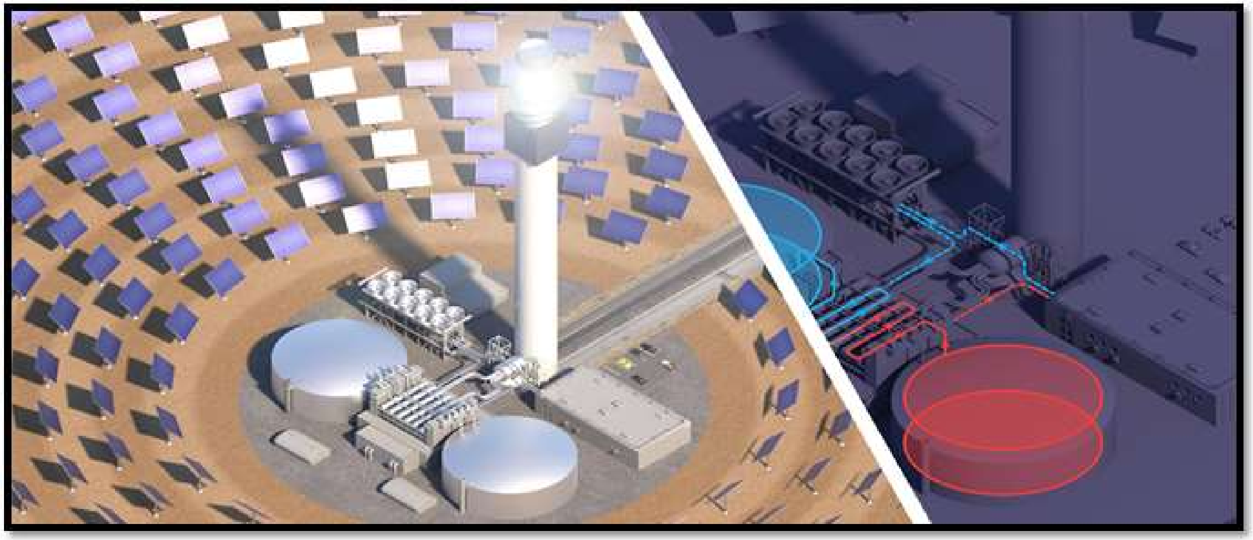
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

Liquid-Phase Pathway



Gen3 CSP Summit
August 25, 2021

Sandia National Laboratories

NREL NATIONAL RENEWABLE ENERGY LABORATORY

ARENA Australian Government Australian Renewable Energy Agency

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Principal Investigator
National Renewable Energy Laboratory

NREL Award # 34209 (agreement number)

Liquid Pathway Challenges

Major Risk Factors:

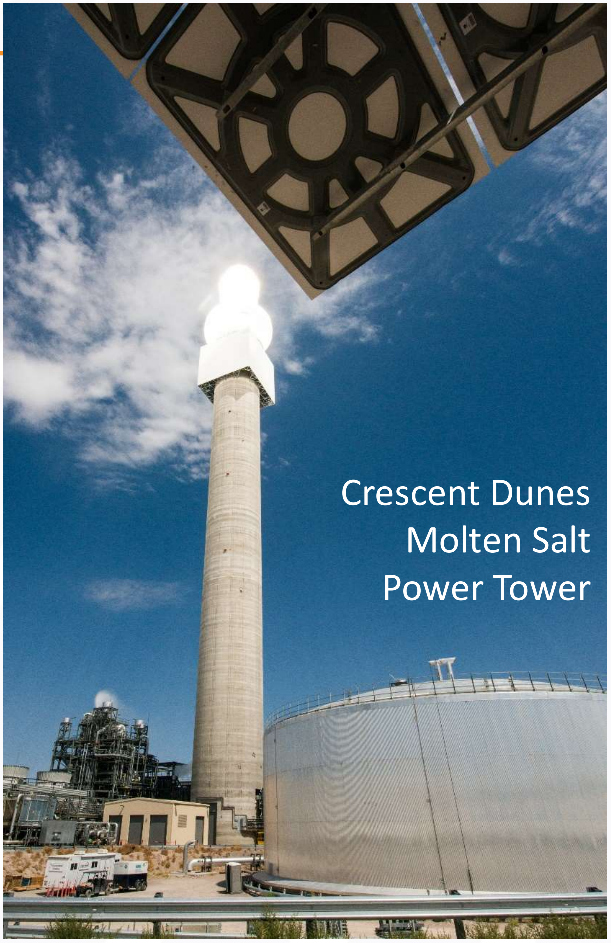
- Salt materials compatibility and corrosion control
  - Salt piping, valves and flanges
- Salt tank cost and durability
- Sodium safety and acceptance
- Salt vapors ?
- Sodium materials compatibility at > 650°C ?

