Sandia National Laboratories

From Photons to Process Heat: Demonstrating PV-Charged Radial Packed-Bed Thermal Energy Storage for Coffee Roasting

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Terrestrial Heat Repository for Months of Storage (THERMS)

Overview

Energy storage in the form of sensible heat, stored in earth material like rocks or gravel. The thermal energy storage (TES) system is charged from electrical or heat sources, holds energy, and later dispatches energy to a heat process (e.g. food and beverage, agriculture, HVAC, drying, and more). System functions autonomously, storing and delivering heat as required. Air used as primary discharge heat transfer fluid. Secondary transfer to steam possible via steam generator.

TECHNOLOGY BENEFITS

- Ultra-low cost heat storage (~10-50/kWh vs $200-300/kWh Li-ion batteries)
- Utilization of earth materials as storage media
- Minimal system components for heat delivery
- No cyclic degradation below 500 C

COMMERCIAL APPLICATIONS

- Industrial coffee, cacao, and barley roasting
- Chemical and food & beverage steam generation
- Asphalt, concrete, and steel production

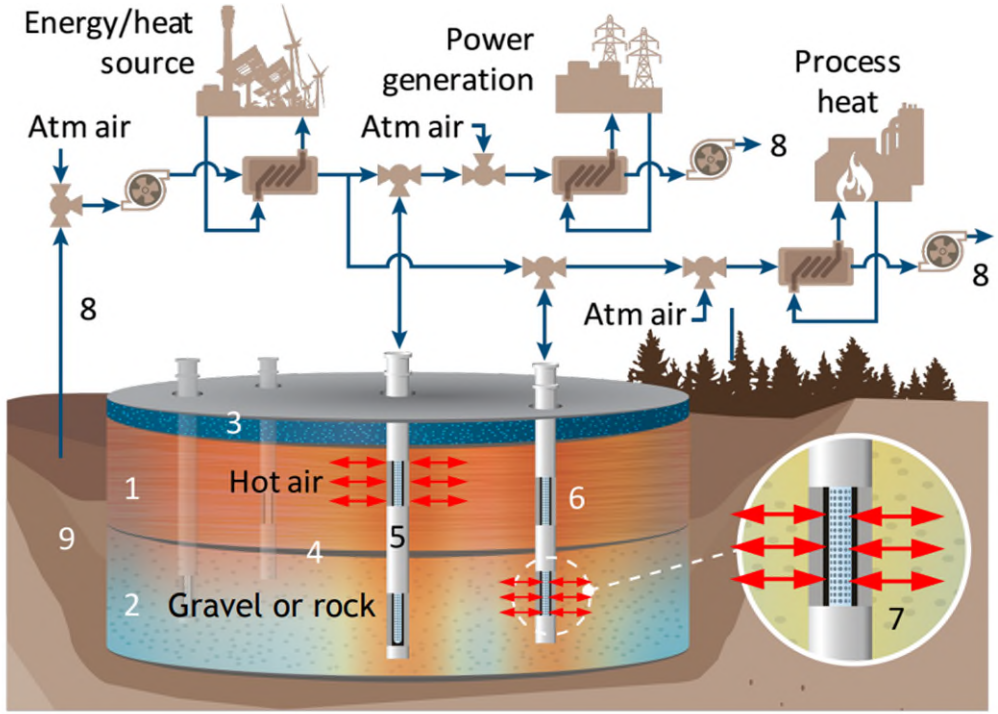


Figure or Image Caption: THERMS concept by Cliff Ho.

