Gen3 Liquid Pathway

CSP Program Review
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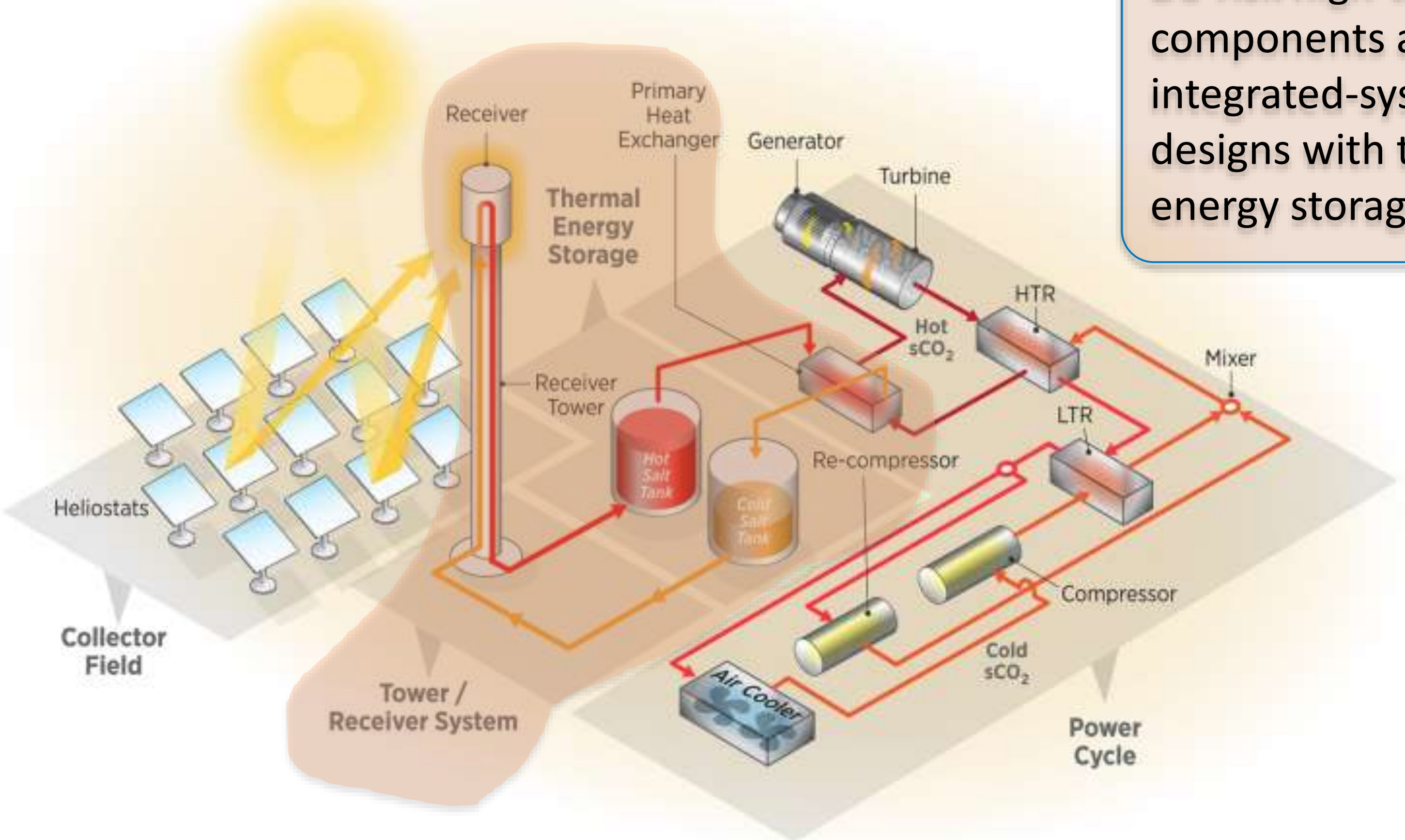
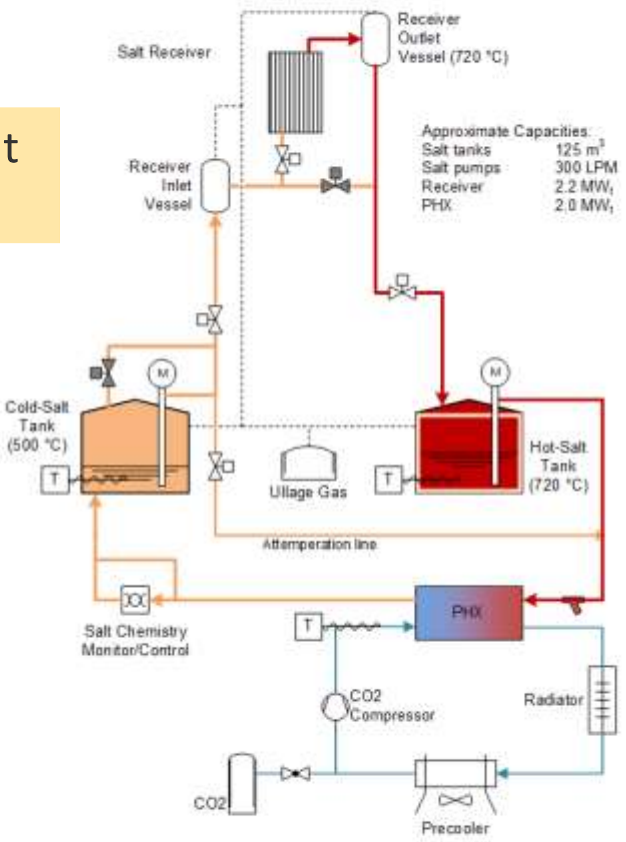
Liquid Pathway
Thermal Transfer System



