STUDY OF ELECTRIC TRANSMISSION

IN CONJUNCTION WITH

ENERGY STORAGE TECHNOLOGY

August 21, 2003

PREPARED BY
LOWER COLORADO RIVER AUTHORITY

REPORT FOR
TEXAS STATE ENERGY CONSERVATION OFFICE

CONTRIBUTORS

NISHA DESAI
Ridge Energy Storage & Grid Services
Houston, Texas

SERGIO GARZA, P.E.
Lower Colorado River Authority
Austin, Texas

DEBORAH LEWIS, P.E.
RnR Engineering
Wimberley, Texas

SYLVAIN LACASSE
Lower Colorado River Authority
Austin, Texas

LEAH M. MANNING, P.E.
Lower Colorado River Authority
Austin, Texas

STUART NELSON, P.E.
Lower Colorado River Authority
Austin, Texas

DAVE PEMBERTON
Ridge Energy Storage & Grid Services
Houston, Texas

WALTER REID
Consultant
Austin, Texas

RUSTY SPENCER
Ridge Energy Storage & Grid Services
Houston, Texas

ROGER WILSON
Ridge Energy Storage & Grid Services
Houston, Texas

Contact Information:

Lower Colorado River Authority	(512) 472-3200
Ridge Energy Storage & Grid Services	(713) 552-9300
RnR Engineering	(512) 636-9309
Walter J. Reid Consulting	(512) 335-0664

FINANCIAL ACKNOWLEDGEMENT

This study was developed as part of the Oil Overcharge Restitutionary Act, Chapter 2305, Texas Government Code, and the State of Texas Oil Overcharge Funds Disbursement Plan. Funding for this study is provided by Exxon Oil Overcharge Funds and/or Federal Funds received from the United States Department of Energy. The Lower Colorado River Authority and Ridge Energy Storage & Grid Services provided matching funds. Mention of companies, trade names or commerical products does not constitute or imply endorsement, recommendation or favoring of any agency.

DISCLAIMER

In performing this study, LCRA used data and information provided by others, assumptions that were considered reasonable and valid, and information regarding the state of the ERCOT system at the time this study was performed. LCRA performed the study in a reasonably prudent manner using information obtained from the third parties noted in the study. However, because it had no control over information provided by others, LCRA is not responsible for the accuracy of any information and/or data provided by other parties and, therefore, LCRA cannot warrant, guaranty or represent the accuracy of the results outlined in this study. Other entities using the same or similar information and/or data as that used in this study may reach different results. Persons relying on the results and conclusions discussed in this study do so at their own risk, and LCRA makes no warranties, guarantees or representations of any kind regarding the data, information, or conclusions discussed herein, including without limitation express and implied warranties of merchantability and fitness for a particular purpose.

Dated: August 21, 2003

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This paper documents the results of a study examining the impact of energy storage on wind generation problems in the McCamey area of West Texas. The study was conducted in three main parts.

First, an assessment was made of the current problems facing wind generation in the McCamey area. The problems can be quantified in the form of economic losses stemming from energy curtailments and additional costs associated with the need for reactive support for the grid. Based on 2002 criteria, economic losses for the system are estimated to be $21-25 million for the year 2002 alone. Above market cost for the provision of reactive support to the McCamey area is estimated to be almost $7 million in year 2002. With about $30 million/year in system losses, it is clear why policy-makers, regulators, and industry are interested in studying potential solutions that reduce these losses and prevent similar problems as additional wind generation in McCamey is developed in the future.

The next section of the study focuses on compressed air energy storage (CAES) technology and the parameters of a CAES project that could serve the McCamey wind resources in a curtailment reduction function. Along with a description of CAES and the design details of a typical CAES plant, the study also developed the key assumptions that were used in modeling the transmission impacts of CAES. These assumptions included the configuration of the CAES plant ("pumping" capacity, generation capacity, and storage capacity) and the technical assumptions, such as ramp rates and the ability to provide leading or lagging volt-amperes reactive (VARs) to the system for reactive support. The study also developed the operating regime assumptions for using the CAES plant to reduce wind energy curtailments. Finally, the study provided estimates that could be used to determine the cost to use CAES to reduce wind energy curtailments, such as heat rate and fixed and variable costs. These assumptions were used in the analysis conducted in the wind modeling/load flow analysis stage of the study.

The third section of the report focuses on the wind modeling, load flow analysis, and curtailment reduction analysis. In order to translate wind energy capacity curtailment to energy curtailment, it was necessary to develop data sets representing various hourly wind energy production profiles. Three sets of data were developed, each assuming a net average annual wind capacity factor of 41%. Load flow analysis was performed using the CAES assumptions, the ERCOT cases, and several scenarios for different levels of buildout of transmission and wind development to determine available transfer capacity (ATC) for each transmission scenario with and without CAES. ATC was defined by the lower of thermal or reactive limits on transfer capability. The ATC was then incorporated into a model with the hourly wind profiles to determine the impact of CAES on energy curtailment levels, as well as the CAES operating cost to provide the curtailment reduction service. A copy of this model is being provided with this paper as a wind curtailment calculator whereby interested readers can perform their own curtailment reduction analyses using their own wind profiles. It is likely that proprietary wind profiles will have different annual capacity factors and generation duration curves, and readers can perform their own analyses on how these differences impact the curtailment reduction estimates made in this study.

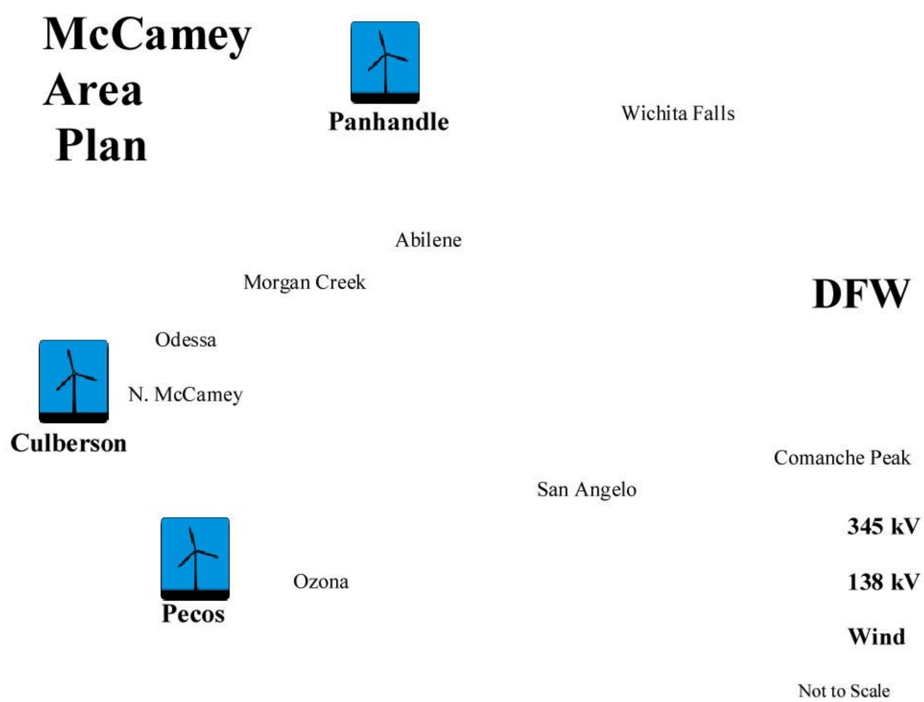
The primary goal of the study was to focus on the technical capabilities of CAES to alleviate the major transmission related problems affecting wind generation in McCamey, namely, curtailments and reactive support. With a narrowly defined scope, there were several issues that were not looked at or that were analyzed only at a first cut level. This study did not address regulatory issues or payment/compensation mechanisms for the curtailment reduction service. The study was also not intended to address the economic feasibility of a CAES plant in the McCamey area. To do so would have required additional work in optimizing the CAES plant configuration to meet the specific needs in West Texas, assigning compensation schemes for the plant, and evaluating non-transmission benefits of CAES, none of which were in the scope of the study. Finally, the study was not a comprehensive study of all transmission issues. For example, dynamic stability could not be addressed within the budget and time limitations set for the study, and indeed, a study of CAES impacts on transient stability would have been premature without completion of the underlying models to assess the impact of large amounts of wind on dynamic stability.

The modeling and analysis showed the following results: First, a CAES plant would provide wind energy curtailment reduction relief of over 600,000 megawatt-hours (MWh) in a number of different scenarios. However, the ability of energy storage to remove curtailments completely is limited due to practical constraints in the storage capacity. With the assumptions of wind profile used, on occasion the energy storage capacity gets full, and the CAES plant therefore becomes unavailable to provide additional energy storage. The benefit of delivering more wind energy is gained at the cost of installing more CAES storage capacity; the optimization is beyond the scope of this study. Because the CAES plant as modeled cannot reduce curtailments 100%, it does not substitute for transmission lines on a purely technical basis. Nevertheless, within a particular transmission plan, a CAES plant can allow more wind generation to be served, up to 400 MW more, with minimal residual curtailment levels.

This study also identified areas that should be addressed in further studies of large-scale energy storage and wind. A more detailed analysis of how several wind farms within a particular region would operate together would be needed to make better estimates of aggregate curtailment levels and transmission requirements. The optimization of the CAES configuration is a key area, since additional storage capacity or higher generation capacity would improve the ability to provide curtailment reduction. Designing the CAES plant to provide additional reactive support, particularly when the CAES plant is neither compressing nor generating, would have even greater benefits for the transmission grid. Once the underlying dynamic stability models for wind have been completed, the impact of energy storage on dynamic stability should also be addressed.

INTRODUCTION

In the year 2001, wind developers installed more wind generation in the McCamey area of West Texas than the transmission infrastructure could transfer from the region. The wind energy in the McCamey region is curtailed due to capacity transfer limitations. This curtailment is projected to continue through 2006. Major capital improvement projects to supplement the existing transmission system are on-going to resolve this curtailment, which will result in a hub and spoke transmission system configuration. This configuration will gather the wind energy at North McCamey substation and transfer it to the grid backbone on 138 kilovolt (kV) transmission lines. This plan can support from 900 – 1300 megawatts (MW) of total wind power, depending upon the installation and operation of special protection scheme (SPS) devices. If more than 1300 MW of wind generation is built in the area, additional transmission resources would be required. According to the current plan, the next transmission line to be constructed would be a new 345 kV line from McCamey to an existing 345 kV transmission line near San Angelo, which could support up to 1500 MW of wind generation under an N-1 contingency criteria. To serve wind in excess of 1500 MW, a second 345 kV transmission line would be required from North McCamey substation to Odessa substation, which would connect it to the main west-east 345 kV transmission corridor. The second line would support up to 2000 MW of McCamey area wind generation capacity.



