

# Mini-Compressed Air Energy Storage for Transmission Congestion Relief and Wind Shaping Applications<sup>1</sup>

(Prepared for New York State Energy Research and Development Authority)

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## Introduction

Compressed air energy storage (CAES) is a cost-effective technology for bulk storage applications at utility scale. In a CAES plant electrical energy is stored in the form of high-pressure air. A compressor driven by an electric motor/generator compresses air with off-peak power, and stores it in a suitable underground geologic structure such as a salt cavern. When the CAES plant generates power, the compressed air is released from the cavern, heated in a recuperator before mixing and combusting with fuel, and expanded through a turbine to generate electricity.

This project will investigate the feasibility of adapting a high-pressure natural gas storage technology based on manifolded pressure vessels for storing compressed air, and combining it with small-scale, low-cost CAES energy conversion equipment, to provide a geologically independent energy storage option for locations throughout New York State. This ~12MW “mini-CAES” concept could be suitably sited to enhance the value of unpredictable renewable energy sources such as wind power generation.

The system design is optimized around general capabilities so that a package can be assembled from existing components with minimal adaptation. Since the unit is relatively small, for CAES, our plan is to develop a package that has flexible design characteristics that could be applied in various locations without customizing each package.

## How CAES Works

A CAES plant stores electrical energy in the form of air pressure, then recovers this energy as an input for future power generation. Essentially, the CAES cycle is a variation of a standard gas turbine generation cycle. In the typical simple cycle gas fired generation cycle, the turbine is physically connected to an air compressor. Therefore, when gas is combusted in the turbine, approximately two-thirds of the turbine’s energy goes back into air compression. With a CAES plant, the compression cycle is separated from the combustion and generation cycle. Off-peak or excess electricity is used to “pre-compress” air, which is held for storage in an underground cavern, typically a salt cavern. When the CAES plant regenerates the power, the compressed air is released from the cavern and heated through a recuperator before being mixed with fuel (natural gas) and expanded through a turbine to generate electricity. Because the turbine’s output no longer needs to be used to drive an air compressor, the turbine can generate almost three times as much electricity as the same size turbine in a simple cycle configuration, using far less fuel per MWh produced. The stored compressed air takes the place of gas that would otherwise have been burned in the generation cycle and used for compression power. Figure 1 – “How CAES Works” illustrates this system.

The volume of air storage required for a typical CAES plant is most economically provided by geological structures. Salt caverns, aquifers, depleted oil and gas reservoirs and rock mines have all been considered as possibilities for air storage in a CAES application. However this study considered the viability of “mini-CAES” facilities, which require a much more limited amount of storage than CAES plants of traditional scale. In addition, if the concept is to be viable it needs to be flexible in its siting.

For these reasons our design eschewed geological storage and used a form of compressed air storage designed by EnerSea Transport LLC: VOLANDS™ Gas Storage. This method utilizes banks of high strength steel

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<sup>1</sup> This project is part of the Joint Energy Storage Initiative between the New York State Energy Research and Development Authority (NYSERDA) and the Energy Storage Systems Program of the U.S. Department of Energy (DOE/ESS), and managed by Sandia National Laboratories (SNL).

pipng in vertical configurations to achieve the desired result. Although the storage units would be in a 10-12 story building if built at ground level, they would most likely be placed in an excavation, resulting in a 4-6 story building. This provides flexible storage quantities at a constant pressure and temperature without the conventional geological constraints. Figure 2 – “VOLANDS™ Gas Storage” illustrates this concept.