Goal:
De-risk high-temperature components and develop integrated-system designs with thermal energy storage at >700 °C

Liquid-HTF Pilot System Alternatives

Cl-Salt HTF



Liquid-HTF Pilot System Alternatives

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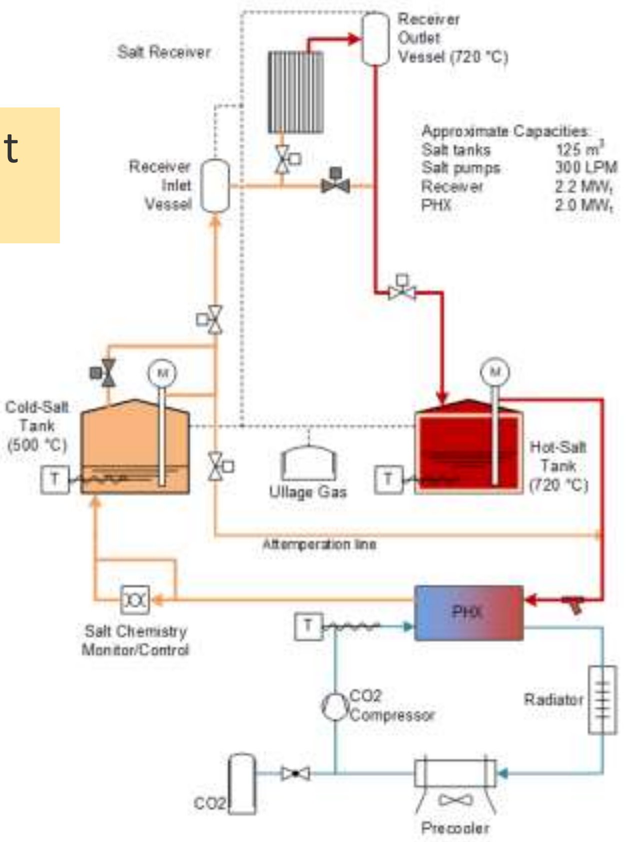
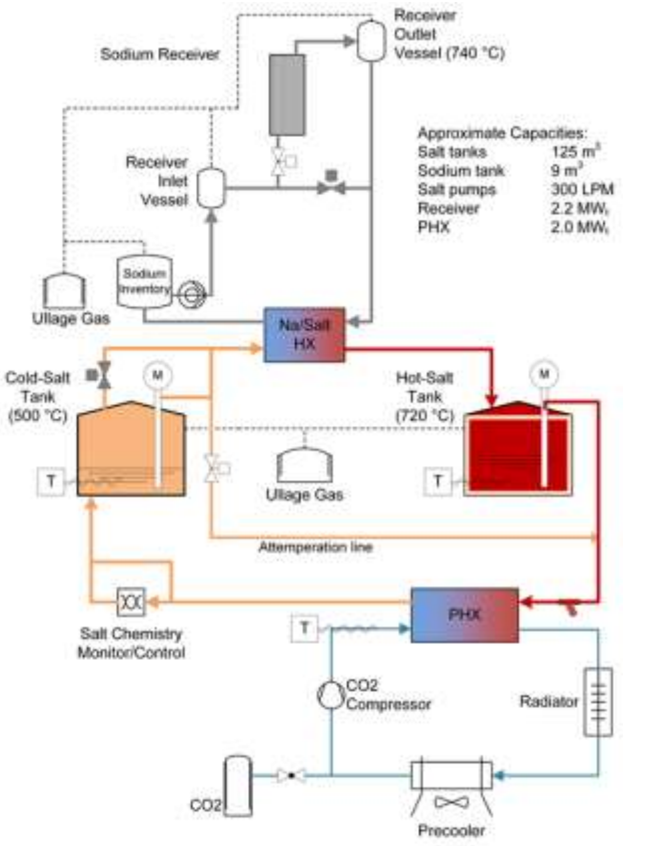
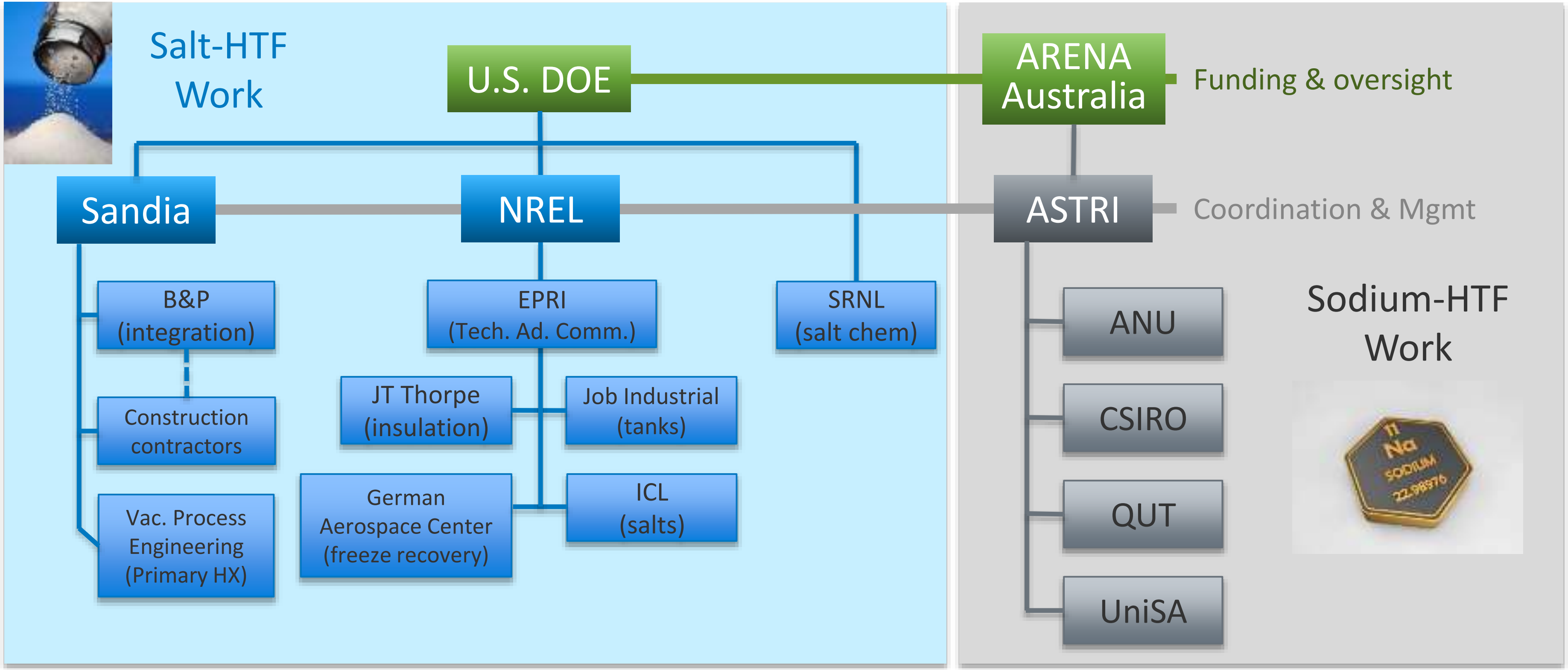


