Capital Cost Reduction Tips for High Temperature Thermal Storage: Salt and Glass

ARPA-E Long Duration Storage Workshop

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HALOTECHNICS

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Key points

Lessons learned from Halotechnics work 2009-2015 (funded by ARPA-E HEATS award)

1. Selecting a low cost storage media is tempting, but you must consider the complete system costs.
   > Molten salt at 565 °C: $9/kWh fluid only → $30/kWht → $75/kWhe
   > Molten glass at 1500 °C: $1/kWh fluid only → $85/kWht → $170/kWhe

2. Thermal storage system cost drivers
   1. Storage fluid
   2. Container cost (steel tanks for salt, fused cast zirconia for glass)
   3. BOP

3. Integration with power block for discharge is costly. How to blow around a bunch of hot air?

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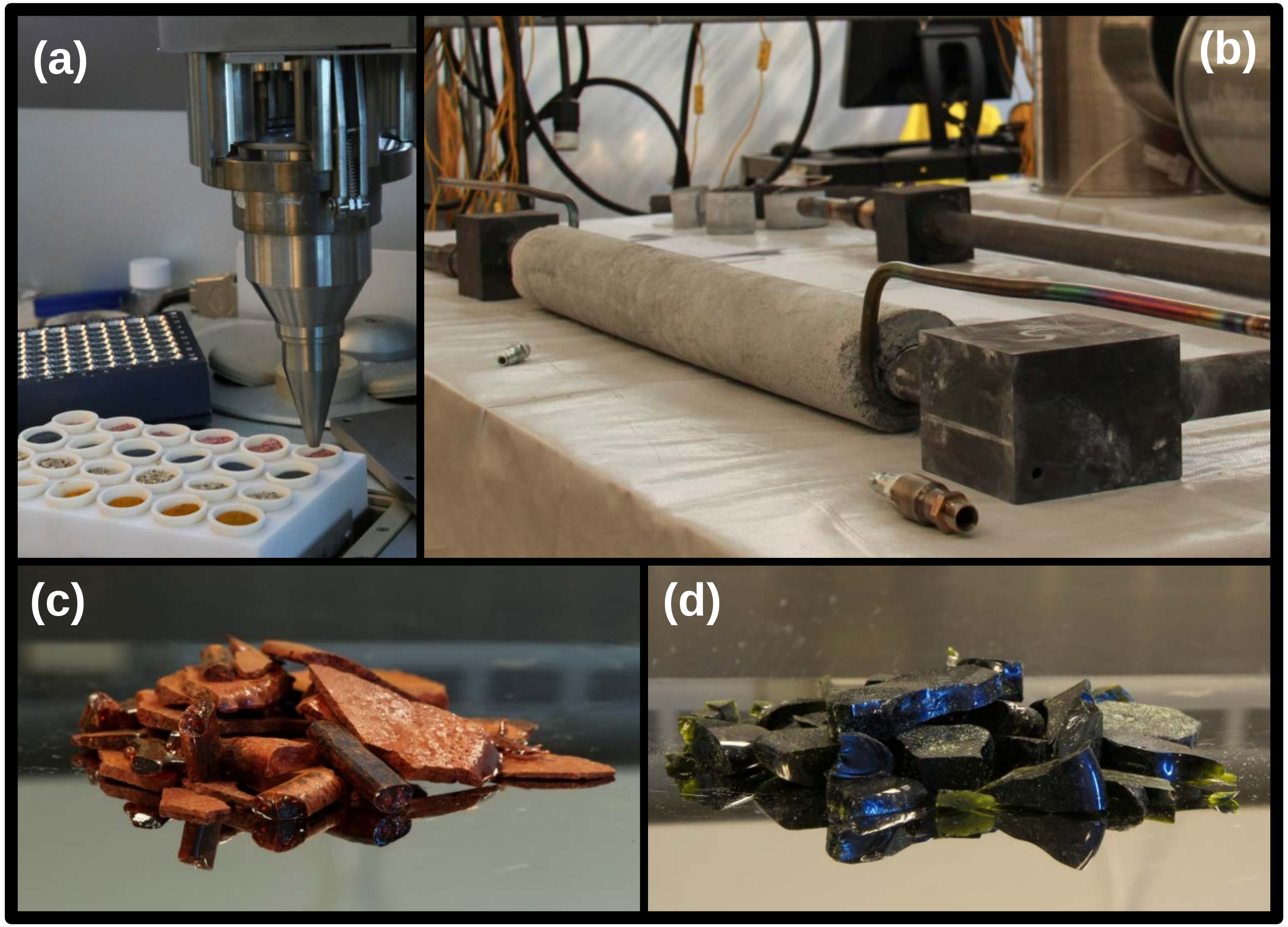
Reduce storage fluid cost tip 1: Use glass

(a) High throughput glass chemistry screening
(b) Graphite piping from molten glass test loop after testing at 1100 °C
(c) Proprietary vanadium-based glass
(d) Proprietary phosphate-based glass



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Glass properties

Glass could be used as a stable, low-cost thermal energy storage media ✓

- Glass cullet (sorted, recycled glass) available in millions of tons annually at <\$200/ton
- Want low-iron clear glass for better radiative heat transfer from bulk (<0.1% Fe_2O_3)

Property	**Value**
Typical composition by weight (soda lime window glass)	73% SiO_2, 14% Na_2O, 9% CaO, 4% MgO, 0.15% Al_2O_3, 0.1% Fe_2O_3
Heat capacity (Cp)	1.45 kJ/kg-K
Density (ρ)	2300 kg/m^3
Maximum temperature stability (alkali volatilization)	1500-1600 °C
Softening point	700-800 °C