Figure 1: How CAES Works<sup>1</sup>

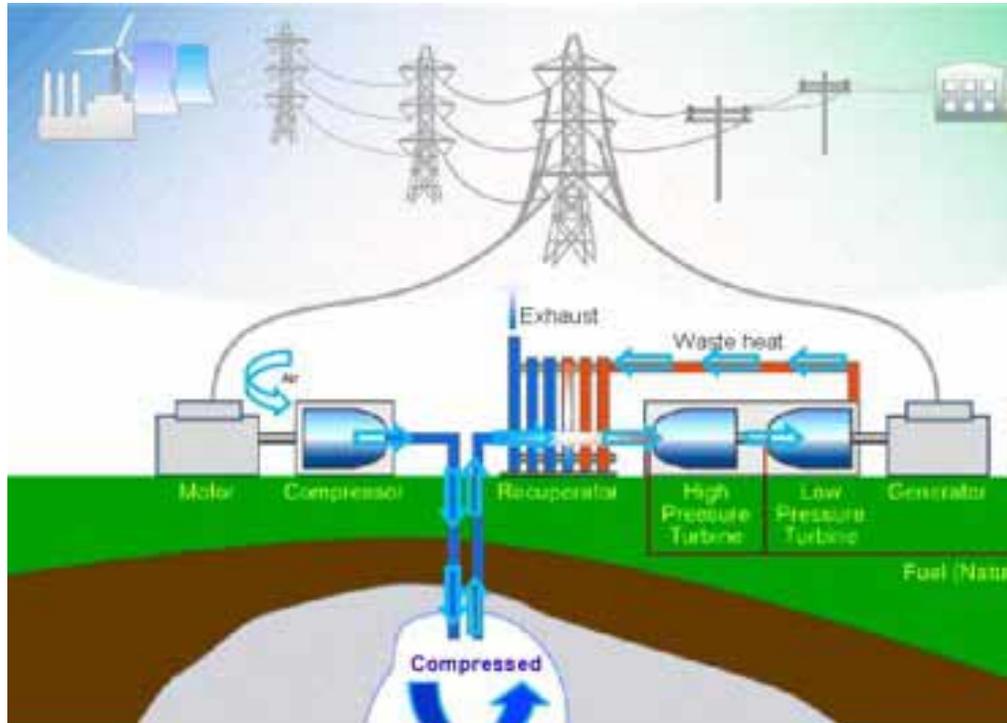
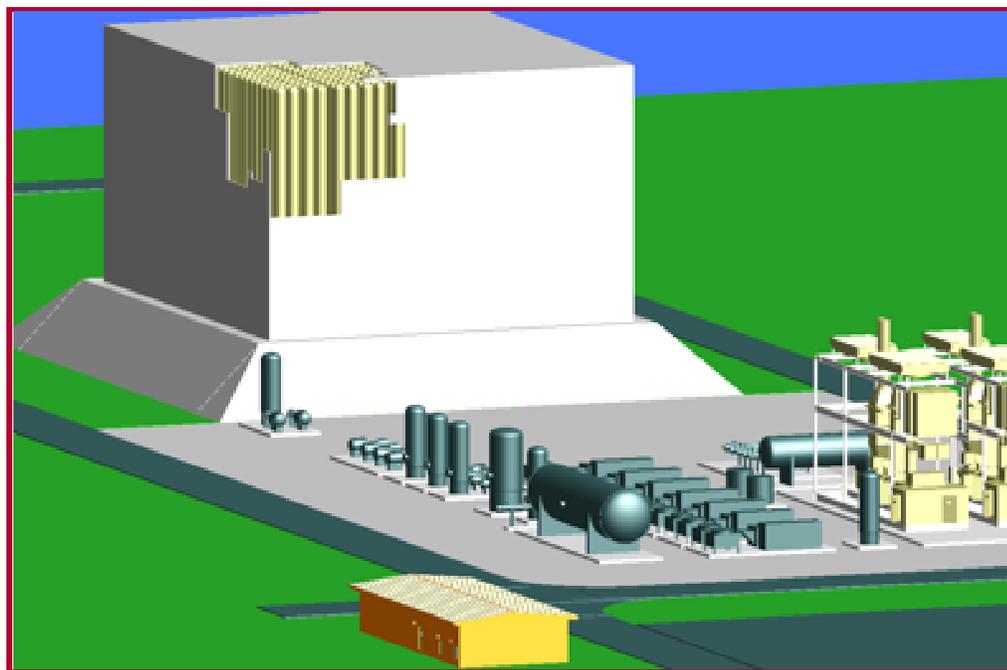


