Apex Compressed Air Energy Storage, LLC

<table>
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<th>Technology Type:</th>
<th>Mechanical</th>
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<td>Storage Resource:</td>
<td>Compressed Air</td>
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<tr>
<td>EPRI Participation:</td>
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**Development Status:** Active
- **Current TRL:** 7
- **Last Updated:** 10/10/2018

**Introduction**

Texas-based Apex Compressed Air Energy Storage, LLC (Apex CAES) is developing a CAES demonstration at the 320-MW Bethel Energy Center (BEC) near Palestine, TX, for operation in the Electric Reliability Council of Texas (ERCOT) market. The BEC will feature a single, independently operable compressor train and two 162-MW expander trains, with compressed air storage in a solution-mined salt cavern sized for 48 hours of full-load output, (over 15,000 MWh of discharge capacity) [1, 2]. The project was originally developed in the early 2010s, and underwent a major redesign in 2016–17, evolving from chiefly Dresser-Rand process equipment to a combination of Siemens and Dresser-Rand equipment. Dresser-Rand is now a Siemens company as of 2014.

The Apex CAES BEC design features a larger and deeper cavern than the only existing CAES facility in the US, that at Power South’s McIntosh plant in Alabama, allowing a higher maximum operating pressure and a wider operating pressure range. Maximum pressure at the well casing shoe (effectively the entrance to the cavern) for a salt-based storage cavern is typically limited by regulatory authorities to 0.85 times the casing shoe (drilling) depth in feet. The casing shoe depth for the Apex CAES BEC cavern will be set at 3750 feet (1140 meters), resulting in a maximum casing shoe pressure of 3188 psia (220 bara), corresponding to a wellhead pressure of 2830 psia (195 bara). This higher wellhead pressure supports inclusion of a third stage of expansion. The cavern design (volume of storage, casing shoe depth, well bore size, etc.) was selected to produce the optimum economic return against ERCOT market parameters, with consideration to the performance characteristics of the Siemens/Dresser-Rand process equipment.

Apex CAES has updated its front-end engineering design for the BEC project. It has an interconnection agreement in place and has received appropriate permits. As of mid-2018, the Apex CAES team was finalizing an agreement with an engineering, procurement, and construction contractor and is working to achieve financial closure. Haddington Ventures and Siemens are investors. With a timely construction start, Apex CAES expects the BEC to be on line by 2022. The BEC project will help balance the high levels of intermittent renewables, especially wind, on the ERCOT grid and also provide reserve capacity and ancillary services. Figure 1 shows a rendering of the BEC operations.

**Process Description**

The BEC project draws upon the nearly 30-year operating history of the Power South McIntosh CAES plant in Alabama, which uses Dresser-Rand compression and expansion equipment. The design features elements from Dresser-Rand’s current SMARTCAES® system, which expands CAES capabilities through independently operable expansion and compressor trains. The design includes seven stages of compression with a maximum discharge pressure of 2830 psia (195 bara), and a design flow rate of 428 lb/sec (194 kg/sec). Following each stage of compression, the air is cooled via a circulating water system, shell-and-tube heat exchanger, and a cooling tower. The compressor motor is started using a variable-frequency device, enabling the unit to go from cold start to full compressor power in five minutes. Nominal
Compressor power consumption is 128 MW. Compressor flow rate and power consumption can be modulated by variable inlet guide vanes, with an allowable turndown capability of 30%. Additionally, the compressor can be automatically tripped by an under-frequency relay, allowing the compressor to provide spinning reserves.

Figure 1 – Artist rendering of Apex CAES Bethel Energy Center operation

The Apex CAES BEC design employs three stages of expansion. The very high-pressure (VHP) and high-pressure (HP) stages of expansion are housed in a single body Siemens SST-800BH50 expander. When generating power, high-pressure air from the cavern flows through a recuperator, allowing recovered energy from expander exhaust gases to preheat the incoming air. Additional thermal input is produced by supplemental firing of natural gas in the recuperator, resulting in a gas temperature of 1000°F (537°C) entering the VHP expander, at a pressure of approximately 2025 psia (140 bara). Following the first stage of expansion, exhaust gases are routed through the recuperator for a second pass, where “duct” firing of natural gas reheats the air to 1000°F (537°C) for entry to the HP expander, at a pressure of approximately 690 psia (48 bara). Exhaust gases exit the HP expander flow to the low-pressure (LP) expander combustors at a pressure of approximately 345 psia (24 bara). The LP expander is a derivative of Siemens’ SGT-800 gas turbine (absent the compressor section). Additional natural gas firing produces an LP turbine inlet temperature of approximately 2240°F (1230°C). Approximately two-thirds of the expander train power output is produced by the LP expander. Exhaust gas exiting the LP expander flows through a selective catalytic reduction (SCR) section for control of NOx emissions and unburned hydrocarbons. Exhaust gases exiting the SCR section flow through the recuperator and are vented to the atmosphere through the stack at a temperature of approximately 195°F (90°C).
Minimum expander load is 10% of rated output (efforts are under way to extend this operating range lower), and ramp rate is 20% of rated capacity per minute. The expander heat rate curve is relatively flat as output is reduced to the minimum, allowing cost-effective provision of ancillary services and ramping capability. The project will have black-start capability.

