Coal Repowering
a White Paper Series

Repowering Coal-Fired Power Plants for Bulk Energy Storage

EPRI

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Abstract

In response to mounting pressure to retire coal-fueled generating assets, U.S. utilities have announced thousands of megawatts of coal plant retirements to take effect over the next 15 years [1]. Until recently, newly constructed natural-gas-fired units typically replaced decommissioned coal plants. However, other options are available.

Recent advances in bulk energy storage technology provide a viable way to repower coal plants. In the same time frame as the projected coal retirements, large-scale intermittent renewable resources are expected to expand greatly, creating a parallel need for large-scale energy storage. However, building a stand-alone, storage-only facility on the coal site fails to leverage a large amount of existing equipment (for example, expensive, long-lead-time turbomachinery) on the site, effectively stranding these assets. Hence, this paper examines the considerations for incorporating bulk energy storage to provide the energy to drive existing on-site turbomachinery.

This paper summarizes key issues to consider and understand when evaluating whether a closing coal-fired plant can effectively be repurposed with bulk energy storage. It is part of a series of EPRI papers addressing different options for repowering coal sites.

Contents

Introduction

As economic, regulatory, and carbon-reduction goals evolve, the viability and desirability of operating coal-fueled generating assets continue to decline. Since 2000, at least 90 gigawatts (GW) of older, smaller, and less-efficient coal units have been retired in response to environmental and economic changes [1]. Global goals for managing climate change have put intense policy pressure on the coal fleet while driving significant financial change, including an increasing difficulty in financing coal-related projects [2]. Pressures to retire and decommission the remaining coal fleet continue to mount as power generators worldwide transition to low-carbon or carbon-free energy sources.

In the United States, utilities have announced thousands of megawatts of coal plant retirements, with anticipated closure dates within the next 15 years [1]. This round of plant retirements presents new challenges. The average name-plate capacity for this group of retiring coal plants is about 420 MW, compared to an average of 152 MW for those retired in the past 15 years. Globally, including the United States, expected coal retirements over the next 15 years amount to nearly 290 GW [3]. Further, the World Economic Forum has noted that international coal plant retirements are preferred when combined with conversion to cleaner energy, and so must be accelerated to meet International Panel on Climate Change (IPCC) goals by 2050 [4].

The plants slated for retirement now are more complex than the older plants due to the presence of equipment such as air emission controls. Regulatory changes have resulted in stricter environmental air emissions and effluent limits, new regulated materials, and more public scrutiny on the closure process. These new challenges are adding cost and risk to the decommissioning process for the larger plants.

Utilities have typically addressed replacement of decommissioned baseload generation by constructing natural-gas-fired units at existing facilities. However, the transition to low-carbon generation suggests this type of baseload replacement may no longer be desirable. Rather, companies need to assess the coal-fired facilities to identify the assets, limitations, and options for developing new clean energy generation and bulk storage as the existing fossil-fueled fleet is retired.

The efficient use of rapidly expanding renewable resources calls for concurrent development of large-scale energy storage. Without it, central station renewable resources suffer from the limitations of intermittency, complicating their dispatch. Installing stand-alone, storage-only facilities on existing coal plant sites can leverage existing buildings, substations, and other critical infrastructure, but fails to leverage certain expensive, long-lead-time equipment, such as turbomachinery, effectively stranding these assets. Hence, this paper examines the considerations for incorporating bulk energy storage able to provide the energy to drive existing on-site turbomachinery.

In the current scenario, converting existing challenges to opportunities can be addressed by systematically creating an inventory of the existing site infrastructure, characteristics, permits, and other attributes, and correlating it with the needs of the evolving network and the proposed alternative—in this case bulk energy storage—with attention to maximizing useful service for both the utility and the local community.

Following are potential benefits of repowering an existing site for clean energy generation and storage:

- Operating coal plant sites have existing transmission infrastructure and interconnection permits.
- Many such sites have access to well-developed transportation infrastructure via road, rail, and waterways, as well as existing utility connections for buildings.

- The existing environmental permits for a coal facility may be modifiable for application to the new storage facility, possibly forestalling lengthy permitting processes that require multiple periods of public input.
- Larger facilities that already have a land use permit and certificate of occupancy, as well as buffer property to provide a visual and physical barrier from nearby neighbors, provide siting advantages that may allow the new system to be constructed and commissioned more quickly than siting the plant in a new location.
- Existing buildings, warehouses, and some other on-site equipment, such as fire suppression equipment, may offer opportunities to lower the cost of construction by repurposing those for the new generation.
- Many current sites offer the advantage of access to a large daily water withdrawal and water discharge allowance In the United States, the right to withdraw water is under more scrutiny. Modifying existing water withdrawal and discharge permits, rather than undergoing the permitting process at a new site, offers reputational and permitting advantages.

In addition to the benefits of existing equipment, infrastructure, and permits, repowering a site for new generation and storage may benefit the surrounding community. Local, state, and federal governments, municipalities, nongovernmental organizations, development commissions, and environmental justice advocates increasingly call for fossil-fuel-based power generation facilities undergoing decommissioning to transition via site redevelopment to a new use for the property. The goal is to replace the taxes, jobs, and community support that are lost when plants retire and potentially provide retraining and continued employment of a portion of the workforce.