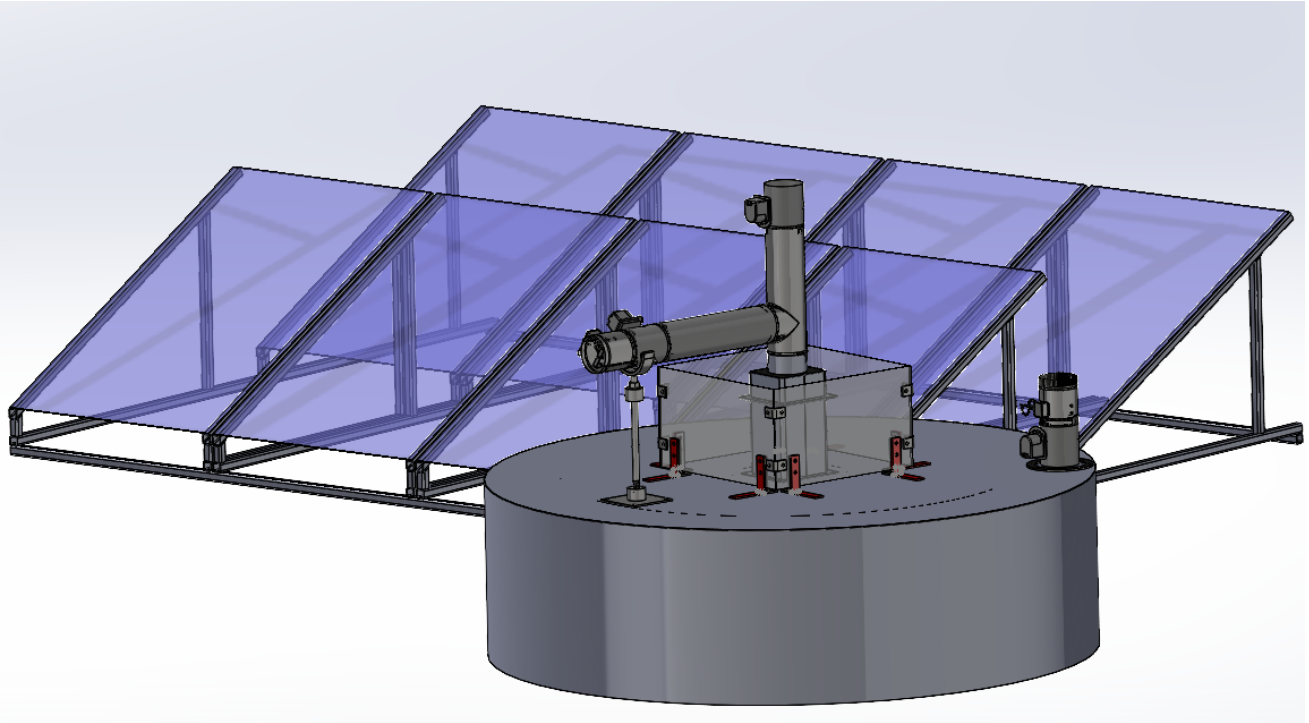
IP DETAILS

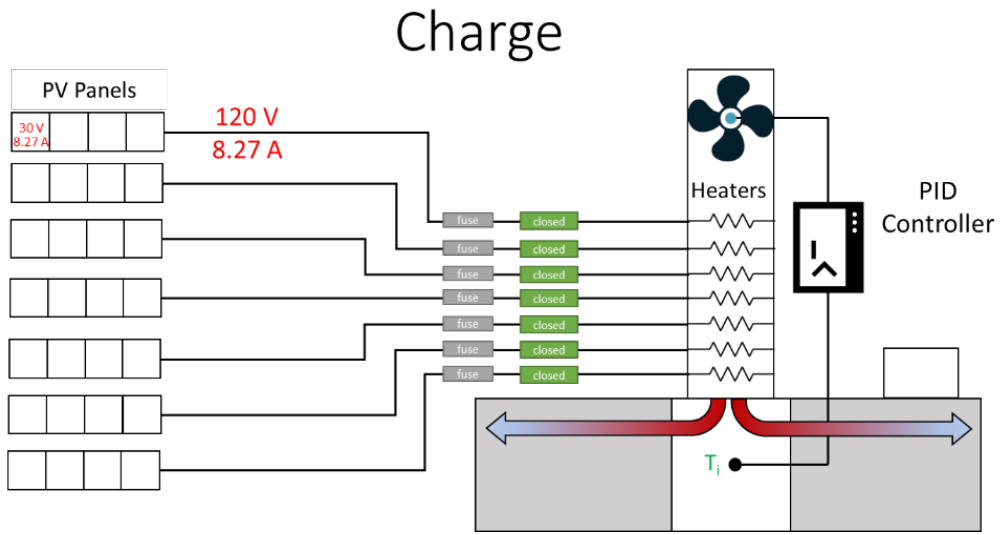
- *Sandia Disclosure: SD15304.0*
- *Patent No.: US 11,549,761 B1*
- *TA# 16742*
- *TA# 16808*

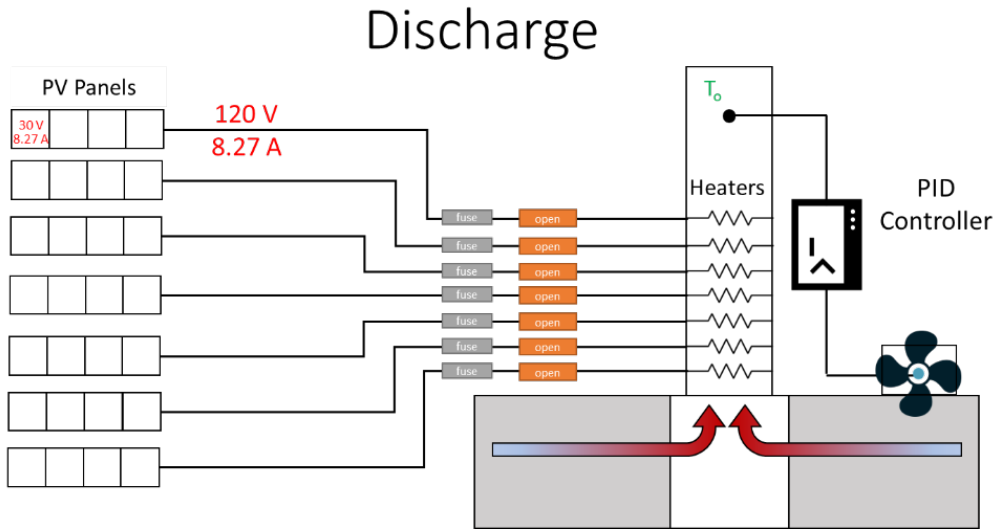
THERMS/Radial Packed Bed Demo System

System Highlights

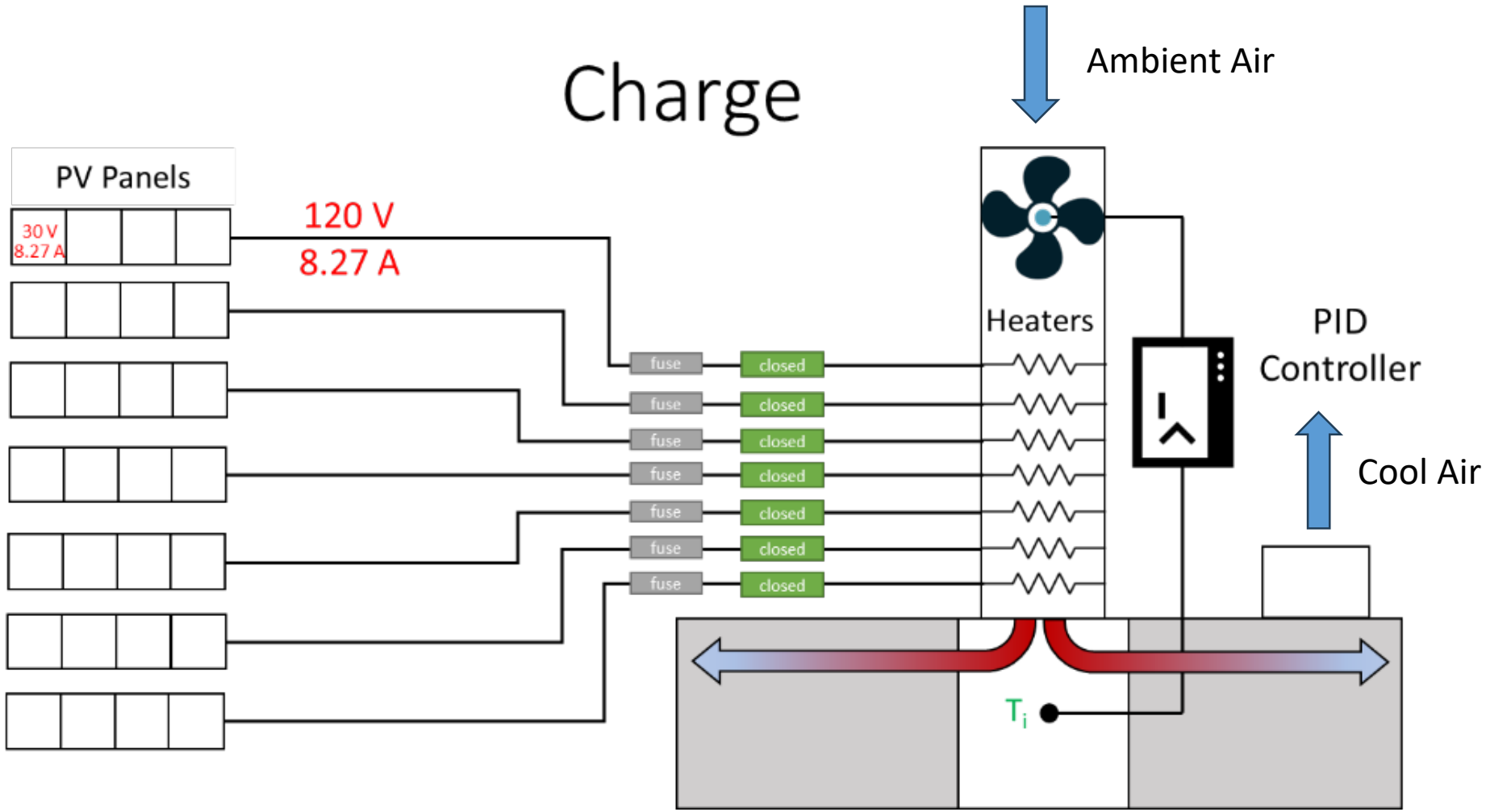
- 12 kW nameplate PV charging power
- 100 kWh thermal energy storage capacity at 550 C
- Air heat transfer fluid
- COTS blowers, valves, controls



