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Second Generation Compressed Air Energy Storage

What it is

Why it's important to widespread renewables deployment

Support needed to assist in deploying energy storage

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President – PSEG Energy Holdings and
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Key Takeaways

- Energy storage is an under-appreciated ***"piece of the energy puzzle"*** that is critical to ***enabling the widespread deployment of renewables***
- Energy storage is the key to achieving several strategic national goals:
  - ***Converts variable renewable resources (wind and solar) into firm, dispatchable resources available when customers need power***
  - ***Enhances grid reliability,*** which will become increasingly important as variable renewable resources become a larger part of the supply equation
  - ***Increases the value of renewable resources*** by shifting their production from low-demand, low-price periods (wind generation is greatest at night) to high-demand, high-price periods ***(thereby reducing the overall price of power to customers)***
  - ***Reduces the greenhouse gas profile of the industry*** by displacing fossil fuel-fired peaking generation
  - ***Optimizes the utilization of transmission***, minimizing new required construction
- Compressed Air Energy Storage (CAES) provides several important advantages as an energy storage alternative:
  - ***Lowest all-in cost of energy storage, highly scalable, very energy-efficient, relatively short construction period, highly reliable (using off-the-shelf components), does not use water or toxic chemicals to produce power***
- ***Incentives for energy storage deployment are important to ensure that renewables can achieve widespread deployment***

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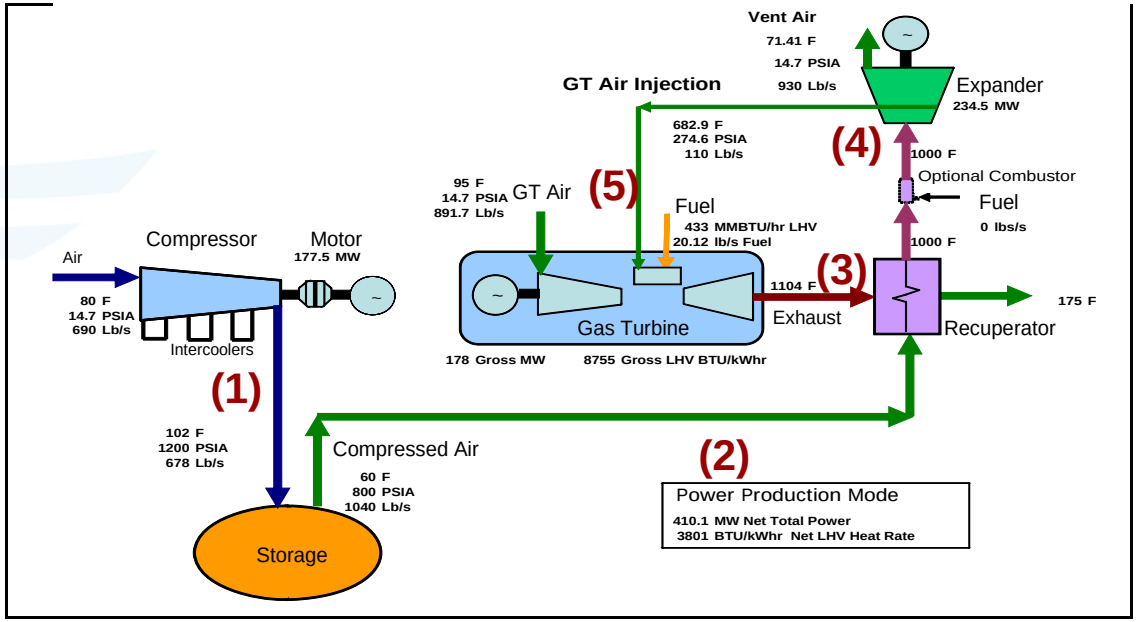
How Does CAES Work?