The BEC storage cavern will be created by conventional solution-mining methods, where low salinity water is pumped into the target cavern region, thereby dissolving the salt before being extracted. The produced brine is then injected into a deep saline formation. The BEC salt dome is home to five natural gas storage caverns, and construction of the CAES cavern will take advantage of existing freshwater and brine injection wells used during construction of the natural gas storage caverns. The volumetric capacity of the CAES cavern will be approximately 3.5 million bbl, with a depth of ~5000 feet (~1525 meters), a “neck” of ~250 feet (~75 meters), a top of cavern of ~4000 feet (~1220 meters), and a radius of ~75 feet (~23 meters).

**Figure 3** shows a schematic of the CAES cycle being used at the BEC and **Figure 4** shows the configurations for the expander and compressor trains. Overall, Apex CAES expects that the system will operate in charging (compression) mode roughly 12–14 hours per day and in power production (expansion) mode about 8–10 hours per day, depending on hourly market prices. During charging mode operation, Apex CAES expects that it will still run the generator at minimum load, about 7 MW, to provide ancillary services to the grid [4].
Figure 3 – CAES cycle schematic for the Bethel Energy Center

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Figure 4 – Configuration of the expander train (top) and the compressor train (bottom) for the Apex CAES Bethel Energy Center
Technology Status

Commercial, utility-scale CAES technology has been in operation for nearly 30 years at the Power South McIntosh plant in Alabama and for nearly 40 years at the Huntorf plant in Germany. Both plants have demonstrated high reliability and the technical viability of the CAES technology to supply ancillary services, load following, and intermediate power generation. Siemens, the equipment supplier for the BEC project can leverage the operational experience from the McIntosh facility following the acquisition of Dresser Rand in 2014.

In addition to the BEC project, Apex CAES has conducted feasibility studies for CAES projects in the territory of the Southwest Power Pool using layered salt beds for compressed air storage rather than salt dome structures. Other developers have studied air storage in shale-sealed sand formations, akin to hydrocarbon-producing reservoirs or the saline formations being considered for CO2 sequestration. However, no utility-scale CAES projects have been developed to date in such geologic formations. Apex CAES believes that subsurface geologic considerations are fundamental to project site selection.

Benefits and Costs

Apex CAES estimates the capital cost of a commercial system be $1300–$1400/kW. The effective heat rate for the natural-gas heated expansion train is 4278 Btu/kWh (4513 kJ/kWh) HHV at full load. In terms of electrical energy in and out, Apex CAES expects that 0.6 MW of compression will yield 1.0 MW of output, noting that this is possible due to the boost from natural gas heating. An economic analysis by Apex CAES suggests a total variable cost of energy of $20/MWh, net of an assumed credit for supplying spinning reserve [4]. In the ERCOT market, which often has low energy prices, the ability to garner ancillary services income is key to overall energy storage project economics [6].

Apex CAES expects that the costs for compressor maintenance will be like costs for maintaining compressors in gas pipeline service or in refinery catalytic cracking operations. It expects staffing requirements will be similar to a simple cycle gas turbine power plant, but because the capacity factor of a CAES plant is by definition less than a gas turbine plant due to charging time, costs on an exported $/MWh basis will be higher. In addition, Apex CAES expects that the cost of major maintenance for its turbine train will be lower because the imposed thermal stresses are less than those in a gas turbine, which faces greater challenges managing the air flow-to-power relationship during lower load and ramping situations, resulting in thermal stresses.

CAES projects have relatively small surface footprints, about 22 acres (9 hectares) for the 320 MW BEC (see Figure 5) [2].
Barriers and Challenges

The equipment being used for this technology is mature on an individual unit perspective. Given the high storage pressure selected for Bethel Energy Center design, the addition of a 3rd expansion stage (the CHP expander) introduces a minor technical challenge. The compressed air storage strategy is also a mature technology, both in terms of creating the cavern and for the long-term management of the cavern resource due to natural gas storage projects. The main challenge is therefore the cost of the equipment and the potential revenue streams that can be generated from a given market.

In the ERCOT market, Apex CAES sees its primary competition as natural gas reciprocating engines, rather than simple-cycle combustion turbines or battery plants [2]. Engine plants in the 200-MWe range, made up of nominally 10 or 20-MWe class units, are operating commercially in Texas, and target similar load balancing and ancillary services markets as Apex CAES. However, engine and gas turbine plants cannot perform energy arbitrage and take advantage of low (or negative) off-peak energy prices in the manner that CAES (or batteries) can as they cannot absorb excess electrical energy.

To date, energy storage installations in ERCOT have been battery based, focusing on supplying “Fast-Regulation” services and not engaging in energy price arbitrage, which would entail at least a full depth of discharge cycle, degrading the operating life of the battery storage modules. CAES can contribute to this type of application as full depth of discharge cycling does not degrade the storage media.
References


