Liquid Pathway Receiver Design: Molten Salt and Liquid Sodium

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Overview

- *Gen3 Liquid Pathway* project seeks to demonstrate potential of chloride-based molten salt for energy storage at > 700°C.
- Chloride salt’s high freeze point and poor thermal conductivity are challenges for use in a solar receiver.
- Project evaluated molten chloride salt and liquid-metal sodium as alternatives for a liquid receiver at > 700°C operation.

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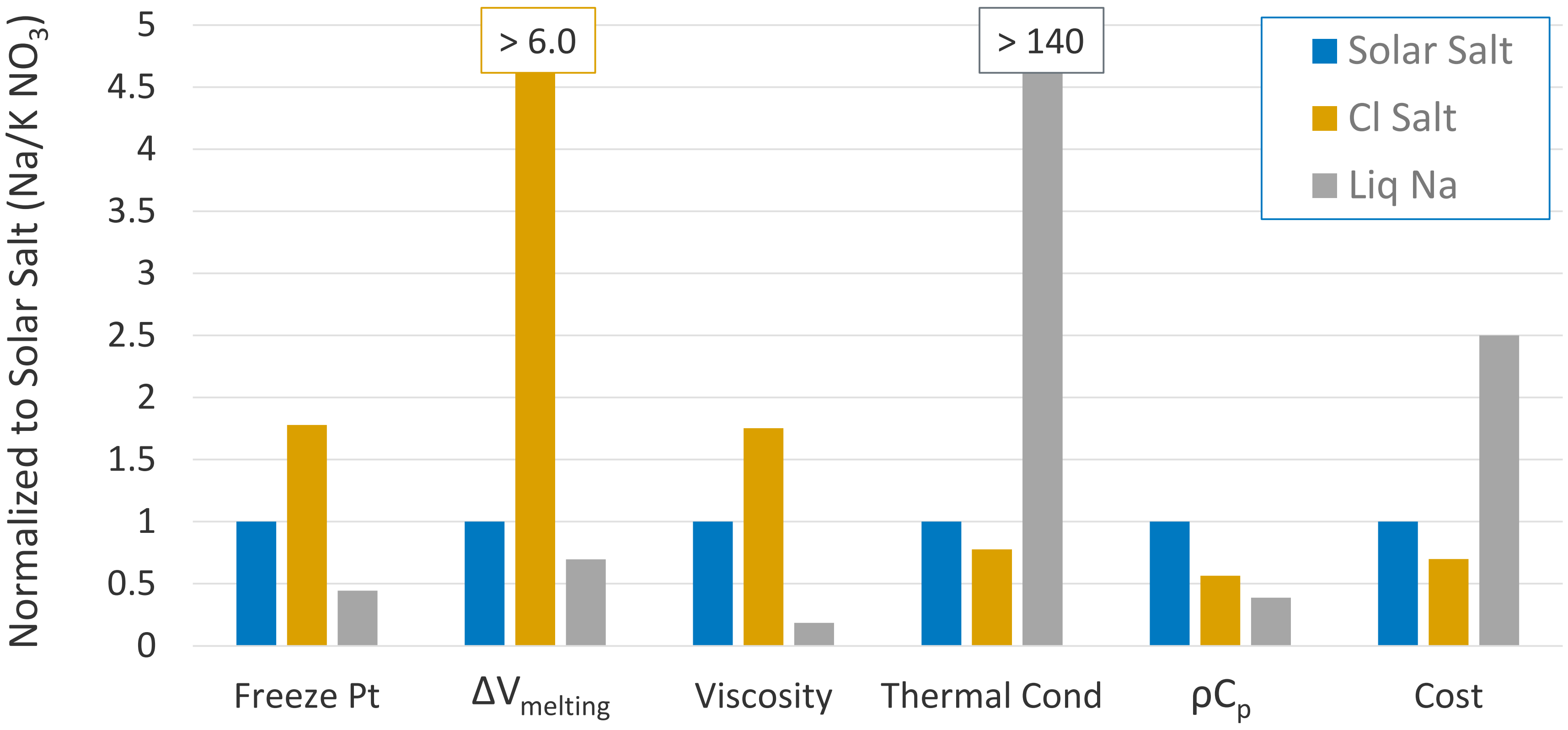
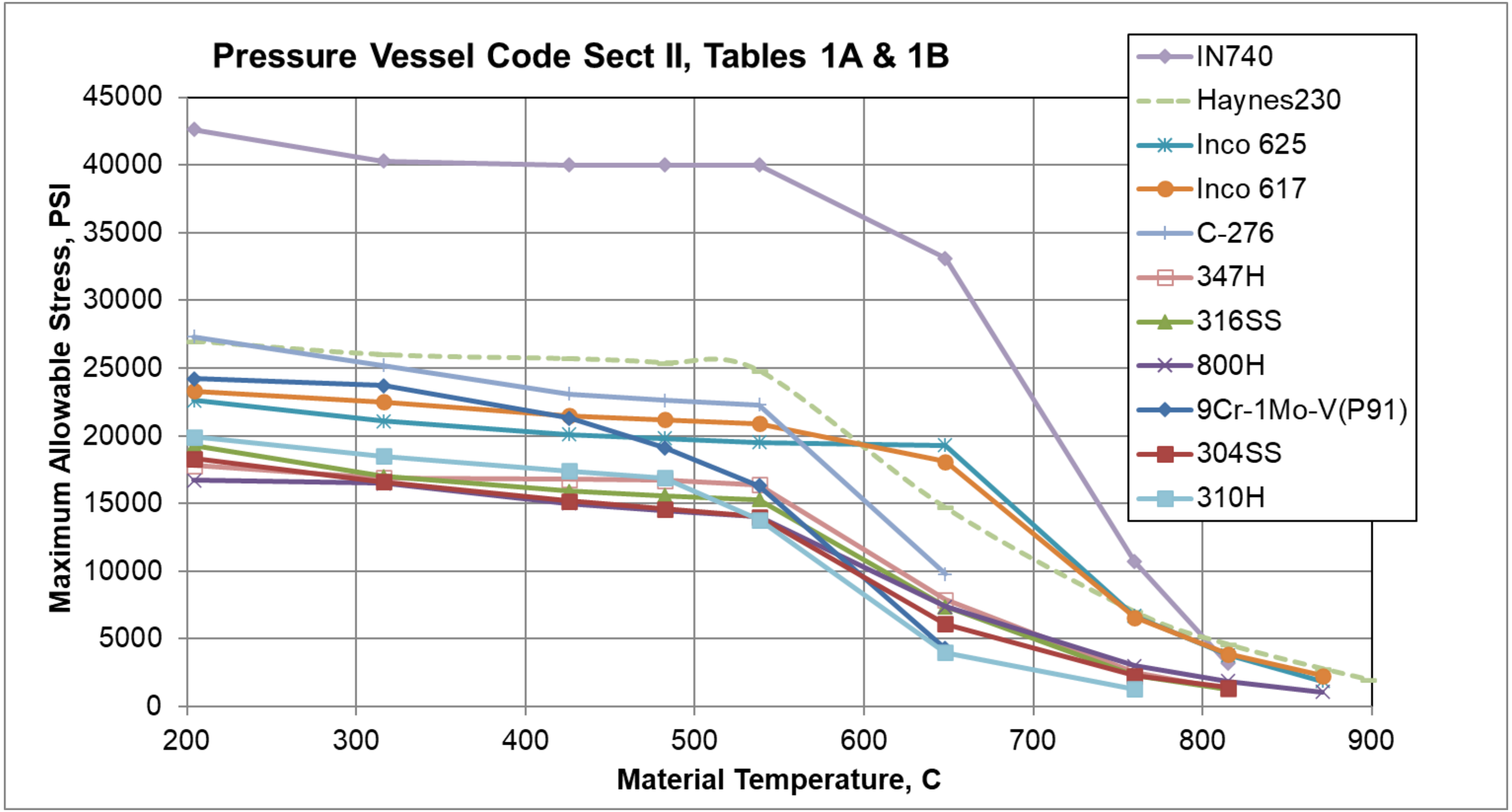
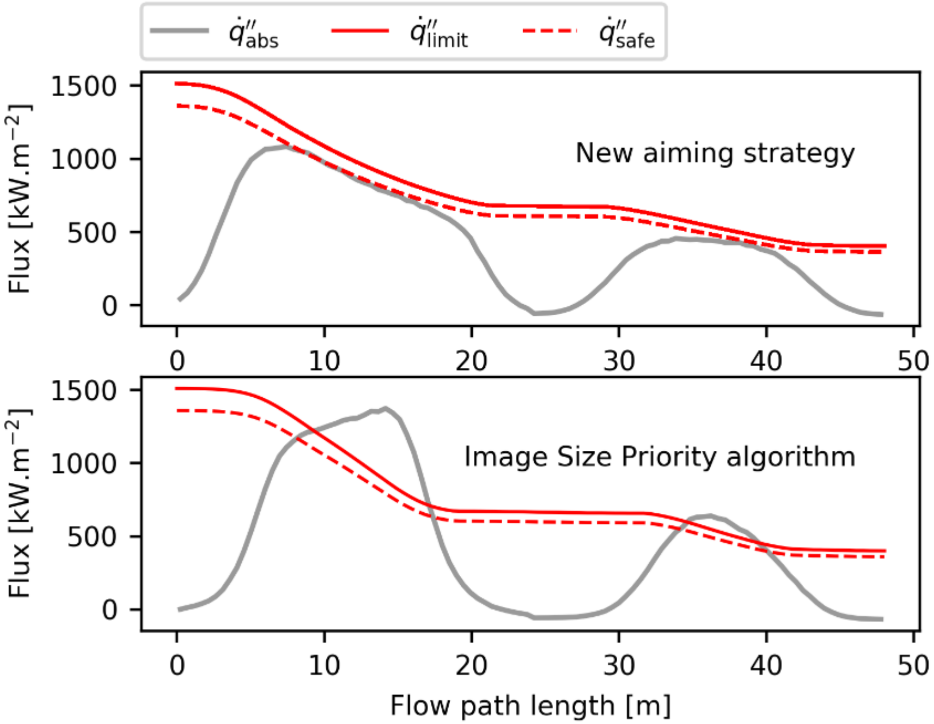
Gen3 Heat Transfer Fluids vs. Current Solar Salt