(1) At night, electricity-powered air compressors are turned on and compress air into a storage device (either an underground cavern or metal storage canisters)

(2) During the day, the pressurized air in storage is released; this air becomes very cool as it expands and needs a heat source to make it more usable

(3) A relatively small natural gas-fired turbine is activated, generating power and also producing exhaust heat which is combined with the cool, expanding air in a recuperator

(4) The heated, expanding air flows through an expander (a turbine), creating electricity

(5) The air flowing through the expander can be harnessed to increase the output of the gas-fired turbine; this air is routed to the turbine and increases the megawatt (MW) output of the turbine

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About Energy Storage and Power LLC

- CAES technology leader, with a proprietary second generation compressed air energy storage (CAES2) product suite
- Team has experience dating back to the development of the first generation of CAES technology in the 1980s, culminating in the design and construction in 1991 of the 110 megawatt (MW) CAES plant for Alabama Electric Cooperative
- Strategic alliance between:
  - Public Service Enterprise Group, a Fortune 200 company with an over 100 year history in the power industry
    - Chairman and CEO: Ralph Izzo, who has testified frequently before Congress regarding ways the power sector can address climate change objectives
    - PSEG has one of the largest utility-supported solar programs in the country, is involved in offshore wind development, and is preparing an Early Site Permit (ESP) for a new nuclear unit to be constructed in southern New Jersey
    - PSEG's regulated utility business, Public Service Electric & Gas, was again recognized in 2008 as the Most Reliable Electric Utility in the U.S.
  - Dr. Michael Nakhamkin, the leading voice in the Compressed Air Energy Storage field for two decades
    - Dr. Nakhamkin led the team providing design and project technical supervision for the first generation, 100 MW CAES plant in Alabama (working well to this date)

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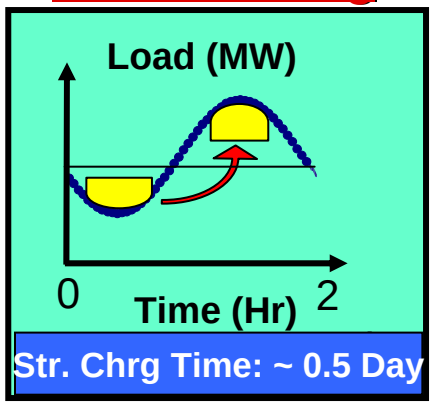
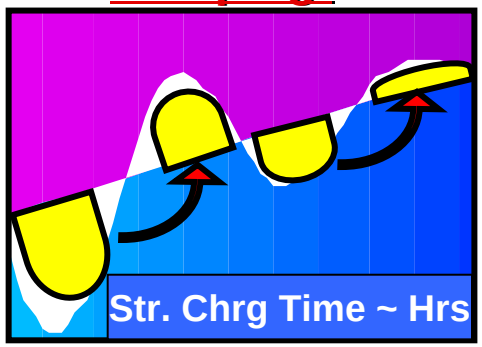
CAES 2 Provides Critical Transmission System Support

Load Leveling



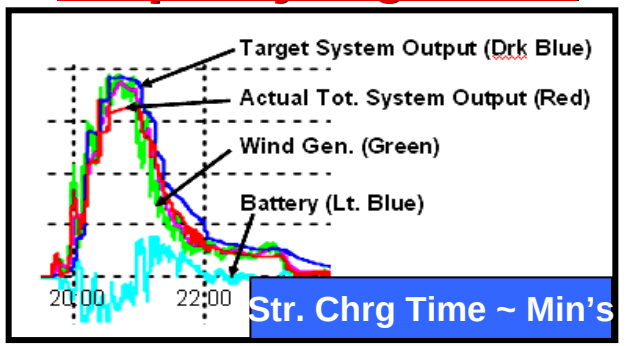
- CAES
- Pumped Hydro

Ramping:



- CAES
- Pumped Hydro
- Battery, Flow type

Frequency Regulation:



- CAES
- Battery, Regular or Flow Type
- SuperCap
- Flywheel
- SMES

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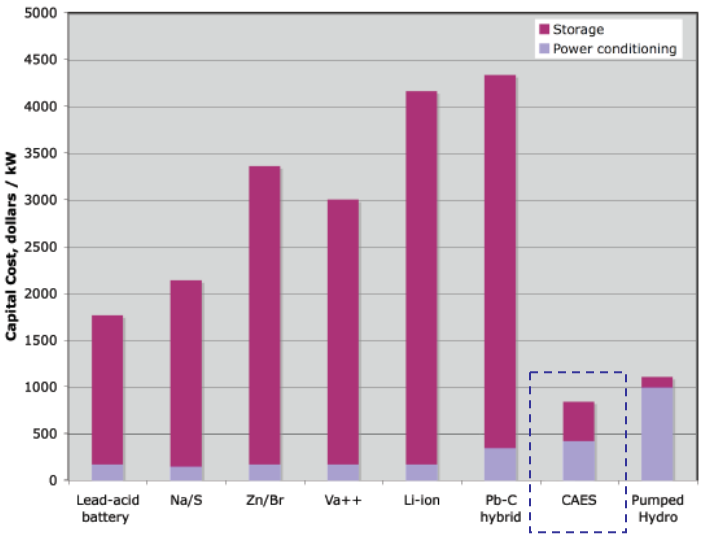
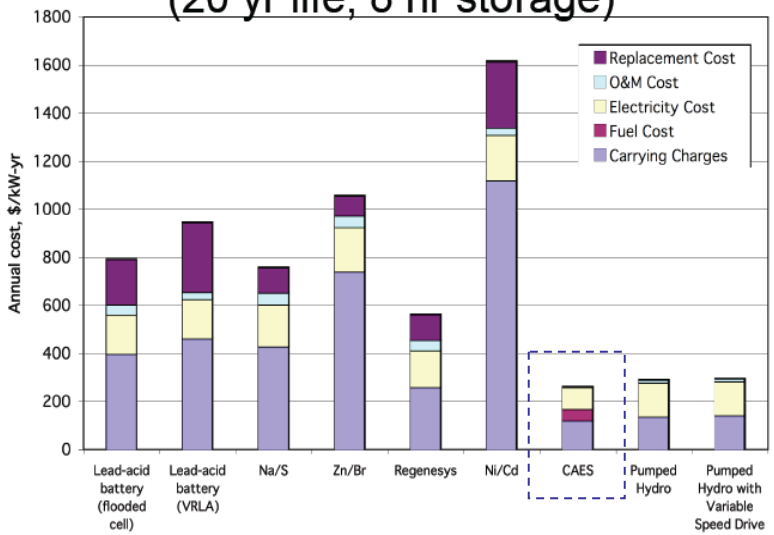
CAES 2 is a Highly Economic Energy Storage Option

Example for bulk storage (8 hr)



Example annual cost for bulk storage (20 yr life, 8 hr storage)



Source: 122 West analysis completed for DOE

CAES is significantly cheaper upfront on a capital cost ($ per kilowatt of capacity) basis than other developed bulk storage solutions, and saves money on replacement costs due to its longer expected life than batteries.

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CAES Technology Efficiency

The CAES 2 technology has two features – power generation and energy storage

- The power generation component of the CAES plant is derived from a combustion turbine, fired by natural gas or fuel oil, with an efficiency of 33-35% or heat rate of approximately 10,000 Btu/kWh – however, *the waste heat from this process is captured by the CAES plant* and used to provide greater power output from the compressed air that is expanded
- The stored energy component is the bottoming cycle (power is produced when the compressed air is pre-heated with waste heat from the combustion turbine and run through an expansion turbine) with *efficiency of approximately 90%,* i.e. if 1 kWhr is stored, 0.9 kWhr is released without any fuel combustion
- The practical efficiency of the CAES pant is the combustion turbine's heat rate (~10,000 Btu/kWh * CT energy) / (total energy produced: CT energy plus released stored energy) and is equal to 3,800-3,900 Btu/kWh when wind or solar power is the source of stored energy ***(~3x as efficient as a coal plant or a combustion turbine when CAES uses renewables as its power input)***