The State Energy Conservation Office (SECO) contracted with the Lower Colorado River Authority (LCRA) to study the transmission benefits of large-scale energy storage for the curtailment issues facing wind generation in the McCamey area of West Texas as an alternative and/or supplement to the planned transmission system upgrades and additions.

In order to study the transmission benefit, a storage technology was selected and modeled. Several technologies exist for providing energy storage to the electric grid, such as flywheels, supercapacitors, superconducting magnetic energy storage, batteries, pumped hydro, and CAES. Most of the technologies available for electric energy storage do not actually store electricity rather, they convert electric energy to another form of energy, such as potential, kinetic or chemical energy, then convert the stored energy back to electricity at a later time. Nevertheless, these technologies are valid means of providing energy storage for the electric grid.

These technologies have various features and are targeted to solve different problems. The first step in deciding which storage technology to select for further evaluation was to define the critical features necessary to address the issues facing West Texas. Since the problem is congestion management for large-scale wind generation, an energy storage solution requires the capacity to store thousands of MWh for hours and even days. In order to increase the amount of wind energy transported by the existing transmission system, the storage technology must be able to absorb several hundred megawatts (MW) of excess wind generation at a time. Pumped hydro and CAES are the only energy storage technologies that have been field proven to provide several hours worth of energy storage at the 100+ MW scale. Since geologic conditions in West Texas are conducive to development of CAES, and topography and water supply are unlikely to support pumped hydro, CAES was selected as the appropriate technology to evaluate in this study.

CURRENT WIND CURTAILMENT COSTS

Enactment of the Texas renewable portfolio standard in Senate Bill 7 generated tremendous response from wind developers. In 2001, 912 MW of wind generation was developed in Texas, 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. Another 240 MW wind project, Noelke Hill, was announced in July 2002, promising to bring the region's total wind generation capacity up to a whopping 1,000 MW by the end of 2003.[1]

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. ERCOT records showed that 380,000 MWh of wind energy was curtailed i.e. not produced in 2002. These curtailments resulted in several kinds of economic losses.

First, with marginal energy production costs that are close to zero, wind curtailments result in significant additional production costs for the energy used to replace the wind generation. ERCOT tracked these costs, since payment was made to the owners of the wind energy to compensate them for lost production. Total payments for 2002 totaled $9 million, or approximately $23.70/MWh on average. Note that for much of 2002, gas prices were in the $2-$3 range; however, in October, gas prices rose dramatically, eventually exceeding $6/mmBtu by the end of December. These high prices for gas are apparent in the replacement cost of energy for the latter months of 2002, when the prices were over $30/MWh in what should normally be low price months. In the current high gas price environment, it is reasonable to expect that future energy losses associated with curtailed wind generation would have an opportunity cost at least in the $30/MWh range.

Table A

Date	Wind Curtailments (MWh)	Wind Curtailment Payments ($000's)	Average Payment ($/MWh)
Jan-02	15,300	272	17.80
Feb-02	31,000	445	14.34
Mar-02	79,500	2,032	25.56
Apr-02	59,800	1,276	21.33
May-02	55,300	1,253	22.67
Jun-02	42,800	1,030	24.07
Jul-02	27,500	733	26.65
Aug-02	15,200	367	24.16
Sep-02	12,100	324	26.74
Oct-02	9,500	286	30.15
Nov-02	20,200	615	30.45
Dec-02	11,800	372	31.49
Total	**380,000**	**9,005**	**23.70**

[1] The Noelke Hill interconnection request was withdrawn during the study period.

Source: "Uplifted Wind Generation Curtailment Info.xls" spreadsheet from ERCOT, available at http://www.ercot.com/ercotPublicWeb/PublicMarketInformation/marketinformation/UpliftedWind%20GenerationCurtailmentInfo.xls

The production costs for replacement energy are not the only losses that accrue to the system when wind generation is curtailed. Owners of the wind farms also experience losses of production tax credits (PTCs) that would have been earned for each MWh of renewable generation. In 2002, the value of the PTC was 1.8c/kWh, or $18.00/MWh. Using an assumed 35% corporate tax rate, the pre-tax value of the PTC represented equivalent revenue losses of an additional $27.69/MWh.

Furthermore, renewable energy credits (RECs) are also lost when wind production is curtailed. The RECs represent obligations of retail energy providers (REPs) to purchase a certain amount of renewable energy. If wind energy that was expected to satisfy the requirement is not produced as expected, then REPs need to secure enough replacement RECs to satisfy both their regulatory requirements and their customers' demand for additional renewable energy. Anecdotal evidence suggests that RECs were traded in the wholesale market at prices that ranged from $3.00/MWh to over $17/MWh. We are using a range of $5.00 to $15.00 to represent high and low estimates for the value of the entire basket of lost RECs.

With the estimates outlined above, the total value of the lost wind production for 2002 is estimated to be from $56-66/MWh.

Table B

	Low Estimate ($/MWh)	**High Estimate ($/MWh)**
Energy value (OOME down)	$23.70	$23.70
Pretax value of PTC	27.69	27.69
REC value (hi-lo estimates)	5.00	15.00
Total lost value ($/MWh)	**$56.39**	**$66.39**

Multiplying by the curtailed volume of 380,000 MWh, we find that the actual cost of wind curtailments in 2002 was from $21.4 to $25.2 million dollars.

WIND ABILITY TO RESPOND TO SYSTEM CONDITIONS

Wind generators in west Texas have varying capability to respond to requests from ERCOT that may be necessary for maintaining grid stability. The basic design objective of all wind turbines is to maximize output for given wind conditions and to manage voltage to assure proper operation of the generators. The turbines are not designed to provide dynamically controllable power and reactive output. Currently the only available option to change power output is taking the turbine on/off line. Voltage control can be managed by dynamically adjusting generation voltage and VAR levels for one available turbine design, but is accomplished by switching static capacitors for all others to meet the ISO voltage requirements.

Typically, power output changes can be performed remotely and can take from several minutes to several hours to execute. Voltage is controlled automatically and takes seconds to minutes to respond to the system needs. The timing variations are a function of the turbine manufacture vintage, the type of controls and software installed and the configuration of the wind turbine integration with the grid connection substation. Depending on the OEM, O&M costs associated with these ISO responses can vary from minimal to significantly over what has been budgeted by the wind turbine operator.

GE wind turbines are presently the only machines capable of dynamic voltage and VAR response to grid operator requests. Other OEM attempts to offer a level of response comparable to the GE turbine are effectively what could be accomplished by the transmission service provider utilizing commercially available components such as static VAR compensation devices.

RELIABILITY MUST RUN (RMR)

Another cost related to the wind farms in the McCamey area has to do with the gas-fired generation plant Rio Pecos, owned by AEP. Rio Pecos is a late 1950's vintage gas-steam facility with a heat rate in the 11-12 thousand Btu/kWh range. Although it would not have run for economic reasons, Rio Pecos has been operated to provide grid support for the McCamey area through out-of-merit energy (OOME) and out-of-merit capacity (OOMC) transactions with ERCOT. The compensation mechanisms for OOME and OOMC were not enough, however, to justify keeping the Rio Pecos plant operating. Therefore, AEP entered into a reliability must run (RMR) contract with ERCOT in October 2002 to ensure that Rio Pecos could be kept operating to provide the grid support needed for the area.

The Rio Pecos plant primarily provides reactive power, though in order to do so, it must generate some amount of power, thereby exacerbating the transmission constraint on the wind farms. As a high heat-rate plant, providing this reactive power results in additional costs to the system for the energy that was provided by Rio Pecos compared to renewable generation sources.

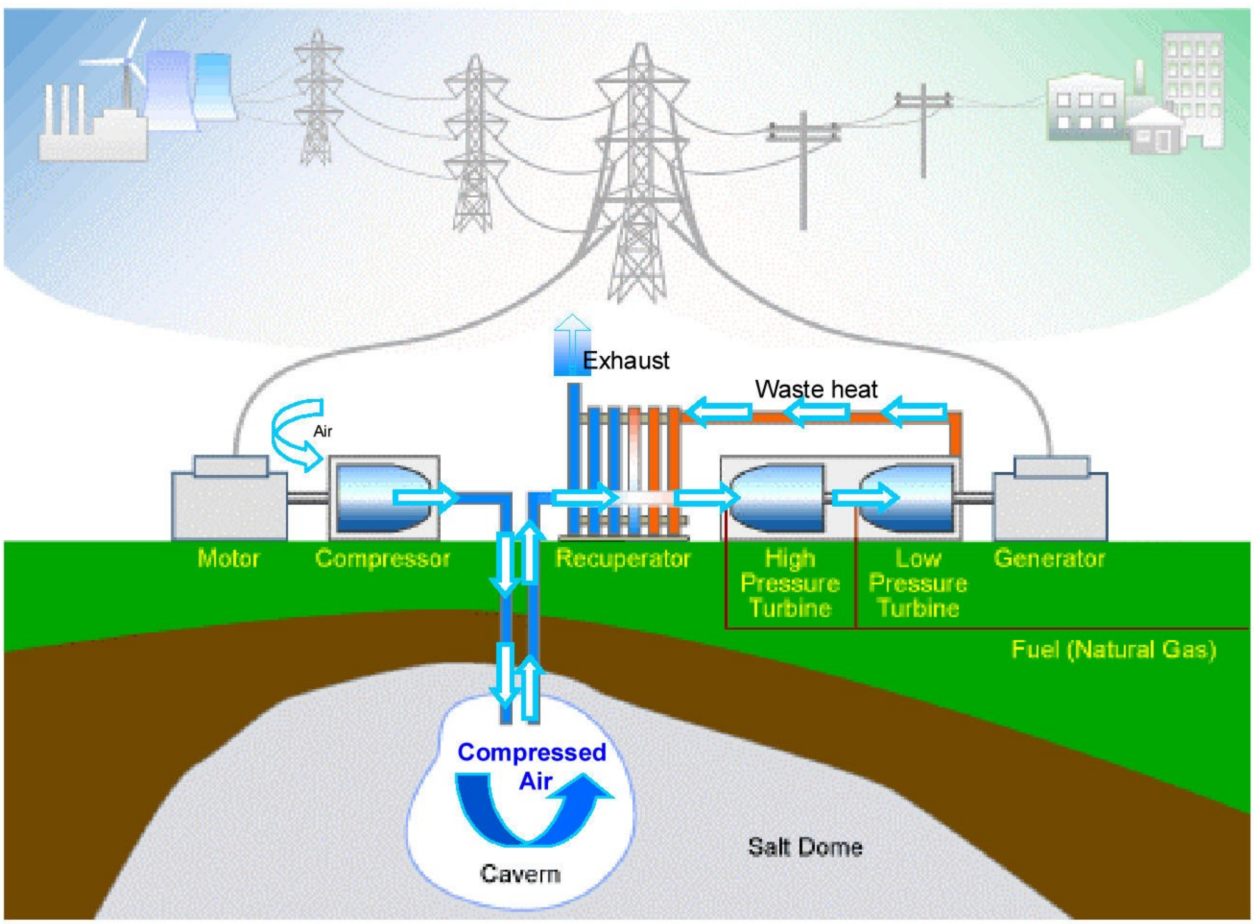
Payments to the Rio Pecos plant for energy and associated reactive power from January to September 2002 were not publicly available. However, the terms of the RMR contract for October through December are public, as well as the amount of payments made through the contract to AEP and the net cost to ERCOT after comparing the RMR payments to the cost of balancing energy. Using the RMR contract terms as a proxy for the cost to operate Rio Pecos in the first 9 months of 2002 and netting them out versus the average published balancing energy prices for West Texas, we estimate that the above-market cost for Rio Pecos' production was $6.7 million for all of 2002.

