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Thanks for the opportunity to participate in the work shop, Electricity or Energy Storage within the USA and worldwide, for that matter has been a topic of several studies, so I will be drawing on some of these studies and recent publications and in particular one of my papers that was presented at ECOS 2004 (Efficiency Cost Optimization Simulation) held in Guanajuato Mexico, which was selected for the Energy Journal International, titled: **The Potential for Bulk Energy Storage in the USA, Current Developments & Future Prospects.**

Introduction

The demand for electricity has considerable daily and seasonal variations and the maximum demand may only last for a few hours each year. As a result, some power plants are only required to operate for short periods each year—an inefficient use of expensive plants. Without any additional storage above the present 2.5%, mainly PHS, of the installed base load in the USA, base loaded plants are being detrimentally cycled at higher frequency and the situation is further exacerbated by the latest growing demand for renewable energy such as wind energy. In the US, this capacity has now reached 6800 MW and the AWEA (American Wind Energy Association) projects up to 30 GW by the year 2020.

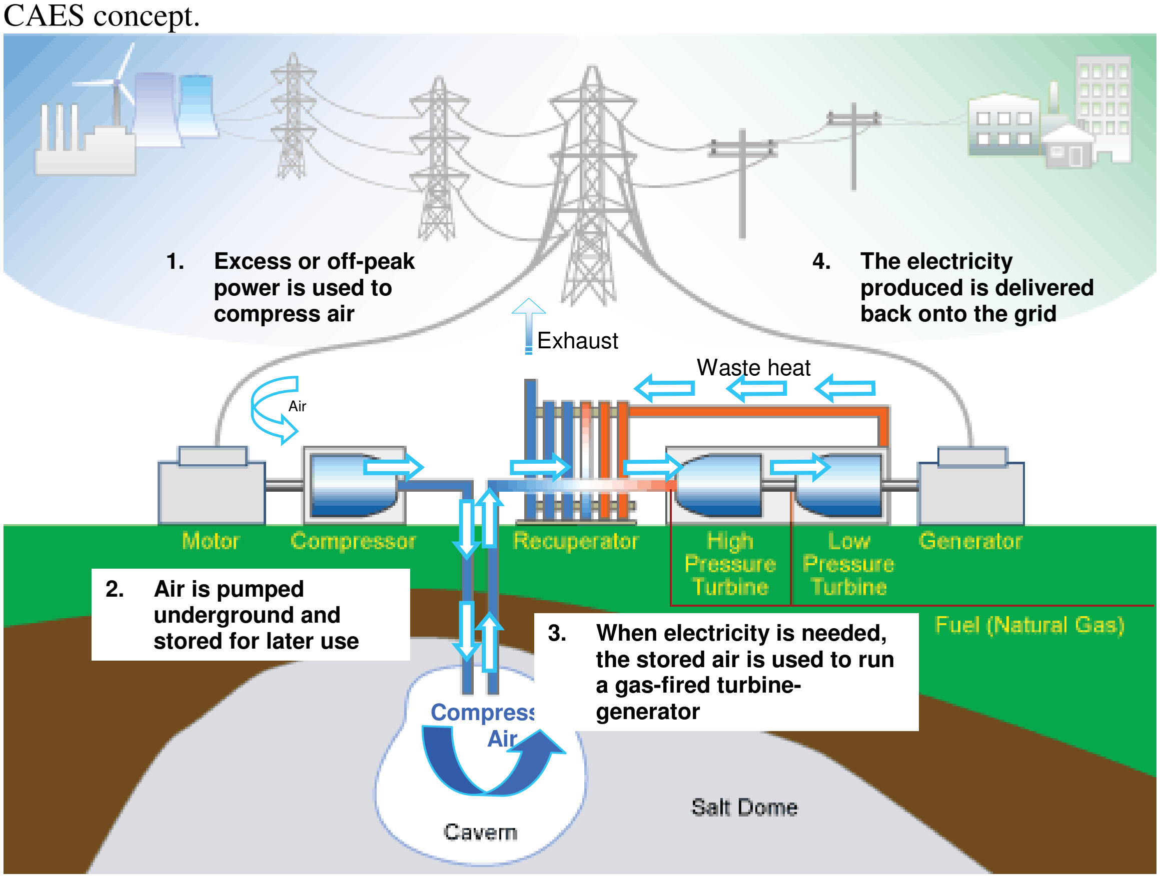
Storage allows energy production to be **de-coupled** from its supply, self-generated, or purchased. By having large-scale electricity storage capacity available over any time, system planners would need to build only sufficient generating capacity to meet average electrical demand rather than peak demands. The different Storage technologies can be used in different combinations to suit the specific needs of site, not only in plant output capacity, but in response times as well. The response systems such as Flywheels or Flow batteries (seconds or milliseconds) can be combined with larger bulk systems (minutes and hours) such as CAES, or with SSCAES (surface storage), 60MW/hr systems or larger 135 MW and 300 MW units in several configurations up to 1000 MW or more depending on storage cavern volume.