In the United States, redevelopment of decommissioning coal plants became a federal priority in 2021, with Congress and the Environmental Protection Agency (EPA) encouraging the transition of closed or closing power plants and the industries that support coal-fired electricity generation to adopt clean energy technologies. A 2021 report from the U.S. Department of Energy shares recommendations from a twelve-agency working group highlighting the need for job-creating investments, funding for local infrastructure and economic development, and worker training to empower local communities impacted by the transition away from coal [5]. Repowering a site with new generation and storage can support both owner and stakeholder goals, while allowing the owner to maintain ownership of sites that may have legacy environmental impacts.

Utilities can develop long-term plans to support their corporate objectives for transitioning to low-carbon or carbon-free generation by developing a corporate strategy to thoroughly examine the assets, liabilities, obligations, and limitations of coal-powered facilities slated for decommissioning. Currently-available options include repowering the site to a(n):

- Bulk energy storage facility (most likely, thermal energy storage) that would store energy from the grid (when electricity prices are low) and discharge power to the grid when demand is high, while also leveraging existing turbomachinery (the subject of this paper)
- Battery energy storage facility that stores energy from the grid when electricity prices are low or renewable energy production exceeds demand and discharges power to the grid when demand is high
- Photovoltaic (PV) power generation facility that directly converts sunlight to electricity
- Concentrating solar power (CSP) facility that would create energy from solar thermal heat, potentially using the existing steam power island at the site to create power
- Natural-gas-fueled (and potentially hydrogen-fueled) simple-cycle or combined-cycle power plant
- Hydrogen production plant (most likely using electrolysis), with possible conversion to ammonia for higher-value shipment off-site for various industrial and power-production needs
- Advanced nuclear generating station

- A wind energy facility
- Hybrid plant using two or more low-carbon or carbon-free technologies, such as wind and solar, or solar and hydrogen

EPRI is exploring low- or zero-carbon repowering options for coal plants through a screening-level evaluation of the available infrastructure, permits, site characteristics, equipment, and water access typical of coal-fired generation that may be beneficial for repowering applications. A series of documents will provide information on primary siting and redevelopment criteria for PV, CSP, bulk energy storage, and low-carbon fuels to support decarbonization efforts.

This paper provides a high-level overview of the process of determining whether a coal-fired power plant slated for decommissioning is suitable for repowering for bulk energy storage, vis-a-vis alternatives such as a PV plant, low-carbon power generator, or other options listed above. The paper covers the key issues to consider when performing this evaluation, including the following (see Figure 1):

- Identify existing infrastructure, including grid interconnection and transportation access that may be available
- Assess physical site characteristics, including available land, and other attributes to determine suitability for this repowering option
- Consider potential reuse of structures and equipment
- Review opportunities to renew or modify existing permits applicable to bulk energy storage
- Consider water availability and the capacity of stormwater management systems for this application

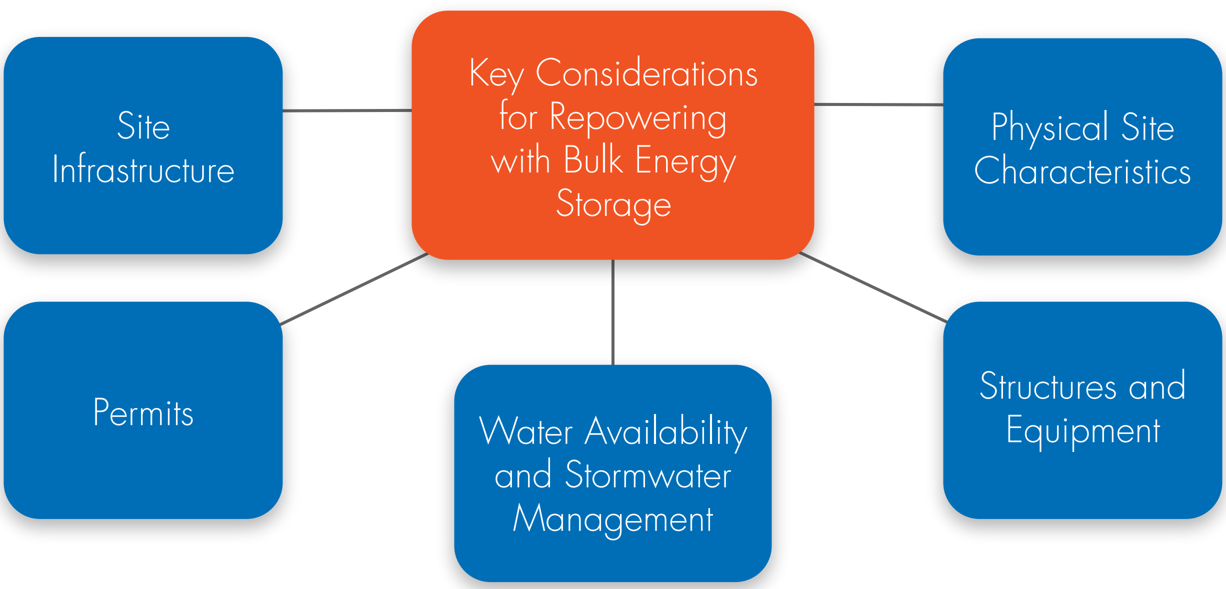

Figure 1. Key issues when evaluating coal plant sites for repowering with bulk energy storage

Countries such as Chile and Germany are seriously considering or actively working on converting existing coal plants to thermal bulk energy storage systems, as this conversion could enable the reuse of existing plant assets and human assets [6,7,8].