ERCOT is planning to add static VAR devices to provide reactive power support for the McCamey area, so the costs associated with having Rio Pecos generating to provide RMR services will soon be replaced by the costs of the new devices. Nevertheless, the purpose of examining these costs is to establish a benchmark for measuring the benefits a CAES plant may be able to provide in similar situations.

COMPRESSED AIR ENERGY STORAGE

HOW IT WORKS

The CAES plant stores electrical energy in the form of air pressure, then recovers this energy as an input for future power generation. The CAES concept has been well proven through the operating history of two existing CAES plants, one in Huntorf, Germany and the other in McIntosh, Alabama. 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 electricity takes the place of gas that would otherwise have been burned in the generation cycle.



DESIGN DETAILS

The major equipment in a CAES plant can be divided into four parts: the power island, the compression island, the underground portion, and the balance of the plant. The power island consists of the air turbine, the combustion turbine, the generator and the recuperator/selective catalytic reduction (SCR) unit. The compression island consists of the axial and centrifugal compressors complete with coolers. The underground facilities consist mainly of the air storage cavern and the airflow piping and controls. The balance of plant equipment consists of plant control equipment, the substation, the cooling tower system, the switchgear and all other equipment required to operate the plant

Power Island

High Pressure (HP) Air Turbine – The HP air turbine consists of a modified expander turbine section, which has been designed to accept the design flow rate of 400 pounds per second (lbs/sec) of 1200 pounds per square inch gauge (psig) air from the cavern. Prior to entering the HP turbine, air has been heated in the recuperator. The HP exhausts into the low pressure (LP) combustor duct. The HP generates approximately 35 MW. The HP air turbine reduces technical risk because it allows the combustion turbine to operate at exactly the same pressure, temperature, and airflow that it would experience if the unit still contained an air compressor.

Turbine - The LP turbine is a standard gas turbine from which the compressor section has been removed. The air from the HP expander enters the eight LP combustors, is fired to 1620 ºF and enters the LP at 252 pounds per square inch absolute (psia). The heat rate is approximately 4,300 British thermal unit per Kilowatt Hour (Btu/kWh) (higher heating value). The LP turbine exhausts into the recuperator in which the SCR unit is installed. The LP turbine generates approximately 100 MW and the whole CAES train generates 135 MW. An additional CAES generation train can be installed to generate the design output of 270 MW.

Recuperator - The recuperator in the CAES cycle is an air-to-air heat exchanger, which has been designed to handle the high volume of air required by the combustion turbine. The purpose of this exchanger is to increase the efficiency of the cycle by capturing the heat contained in the 664 ºF exhaust of the combustion turbine and utilizing this heat to increase the HP air turbine inlet temperature from the 100 ºF cavern temperature.

Electric Generator - The generator is rated at a nominal 135 MW with a 0.85 power factor

Selective Catalytic Reduction - Selective Catalytic Reduction (SCR) units are incorporated into the design of the project. These units are fixed catalyst beds that convert NO_x to nitrogen by introducing small quantities of aqueous ammonia into the gas turbine exhaust stream just upstream of the SCR unit. The SCR is built into the recuperator ducting.

Compression Island

The purpose of the compression process is to provide the air volume necessary to increase the air pressure in an air storage system from atmospheric pressure to approximately 1200 psig. The air is subsequently used as expansion air by the HP air turbine and as combustion air by the gas turbine. The compression cycle for CAES consists of multiple compression trains made up of axial and centrifugal compressors. The compression train operates when needed to capture wind energy in excess of available transmission capacity and recharges the cavern to full pressure of 1200 psig.

In the compression cycle, ambient air is drawn into the LP compressor, a five stage axial compressor, and is discharged at 120 psig. The compressor is equipped with three pairs of integral coolers and an aftercooler. The pressure is then boosted to 1200 psig in the HP compressor. The HP compressor has two stages of intercooling and an aftercooler, which reduces the air temperature of the air delivered to the storage cavern to 100 ºF. Both the LP and HP compressors have electric drivers. Each compression train (LP plus HP) is sized to handle 400 lb./sec. of air. Typically, two compression trains would be installed to match the air requirements for 270 MW of power generation. The compression trains would be connected to a large underground salt cavern air storage system. For the McCamey area study, 400 MW of compression has been selected in order to manage the wind resources and supply grid support in the area.

Underground Facilities

The storage system is comprised of several (~6 depending on final volumes of each solution mined cavern) air injection/withdrawal wells and storage caverns. Each cavern is capable of shut-in via separate closure valves and each cavern is connected via manifold piping arrangements to a header system that feeds directly into the discharge of the HP aftercoolers or the recuperator, depending on the mode of operation. During the storage mode, air leaving the HP compression aftercooler flows via the header piping and manifolding into the storage caverns. During the energy recovery mode, airflow via the header to the aftercooler is restricted via a shut-in valve; this results in air flowing via the header into the recuperator. The flow rate and pressure into the recuperator is controlled by the main airflow control valve resulting in a pressure of 800 psig at the recuperator inlet flange.

Balance of Plant

Most of the equipment in the balance of the plant, the cooling tower, the switchgear, the substation, the plant distribution and control and the step up transformers are all standard in many power plants. The main difference in the equipment at a CAES plant is the auxiliary transformer, which handles power coming into the plant from the grid. The auxiliary transformer in a CAES plant is sized to handle 400 MW of compression power. For a McCamey facility, the step up transformers would be designed for 13.8 to 345 kV service. The balance of plant also includes the control room, maintenance facilities, fuel metering & control valves, water treatment and related facilities (pumps, tanks).

FEASIBLE LOCATION FOR AIR STORAGE

The geology of Upton, Crane and Pecos counties in West Texas was reviewed using information from the U.S. Geological Survey, the Texas Railroad Commission, and the Bureau of Economic Geology at the University of Texas. From these published and archived reports, maps and well logs, contours were created for the top of salt and salt thickness in the area around McCamey and east towards Rankin. This information was reviewed by two professional geologists to confirm that salt caverns could be solution mined to an appropriate depth to store adequate volumes of high pressure air for a CAES plant. A number of 2-3 million-barrel (10-15 million cu. ft.) air storage caverns would be needed to provide a total storage volume of 10,000 MWh.

While the current level of geological analysis suggests that air storage would be potentially feasible in the McCamey region, additional formation analysis would be required to optimize the exact location of a CAES plant if a project were to proceed.

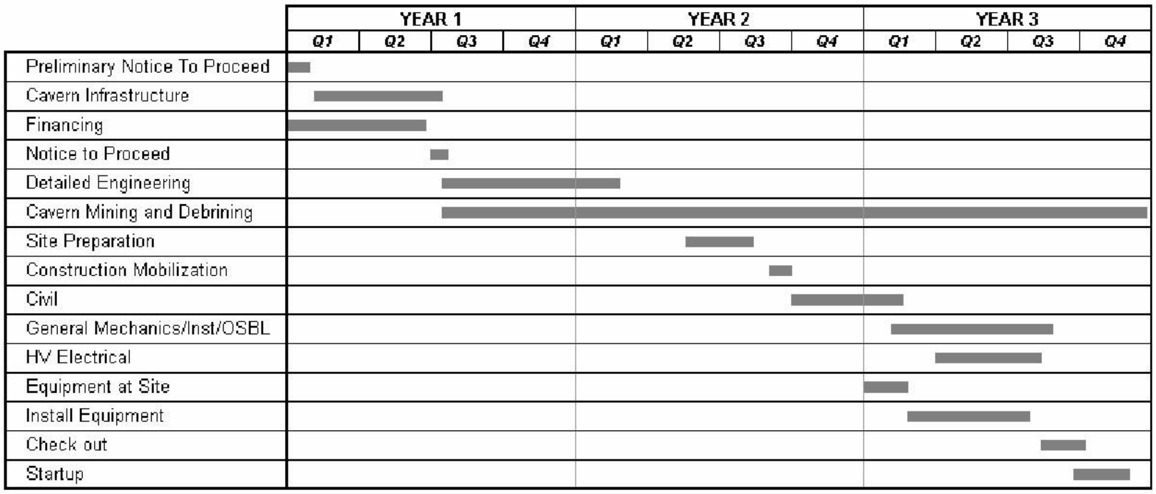
CONSTRUCTION TIMELINE

Once a commitment for a CAES project is in hand, the remaining development and construction can be concluded within three years. This assumes that major project development tasks have already been completed prior to the commitment. These prior tasks would include equipment selection, preliminary engineering and permitting for air emissions and underground storage.

Preliminary notice to proceed is given to the equipment manufacturer in order to keep delivery of long lead-time items in line with the overall project schedule. Some of the above ground-supporting infrastructure for the air storage caverns is constructed while permanent financing is put in place for the project.

Once final notice to proceed is given, the schedule is driven by the delivery of the major equipment to the site and the solution mining and debrining of the air storage caverns. The project proceeds on a normal power plant construction schedule with the following assumptions:

- Major equipment is delivered to the site 15-18 months after the notice to proceed
- 15 months of field construction
- Startup occurs 7 months after major equipment is delivered to the site



CAPITAL AND OPERATING COST PARAMETERS

Fixed Costs

The total project cost of a CAES plant in the McCamey area with the modeled configuration is estimated to range from $215 to $225 million. This estimate includes the engineering, procurement and construction (EPC) costs for cavern development and for the CAES plant and contingency, as well as soft costs such as development costs and fees, financing, startup costs, and working capital.

The capital cost of a McCamey CAES plant translates into an annual carrying cost of approximately $30 million. This carrying cost would cover interest and principal on debt as well as a reasonable return to equity investors under an appropriate financing structure, and would also include recurring expenses such as fixed O&M, property taxes, insurance, business management, utilities, and auxiliary power.

Variable Costs

This study was intended to calculate net system benefits from the operations of CAES, not the payments that would be made to or by the CAES plant. Therefore, only costs that are truly incremental costs from a system perspective are included in this analysis.

The major variable cost for a CAES plant is the incremental fuel for regeneration of stored power. The total cost of fuel is dependent on the heat rate of 4,300 Btu/kWh of CAES generation, as well as the delivered price of gas. CAES cost was analyzed over a gas price sensitivity range of $3.00 to $5.00/mmBtu (million Btu).