Typical clear glass cullet

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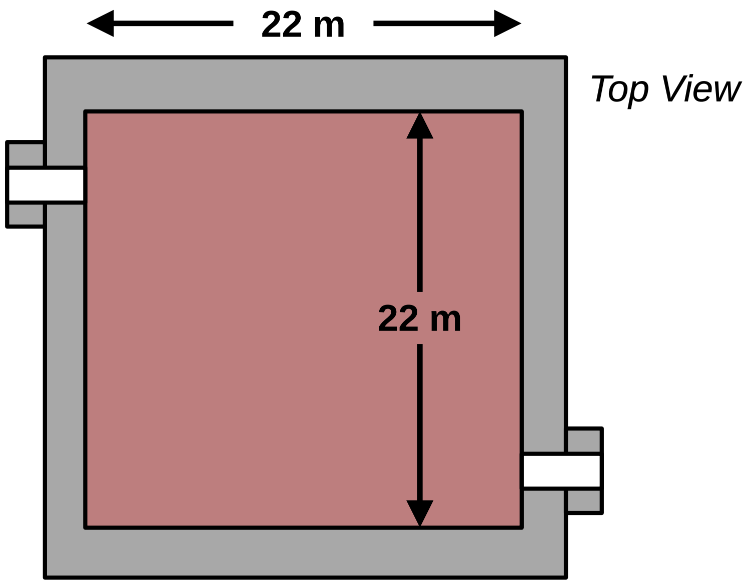
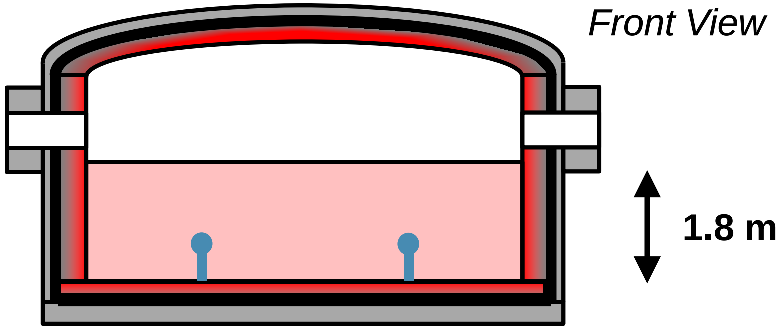
Molten glass thermal storage tank





Base-case design:

- Glass reservoir sized for 2000 ton inventory (common in glass industry)
- Square footprint (22 m x 22 m) to reduce surface area and cost
- 1.8 m (72") glass pool depth is feasible with standard furnace designs

At target ΔT of 500 °C, design can store 400 MWht, enough for <u>40 MWe, 4 hours storage</u>

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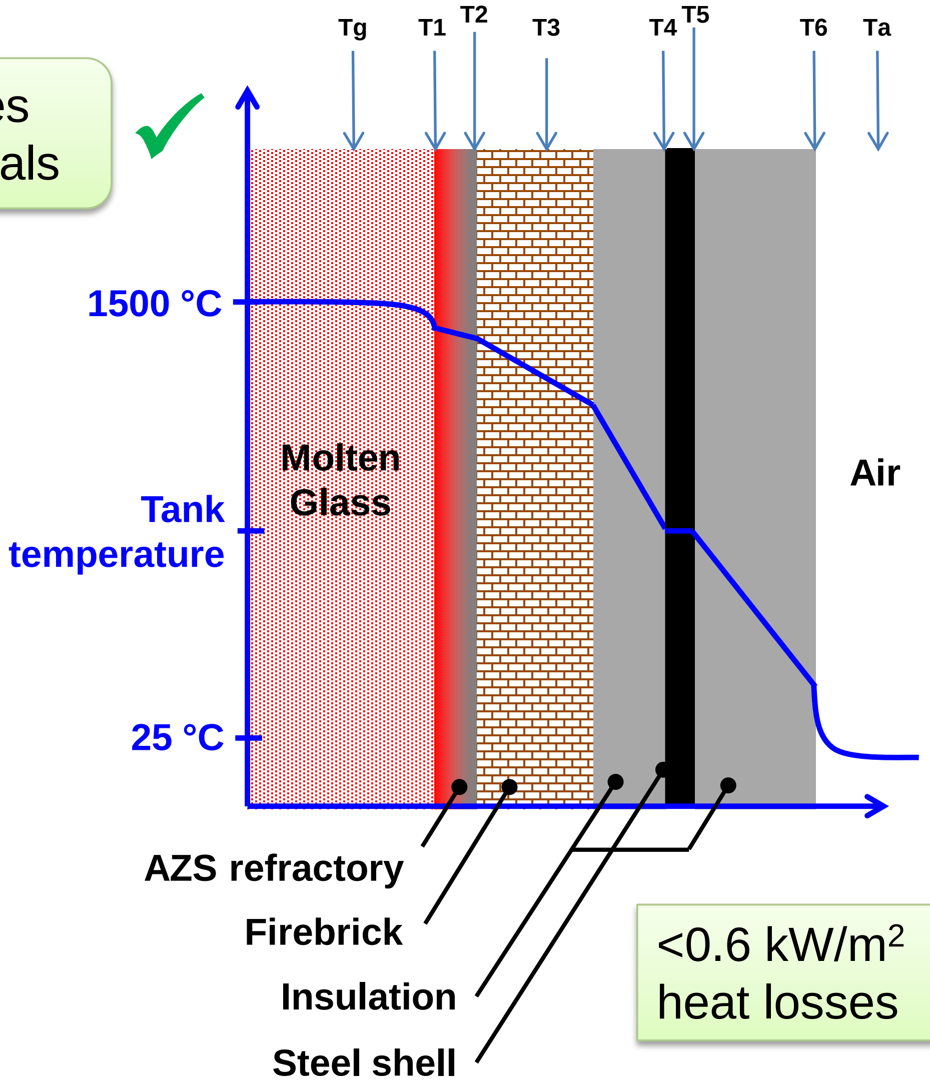
Watch out for expensive containment materials

It is feasible to achieve <5% heat losses per day with standard insulating materials ✓

- Assume 2000 ton glass inventory (size of large commercial float glass furnace)
- Thin AZS refractory layer for corrosion resistance
- ~18” firebrick layer for low-cost, resilient insulation. Forms “self sealing” cold zone
- Steel shell for structural strength
- Additional external insulation to reduce heat losses