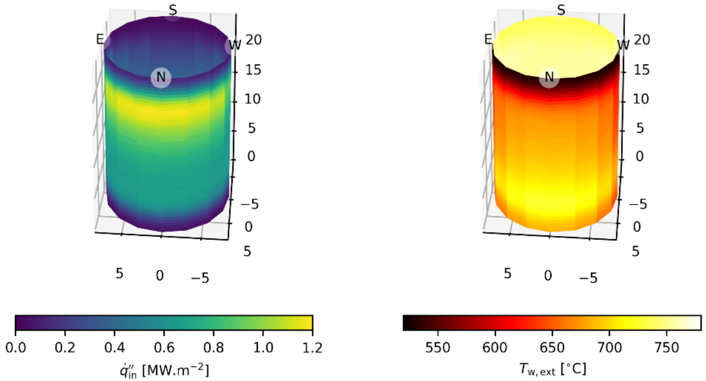


Alloy Strength with Temperature



Critical to Maintain Flux within Allowable Limits





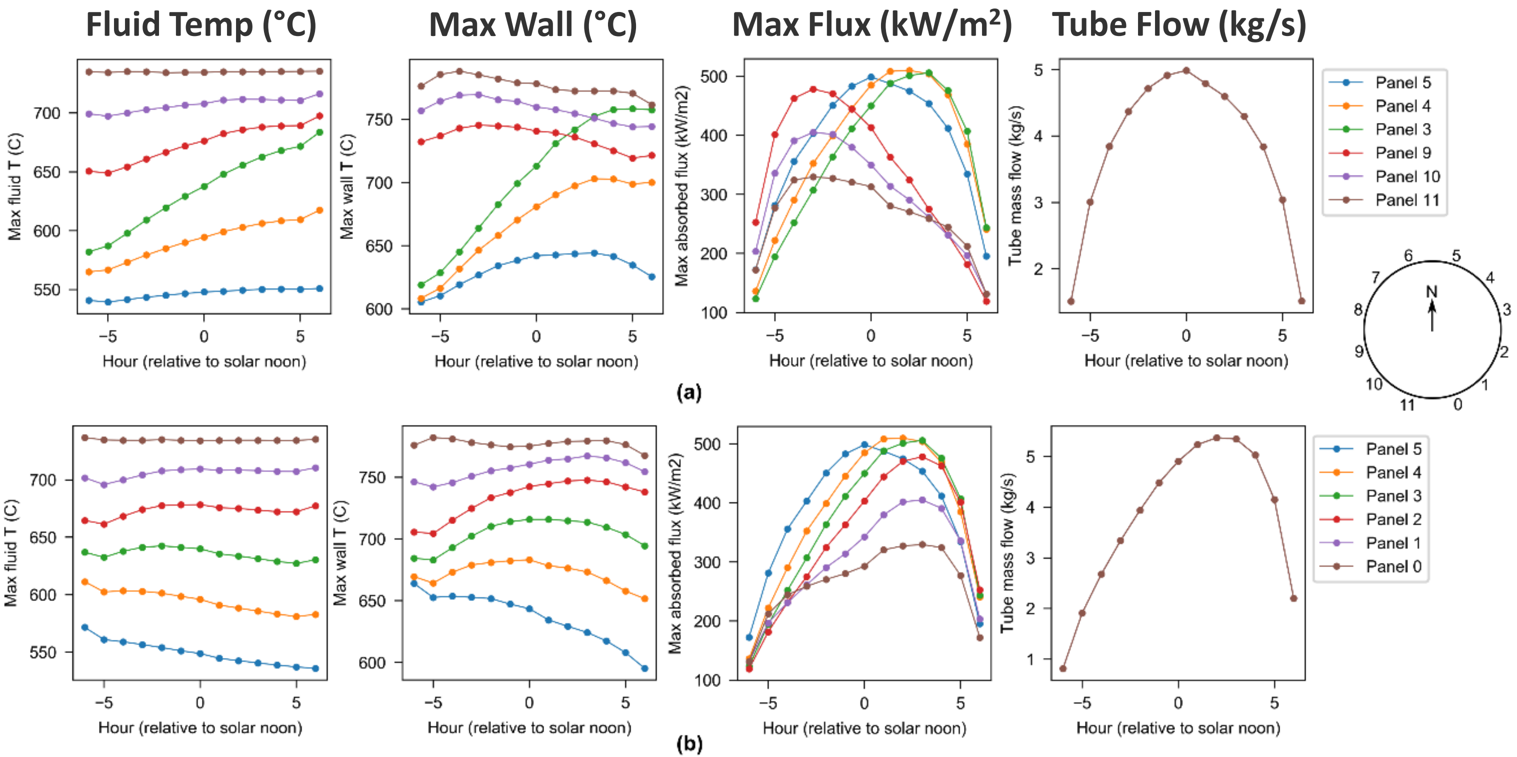
Flux Profile

Temperature Profile

Rethink Conventions

Conventional flow circuit spans panels (5, 4, 3, 9, 10, 11)

Bottom Row: Flow circuit spans panels (5, 4, 3, 2, 1, 0)

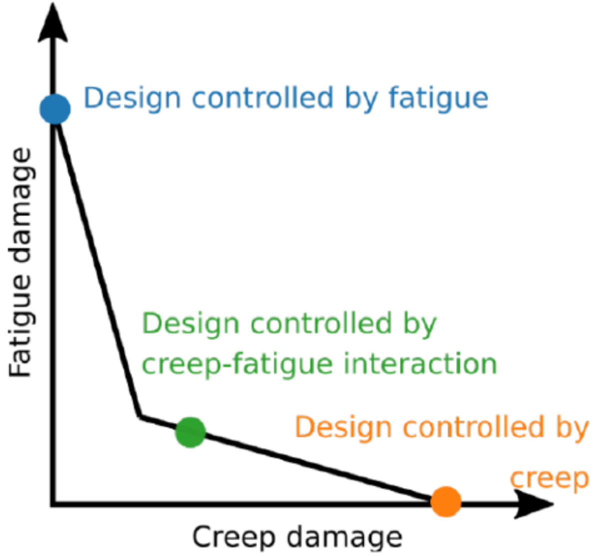


- *The bottom flow circuit limits the co-incidence of high-flux and high-temperature and the expected design life increases 5-6x versus the conventional (top) design.*

Creep / Fatigue Analysis

Solar Central Receivers:

- Aren't technically *pressure vessels* (no primary load)
- Diurnal cycling (of secondary load) means failure by:
  - Fatigue <600 °C
  - Creep-fatigue 600 °C to ≈750 °C
  - Creep ≈750 °C to 850 °C