The system cost of compression energy was assumed to be zero, since the source is wind that would have otherwise been curtailed, with negligible marginal production costs. Note that this is not meant to imply that the CAES plant owner/operator would not make payment for compression power. However, from a system benefit perspectives, any payments from the CAES plant owner to the wind energy provider would be netted out in the final analysis.

Variable O&M cost is estimated to range from $3.00 to $4.00 per MWh of CAES generation. This number includes consumables such as chemicals and spare parts as well as accrual for major maintenance on the turbines as well as all costs associated with maintenance of motors and compressing equipment. Start costs are also rolled into this estimate, with an upward adjustment to account for the fact that the typical number of starts per year is likely to be higher for a CAES plant that is operating in a wind management function.

It was assumed that QSE (Qualified Scheduling Entity) fees costs would be incurred for the power that is scheduled into storage. These costs are estimated to be up to $.50 per MWh delivered into storage. Any other payments for associated transmission and/or distribution costs were assumed to net out against reduced T & D charges to other ratepayers or gross profit to the transmission and distribution providers and were therefore assigned a value of zero in calculating net system benefits.

CAES PLANT OPERATING CHARACTERISTICS

Configuration

For study purposes, the configuration of the CAES plant is assumed to be as follows:

- 270 MW generation (2 X 135 MW generation units)
- 400 MW compression (4 X 100 MW compression trains)
- 10,000 MWh of energy storage capacity

Operating Characteristics

With pressurized air feeding the combustion turbine there is no loss of generating output, i.e. no "derate," as ambient temperatures increase. The CAES plant maintains its rated generating capacity throughout all the seasons of the year.

The gas-fired heat rate of the CAES plant is 4,300 Btu/kWh (HHV). This is achieved by the installation of an 85% efficient recuperator on the exhaust of the LP expander. This configuration allows the plant to maintain this low heat rate with minimal degradation as the generating unit is turned down to 50% of capacity.

The energy ratio for a CAES plant is defined as the amount of compression energy required to produce one unit of energy with the generation equipment. The energy ratio for a plant operating the compression equipment at full output is 0.75.

The physical separation of the generating and compression equipment allows both functions to operate simultaneously. This gives the operator a great deal of flexibility in managing wide variations in wind output.

Generation Mode

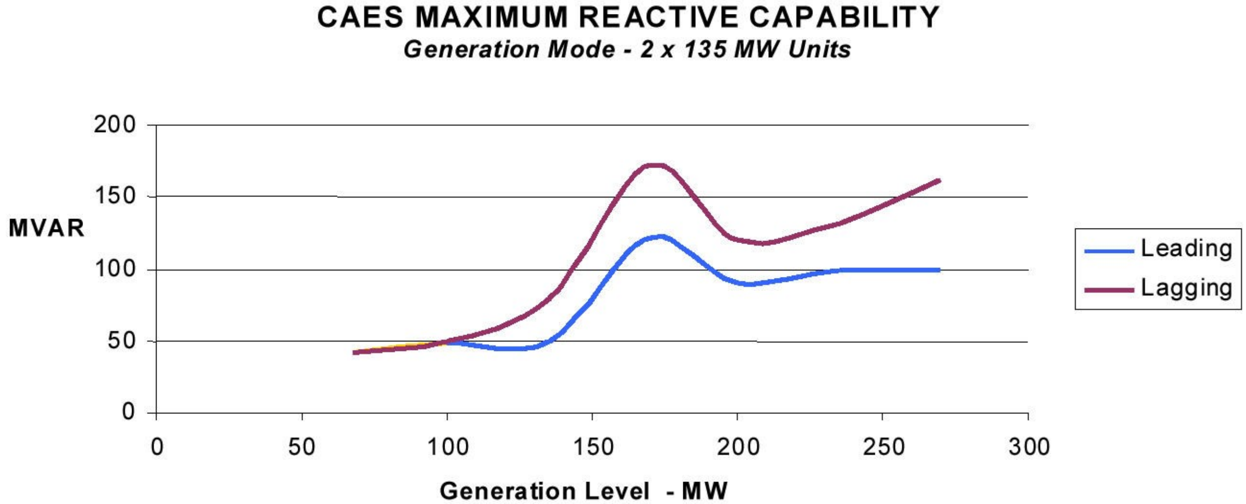
The minimum generation level for the CAES plant is determined by the minimum operating level for a single generation unit. The generation unit is flame stable at 11% (~15 MW), though the efficiency penalties for operating at this level are significant. Therefore, for modeling purposes, 50% of one unit (67.5 MW) is used as the working assumption for minimum operating level.

The CAES plant can economically operate anywhere in the range from 67.5 MW to the full output of the plant (270 MW) by having a combination of units on. Table C provides examples of how the generation units would be deployed to meet various plant generation levels.

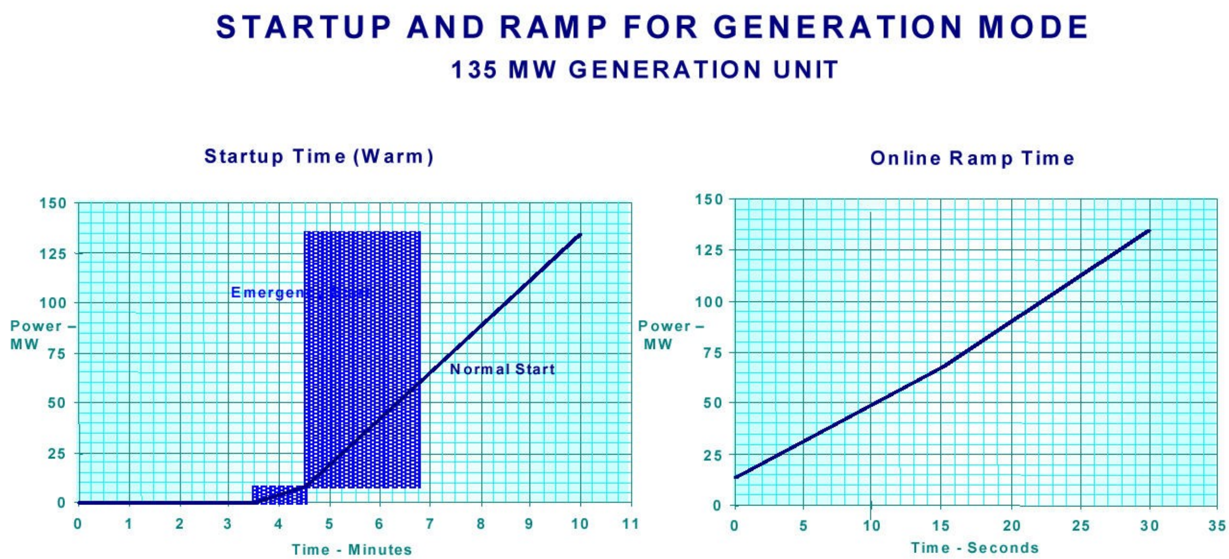
Table C

Required Generation Level	Operating Unit Configuration
67.5 MW	One unit operating at minimum level of 67.5 MW
100 MW	One unit operating at 100 MW
135 MW	One unit operating at full output of 135 MW -or- Two units operating at 67.5 MW each
200 MW	Two units operating at 100 MW each
270 MW	Two units each operating at full output of 135 MW

The excitation on the generators can be adjusted to provide leading or lagging VARs as necessary to support the voltage level on the system. The maximum reactive capability of the generation units when operating in concert at various levels is described in the following graph:



The generation units are designed for rapid deployment and response. Under normal warm start conditions, a generation unit could be at full load in 10 minutes. Each unit has a ramp rate of 4.5 MW per second when online.

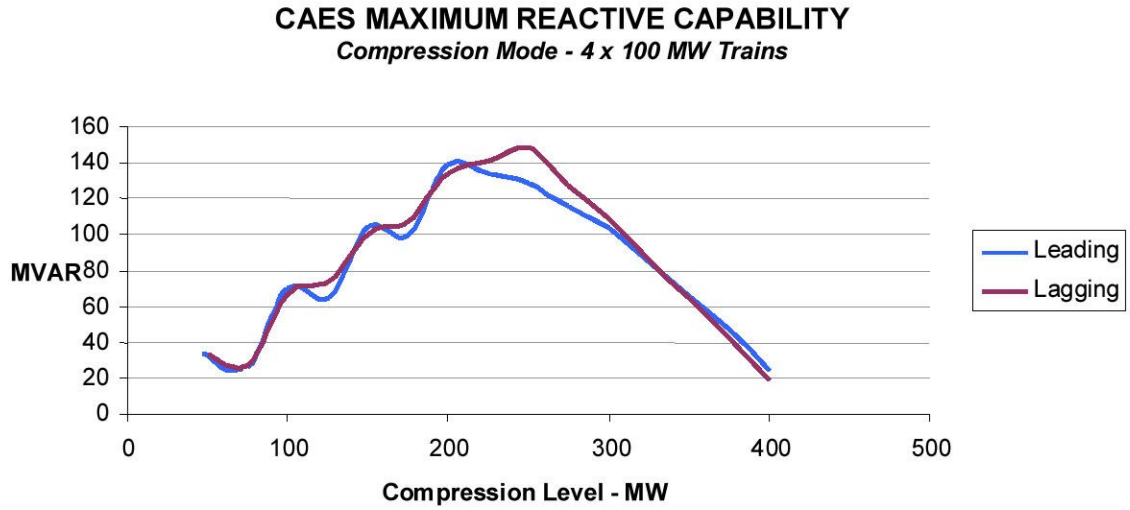


Compression Mode

The minimum operating level while in compression mode is approximately 40% of a single 100 MW compression train, or 40 MW. However, at this level, air is being recycled through the compressors in order to prevent compressor surge, resulting in an efficiency penalty. For economic modeling purposes, 50 MW is used as the minimum desirable compression operating level.