<0.6 kW/m² heat losses

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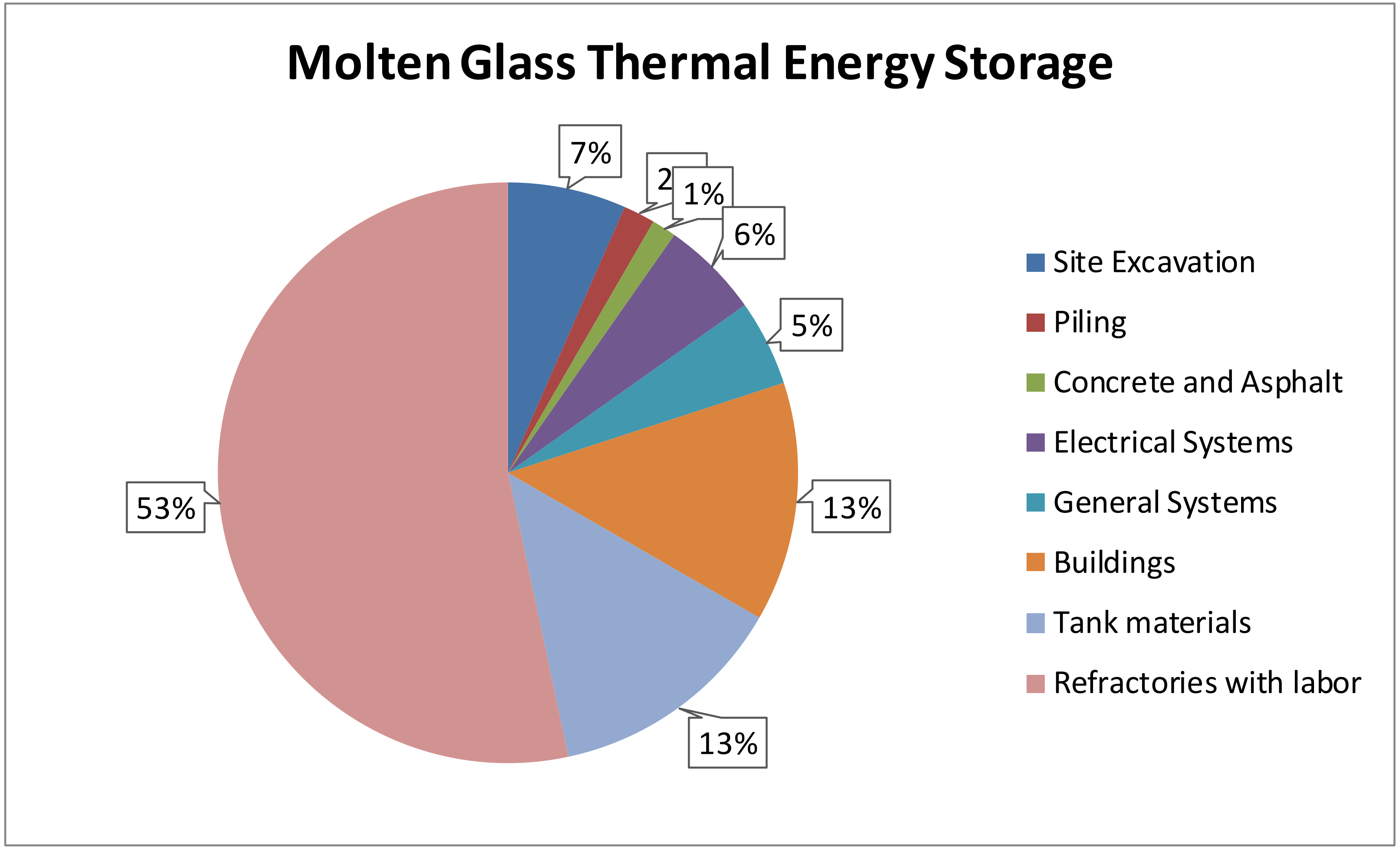
Glass TES cost breakdown

Item	Cost
Site Excavation	$ 2,200,000.00
Piling	$ 590,000.00
Concrete and Asphalt	$ 455,000.00
Electrical Systems	$ 1,828,000.00
General Systems	$ 1,596,000.00
Buildings	$ 4,448,000.00
Tank materials, BOP	$ 4,450,000.00
Refractories with labor	$ 17,800,000.00
Total	$ 33,367,000.00
	83.42 $/kWht

Cost estimates with input from glass industry executive



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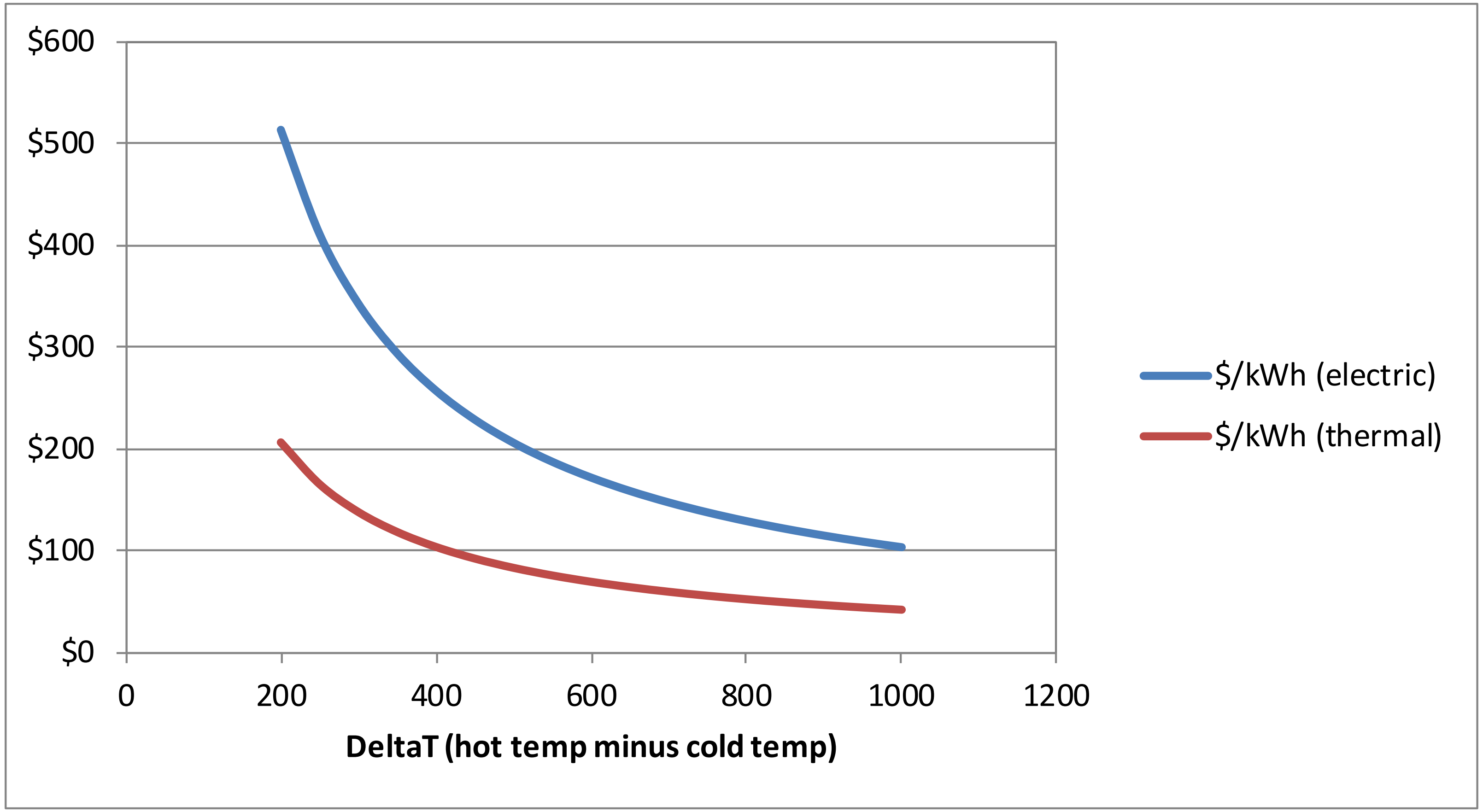
Reduce storage fluid cost tip 2: Increase ΔT