In theory, a typical plant could operate with 40% less generating capacity than would otherwise be required. This represents considerable financial savings in peaking and intermediate plants. Additional reductions in emissions and capital investment can occur due to the base load generators operating more efficiently at steady state output.

Grid instability does lead to regional blackouts. This does open the door for more consideration of Energy Storage. While this is encouraging, there are, institutional hurdles to overcome—one being the lack of understanding of the **value and benefits** of Bulk Energy Storage and some perceived concepts that simply adding more new power plants and transmission capability will cure blackout problems experienced in recent times in the USA. Storage is probably the better solution! Storage of electricity **(energy)**

will significantly change the Power Industry for the better—**better utilization of resources—better system efficiency—lower emissions—better reliability and security.**
Geologically suitable identified sites for bulk energy storage using salt domes, hard rock or aquifer can be readily exploited for 20/30 GW capability by 2020 or sooner, a fact not fully recognized by power entities.

How does a CAES System work?
The fundamentals of a Gas Turbine are well understood, atmospheric air is compressed to a higher pressure, fuel is added in a combustion chamber and the hot high pressure combustion gas expands through a turbine, that provides both the motive power for the Compressor (60% or more) the balance of the power (40% or less) as mechanical energy to drive an electric generator. In a CAES cycle a variation of a standard gas turbine, the compression cycle is separated from the combustion and generation cycle, by using low cost off-peak or excess electricity, motor driven inter-cooled compressors provide the compressed air held in storage, to be released from storage to the modified Gas Turbine for power generation on demand**. In this process some dramatic changes in the power and economic cycles have occurred,** the Gas Turbine expander absent its large parasitic load delivers approximately two-thirds more power with no increase in fuel consumption, and the required compressed air comes at a much lower cost, thus enabling lower cost of electricity generation during high demand cycles from other intermediate load systems such as gas fired thermal or Combined Cycle power plants, or even the lower capital cost Simple Cycle Gas Turbine power plants. The illustration below will help clarify the CAES concept.



Bulk Energy Storage Systems—CAES

Energy (Electricity) storage is well-known primarily on smaller scale systems such as batteries or capacitors, and in Bulk Storage systems such as Pumped Hydro Systems (PHS). Bulk systems such as CAES are lesser known, however two large systems, Huntorf Germany, 290 MW [Ref 1] and McIntosh, Alabama Electric Cooperative, 110 MW, have been operating successfully and reliably for over 25 and 11 years respectively. Improvements in the turbo machinery and Heat Recovery Unit (HRU) have enabled improved performance in 60 Hz sizes 135 MW and 300MWand larger units, with heat rates below 3900 Btu/kW/hr (LHV). Low emission combustion systems and selective catalytic reactors (SCR) in the HRU allow Nox values to be maintained below 5.0 vppm or as low as 2.5 vppm. While both units are similar in Turbo-machinery layout (single shaft with disengaging clutches) they were intended for different purposes. Huntorf, primarily designed for short, fast responses in order to support a Nuclear power station, the system has now been operationally modified to provide overall grid support for 3 hours daily [Fig 1].