Creep-fatigue damage diagram

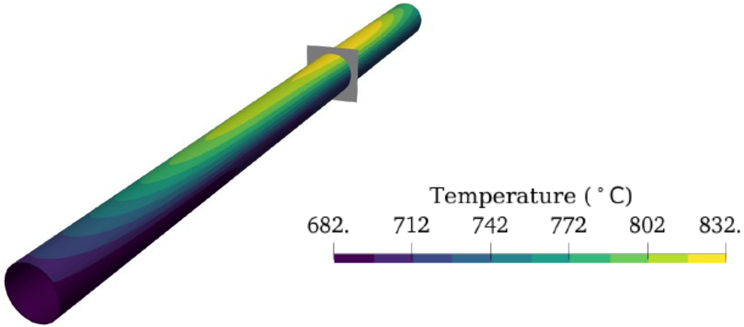
- Logie, "Structural Integrity of Advanced Solar Central Alloy 740H Receiver Tubes" SolarPACES 2020
- Bipul Barua et al., "Design Guidance for High Temperature Concentrating Solar Power Components," Argonne National Laboratory, Technical Report ANL-20/03, 2020.

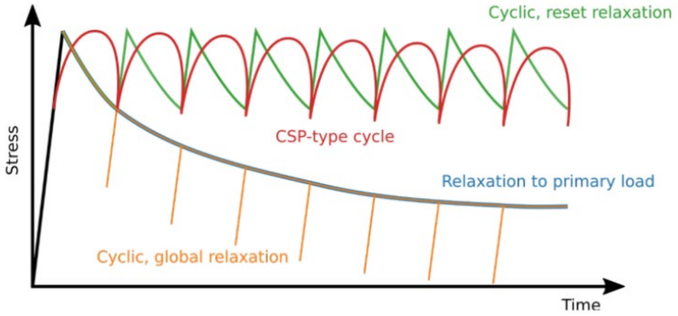
Design Methods for Creep-defined Systems

Simpler and conservative

More complex and more accurate

1. Design by elastic analysis using ASME Section III, Division 5
2. Design by elastic analysis using ASME Section III, Division 5 with reduced margin and simplified creep-fatigue evaluation
3. Design by inelastic analysis





Loading histories

- Logie, "Structural Integrity of Advanced Solar Central Alloy 740H Receiver Tubes" SolarPACES 2020
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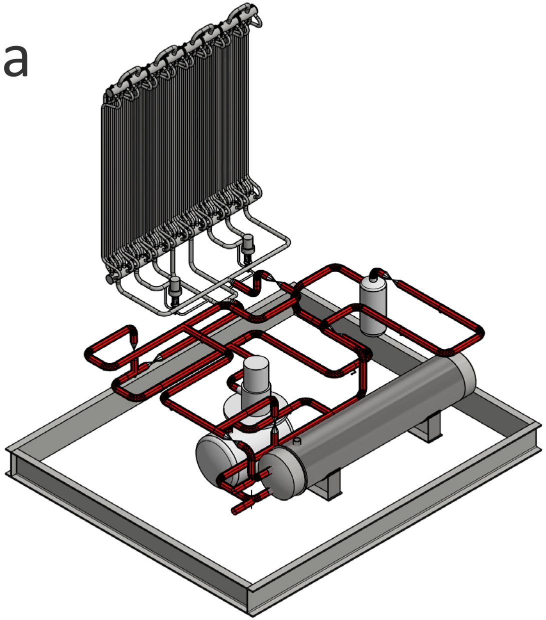
Pilot Scale Objectives