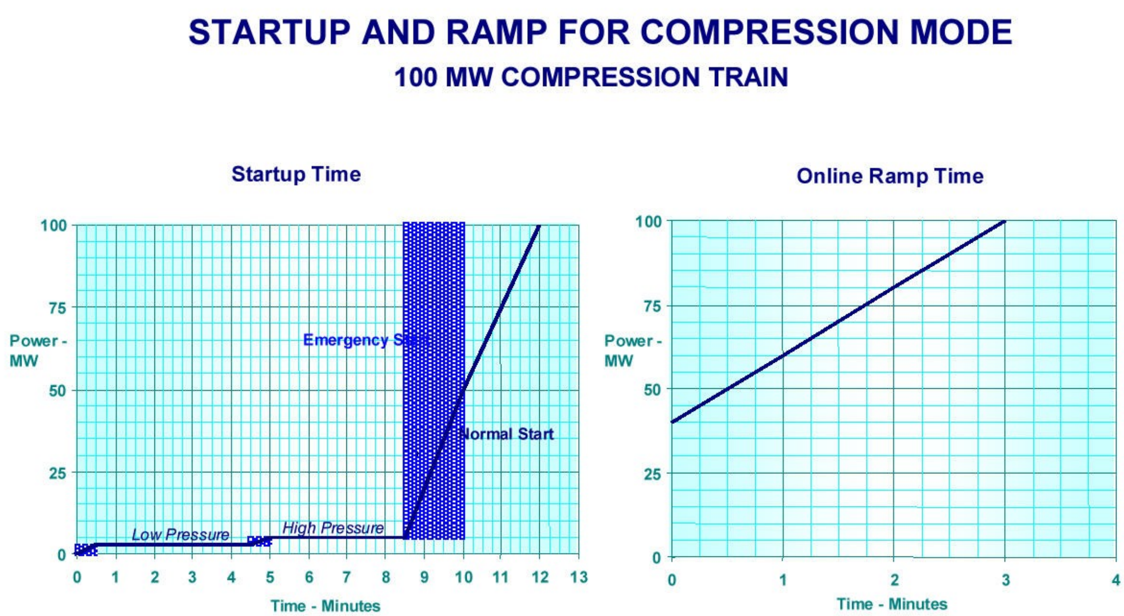
The CAES plant can operate in compression mode anywhere in the range from 50 MW to 400 MW by varying the number of compressor trains that are online. Since there are more than 2 compressor trains, the configurations are more varied than for generation. For example, compression at a level of 210 MW can be done with 3 compressor trains operating at 70 MW each, or 4 compressor trains operating at 52.5 MW each.

While the compressor trains are in operation, the excitation on the motors driving the compressors can be adjusted to provide leading or lagging VARs as necessary to support the voltage level on the system. The maximum reactive capability of the motors when operating in concert at various levels is described in the following graph:



The motors can also be designed to operate independently of the compressors in synchronous condenser mode to provide VAR support. This would enable the CAES plant to provide reactive power to the grid when the plant was offline. This capability would be particularly important for times when the CAES plant is unable to run in compression mode due to the storage caverns being full. However, further analysis of the design changes and resulting costs and benefits has been left for a future study.

A compression train can be started and come to full load in 12 minutes. While operating, each train can move between minimum and maximum load at a rate of 20 MW per minute, or minimum to maximum (or maximum to minimum) in two and one-half minutes – 150 seconds.



 August 21, .2003

CAES PLANT OPERATIONS IN CONJUNCTION WITH WIND

For the purposes of this study, it was assumed that the CAES plant only operates in a mode that would enable the plant to relieve congestion in the McCamey area. Therefore, some operating rules were assumed for the CAES plant that do not necessarily represent physical constraints on its operations.

The compression side and generation side of a CAES plant are physically separate, and are linked only via the compressed air storage cavern. As long as the cavern has the ability to accept additional air, the compressors can provide load to the grid, and the generators can provide full power to the grid if there is sufficient pressure in the cavern. Since the compression trains are separate from the generation units, it is possible for a CAES plant to operate in compression mode and generation mode at the same time, with the net power delivered to the transmission system. For example, if the generation units were running and a need emerged to provide short term balancing down energy (load) to the grid, the operator might choose to provide that load through the compression trains in order to avoid a shut-down and restart of a generation unit. However, to avoid unnecessary complexity in the modeling, it was assumed that the CAES plant would not be in generation mode and compression mode at the same time.

Modeling was performed on an hourly basis. It is reasonable to assume that the ability of the CAES plant to react to the wind within the hourly time frame is plausible because the start times and ramp rates for CAES compression and generation is well within the time frame required for an hourly study. Further studies that attempt to look at energy storage and wind on a real time basis would have to make adjustments in the way the storage facility and wind are modeled and presumably this would create a difference in results. The exact differences are unknown at this time.

For each case examined, an identical approach was used to model the operations impacts of CAES on wind generation in the face of transmission constraints. A typical hourly profile for the energy output of a wind farm was scaled up based on an assumed wind generation capacity for the entire McCamey region. This was matched against the available transmission capacity for the area as determined through load flow studies, also on an hourly basis. In the absence of additional load or generation in the area, the difference between the potential wind energy production profile and the transmission capability was considered to be the amount of wind energy curtailed or the ability of the system to accept additional McCamey area generation for that hour.

The CAES plant was modeled as providing additional load or generation to the system depending on whether it was assumed to be in compression mode or generation mode for a particular hour. Unlike many CAES studies that assume a standard operating schedule, for example, 12 hours of compression followed by 12 hours of generation at fixed MW levels, the modeling for this study reflects the fact that a CAES plant can be operated to respond to the variable wind generation level and provide congestion relief.

Compression Mode

The CAES plant was assumed to be in compression mode any time that the potential wind generation was higher than the available transmission capacity. Since the compression trains can be equipped with a control system that allows the CAES plant to follow load, or in this case wind generation, in a manner equivalent to AGC, the CAES plant was modeled so that the compression operating level was equal to the amount of wind generation that would have otherwise been curtailed, as long as the amount of compression was between the minimum and maximum capabilities of the plant. The CAES plant can have anywhere from 1 to all 4 compression trains operating when it is in compression mode, as long as each individual train is operating above its minimum operating level. The minimum compression level was assumed to be 50% of one 100 MW train, or 50 MW. The compression level can move from 50 MW all the way to 400 MW by turning on or off additional compression trains and adjusting the level at which each train is operating. The online ramp rate of 20 MW/minute for 1 train, 80 MW/minute for 4 trains moving in parallel was assumed to be sufficient to manage the intra-hour variations in wind energy volume.

As the excess wind energy is used to compress air, the air pressure builds in the caverns used to store the air. For modeling purposes, this build-up of pressure is represented by a running inventory of stored MWh. With the assumption of 10,000 MWh of storage capacity over several caverns, an inventory of 0 MWh corresponds to the minimum working pressure of the cavern, while an inventory level of 10,000 MWh means that the caverns have reached their maximum working pressure. The inventory of stored air in MWh is accounted for by the amount of compression energy used to pump air into the ground. So, for example, if the compression trains run for 10 hours at a level of 400 MW, the cavern inventory increases by 4,000 MWh. Note that in this context, the 4,000 MWh is not a reference to the enthalpy value of the air in the cavern, but is merely an accounting convention to quantify the amount of electrical energy that is put into the CAES system. Another way to think about the cavern size is that if the compressor trains were operating at the maximum 400 MW level, it would take 25 hours, or a little more than one day to fill the air storage caverns.

As compressed air is released from the cavern for use in generation, the inventory level declines as a function of the generation volume and the energy ratio

There are two cases in which the compression level does not equal the amount of potentially constrained wind energy. The first case is if the cavern has reached its maximum air storage capacity. In this case, the compressors do not operate and the excess wind energy is curtailed. Though this does not happen very often, with the wind patterns at McCamey, it is possible for the wind to blow hard enough for the wind farms to operate at very high capacity factors for several days in a row. As noted above, the compressor trains can only operate to provide maximum load to the system for 25 hours, at which point the cavern will be full. Any starting inventory reduces the amount of time it takes to fill the cavern.

The second case is when the amount of potentially curtailed wind energy is less than the minimum compression level of the CAES plant. In this situation, the CAES plant is assumed to operate at minimum level (50 MW) rather than not operate at all, and the net wind energy delivered to the grid in that hour is then slightly less than the maximum that could have been delivered with the transmission system. However, the wind energy is not curtailed; but more of it goes into storage. The amount of compression is limited by the size of the CAES compression modeled in the storage which was 400 MW.

Generation Mode

The purpose of CAES generation in this study is to redeliver stored energy to the grid as quickly as possible without causing additional wind curtailments. The need to empty the cavern quickly was based upon the need to minimize situations and time when the storage cavern might get full and prevent the CAES plant from operating in compression mode to provide congestion relief when needed. Since the CAES plant is dispatchable, in a curtailment relief function, it should not compete with wind for transmission capacity. Therefore, the CAES plant was assumed to be in generation mode only if the wind generation levels were low enough for the CAES plant to have one of its generation units on at minimum operating level, or 67 MW, and if there were enough compressed air in the cavern to generate at minimum operating level for one hour.

If the CAES plant was in generation mode, then it was assumed to generate at the maximum capacity possible within the transmission constraint until the cavern became empty or until it was required to switch back into compression mode to provide wind curtailment relief. With two 135 MW units, CAES generation can move from 67 MW to 270 MW by turning on and off the second unit as needed. AGC controls on the CAES turbines allow the CAES generation to vary with the wind generation such that the sum of the wind farm output and CAES generation output equaled the maximum transmission capacity, as it may vary from time to time. At lower levels of wind output, the CAES plant was assumed to generate at the maximum 270 MW until the storage caverns emptied. The online ramp rate of 4.5 MW per second for one unit and 9 MW per second for two units was assumed to be more than sufficient to balance the combined wind energy production from McCamey area wind farms.

Considerations

These operating rules reflect the underlying purpose of this study, which is to show the ability of CAES to reduce curtailments of wind generation. However, some of the constraints that were placed on CAES operations for this study do not represent physical operating restrictions.

CAES can operate to provide additional firming and shaping for the wind energy. In this study, the off peak compression level was limited to the amount necessary to prevent curtailments. However, in a live application, CAES compression could easily be increased during off peak hours to reduce the net amount of energy being delivered to the grid during low value time periods. The stored energy could then be delivered ratably during on-peak times when the wind levels are low. There is certainly opportunity to apply much more strategy on when to regenerate the stored energy so that the highest value can be achieved in the energy markets.

In a related application, CAES compression or generation could be used to match wind generation and guarantee a smooth, constant delivery of a certain number of MW to the grid. CAES compression load would be varied such that the wind generation minus compression load was a constant, or CAES generation could be varied such that the sum of that with the wind generation would be a constant. This was not incorporated into the modeling unless necessary to avoid curtailments of wind.

TRANSMISSION SYSTEM STUDIES

Five individual transmission system studies were completed. The studies, labeled A through E, are different in the level of detail examined. For example, Study A is a very detailed analysis of the wind capacity transferable from the region at different levels of CAES generation and compression. Studies B thru D primarily examine the CAES compression and generation "endpoints" of 400 MW and 270 MW, respectively. The load flow analysis for Study E was minimal as the exercise basically repeated what was examined in the previous four studies.

Plans for the transmission system in the McCamey area have changed continually over the past few years, and at the start of the load flow analysis, substantial pieces of the model were still being developed concerning SPS installation and reactive equipment requirements. Studies A through C examine the wind capacity transfer capability of the completed 138 kV rebuild with different levels of SPS installation. The 1000 MW wind capacity transfer level in study A was chosen as a starting point to examine the impact of CAES generation and compression and is not necessarily representative of the wind capacity transfer capability of the completed 138 kV system. None of the wind capacity totals in the studies may truly reflect the actual wind capacity transfer capabilities of the various transmission configurations as many assumptions were made during load flow analysis which may or may not be indicative of the transmission system operation after construction is completed. For example, short 69 kV transmission lines near McCamey were allowed to overload; it was assumed they would be protected by radial operation or be upgraded.

