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Thermal Batteries/Heat Batteries

How thermal batteries can replace natural gas powered industrial heat, reduce pollution and support increasing renewables on the California grid.

Introduction

Emissions from industrial heating in California are a significant source of both greenhouse gas emissions and criteria pollution due to the combustion of natural gas. The majority of industrial facilities are in disadvantaged communities and 81% of industrial emissions occur in low income and disadvantaged communities[1]. The CARB inventory for industrial emissions shows[2]:

	Load MW	GHG CO2eq MTCO2/year	% of CA GHG	NOx Tons/ year	SOx Tons/ year	PM10 Tons/ year	PM2.5 Tons/ year
Industry excluding oil & gas	5,201	18,387,156	5%	17,228	3,789	5,376	3,115
Industry including oil & gas	13,756	59,037,911	15%	24,839	6,160	8,020	5,604

A significant portion of the emissions comes from using fossil fuels to create medium and high temperature heat for industrial applications. Those temperatures are not achievable by heat pumps that are common for lower temperatures applications such as space heating and hot water. Using a thermal battery powered by renewable energy for heat can cost effectively eliminate a significant source of greenhouse gas and criteria pollution. Thermal batteries are well matched with wind and solar generations because they do not require continuous electricity. They can be charged when the sun is shining and/or when there is surplus electricity generation that otherwise would be curtailed. In addition, the stored heat can be converted back to electricity. This paper discusses how thermal batteries can fully benefit the electric grid if policy changes are considered to allow neighborhood behind the meter renewable connections, grid tariffs based on the thermal battery being treated as a demand and a generator, and the potential for the Load Serving Entity to be able to optimize the demand and generation of power.

Why a Thermal Battery?

A thermal battery – also called a heat battery – is a technology that allows for storing and releasing energy in the form of heat. It is much less expensive to store heat than it is to store electricity. Thermal batteries use commonly available, low cost materials. A thermal battery can take in large quantities of electricity over a short period of time (e.g. when solar energy generation is peaking across the state and exceeds demand) and use the power to heat a thermal storage material such as refractory brick and then continuously transfer the stored heat to where it is needed. Its energy efficiency – conversion of

[1] https://data.cnra.ca.gov/dataset/low-income-or-disadvantaged-communities-designated-by-california

[2] https://www.arb.ca.gov/ei/tools/pollution_map/

power input to heat output - is well over 90%. Thermal batteries can deliver temperatures of 1,500°C which is enough for almost all existing industrial applications.

Heat batteries can be an important way to cost-effectively deal with the intermittency of renewable energy. They can be dynamically charged when electric power is available or when it is at its lowest cost. In addition, heat stored in heat batteries can be converted back to electricity, if needed. This can be beneficial in certain situations that we describe next. The economics are driven by the price of delivered electricity compared to the natural gas it replaces. Energy Innovation recently released a detailed report on Industrial Thermal Batteries[3].

We will describe a number of example situations and then discuss the policy options that would allow thermal batteries to work for industrial facilities while also providing grid benefits. There are two major dimensions to the examples. First - does the industrial facility have access to “behind the meter” renewable electricity? This means it directly contracts for the power and the power does not flow through the grid nor are there any distribution or transmission fees. Second - is the thermal battery configured to convert heat back to electricity that can be put on the grid? This means the thermal battery can appear to the grid like an electric storage system, that is, it both creates demand but also generates power. California’s two thermal battery companies do this in very different ways. Rondo Energy[4] stores heat in refractory bricks in an insulated chamber and converts heat to steam to power in a separate combined-cycle turbine electric generator. The waste heat from the turbine can then be used in industrial applications. Antora Energy[5] stores heat in a solid graphite system which emits radiant heat light. Antora’s thermal battery can deliver high-temperature heat to industry, or convert the stored heat to electricity using a special thermo-photo voltaic system integrated into their battery, which converts the ultraviolet light from the glowing-hot storage medium to electricity with no moving parts.. For both companies, the energy efficiency if you do not include the use for industrial heat is low (40-45%) but there are still many cases where it will be economic and beneficial.

Case 1: Behind the meter, adjacent renewables

Benefits: Significant pollution reduction, economic parity with historic natural gas prices, fast implementation

Issues: Current California regulations require renewable generation be in physically adjacent land.

Several California industrial companies have adjacent land under their control that is suitable for solar and/or wind. The cost of power would be $0.03 - $0.05/kWh since it would be able to avoid grid connection. With a reliable and guaranteed price for electricity, the economics of replacing natural gas can be compelling. For example, Project 2030 modeled[6] the economics of using a heat battery with behind the meter renewables for a dedicated calciner for cement facilities.