- Higher ΔT reduces system cost
- Minimum soda lime glass temperature to be pumpable is ~1000 °C
- Can glass get cheap enough?



TES cost in $/kWh with using molten glass

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Reduce storage fluid cost tip 3: Use regenerator

- Glass melter regenerator is an interesting proven thermal storage design
- Stores combustion gases exhaust heat at 700 °C
- Alternates air flow every 20 minutes to capture waste heat / preheat combustion air

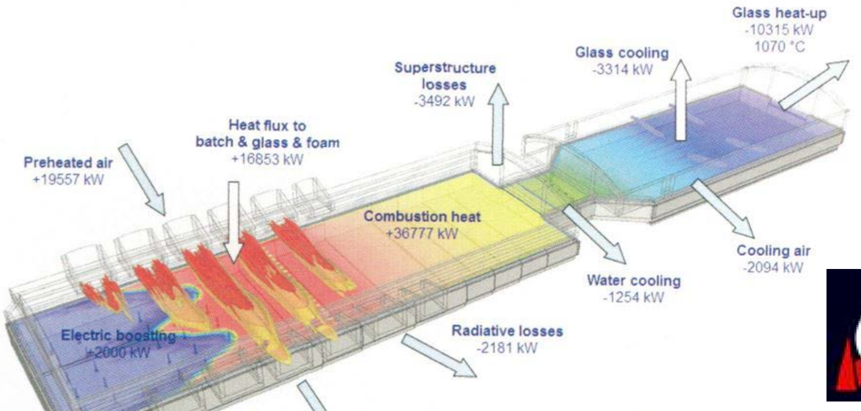
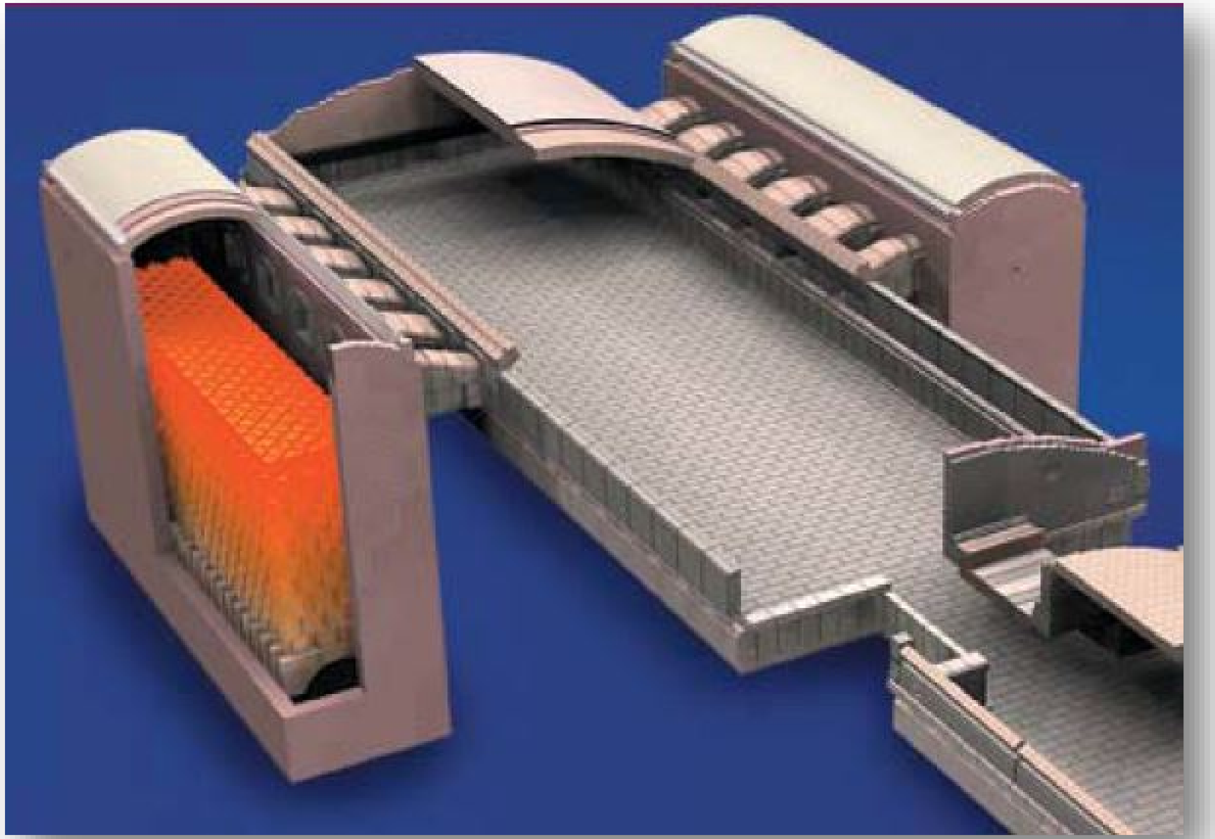


Figure 2: Example of a float furnace design including heat balance in GS GFM.