Sodium HTF



Liquid-Pathway Team



Key Technical Risks

- Identified 14 components/subsystems for risk assessment:

Salt Properties [2]	Hot-Salt Tank [2]	Sodium Receiver
Salt Chemistry [2]	Cold-Salt Tank	Sodium TES System
Salt Melter	Salt Pump [2]	Thermal Transport System
Salt Receiver	Primary HX [2]	Infrastructure & Permitting

[2] indicates Topic 2 technology role

- Rated the probability and impact for 45 failure modes (on average) for each component/subsystem to yield a relative risk score.
- Developed workplan and milestones to address greatest risks

Technical Risk: Salt HTF

Aspect	Failure Mode	Risk score
Salt Thermodynamic Potential	Corrosive	4.5
Salt Thermodynamic Potential	Variable	4.5
Salt Particulates Form	Clogging	3.2
Exhaust scrubber	Insufficient contaminant removal	2.8
Sensors and controls	Accuracy, availability, suitability	2.8
Heater Freeze Recovery	Salt Compatibility	2.8

Industrial Experience: Salt Handling

ICL

DSM Dead Sea Magnesium Ltd

ICL/DSM Handling Molten Chlorides for Magnesium Production:

- 260,000 tons per year of carnallite ($MgCl_2$/KCl) is dehydrated, melted, and mixed with NaCl as feedstock for Mg production
- This molten salt, and the melting/ purification technology, is being applied for the Gen3 project
- The salt melter and electrolytic vats are lined with refractories, to protect the carbon steel vessels; carbon steel tank shells have been in use for over 20 years

