Defining a Business Model for Utility-Scale Thermal Energy Storage – Value Proposition, Needs, and Opportunities

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Abstract. The need for reliable, cost-effective, utility scale energy storage that is universally applicable across different regions is becoming evident with the global transition towards non-polluting renewable energy resources. The operations and management of these energy storage technologies introduces a unique challenge that is inherently different from the conventional energy storage in the form of fossil fuel. The investigation into the business model, value proposition and economic viability of a utility scale thermal energy storage was part of a program sponsored by the United States Department of Energy, called Energy I-Corps. During this program, the project team reached out to a series of industry stakeholders to conduct interviews on the topic of thermal energy storage for utility scale power generation. Specific focus was placed on the business model based on the market needs in the context of the power grid in the United States. The utilization and re-use of infrastructure at existing thermo-electric power plants yielded the most viable business model for the implementation of the form of thermal energy storage discussed here.

INTRODUCTION

The intermittent nature of renewable energy resources requires a firming capacity in the form of energy storage to provide base load energy, available on demand. An alternative is to overbuild the generation capacity of renewable energy installations to always have surplus energy and theoretically eliminating the need for energy storage, but this philosophy is not economically competitive to other energy sources in the market like fossil fuel and nuclear. Since a large portion of renewable energy generation is directly produced by solar resource, this generation source has a fixed diurnal cycle, limiting to only daytime operation. Increasing penetration of intermittent renewable generation introduces a new operations philosophy, which involves the maintenance and management of energy storage facilities with significant power and energy capacities [1].

After conducting over 90 interviews with industry we have concluded the major driving factors for the selection of a suitable energy storage solution in the evolving energy market are 1) economics, 2) reliability, and 3) policy/regulations like low-carbon or clean energy mandates. Thermal energy storage (TES) in the form of sensible heat is a proven technology in commercial concentrating solar power (CSP) stations globally. Current commercially deployed TES consists primarily of two-tank molten-salt configurations, which have experienced some challenges [2]. Thermal energy storage in solid media has the potential to overcome many of these challenges. A Thermal Heat Repository for Months of Storage, THERMS has been identified as a suitable candidate for utility scale application. THERMS provides a safe energy storage solution that makes the transition to a low-carbon grid possible by maintaining reliability, scalability, and flexibility of existing infrastructure while avoiding significant costs [3]. See Fig. 1 for the process flow diagram of the THERMS concept with air as a heat transfer fluid and the storage medium a solid medium like rocks.

The basic description of the THERMS technology is the storage of thermal energy in the form of sensible heat in a solid medium. Natural crushed rocks that formed by metamorphic processes under high temperature and pressure is a great candidate for use as a storage medium. This is a material that is widely available around the globe and typically low cost. Fire bricks and some high temperature rated construction materials can also be used for this application of storing thermal energy at high temperatures, providing the option to repurpose suitable construction waste. Natural rock is an environmentally friendly material and does not add any additional pollution to the local environment. Thermal energy storage in solid media at high temperature is a proven concept, with commercial entities like Siemens Gamesa pursuing the industrial application of TES for power generation [4].

In recent years, there has been substantial investment in energy storage technologies for various applications, ranging from stationary energy storage for utility scale power generation to synthetic fuels for the transport industry. Looking forward, an estimated investment in energy supply and infrastructure between \$92 trillion and \$173 trillion over the next thirty years is expected [5]. A study presented by NREL describes the estimates that energy storage capacity could grow nearly 30 fold from 2020 to 2050 and that under all scenarios, a dramatic growth in grid energy storage is the most cost-effective solution [6], [1].

