Sulfur Thermal Energy Storage for Industrial Decarbonization

Presenter: Karthik Nithyanandam

Event: 2023 HPC4EI Workshop

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ELEMENT16 TECHNOLOGIES

U.S. DEPARTMENT OF ENERGY

HPC4 ENERGY INNOVATION

NREL Transforming ENERGY

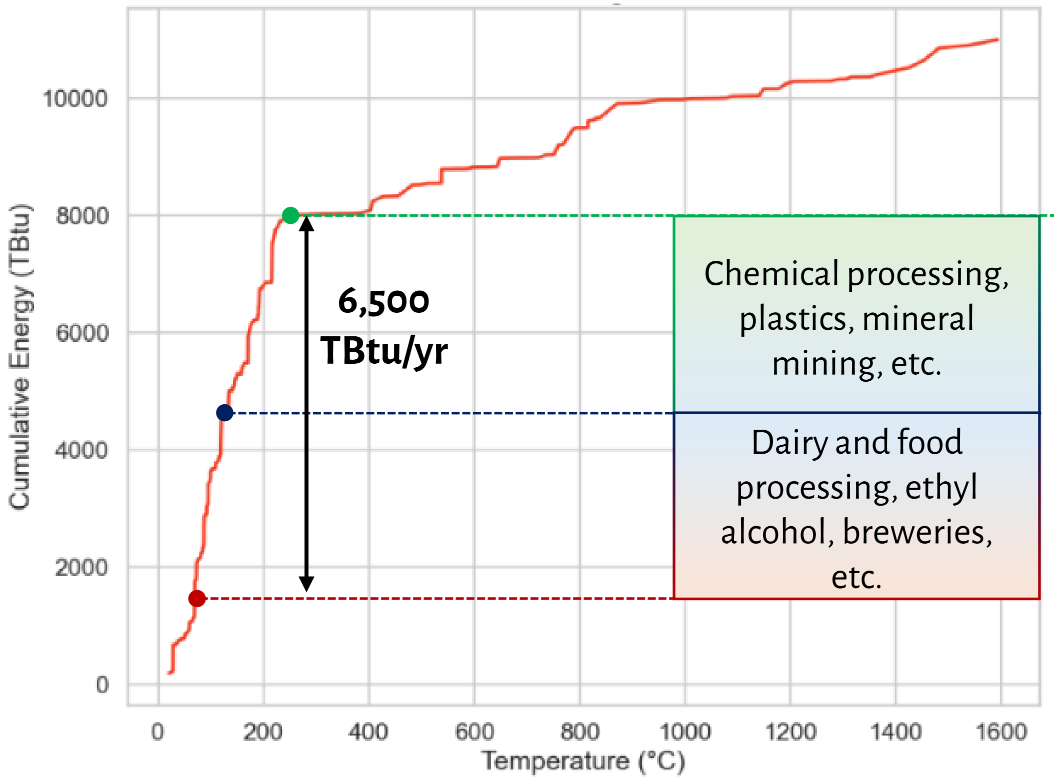
CALIFORNIA ENERGY COMMISSION

The Problem

1900 Terawatt-hours of industrial process heat are consumed every year below 300 Celsius.

of industrial process heat is from fossil fuels

Cumulative energy used for process heat in US Manufacturing industries



(Adapted from McMillan et al., 2023, NREL/TP-7A40-83020)

1. *DOE SETO CSP Program Summit 2019 Presentation*
2. *EIA Electric Power Monthly Table 1.1.A Net Generation from Renewable Sources*
3. *McMillan et al., 2023, NREL/TP-7A40-83020*

The Opportunity

For the first time, heat from renewables can be cheaper than fossil fuels.