COLLECTOR FIELD	RECEIVER	THERMAL TRANSPORT	THERMAL STORAGE	HEAT TRANSFER MEDIA	HEAT EXCHANGE	POWER CYCLE
SOLID MEDIA	• Thermal Efficiency: • Particle Loss • Flow Velocity Control and Monitoring	• Reliability • Mechanical and Thermal Efficiency • Scalability • Insulation	• Charging and Discharging Particle loss, Efficiency, Scalability	• Particle Attrition • Optimized Performance Character	• Low Cycle Fatigue • Particle Mass Flow Control • Ramp Rates & Transients	
MOLTEN SALT	• Thermal Conductivity • Thermal Stability • Tube Strength and Durability	• Pipe Material Compatibility • Freeze Recovery • Pumps Valves Seals • Leak Detect	• Corrosion Behavior • Chemistry Monitoring and control • Tank Cost	• Characterize Material Properties • Cost / Supply Chain	• Material Compatibility w/ salt & CO_2 • Freeze Protection • Thermal Ramp Rates	
GAS	• High Pressure Fatigue • Absorptivity Control and Thermal Loss Management	• Recirculator Cost & Operating Power • Large Pipes High Cost	• Storage Concept not Determined	• Low Thermal Conductivity • Low Heat Capacity	• Requires High Area • Multiple Heat Exchangers • Cascading Temperature	