Salt Melting & Purification

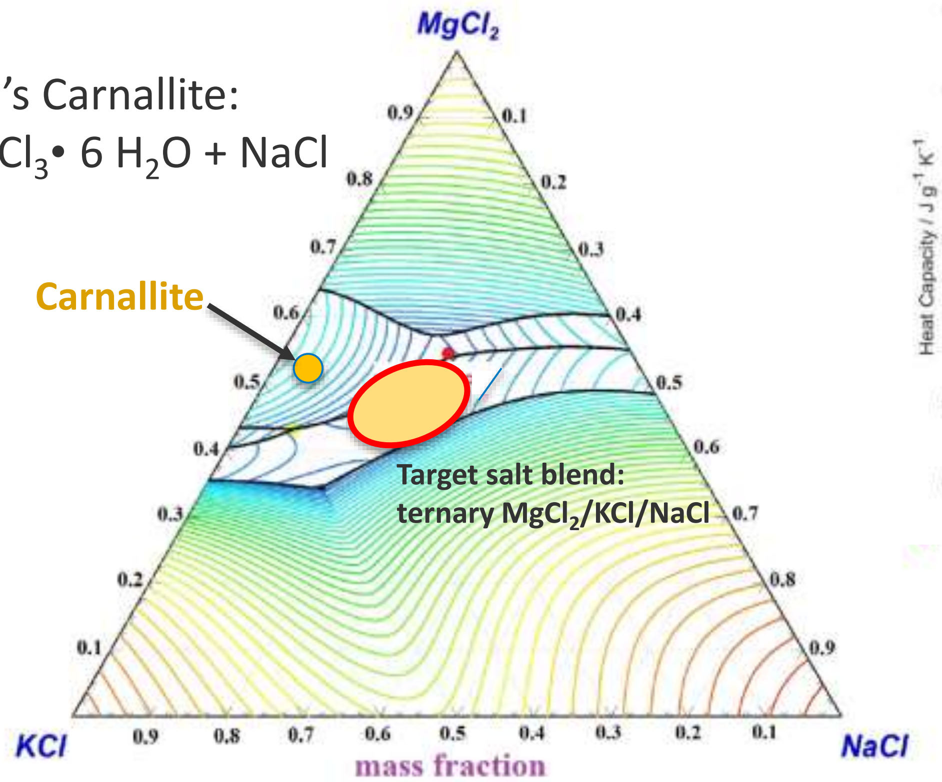
Dead Sea Magnesium Ltd

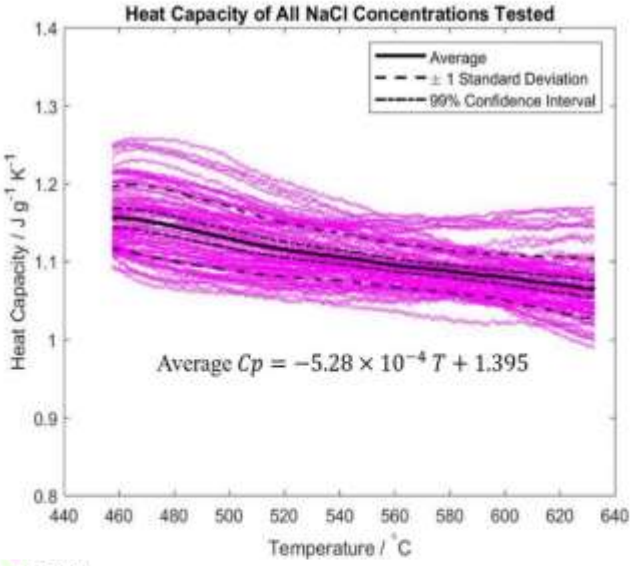
- 150 ton/day carnallite melters at the Dead Sea Magnesium works in Israel (4 units shown)
- These units melt the less-pure precursor to our target salt
- Design and materials of construction will be adapted for planned CSP salt melter

Cl-Salt Formulation

DSM's Carnallite:

$MgKCl_3 \bullet 6\ H_2O + NaCl$





Phase diagram of Na/K/Mg–Chloride modeled with FactSage [Mohan et al., Energy Conversion and Management 167 (2018).

Technical Risk: Sodium HTF

Aspect	Failure Mode	Risk score
Safety and Acceptance	Perception of risk	3.2
Safety and Acceptance	Sodium inventory too large	2.4
Safety and Acceptance	Operator error	2.4
Valves	Chemically incompatible w/sodium	2.0
Safety and Acceptance	Fire hazard	1.8
Panels/tubes	creep/fatigue fail	1.6
Panels/tubes	Corrosion due to high skin temps, trace contaminants	1.6

Sandia sodium receiver tests in 1990s logged 7500 hrs on sun at HTF temps up to 800°C

Vast Solar Jemalong
Sodium-HTF pilot facility (Australia)

Safety and Acceptance

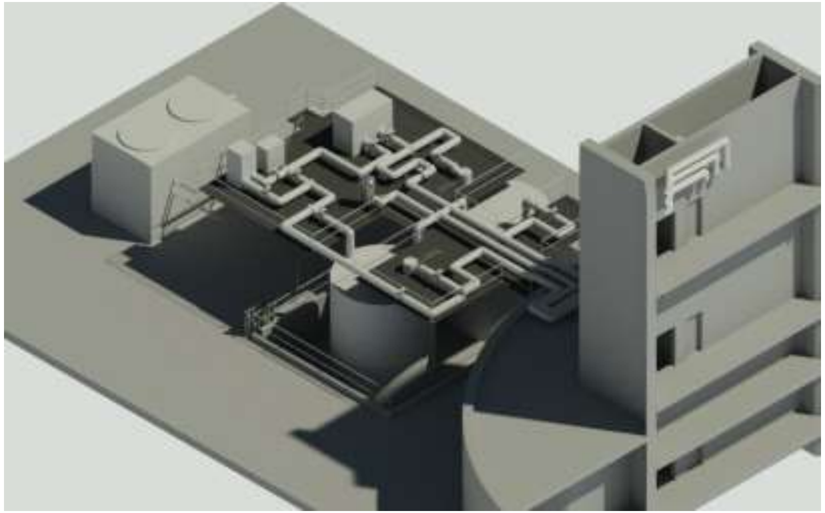
- Learning from the experts
  - Support from liquid metal experts at Karlsruhe Institute of Technology, Germany; Sodium Safety & Handling workshop at Argonne National Laboratories
  - Support of experienced consultants (SAAS, GHD)
- Stakeholder engagement
  - Technical, e.g. Fire Training and Demonstration day at ACT Fire and Rescue training center, Canberra
  - Commercial, e.g. Vast Solar development of a 30 MW plant in Queensland, Australia
- Safety by Design
  - Integration of hazard identification and risk assessment methods early in the design process
  - Automatic drain back to sump tank in case of emergency
  - No sodium-water interfaces
  - Sodium inventory minimized

