Economic Value of Compressed Air Energy Storage in Conjunction with Large Scale Wind in McCamey

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Introduction

Texas ranks second amongst the 50 states for its wind resource potential, and developers in Texas have not hesitated to take advantage of the state's favorable renewable resource development climate to build several hundred megawatts (MW) of wind generation. Thanks to enactment of a strong renewable portfolio standard, 912 MW of new wind generation was developed in Texas in 2001 alone, 683 MW of which was built in the McCamey area of West Texas. With average annual wind speeds of 19-20 mph and incentives from local economic development authorities, it was not long before McCamey was dubbed the "Wind Capital of Texas." By the beginning of 2002, McCamey's total wind power capacity totaled 758 MW, spread over 5 wind farms. While the amount of wind generation was hailed as a great success for renewable energy, the true picture presented far more complications for integration of the wind energy into the grid. Available transmission capacity out of the McCamey area, a remote location with little local load, was only about 400 MW. Therefore, the presence of 758 MW of wind power created severe local congestion problems that could only be solved via curtailment of the wind farms when the wind speeds were high enough for total wind generation to exceed the thermal limits on transmission. Developers, eager to build even more wind farms on the McCamey mesas, and suffering economic losses from the curtailments of existing wind generation, lobbied heavily for accelerated development of transmission solutions to solve existing congestion issues and to keep the door open for further wind resource development in Texas' best wind regime. With this backdrop, the Texas State Energy Conservation Office (SECO) commissioned a study in the spring of 2003 to examine what benefits, if any, large scale energy storage would have in addressing the transmission issues facing wind generators in McCamey.

The SECO sponsored study, led by the Lower Colorado River Authority (LCRA) with contributions from Ridge Energy Storage & Grid Services and other parties, showed promising results for the ability of compressed air energy storage (CAES) to significantly reduce curtailments under a range of future wind and transmission buildout scenarios. The study focused on the technical capability of CAES to perform as a substitute for traditional transmission assets. While operating in compression mode, a McCamey area CAES plant was found to allow wind energy production above the thermal limits on transmission out of the McCamey area in an amount equal to the level of compression. Thus, if the CAES plant were compressing at a level of 400 MW, then wind generation would be able to be at 400 MW higher than thermal limits on transmission without creating an overload situation that would require curtailment. In other words, nameplate wind generation capacity theoretically would be able to be 400 MW higher than transmission capacity. However, the storage capacity of the CAES air cavern presents a practical limit on the amount of curtailment reduction that a CAES plant can achieve. Even with a modeled storage capacity of 10,000 MWh, with the assumptions regarding wind patterns in McCamey, there are times when the cavern would get full, temporarily preventing the CAES plant from storing wind energy until transmission capacity opens up for the CAES plant to release the stored compressed air and regenerate electricity into the grid. Since the CAES plant could not be shown to reduce curtailments 100%, it was not considered to be a substitute for an incremental transmission wire on a purely technical basis. However, the study did show that a CAES plant with 400 MW of compression and 270 MW of generation capacity would enable an additional 400 MW of wind to be accommodated within an existing

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Ridge Energy would like to acknowledge the support of the Texas State Energy Conservation Office, which provided funding for a prior study that was the basis for this paper. The prior study was entitled *Study of Electric Transmission in Conjunction with Large Scale Energy Storage Technology*, and the study report can be accessed at www.seco.cpa.state.tx.us/seconews_wind%20storage.pdf. The prior study will be referenced several times in the body of this paper, and will be simply called the "SECO study" for ease of nomenclature. Ridge Energy would also like to acknowledge the contributions of the other participants in the SECO study, including the Lower Colorado River Authority, RnR Engineering, and Walter J. Reid Consulting.

transmission plan with minimal residual curtailments and with a reduction in curtailments of over 600 GWh annually compared to the congestion that would have been present without the CAES plant.