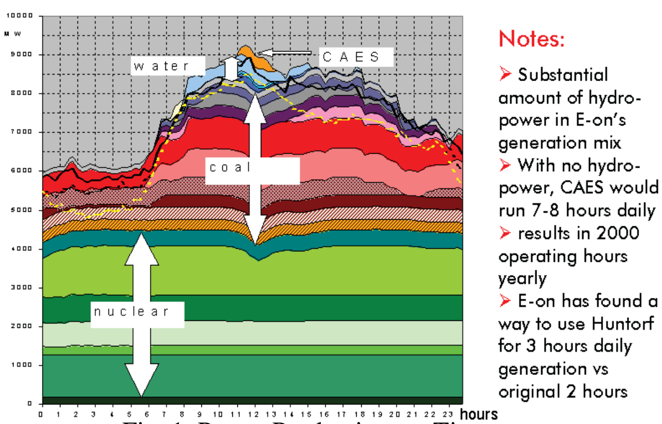


Fig. 1. Power Production vs. Time

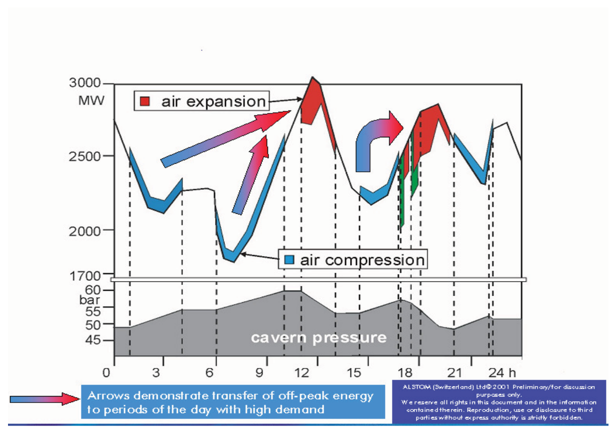
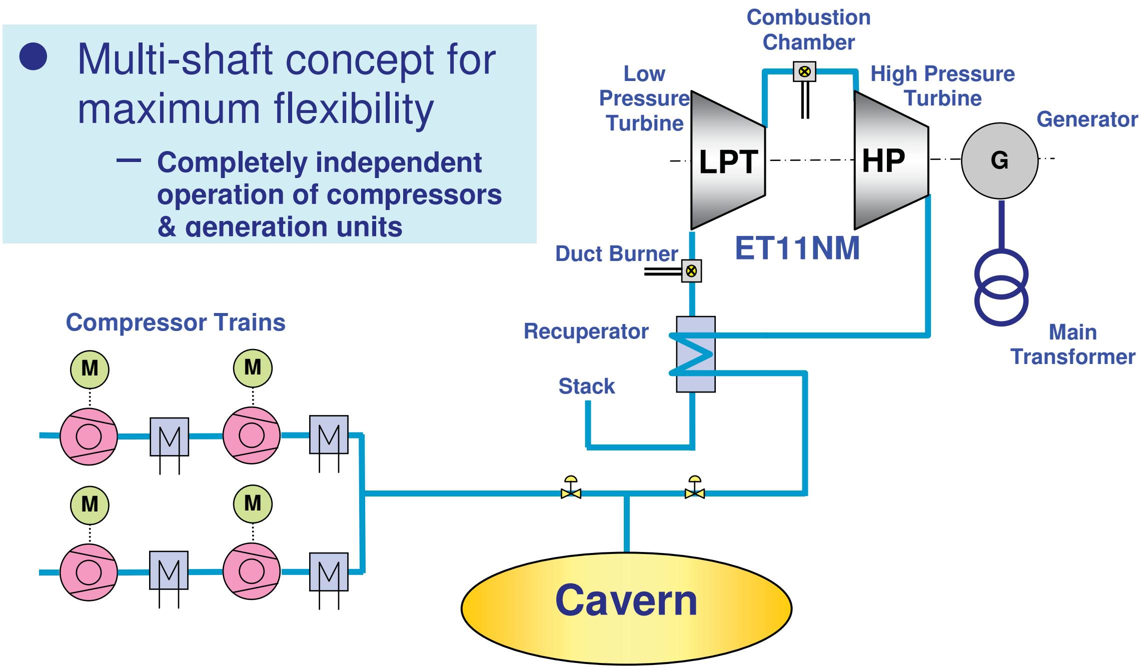


Fig. 1A. Example of Utility 24 Hour Load Profile & CAES Operation

McIntosh, with a much larger cavern storage volume, and the application of an HRU to preheat the cavern air, has a better heat rate and can generate continuously for 26 hours (2600MW/hrs) before reaching cavern draw down.