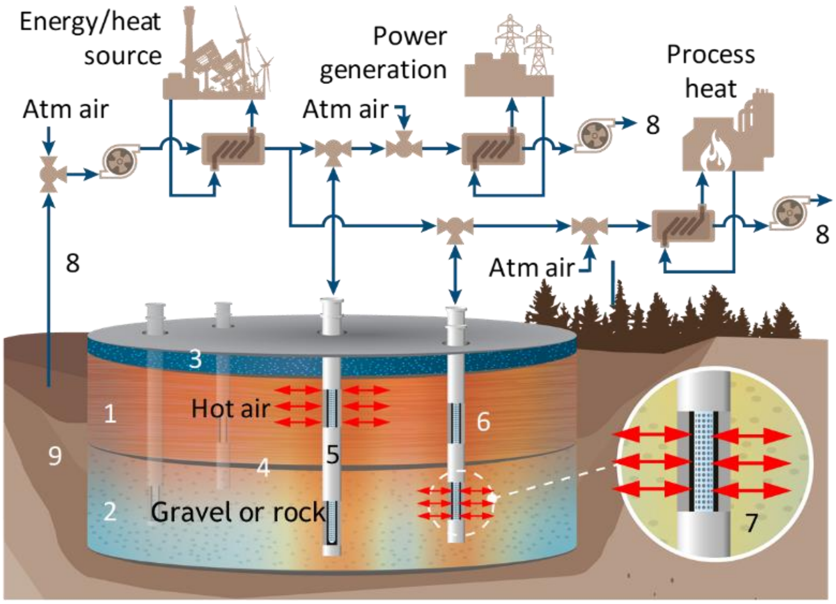

FIGURE 1: THERMS process layout diagram [3].

BUSINESS MODEL DEVELOPMENT

Value Proposition

The main value proposition of adding utility scale TES capacity to the electricity grid is the capability to provide grid reliability with intermittent generation sources, while maintaining a cost-effective approach relative to alternative large-scale energy storage solutions. With the evolution of the electrical grid (consisting of majority legacy conventional synchronous generation assets) towards a grid with a majority renewable generation sources (mainly inverter-based, asynchronous generation), that are intermittent in nature, there is a need to firm the generation injected to the grid. Commercial deployment of utility scale energy storage needs a financial incentive to upgrade the current fleet of grid assets to include significant energy- and power capacity storage infrastructure. Without the additional revenue generation capability or cost savings potential, the return on investment is not attractive for investors. Large scale TES has the potential to be the revolutionary component to enable this financial incentive.

Identifying the Market

For evaluation of the potential market and revenue streams of a new business, it is necessary to identify what the financial viability and sustainability of the business looks like. There are three main categories to consider, narrowing down to the real market. These are the Total Available Market (TAM), Serviceable Available Market (SAM), and the Serviceable Obtainable Market (SOM). Of these three categories, the SOM is the tangible market that is most relevant and can be factored into the business model as a potential revenue generating market. In the case of utility scale energy storage in the form of thermal energy, any form of thermo-electric power plants are potential candidates for implementing this technology. In the Customer Segments section, the identified SOM is described in more detail.

Customer Segments

The identified customer segment for the application of TES is utilities/grid operators, who could potentially retrofit coal fired power plants with useful life left. Retiring conventional power stations are suitable for partial re-use in this energy transition, because of their strategic location on the grid, existing thermo-electric power machinery, and existing operating workforce which can be repurposed to operate the power plant with the addition of a large capacity energy storage facility. The criteria valued by utilities is safety, cost, reliability, lifetime, and environmental impact, which can be delivered by retrofitting TES to suitable existing infrastructure. The addition of thermal energy storage in this context is referred to as THERMS+. The capacity of installed coal fired power stations is summarized in Fig. 2, with the plants installed since 1990 being targeted.

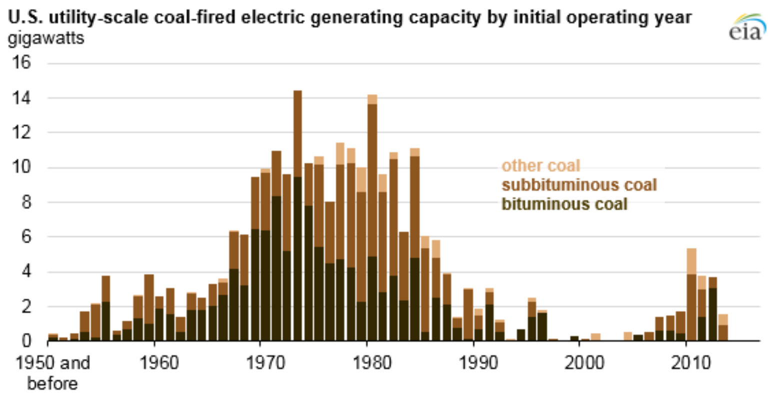

FIGURE 2: Coal power stations in the United States by initial operating year [7].