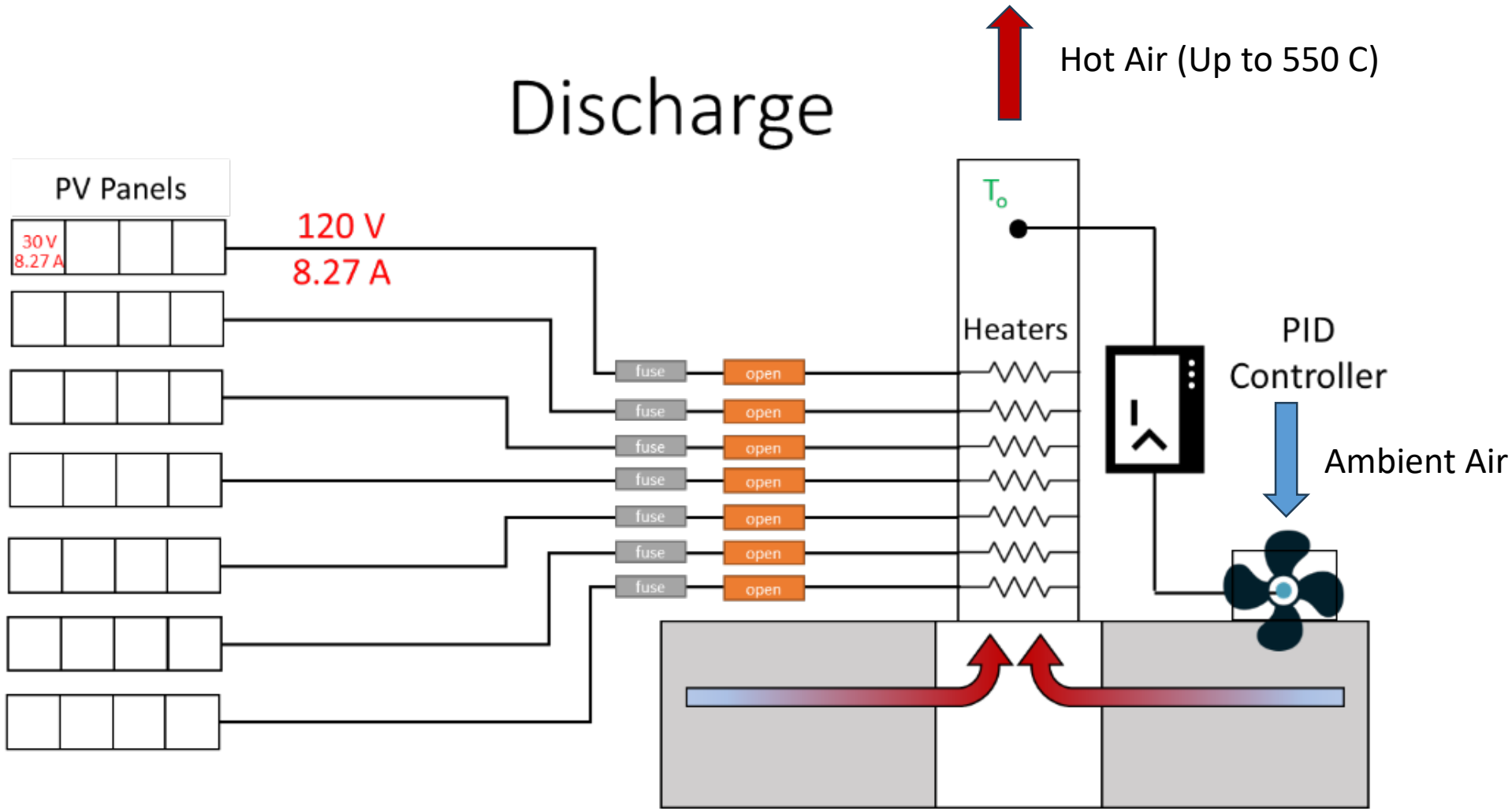




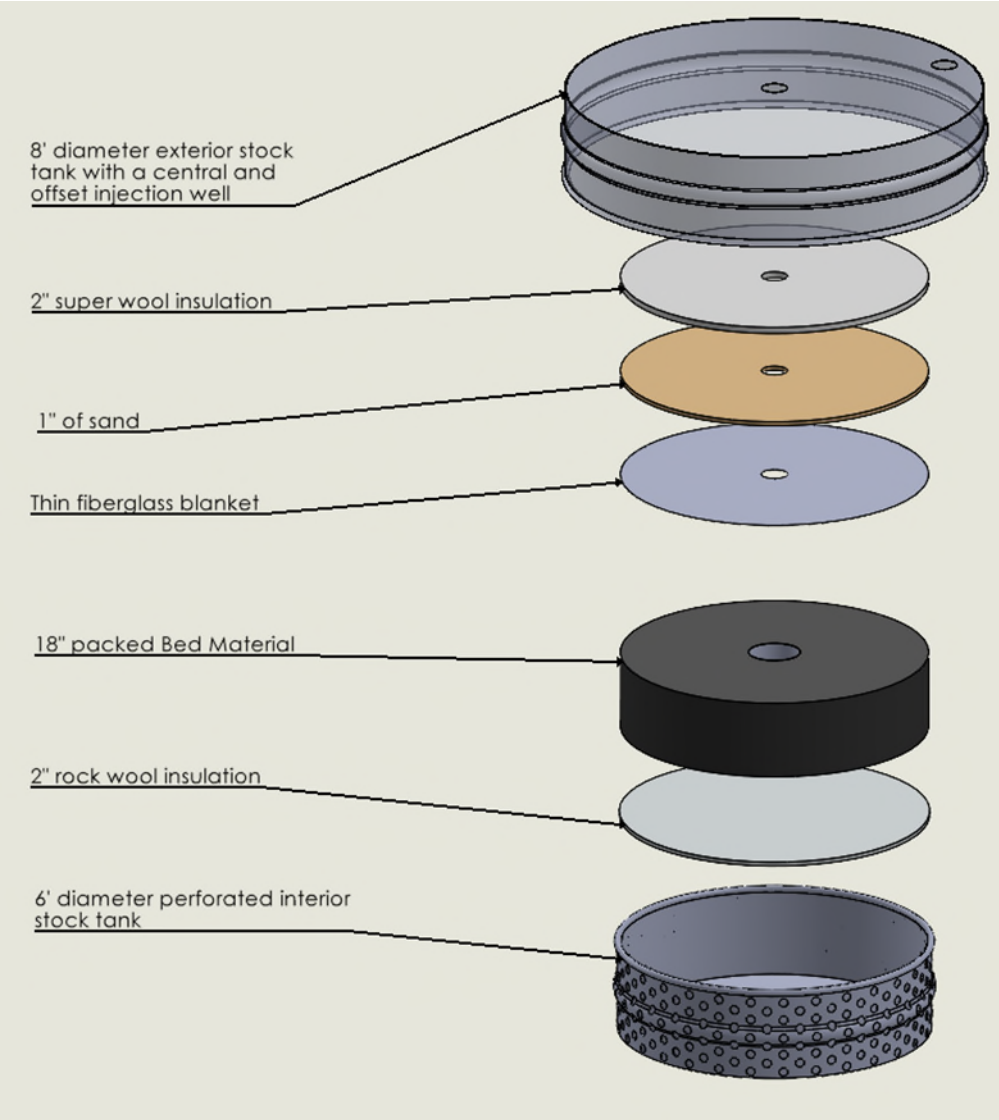
System Charging

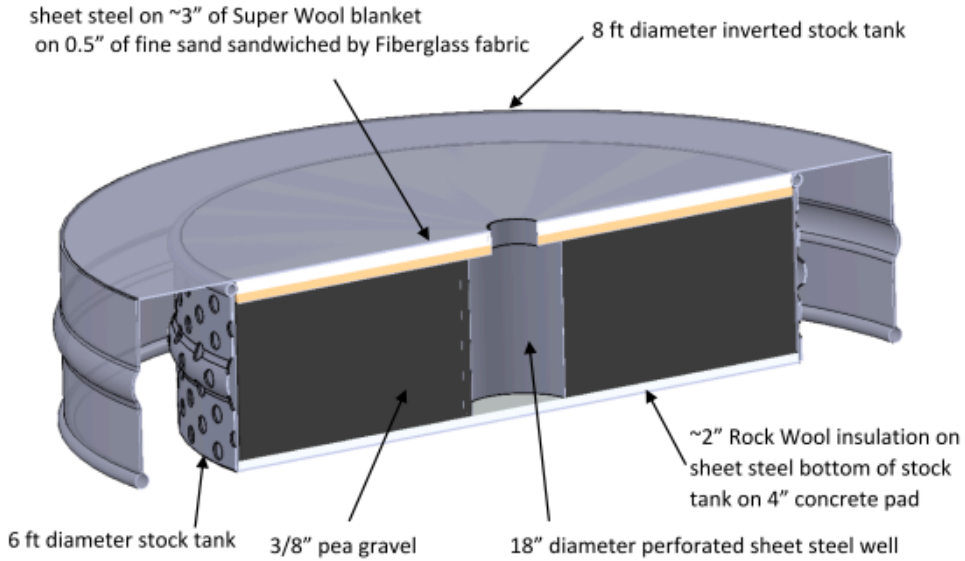


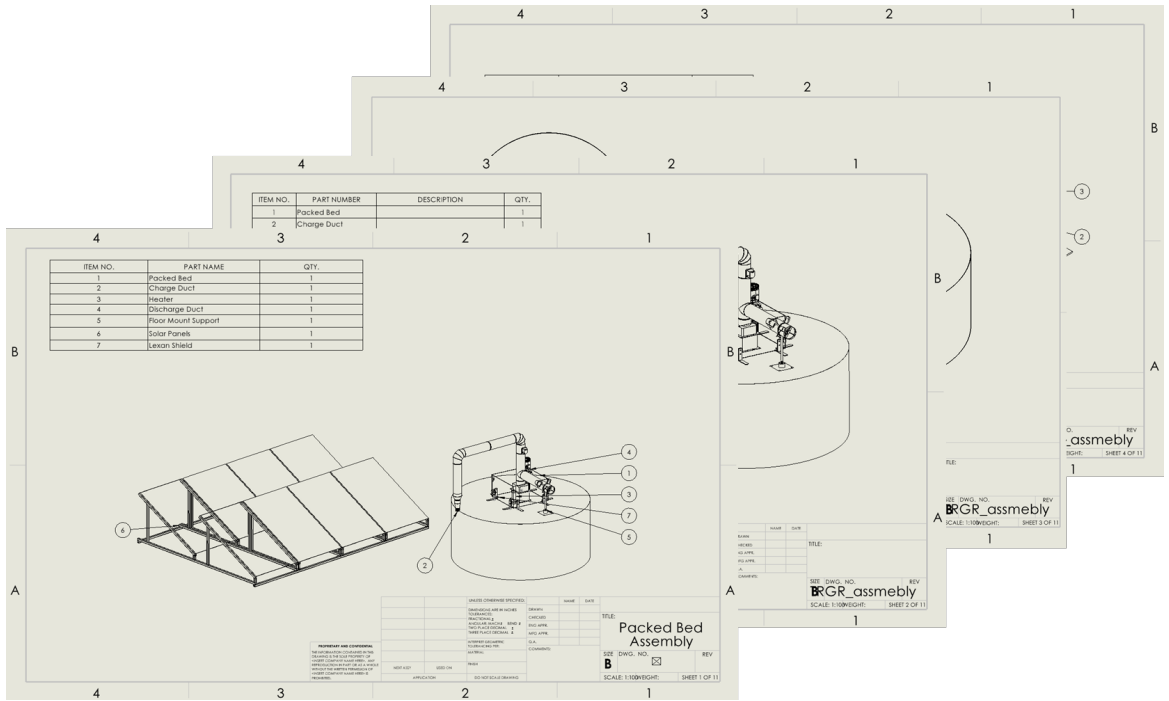