Refractory checker-brick regenerator

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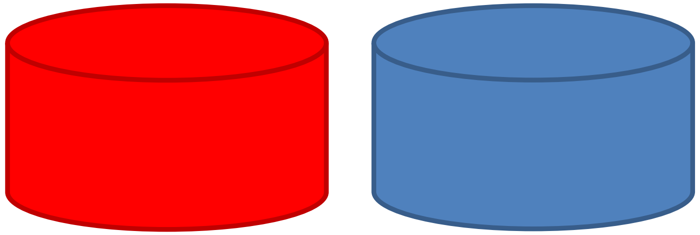
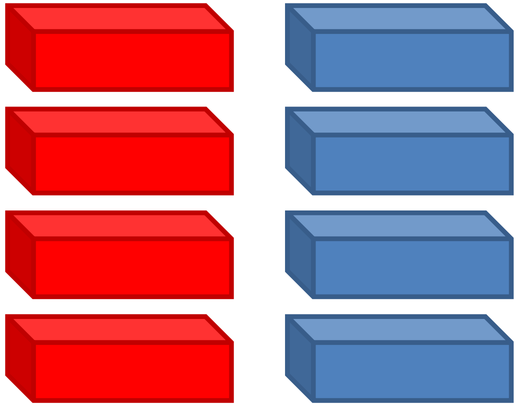
Reduce tank cost tip 1: Cascaded design

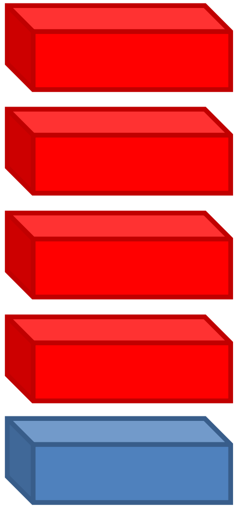
Traditional design
Expensive, 2x salt volume



Halotank™ modular design
Lower cost, 2x salt volume



Cascade™ Storage System
Lowest cost, ~1x salt volume



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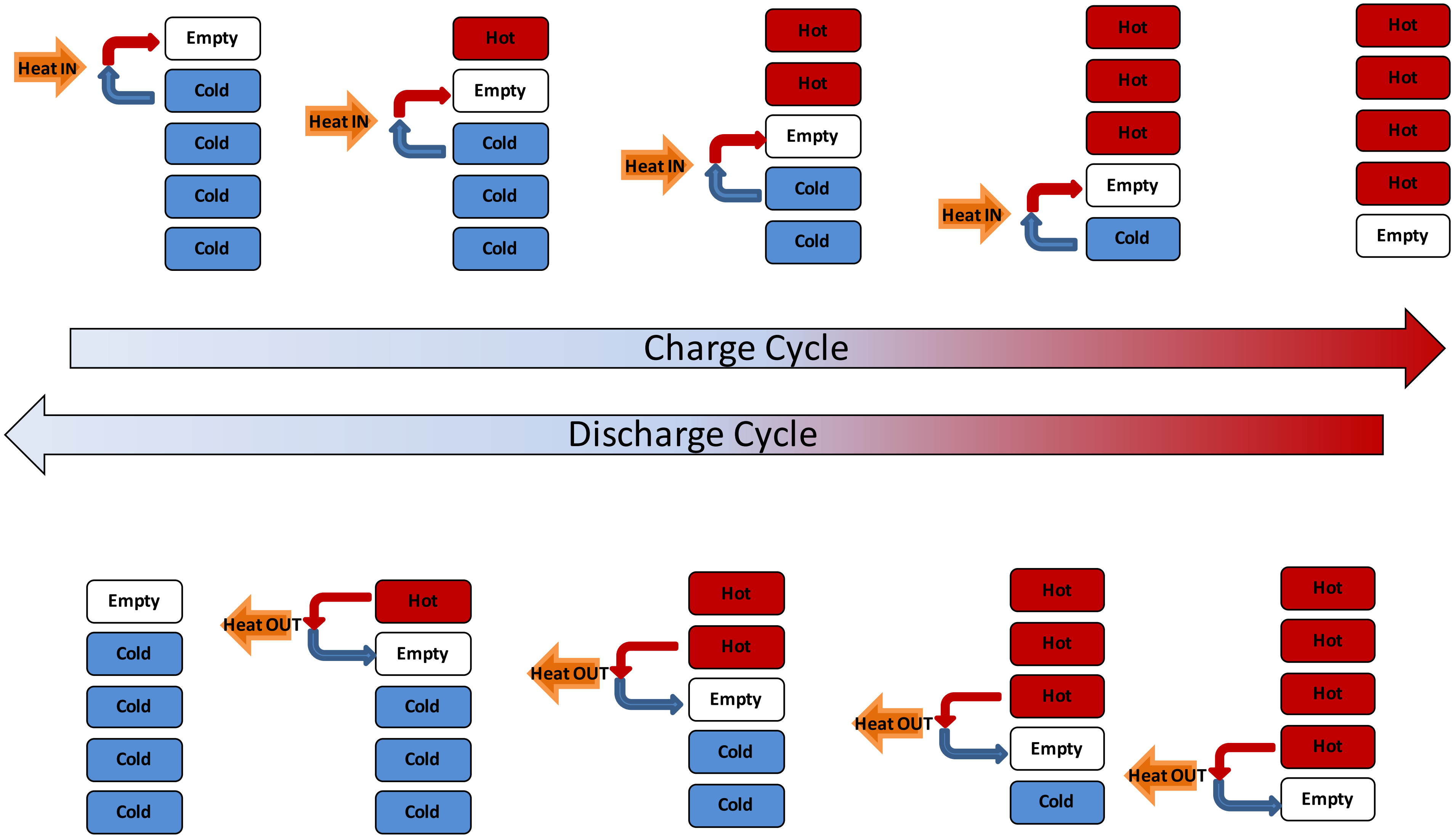
Reduce tank cost tip 1: Cascaded design



Less total tank volume, but:

- Must allow thermal cycling of tanks
- More complex BOP
- Higher heat losses from smaller tanks

