Thermal Energy Storage

(and Industrial Heat Electrification)

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adhoc

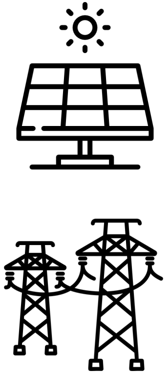
Agenda

- Thermal Energy Storage Basics
- Economics of Electrifying Heat
- Role for TES on the Grid
- Barriers to TES and Heat Electrification

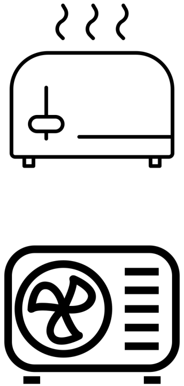
Thermal Energy Storage Basics

Thermal Energy Storage (TES): A Play in Four Acts

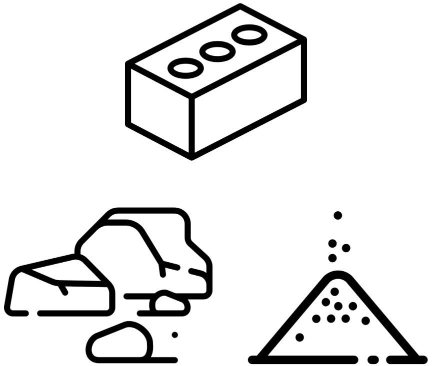
1. Charge system with low-cost electricity from renewables or the grid



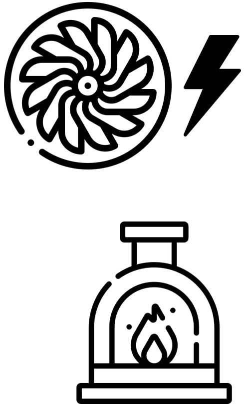
2: Convert electricity to heat via resistive heating or a high temperature heat pump



3: Store heat in a low cost medium like bricks, rocks, or molten salt



4: Discharge thermal energy to generate electricity or provide industrial heat

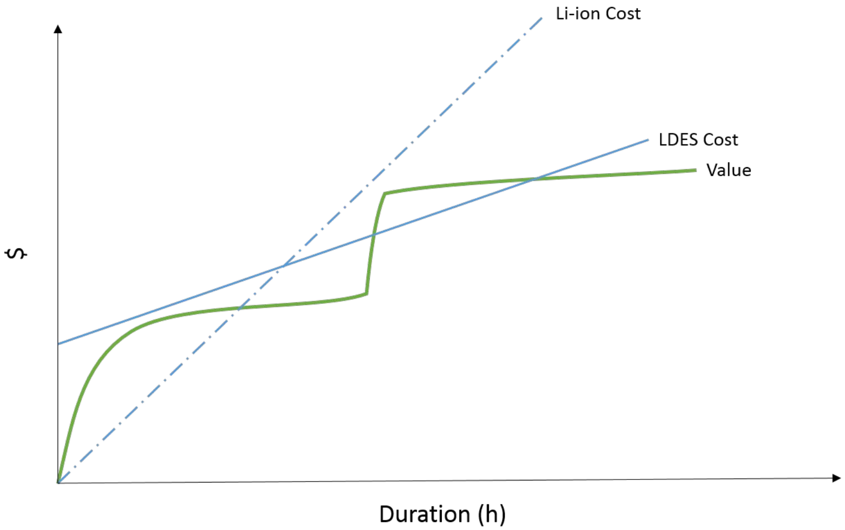


Thermal Storage as Long Duration Energy Storage (LDES)

Incredibly cheap storage media makes TES attractive as an LDES solution

- TES is part of a class of LDES technologies, like flow batteries, that have decoupled power and energy components, and incredibly cheap energy components (e.g. bricks)

- This combination of energy and power decoupling, and low cost energy, makes the marginal cost of increased duration much smaller than incumbents like li-ion, leading to lower overall costs at long durations

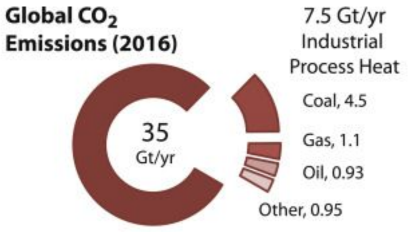


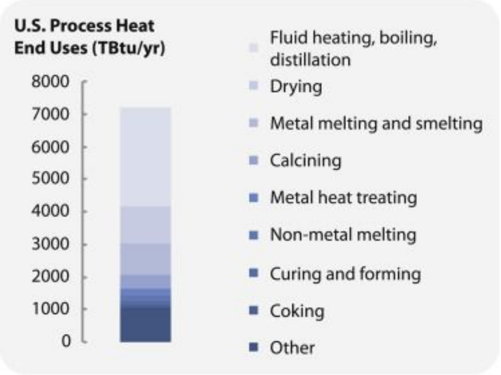
https://arpa-e.energy.gov/news-and-media/blog-posts/why-long-duration-energy-storage-matters