System Discharging



Storage Design



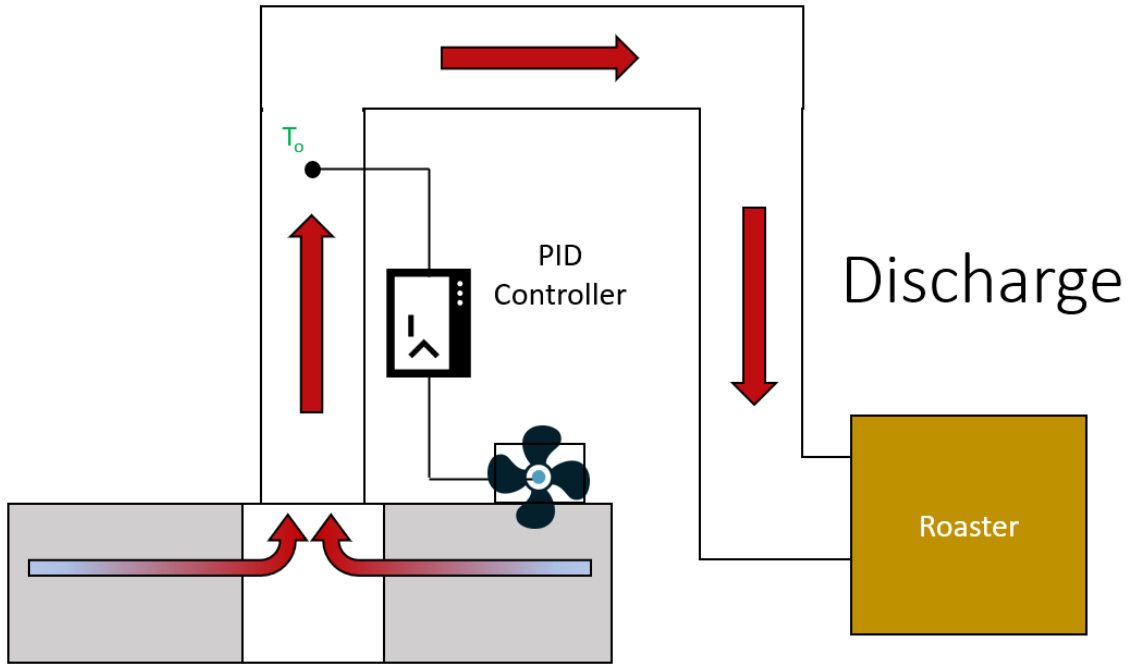


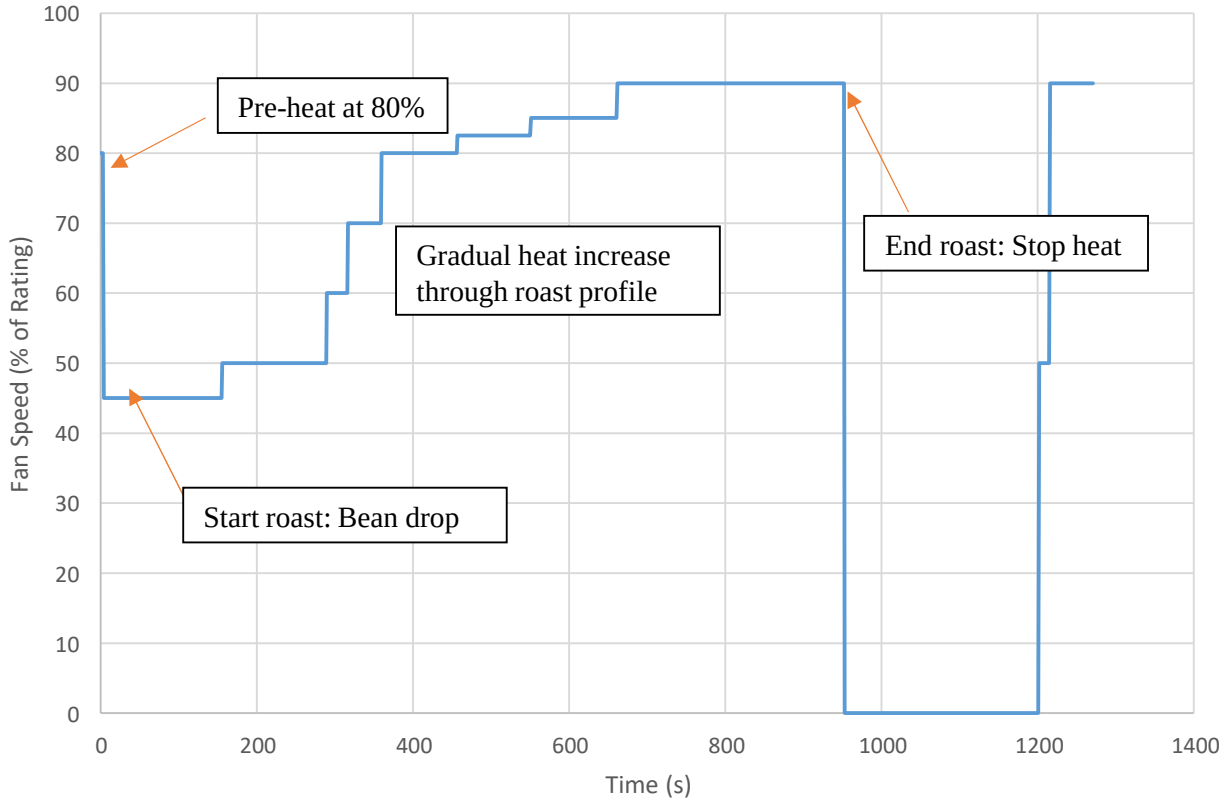


Our System In It’s Element

Packed Bed TES for Coffee Roasting