01

Renewable Levelized Cost of Energy (LCOE)

$0.03
per kilowatt-hour

02

California NG Industrial Price

$0.04
per kilowatt-hour

03

Annual Industrial Natural Gas in US:

$36
Billion

1. *Lazard's Levelized Cost of Energy and Levelized Cost of Storage 2019*
2. *Adapted from EIA California Natural Gas Industrial Price: https://www.eia.gov/dnav/ng/hist/n3035ca3m.htm*
3. *Adapted from EIA U.S. natural gas consumption by sector*

Our Solution

Supply ≠ Demand

Process heat demand is constant. Renewable energy is not.

Cheap storage is needed

Thermal energy storage (TES) is necessary to match energy supply with heat demand.

Cost-focused solution

Breakthrough material repurpose dramatically reduces storage cost.

Our Innovation

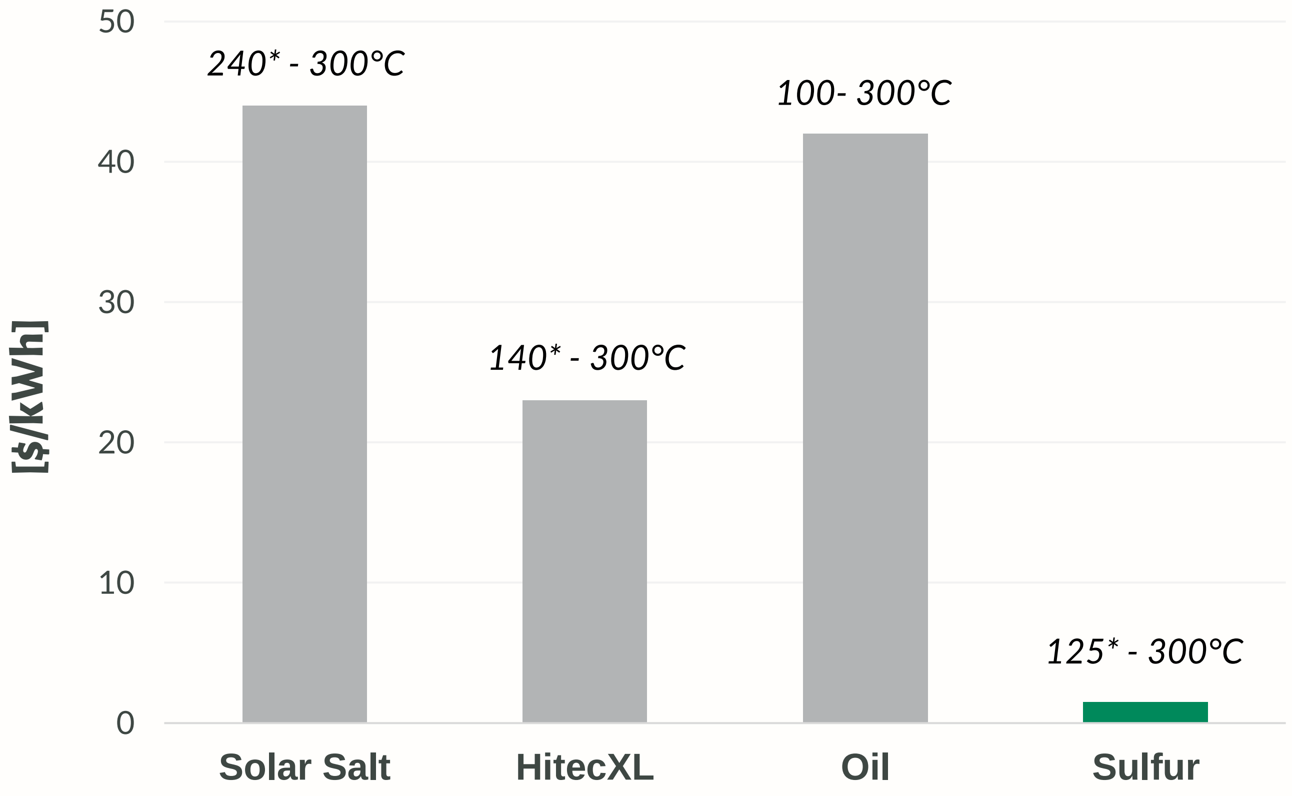
Sulfur replaces

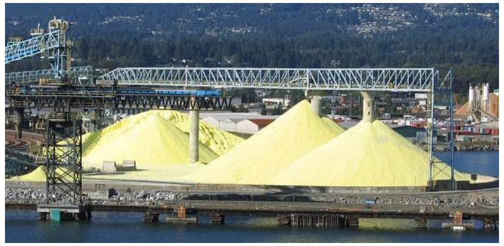
60%+

of the thermal energy storage (TES) cost with an ultra low-cost fluid.

**In the comparison chart, bottoming temperature for molten salts and sulfur are set to be 20 °C above their freezing point.*