While the SECO study showed significant curtailment reduction benefits, the study was designed to focus strictly on the transmission benefits of CAES. The study costed out CAES operations, but did not address the value of the service that the CAES plant could offer, nor did it address any generation-related benefits of combining CAES with wind, such as any value from firming the wind production or shaping the resulting deliveries. The objective of this paper, therefore, is to build on the analysis conducted in the SECO study and take the evaluation of CAES with wind at McCamey to the next level. Using the same basic assumptions that were developed for the SECO study, Ridge Energy Storage has quantified the value of the curtailment reduction and compared it to the cost of a CAES plant to show the cost/benefit comparison of a CAES facility. The economic and operations analysis was also expanded to include non-transmission values of CAES, such as firming and shaping of the wind energy. Furthermore, this paper shows how the function and value of the CAES plant change over time as new wind and transmission additions are made to the system.

Generic Value of CAES to Wind

Because of its ability to provide long duration bulk power storage and rapid response in generation and compression modes, CAES offers benefits to wind in several areas.

Voltage/VAR support. The CAES plant generators and motors can supply leading or lagging VARs to the grid. In situations where the CAES plant site is located in the proximity of the wind generation, the compression motor load provides grid stability in an area with excess wind generation during low system load periods.

Regulation/Spinning Reserve. The CAES components can ramp between minimum and full output in minutes, allowing CAES to smooth the variable output of wind generation and to maintain system frequency within required limits. This capability is available during both the compression and generation modes of operation.

Firming/Shaping. The rapid response capability of the CAES plant can be used to shape the wind output to produce a generation profile that is more compatible with grid requirements and demand for power. This minimizes the need to have other system thermal resources standing ready to replace or supplement variable wind generation output. Coincidentally, the storage of off peak wind generation during the shaping process allows the energy to be redelivered during on peak periods, thus providing an additional benefit to the system.

Capacity Value. The ability to store energy and redeliver on a dispatchable basis means that CAES provides capacity that can be used to meet a utility or retail energy provider's requirements for operating reserve capacity. ERCOT requires a 15% reserve capacity margin. Since the point of a reserve margin requirement is to ensure ability of the grid to serve peak demands with reliability and relative price stability, it is essential that any generation capacity used to satisfy the reserve requirements be on call to serve peak demand. Wind generation has a hard time satisfying this requirement in ERCOT. West Texas wind patterns are such that wind generation is relatively low during the peak month of August. In addition, the wind exhibits strong diurnal profiles, making it more likely that wind generation is dropping during the day, while demand for electricity is rising. Combining wind with storage ensures that wind can get credit for operating reserve capacity in an amount at least equal to the generation capability of the CAES facility.

Transmission Benefits/Curtailment Reduction. Congestion is caused by too much wind generation relative to available transmission capacity (ATC). Without other thermal resources in the area that can back down, the only solution to maintain system stability when wind speeds are high is curtailment of a portion of the wind generation. CAES in compression mode can provide load to the grid to absorb the excess energy and can store the energy for redelivery when the wind speeds die down and transmission capacity opens back up.

For the purposes of this paper, a limited number of functions were modeled for CAES operations due to the complexity of optimizing across all of the potential value generation strategies. The functions modeled were the provision of capacity, shaping and firming energy deliveries, and reducing wind curtailments.

Assumptions and Methodology

We have developed an 8760 model to simulate wind energy production and CAES operations in conjunction with the wind. The model starts with an assumption of what an hourly wind power production profile would be for a sample year. We have used a profile similar to the ones analyzed in the SECO study. In that study, 41% was used as the capacity factor assumption for the wind, and we used the same capacity factor assumption. The profile we used is indicative of west Texas diurnal and seasonal profiles, and also incorporates the propensity of wind to blow at high intensity for several days in a row during the windy season. The profile is scaled by the amount of the wind capacity to project potential wind energy production for each hour. Since the profile shows potential wind power generation, if that generation level were higher than the ATC for a particular hour, then the model assumes that a portion of the wind generation would be curtailed to maintain system reliability.