Figure 2: VOLANDS™ Gas Storage<sup>2</sup>



### **Value of CAES in Service**

The value that CAES facilities provide is estimated by considering a series of values that are provided in different ways. The total of these separate values provides the complete answer. At a large scale facility the value may be attributed to:

- Store power in the production region for delivery during a period when the transmission system is not constrained,
- Conversely, store power in a consuming area for delivery during periods when constraints might otherwise impair delivery,
- Store intermittent power for delivery as block power,
- Deliver power in accordance with dispatch, avoiding penalties,
- Provide any or all of the above services in situations with wind generation,
- Absorb power during off-peak periods, shadow ramp up, or shadow ramp down to reduce changes in dispatch of “baseload” units, which cause added maintenance,
- Provide significant system reserves, and
- Deliver VAR support, black start, and related ancillary services.

Because CAES systems are highly flexible in dispatch the operational costs for intermittent operation are limited. Since the unit uses compressed air there is no capacity derating of the turbine due to elevation or summer operating temperatures. Permitting issues are similar to a small low emissions generation plant, which is often less significant than permitting a transmission line.

The value of a large scale CAES system is often misunderstood. Because it is common to fill the CAES plant off-peak and to sell on-peak, it is generally assumed that the value is found in this “peak to base” spread income. While it is correct that some value is realized this way, the greater value is usually found in extra production of wind resources, relief of transmission congestion, deferring transmission upgrades, and relief of maintenance costs associated with cycling of “baseload” generation units.

### **Value of Mini-CAES in Service**

Upon examination it appears that mini-CAES facilities are probably more applicable to sites near the consuming load. While certain specific applications in the wind and generation producing regions can benefit from 50-150 MWh of energy storage with ~12MW discharge capability, in general larger bulk requirements prevail at those locations.

Since Mini-CAES is a form of distributed generation [and storage] it is more amenable to parts of that value chain, including:

- Spread value (buy low cost power and generate during peak value hours),
- Dispatch benefits (matching retail strategies and in particular renewable retail strategies to appropriate generation in the more economical day ahead markets),
- Deferral of transmission and distribution expansions, together with improving utilization of existing facilities,
- Reduction of outages (grid stability),
- Capacity as a generation source, and
- Other values, including reduction of losses, VAR supply, voltage support, and black start.

### **Cycle Description**

As mentioned, the CAES concept basically is a cycle with 2 major components or sections; the first being air compression and storage, and the second being extraction of the stored air, mixing with a fuel in a combustor, and expansion across a turbine to generate power. Some heat recovery for overall economy of fuel use is also

integrated into this section of the plant. The idea is to 'store' energy in the form of compressed air during times of low demand and cost for power on the grid; and then use the stored energy to generate power at 'peak' rates.

### **Concept Parameters and Components**

The concept of 'mini CAES' is an attempt to take a Compressed Air Energy Storage concept, demonstrated successful in at least 2 large (>100MW output) commercial plants, to a lower level of output where it may prove useful to store randomly available wind energy and/or meet peak requirements in an area where local transmission is not constrained, but the major regional inputs are constrained. A nominal size of 15-20 MW output was initially selected.

In order to make this as cost effective as possible, a focused effort was made to find machinery that was developed for other uses and apply it to the requirements of the overall CAES cycle. The most challenging component proved to be the expander driving the generator, which will be exposed to both high temperature (~1500-2000F) and high pressure (500-1000 psig). The choices from current industrial applications appear to be limited to either power recovery turbines from the process industry (Nitric Acid or Ethylene Oxide), or currently available combustion turbines used for either power generation (driving a generator) or mechanical drives which drive compressors, pumps, or other large industrial loads. The other choice might be to use a steam turbine adapted to this cycle.

