National Renewable Energy Laboratory
Innovation for Our Energy Future

LCA of Parabolic Trough CSP: Materials Inventory and Embodied GHG Emissions from Two-Tank Indirect and Thermocline Thermal Storage

ASME ES2009
San Francisco, CA

Garvin Heath
John Burkhardt
Craig Turchi
Terese Decker
Chuck Kutscher

July 20, 2009

NREL/PR-6A2-46875

Issue

- Significant env. impacts from energy systems
- Renewable energy systems shown to be much better than conventional (fossil), but requires different approach to estimate
  - Vast majority of env emissions from conventional systems in operation (fuel combustion)
  - Majority of env emissions from RE in component manufacture
- Requires accounting for all life cycle stages to evenly compare
- CSP touted as an important RE technology
  - Especially for ease of integration of energy storage to smooth solar resource fluctuations and extend into evening peak hours or longer
- Very few LCAs of CSP, especially of modern design and on US-based systems

NREL's LCA of CSP

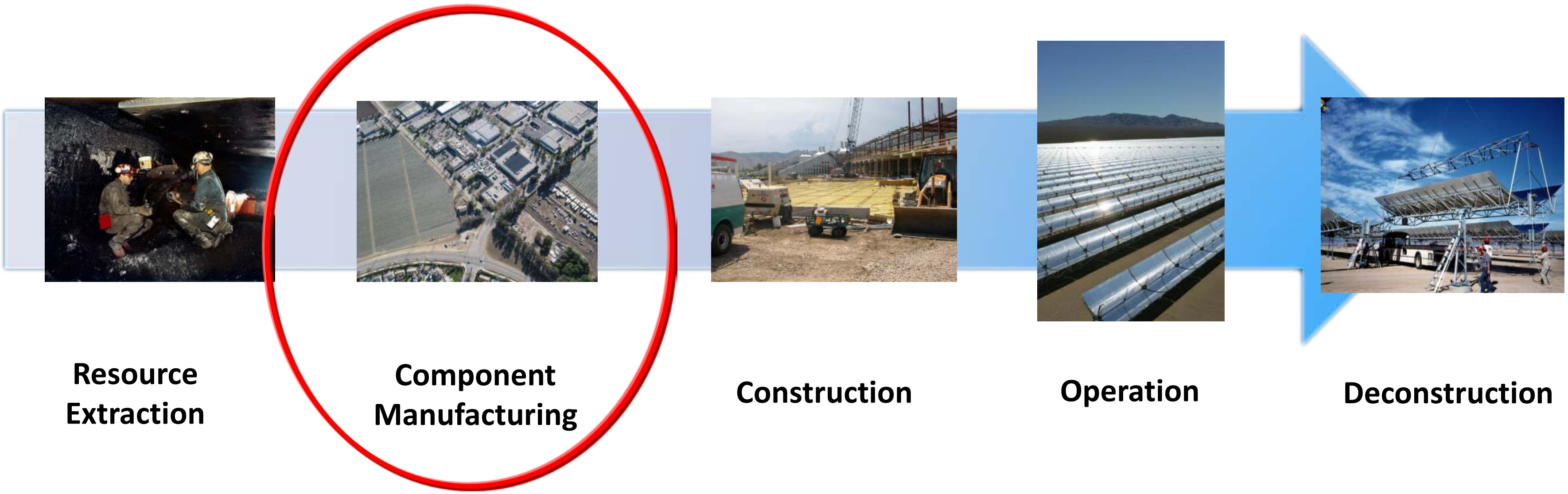
Goal: determine the life cycle environmental impacts (e.g., GHG emissions) and net energy balance of modern parabolic trough CSP in US

Today: comparison of materials inventory and embodied GHG emissions from two-tank and thermocline thermal energy storage sub-systems

- TES ~40% of CSP system embodied GHG emissions (Lechon et al., 2006)

Approach

- Life cycle assessment
  - Inventory level
  - Conforms with ISO standards
- Significant industry input
- Focus on impacts embodied in component manufacture
  - Construction, operation and decommissioning impacts generally found to be small for RE technologies, including CSP (Veibahn et al., 2008)