Selection of Bulk Energy Storage Technology

Bulk energy storage is a key enabler for a low-carbon future. As more variable renewable energy (VRE) in the form of solar and wind are installed and fossil power is displaced, substantial energy storage will be needed to provide grid stability and reliability. Energy storage can shift energy in time, storing excess energy when available, and then provide it later when needed. Energy storage can also provide critical ancillary services, such as inertia, spinning reserve capacity, and frequency response. As VRE continues to grow, the specifications for energy storage are changing, requiring larger energy storage plants that provide longer durations of storage [9].

Several types of bulk energy storage technologies can in principle be employed to provide energy for electricity generation at these sites. Some types of bulk storage technology can also provide natural system inertia in the same way as the original plant, with a rotating mass providing fast frequency response through synchronous power generation. This helps prevent sudden changes in system frequency. System inertia is increasingly important as a growing portion of electric generation does not support system frequency (for example, DC-connected resources such as solar PV and wind). Ideally, the storage medium at the repowered plant can be charged using zero-carbon renewable energy resources, such as night-time and off-peak energy from wind and partial-peak energy from solar PV.

A detailed examination and comparison of these bulk energy storage technologies is addressed elsewhere in papers and reports from EPRI [10] and other organizations [11,12]. However, an overview of the bulk energy storage technologies most applicable to use in a coal plant repowering scenario and key considerations of these technologies in this scenario are useful. Bulk energy storage technologies can be categorized in the following four groups:

- **Electrochemical energy storage** (that is, battery storage) is addressed in a separate EPRI white paper in this series.
- **Thermochemical energy storage** includes hydrogen or ammonia production and is also addressed in a separate white paper in this series.
- **Mechanical energy storage** includes compressed air energy storage, pumped storage hydro, and liquid air energy storage.
- **Thermal energy storage** includes electrothermal energy storage, concrete thermal energy storage, and molten-salt thermal energy storage.

Some of these bulk storage technologies enable reuse of existing on-site turbomachinery (such as steam turbines and generators); others require new turbomachinery.

Mechanical Energy Storage Alternatives

With regard to mechanical energy storage, the primary application of commercially available compressed air energy storage (CAES) is air storage in underground natural caverns. This means that the existing coal plant to be repowered must be located above (or near) such an underground storage medium. Due to this geographic limitation, CAES is not a widespread viable application for coal repowering. For similar reasons of geographic limitation, as well as very long lead times (e.g., 10 years) for development, pumped storage hydro is also not a viable application for coal repowering at plants retiring in the next few years. It can be a viable option for plants with retirement dates 10 years or more in the future.

To avoid the need for underground caverns and the associated geographical limitations, liquid air energy storage (LAES) compresses air (see Figure 2) before cooling it to a cryogenic liquid state (around -320°F [-196°C]) for aboveground storage at low pressure. When power is needed, the liquid air is heated to its boiling point and expanded through a turbine generator. This technology is not yet commercially available, the largest demonstration to date being a 15-MWh system [13]. Another challenge is thermal management of its cryogenic process. LAES requires its own turbomachinery, limiting reuse of coal plant on-site equipment. However, this technology is nearing commercial viability, “the compression equipment and power generators come from established supply chains in mature industries” [11], and Highview Power is constructing a 50-MW, 250-MWh LAES plant in Carrington Village, Greater Manchester, United Kingdom [14].

Figure 2. Liquid air energy storage (Source: Highview Power. Used by permission.)

Another company, Energy Dome, offers a technology that seeks to eliminate the limitations or complexities of two systems that compress air—the geographical constraints of CAES, and the cryogenic challenges of LAES—by substituting carbon dioxide (CO_2) as the working fluid. Drawing CO_2 from a large gasholder (the dome) at atmospheric pressure, the system pressurizes the CO_2 and stores it as a high-density liquid at ambient temperature. This eliminates the cryogenic complexities of LAES and increases storage density by a factor of 10–20 compared to CAES. The company recently began operation of a 2.5-MW/4-MWh facility in Sardinia, Italy, and plans a 20-MW/100-MWh project. [15]

Thermal Energy Storage Alternatives

With regard to thermal energy storage (TES), electro-thermal energy storage uses a supercritical carbon dioxide (sCO_2) heat pump cycle for charging, and a closed sCO_2 cycle for generation. This technology remains in a laboratory stage of development, without demonstration at scale of its turbomachinery, and a largest pilot size of 100 kWh. Hence, it is not a current viable technology for coal repowering.

