# How a New Category of Electric Demand Can Reduce Consumption of Fossil Fuels and Improve Electric Grid for All Customers

How "Heat Batteries" Can Replace Natural Gas for Industrial Heat and Provide "Anti-Duck" Grid Services

*Updated February 10, 2023*

## Introduction

"Heat Batteries" represent unique opportunities for optimization of electricity demand. They can be flexibly charged and can be matched to times when the electric grid has extra capacity and generation.[1] This document describes the multiple opportunities and policy suggestions to accelerate the market for Heat Batteries and provide many of the following benefits:

- Provide cost competitive, continuous high temperature, industrial heat through renewable electricity that replaces fossil fuel combustion
- Provide industrial heat at ½ the energy requirement of green hydrogen
- Provide flexible electric demand matching renewable generation
- Provide the equivalent benefit of electric storage at ½ the cost
- Store and convert heat back to electricity providing local power in anti-duck curve
- Significantly reduce greenhouse gases and help reduce local criteria pollution in AB 617 communities

Heat Batteries are a new concept that are coming into production use in California in 2023 providing temperatures up to 1,500°C. A Heat Battery provides continuous heat from intermittent, preferably renewable electricity for industrial use replacing natural gas. Currently industrial use of natural gas accounts for 25% of the 21-million cubic feet of natural gas consumed in California (21 x $10^{12}$ CF). A significant portion of consumption is used for industrial heat for everything from food processing to making cement.

A Heat Battery uses electricity to heat solid materials in an insulated environment and then transfers the heat as needed. 4-6 hours of electricity can generate enough heat to provide 24 hours of continuous heat. For applications where heat is the primary need, it is significantly less expensive to store heat whenever electricity is available rather than storing electricity to generate continuous heat.

Consider the following characteristics *(some apply to EV charging and all apply to Heat Batteries)*:

**Dispatchable**: A Load Serving Entity (LSE) or the owner operator of a heat battery can select which hours of the day to supply/consume electricity based on availability of supply and economics.

**Efficient**: It is extremely efficient to convert electricity to heat (>90%) and it is relatively inexpensive to store heat using commonly available, abundant material. By contrast, we estimate storing electricity is twice the cost and if the goal is to provide heat, it is beneficial to save electric batteries and the critical materials they require for applications that require electricity.

[1] EV Charging is another example of flexible energy demand with grid benefits. Time-scheduled EV charging combined with pulling power from the vehicle back to the GRID has been tested in several trials

**Compares Favorably to Green Hydrogen:** While there are many applications for green hydrogen derived from electrolysis, it is not a very efficient way to supply industrial heat since creating, storing and distributing hydrogen is very energy intensive. Our estimate is it would take twice the amount of renewable electricity to supply distributed industrial heat than it would take to use renewable electricity to power a heat battery, and there is no new infrastructure to be developed so deployment can be much faster.

**Co-Generation:** Steam produced from heat batteries can be combined with electric generation providing local grid power. In this model, the customer/owner would overbuild the heat storage so there is surplus energy to supply back to the LSE during times of increased local demand. The system can be re-optimized seasonally between heat and electricity production *(see example, Appendix 2)*. For some operations such as food processors, the demand for heat varies seasonally.

**Community Benefits:** Many existing industrial heat applications operate using natural gas in disproportionally impacted communities as identified under AB 617[2]. By triangulating facilities that can replace natural gas heat with heat batteries combined with local grids that have capacity to accept local generation, one could reduce local pollution, increase the usage of renewables, reduce the use of natural gas electric generation and reduce the need for electricity storage or expansion of the local distribution network.

## How Heat Batteries Can Help Achieve The 2022 California Scoping Plan Goals

The 2022 California Scoping Plan calls for reductions in the use of natural gas for heating, significant investments in renewable electricity and electric storage, and addressing the impacts of pollution on disadvantaged communities.