In the 345 kV analysis of studies D and E, specific wind capacity levels were chosen and the transmission system reactive requirements to support the wind transfer were modeled. In short, the studies were conducted to determine the impact of CAES generation and compression on the wind capacity transfer level, not to validate future transmission construction plans. The studies confirmed a one for one MW relationship between the wind generation and CAES operation. The 400 MW CAES compression mode allowed local wind generation to increase by 400 MW, and the 270 MW generation configuration required wind generation to be reduced by 270 MW. The increase in transmission losses associated with replacing east Texas generation, which is local to the load centers, with wind generation in west Texas was not accounted for in this study.

Appendices A through E contain information regarding load flow analysis for each study. They were written for the reader with significant load flow analysis experience and a thorough understanding of the transmission limitations of the McCamey area and construction plans for the future. Because of the technical nature and volume of these appendices, they are not included but are available upon request.

LOAD FLOW STUDIES

The latest Electric Reliability Council of Texas (ERCOT) approved load flow cases were utilized for this phase of the study, including March 6, 2003 updates. The wind generation in the McCamey area was set to 97 MW in the summer peak "maximum" ERCOT load flow case, and to 173 MW in spring "minimum" ERCOT load flow case. The Rio Pecos generation plant, a 98 MW conventional power plant located in the center of the wind area, was on in the summer peak (maximum) load flow cases and was turned off for the minimum cases. At the beginning of 2003, it was operating under a Reliability Must Run (RMR) contract with ERCOT. During these studies, reactive difficulties were encountered during load flow analyses, particularly under low load, high wind speed conditions. An April 10, 2003 announcement from ERCOT suggested the addition of reactors as a solution, and for the purpose of this study, three were modeled for this analysis at the ERCOT suggested sites. Reactive devices throughout ERCOT, but primarily in and around the wind area, were added as wind was added to the system.

WIND DATA DEVELOPMENT

The historical operational data for the various wind plants in the McCamey area is not publicly available, though the area is known to contain class six wind sites. The wind developers flocked to the McCamey area primarily for this reason. When the class six wind regime is applied to current turbine power curves, various wind power output levels are possible due to variances in the turbine technology and the exact nature of the wind.

The first step in developing the wind data for this study required the selection of a capacity factor that could represent the geographic diversity, the various turbine technologies and future growth. After discussion with wind developers that built in the McCamey area, the Texas Wind Coalition, the Texas Renewable Energy Industries Association and the National Renewable Energy Laboratory, a capacity factor of 41% was selected for this study. The more advanced turbine technology, when applied to the statistical wind data in the McCamey region, yields a net capacity factor close to 41%. The 41% capacity factor turbine technology for the McCamey wind class is already available, therefore, it is not an unreasonable assumption that future developments would meet or possibly exceed the 41% level.

Three separate wind plant hourly data sets were developed, each representing the 41% net capacity factor. They were assembled utilizing different techniques. The capacity curtailment to energy curtailment conversions were made on all three data sets in an attempt to best represent the McCamey area. Final energy curtailment values for each transmission configuration are *averaged* energy curtailment values from the three data sets. The energy curtailment values are highly dependent upon the wind plant hourly data sets, particularly the length and frequency of consecutive maximum output hours as this fills the storage cavern and limits the curtailment reduction benefits of CAES.

It is important to understand that the wind plant hourly data set is not based on historical data. The wind plants are dispersed throughout the region, and no one knows at this time how all of the wind plants will operate together once curtailment ends. In addition, future build-out will presumably incorporate wind turbine technologies with increasingly better capacity factors.

WIND MODEL DEVELOPMENT

The wind generator models in the published ERCOT cases have no reactive capabilities. Some of the existing wind generators most likely have some reactive capabilities, but the capabilities have not been sufficiently communicated. There is an ongoing effort to require future wind plants to supply ±5% of their capacity in the form of reactive power (VARs) to the grid. In this study, effort was made to model future wind development projects in the area with this ±5% reactive capability. The reactive needs for the region are significantly higher than the potential reactive capabilities of the wind plants.

To date, there are 755 MW of interconnected wind generation in the McCamey area (see Table D below). In the ERCOT load flow cases, the existing wind generation capacity was modified so that all of the wind plants operated at a similar level, up to their individual generating capacity, as the wind generation was increased across the area. In the lower level wind studies, additional wind generation was added onto the existing circuits. The new wind plant location was based on previous interconnection announcements by ERCOT. As the wind was increased beyond the abilities of the existing circuit, wind generation was modeled directly at the hub, representing the second circuit in the current hub and spoke design.

Table D: Wind Generation Interconnections in the McCamey Area

Plant	In-Service	Capacity
Southwest Mesa / FPL	1999	75 MW
Indian Mesa / FPL	2001	80 MW
Woodward / FPL	2001	160 MW
King Mt./ FPL	2001	280 MW
Desert Sky / AEP	2001	160 MW

CAES MODEL

The CAES plant was modeled for 270 MW generation and 400 MW compression at the North McCamey substation. The generation mode was modeled as a generator bus linked to North McCamey. Reactive capabilities of the generator are different for the discrete levels of generation. Data records were entered each time the model operation was changed. The compression mode was modeled as a load at North McCamey. The switched shunt data record was utilized to represent the discrete levels of reactive capabilities. When both the North McCamey switched shunt and Facts device (Statcom) were needed for reactive support, the shunt value was added to the Facts device value before the CAES compression model was entered into the load flow. Otherwise, the CAES model would have decreased total reactive available (the opposite of what is needed as wind is added to the transmission system). When the CAES plant is neither generating nor compressing, no reactive support is available with the CAES design used for this study. (i.e., the capability to use motors as synchronous condensers has not been included in the modeling.)

TRANSMISSION CONSTRUCTION SCHEDULE AND COST

Per the McCamey area plan approved in May 2003 by the ERCOT Board, the 138 kV transmission system upgrades are scheduled to be completed by the end of 2006. The 2006 load flow cases represent the final configuration in anticipation of 345 kV transmission line additions from McCamey to Twin Buttes and McCamey to Odessa. No construction was noted in the 2007 summer peak case for the McCamey region. However, the 2008 summer peak load flow case contains both 345 kV transmission lines.

Based on the McCamey Area Transmission Plan, the three phases of transmission system upgrades, 138 kV, first 345 kV and second 345 kV, are reportedly capable of handling 1000, 1500 and 2000 MW of wind generation capacity, respectively, with the North McCamey – Twin Buttes 345 kV line placed in service first. In general, the published ERCOT load flow cases were not able to handle the future wind installations without additional equipment including reactive devices, radial line operation, SPS, and/or the rebuilding of lines. Although the two 345 kV transmission lines are included in the ERCOT 2008 load flow cases, the intricacies of interconnecting the wind plants and determining the correct placement of the reactive support in the region (or what support the wind plants themselves will provide) is in the early planning stages. Table E indicates the cost for system upgrades, and is provided for information purposes only. This information was derived from a March 26, 2003 letter from LCRA System Planning to ERCOT.

Table E: Transmission Cost

Incremental Transmission Capacity (MW)	Incremental Transmission Cost	Cumulative Transmission Capacity (MW)	Cumulative Transmission Cost
0	$0	330	$0
670	$157,095,000	1000	$157,095,000
500	$ 90,300,000	1500	$247,395,000
500	$ 65,400,000	2000	$312,795,000

STUDY A: 1000 MW OF WIND GENERATION AND YEAR 2006 138 KV TRANSMISSION SYSTEM COMPLETED

This study is the detailed analysis of the different CAES compression and generation levels. The 1000 MW wind generation capacity value was selected because it has been referred to as the level the 138 kV transmission system planned for 2006 can support. The planned 2006 system can actually support more wind generation, depending upon the SPS installations, so this study should not be thought of as an analysis of how much wind generation the transmission grid can support. Subsequent studies only examined the top levels of CAES generation and compression. Study "A" looked at a range of levels. This study was intended to pinpoint (identify and quantify) potential problems with wind generation additions to the ERCOT load flow case and with the operation of the CAES plant.

Transmission Capacity Analysis

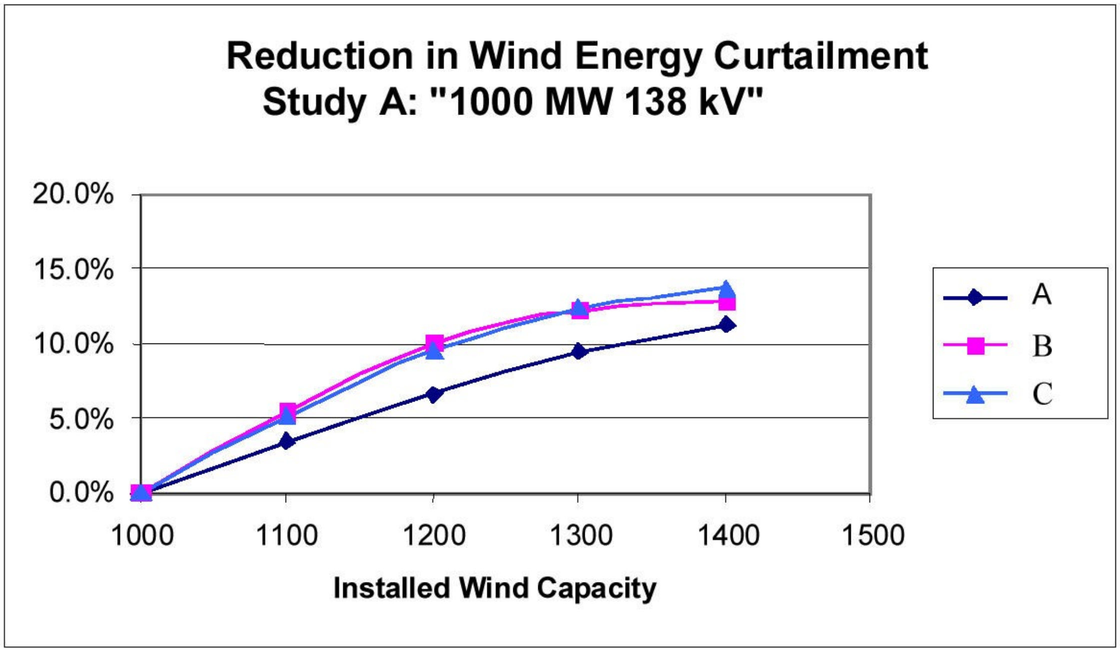
A contingency study was conducted on the system without CAES generation. CAES generation or compression was then added and the wind capacity was scaled proportionally. Contingency analysis of the system was then performed after the CAES addition. Overload values of the CAES scenario were then compared with the non-CAES scenario.