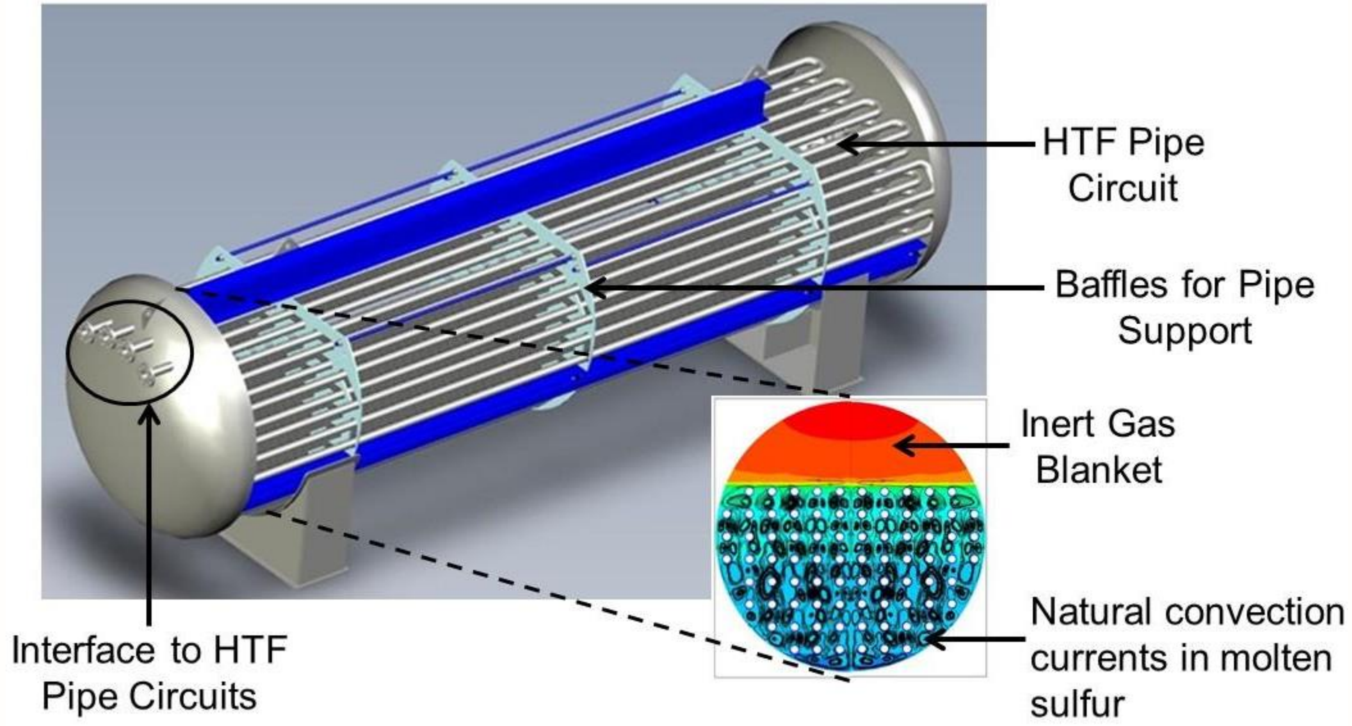
Storage Fluid Cost





Technological Breakthrough

Sulfur Thermal Energy Storage (TES) Design



1.5 Megawatt-hour sulfur TES

- Single tank design that involves HTF tubes located within molten sulfur bath.
- Natural convection currents enable efficient storage and retrieval of heat from sulfur thermal storage.
- Sulfur has low freezing point (~105 °C) compared to SOA solar salt (~220 °C) that ensures low parasitic load and low O&M cost.

The First Prototype

Market Readiness:

- Sulfur heat storage pilot: 350 kilowatt-hours & 300 °C.
- Over 85% thermal efficiency, 3rd party verified by Exponent.
- Three US patents awarded.

CALIFORNIA ENERGY COMMISSION

intertek

Advisian
Worley Group

PCL
CONSTRUCTION

Ongoing Renewable Energy Pilot Projects

To demonstrate with solar thermal and electricity

- $3m California Energy Commission
- Demonstrates charging from electricity
- Generate pressurized hot water for industrial process heat

Solar PV + storage < fossil fuels

- $1.4m Department of Energy