With today's emphasis on new clean-coal plants, a modern 500 or 800 MW clean coal plant can be extended by 300 MW or more during the day time or high demand periods up to 16 hours a day. The compression load of 200 MW in such a system will allow a large "virtual" turndown of the clean coal plant at night from its 85% Maximum Continuous Rating (MCR), enabling 800 MW to be delivered from a 500 MW clean coal plant, with the equivalent premium fuel, such as natural gas, addition of only a 90 MW gas turbine.

Decoupling the Compressor trains from the Generating train allows for more flexibility in Compression optimization and utilization. Motor driven compressors in 50 MW or lesser increments allow sites and storage volume to best serve the transmission grid needs, as well as act as load sinks of 100/200 MW or 300 MW, to avoid unnecessary cycling at base loaded plants. The illustration below captures the decoupling of compression from the power cycle.



The chart [Fig 2] shows the aging generation fleet in the USA. The retirement of such plant, and replaced with CAES technology will improve overall efficiency and lower emissions per MW/hr generated.

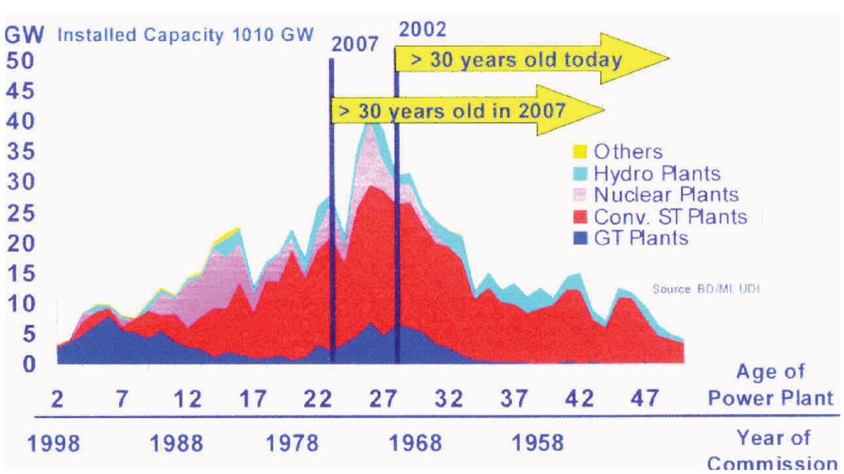


Fig.2. Age and year of commission of U.S. coal power plants. The red portion represents conventional steam plants.

Applications

Stored energy integration into the generation-grid system is best illustrated in [Fig4] "Energy Storage Applications on the Grid". This covers a wide field in every aspect of generation-transmission and distribution. The ability of the various technologies to react quickly, converting the stored energy back to electricity readily provides three primary functions: **Energy Management** (hours of duration) load leveling, or peak period needs; **Bridging Power** (seconds or minutes duration) assuring continuity of service, contingency reserves or UPS (Uninterruptible Power Supply); and **Power Quality & Reliability** (milliseconds to seconds duration) in support of manufacturing facilities, voltage and frequency controls.