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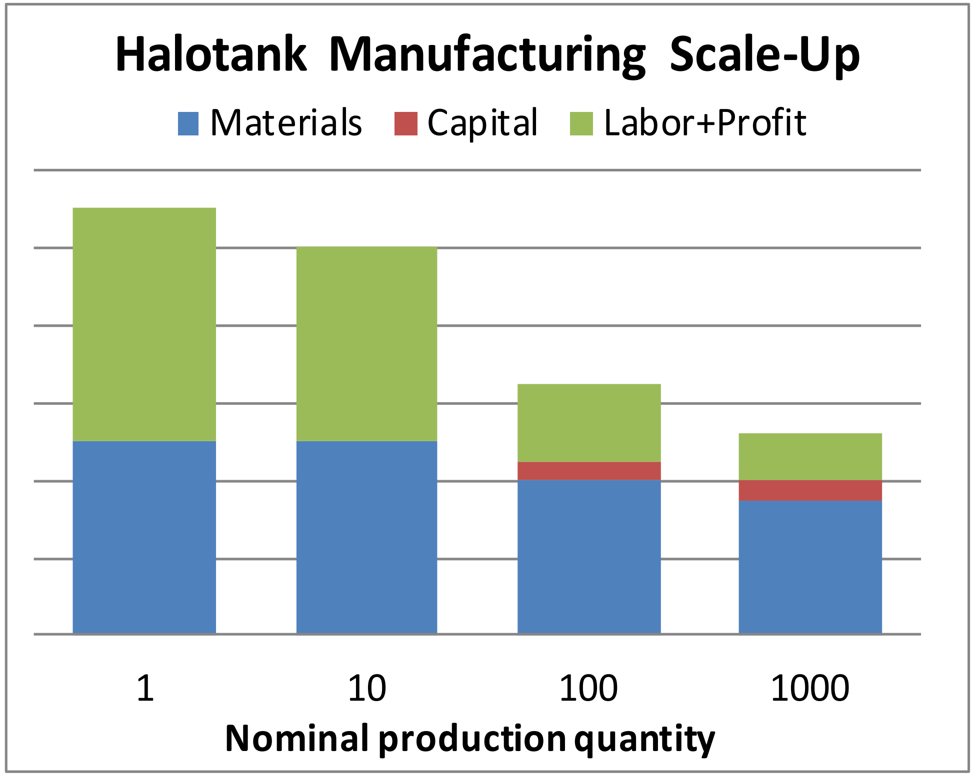
Reduce tank cost tip 2: High volume manufacturing

- Need big projects to bring unit costs down ←→ Need to bring unit costs down to get big projects

Propane tank manufacturing

Halotank modular tank prototype



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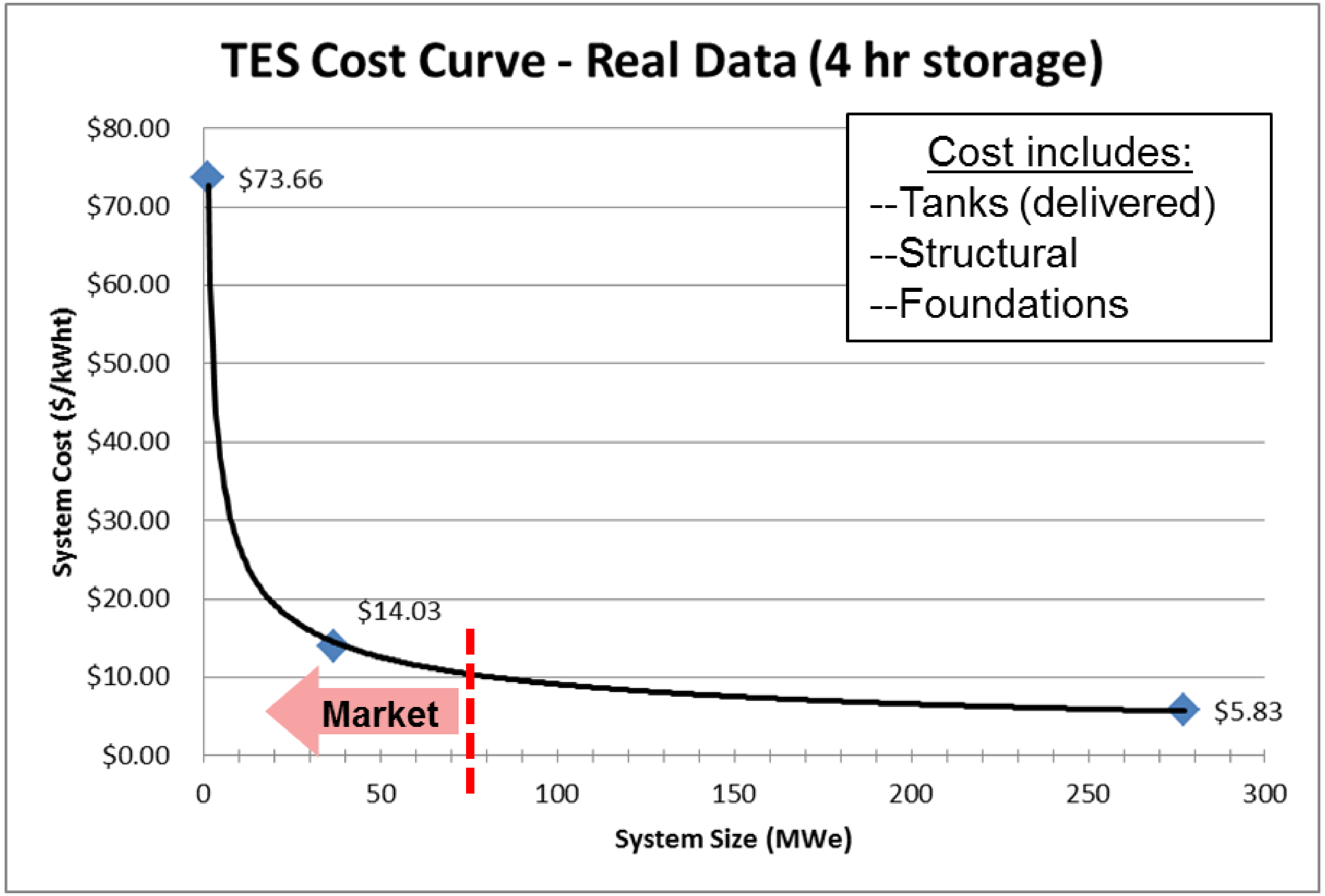
Reduce tank cost tip 3: Larger tank size