The California Greenhouse gas inventory[3] identifies 23% of emissions coming from industrial sources – separate from their use of grid electricity. A significant percentage of emissions comes from the on-site burning of natural gas for heat. We estimate that California burns more natural gas for industrial heat than it does for electric power generations[4]. The Scoping Plan expectation is that energy used for producing heat will come from electricity or green hydrogen produced by electricity. Heat Batteries can replace natural gas with the most efficient use of electricity and timed to avoid increasing base-load demand.

The Scoping Plan is sensitive to the economics of reduction methods. The economics of Heat Batteries is dependent on the price of renewable electricity, the price of natural gas, the price of GHG allowances and any potential carbon credits (the main one being the Carbon Intensity score for transportation fuels). A reasonable maximum price is $11/mmbtu (delivered)[5] which equates to renewable electricity at $38/mWh. For industrial facilities that are adjacent to good renewable resources, we expect them to contract directly for intermittent renewables. This is an excellent match because the renewable electricity field can be developed much faster without a grid connection requirement and the intermittency of power is not a problem for a heat battery. However, from our assessment only 40% of industrial heat applications in California are adjacent to potential renewable energy sites. For the rest access to affordable renewable power on the grid is necessary. This is both a challenge and an opportunity.

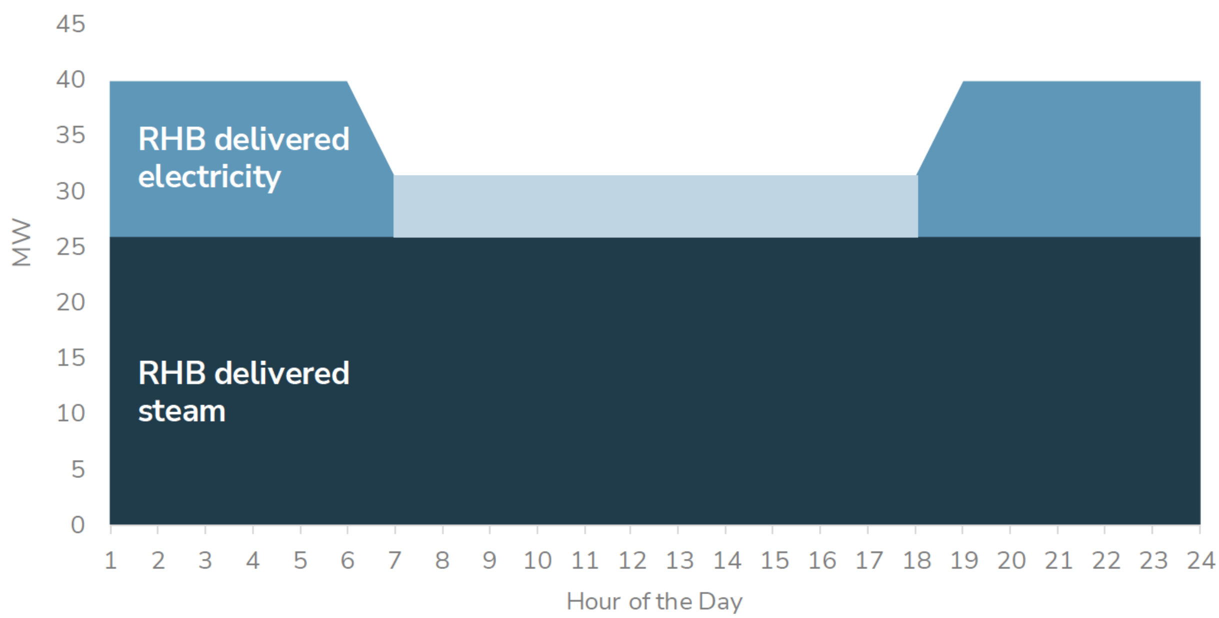
[2] https://ww2.arb.ca.gov/capp-communities
[3] https://ww2.arb.ca.gov/ghg-inventory-data
[4] Based on analysis of the CARB GHG Inventory
[5] City gate price of $7.5/mmbtu utilized at 85% efficiency in fossil fuel boiler, plus a carbon tax of $40/t$CO_2$ (CA 5 ETS)