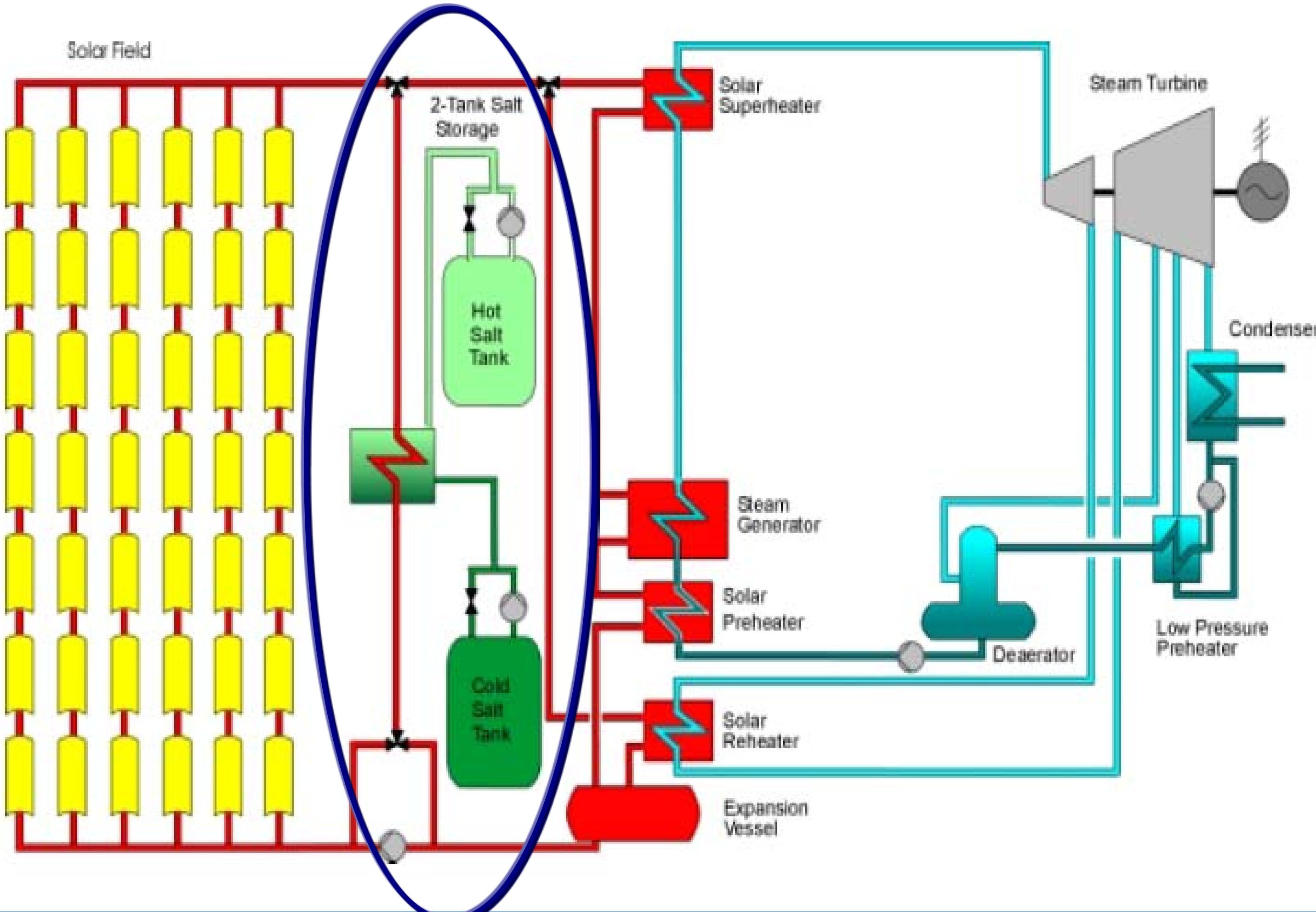


Data Sources

- Two-tank
  - Supporting spreadsheets to Kelly, 2006, *Nexant Parabolic Trough Solar Power Plant Systems Analysis, Preferred Plant Size* (NREL/SR-550-40162)
  - Extensive conversations with Kelly
- Thermocline
  - Uses two-tank as base, from which subtractions and substitutions were made based on expert judgment
- Materials life cycle GHG emissions
  - EcoInvent v2 LCI database (1^{st} choice)
    - Mass-based
    - www.ecoinvent.ch
  - US Economic Input Output (EIO-LCA)
    - Cost-based
    - CMU: www.eiolca.net
- Global warming potentials
  - 2007 IPCC

