



Sustainability Research

Boise State University

Office of Energy Research, Policy and Campus Sustainability

Overview of Compressed Air Energy Storage

ER-07-001

## Overview of Compressed Air Energy Storage

Prepared by  
**John Gardner, Ph.D., P.E.**<sup>1</sup>  
**Todd Haynes, M.E., EIT**<sup>2</sup>  
 Boise State University  
 December 2007

### Overview:

Compressed Air Energy Storage (CAES) is the term given to the technique of storing energy as the potential energy of a compressed gas. Usually it refers to air pumped into large storage tanks or naturally occurring underground formations. While the technique has historically been used to provide the grid with a variety of ancillary services, it is gaining attention recently as a means of addressing the intermittency problems associated with wind turbine electrical generators.

Figure 1 shows a schematic of the approach.

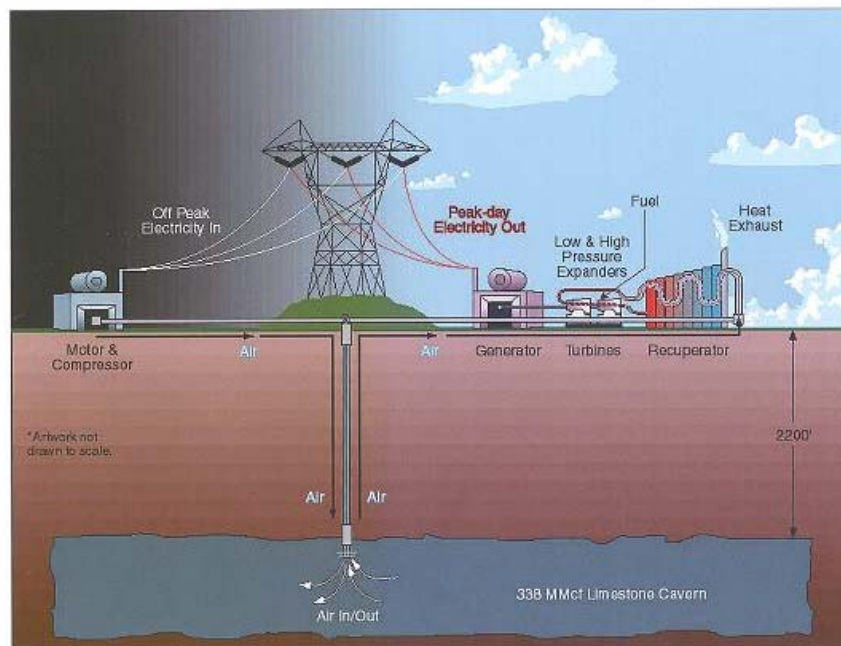


Figure 1: Conceptual representation of CAES (from <http://www.caes.net/>)

When energy is available, it is used to run air compressors which pump air into the storage cavern. When electricity is needed, it is expanded through conventional gas

<sup>1</sup> Associate VP for Energy Research, Policy and Campus Sustainability

<sup>2</sup> Energy Systems and Research Engineer

turbine expanders. Note that some additional energy (typically natural gas) is used during the expansion process to ensure that maximum energy is obtained from the compressed air (albeit as much as 67% less gas than would be used for an equivalent amount of electricity using gas turbine generators without CAES).

### History:

#### *Huntorf Plant*

The world's first compressed air storage power station, the Huntorf Plant has been operational since 1978. The 290 MW plant, located in Bremen, Germany, is used to provide peak shaving, spinning reserves and VAR support. A total volume of 11 million cubic feet is stored at pressures up to 1000 psi in two underground salt caverns, situated 2100-2600 feet below the surface. It requires 12 hours of off-peak power to fully recharge, and then is capable of delivering full output (290 MW) for up to 4 hours. This system operates a conventional cycle and combusts natural gas prior to expansion.<sup>3</sup>

#### *McIntosh*

Alabama's Electric Cooperative (AEC) has been running the world's second CAES facility since 1991. Called the McIntosh project, it's a 110 MW unit. This commercial venture is used to store off-peak power, generate peak power and provide spinning reserve. 19 million cubic feet is stored at pressures up to 1080 psi in a salt cavern up to 2500 feet deep and can provide full power output for 26 hours. This system recovers waste heat which reduces fuel consumption by ~25% compared to the Huntorf Plant.<sup>3</sup>  
<http://www.caes.net/mcintosh.html>

#### *Iowa Stored Energy Park*

Announced in January of 2007, the Iowa Stored Energy Park is partnership between the Iowa Association of Municipal Utilities and the Department of Energy. They plan to integrate a 75 to 150 MW wind farm with underground CAES, 3000 ft below the surface. The ISEP is currently in design phase with anticipated generation starting in 2011.  
<http://www.isepa.com>.