Concentrating Solar Power Gen3 Demonstration Roadmap, NREL/TP-5500-67464, 2017

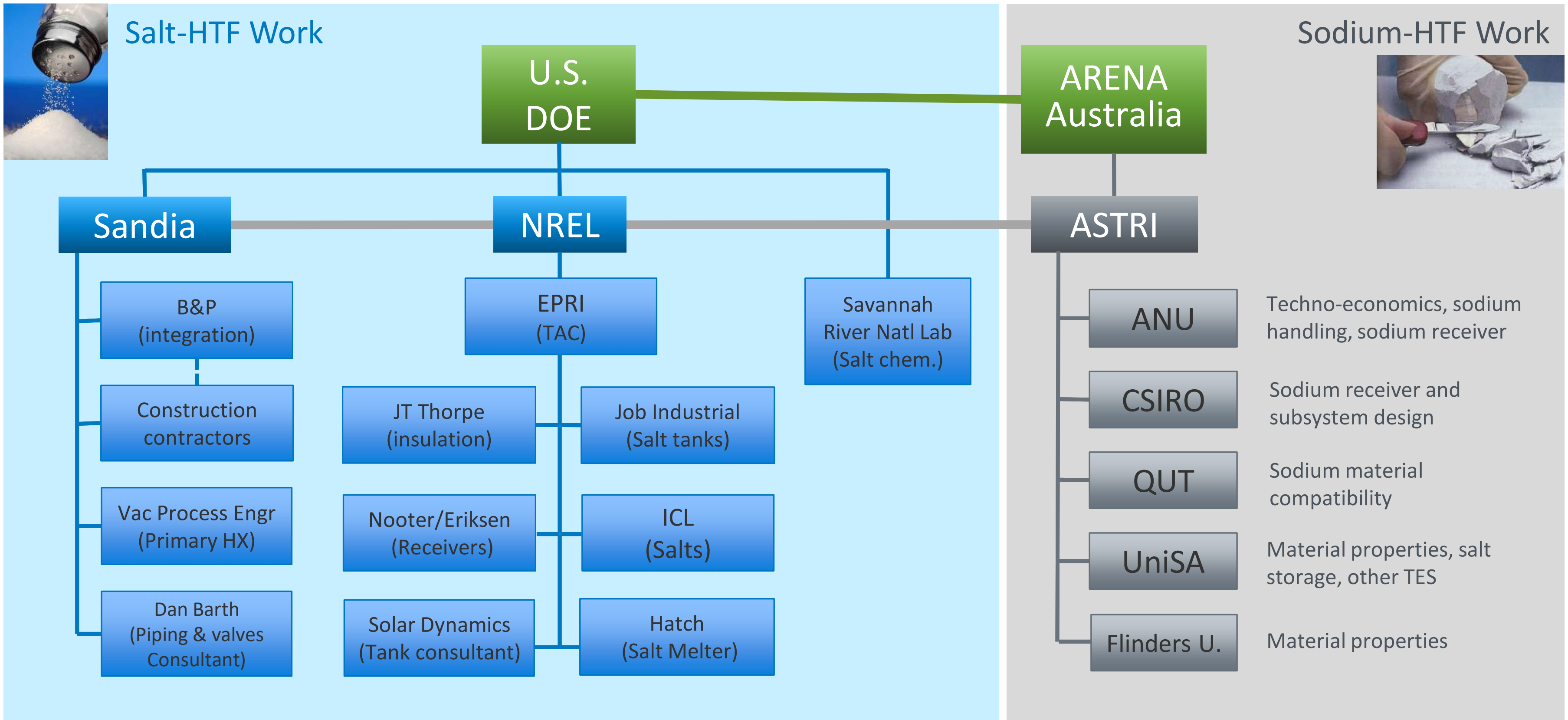
Liquid Pathway Strategy

- **Leverage experience in liquid heat transfer fluid (HTF) and thermal storage media**
  - Modest operating pressure
  - Known correlations for heat transfer performance
  - Known pumping and transfer methods
  - Ecosystem of industrial suppliers and developers working with molten salts
- **Consider the superior heat transfer properties of liquid metal sodium as a receiver fluid**
  - Relevant CSP industry experience from Vast Solar, John Cockerill
  - Extensive safety and handling data from industrial and nuclear sector usage
- **Coordinate with ongoing industry-, federal-, and international-funded R&D to overcome challenges**
- **Develop Risk Registry to identify, track, and manage risk**
- **Establish Advisory Committee to guide AHP decision process**



NREL image 46196

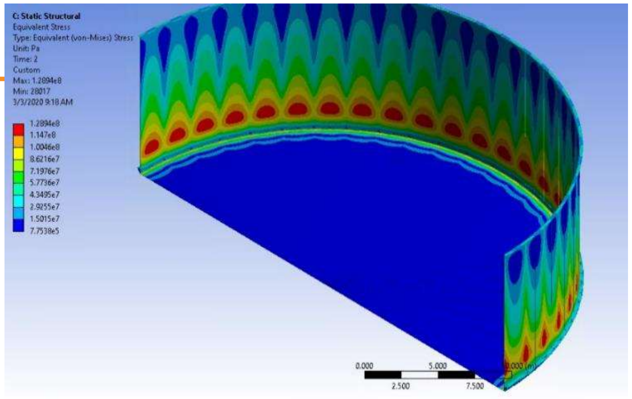
Liquid Pathway Project Team



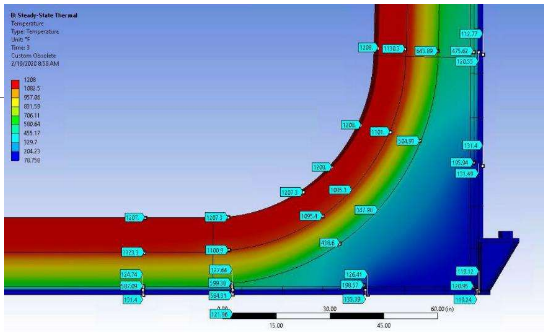
Break to other panelists

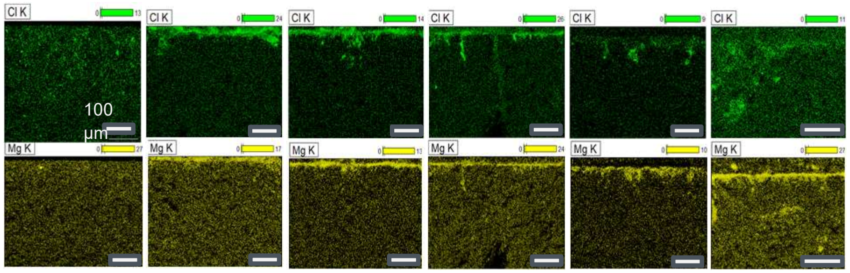
Molten-Salt Storage Tanks: Design Summary