The model calculates the cost/benefit of CAES by determining what types of power products could be sold with a wind/CAES combination and what value those products might have in the wholesale power markets. Adjustments are made for other values that would not be reflected in the power markets, such as the value of production tax credits (PTC) for wind energy that would otherwise have been curtailed. The value of PTCs in 2003 dollars is $18/MWh, which is equivalent to $27.69/MWh on a pre-tax basis using a 35% tax rate.

The products considered for sale under a combined wind/CAES approach include renewable energy credits (RECs), scheduled power and intermittent power. RECs are assumed to be stripped off from the wind energy as generated and sold to the customer separately. The scheduled power is considered to be a combination of wind energy, compression load, and CAES generation delivered in a particular shape. For now, the shape has been defined rather simply as a combination of various power blocks. The user defines a target shape for firm power deliveries by specifying what combination of 7x24, 7x16, 5x16, and 5x8 blocks is desired. The specification can vary by month to reflect expected wind and system conditions. For example, the shape for March can be defined to contain more baseload 7x24 deliveries because of the heavy wind production, while in August, a typically low wind month, the shape can be defined to include more 5x8 energy to meet the highest demand hours in the peak month.

Once the user has defined the target shape for the scheduled power deliveries, the model determines how a CAES plant would have to operate in conjunction with the wind in order to create the desired shape. Generally, if hourly wind generation is higher than the amount of scheduled energy, then the CAES plant uses the compressors to balance the wind energy to the scheduled level. Similarly, CAES generation is used to supplement wind generation if the scheduled level is higher than potential wind generation. The model takes into account minimum load and generation levels for the compressors and turbines, so on occasion, the shaping is imperfect. Furthermore, as in the SECO study, the cavern size limits the amount of energy that can be taken off the grid at times – i.e. the cavern gets full, and compression is no longer available as a resource for balancing the wind energy. The parameters for the shaped energy definition are set such that the cavern is never allowed to run out of air and supplemental CAES generation is always available to provide the required amount of scheduled energy. The energy delivered in excess of the scheduled energy is considered to be intermittent energy.

The scheduled energy is valued as a function of the blocks that make up the desired shape, with each block being valued as a function of gas price. The 7x24 block was assumed to be priced comparably to combined cycle baseload power, and the 5x8 block was assigned a heat rate value comparable to a gas turbine. Gas price was set at $5.00.

The intermittent energy, having the characteristics of wind, is valued at $15/MWh. This value comes from the difference between an assumed contract price of $25 for bundled wind energy and associated renewable energy credits (RECs) and the value of the RECs themselves. We used $10/MWh for REC value.

In a situation where there are potential curtailments of wind, CAES compression was used to capture energy that would have been curtailed, as long as there was room in the cavern. There is a tradeoff between maximizing the ability of a CAES facility to reduce potential curtailments and trying to use any of the CAES capacity in a wind shaping function. The reason for this is that shaping activities require use of the limited air storage capacity, and therefore it becomes more likely that when compression is needed for curtailment relief, that the CAES plant would be unavailable due to the cavern being full.

The CAES plant can also be used to sell capacity in support of operative reserve requirements. Currently, ERCOT is in an overcapacity situation, and operative reserve capacity does not have much value in the market. However, several companies have announced that they will be shutting down or mothballing certain generation plants, and by 2006, which is the start year for the analysis, growth in peak demand will have lessened the overcapacity situation, encouraging companies to resume placing value on capacity. We have used an assumption of an annual average of $3.50 per kw-month, which is a substantial discount from what it would cost to construct a new gas turbine peaking plant to meet reserve requirements. Capacity value applies whether CAES is operating in wind shaping mode or curtailment reduction mode.