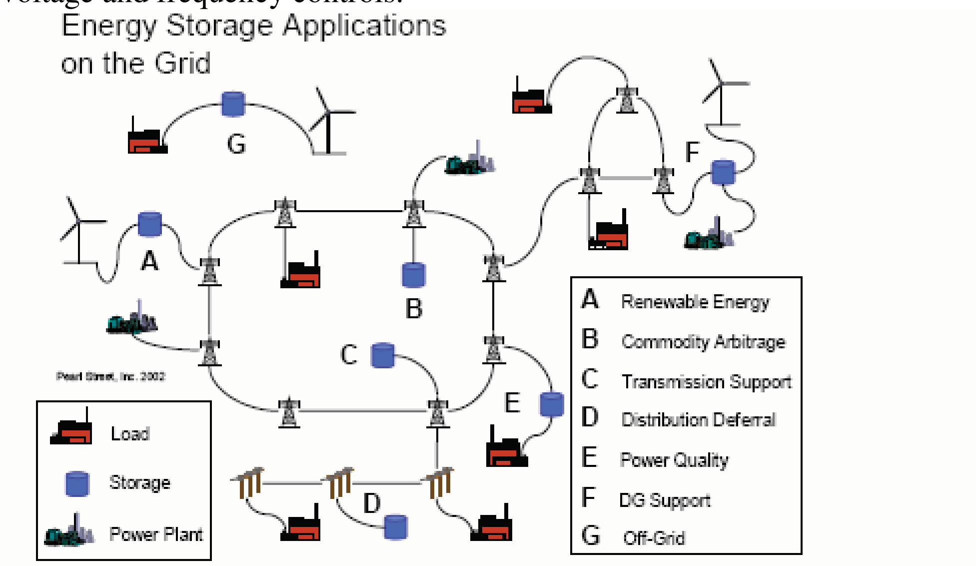


Fig.4. Energy Storage Applications on the Grid

Benefits from Energy Storage

One of the first benefits would be to fully utilize capital assets, considering that the national average for generation capacity factor is 58/60% and transmission 50/52%. Bulk Energy Storage will allow the most efficient units to be fully-utilized, and allow optimization of the generation mix. Furthermore it will avoid the use of inefficient units using premium fuels during peak periods. Needle peaks can be readily met with storage at the distribution level, or with current installed "peaker" unit capacity.

The market or economic benefits from Energy Storage can be quantified in four major areas of the electricity supply chain, namely**: generation; transmission & distribution; energy services; and renewable energy storage**. Projected benefits over a 15 year period for the USA Generation and T&D system could exceed $100 Billion.

Market Potential

Current studies and CAES projects in advanced stages of development clearly indicate that power modules from 100 to 300 MW are competitive with CC power plants for Mid-Range or Mid-Merit generation up to 4200 hrs/yr. Most base-load capacity is provided by Coal-fired power plants, with Nuclear accounting for 72% of the electric energy production in the US. This readily translates to a lot of daily cycling of base-load plants and specific to GT/CC power plants, this increases wear and tear and maintenance costs, such costs quantified in a study by Aptech. [Ref.2] The bottom line is higher energy production costs without storage facilities. It is to be noted that the installed base of GT/CC plant represents 34% of the installed capacity, providing only 17% of the MW/hrs. In a competitive environment many of these plants will not earn sufficient revenue to pay off their debt financing.

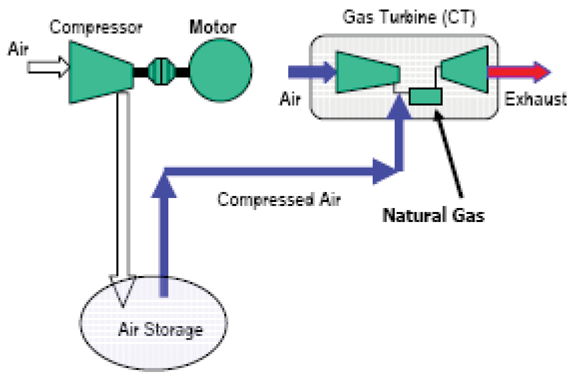
With the installed generating capacity in the US heading for 1000 GW, a simple goal of a modest addition of 5% of the installed capacity assigned to Bulk Energy Storage, a potential of 50GW could be realized in the near future. Present available storage sites readily account for 15/20 GW of Bulk Energy Storage-- a reality in the next 10/15 years. The technologies considered in this paper can readily address these projected needs.