In a concrete thermal energy storage system (see Figure 3), in charging mode, resistive electrical elements heat concrete using a heat transfer fluid. To discharge the system, air is blown through channels in the concrete to extract heat. The hot air is then used to generate steam in a heat exchanger to drive a steam turbine generator. Hence, this technology is able to re-use on-site existing turbomachinery. This technology is also not currently commercially available, but its promising combination of a small plant footprint, provision of synchronous power (system inertia), relatively low fire risk, and low-cost storage material makes it a viable option in the future. At about $65 per ton, concrete is less than 10% of the cost of molten salts currently used for thermal storage.

EPRI and storage developer Storworks Power are examining a technology that uses concrete to store energy generated by thermal power plants. Recent laboratory tests validated a Storworks Power design, setting the stage for a 10-MWh pilot-scale demonstration at an operating Alabama Power coal-fired power plant [16]. While concrete production is extremely carbon intensive, some concrete production strategies can reduce (by capture) or eliminate (by changing chemistry) CO_2 emissions, reducing carbon emissions associated with initial plant installation.

Figure 3. Concrete for a concrete energy storage plant (Source: Storworks. Used by permission.)

Molten-salt TES (MSTES) currently provides the most promising combination of commercial availability, demonstration at large scale, ability to provide synchronous power, and reuse of coal plant existing turbomachinery (see Figure 4). In an MSTES system, molten salt is heated and stored during off-peak hours. When energy is needed, the molten salt is circulated through a heat exchanger that produces steam to drive a steam generator. This technology has been demonstrated at large scale (hundreds of MWh), in the concentrating solar power (CSP) industry. Nonflammable and nontoxic, the molten salt has thermophysical properties that make it suitable as both a heat transport fluid and a storage medium, including high density, acceptable thermal conductivities and specific heats, low viscosity vapor pressure, and corrosion rate [17].

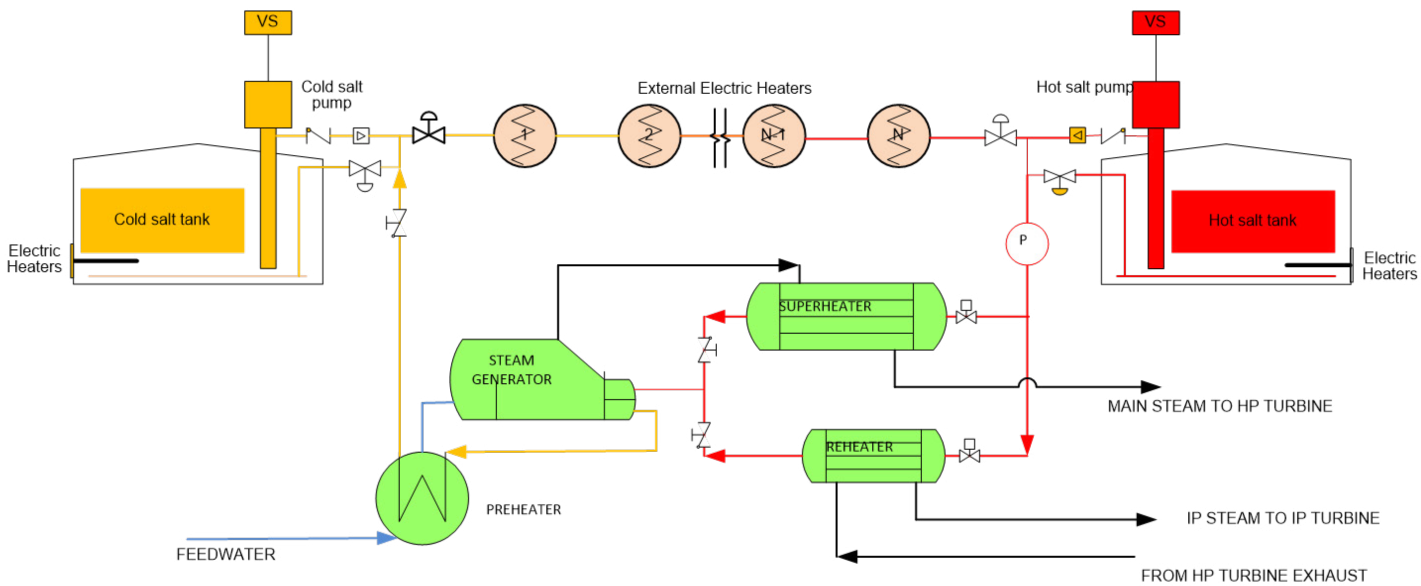

Figure 4. A molten-salt steam generation system [17]

A recent EPRI study evaluated the feasibility of retrofitting an MSTES system to generate the steam conditions required to operate a steam turbine at an existing subcritical coal-fired power station while leveraging the existing infrastructure at the plant [17]. The study provided the design basis for the molten-salt system, including the molten-salt storage tanks, electric resistance heaters, salt pumps, associated piping and auxiliaries, and steam generation equipment. Key findings of this study include the following:

- MSTES systems are commercially available technology, deployed in CSP and the chemical process industry for many years and can be applied to a steam generating unit.
- Sodium/potassium nitrate salt (the raw materials for the molten-salt thermal storage medium) is commercially available with documented thermal properties and can be used to generate steam at subcritical conditions to generate power.
- All major components for the molten-salt system are commercially available and can be integrated into a viable TES system and erected for immediate deployment.
- Detailed cost estimates for retrofitting existing coal plants with an MSTES system were developed based on recent experience from CSP plants using molten salt for economic evaluation.
- The proposed concept offers a large-scale energy storage system and provides a large dispatchable, synchronous power source for grid stability.
- The electrical resistance heaters and the molten-salt storage tanks are modular equipment and can be replicated for steam turbines in the 25- to 600-MWe range.

Based on these findings, MSTES is the baseline bulk energy storage technology used in this paper. Where appropriate, the paper also indicates considerations that apply to other relevant emerging bulk storage technologies. These include concrete TES and liquid air energy storage for the reasons described above.

Site Infrastructure

One of the benefits of repowering a coal-fired power plant site with bulk storage is the opportunity to reduce costs by reusing existing site infrastructure. In general, evaluating the site infrastructure for suitability includes a complete inventory and analysis that includes age, condition, value, suitability for supporting generation and bulk storage, and estimated costs to adapt it for incorporating the bulk storage system. The evaluation should also consider demolition and/or removal costs for infrastructure elements that will not be used. This section describes infrastructure reusability issues that are specifically relevant for incorporation of bulk storage.

Grid Interconnection

Coal plants have existing high-voltage power connection infrastructure, interconnection studies, and a site-permitting evaluation in place, as well as established land use rights and offtaker (especially electrical) to facilitate the repowered plant's grid interconnection. Using the existing structures and connection avoids the cost of installing new hardware and saves time to secure the necessary authorizations from the authorities having jurisdiction. The available carrying capacity of transmission and distribution (T&D) lines near the site can impact overall costs. For example, the round-trip efficiency (RTE)[1] of an MSTES system is 35–42%, depending on the Rankine cycle efficiency of the steam turbine [10]. For example, the MSTES EPRI evaluated has an RTE of 41.7%. This means that about 2.5 times as much input energy as output energy is needed. As a result, the local T&D system may need approximately 2.5 times the capacity of the

Utility Grid Connection Process for Repowered Generation and Storage: MSTES Example

The EPRI study of repowering an existing coal plant with an MSTES system identified the steps for a grid connection analysis. In this scenario, since the existing power station's turbine generator is already connected to the high-voltage grid, no further analysis is required for the generator interconnection. The electrical load for the electric resistance heater charging system will be new, potentially requiring a new substation with multiple step-down transformers to support the resistance heating load. The local grid operator will set the technical requirements for voltage, current, power factors, and required electrical protection systems. The transmission grid operator will determine specific system protection requirements to be incorporated into the design to accommodate the reverse power flow into the plant. The grid connection analysis will be a joint effort between the grid operator and the plant. The following is the high-level summary of some of the items that will need to be analyzed by the design engineer [17]:

- System Planning
  - Short-circuit study
  - Load flow study
  - Insulation coordination study
- Electrical – substation design calculations
  - Protection and control analysis
  - DC system – for system protection calculations
  - AC system – auxiliary power transformer calculations
  - Ground grid study
  - Lightning protection calculations
  - Voltage drop calculations
    Conduit fill calculations
  - Physical separation for corona discharge and arc prevention

In addition, the following analyses are required before these systems can be connected to the grid:

- Transformer noise calculations
- Harmonic analysis
- Fire protection study

1. Round-trip efficiency (RTE) is the net energy produced (when discharging) divided by the total energy input (when charging). For example, for the MSTES that EPRI evaluated, RTE is the net daily energy that the steam turbine cycle delivers to the high side of the main transformer (after subtracting house load) divided by the total daily energy input (for example, power to the electric resistance heaters to charge the TES system, plus energy consumed by auxiliary equipment).

repowered plant if charging time periods are to be similar to discharging periods. Hence, existing T&D equipment and utility lines may need to be upgraded to accommodate this increased power demand. Interconnection studies will be required to determine any changes needed to the existing interconnection and the cost and timeline for upgrades. The sidebar lists key steps to plan and implement changes to the utility grid connection.

Closely related to grid connection is consideration of the current (and likely future) local generation mix. In an optimal decarbonization scenario, renewable energy would primarily (or completely) supply energy to charge the bulk energy storage system during off-peak and partial-peak hours. This requires an assessment of the amount of local renewable resources that can provide this charging, its forecasted future levels, and the ability of the local T&D system to support import of this energy to the repowered plant as needed. If the renewable energy generation is part of the coal plant repowering strategy, the connection to the bulk energy system could be incorporated into the design for both assets. Colocation of the renewable energy generation may be advantageous to reduce or avoid grid connection upgrades.