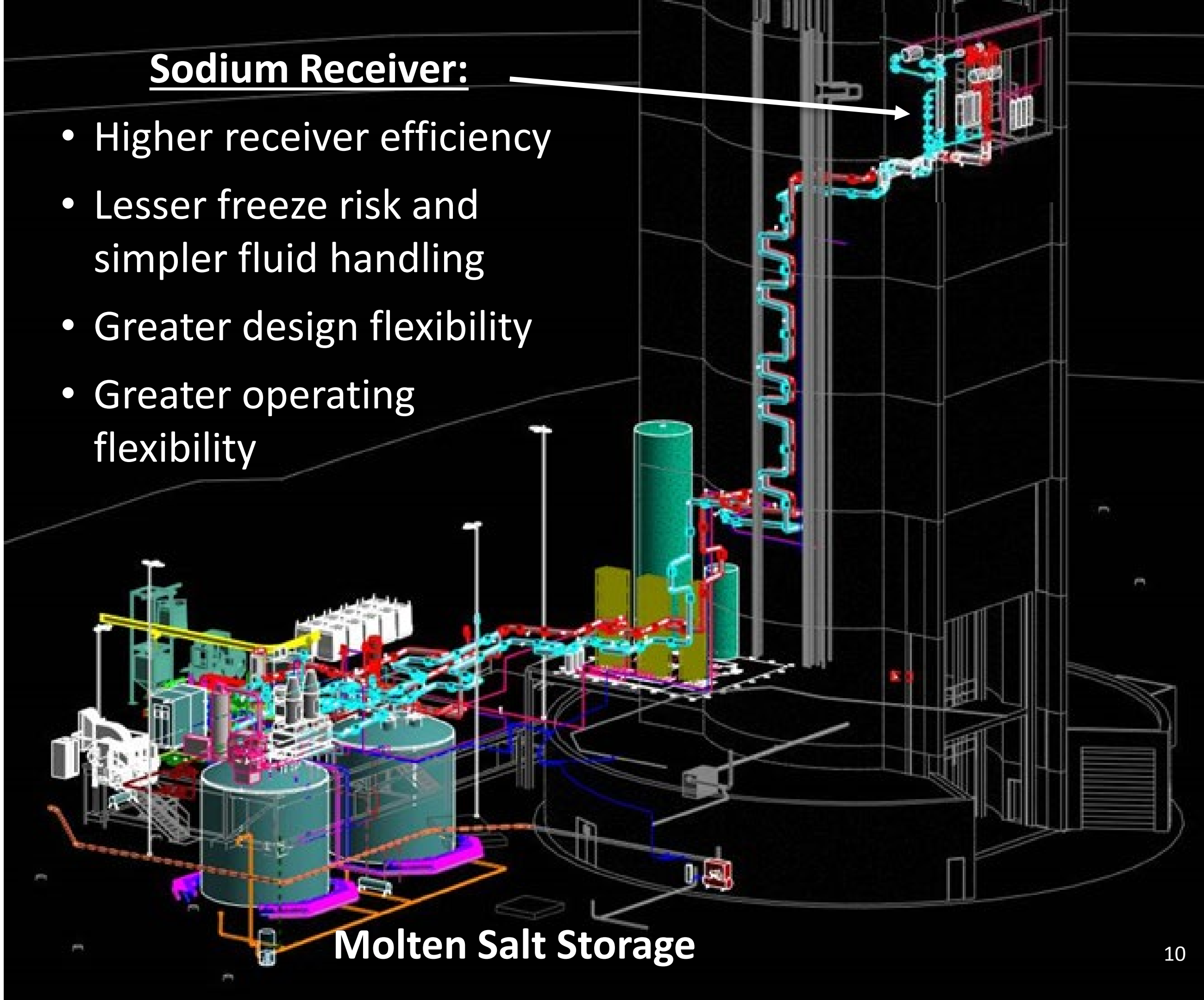
- Demonstrate operational control and reliability
  - Fill, control transients, drain, repeat
- Validate model results with performance data
  - Heat transfer coefficients
  - Temperatures (fluid and tube)
  - Ramp rate behavior
- Freeze recovery
- Corrosion rates and creep damage



Proposed Integrated System Design

Sodium Receiver:

- Higher receiver efficiency
- Lesser freeze risk and simpler fluid handling
- Greater design flexibility
- Greater operating flexibility



Molten Salt Storage

Summary

- Start with commercial design, use that to define what the pilot-scale system needs to do.
- > 700°C requires creep-regime analysis. Detailed inelastic analysis is necessary for accuracy and to avoid overly conservative limits.
- Material availability, code qualification, physical data, welding knowledge, etc. can be constraining.
- Transient operations will be the challenge.
- Rethink convention

Thank you!