Future Prospects (Developments)

Pumped Hydro has clearly demonstrated the value of bulk energy storage. While these benefits are recognized and utilized, new facilities have languished; projects in development do show promise and opportunities for implementation. The requirement for efficient Clean Coal concepts, such as IGCC (gasification) can be enhanced with storage systems to keep the plant at an 80% or better load factor during the off-peak demand periods, and deliver the added stored capacity during high demand

New concepts are being proposed especially with the growing capacity of wind energy, currently backed by tax incentives; however, at 6800 MW and projected substantial growth, energy storage and wind energy integration using CAES or Flow batteries, ganged Flywheels could lead to better economic utilization of a substantial resource operating at below 30% capacity factor—storage could drive this capacity factor to 65% or higher. Concepts outlined in a recent paper at EESAT 2003 Conference [Ref.3] suggested sub-surface storage using large diameter pipes such as typically used for natural gas transportation. Using a storage complex of 2000 meters of pipe, a system that will provide 60 MW/hrs (15 MW x 4hrs) could enhance power supply at remote wind farms.

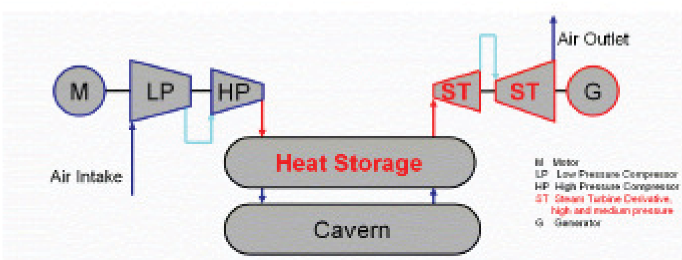
This storage pipe concept could be applied to existing GT/CC plants, increasing the hot day output 20/25%, by injecting the stored air into the combustors with or without humidification. By applying the humidification concept, the air supply in a CAES plant could reduce the required storage volume by 30% or more, or increase the operating hours by 30% of the specific cavern storage volume. In another Hybrid concept proposed, a conventional gas turbine could be coupled with storage and a separate unfired air expander for increased flexibility of operation.



. Using a 180 MW GT, the plant output would exceed 400 MW. The advanced technology GT with 38% efficiency can be operated independently when the cavern air supply has been drawn down.

.**Advanced** concepts of Adiabatic Compression & Expansion, requiring Thermal Energy Storage (TES) have been studied; such systems would ideally benefit renewable energy systems such as solar bio-mass and wind, adding capacity with no premium fuel consumption.

Diabatic CAES plant loses heat from the compression cycle, which must be re-generated or added to the compressed air before entering the Turbine expansion cycle. ***Adiabatic*** CAES will benefit from the thermal energy storage to preheat the stored air, which will be expanded adiabatically through a sliding pressure air turbine, with the added benefit that no CO2 is generated in this process .Such studies have been completed in Europe with 19 different partners with support and involvement of European Commission through a research contract. Thermal storage devices have been investigated such as the "Cowper" heat storage devices in glass and metallurgical industries. Sizes of 30, 150 and 300 MW have been defined.



Smaller adiabatic systems suitable for isolated Wind Turbine systems where no fuel is added are under development, with utilization of the cold exhaust air to be used for cold storage systems or advanced concepts of "freeze" desalination

Projects in Development (Brief *Summaries/current status probably delayed or deferred)*

Several large CAES projects, with different storage media, are in development. Two are fully permitted and of particular note, even when the financial climate for new projects, requiring major investments, has slowed for such innovative concepts.

1. Norton Energy Storage, Ohio

One of the first potential CAES projects in the USA, developed by Haddington Ventures Inc., is the huge facility at Norton, in Ohio, which is permitted for 2700 MW of capacity, and as a commercial project when completed, will be one of the largest Bulk Energy Storage facilities, including PHS, to be built in the USA. As currently planned, this will consist of 9 x 300 MW (or larger)nominally rated CAES units, supported by an underground storage cavern volume of 338 million cubic feet (120 million cubic meters), 2,200 feet (722 meters) below the surface, originally mined in a limestone formation.

Using 200 MW (4 x 50 MW) compression trains for each 300 MW power train will allow for 16 hours generation by day for 5 days a week. Four units producing 1200 MW could operate for 4x16 hour days with out requiring recharging of the cavern. With more available surface space, cavern volume could support 5400 MW or more for 8 to 10 hours operation, 5 days a week. This cavern was originally permitted for a PHS that would only support a small fraction of that capacity.