Thermal Storage for Industrial Heat Decarbonization

TES enables the use of low-cost, low-carbon electricity to decarbonize industrial heat

- About 21% of global CO2 emissions result from a single process: the generation of heat for industrial process
- Resistive heating is limited only by the properties of the materials, allowing for heat to be stored at temperatures in excess of 1500 ^{0}C in these systems
- At these temperatures, 95% of all industrial heat applications can be served



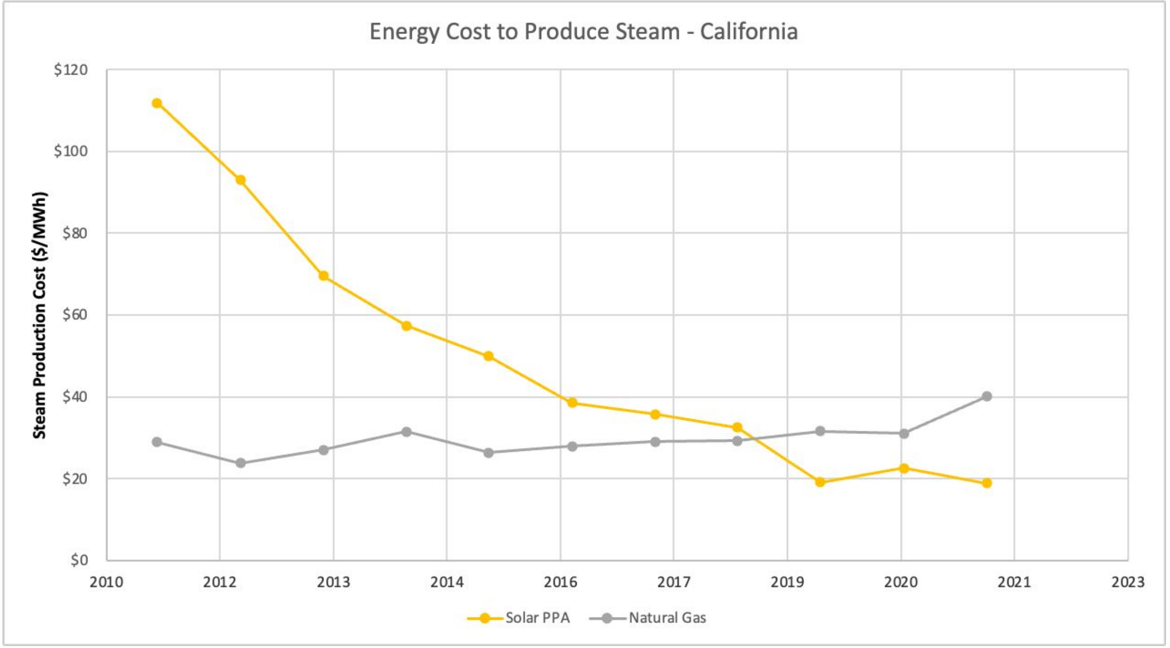


https://doi.org/10.1016/j.joule.2020.12.007

Economics of Electrifying Heat

The new economic opportunity for electrified heat

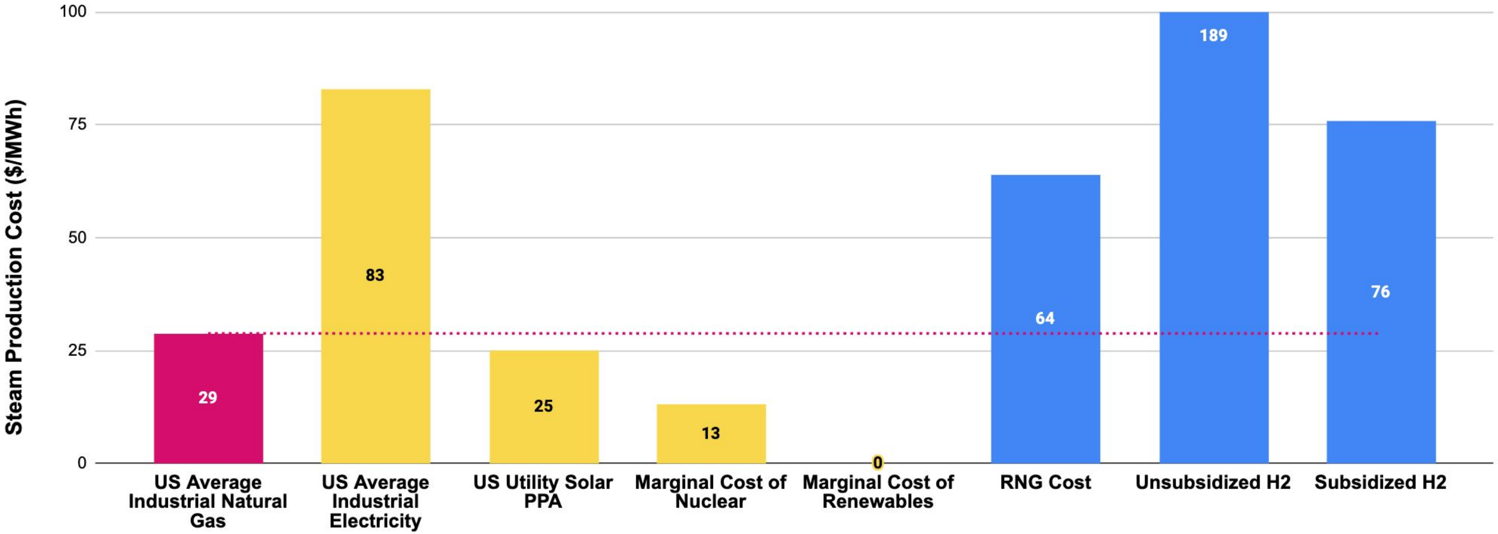
The falling prices and increased deployment of renewables have created a dynamic in which electricity during periods of low net-demand, or directly from a renewable sources, is now lower cost than natural gas on a unit energy basis in many markets



LBNL Utility-Scale Solar, 2022 Edition
EIA Natural Gas, Industrial Price

Unit Economics of Heat