The Scoping Plan requires a rapid decarbonization of the California electric grid. The grid is under tremendous pressure to accommodate the growth in demand as electric vehicles replace fossil gasoline and diesel and homes and businesses are increasingly required to use electric appliances instead of gas appliances. Most EVs and electric appliances will place new demands on the grid that will have to be balanced with additional electric storage since their usage is unlikely to be aligned with renewable generation.

Heat Batteries are different since their demand can be aligned with renewable energy generation. They are the primary example of significant new electricity demand that can be aligned with generation with both policy and private contracts. Renewable generation facilities are commonly curtailed due to lack of real-time demand and this results in both lost power and the possibility of increased use of natural gas generation when the power is needed. The demand provided by Heat Batteries during peak renewable generation can reduce curtailment, provide revenue to renewable projects, and support the grid in integrating additional renewables.

Going further, Heat Batteries can be become a new category of combined heat and power. They can receive local, off-grid renewables, produce heat for internal consumption and dispatchable electric power back to the local grid at the time and volume chosen by the LSE. In fact, a Power Purchase Agreement (PPA) with the LSE can become an important commercial credit enhancement that lowers the overall cost of installing a Heat Battery.

In the illustration below, an industrial operation has a 40 MW local renewables contract and uses 25 MW for continuous heat for their operations and ramps up 15 MW at 7PM for delivery to the local LSE and ramps it back down at 6 AM. We refer to this as “anti-duck curve” renewables!




As a final connection to the Scoping Plan, target locations for heat batteries with combined heat and power can be based on AB 617 communities with significant use of local industrial heat and local electric distribution needs for more energy storage and delivery of power when renewable resources are inadequate. While the example above assumes a local renewable electric resource, with the right policy designs, the renewable power can come from anywhere on the California grid.

## Obstacles

The operations of the current power markets in California are not designed to take advantage of Heat Batteries or Heat Batteries with combined heat and power. Without policy changes, Heat Batteries will be limited mostly to connections to local renewables and the benefits to the grid will not be realized. Given the scale of the demand, this would be a lost opportunity.

Current regulations provide for two primary structures - Direct access (limited to select loads) and Fixed Industrial Tariff (majority of loads). Direct access allows participation in CAISO wholesale markets but also includes a fixed access fee of $30/MWh. The fixed fee is already in excess of historical natural gas wholesale prices.

The Fixed Industrial Tariff is designed for large loads requiring high reliability and are subject to a lengthy interconnection study accompanied by a fixed “demand charge” intended to be used by the LSE to cover their need for providing reserves. This tariff structure provides no visibility on congestion in T&D nor wholesale market pricing. The lack of real-time pricing prevents dispatchable load from optimizing against unused resources, such as when curtailment is occurring (wasted power resource).

Ultimately, the tariff structures are intended for fixed loads requiring high reliability of the grid. The current regulations assume dispatchable loads have the same needs as typical industrial loads, and therefore are not a good fit and prevent the use of this new solution to solve the industrial heat load of the state and support the state’s grid operation. Fortunately, California regulators have shown great capacity to create new tariffs and structures (e.g., batteries), and we hope that Heat Batteries are recognized as a new type of load.

## Summary

Heat Batteries and EV charging both represent a new category of electric demand that is unique in their ability to select the time at which they receive power from the grid. Heat Batteries have the additional properties of being stationary with total flexibility on the timing to receive power.

With a local renewable electricity supply, Heat Batteries are already cost effective at replacing natural gas powered, high temperature industrial heat. Heat Batteries can accomplish this with greater efficiency that other energy options because of the low cost and high efficiency of storing heat as compared to electricity or hydrogen.