When the wind generation was increased the same amount that the CAES was compressing, the contingency overload values were similar. When the wind was decreased the same amount that the CAES plant was generating, the contingency overloads were similar. In the maximum scenario, the limiting elements were: 1) the Rio Pecos – Crane transmission line for loss of the Crane - King Mountain transmission line; and 2) the Friend Ranch autotransformer for loss of the Sonora - Friend Ranch transmission line. Several other 69 kV overloads were noted. In the minimum scenario, the Rio Pecos – Crane transmission line was a problem in the same scenario. However, the Friend Ranch auto-transformer overload went away and a Permian – Barilla Junction 138 kV transmission line overload for loss of the Crane – Arco 138 kV transmission line appeared.

A few interesting things were noted in additional studies on the 1000 MW 138 kV system. In the maximum scenario, the wind had to be at least 100 MW above the CAES compression level or overload conditions were noted. In addition, the CAES plant could not compress off the grid without causing overload conditions. Neither condition is pertinent to the study so they were not investigated further.

Wind Energy Curtailment Analysis

Wind generation capacity for the analysis was not modeled as a function of ERCOT load, as both the minimum and maximum scenarios were set to 1000 MW. However, the energy curtailment studies give an indication of the reduction of wind energy curtailment that can be achieved utilizing the CAES.



INSTALLED WIND		CURTAILMENT WITHOUT CAES		CURTAILMENT WITH CAES		REDUCTION IN CURTAILMENT	
MW	**MWh**	**%**	**MWh**	**%**	**MWh**	**%**	**MWh**
1400	5,028,240	16.8	842,326	4.2	210,743	12.6	631,583
1300	4,669,080	13.0	608,250	1.8	82,356	11.3	525,894
1200	4,309,920	9.0	386,555	.2	8,865	8.8	377,690
1100	3,950,760	4.8	190,928	0	0	4.8	190,928
1000	3,591,600	0	0	0	0	0	0

STUDY B: YEAR 2006 138 KV TRANSMISSION SYSTEM WITHOUT 345 KV

In this study the assumption is that the two 345 kV lines are not built and construction ends with the 138 kV transmission configuration consistent with the McCamey Area Transmission Plan.

Transmission Capacity Analysis

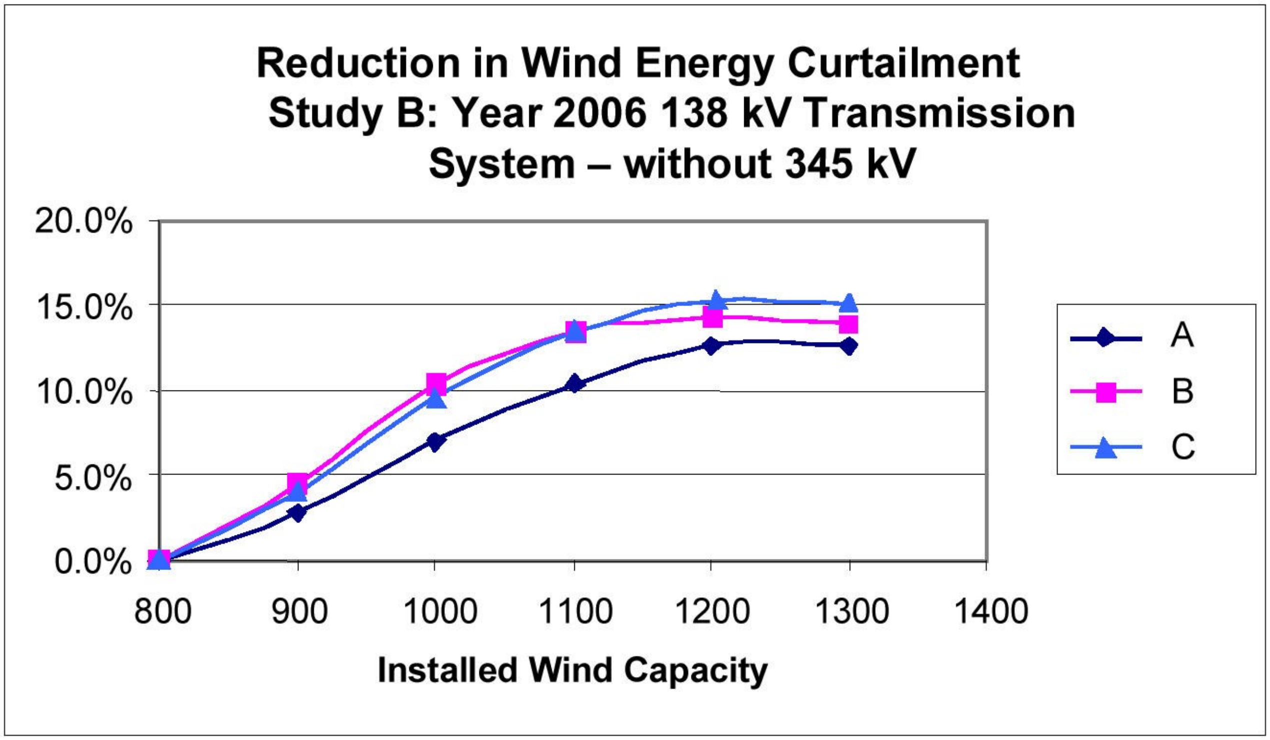
The wind generation limit was a function of the thermal overload of 138 kV circuits. In the maximum scenario, the Rio Pecos – Crane transmission line overloads for loss of the Crane - King Mountain circuit, and the Friend Ranch transformer overloads for loss of the Sonora - Friend Ranch transmission line. In the minimum scenario, the contingency of concern is the Crane – King Mountain, which overloads Rio Pecos – Crane.

In the maximum scenario, the maximum wind limit is approximately 900 MW. In the minimum scenario, the wind limit was approximately 805 MW. The CAES generation mode is as expected, but CAES compression mode allows approximately 30 additional MW to be operated in the minimum scenario. In the maximum scenario, CAES generation mode and compression mode were as expected. The maximum scenario was checked to see if an additional 30 MW could be exported under 400 MW compression as was observed in the minimum scenario. It could not.

Scenario	CAES Operation	Wind Capacity
Maximum	None	900
Maximum	400 MW Compression	1300
Maximum	270 MW Generation	630
Minimum	None	805
Minimum	400 MW Compression	1235
Minimum	270 MW Generation	535

Wind Energy Curtailment Analysis

The available transfer capacity (ATC) was included as a linear function of the ERCOT load in the energy curtailment calculations.



INSTALLED WIND		CURTAILMENT WITHOUT CAES		CURTAILMENT WITH CAES		REDUCTION IN CURTAILMENT	
MW	MWh	%	MWh	%	MWh	%	MWh
1300	4,669,080	22.2	1,035,533	8.2	380,684	14.0	654,849
1200	4,309,920	18.2	782,899	4.2	180,198	14.0	602,701
1100	3,950,760	13.8	545,024	1.5	57,344	12.3	487,680
1000	3,591,600	9.0	322,295	0	1,660	8.9	320,635
900	3,232,440	3.7	120,295	0	0	3.7	120,295
800	2,873,280	0	0	0	0	0	0

STUDY C: YEAR 2006 138 KV TRANSMISSION SYSTEM WITH SPS (N-0)

The predominant assumption for this study is that all contingency condition overloads would be protected by SPS.

Transmission Capacity Analysis

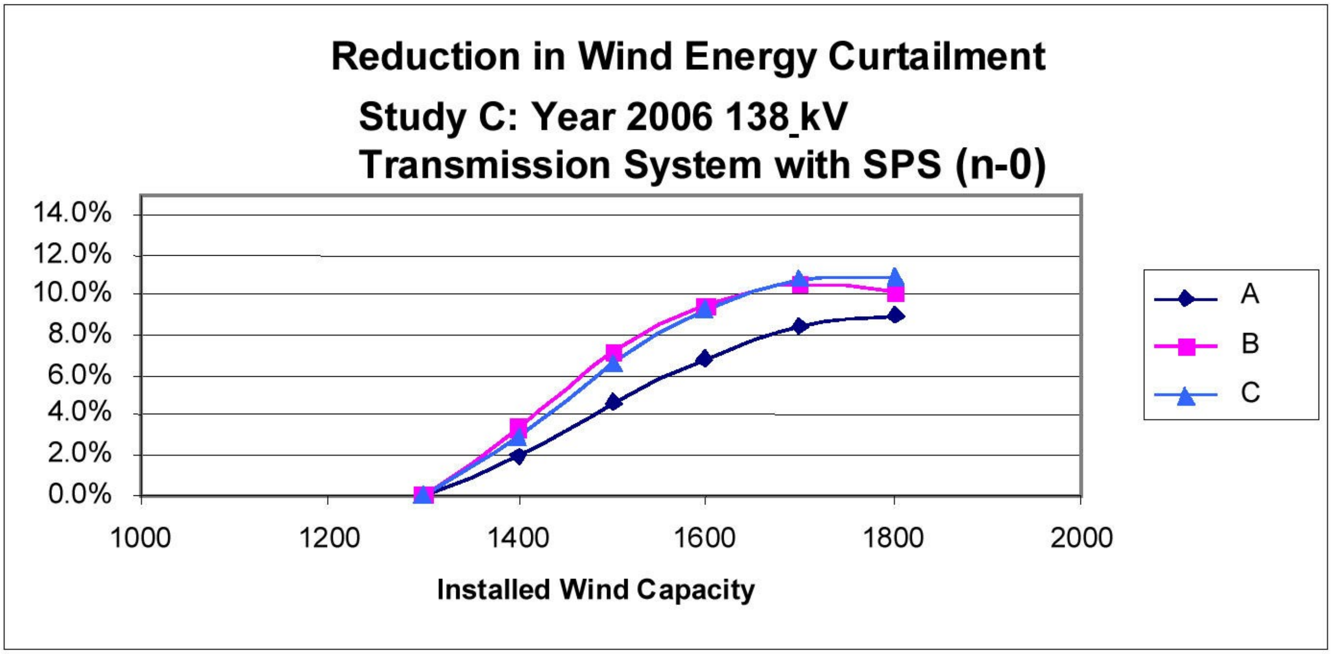
The wind generation limit was a function of the thermal overload of 138 kV circuits. The Sonora – Friend Ranch 138 kV transmission line was the limit of the maximum scenario. It overloaded when wind generation capacity reached 1375 MW. The Permian - Barilla Junction 138 kV transmission line was the limit of the minimum scenario. It overloaded with a wind generation capacity of 1300 MW. A few short 69 kV transmission lines in the Permian area did overload, but were not considered to be limiting factors.