Capacity Factor Considerations

The repowered plant's capacity factor (CF) may be significantly different from the existing plant's CF. The average capacity factor of existing U.S. coal plants was 49% in 2021 (down from 67% in 2010) [18]. Figure 5 shows for the MSTES system evaluated by EPRI the charging cycle, plant output, and thermal energy in storage on an hourly basis over a representative 24-

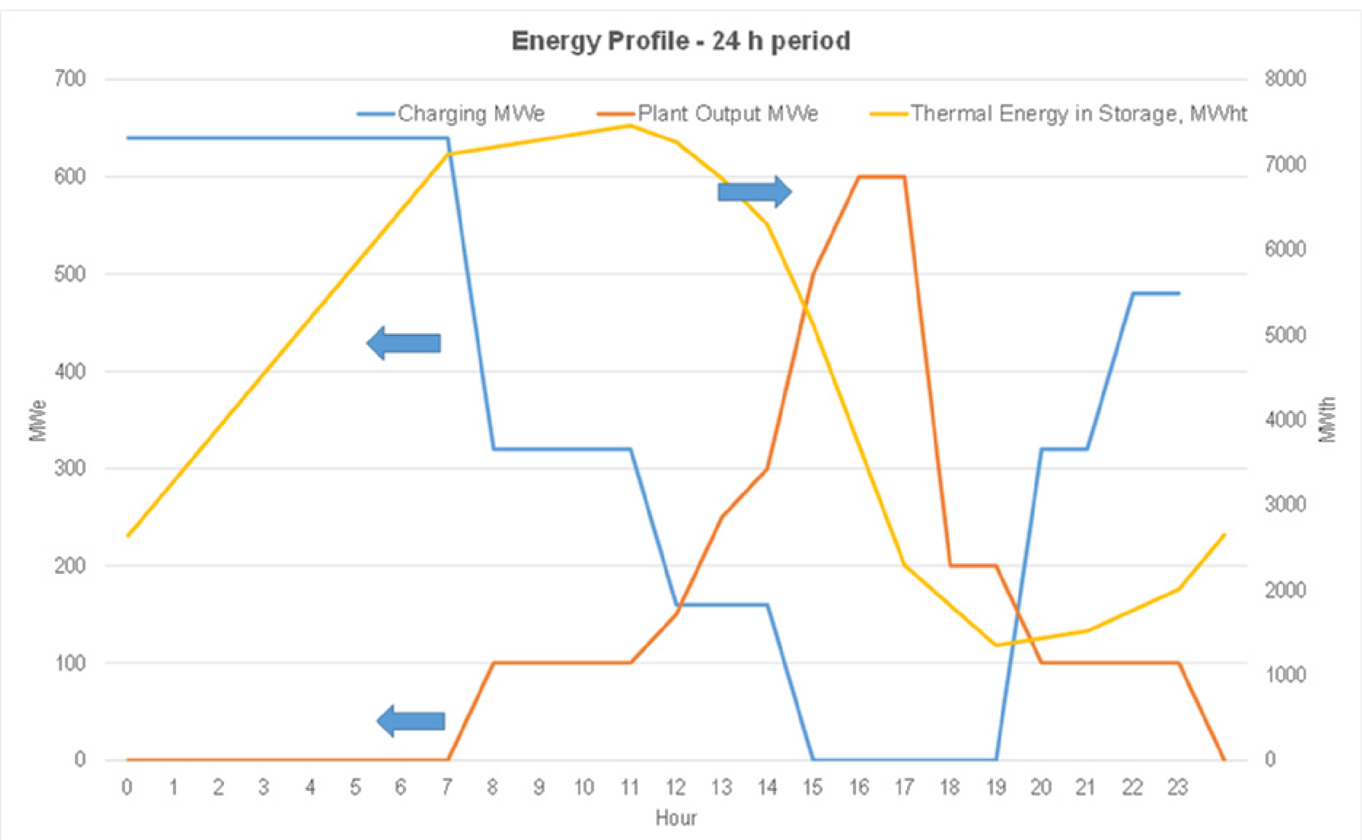

Figure 5. Plant load profile for an MSTES plant (minimum turbine operation at 100 MWe) [17]

hour period. This plot shows that charging occurs primarily from midnight to 8 a.m., the thermal energy in storage is gradually discharged from noon to 7 p.m., and plant output peaks from about 2 to 6 p.m. Overall, the team estimated a CF of 16.7–25%.[2] Design of a new bulk energy storage facility on a coal plant site where an existing grid interconnection to T&D lines is to be used must account for such differences in capacity factor.

Transportation Access and Utilities

Transportation requirements encompass the construction period and the operating life.

- **Plant Construction.** A key aspect of repowering a coal plant is minimizing the length of the downtime between coal plant operation and repowered plant operation. This is advantageous because the grid currently relies on the coal plant capacity being available. When this capacity is eliminated, alternative sources of power are needed, placing strain on the grid. One way to minimize downtime is to construct parts of the repowered plant components off-site prior to coal plant decommissioning, to minimize the on-site construction period. One byproduct of this approach is a need for roadway and/or railway access to the site that can accommodate the series of larger prebuilt components. Assessments should include whether existing roadways and/or railway access at the site is sufficient or if additional transportation infrastructure is required.
- **Plant Operation.** During plant operation, the molten salt should require minimal replenishment so long as the salt id not heated beyond 1050°F (565°C) or leaks occur. However, transportation access will be required through the plant lifetime to perform maintenance on heaters, tanks, and other components and to provide access to transport damaged and replacement equipment.
- **Utilities.** Existing utilities, such as water, gas, and sewer, may be useful during repowered plant construction and operation. Availability of these utilities may avoid or minimize the need to truck in water, portable generators, and restrooms.