- Prepare for integration with solar thermal
- Will demonstrate 24-hour renewable process heat

Solar thermal + storage < fossil fuels

Client Projects

شركة تنمية نفط عمان
Petroleum Development Oman

- Started $500k Engineering for $6M+ Pilot project
  - Design, install, and test a pilot sulfur TES integrated
  - Integrate with Miraah Solar Field (300 MW-thermal)
  - Verify system performance at 50 tons per day of steam
- Full-scale system over 500 MWh

Searles Valley Minerals

- Preparing a 1.5+MWh sulfur TES pilot project integrated with renewable electricity
- Client requires 700 MWh TES to meet their process heat requirement

HPC4EI Project: High-Fidelity and High-Performance Computational Simulations for Rapid Design Optimization of Sulfur TES

NREL PI: Zhiwen Ma and Michael Martin

CHALLENGE

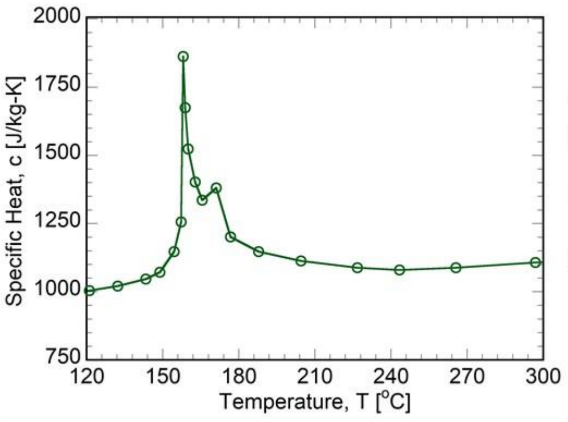
- Prototypes are expensive and optimizing the product design through simulations will minimize design iterations.
- Complex multiscale physics and non-linear properties.