Revenue Generation Streams

The market incentive is essentially the cost avoidance for coal fired power plants by implementing THERMS as a means of energy storage compared to other utility scale energy storage technologies. In the industrial energy storage sector, the average cost for Compressed Air Energy Storage (CAES), pumped hydro, hydrogen and long duration battery storage is ~\$0.20/kWh [8], [9], [10]. The average cost of THERMS+ can be ~\$0.10/kWh [3]. The cost comparison of THERMS+ relative to other technologies is shown in Fig. 3. As an alternative to other utility scale energy storage technologies that are available to use on the market, THERMS is well suitable for combining with the existing infrastructure of a thermo-electric power plant. Considering the installed capacity of coal fired power stations in the United States, more than 10% of the coal plants have over 20 years of useful life left and will be retiring within 10 years due to emission-reduction mandates initiated by local state or federal regulations. By utilizing the surplus energy generated by renewable energy resources, storing energy in the form of heat, and providing electricity to the grid when the demand is present, an estimated annual cost savings potential of ~\$10B/year in the U.S. is possible.

In the year of 2019, there were 241 coal fired power plants operating in the U.S. with a total capacity of 236 GW [7]. The annual estimated cost saving is thus calculated by the following rationale: 236 GW x 10% x 10^6 kW/GW x 8760 hours/year x 0.5 (capacity factor) x \$0.10/kWh (savings) = \$10B/year.

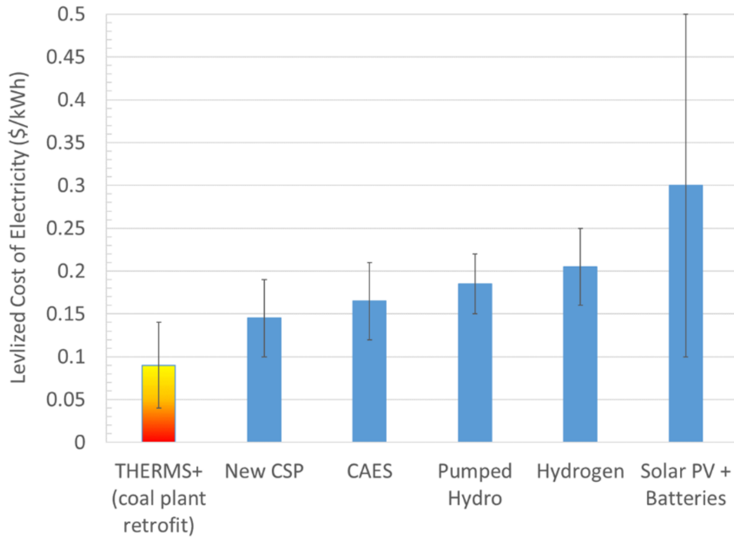

FIGURE 3: Levelized cost of electricity of THERMS+ compared to other technologies; [8], [9], [10].

The global yearly estimate of cost savings is ~$100B/year. On average, each major utility can save ~$100M per year using THERMS+ relative to other storage options. Here it is assumed that ~100 – 200 major utilities implement this energy storage technology. Additional savings is also possible by utilizing the existing distribution and transmission networks, which is a huge capital expenditure if an energy storage system is built in a spot that is not close to an existing substation or grid interconnection point. Expenses incurred by the supply chain of coal should be considered. When this is removed from the equation, there are further savings of capital on a recurring basis since the plant will no longer need to mine, process, and transport the coal.

The revenue potential for a business installing this form of TES includes a profit margin of ~$0.01/kWh after the ~$0.10/kWh is costs to install THERMS+. An estimated $44M/year profit per retrofitted 1 GW coal fired power plant is possible, assuming the following: 1 GW x 10^6 kW/GW x 8760 hours/year x 0.5 (capacity factor) x $0.01/kWh = $44M. This is based on the mode of an energy storage as a service. The SOM in the U.S. is ~$1B per year, assuming a total of 20 plants are converted per year.