In the absence of monetizable decarbonization value, the economics of electrifying heat are underpinned by the availability of intermittent electricity for a per unit energy price less than the incumbent source used for industrial heat (generally natural gas)



TES's operational costs are less than natural gas with a competitive solar PPA, and significantly less than natural gas if using excess energy priced at its marginal cost

Role for TES on the Grid

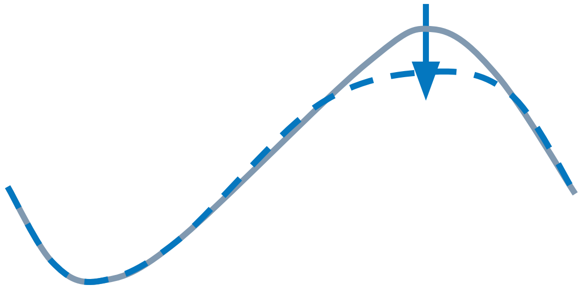
As a dispatchable load, TES is a new breed of flexible resource

Dispatchable Load ≠ Demand Response

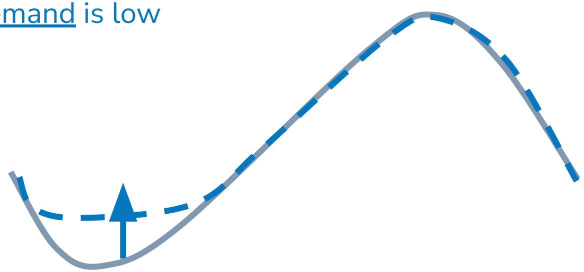
- Traditional **demand response** programs assume that a load runs for most hours, and will only curtail from baseline conditions if incentivized to do so. These programs are designed to provide capacity to the system and relieve strain at the highest net-demand hours

- Rondo's **dispatchable TES** only charges when there is excess generation and network capacity. The RHB has no baseline power draw, as it will idle at zero load until dispatched either by a utility or system operator, or in response to price signals.

Traditional demand response is incentivized to curtail load when net demand is high