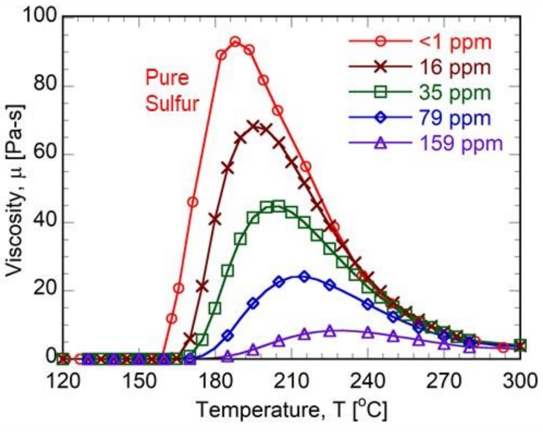
APPROACH

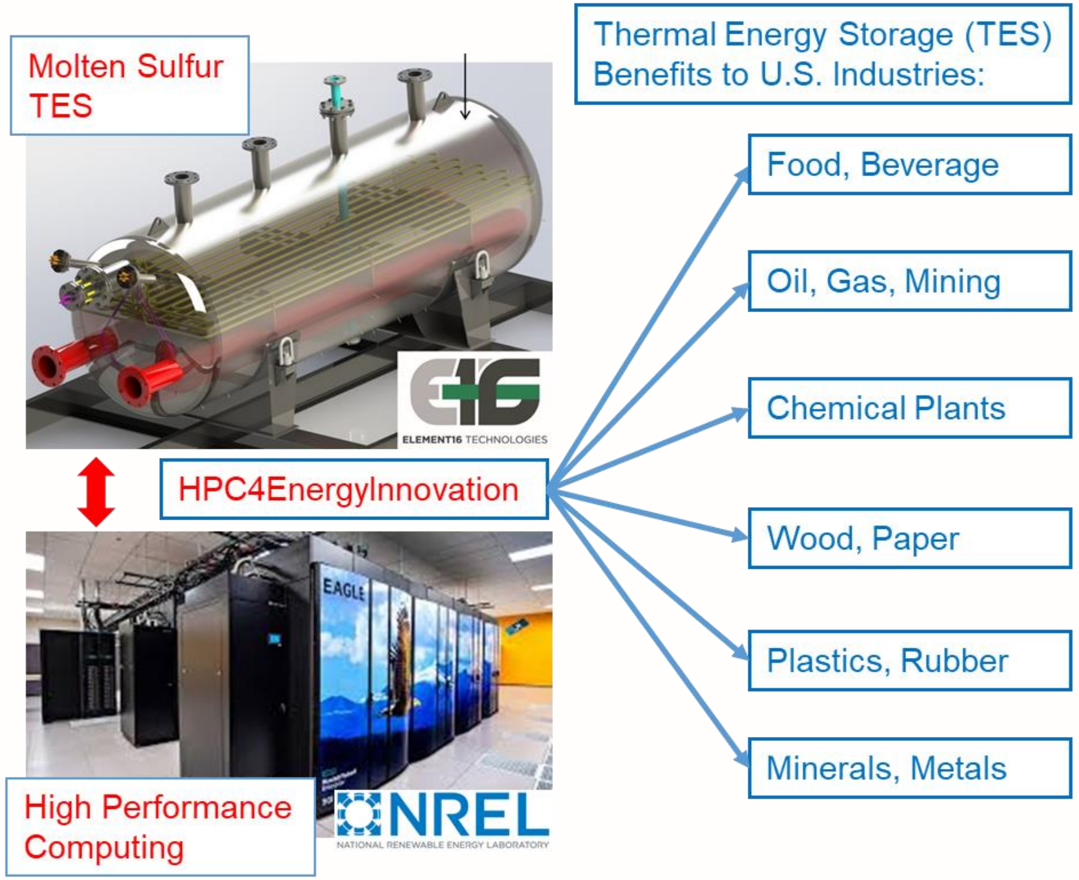
- Apply NREL center experience in complex fluids (sCO_2, cryogenic helium) to model heat transfer in the system.
- High-fidelity computational tools to simulate, and machine learning (ML) tools to optimize designs.

IMPACT

- Accelerate development of this technology while building NREL expertise in thermal energy storage.
- Valuable experience for student interns who contributed to the field through journal publications and conference presentations.