The SECO study provides background information on CAES, and we are using the same design and configuration for this follow-on analysis. The CAES plant considered was sized to have 400 MW of compression, 270 MW of generation, and 10,000 MWh of storage. The heat rate is 4,300 Btu/kWh, and the energy ratio is .75. We also assumed the same capital cost for the CAES plant, which translates into an annual carrying cost of $30 mm per year.

All of the economic values are in constant 2003 dollars. Thus, in making projections for future years, there is no built-in escalation factor for inflation.

Initial Case

We picked 2006 as the starting year for the analysis. First, it would take until at least 2006 to get a CAES plant developed and constructed in McCamey. Second, by 2006, the current transmission improvement plan involving the buildout of the 138 kv sytem for the McCamey area should be completed. According to loadflow analysis from the SECO study, the buildout should result in at least 800 MW of ATC from the McCamey area. Thus, the issue of wind curtailments for existing wind capacity should also be resolved by 2006, unless new wind is built such that nameplate wind generation capacity exceeds 800 MW.

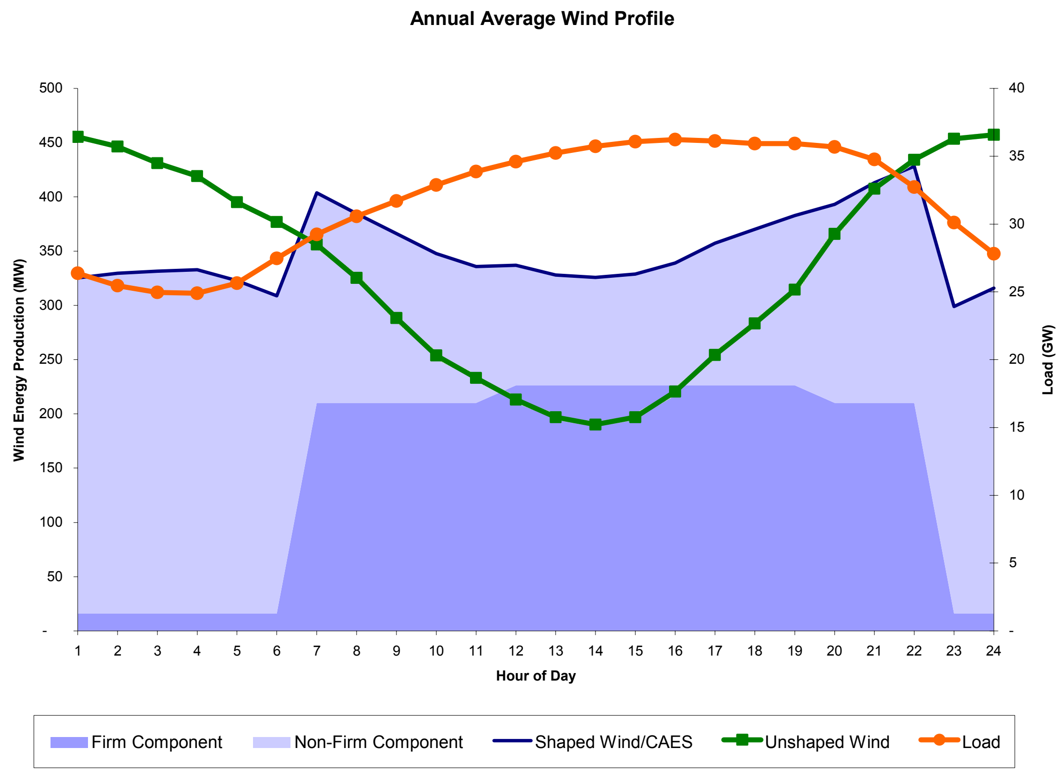
We assumed that the wind generation would be built up to equal the ATC, thus contemplating the existence of 800 MW of McCamey area wind generation. We also assumed that a 400/270 MW CAES plant would be in service for the entire year. Without the need to manage potential curtailments, the full capacity of the CAES plant can be used for firming and shaping functions.