TES only charges at times when net demand is low



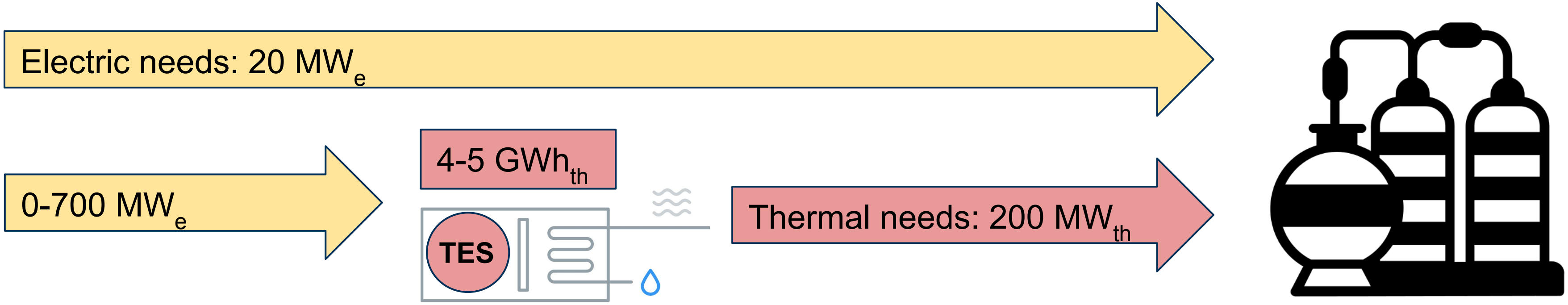
Net demand is the difference between load and renewable generation. Rondo aims to charge when net demand is at its lowest points (i.e. mid-day in a solar heavy region like CA)

TES Market Participation: An Example

An industrial facility, like a chemical plant, has a thermal load many multiples higher than its electric load, and this load can be made fully flexible with TES

Example day ahead bid structure:

- 20 MW_e @ market cap: required for base electricity needs
- 100 MW @ $30/MWh: ensure that storage remains charged
- 600 MW @ $5/MWh: capture low price periods to top off storage



System-Wide Opportunities for TES Deployment

Thermal energy storage systems bring a number of highly desirable attributes into electricity systems and markets:

- **Non-coincident peak load that increases the utilization of system assets**
  - Industrial heat electrification with TES adds significant new load, but only at off-peak times, which minimizes the requirement for new infrastructure, and allows existing grid investments to be amortized over a larger user base.
- **Quick response times enabling provision of ancillary services**
  - Turbomachinery and resistive heaters have the ability to follow a control signal and ramp up and down quickly, providing needed grid services lost due to the retirement of dispatchable generators
- **Large scale (GWs) flexible assets enabling economic integration new clean resources**
  - TES installations add meaningful renewable integration potential for any given project given the scale of industrial heat and its ability to dispatch in accordance with resource availability
- **Price responsive demand that can set prices**
  - Because TES is both large and highly price sensitive (will only want to charge during hours where electricity<natural gas), it provides the market with a strong demand price signal, which is increasingly important as zero-marginal cost resources proliferate

Barriers to TES and Heat Electrification

Challenges keeping TES off the grid

Adding large flexible loads, like TES, to the grid will benefit all consumers, but several elements are driving projects to use behind the meter resources

- **Interconnection bottlenecks** for both large loads and renewable generation creating a market for bi-lateral agreements, in which a large (10s of MWhs) dedicated off-grid renewable facilities are used to power industrial heat TES systems

- **Accounting in Low Carbon Fuel Standards (LCFS) and similar GHG reduction programs** often only give credit for the use of renewable energy if provided by a dedicated source. If grid power is accounted for with its average emissions factor, rather than its real time, or marginal emissions factor, the GHG reductions for electrification with a flexible TES system are under counted.

- **Unaccommodating rate structures and market participation models** that do not incentivize flexible operations, or only account for traditional demand response, make grid power uneconomic for industrial electrification with TES

Market rules will dictate whether all stakeholders can benefit from the services that TES can provide

Full market participation of TES and industrial heat is enabled by:

- **Access to underlying dynamic price signals (e.g. LMPs)**
  - TES economics rely on dispatching in accordance with price signals that convey when renewables, or similarly low priced resources are on the margin

- **Fixed, vs volumetric, non-energy fees**
  - Adding non-energy charges as volumetric adders distorts operational decision making by inflating the marginal cost of electric TES charging versus fossil heating

- **Coincident peak, vs non-coincident peak, demand charges**
  - Because TES systems charge at high powers, but during off-peak times, demand charges based on peak demand, rather than coincident peak, artificially inflate their power costs, and makes projects uneconomic

TES for industrial heat electrification is arriving

The past few years have seen an explosion of activity in thermal energy storage

- **Funded by private and public capital**
  - Antora, RedoxBlox, ETS, NREL, Sandia and others funded by DOE to develop TES solutions
  - Top tier climatetech investment firms such as Breakthrough Energy Ventures, Energy Impact Partners, and Clean Energy Ventures all backing TES companies
- **Demonstration projects in field**
  - Demonstration projects, like Rondo Energy's California Facility at Calgren Renewable Fuels are entering the market
- **Engagement ramping up with industrial customer**
  - Industry coalitions like the Renewable Thermal Collaborative are connecting industrial loads with TES providers

Rondo Energy's California Facility in Pixley, CA at Calgren Renewable Fuels

https://rondo.com/calgren-case-study

Questions?

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