Fire Training and Demonstration day, Canberra 2016

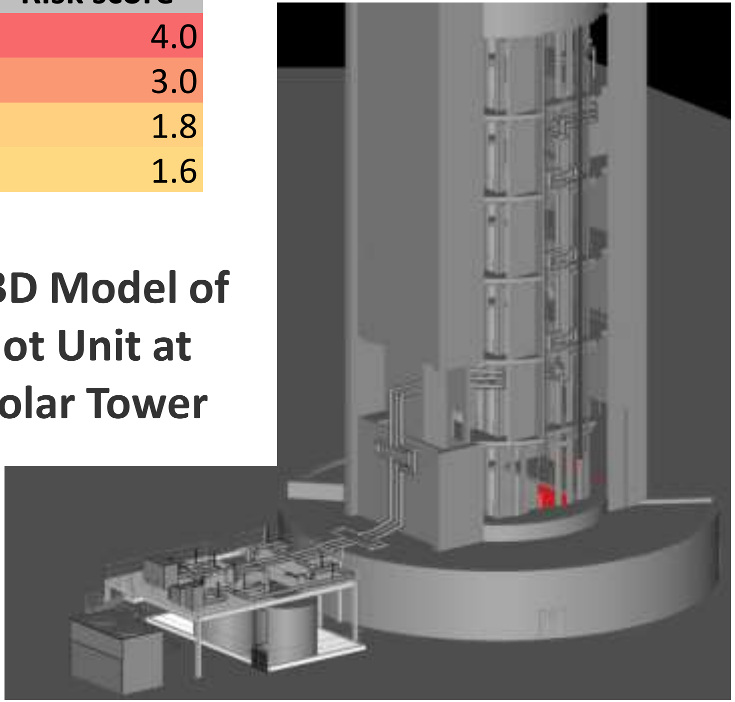
ANU visit to KIT sodium loop, Karlsruhe, Germany, 2017

Technical Risk: Thermal Transport System Materials

Aspect	Failure Mode	Risk score
Valves, pipes, sensors, welds	Chemically incompatible w/salt	4.0
Insulation	Cost, compatibility	3.0
Corrosion sensors	Poor Precision, accuracy, or availability	1.8
Heat Trace	Cost, Control & Precision Issues	1.6



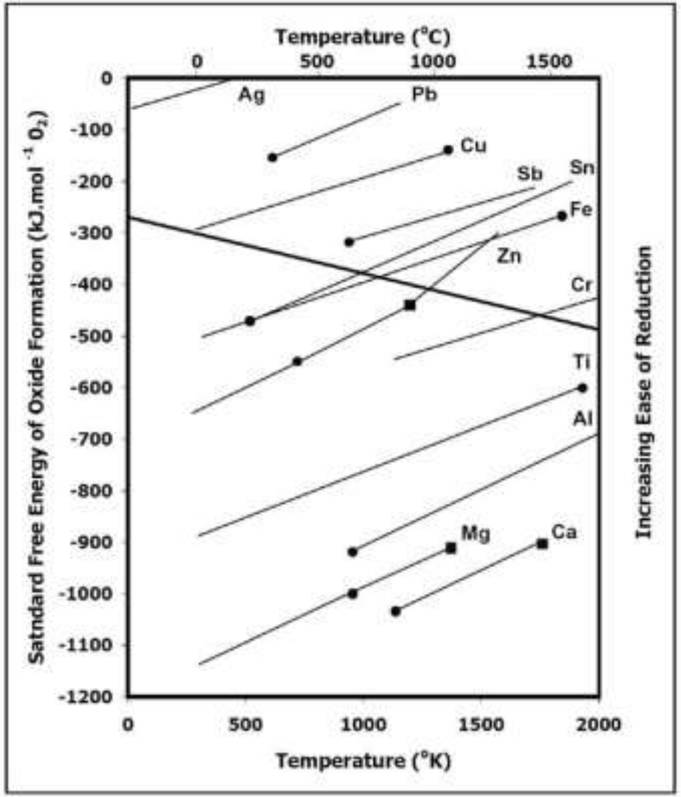
Rendered 3D Model of 2-MW Pilot Unit at Sandia's Solar Tower



Corrosion Protection

Concept:

- Use Mg^0 to protect other metals (e.g., Fe, Cr, Ni) within containment alloys against oxidation



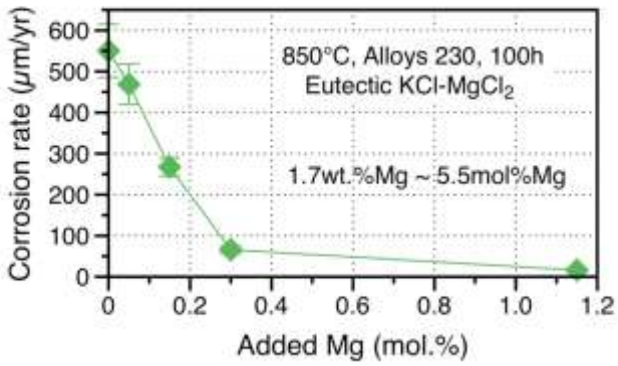
Simplified Ellingham Diagram

Gordon Turner-Walker, *A Practical Guide to the Care and Conservation of Metals*, 2008.

● = melting point; ■ = boiling point

Corrosion Protection

- Mg metal added to the melt acts as an oxygen getter and redox control to protect against corrosion
- Testing at Savannah River National Lab
- Loop testing will occur at Oak Ridge



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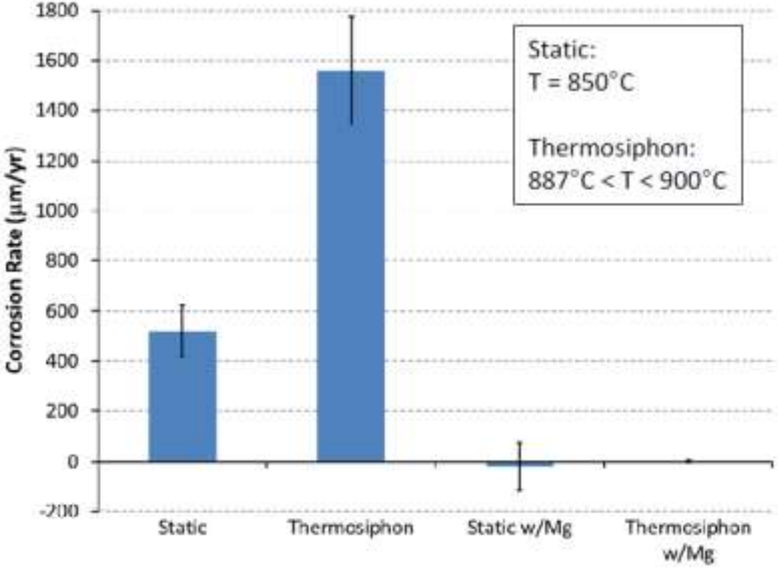

Chemical Sensors

Argonne National Lab's Multifunction Voltammetry Sensor

Measure concentration of:

- impurity species, e.g., MgOHCl,
- corrosion products, e.g., Cr^{2+} , Fe^{2+}, etc.,
- soluble Mg,
- as well as Salt Redox Potential
  - Measurements of salt potential indicate salt health and the propensity for corrosion of structural metals to occur

Relevant Topic 2 Projects

- Collaborative Work: Salt Properties
  - DOE Salt Collective (NREL, ORNL, SRNL, Argonne, plus others)
  - Ga Tech and U. Arizona assisting with salt property measurement
- Essential Topic 2 Work: Salt Pumps
  - Hayward Tyler
  - Powermet (Sulzer Pumps)
  - MIT (Flowserve)
- Alternative Topic 2 Work: Tank and PHX
  - MIT team working on alternative tank design
  - Purdue developing cermet material for PHX designs

Integrated System Test in Phase 3

Phase 3 testing planned for Sandia’s National Solar Thermal Test Facility

Key Risks to be Addressed:

1. Demonstrate effective salt chemistry and corrosion control
2. Fabricate cost-effective thermal storage tanks
3. Operate liquid-HTF receiver at 720°C
    - Confirm temperature and heat transfer rates
    - Demo startup, shutdown, and power ramping
    - Define guidelines for receiver operations
4. Validate pumps, valves, and piping
5. Validate primary HX performance
6. Perform component and system modeling and simulate full-scale performance

Image credit: Oster.com

Thank you

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