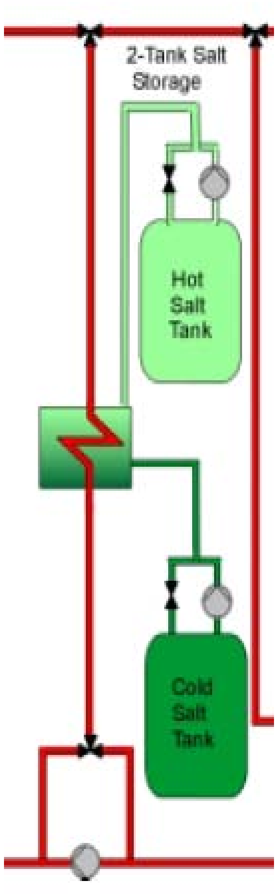
System Definition and Boundary

- 50 MWe parabolic trough plant
- 6 hours thermal storage



Systems – Indirect two-tank

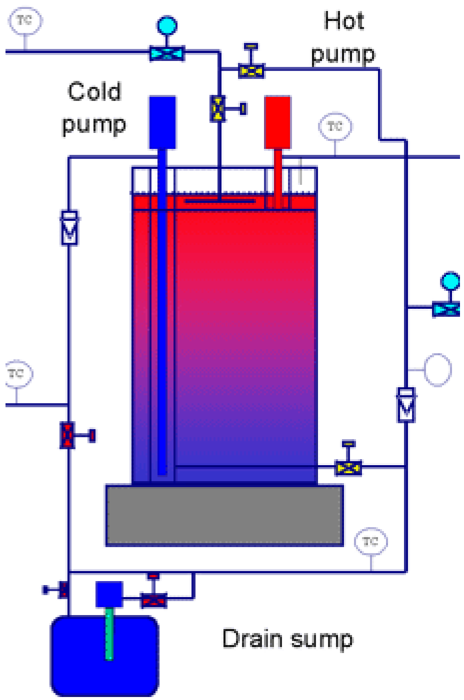
- Storage tanks
  - Hot and cold tanks (2)
  - Immersion heaters
  - Insulation
  - Nitrate salt and therminol pipes, heat tracing pipes and insulation
- Thermal mass – molten salt
  - 60% Potassium nitrate;
  - 40% Sodium nitrate
- Tank foundations
  - Concrete and rebar
  - Insulation
  - Steel plate
  - Thermal slab and rebar
- Oil-to-salt heat exchangers
  - Tubes, shells, covers
  - Insulation
  - Heat tracing pipes



- Pumps
  - Nitrate salt pumps for each tank
  - Oil-to-salt HX
- Elevated platform
  - Structural steel
  - Structural concrete
  - Rebar
- Nitrogen ullage system
  - Nitrogen
  - Tank
  - Compressor
  - Pipes
  - Insulation
  - Heat tracing
  - N2-to-air heat exchanger

Systems – Thermocline

- Single tank
  - Model as hot tank (slightly larger)
- Replace 70% of salt with silica sand
- Half of most materials
  - Some retained in full (N2 system)



Source: Sandia National Laboratories test

Materials and Proxies

- Nitrate salts (40% Potassium Nitrate, 60% Sodium Nitrate)
  - Neither in LC databases
  - Decided that both could be approximated by same material
  - Most nitrate salt used in CSP application is mined
  - Surrogate = KCl, a known mined product
- Steels
  - Carbon steel (tanks, pipes, rebar)
  - Stainless steel (oil-to-salt HX and piping, immersion heaters)
- Concrete
- Insulations
  - Calcium Silicate
    - Also not in LC databases
    - Closest analogue = sand-lime brick
      - Closest based on peak process temperature and process steps
  - Refractory bricks
  - Mineral wool
  - Foam glass
- Pumps
  - Because highly manufactured, used economic value with EIO