MARKET NEEDS

Providing Grid Services

Energy storage for utility scale application is primarily required for providing a dispatchable energy source. Since a fully renewable energy grid makes use of generating a significant amount of power from energy storage devices, which primarily have an inverted based interface, ancillary grid services like frequency response, voltage regulation, reactive power management, and fault ride-through are not provided as they would be in conventional generation. The main reliability related categories of ancillary services have been identified as 1) energy and capacity, 2) operating reserves, and 3) voltage support, 4) and black-start capability [11]. Due to zero-carbon mandates that had been adopted in the U.S. and globally, there is a growing need for cost effective, environmentally friendly energy storage that can be deployed on utility scale.

With the current energy market still functioning in the majority from conventional power generation assets, the immediate need for utility scale energy storage is not yet urgent. Incentives created by the current energy market do not currently favor energy storage, but the growing penetration of renewable energy generation on the regional, statewide, and eventual national electricity grid will require significant amount of energy storage to maintain the same resiliency and reliability. With natural energy resources being intermittent and unpredictable to some extent, a buffer energy storage will enable the grid to stay healthy and reliable. In addition to the market need for energy capacity, there is also the need for power generation capacity that goes with the immediate demand-supply management philosophy of operating a large grid. Ramp up times of equipment, reaction of the power generation systems to anomalies on the consumer network and general grid services need to be managed to maintain power quality reaching the end user. The power quality and the health of the grid can be quantified in how well the voltage and frequency in various points in the network can be maintained within the normal allowable operational band.

Quality and Reliability: Evolving Energy System Architecture

With the energy generation and storage assets evolving from conventional to more renewable energy based, the existing network infrastructure has to evolve with this change to maintain compatibility. The architecture of a conventional power grid is based on synchronous alternating current generation at a constant frequency of 60 Hz in the U.S. Replacing grid infrastructure to accommodate new generation technology is costly and can also cause unwanted disruption in service. Conventional spinning machinery like generators driven by steam turbines, generate a clean electricity signal (without residual noise) with the main source of harmonics primarily coming from the consumer side, caused by fluctuating analog loads (macro scale) and operation of digital machinery (micro scale). With more asynchronous generation in the form of an inverter-based interface to the grid, there is a growing need for robust synchronous generation to provide grid stability. Power electronics have developed and evolved to provide a substitute for some of the conventional grid services like fast voltage response and frequency regulation, but is still limited in the capability of providing synthetic inertia. Means of mimicking or replacing the characteristics of conventional generation helps to maintain the functionality of the existing energy infrastructure. A representation of synchronous and asynchronous generation connected to the same grid is illustrated in Fig. 4

The renewable energy development in South Australia is a good example of the future issues that electrical operational grids can see with high penetrations of inverter-based generation in the form of renewable energy. Synchronous condensers are deployed to provide mechanical inertia to maintain grid stability and reliability, with the capability to provide power factor correction and reactive power management in the same basic way that conventional synchronous generators do. The long term cost benefit relation makes synchronous condensers a viable method of providing inertia and other conventional operational capabilities to the system operator [12], [13], [14]. Controls and power electronics provides fast response controls, but it lacks the ability to provide the capacity to absorb longer lasting anomalies and instabilities like short circuit conditions on the consumer side.

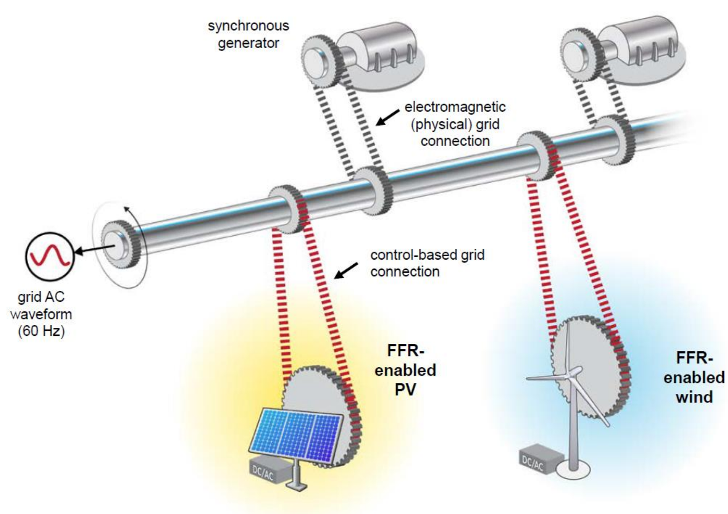

FIGURE 4: Wind and solar providing frequency response through inverter-based (control-based) grid connection [15]