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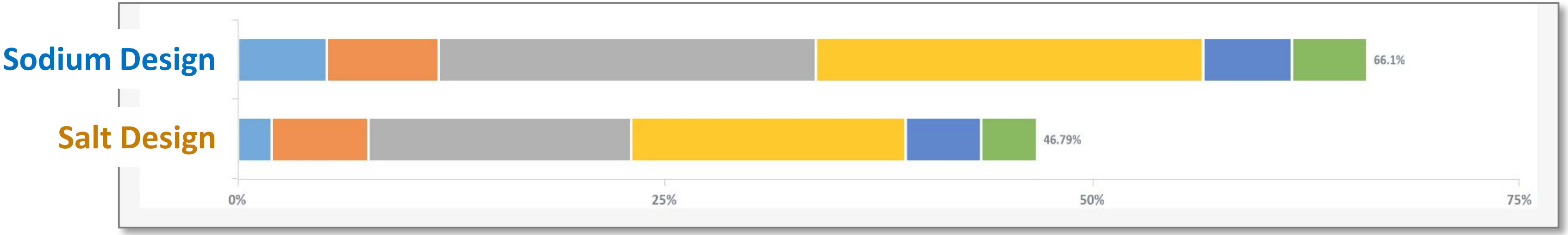
Supporting Slides

CSP Heat Transfer Fluids

Parameter	Solar Salt (Gen2)	Chloride Salt (Gen3)	Liquid Sodium (Gen3)
Composition	Binary $NaNO_3$-KNO_3	Ternary $MgCl_2$-KCl-NaCl	100% Na
Freezing Point (°C)	~238	~400	98
Volume change on melting	+3.3%	+20%	+2.6%
Stability Limit (°C)	~600	> 900	882 (bp)
Density (kg/m^3)	1770 @ 500°C	1560 @ 700°C	835 @ 700°C
Specific Heat (J/g-K)	1.53 @ 500°C	0.98 @ 700°C	1.26 @ 700°C
Viscosity (cP)	1.30 @ 500°C	2.28 @ 700°C	0.24 @ 700°C
Thermal Cond. (W/m-K)	0.54 @ 500°C	0.42 @ 700°C	64.2 @ 700°C
Major Concerns	NO_x formation Thermal stability	High freeze point Corrosion	Burns in air

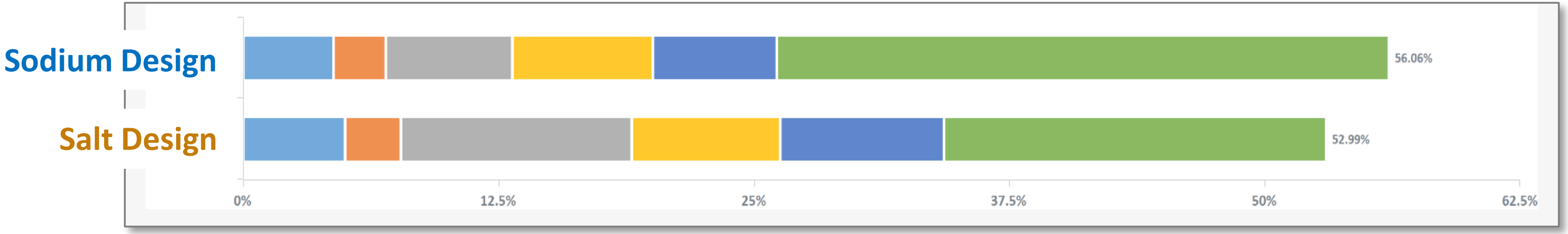
Benefit Scoring
(Higher Scores = Higher Benefit)



Criteria Legend

Accommodate different plant sizes and configurations	Maximize ease of operations and maintenance	Maximize efficiency and performance	Maximize long-term reliability and availability	Maximize stakeholder support	Minimize the time required to transition from the pilot phase demonstration to large-scale plants

Risk Scoring
(Higher Scores = Higher Risk)



Criteria Legend

- Minimize the risk of manufacturing issues
- Minimize the risk of a schedule delay
- Minimize the risk of design issues specific to the solar receiver
- Minimize the risk of obtaining bank financing and insurance for a commercial plant
- Minimize the risk of unplanned outages due to operational instability
- Minimize the risk to people and the environment

- Sodium case estimated at 11% lower LCOE
- Sodium case had better Benefit/Risk ratio: Sodium = 1.19, Salt = 0.86

➢ ***Team selected the Sodium Receiver design***