Solar Electricity with Thermo-Electro-Chemical Storage (TECS)

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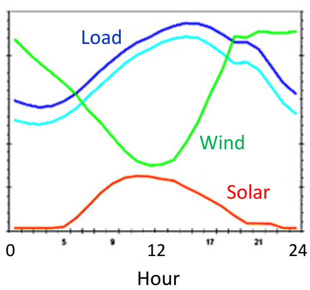
Electricity Storage

- Variability in energy demand
- Intermittent renewable resources



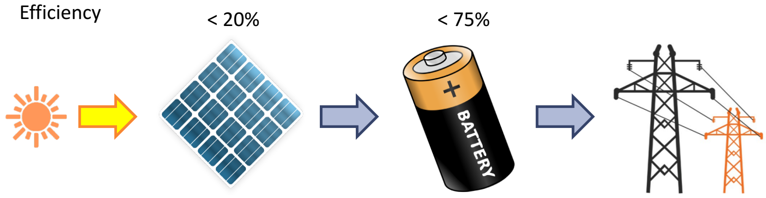
Electro-chemical storage – Batteries

Cost

Energy density

Time to charge

Efficiency



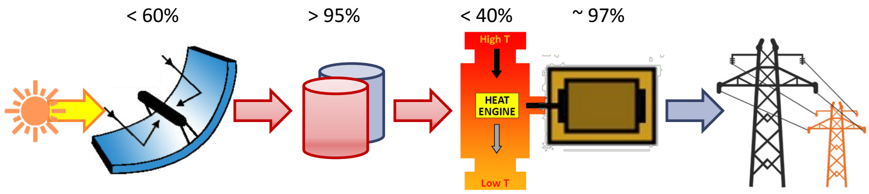
Thermal Storage

Molten salt in solar thermal power plants

Cost / Complexity

Slow response

Conversion efficiency



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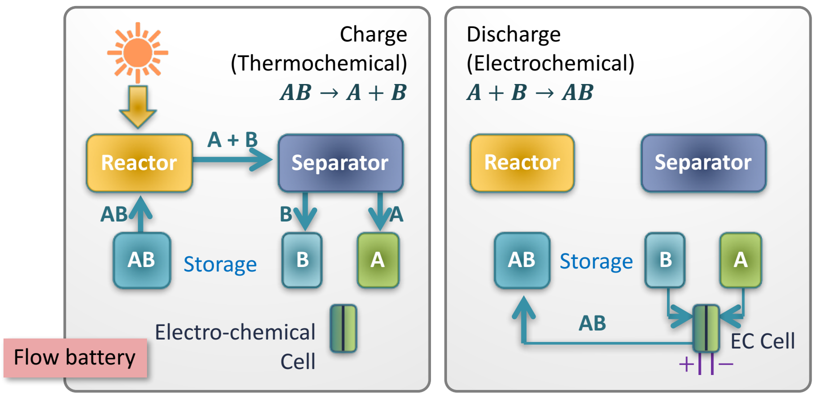
Thermo-Electro-Chemical Storage (TECS)



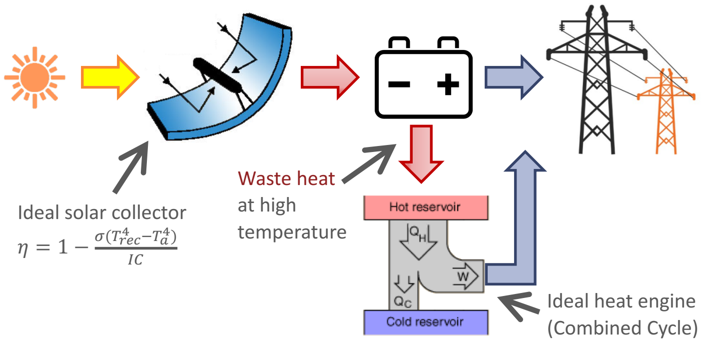
Thermally regenerative battery (Yaeger, 1958)

- Unified: **electricity generation** and **storage**
- Heat → Electricity **without a heat engine**

TECS Cycle Efficiency

Ideal components
Chemical equilibrium

→ **Upper limit** on cycle efficiency



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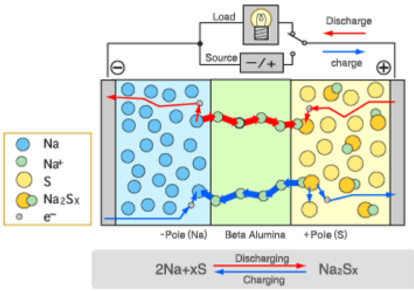
Sodium-Sulfur (Na-S)

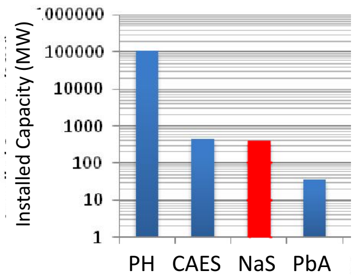
Commercial Battery, utility scale
High Efficiency
High Energy Density (760 Wh/kg)
Long Life (10,000 cycles)

Liquid at ~ 300°C

7.2 MWh Na-S batteries
NGK, S. Dakota wind farm

Anode: $2Na \leftrightarrow 2Na^+ + 2e^-$
Cathode: $xS + 2Na^+ + 2e^- \leftrightarrow Na_2S_x$