OPPORTUNITIES

Techno Economics, Socio Economics and Social Equity

To adopt and deploy a new technology at commercial scale in the industry today, it needs to make financial sense. This goes with the assumption that the technology is techno economically viable to implement the first time and financially self-sustainable over the operational lifetime. Referring to renewable energy as an example, the most sustainable way of utilizing resources is to utilize what is locally available. Most regions have some form of an abundant renewable energy resource. Conversion of the energy to electricity makes it a universal 'energy currency' that can be used to charge the THERMS+ energy storage asset. Co-location of a TES system with a coal power plant puts this concept ahead of most other competitors due to the strategic location on the existing electricity grid. Re-using the existing infrastructure of coal plants forced out of operation at an earlier stage than its normal end of life, saves the developer major capital expenses.

The carbon footprint from constructing retrofits of existing thermo-electric power plants are smaller than new plant construction and also offset by providing a second life to the existing hardware and by contributing to renewable generation. Steam based power plants are composed of mature technologies, operational procedures, and engineering that is well known. This provides a robust solution to utilities that are inherently risk averse. This makes it even more economically viable to implement TES on coal power plants, since the risk is low on the majority of the equipment and only the steam generation portion need to be upgraded to accommodate steam generation from a different source than combustion.

Socio economics and social equity plays a large role in the viability of a business today and availability of a local trained workforce plays a big role. Many jobs at existing coal power plants can be maintained, since the operation of THERMS+ entails the same basic operation as a conventional power plant on the electricity generation side and the steam turbine operation side. Steam generation is inherently different from the traditional boiler operation in fossil fuel fired power station, but since the existing workforce is capable of operating a thermal power plant, the basic methodology of heat supply to vary the production of steam is similar. Human resource in the form of local and regional jobs up and down the chain can be maintained if a coal power plant can remain operational for decades after it has switched to a renewable primary energy source in the form of surplus electricity produced by renewable energy generation.

Potential Market for Grid Services

With the foreseen decline of conventional power generation assets like fossil fuel and nuclear in the coming decades, there will be a need to replace the capabilities of synchronous generation assets with alternative solutions. If this can be accomplished by using existing and mature technologies from the power generation industry, there is a great potential for stepping into the role of providing the system inertia similar to what synchronous condensers are doing today while providing the capability of offsetting the energy use to a higher time value of electricity. This adds to the value stacking of providing energy and power generation capacity in addition to auxiliary services like reactive power management, voltage regulation, frequency control and fault ride through capability.

Business Potential and Market Opportunity

The capacity of installed coal fired power stations located in the United States of America is summarized in **FIGURE 2**, with the plants installed since 1990 being targeted. Thus, the value added by the addition of utility scale energy storage (THERMS) to renewable energy generation technologies can make renewable energy production economically competitive with conventional electricity generation technologies for the base load electricity market. The THERMS concept, combined with renewable energy sources, can be an ultra-low cost method of providing utility scale power compared to renewable energy sources combined with other energy storage options. Supply chains for construction and installation of THERMS+ already exist, since it is all based on commercial construction techniques and processes.

Since the primary form of energy storage is thermal energy, this creates the opportunity to directly match a concentrating solar power plant with this type of TES. Industrial process heat can also be a potential end use. This can make a huge contribution towards industrial decarbonization, since such a large percentage of energy used is for the purpose of heat.

CONCLUSION

In conclusion, this study for defining a business model for utility-scale thermal energy storage yielded an interesting perspective that the market for large scale, long duration energy storage does not yet exist. The retrofitting of existing coal fried power plants with thermal energy storage is investigated in many places in the world, including Germany, who has a demonstration pilot plant running and producing electricity [4], [16]. In additional to current challenges in the policy and regulation to adopt new energy storage technologies, the three main factors for driving commercial deployment were identified as: 1) economics, 2) reliability and safety, 3) and low-carbon/ clean energy mandates. Value stacking of multiple economic advantages, combined with generating electricity in the conventional fashion of spinning machines has an added benefit that contributes to grid stability and resiliency of the electrical grid.

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