As this paper illustrates, the greatest societal benefit comes from the integration of Heat Batteries into a combined heat and power application in concert with the Load Serving Entity or other energy purchaser. As an integrated concept with the associated policies, Heat Batteries can significantly contribute to industrial heating applications, decarbonize the grid, reduce the demand for electrical storage and provide community benefits to over-burdened communities.

## Appendix 1: Partial List of Companies Developing Heat Batteries

**Rondo Energy** - https://rondo.com/
*Alameda, CA*

**Electrified Thermal Systems** - https://www.electrifiedthermal.com/
*Medford, MA*

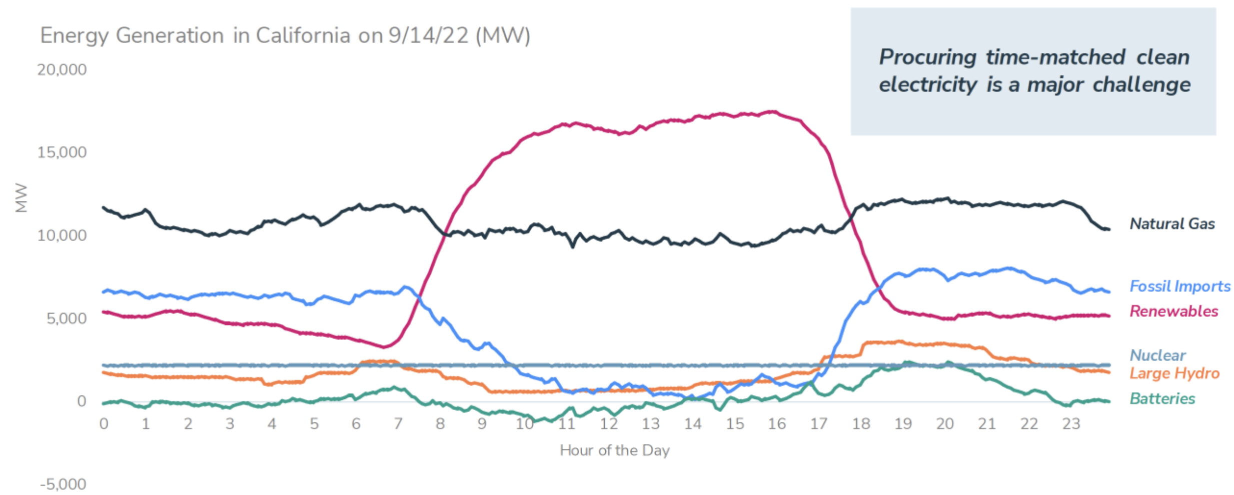
**Antora** - https://antoraenergy.com/
*Sunnyvale, CA*