As can be seen in Chart 1, the average diurnal profile of the unshaped wind is almost exactly opposite to that of load. This means that wind energy tends to be produced when the power is less valuable to the grid. In addition, the fact that the wind energy tends to drop as system load increases means that an additional burden is placed on load-following resources in the system to compensate for the wind. This burden is fairly minor if wind energy is a small percentage of the system generation resources, but becomes more significant as the penetration of wind into the grid increases.

Comparing the net wind/CAES deliveries to the original wind profile shows a tremendous increase in the amount of energy delivered during the on peak hours of the day, with a commensurate decrease in the wind delivered in the off peak hours. In addition, the shaded areas show how the net wind/CAES deliveries are split between scheduled, firm power and intermittent or non-firm power. Even with the small CAES size (270 MW gen) relative to the size of the total area wind resources (800 MW), the CAES plant is successful in converting a substantial portion of the wind energy into power that can be scheduled as firm power, comparable to power from thermal resources, and available during the highest value hours of the day.

After accounting for the variable operating costs of the CAES facility in this scenario, we calculated the value from the conversion of intermittent wind into firm, shaped power and the provision of capacity to be $34 mm.

Chart 1



Additional Wind

Next we assumed the addition of 250 MW of wind to the McCamey area in 2007, with no increase to the ATC, resulting in 250 MW of excess wind. This assumption seems reasonable since that we have already witnessed the willingness of developers to build wind in excess of transmission capacity. Now we had a situation where curtailment issues come back into play. Therefore, the CAES plant had the opportunity to create additional value from providing compression load at times when the wind was high and the transmission system was constrained. This compression load would enable the wind farms to generate at higher levels, avoiding curtailments, and recovering the value of lost PTCs, RECs and energy. What we saw was that the total value created by having the CAES facility available to manage curtailments while also shaping wind was now almost $43 mm. The capacity value stayed constant, and the shaping value went down, because some of the CAES plant was being used for curtailment reduction. The value of curtailment reduction was determined by the recovered PTCs, RECs, and energy, and totaled almost $9 mm for the year.

Full Curtailment Scenario

With the addition of another 150 MW of wind in the 2008 scenario, we now had 400 MW of excess wind, and 1200 MW of wind total. Without a CAES plant, this excess wind would have caused significant curtailments, but using the CAES plant to perform a combination of curtailment reduction and wind shaping functions, the annual curtailments were reduced by 351 GWh, contributing $18 mm of annual value based on assumed contract value and PTCs for the recovered energy. Note, that if the CAES plant had been operating solely to maximize its ability to reduce curtailments, curtailment reduction would have been 577 GWh. This highlights the tradeoffs that can be made in deciding how exactly to use a CAES facility. Although the amount of curtailment reduction that was achieved by operating the CAES plant in wind shaping mode was lessened, the total annual value created by the CAES plant was estimated at $51 mm for this scenario.

More Wind, New Line Planned

Projections of additional wind development beyond 2008 depend on various factors, including the cost of other power generation alternatives, an increase in the Texas renewable portfolio standard, significant demand from green power pricing programs, and/or the implementation of a national renewable portfolio standard. Assuming that for some reason there is continued interest from wind developers in building new wind farms, we can continue on with our wind and transmission buildout scenarios.

If we assume that in 2009, another 300 MW of wind is developed, two things happen. First, since the total amount of wind interconnect agreements in the McCamey area would total 1500 MW, transmission developers could start work on the next increment of transmission, expected to be a 345 kv line from McCamey to Twin Buttes. Second, because a new transmission line is being planned, under ERCOT guidelines, special protection schemes can be implemented in McCamey that increase the available transmission capacity to 1300 MW. This means that the amount of excess wind becomes only 200 MW. In this situation, with more wind to manage, the value created by the CAES plant was estimated at $43 mm. Assuming five years to develop and complete construction of a new 345 transmission line, the CAES plant continues operating in the same mode through 2012.