Physical Site Characteristics

This section summarizes the physical coal-fired power plant site characteristics that may be beneficial for development of generation with bulk energy storage.

Land Area

The following site characteristics are desirable for a generation site repowered with bulk energy storage:

- The site is spacious. Adequate space to construct and implement the bulk storage plant alongside the existing operating coal plant (close enough to facilitate straightforward connection to the existing turbomachinery) is advantageous. Even if off-site prefabrication and testing approaches can be used, siting the bulk storage plant before dismantling any existing site equipment requires significant land area.
- The land does not require significant regrading to level surfaces (e.g., terracing of the site to maintain sheet flow conditions).

2. In the EPRI MSTES study, the team assumed a CF of 16.7% of maximum continuous rating (equivalent to 4 hours of operation out of 24 hours) for minimum steam turbine operation at 100 MWe, and a CF of 25% of MCR (equivalent to 6 hours of operation out of 24 hours) for minimum steam turbine operation at 150 MWe.

Available land area is a significant site consideration for incorporation of bulk energy storage. As a reference point, a 2022 EPRI report that examined coal plant repowering options for ESKOM in South Africa listed approximate energy density figures for various bulk storage technologies (see Table 1).

Table 1. Approximate energy density of selected bulk energy storage technologies [19]

Bulk Energy Storage Technology	Approximate Energy Density (MWh/acre)
MSTES	400-800
Concrete thermal energy storage	800-1000
Liquid air energy storage	200-300
Lithium-ion battery storage	100-300

Using the metric for MSTES, the system that EPRI evaluated (with a thermal storage capacity of 7720 MWHth [20]) would require about 10–20 acres. Additional acreage will be required for construction laydown and parking.

A 2013 study by the National Renewable Energy Laboratory and EPRI estimated total land available at U.S. pulverized coal plants, including adjacent land within a 2-mi (3-km) radius. The potential land area ranges from around 400 acres (1.62 km^2) to nearly 7000 acres (28.3 km^2), with an average of about 3900 acres (15.8 km^2) [21], which provides a very large area for development of bulk energy storage.

Closed CCR Management Units

Depending on the particular implementation of a bulk energy storage facility, some elements of the installation may call for a significant foundation, including a piling system. In that case, such systems would be incompatible with siting on a coal combustion residual (CCR) landfill. It may be possible to use the landfill for construction parking and light laydown; however, certain types of construction and maintenance vehicles are restricted on landfills, due to weight.

To the extent that any part of the project will be sited on CCR landfill, the design of the installation must be compatible with the cap to ensure the cap's integrity, including attention to the load of the hydrogen production facility. The design must minimize disturbance of the landfill cap. Vehicle restrictions on landfills may also affect operation and maintenance (O&M) practices.

Another consideration is the geometry of the closure cap. Landfills with minimal grades are more suitable for repowering applications. Benches added to slopes for stormwater control or stability may reduce the area available for the new plant. Caps with benches must be evaluated to determine whether sufficient space is available. Caps with soil surfaces are subject to erosion and sedimentation, and drainage controls may be required.

Structures and Equipment

Overview

According to a 2020 study conducted in Poland, reusing physical plant infrastructure, such as auxiliary buildings, electrical equipment, turbogenerators, cooling water systems, cooling towers, and pumphouses, can help a utility continue to use up to an estimated 40% of their initial investment [22]. Depending on the type of bulk energy system installed, a varying amount of equipment reuse is feasible. For example, an MSTES system designed to reuse the existing coal plant turbomachinery leverages much more existing equipment than a prepackaged system.

Structures

Reusing existing structures can speed construction, decrease costs, and reduce environmental impacts. Depending on the plant size and location, some combination of permanent on-site and remote staff supports operations and maintenance. Plant operators, site technicians, and other maintenance staff could likely use one or more existing administrative buildings and/or trailers. Plant staff can also use communications systems, such as phone and internet access. Warehouses or other buildings on coal-fired power plant sites could be used to store plant spare parts and other replacement components and materials, house maintenance vehicles, and store tools. Reutilizing these spaces with new functions defers the cost of demolition and avoids the need to construct new buildings. Existing fences can continue to deter trespassing, vandalism, and unwelcome wildlife.

Equipment

Depending on the type of bulk power system implemented, existing turbomachinery (which constitutes a large percentage of the total plant cost) may or may not be reused. For example, some thermal energy storage vendors, such as Malta Inc. and EchoGen Power Systems, offer systems that already incorporate specialized turbomachinery; however, these and other vendors also offer alternatives that can operate with existing turbomachinery [23,24]. The MSTES study that EPRI performed assumed a system that could reuse coal site turbomachinery. For most if not all types of bulk storage, existing electrical equipment and interconnections can be used, perhaps with modifications or upgrades (see "Site Infrastructure" section).