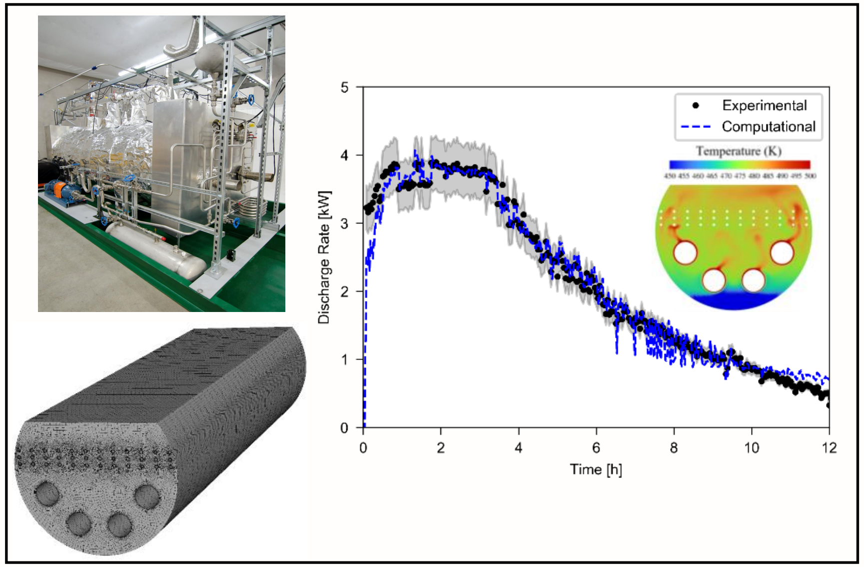




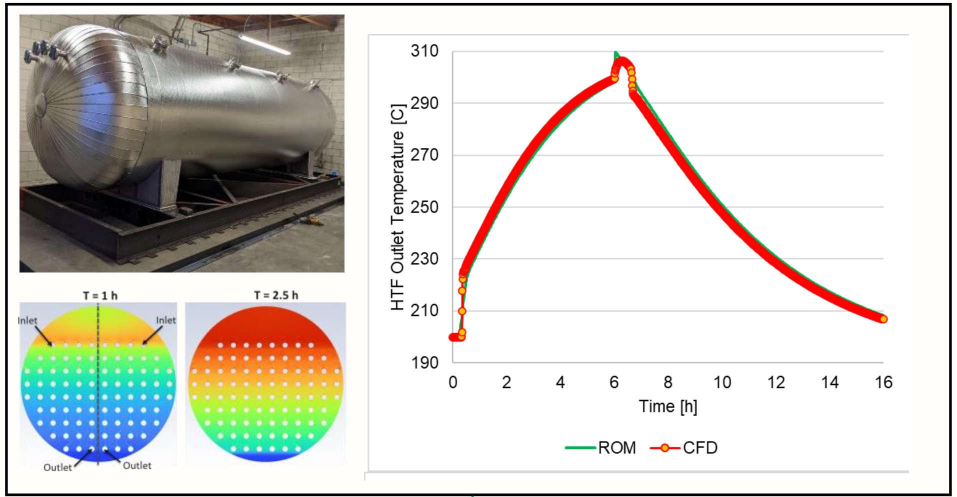


Modeling Tool Development

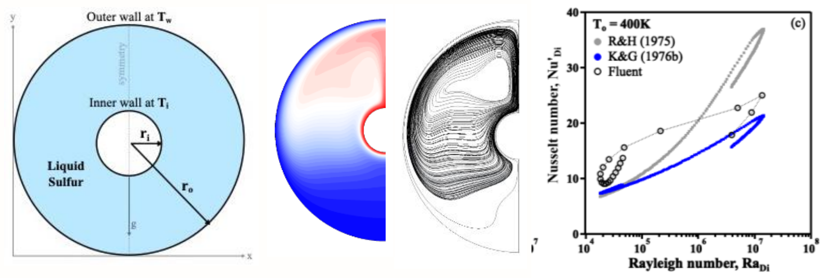
CFD Model Development & Validation



ROM Verification



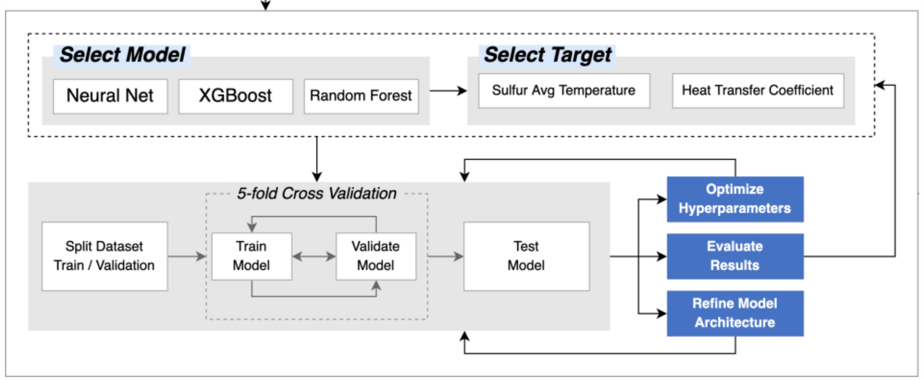
Parametric Analysis



Oliver et al. , ASME J. Energy Resour. Technol., 2023

Machine learning for reduced order model (ROM)