Case 2: Behind the meter, “neighborhood renewables”

Benefits: Significant pollution reduction, economic parity with historic natural gas prices

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[3] https://energyinnovation.org/wp-content/uploads/2023/07/2023-07-13-Industrial-Thermal-Batteries-Report-v133.pdf

[4] https://rondo.com/

[5] https://antoraenergy.com/

[6] https://project2030dotblog.files.wordpress.com/2023/02/project-2030_the-economic-case-for-two-emerging-decarbonization-options-for-cement-production.pdf

Issues: Current policy prohibits transport of electricity without going through the grid

Case 2 significantly expands the number of facilities that would have economic and community benefits from use of a thermal battery. However, existing California regulations disallow this configuration in part because it could create departing load which in turn unfairly shifts costs to other electric customers. Other states allow a much simpler path for renewables to be directly connected across properties, and changing these regulations in California is likely the single biggest action that can be taken to accelerate the deployment of industrial thermal batteries. There are at least two arguments for considering a policy change to allow “neighborhood renewables”, that is renewables with a dedicated distribution line and some limited distance away from the demand.. The first is that thermal batteries would replace natural gas to meet new electricity demand with no impact on the Load Serving Entity (LSE) or other customer. In fact, as we will discuss in case 4, it could create benefits for the LSE and its customers. The second reason is that connecting new renewables to the grid is a slow process and there is already a large bottleneck. A behind the meter connection would be on its own parallel path thus increasing the rate of installing new renewables. Furthermore, many of the industrial facilities are in the central valley where there is great potential to use agrovoltaics to generate electricity on farms with minimum impact on production.

Case 3: Grid powered thermal battery

Benefits: Significant pollution reduction, potential to avoid curtailment of renewables

Issues: Cost of grid power makes economic case unclear

In this case, the industrial customer would buy power from the grid. A thermal battery has the flexibility to use power whenever it is least expensive. A typical thermal battery requires approximately 5 (non-contiguous) hours of electricity to store 24 hours worth of heat. Due to this highly flexible nature the thermal battery can limit it’s charging to only super-off peak periods, when grid assets are underutilized. This means that the economic costs of serving this power are incredibly low, potentially even negative at periods of extreme renewable over generation. However, most existing rules for purchasing grid power have fairly limited differentiation in cost between high and low load periods.

Case 4: Grid powered thermal battery with electric generation

Benefits: Significant pollution reduction, potential to avoid curtailment of renewables, time-shifted renewable with local generation

Issues: Missing pricing policies to treat a thermal battery as another electricity storage device

A thermal battery installation has the potential to also provide grid benefits beyond reducing curtailment of renewables. The thermal energy can be converted back to electricity that can be placed back on the grid and/or used to meet the energy demand of the facility . This currently exists with co-generation facilities that are powered by natural gas. The underlying assumptions are:

1. There is surplus heat available. This can happen because (a) the need for industrial heat is seasonal so in the off-season the heat battery can be configured to time-shift renewable power to when it is needed; (b) the industrial facility overbuilt the heat storage capacity to take advantage of the economic opportunity of serving as a grid battery; (c) the real-time value of the electricity is compelling.
2. The thermal battery is treated as a grid battery for tariff purposes. Chemical batteries and to a lesser extent reversible hydrogen fuel cells are treated differently than commercial demand customers. Thermal batteries can be viewed as a combination of a commercial demand load and as a grid battery.

Choosing the timing to charge the thermal battery can redone by the facility management itself. To optimize the local grid, thermal battery charging and electric generation could alternatively be managed by the LSE under contract with the facility. The LSE is in the best position to know when to charge the thermal battery and when to generate power. The power generation would be limited by contract to ensure that the facility's heat requirement can always be met.

Case 5: Grid powered thermal battery with electric generation and carbon free peaker plant

Benefits: Significant pollution reduction, potential to avoid curtailment of renewables, time-shifted renewable with local generation, reduce need for spinning reserve peaker plants and operating emergency diesel generators.

Issues: Missing policies

An additional variation of case 4 would be the ability to contract with facilities to have the standby ability to provide peaker power on the rare occasions when that is needed. The contract value would need to be sufficient so the facility can either operate under reduced heat output by curtailing some operations or has additional heat capacity specifically for the case of being a peaker plant.

Impact on California Scoping Plan

A range of benefits in terms of GHG reductions, criteria pollution reductions, environmental justice benefits and electric grid benefits are possible depending on changes to grid connection and tariff policies and the potential benefits of enabling the LSEs to optimize the thermal battery energy demand and generation.

At a minimum, the direct benefits of replacing a natural gas fired boiler with a thermal battery provides immediate reductions in criteria pollution and GHGs. The economics are always very dependent on access to affordable renewable electricity. As such the early market will be limited to facilities which either: (1) are in the fuels market which places a premium on a low carbon intensity score or (2) have access to behind the meter renewables. An example of the former is Calgren Renewable Fuels[7]. In March 2023 they replaced a portion of their natural gas heating with a Rondo Heat Battery. The reduced carbon intensity of their fuel made the economics work.

To scale up thermal batteries in this decade will require rethinking how thermal batteries can benefit the grid and make changes that allow local behind the meter renewable connections, grid tariffs based on the thermal battery being treated as a flexible demand and a generator and the potential for the LSE to be able to optimize the demand and generation of power.

A minimum target for California for the rest of this decade would be 2 MMT/year reduction but with the proposed changes in policies, we could see a 5 - 10 MMT/year reduction in GHG by 2030.

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[7] https://rondo.com/calgren-case-study