Highlights



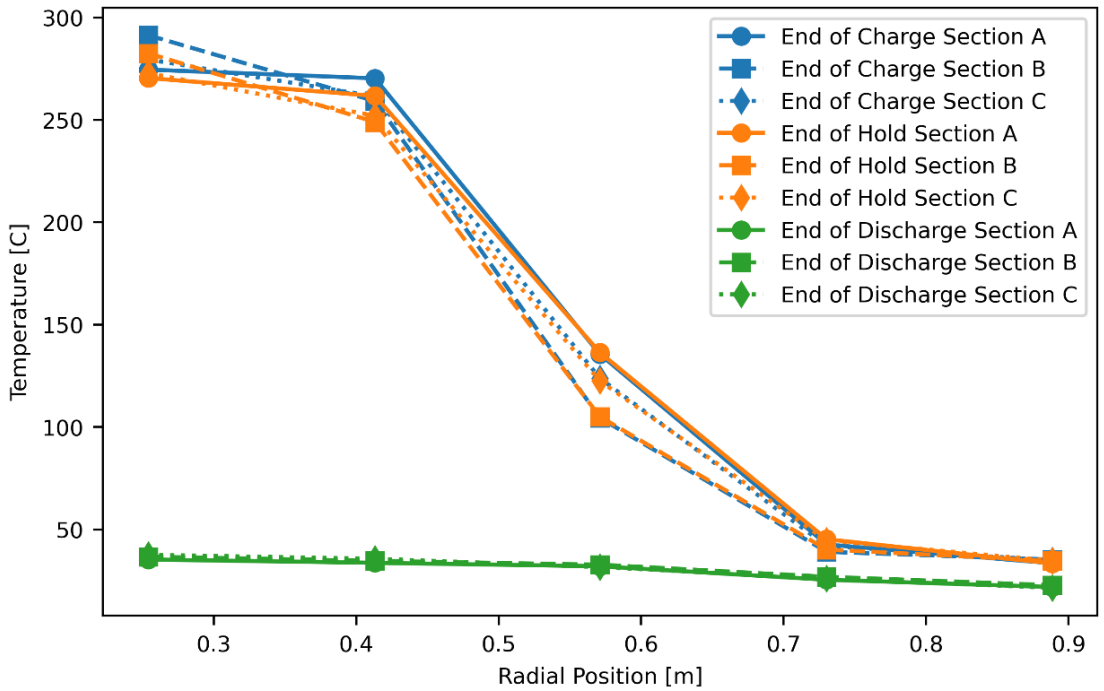


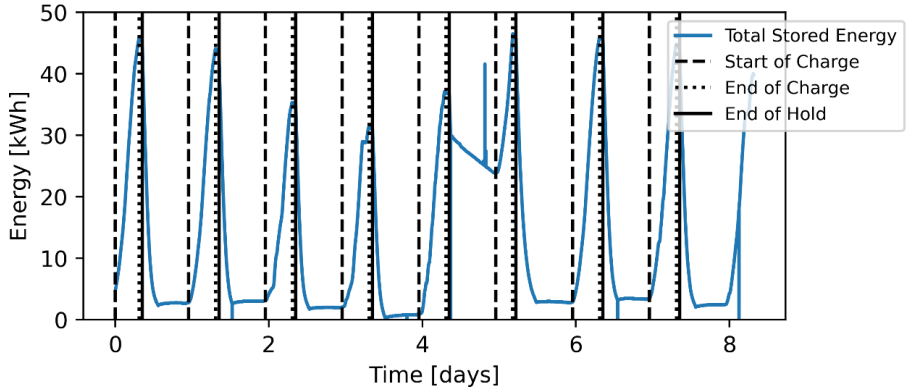
TES Loves Coffee

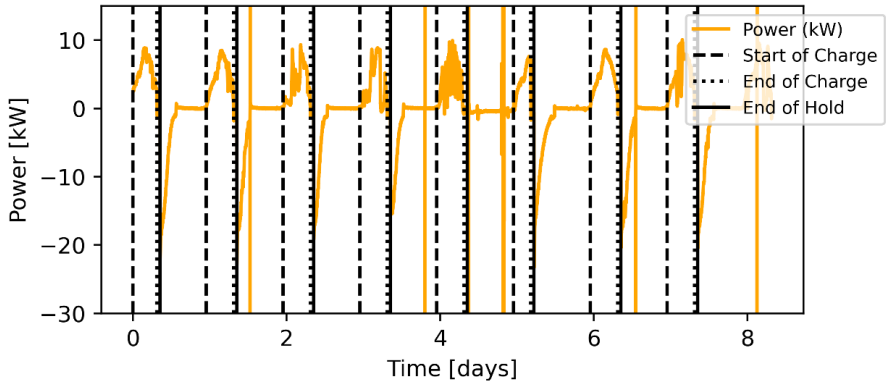
Diurnal Cycling

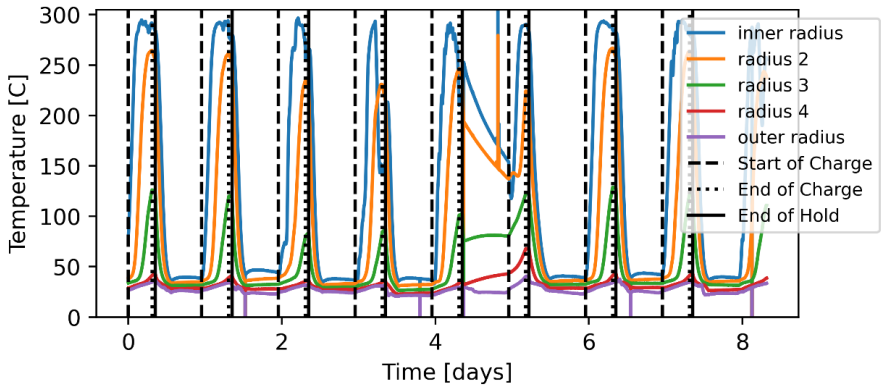
Heat Requirements

- >200 days of diurnal cycling
- Charge variations from 100 C to 550 C
- ~85% energy efficiency,
- Poor exergy efficiency after pro-longed holds