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Example: Renewable Market Dynamics and CAES' Role

- The Western sub-region of the Texas (ERCOT) power market provides an excellent example of how CAES 2 can (1) be highly efficient relative to conventional fossil fuel fired generation and (2) enhance the value of renewable generation
- As a result of substantial wind generation construction in Western ERCOT, wind generation economics have deteriorated in the region
  - Wind generation is produced mostly at night, when load is low; as a result, off-peak power prices in Western ERCOT are often negative (because wind receives a PTC for each MWh generated, power prices fall to zero (or even negative levels because wind receives a PTC with every unit of generation)
  - Wind generation is often being curtailed by ~15% at night because the volume of generation is greater than the load; this is a poor waste of a resource with no incremental cost
- CAES 2 can improve these dynamics substantially while producing on-peak power at a cost lower than conventional natural gas-fired generation
  - At a $0 off-peak power price and $5/mmBtu cost of natural gas, and $5/MWh variable O&M, a CAES 2 unit's variable cost of generation ($24.05, equal to 3,810*$6 / 1000 + $5/MWh variable O&M) is substantially lower than the most efficient combined cycle gas generation ($40.00, equal to 7,000*$5 / 1000 + $5/MWh variable O&M)
  - CAES 2 should also have a positive economic impact on wind generation, by providing an incremental source of demand for the output of the wind generation (generation that would otherwise not be used)

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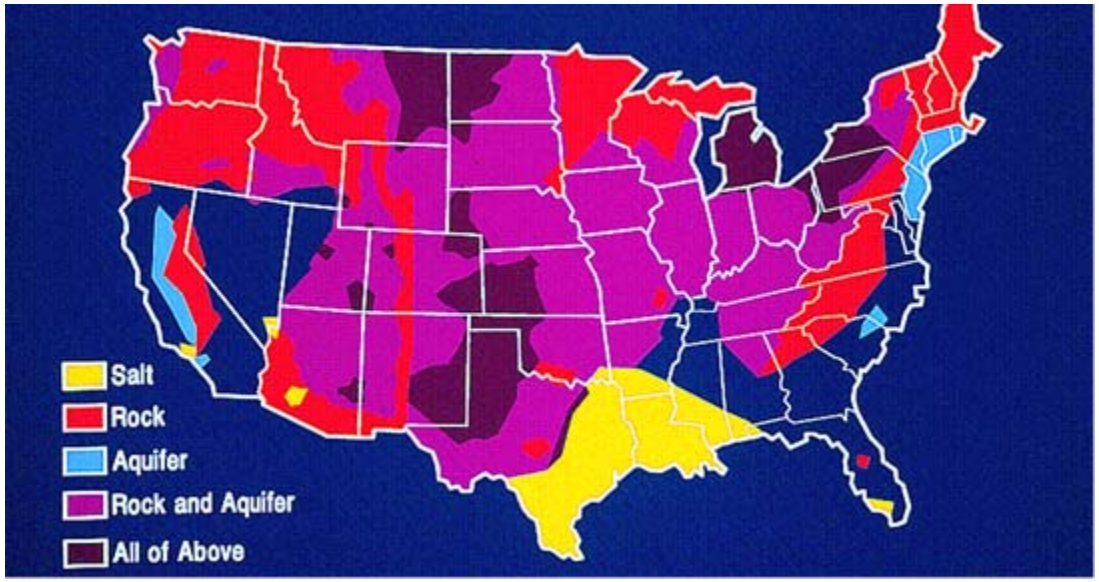
US Geology – 80% of U.S. Favorable to CAES Storage

- CAES 2 storage options are available in large parts of the country
- A 300 MW CAES Unit requires a 21 MMCF cavern for 8 hours of storage
- Fifty 300 MW CAES2 Units require 1,050 MMCF (1BCF) of physical storage capacity
- To put that in perspective, the Natural Gas Storage industry today is 8,323 BCF working gas in size