## Appendix 2: Example Heat Battery, Combined Heat & Power Application

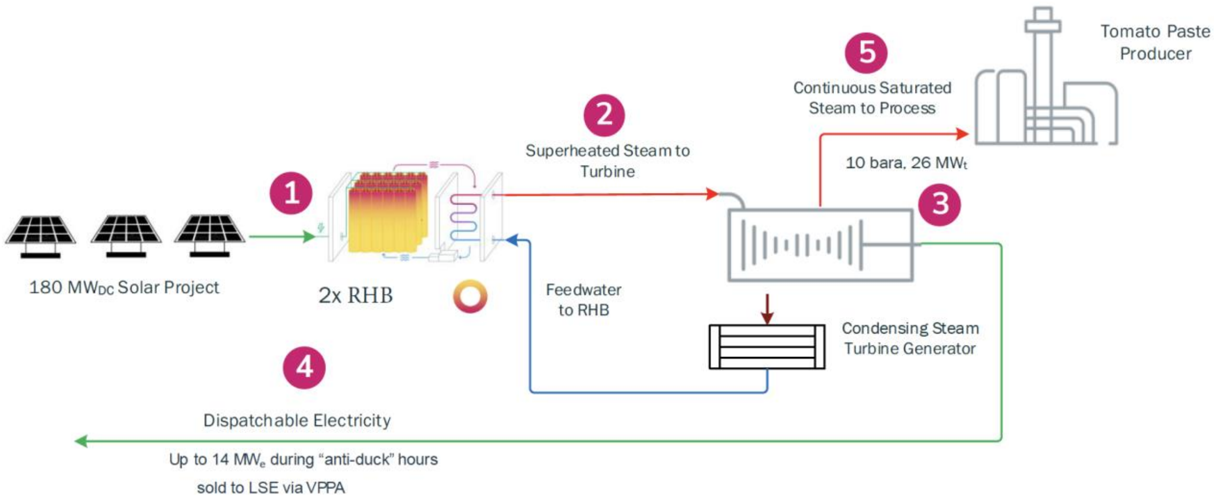
Heat Batteries are a cost-effective way to replace natural gas for industrial heating applications. In this example, we have selected a tomato processing facility in the San Joaquin Valley and modeled the potential impact to both service the facility's heat requirements and also provide "anti-duck" power back to the Load Serving Entity (LSE). We use available, adjacent land to build a dedicate solar-electric field with no electric batteries required.

The grid benefit occurs because the power is provided back to the LSE at a time that the LSE controls so it can be optimized for that day's need and minimize the purchase of carbon intensive energy.

A typical late summer day's power looks like the following:



From a clean-energy perspective, the best time to provide power back to the LSE is to displace the ramp up of fossil imports between 6PM and 7AM the next day. In the example below, we have teamed with Rondo Energy to model their production Heat Batteries in a combined heat and power design:




1. Two Rondo Heat Batteries accept power from a dedicated 180 MWDC solar field located on adjacent property. A new solar field would have a long, difficult time connecting directly to the grid due to the number of projects in the CALISO queue and the analysis required. By contrast a local, dedicate connection is much simpler and faster to develop.

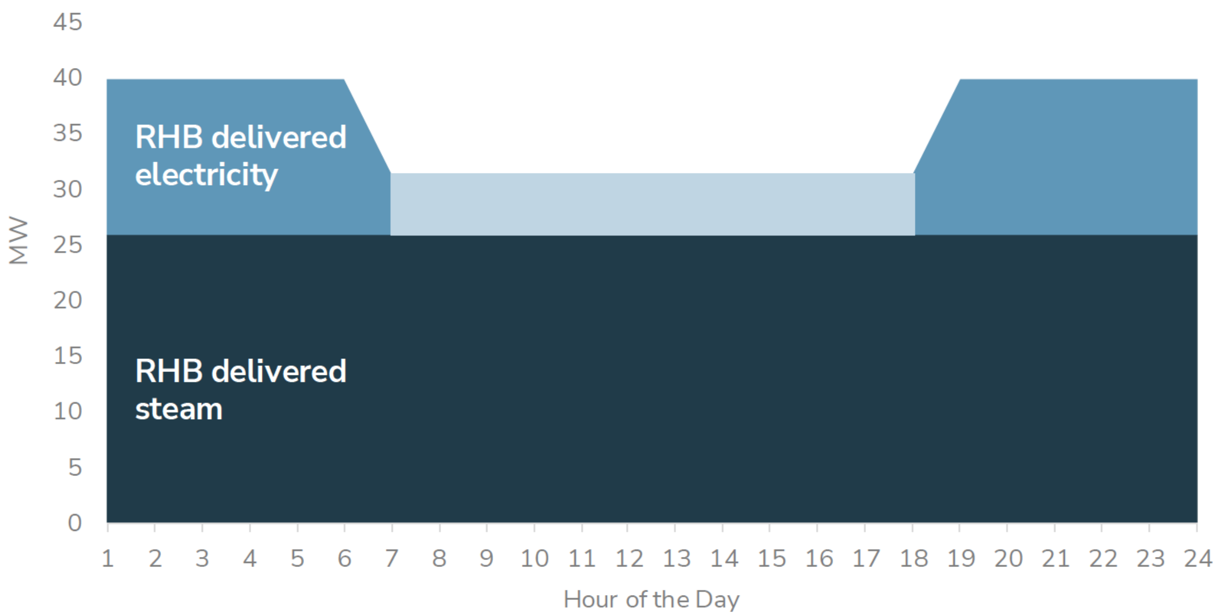
2. The Rondo Heat Batteries deliver 24/7 superheated steam to an extraction steam turbine.