Our initial review of available 'expander' hardware determined that the power recovery turbines from the process industry have a proven operating design limitations in the area of 1400-1500F and 300-350 psig as inlet parameters. The proven combustion turbine designs can accommodate much higher firing temperatures in the 22-2500F region, but the smaller size machines are limited in pressure capability to 150-250 psig. Because Solar volunteered to participate in this study, for the initial plant sizing, a Mercury 50 model machine was selected because the normal rating of ~ 4500 kW at ISO conditions fits the 10-15 MW nominal output once decoupled from the compressor. This machine has nominal inlet conditions of 41.5 lb/sec of air at approximately 140 psig. In addition, the Mercury 50 includes a recuperator that uses gas turbine exhaust energy to preheat the combustor inlet air, thus increasing power generating system efficiency.

Air Compressors proven in repeated industrial and process plant applications compressing air to 125 psig and even to 600 or 1200 psig are readily available from several world wide suppliers. The other major component in the first section was selected to be above ground storage cylinders in an effort to make the plant siting very flexible and not limited to the usual geotechnical restrictions required for the larger facilities using underground salt caverns or aquifers as reliable storage of the compressed air energy. A standard design from other applications was selected with a capability of 1200 psig containment. This approach was chosen because of prior work completed analyzing a combination of vessel cost, primarily related to volume and wall thickness, and total space required for the storage.

Rather than 'waste' the energy represented by expansion of that high pressure air storage, the final block selected was a 'topping turbine' from current industrial steam turbine technology to generate some added power letting the stored air down to the required pressure at the inlet of the combustion turbine. As a preliminary attempt to optimize the heat balance around this section, a small amount of fuel was added in a combustor ahead of this turbine to make the discharge temperature at the appropriate level to make use of the waste heat coming off the main combustion turbine driving the generator. A second recuperator was added to match the standard Mercury 50 recuperator's design conditions.

The final significant equipment component is the water pump, which is sized to maintain constant supply pressure to the generation section turbines. This component improves overall cycle efficiency and total MW generation capability from a specific storage volume. The economics of this feature may vary from site to site.

## Investigations

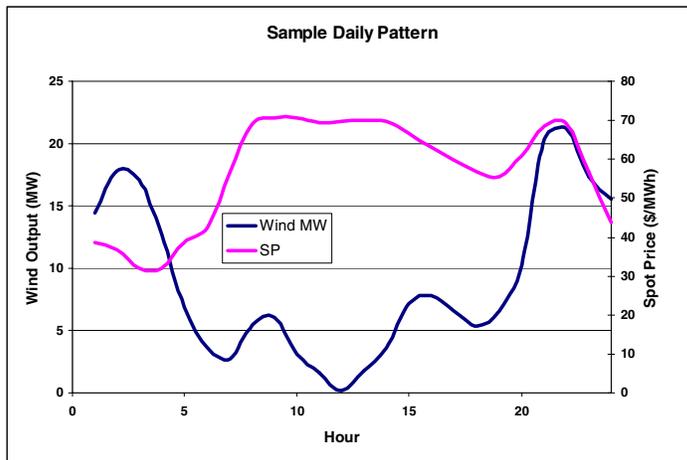
The project is in the process of estimating the value attributable to each of the value drivers. The first step was to establish a quantitative understanding of the New York State grid. An economic analysis was performed for the NYISO system based on the database used in the previous study with NYSERDA. Fuel costs and unit additions were updated to match current projections. Wind generation was added at four locations throughout the state as potential sites for Wind/CAES co-location. Table 1 shows the location and size of the wind sites.

Table 1: Wind Sites

NY Zone	Energy (GWhr)	Capacity (MW)	Capacity Factor
Mohawk	890	300	34%
West	298	110	32%
Hudson	126	50	29%
Long Island	1,125	300	445

Hourly generation and spot prices were developed from a 2008 simulation of the NYISO system. Figure 3 shows sample results for the Hudson site.

Figure 3: Sample Daily Pattern for the Hudson Site



As can be seen, the wind generation is largely out of phase with the value of the energy. The value for the CAES plant has been estimated for each of the wind sites and selected urban locations under a variety of compression to generation ratios and considering different storage capacities.

However this system analysis provides only the base upon which to develop an understanding of the various value components. The first outgrowth from that analysis is a quantitative estimation of the spread value.