- Strong cost reduction with larger tank size
- Data collected from vendor quotes for API 650 steel tanks (hot tank and cold tank pair)



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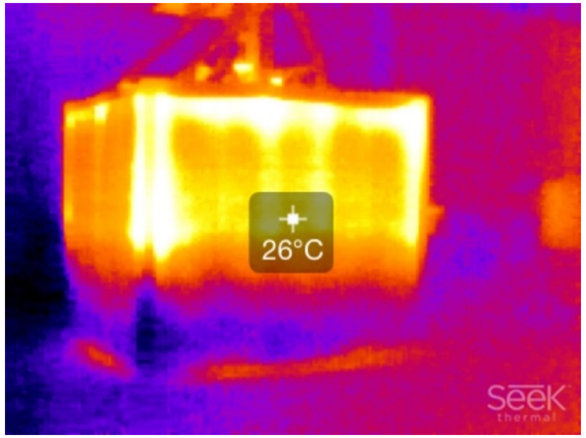
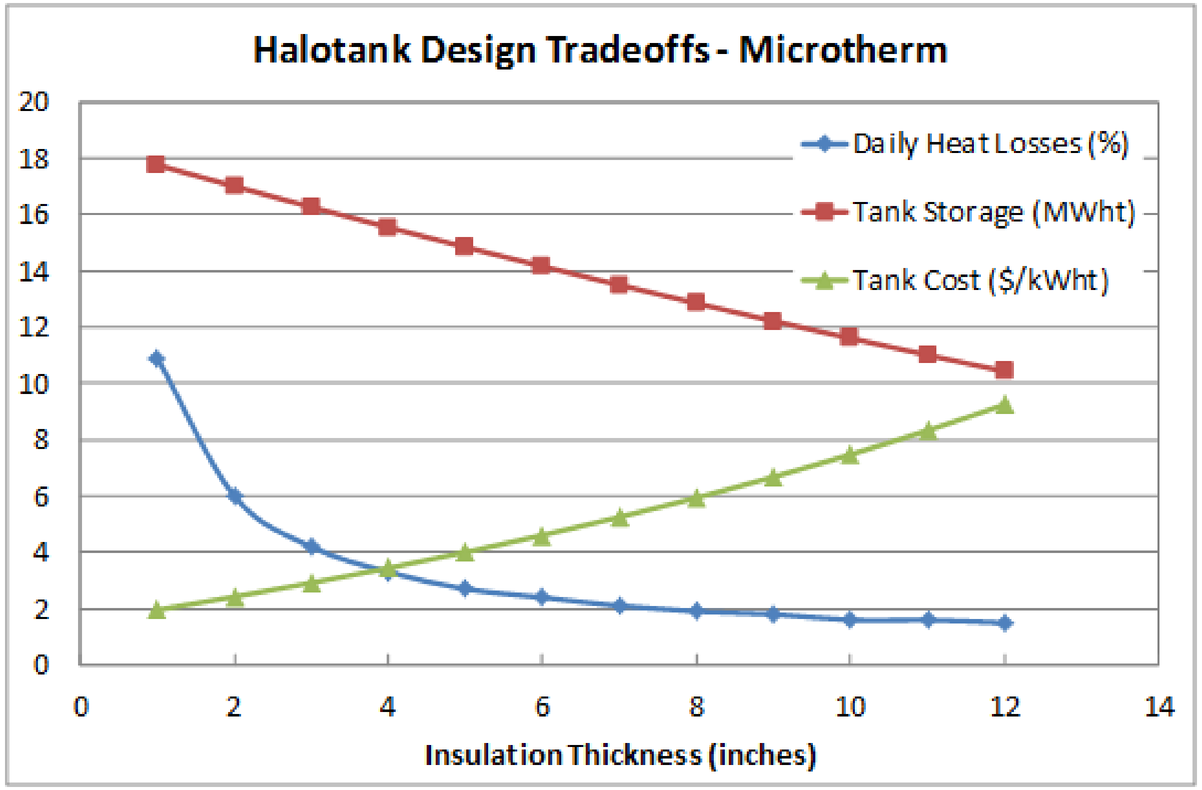
Heat losses in smaller tanks are higher

- Tradeoff between insulation (capex) and acceptable heat losses (opex)