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Source: ES&P, Energy Information Administration and EPRI

Categories of CAES Customers

- Utilities focused on ***maintaining grid reliability as renewables penetration increases***
  - Approach may be for “distributed CAES” – smaller CAES projects (15MW) distributed throughout the grid – these smaller CAES units use metal canisters for air storage and can be sited without consideration to geology (i.e. underground storage cavern availability)
  - CAES economics are significantly better than battery products
  - Utilities, when they issue Requests for Proposals (RFPs) for new renewable projects, may include an energy storage component to enhance the value of the renewables and address grid reliability concerns
- ***Wind and solar plant owners seeking to enhance the value of their renewable assets***
  - CAES provides several benefits: (1) avoids the need to shut down wind assets at night when wind supply exceeds the demand for power (as in West Texas), (2) shifts the output of renewable generation to periods of highest customer demand (increasing the profit of these renewables projects and driving down the price of power), and (3) converting a variable power resource into a firm power resource, delivering power when customers want it (this quality is highly sought after by customers and grid operators)
- ***Competitive power plant owners seeking to “arbitrage” daytime and night time power price differences***
  - Driven by the difference in power prices derived from (low-cost) baseload plant and (much higher-cost) peaking generation assets (fueled by oil and natural gas)
  - Such a strategy would indirectly benefit renewable generation owners and customers (the overall price of power would fall)

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Recent Commentary on CAES

- "Advanced, second generation CAES plants have the capability to augment renewable generators, meet the on-peak needs of utilities, and mitigate the power fluctuation and energy management issues associated with wind and other renewable resources." - *Department of Energy Smart Grid Funding Opportunity Announcement*
- "Second-generation compressed air energy storage technology backed by PSEG is seen as a cost-effective solution for boosting the value of wind generation and stabilizing stressed transmission systems, but the technology faces hurdles that are delaying its deployment—including a wrinkle in the tax code that prevents companies that want to use the technology to store wind-generated electricity from receiving the renewable energy production tax credit. Tax attorneys say lawmakers simply didn't contemplate the possibility of cost-effective energy storage when they established the PTC in the Energy Policy Act of 1992. But they say legislation is needed to add CAES to the list of technologies eligible for the credit." – *Chris Holly, Energy Daily*
- "PJM President and CEO Terry Boston said in an interview that because of an expected expansion of wind capacity, 'major' compressed air storage capacity could be used east of transmission constraints in the Allegheny Mountains. By major, Boston said he meant 1,000 MW or more…other ISOs, including the Southwest Power Pool, also have been encouraging the installation of CAES. The SPP region has 1,800 MW of installed wind generation, mainly in Kansas, Oklahoma, New Mexico, and the Texas Panhandle, with over 50,000 MW in its queue." – *Jeff Ryser, Platt's Electric Utility Week*

Requested Federal Support for Energy Storage

- **Investment Tax Credit**
  - 30% credit for solar energy property and fuel cell property extended to 1/1/2017 and extended to Public Utility Property and small wind
  - 10% credit for micro-turbines extended to 12/31/2016 and extends to combined heat and power system and geothermal heat pumps
- **Removable of Wind Production Tax Credit (PTC) Disincentive**
  - Wind 10-year PTC applies for wind placed in service by 1/1/2010 and through 1/1/2011 for other sources (geothermal). Extended to biomass facilities and marine renewable resources through 1/1/2011
  - Earn PTC on delivery to Grid, not to energy storage
  - Important that the *gross* megawatts of wind *delivered to* energy storage device (not *net* MW, i.e. MW *produced by* energy storage device)
- **Federal funding of CAES units**
  - Department of Energy Smart Grid program has designated $50-$60 million for advanced CAES – this program should emphasize funding for projects that are “shovel ready”
- Other potential areas of support
  - For example, loan guarantees to help enable financing of energy storage projects

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