New Line In Service

With the 345 line in service in 2013 and assuming no new wind development, the curtailment issues are resolved, so the CAES plant can move back into full wind shaping mode. The value created by the CAES plant with 1500 MW of wind was estimated at $37 mm.

Buildout Summary

<u>Chart 2</u>

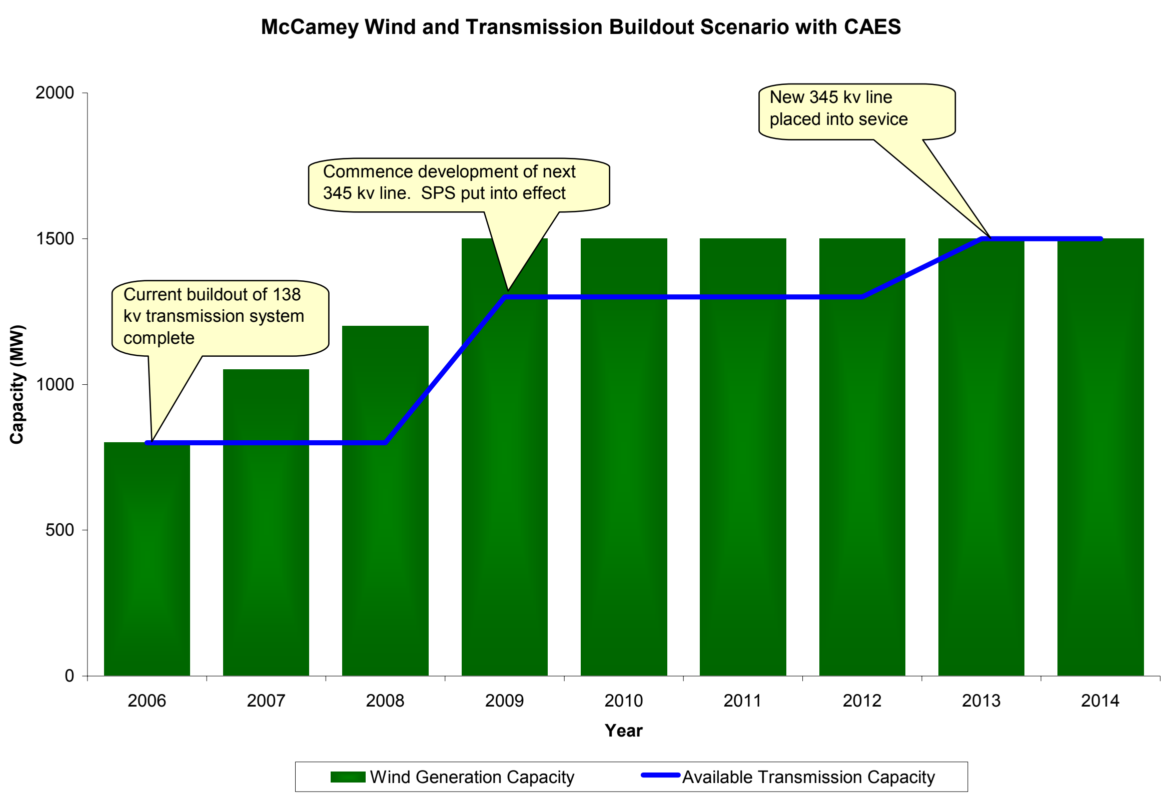
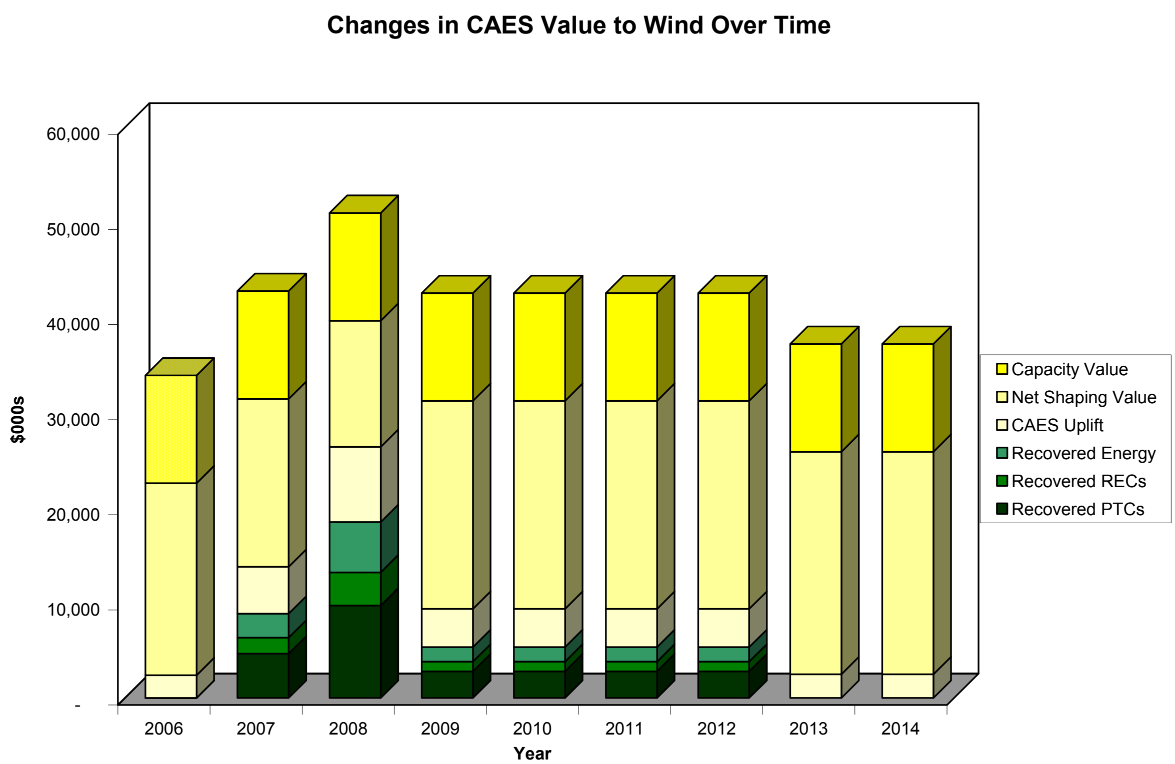