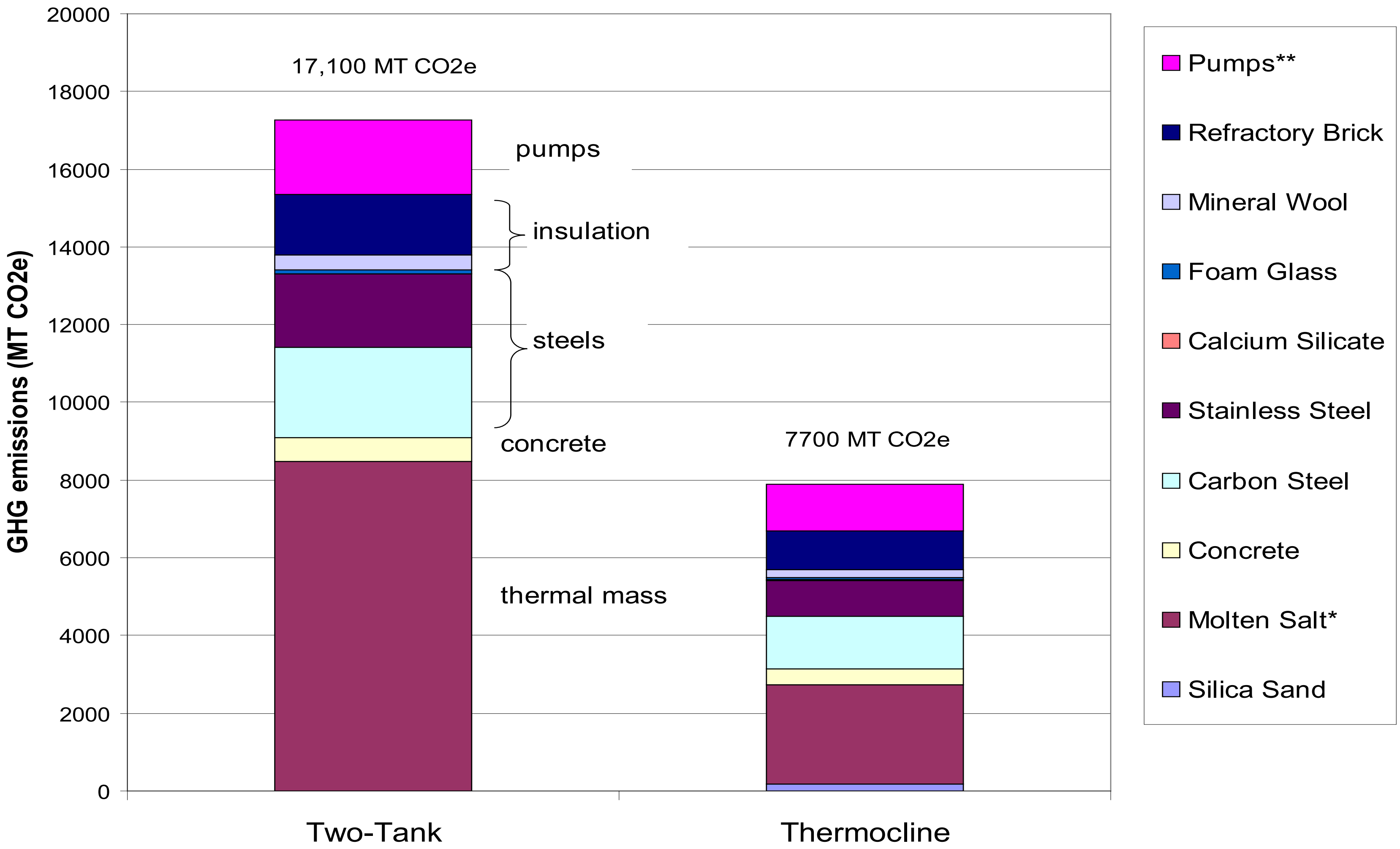
Results: Materials Inventory

	MATERIAL MASS [KG]		Thermocline Reduction (%)
	TWO-TANK	THERMOCLINE	
Silica Sand	-	8,950	
Molten Salt*	25,600	7,680	**70%**
Concrete	5,140	3,360	**35%**
Carbon Steel	1,615	936	**42%**
Stainless Steel	417	182	**56%**
Calcium Silicate	134	67	**50%**
Foam Glass	91	44	**52%**
Mineral Wool	283	158	**44%**
Refractory Brick	667	432	**35%**
Pumps**	-	-	**38%**