#### *General Compression*

A start-up company in the Boston area has teamed up with a compressor company (Mechanology) to produce the world's first wind turbine-air compressor. These new wind turbines will have the capacity of approximately 1.5 MW, but instead of generating electricity, each wind turbine will pump air into CAES. This approach has the potential for saving money and improving overall efficiency by eliminating the intermediate and unnecessary electrical generation between the turbine and the air compressor.  
<http://generalcompression.com>

### Advantages of CAES:

The primary benefits of implementing a CAES system are ancillary services provided to the grid. Applications include: peak shaving; spinning reserve; VAR support; and arbitrage<sup>3</sup>. By utilizing CAES, the energy from a variety of sources (including wind, solar and the grid itself) can be temporarily stored to be recovered at a later time, presumably when it is more needed and, perhaps, more valuable. The advantages of CAES are particularly compelling when coupled with an intermittent source such as wind energy. The proposed wind park in Iowa will result in a wind farm which could conceivably be used by utilities to supplement base loads or in meeting hourly load variations and peaks.

Although CAES systems which use underground storage are inherently site specific, it is estimated that more than 80% of the U.S. territory, including most of Idaho, has geology suitable for such underground storage. CAES utilizes proven technology that can be optimized for specific site conditions and competitively delivered by various suppliers.<sup>3</sup>

### Disadvantages:

As is the case with any energy conversion, certain losses are inevitable. Less energy eventually makes it to the grid if it passes through the CAES system than in a similar system without storage. Some of these losses are mitigated in the approach used by General Compression (using the wind turbine to compress the air directly). In any event, the requirement for additional heating in the expansion process is the most significant disadvantage. By some estimates, 1 kWh worth of natural gas will be needed for every 3 kWh generated from a CAES system. This is particularly problematic if fossil fuels are used for the heat addition. As natural gas prices increase, the economics of CAES, marginal at present, could fail. Again using the wind energy example, one might view a wind farm using CAES as a gas turbine plant with a 3 fold increase in yield over a conventional gas turbine generator. While this is an impressive improvement, it takes some of the 'renewable' luster off the wind farm. It is not clear how policies like the production tax credit or renewable portfolio standards will view this technology.

### Why do we still need natural gas?

One of the confusing aspects of the CAES is the requirement for additional fuel in the expansion process. The reasons lie in the fundamental physics of gas compression and expansion. When a gas is compressed, it gets warmer. This is why air compressors have cooling fins. Conversely, when it expands, it gets cold. This is why frost builds up on the space shuttle fueling lines. The magnitude of expansion envisioned in the CAES expander systems is such that the outflow of the turbine would be nearly cryogenic in nature, making the design of the turbines problematic.

A conventional gas turbine is a compressor-turbine combination, as seen in Figure 2.

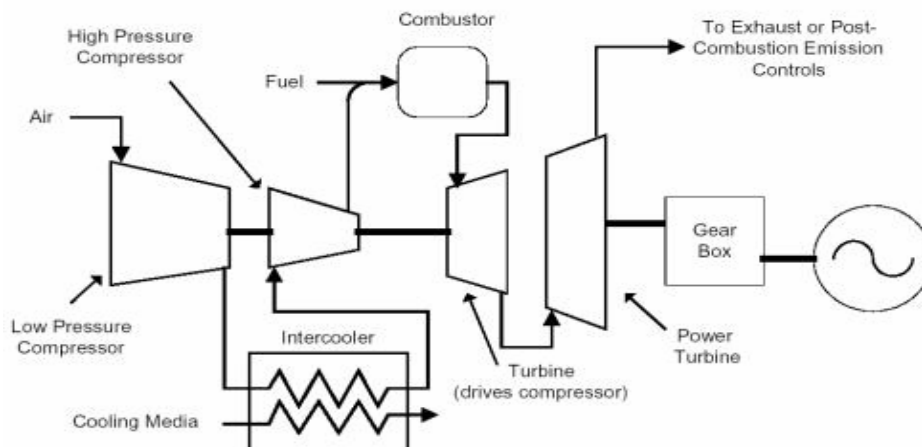


Figure 2: Conventional gas turbine with two-stage compressor and expander.  
<http://www.energysolutionscenter.org>

This particular turbine design uses a two-stage expander section, the first stage of which is dedicated to running the two-stage compressor. None of the energy extracted in the first stage goes to generating electricity. In fact, nearly  $2/3$  of the mechanical energy generated in a conventional gas turbine is used to run the compressor sections of the turbine.

When a CAES system is used the air is already compressed so the expander does not drive the compressor. Therefore, the net yield of the expander goes up by a factor of 3.

Various concepts have been proposed to reduce the amount of gas required during expansion. As noted above, the McIntosh Plant recovers waste heat from the compression cycles, reducing natural gas consumption up to 25% as compared to the Huntorf Plant. Other proposed cycles may further reduce gas consumption, and one concept proposes eliminating fuel altogether by capturing, storing and re-using heat.<sup>3</sup>

### Conclusions:

If implemented in Idaho, CAES can be used to delay or offset upgrades to the electric transmission grid that would otherwise be necessary. Additionally, it can be used to offset the adverse effects of intermittent renewable energy sources such as wind and solar. The energy community, particularly wind developers and grid operators with significant wind capacity, are watching the Iowa project closely. The economics of the concept appear to work out, but significant research and development efforts could address and mitigate some of the disadvantages. Until the improvements discussed above become commercially available, a bio-mass source of combustor gas for the expander would bring the approach to a carbon-neutral status. In the light of looming carbon regulations and rising natural gas costs, that would alleviate most of the economic uncertainty of CAES.

<sup>3</sup> EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications, 2003