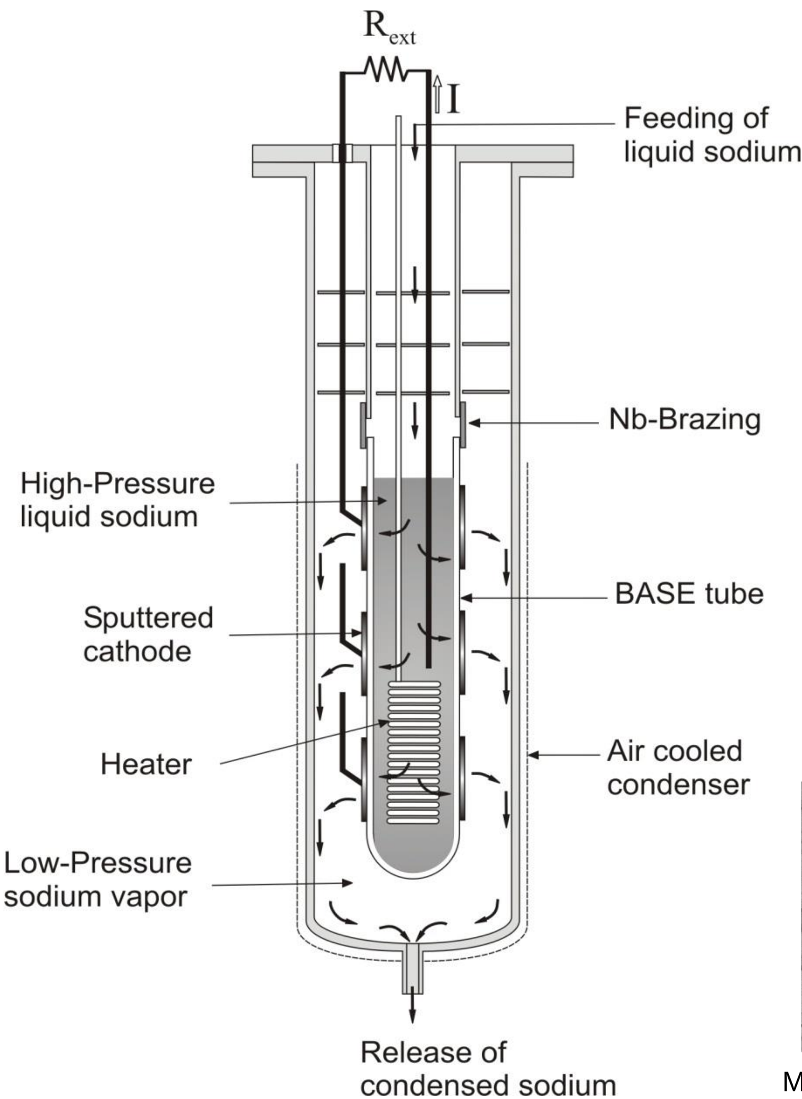
Open voltage	~ 1.2 V
Power density	0.5 – 1 W/cm²
Efficiency	15 – 20 %

AMTEC KIT 1990

Tests*

- Influence of ΔT
- Electrode composition
  (Mo, TiN, TiC)
- Electrode-wire interface
- BASE
  (thickness, chemical stability)
- Ceramic-metal brazing

*in collaboration with other institutes in KIT



BASE

Molybdenum Electrode
(h~ 5 µm)

Summary and outlook

- New CSP concept using Na and AMTEC technology
- Experimental infrastructure (ATEFA facility, AMTEC prototype) to be set into operation by end of summer 2015

- Experimental campaign focused on:
  - BASE and electrode improvement
  - Performance evaluation
- Long term tests:
  - Material qualification (low cycle fatigue)
  - Corrosion/erosion in structure materials
  - AMTEC long term tests
- Feasibility study of an AMTEC cluster for CSP plants as a topping system:
  - Solar receiver
  - Scaled AMTEC demonstrator
  - Na storage tank

LIMTECH Alliance *and HEMCP:*
Helmholtz Energy Materials Characterization Platform

Thank you for your attention

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