Figure 4 displays an example of the value that can be captured from this spread, on Long Island. While this is independent of whether the generation is wind or any other source, it is shifting the generation in the manner described above. The figure ranks the value of the spread from by assuming that the cheapest power is used to compress and is “matched” to the most valuable generation hour.

As discussed previously, the facilities provide a number of different value components. Our current estimate of value is shown in Figure 5. Most of these figures most are reasonable estimates of net present value, displayed as a percent of the facility cost. One exception, the value for “Stability” is essentially a placeholder at this time.

Figure 4: Example Value in 2008

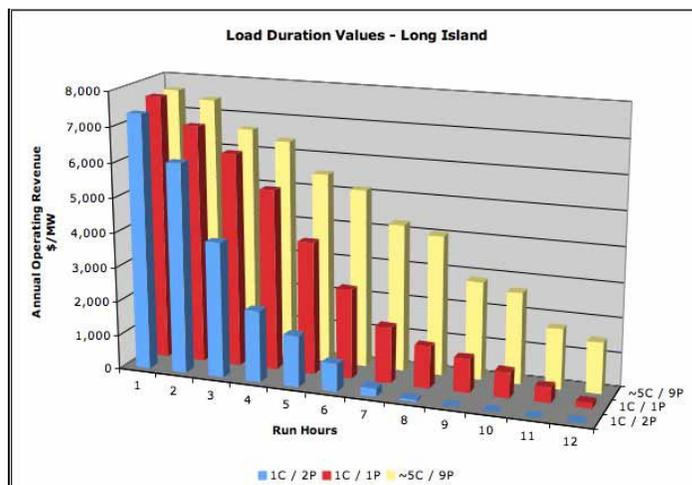
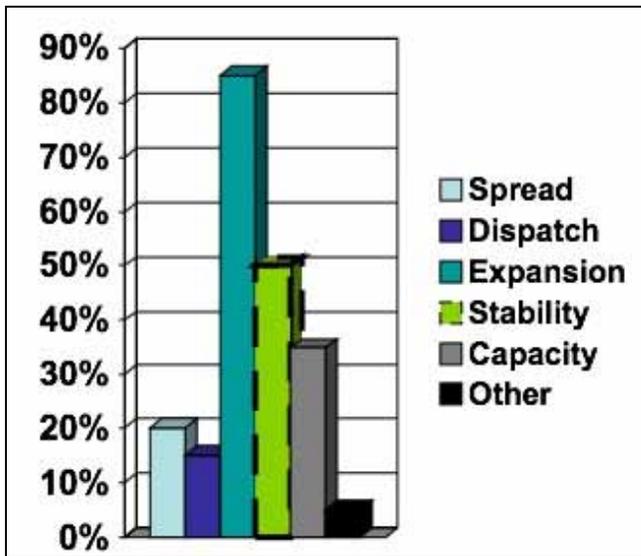


Figure 5: Value Components



### Conclusions

We were disappointed to find the mini-CAES facilities cost multiples of the unit cost of a large CAES plant. Currently we are considering design alternatives that might have a very significant impact on installed cost; and much of the attraction of this concept will depend on whether this effort is successful.

Our analysis to date has focused on urban siting, which appears to have more value than remote locations. The concept is simple, if the costs cannot be reduced we presume that in general the non-urban utility will be delivered by traditional large scale CAES, if at all. If costs become more competitive, then non-urban siting will be considered.

It is apparent from the above figure that the value drivers in urban locations are largely controlled by the utilities that own wires and especially if they serve energy customers. Even if it can be demonstrated to be valuable to end users, this technology may be forever constrained by the commercial barriers to capturing that value.

Also, the value is not likely to be sufficiently attractive as to win support unless the contracts can realize a comprehensive return of value from all sources.

We look forward to the redesign results and further work on the value drivers before concluding whether the concept is economically viable.

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<sup>1</sup> The Economic Impact of CAES on Wind in TX, OK, and NM, Final Report, June 27, 2005, prepared for the "Texas State Energy Conservation Office", p14 © Ridge Energy Storage & Grid Services

<sup>2</sup> Courtesy of EnerSea Transport LLC, which is affiliated with Ridge Energy Storage and Grid Services, L.P.