3. The steam turbine has a dual output of saturated steam and electricity. The combined end-to-end efficiency is about 75%.

4. Electricity is dispatched to the LSE based on the optimal time to avoid carbon-intensive and/ or higher priced power.

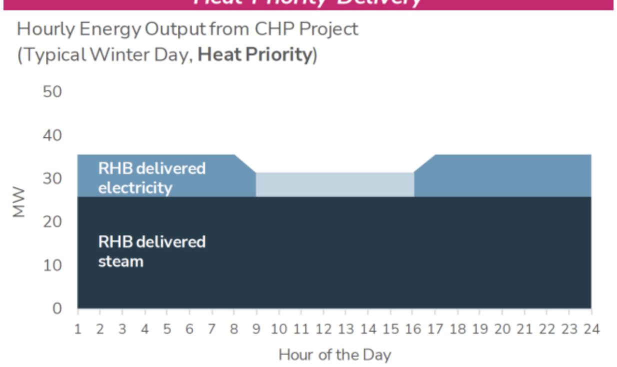
5. Saturated steam is delivered to the Tomato processor.

As the chart below illustrates, the system can shift the amount of heat used for electricity to match the best outcome for the cost of electricity for the tomato processor and the best value for the LSE. During the middle of the day, any electricity generated is used by the tomato processor. At 6PM, electric is ramped up and delivered to the LSE and subsequently ramped down at 7AM. Since the power delivery is controlled by contract and by the LSE, the power is designed to match the available distribution resources and power needs. This can change seasonally as the need for heat and the need for power varies.




Based on publicly available data, Rondo estimates two different Winter scenarios (high priority or electric generation priority):

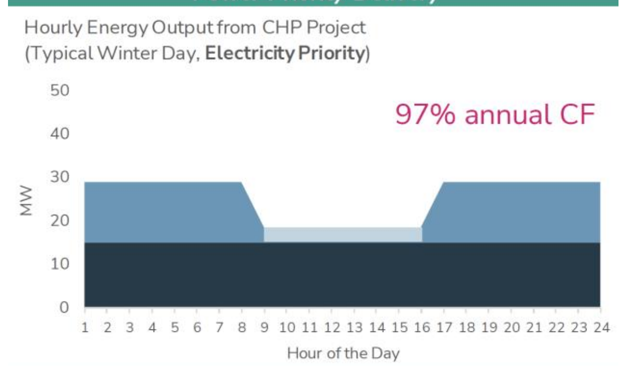
***Heat Priority Delivery***




**Annual electricity delivered (Anti-Duck):** 46 GWh
**Annual electricity delivered (Daytime):** 18 GWh
**Annual emissions reduction from electricity:** ~20,000 tons $CO_2$e

**Annual steam delivered:** 216 GWh
**Emissions impact from steam:** ~49,000 tons $CO_2$e

***Power Priority Delivery***




**Annual electricity delivered (Anti-Duck):** 69 GWh
**Annual electricity delivered (Daytime):** 14 GWh
**Annual emissions reduction from electricity:** ~26,000 tons $CO_2$e

**Annual steam delivered:** 128 GWh
**Emissions impact from steam:** ~29,000 tons $CO_2$e