Menear et al., AAAI 2022 Fall Symposium



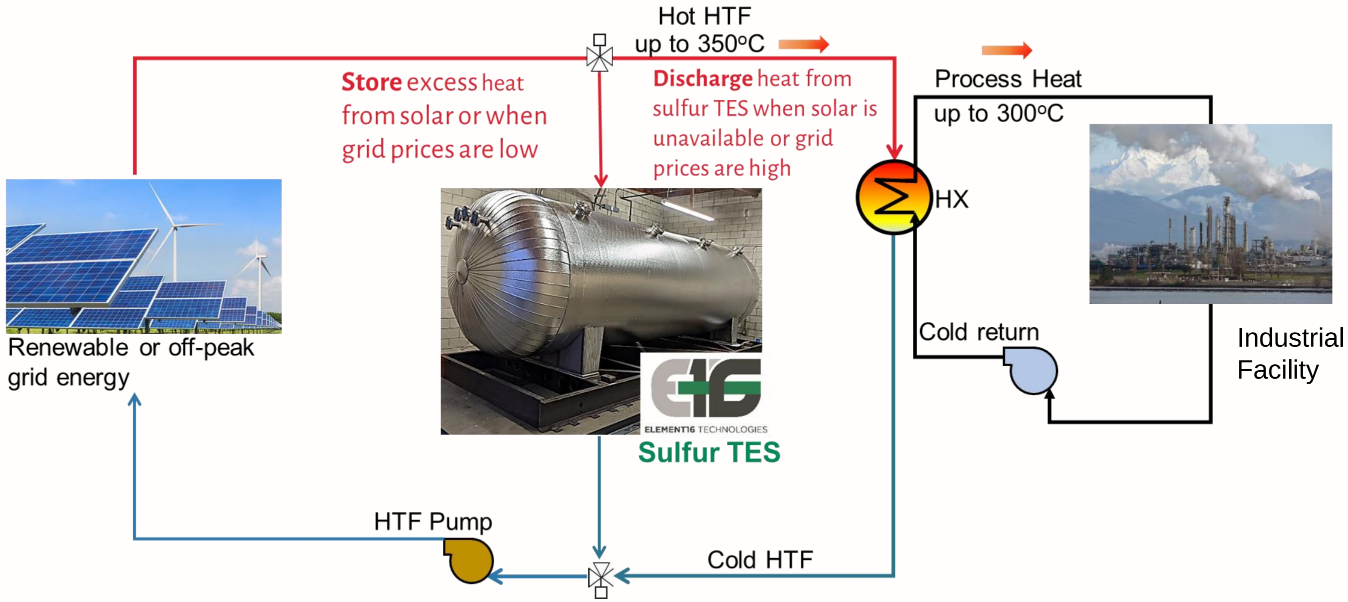
- **Robust modeling tool with short-run time to optimize sulfur TES design for different applications.**
- **Reduce product-to-market time.**
- **Critical for system design (ex. solar + sulfur TES) optimization based on annual technoeconomic simulations.**