With this modular approach, the capacity could be added over 5 years allowing full integration in Ohio and the East Central Area Reliability (ECAR) region. Moreover, CAES technology would not only provide reliable full electric power service for midrange and peaking hours, but would extend the capabilities of large low cost base load generation. This would also allow older, less efficient and polluting power plants to be retired.

1. *Project Markham, Texas*

This 540 MW project in Matagorda County, Texas, developed by Ridge Energy Services, will consist of four 135 MW CAES units, with separate LP and HP motor driven compression trains..

The smaller 135 MW units in this project provide a very wide load range from 10 MW minimum per unit and incremental output until all four units provide the system 540 MW. The full 540 MW can be delivered in less than 15 minutes. This is a tremendous value to the grid, providing reserve capacity, before cycling of base-loaded plant is required. The variable capacity range would be 840 MW (300 MW Compressor + 540 MW Generator). Nox emissions will be controlled to 5.0 vppm with SCR in the HRU.

This site has Salt Dome cavern storage suitable for high pressure air storage, and unique in that natural gas storage is available on the site as well. This is ideal, as energy can be arbitraged either as electrons (electricity) or Btu's (natural gas), or a combination of both. Compression trains totaling 300 MW, for the required shorter off-peak charging period, will also act as a very large load sink on the system

2. Iowa Stored Energy Project(ISEP)

This project under development by Iowa Association of Municipal Utilities, promises to be exciting and innovative. The compressed air will be stored in an underground aquifer, and wind energy will be used to compress air, in addition to available off-peak power.

A separate section of the underground aquifer will be utilized for the storage of natural gas, allowing the CAES facility and other utilities to purchase gas when prices are lower. The plant configuration is for 200 MW of CAES generating capacity, with 100 MW of wind energy. While wind might be the lowest cost generation system, it is variable and not reliable as a constant source. CAES provides the 'battery" storage for wind energy

and makes wind energy a dispatch resource. CAES will expand the role of wind energy in the region generation mix, and will operate to follow loads and provide capacity when other generation is unavailable or non-economic. The underground aquifer near Fort Dodge has the ideal dome structure allowing large volumes of air storage at 525 psig (36 bar.) pressure.

Other States such as Illinois, [“Energy Storage Options for Central Illinois” Ref 4] also have this potential for Wind & Storage, but Iowa is in the forefront, possessing a site ideal for a CAES power plant and wind farm.
These development plans have a future vision for the value of carbon reduction—adding reliable renewable resources with storage concepts such as CAES. In reality there are no shortage of potential projects and suitable sites for Bulk Energy Storage development, there is no policy or incentive to implement the advantages and benefits demonstrated by NG Storage or the Pumped Hydro storage now serving the Nation’s power system.

What are the Economics of CAES Systems?

The best proof of the economics are to look at what Alabama Electric Cooperative are achieving as well as many different studies that have been conducted comparing CAES with current CCPP as well as IGCC and PC coal fired power plants. Renewable energy such as Wind also demonstrates lower grid costs when integrated with CAES. Site and location specifics will obviously indicate different values and a comparison will have to be made for different regions considering “off-peak” power prices or “spilled” wind energy costs as well as the optimized benefits such as Capacity value, Transmission value, Dispatch value, Firming value, shaping value (wind) etc.
CAES power plants like in the Pumped Hydro have to consider the storage volume and type of storage, such as solution mined cavers in Salt domes (as done for NG) hard rock caverns, aquifers or depleted gas wells. Solution mined caverns are the least cost and would add from $50 to $65/kW depending on the volume required (kW/hrs) to the overall installed cost which would be comparable or lower to a CCPP installation of equal size.
From a Pearl Street Executive Briefing Report-“Energy Storage-The Sixth Dimension of the Electricity Value Chain” the following excerpts are provided, indicating the positive economic impact utilizing Bulk Energy Storage.

> The most in-depth review of the direct impact of energy storage on the US electric power industry comes from a 1993 DOE study that estimated a $57.1 billion positive economic impact for the economy from the widespread use of “high-density storage devices to…store power during off-peak periods and deliver it when loads exceed generating capacity.” Using the same methodology, we found a potential value of $174.6 billion.