* Molten salt = 40% Potasium Nitrate 60% Sodium Nitrate

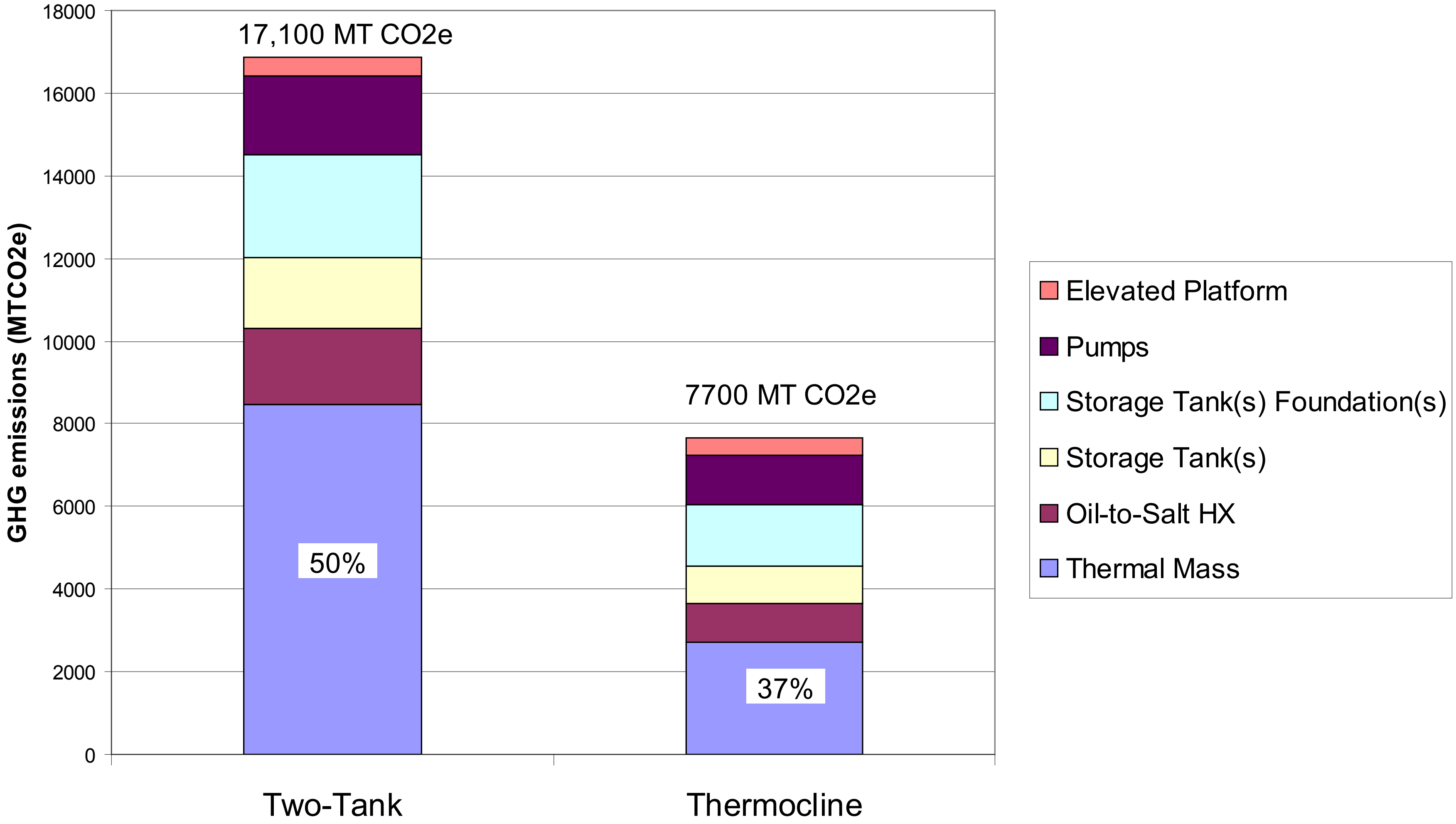
** Based on reduction of GHG emissions associated with pumps, estimated from EIO-LCA.

Results: GHG Emissions by Material



% reduction in GHG emissions per material = % mass reduction

Results: GHG Emissions by Component



Results: Sensitivity Analyses

- Nitrate salts
  - Nitrate salts for thermal storage could also come from synthetic pathway
    - Haber process – uses considerable natural gas and releases N2O
  - Synthetic nitrate salt proxy = KNO3 (fertlizer)
  - Per unit mass, synthetic salt > 8x GWP vs. mined
  - Impact on GHG emissions from TES:
    - **2-tank = increase total emissions nearly 5x**
    - **Thermocline = increase total emissions over 3x**
- Calcium silicate
  - So small a contribution that using different (higher GWP) proxy not matter

Conclusions

- Thermocline system demonstrates greatly reduced
  - Materials inventory
  - GHG emissions (-55%)
  - Cost
- Relative results expected to be robust to
  - Inclusion of construction, operation and decommissioning-related impacts
  - Selection of material proxy for nitrate salts (though difference is enhanced)
- Further research needed
  - Life cycle inventory of thermal storage nitrate salts (underway by manufacturer)
  - Completion of LCA for full plant
  - Comparison to previous work and other power systems

Questions?

Andosol