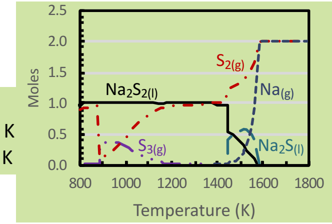


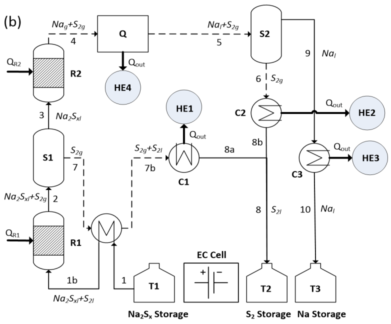
Na-S TECS Efficiency

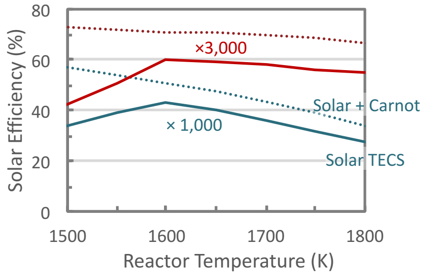
Thermal reaction:

$$Na_2S_{4(l)} + \Delta H \rightarrow 2Na_{(g)} + 2S_{2(g)}$$

Pressure: 10 mbar
Partial decomposition ~ 900 K
Full decomposition at 1,600 K







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Zinc-Air

Commercial : mobile applications

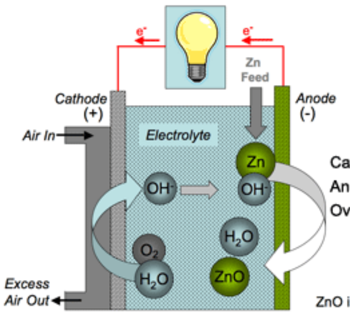
EV, hearing aids, cameras

High energy density

Long life

Stable voltage

http://www.sailmagazine.com/diy/ask-sail/ask-sail-zinc-air-batteries/



Fuel Cell Reactions

Cathode: ½ O_2 + H_2O + 2e- → 2 OH-
Anode: Zn + 2OH- → ZnO + H2O + 2e-
Overall Reaction: Zn + ½ O_2 → ZnO

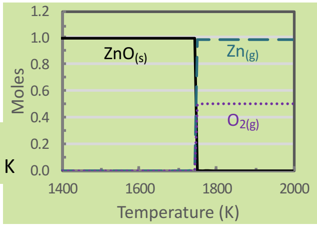
Zn, ZnO: solids

Zinc and air are fed to the fuel cell.
ZnO is removed by the flowing electrolyte.

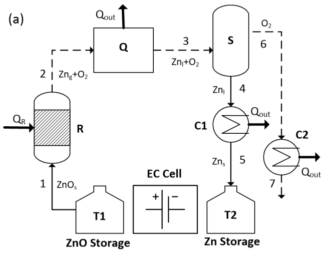
Zn-air TECS Efficiency

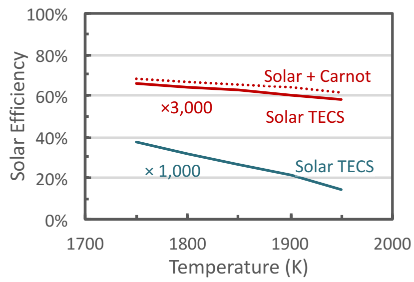
Thermal reaction:

$$ZnO_{(s)} + \Delta H \rightarrow Zn_{(g)} + \frac{1}{2}O_2$$



Pressure: 10 mbar
Full decomposition at 1,650 K





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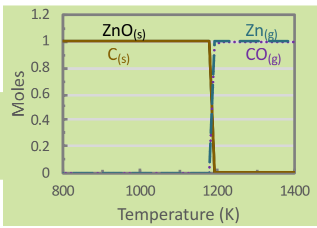
Zn-C-air TECS Efficiency

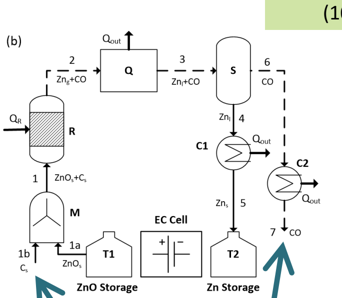
Carbothermic reduction:

$$ZnO_{(s)} + C_{(s)} + \Delta H \rightarrow Zn_{(g)} + CO_{(g)}$$

Epstein et al., JSEE 2007

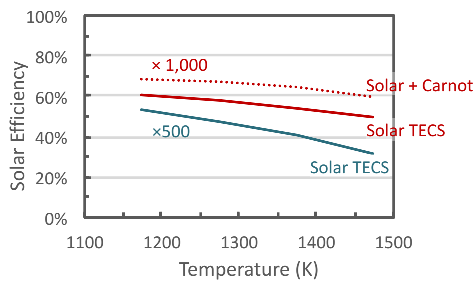


Pressure: 1 bar
Full decomposition at 1,150 K
(10 mbar → 960 K)



C input:
Renewable?

CO output:
→ Electricity



Conclusions

Unified conversion & storage concept with:

- High efficiency (theoretical limit)
- Decouple capacity vs. power (flow battery)

- High operating temperatures
- Need waste heat capture

Future Work

- Other chemistries
- Realistic engineering analysis
- Experimental validation

Solar carbothermic reduction of Al_2O_3, MgO, B_2O_3

Vishnevetsky & Epstein, Solar Energy J., 2015

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