> ***By improving the operational efficiency of the generation segment of the industry, energy storage facilities hold out the potential to provide $10.6 billion worth of positive economic impact to the economy over the next 15 years.***

> ***By improving the operational efficiency of the transmission segment of the industry, energy storage facilities hold out the potential to provide $29.9 billion worth of positive economic impact to the economy over the next 15 years.***

By improving the operational efficiency of the energy services segment of the industry, energy storage facilities hold out the potential to provide $31.2 billion worth of positive economic impact to the economy over the next 15 years.

By improving the operational efficiency of the renewable energy segment of the industry, energy storage facilities hold out the potential to provide $2.9 billion worth of positive economic impact to the economy over the next 15 years.

Conclusions and Recommendations

The current storage concepts are ready for deployment—storage needs to be implemented, not just here in the US, but in all developed and developing countries. The biggest impact is probably the flexibility of operation. Economic dispatch to meet markets needs, absorb excess capacity, or large load swings with compression—these are powerful market tools. It is possible to improve energy management, and obtain better value from bulk power purchase and sales; reduce risks and vulnerabilities from fuel price shocks. The volatility in particular in the US will always be a factor, long term projections show that natural gas prices will continue to rise, with increased demand, which cannot readily be met from new sources other than LNG imports.

The trend of increased harvesting of wind energy will put further stress on the grid reliability. This is already manifested in Europe, where a far greater percentage of its generating base is committed to the variances of wind power production.

Bulk Energy Storage will most importantly "buffer" utilities from the lack of spinning reserve and load following capability as a result of many independent power plants (IPP) installed in the last 5 years. It will remove concerns about power quality, and new threats to reliability.

Energy Storage provides security, reduces transmission constraints, extends (optimizes) the capabilities of efficient clean coal plants, reduces emissions, enhances renewable energy. It provides load management, (rapid response) frequency and voltage control, spinning reserve, black start capabilities, and supports distributed generation.

How to proceed - Some Policy implementations

- Recognition of Storage as the Sixth dimension
- Minimum Storage capacity of 10% should be a goal (Federal)
- R&D Efforts for small scale storage - continued/expanded
- Advanced Technologies for Bulk Energy Storage/to be added
- Return to basic efforts of Energy Storage of 20 years ago

Policy Makers need to recognize the value of Energy Storage - similar to that of the Natural Gas Storage that benefited the Industry and their consumers.

The current storage concepts are ready for deployment - storage needs to be implemented. Steady implementation 5/10 years ago would have avoided the excesses and looming bankruptcies of Power facilities - simply there would have been no need to build that many - baseload plants could have been more fully utilized.

Energy storage provides - Security - Reduces Transmission Constraints - extends (optimizes) the capabilities of efficient clean coal plants - reduces emissions - Enhances Renewables - Provides load management - (*fast response)* Frequency and Voltage Control-Spinning Reserve-Black Start - Supports Distributed Generation

References: ***(from ECOS paper)***

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[3] Nakhamkin, Michael. Wolk, Ronald. van der Linden, Septimus. Hall, Ron. Bradshaw, Dale.- "New Compressed Air Energy Storage Concept Can Improve the Profitability of Existing Simple Cycle, Combined Cycle, Wind Energy, and Landfill Gas Combustion Turbine-based Power Plants"-EESAT 2003 Conference, San Francisco CA. Oct,27-29, 2003.

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Reports and other sources for further information:

a) Energy Storage: The Sixth Dimension of the Electricity Value Chain. Richard Baxter and Jason Makansi, Pearl Street Executive Briefing. www.energystoragecouncil.org
b) The Economic Impact of CAES on Wind in TX,OK &NM. Ridge Energy Storage &Grid Services—67% funded by Texas State Energy Conservation Office and US. Department of Energy.
c) EPRI-DOE Hand Book of Energy Storage for Transmission and Distribution Applications-1001834
d) Energy Storage: A Non-technical Guide. Richard Baxter. Pennwell, 2006.
e) Advanced Adiabatic Compressed Air Energy Storage for Integration of Wind Energy" EWEC 2004, Nov , London, UK. Proceedings of European Wind Energy Conference Bullough, Chris. et al