Techno-economic Analysis

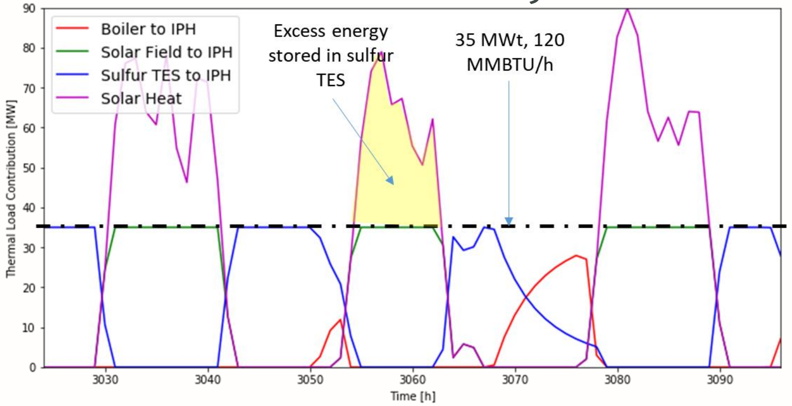
Renewable industrial electrification

- Run in-house economic model for entire year
- Determines when heat would come directly from the solar PV field, from the solar energy stored in Element 16's system, or from fossil fuels
- Optimize for solar multiple (capacity of solar PV field vs. heat load/demand)

- **Key result: Levelized Cost of Heat (LCOH),** or how much the heat costs amortized over project lifetime
- LCOH allows renewable energy projects to be directly compared with fossil fuel boilers

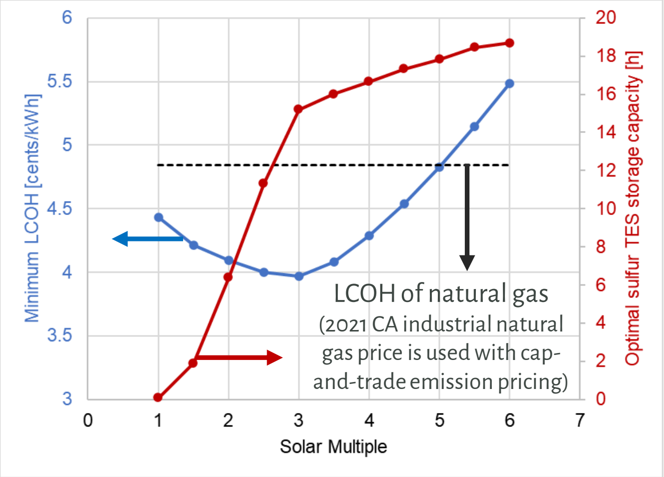


Solar PV + Sulfur TES for industry located in CA



This figure shows the energy generation from all sources over an example three day period

Renewable heat cheaper than natural gas



- Solar multiple of 3 and sulfur TES storage capacity of 14-to-16-hour duration provides the least LCOH.
- CO_2 emission reduction of 2 million metric tons for the 150 MMBTU/h heat demand over 30-year system lifetime.

Thank You

ELEMENT16 TECHNOLOGIES

Startup Program and Financial Backers:

- U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
- techstars
- MASSCHALLENGE SWITZERLAND
- CREATIVE DESTRUCTION LAB
- NSF I-CORPS NSF Innovation Corps
- GINCO INVESTMENTS
- STATE OF CALIFORNIA ENERGY COMMISSION — CALIFORNIA ENERGY COMMISSION
- Start Up Energy Transition
- SparkLabs ENERGY

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