- **Refactory-lined, carbon steel tanks**
  - Liner design patterned after Dead Sea Magnesium electrolysis vats
  - Liner design is identical for both hot and cold tanks
  - Tank wall design temperature is approximately 60°C
- **Mortar made from same material as the hot face brick for compatibility with liner and salt.**
- **Mortar ability to prevent salt penetration remains a risk**



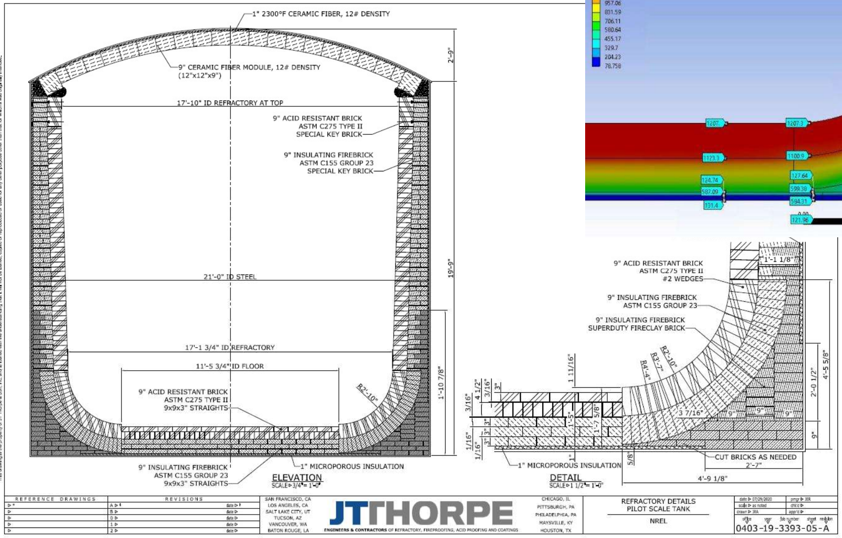
Thermo-mechanical stress analysis





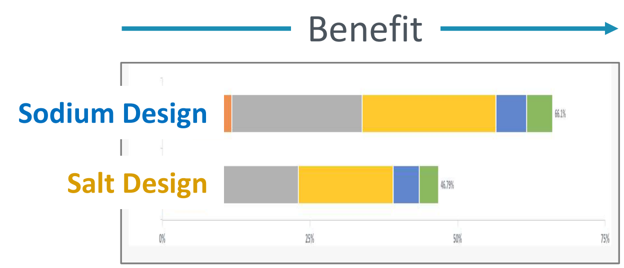
Salt penetration studies

Koch Knight



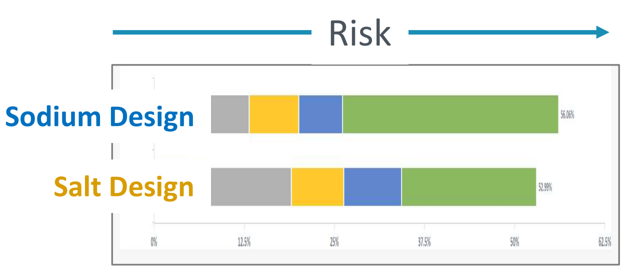
Receiver Down Selection Decision

Analytic Hierarchy Process (AHP) used to systematically compare benefits and risks of the two design approaches:



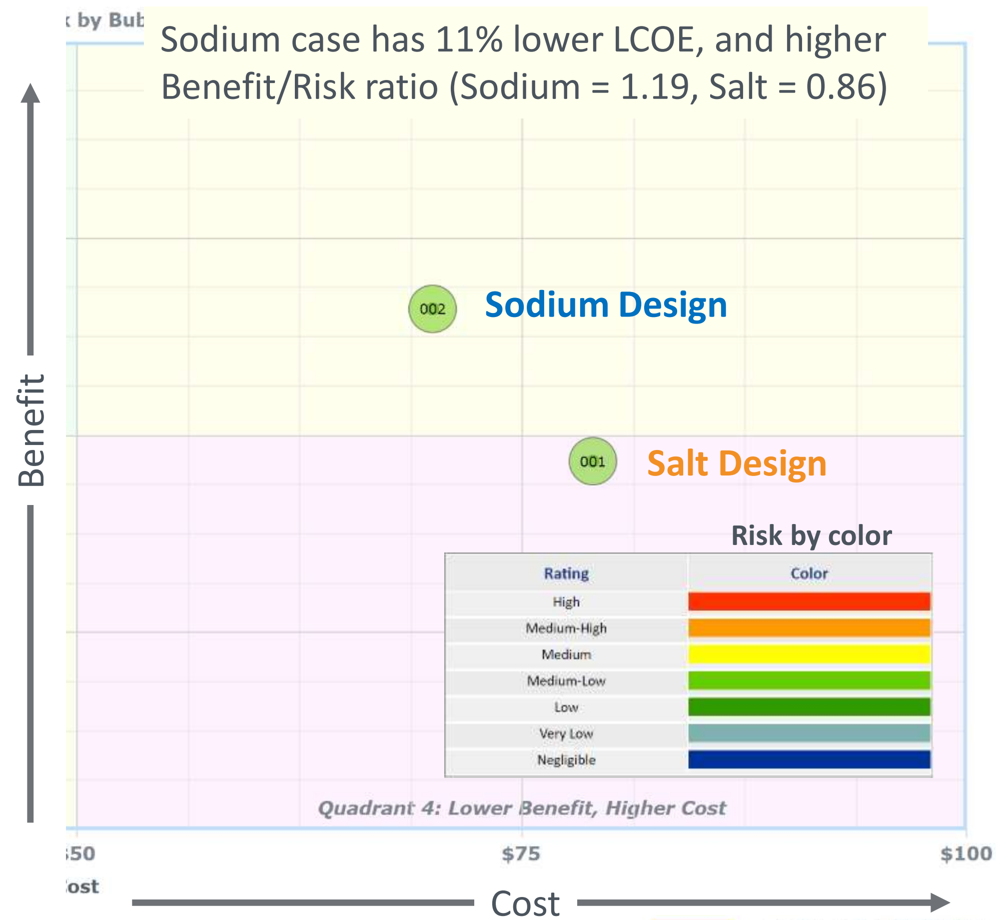
Maximize efficiency and performance

Maximize long-term reliability and availability

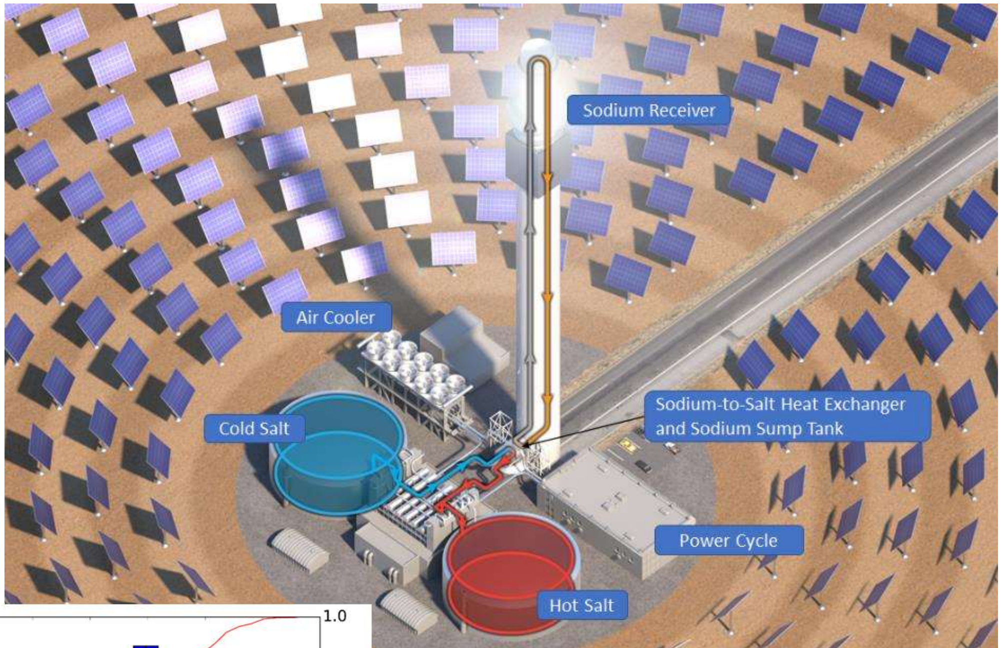


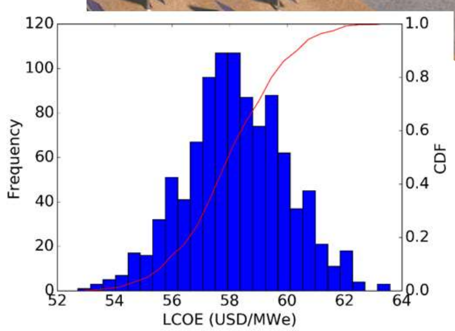
Minimize the risk to people and the environment

Sodium case has 11% lower LCOE, and higher Benefit/Risk ratio (Sodium = 1.19, Salt = 0.86)



Commercial-Scale Liquid Pathway System Design





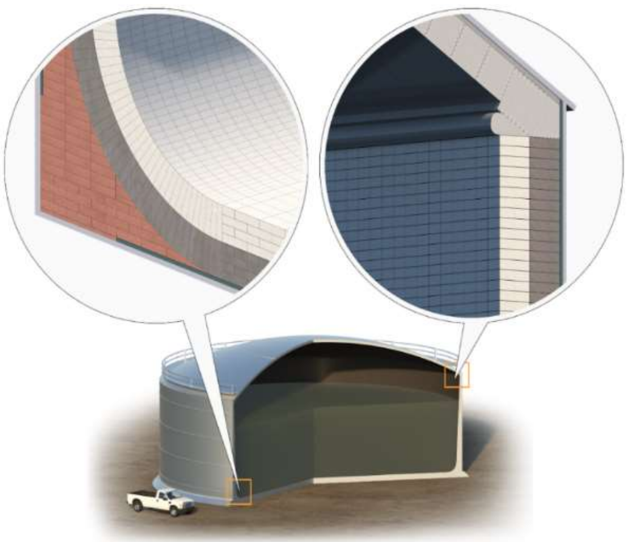
Advantages of the 2 x 50-MW_e Sodium/Salt design:

- Better optical efficiency
- Ability to utilize smaller, lower-cost towers
- Smaller-diameter salt tanks
- Better match to nascent sCO_2 power cycle capacity
- Adaptability to fringe-of-grid and small-grid markets
- Easier financing and shorter construction times
- Faster learning-by-doing cost reduction
- Larger "power park" facilities allow for shared staff and support infrastructure as well as operational redundancy

Risk Status and Future Opportunities

Risk Focus:

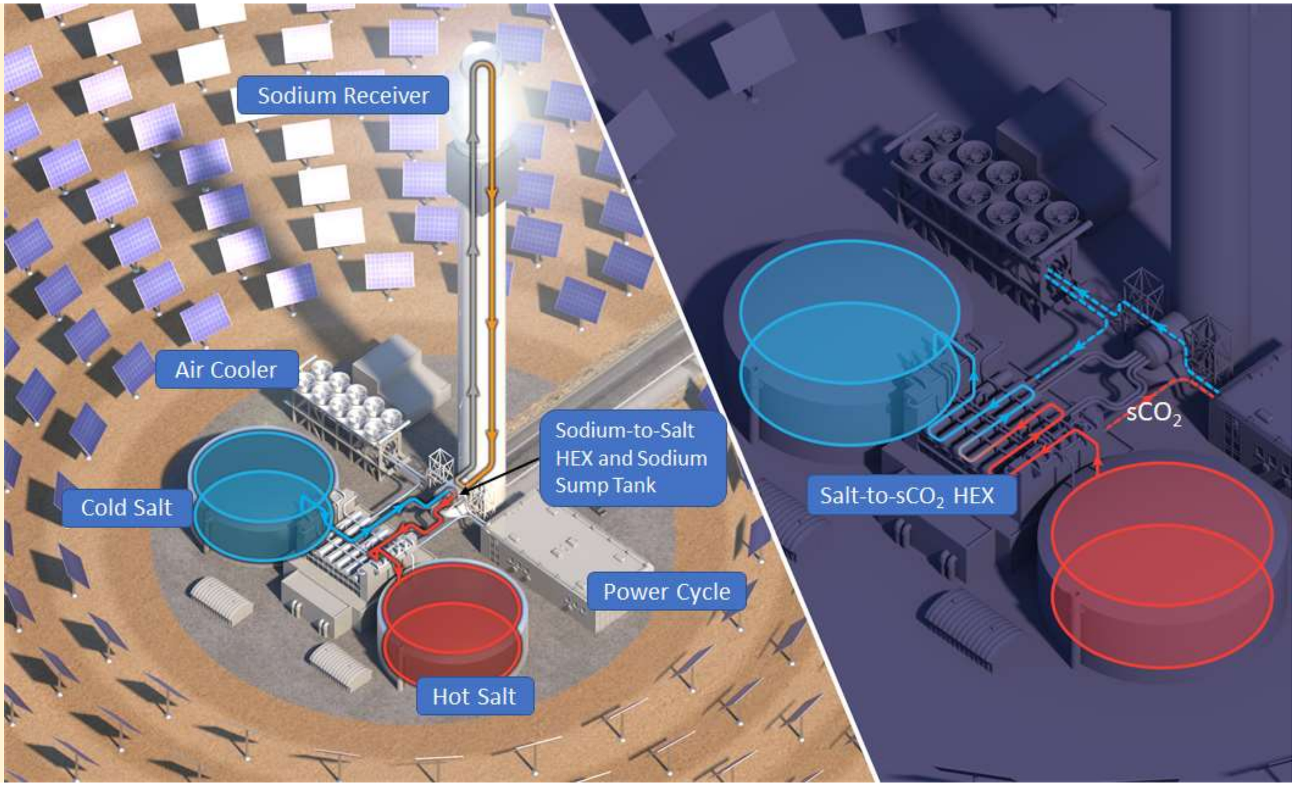
- Tank liner durability
- Salt vapor impacts



Future Work and Opportunities

- Chloride-salt tank test
- Internal insulation for molten-nitrate salt tanks
- Molten-chloride salt handling in Gen IV nuclear systems, e.g., TerraPower
- Sodium/Salt CSP systems, e.g., Vast Solar

Commercial System Design



Project Final Report and Journal Publications

1) C. S. Turchi et al., "CSP Gen3: Liquid-Phase Pathway to SunShot," National Renewable Energy Laboratory, Golden, Colorado, USA, NREL/TP-5700-79323, 2021. https://doi.org/10.2172/1807668
2) J. Martinek, S. Jape, and C. S. Turchi, "Evaluation of external tubular configurations for a high-temperature chloride molten salt solar receiver operating above 700 °C," Solar Energy, vol. 222, pp. 115–128, Jul. 2021, doi: 10.1016/j.solener.2021.04.054.
3) S. Jape, J. Martinek, and C. S. Turchi, "Thermomechanical Modeling of Receiver Tubes for Next Generation Concentrating Solar Power Plants: Thermal Stress Analysis, Structural Damage Calculation, and Lifetime Prediction," Applied Energy, Mar. 2021.
4) S. H. Gage, J. J. Bailey, D. P. Finegan, D. J. L. Brett, P. R. Shearing, and C. S. Turchi, "Internal insulation and corrosion control of molten chloride thermal energy storage tanks," Solar Energy Materials and Solar Cells, vol. 225, p. 111048, Jun. 2021, doi: 10.1016/j.solmat.2021.111048.
5) J. Coventry, "Sodium safety and protocols for CSP," Australia National University, Feb. 2020. (See reference [1], Appendix 15).
6) Y. Wang et al., "Verification of optical modelling of sunshape and surface slope error for concentrating solar power systems," Solar Energy, vol. 195, pp. 461–474, Jan. 2020, doi: https://doi.org/10.1016/j.solener.2019.11.035.
7) N. Klammer, C. Engtrakul, Y. Zhao, Y. Wu, and J. Vidal, "Method To Determine MgO and MgOHCl in Chloride Molten Salts," Anal. Chem., vol. 92, no. 5, pp. 3598–3604, Mar. 2020, doi: 10.1021/acs.analchem.9b04301.
8) Y. Zhao and J. Vidal, "Potential scalability of a cost-effective purification method for MgCl2-Containing salts for next-generation concentrating solar power technologies," Solar Energy Materials and Solar Cells, vol. 215, p. 110663, Sep. 2020, doi: 10.1016/j.solmat.2020.110663.