Bulk storage systems constructed at a coal-fired facility could likely reuse existing site substations as part of the grid interconnection. The size and configuration of the substation may require modifications, but modifying an existing substation may be more cost-effective and reduce construction schedules compared to building a new substation, with transformers having very long lead times. If the original design of the substation was conservative, then additional capacity could be increased with minimal additions such as radiators and fans if loading history is available (depending on whether the unit is oil-insulated/fan-cooled or self-cooled). Substation expansion could be considered on the primary or secondary side, depending on the planned expansion to a different voltage level.

The design engineer will need to conduct the following civil/structural substation-related analyses and calculations:

- Land survey and site-grading analysis
- Geotechnical investigation and foundation calculations
- Structural steel calculations
- Bus bar physical separation calculations
- Miscellaneous – substation design calculations

The existing plant digital control system (DCS) is likely to require replacement. This legacy equipment is unlikely to be adequate, given the extended life of the existing plant. One design decision is whether or not to replace the DCS for the existing steam turbine system, if it is reused.

Water Availability and Stormwater Management

Coal-fired power plants consume a significant amount of water. Hence, existing process and cooling water equipment and systems on-site may be adequate to support the addition of the bulk energy storage system, depending on the type of system specified. Cooling water requirements will be very similar with TES to what they were before; however, with the lower anticipated capacity factors for discharge, the total annual water consumption will be less for TES than for coal. Similarly, existing sites have stormwater management plans and include equipment and features for stormwater control if needed. However, a careful assessment of the impacts of bulk storage addition on both of these is needed.

Permits

A major benefit of siting bulk storage at a coal-fired power plant planned for closure is the possibility of renewing or modifying existing permits instead of applying for completely new permits, which can help eliminate lengthy and possibly expensive permitting processes. Larger facilities that already have a land use permit, certificate of occupancy, and buffer property offer siting advantages that can allow the new storage system to be constructed and commissioned relatively quickly.

Construction and operation permits depend on national, state, and local requirements, and codes and standards that vary by site, host, owner, utility, and contract. Bulk storage requires construction permits due to indirect emissions that heavy equipment produces during construction activities. However, federal and state operating permits are not required because no direct air emissions are produced during operation. (Exceptions to this include emissions from a small generator for black-start capability of most plants that incorporate bulk storage, and provision for unplanned release of stored CO_2 in an energy dome plant, for example.)

Installation of a bulk storage system adds additional complexities for plant decommissioning and solid waste disposal at the plant's end of life. At that time, concrete will be recyclable, and molten salt may have an alternate use that will aid decommissioning, as this material does not degrade during normal operation. The molten salt could therefore be sold as a commodity for a future TES application at another site.

Other types of applicable permits that may already exist at a coal-fired power plant include the following:

- Transmission infrastructure and interconnection permits
- Transportation infrastructure and utility connection permits
- Environmental permits, including noise
- Daily water withdrawal and discharge allowance permits

Permit categories for the bulk storage system may include the following:

- Stakeholder and community approval
- Land use approval
- Temporary use permit
- Stormwater and groundwater discharge permits for construction and industrial activities

- Notice of construction or alteration
- Exempt wholesale generator
- Endangered species review
- National Environmental Policy Act (NEPA) review
- Water appropriation
- Easement, lease, or right-of-way
- Siting permit, including visual impact of tall and/or large structures
- Construction of plant or transmission lines
- Worker safety protection system approval
- Air emissions
- Hazardous waste
- Water quality
- Access or driveway permit (construction entrance)
- Crossing permit (transmission)
- Oversize loads permit
- Archeological and historical
- Building permits
- Certificate of occupancy
- Potable water extension/connection
- Wastewater pretreatment permit/sewer connection
- Potable well permit

For development on a capped landfill, additional factors may influence permitting requirements, including the following:

- Methane gas emission limits (for general landfills)
- Piling/ballasting compatible with site requirements
- Grounding interference from nearby utilities
- Geotechnical considerations
- Corrosivity to subsurface cables, steel, and concrete
- Water management (stormwater control, treatment)
- Potential soil and groundwater contamination
- Viable vegetation types
- Cap (impact)
- Soil penetrations
- Vegetation height and root depth
- Erosion control
- Mowing requirements
- Site maintenance activities

Conclusion

This paper covers bulk energy storage in a planned EPRI white paper series on considerations when repowering a coal plant planned for decommissioning with an alternative type of low- or zero-carbon power generation or energy storage technology. While repowering to bulk energy storage is complex and requires careful planning, it presents significant opportunities to leverage existing site infrastructure, equipment, permits, and other attributes. It also provides a means to reduce environmental impacts and improve community perceptions, while supporting the transition to clean energy.

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CONTACT INFORMATION

For more information, contact Lea Millet, P.G., Senior Technical Leader, lmillet@epri.com

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com