Chart 2 summarizes the transmission and wind buildout assumptions outlined above.

Chart 3 provides the corresponding breakdown of the value estimates achieved by combining a CAES plant with the wind generation resources at McCamey. Note the change in relative contributions of shaping value versus the recovery (curtailment reduction) components. Also, note that in each year, the total value is significantly higher than $30 mm, which is the approximate annual carrying cost for a CAES plant of the contemplated size at McCamey. This carrying cost includes recurring expenses such as fixed O&M, property taxes, insurance, business management, utilities, and auxiliary power, and also includes minimum required returns for debt and equity investors. Therefore, there is several million dollars worth of value above and beyond what would be required for a positive return on CAES investment that can be shared with customers and other stakeholders.

Chart 3



Conclusion

The analysis we have performed shows that a CAES plant in the McCamey area would add tremendous value to the grid by providing capacity and firming and shaping a portion of the local wind generation into a more useful power product, as well as reducing curtailments of wind generation as new wind is added to the grid in that area. The function that CAES performs can adapt to changing requirements for wind shaping services versus curtailment reduction services. Though this is not a comprehensive evaluation of all products that could be sold from a combined wind/CAES project, for example, ancillary services or arbitrage services, this analysis does demonstrate the merit of analyzing multiple value streams in determining the cost justification for a CAES plant.