Physics (Radial Packed Bed)

Radial Energy Equation: Solid

$$\frac{dT_s}{dt} = \underbrace{\frac{H_{sg}}{c_s \cdot \rho_s \cdot (1-\varepsilon)}\left(T_g - T_s\right)}_{\text{Convection}} + \underbrace{\alpha_{sand}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right)\right]}_{\text{Conduction}} - \underbrace{\frac{h_{surf(TOP)} + h_{surf(BOT)}}{\rho_s c_s (1-\varepsilon) B}\left(T_s - T_0\right)}_{\text{Heat Loss}}$$

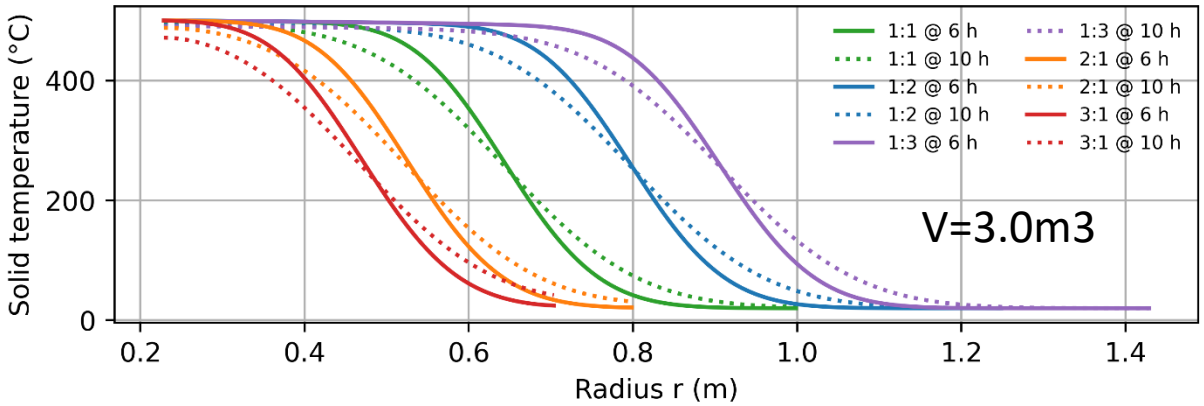
Role of Physics in Each Mode

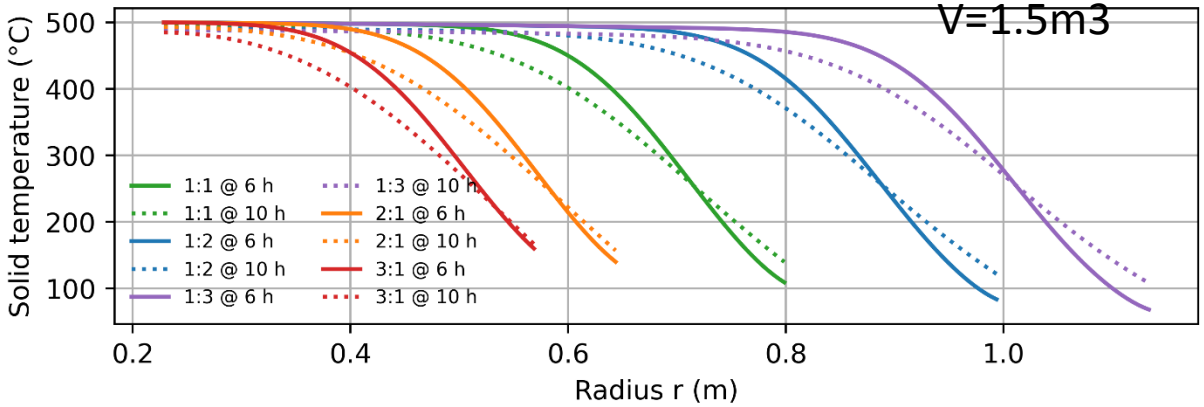
- Convection dominates during **charging** and **discharging** (Conduction ~60x too slow!)
- Conduction becomes much more prominent during a **hold;** Natural convection (buoyancy) and ambient heat loss also can play a major role in real world systems during **hold**

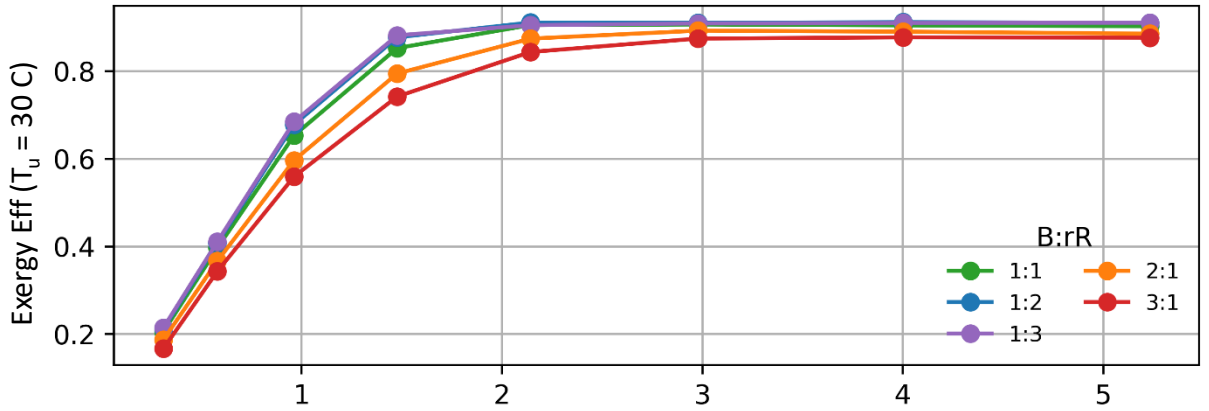
Areas of Improvement:

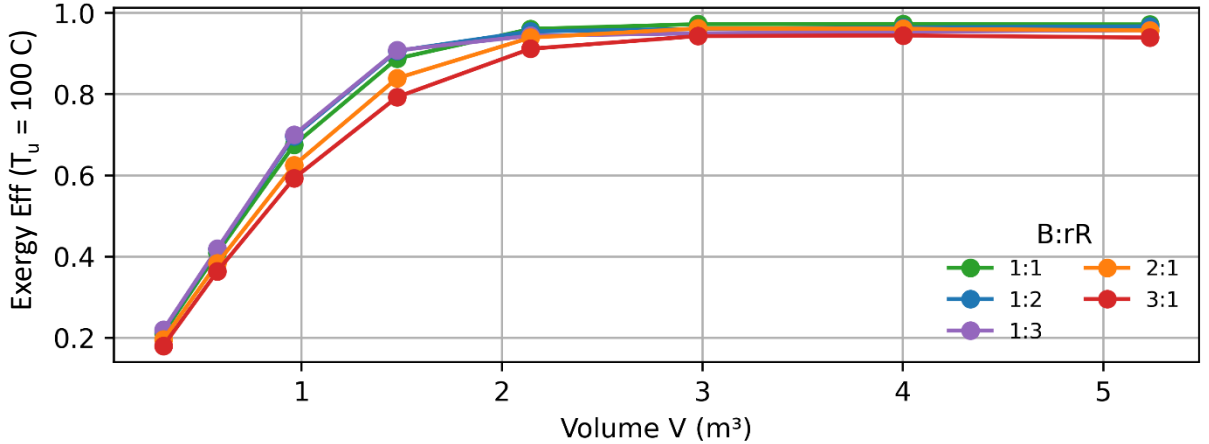
- Injection well + damper/valve sealing (better valving and placement)
- Top/Bottom heat loss (improved sealing and insulation)
- Geometry (Currently 1 Height to 1.4 Radius)

Radial Geometry Investigation







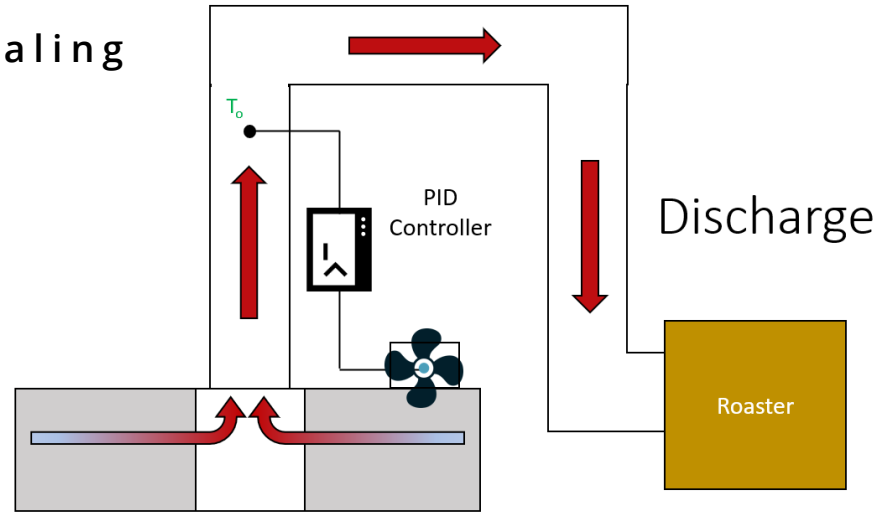


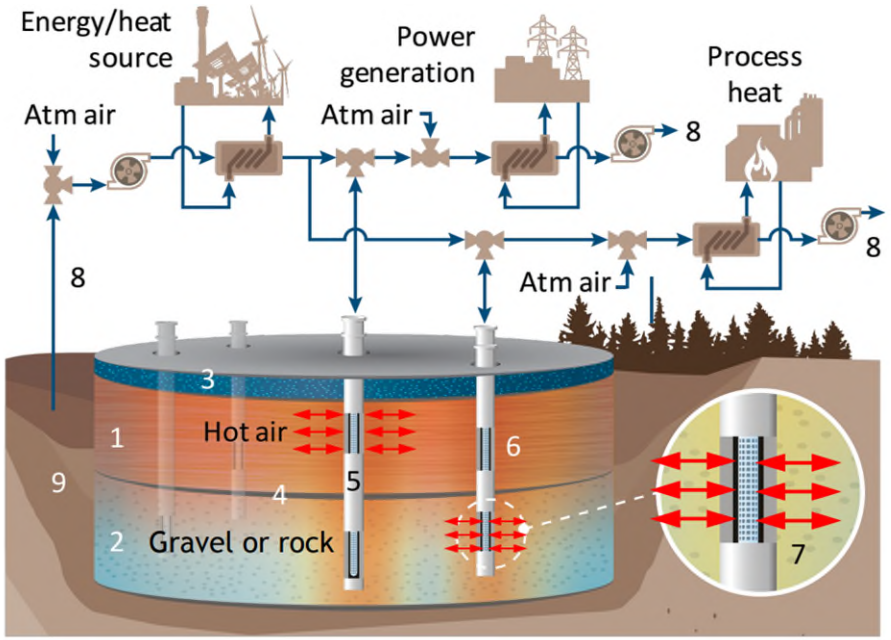
Exploring How Geometry Can Be Optimized

- Balancing large top/bottom surface area with increased superficial velocity & conduction length
- Sufficient volume (dead space) required to retain charge energy & avoid outer radius heat loss
- Parasitic pumping vs heat loss

Conclusions

- THERMS/Radial Packed Bed TES is a promising TES technology for low-mid process heat
- Sandia has demonstrated >200 days of THERMS operations
- Successfully roasted coffee with lined up hops roasting demo
- Challenges with thermocline degradation during a long hold
- Exploring real-world sealing solutions & geometry optimization





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Thank you!

Questions?