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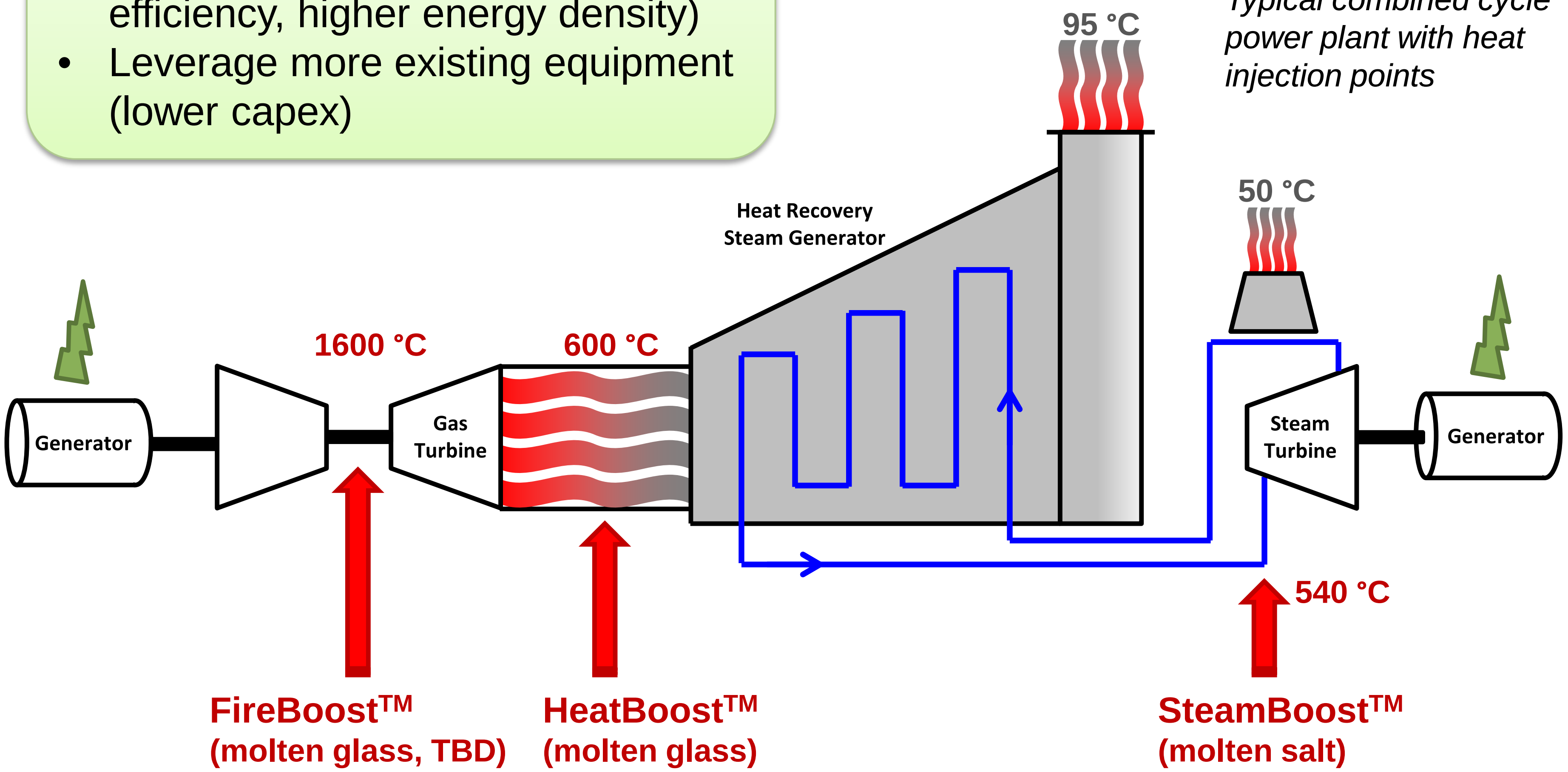
Reduce BOP cost tip 1: Integrate into existing thermal power plants

Inject heat further upstream:

- Higher temperature (higher efficiency, higher energy density)
- Leverage more existing equipment (lower capex)

Typical combined cycle power plant with heat injection points



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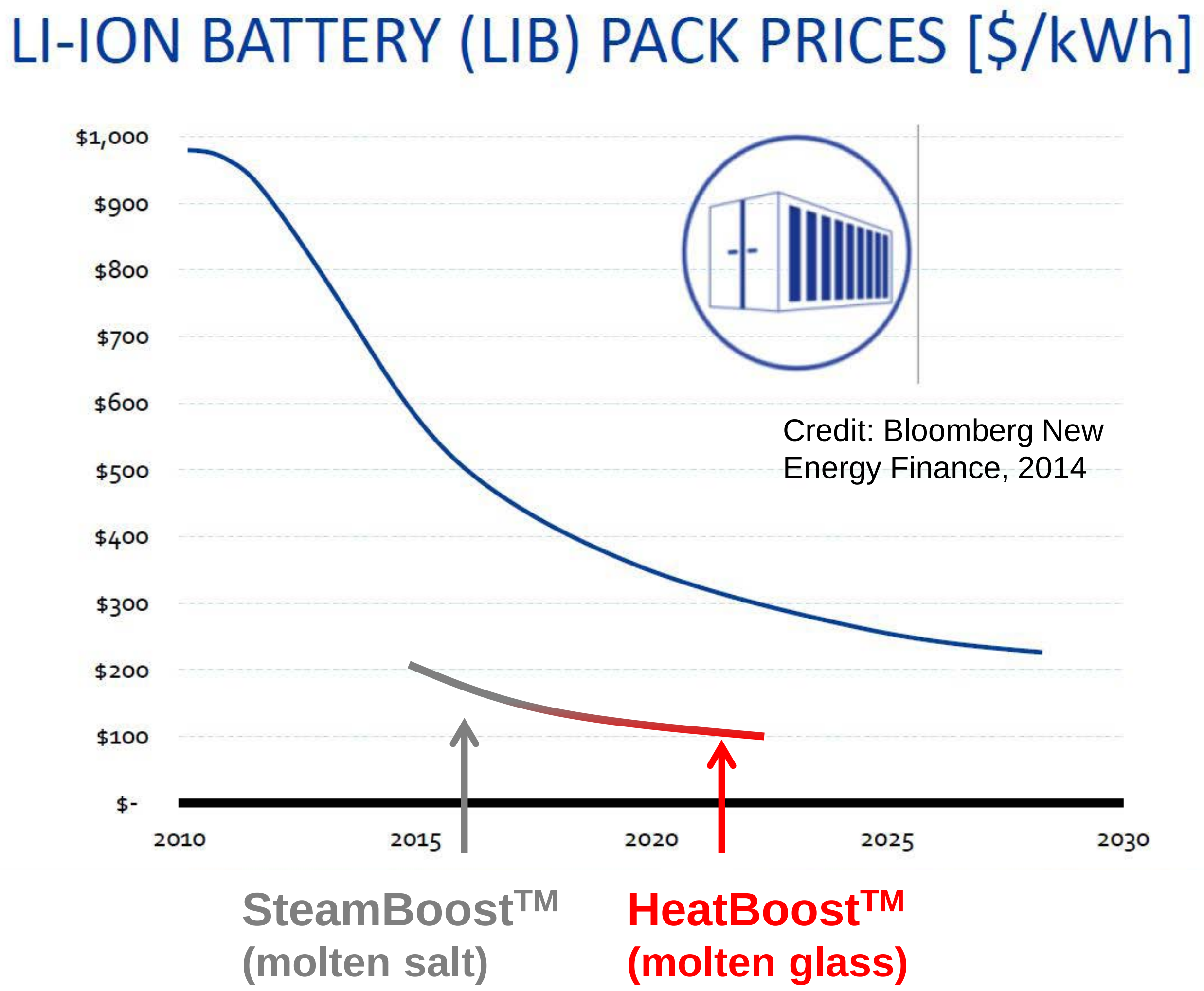
Cost must stay ahead of batteries



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Thank you

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