The transmission system responded to the CAES generation and compression as expected, though in the maximum scenario with CAES generating the wind output was 15 MW higher than expected. The same wind excess was not noted at the lower ERCOT level, so the additional capacity was not utilized in the energy curtailment calculations.

Scenario	CAES Operation	Wind Capacity
Maximum	None	1375
Maximum	400 MW Compression	1775
Maximum	270 MW Generation	1120
Minimum	None	1300
Minimum	400 MW Compression	1700
Minimum	270 MW Generation	1030

Wind Energy Curtailment Analysis

The ATC was included as a linear function of the ERCOT load in the energy curtailment calculations.



INSTALLED WIND		CURTAILMENT WITHOUT CAES		CURTAILMENT WITH CAES		REDUCTION IN CURTAILMENT	
MW	MWh	%	MWh	%	MWh	%	MWh
1800	6,464,880	15.3	991,856	5.3	344,950	10.0	646,906
1700	6,105,720	12.4	760,007	2.6	158,619	9.8	601,388
1600	5,746,560	9.4	539,711	0.9	51,522	8.5	488,189
1500	5,387,400	6.1	330,927	0	1165	6.1	329,762
1400	5,028,240	2.7	137,487	0	0	2.7	137,487
1300	4,669,080	0	0	0	0	0	0

STUDY D: COMPLETION OF 345 KV TRANSMISSION LINE BETWEEN NORTH MCCAMEY AND TWIN BUTTES

This study examines the impact CAES has on the wind generation installations after construction of the first 345 kV line from North McCamey – Twin Buttes.

Transmission Capacity Analysis

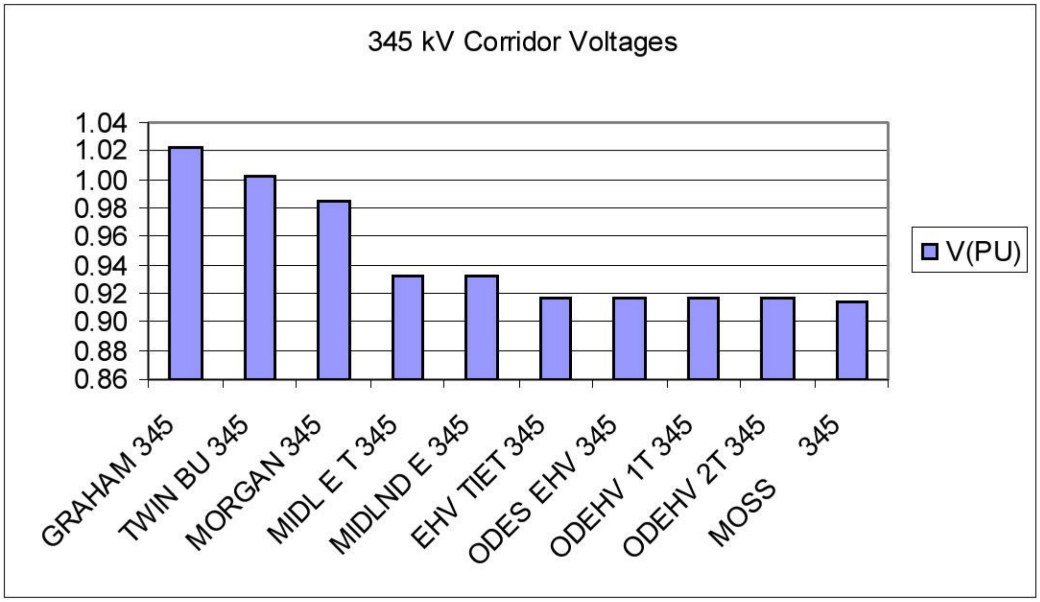
The study considers a single n-1 contingency outage, loss of the newly constructed North McCamey – Twin Buttes 345 kV transmission line. When this transmission line is out of service, the transmission system resembles the 138 kV transmission system represented by the 2006 load flow cases. The system is already operating under n-1 contingency conditions, so no additional contingency studies are necessary.

The maximum case required reactive support at the hub at the 1500 MW wind generation level. A 50 MVar switched shunt was modeled at North McCamey. When the wind was increased from 97 MW in the published ERCOT load flow case to 1500 MW for this study, the overall reactive needs of the system increased significantly as indicated in Table F below. Many of the reactive devices needed were already in place, but they were not needed at the lower level. A few short 69 kV lines in the Permian area surpassed their emergency rating in all scenarios.

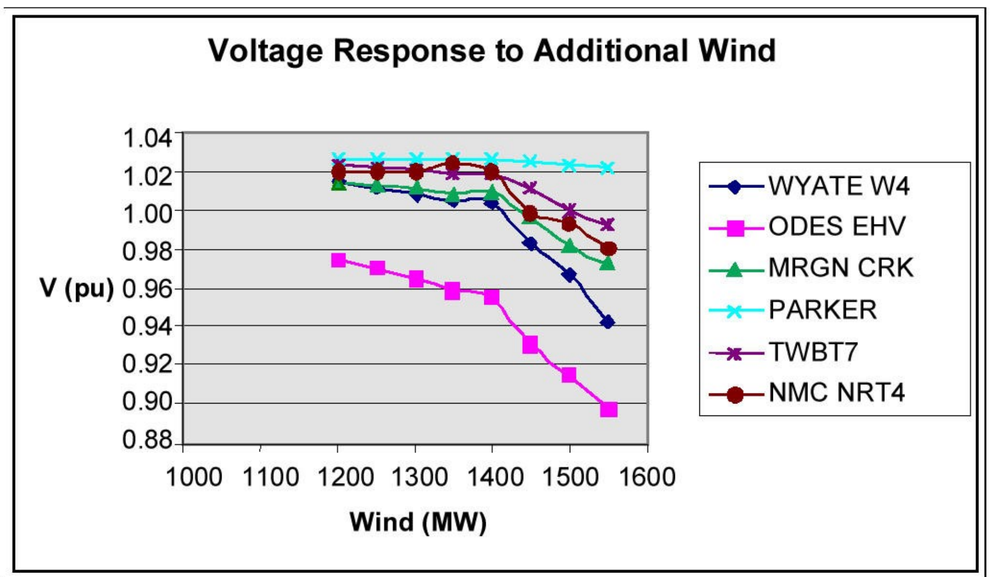
Table F

Study scenario:	Gen MW	Load MW	Losses MW	Swing MW	Gen MVar	Shunts MVar	Charging (MVar)	Losses (MVar)	Swing (MVar)
Published Case Max	71526.2	70005.6	1516.9	590.1	17178.2	-14013.4	9364.4	21742.3	160
345 n-1 1500 MW	71678.7	70006	1669	161.9	17208.9	-14620	9374.2	22387.8	160
345 n-1 1500 MW CAES 400 Load	72,090	70,406	1,681	179	17,273	(14,689)	9,370	22,517	154
345 n-1 1500 MW CAES 270 Gen	71,678	70,006	1,668	161	17,399	(14,449)	9,378	22,410	181
Change published to 1500 Wind	153	0	152	(428)	31	(607)	10	646	-
Change 1500 wind to 1900 load 400	411	400	12	17	65	(69)	(4)	129	(7)
Change 1500 wind to1230 gen 270	(1)	-	(1)	(1)	190	171	4	23	21

The minimum study results were similar to the maximum study results. However, in the minimum scenario, the western end of the 345 kV corridor extending to Odessa experiences low voltages.

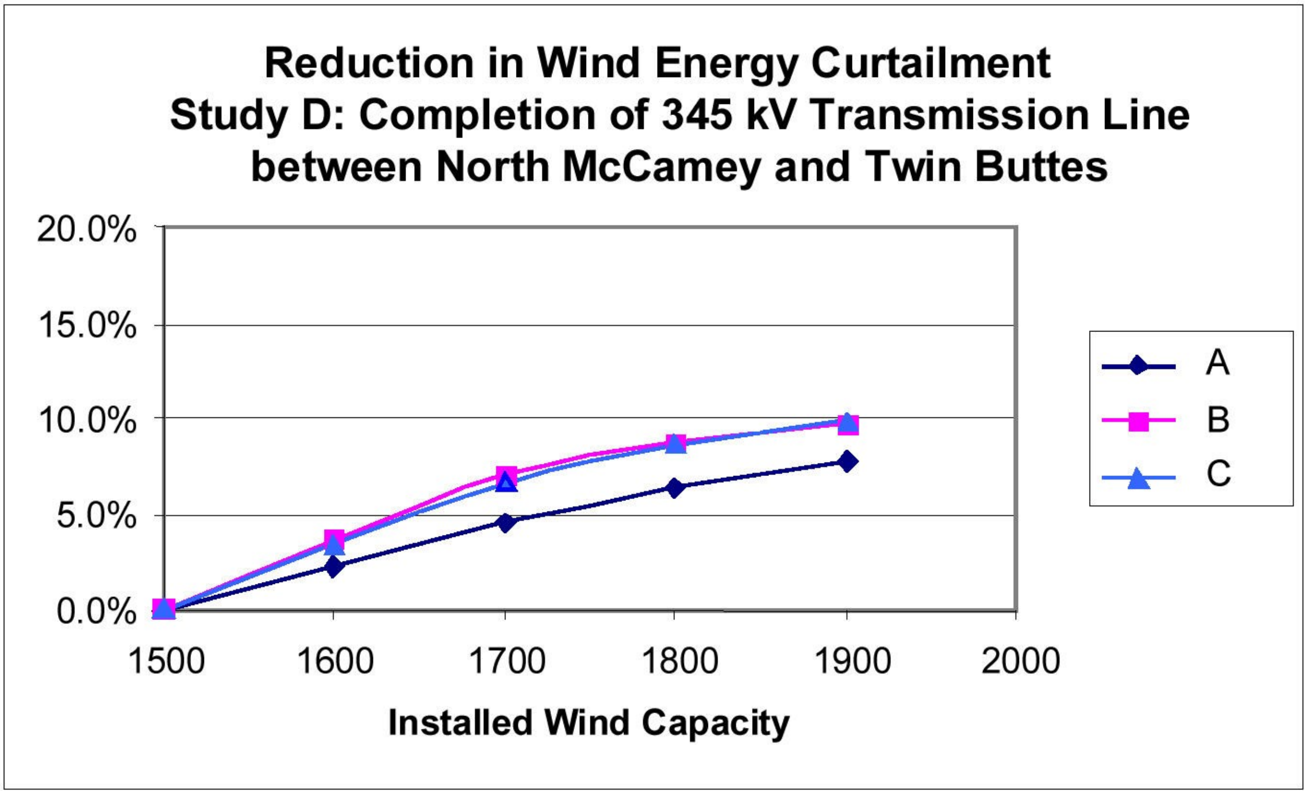


The low voltage problem on the 345 kV corridor is exacerbated by additional wind generation capacity. As the limit was reportedly 1500 MW, no effort was made to fix the problem on the western 345 kV. The situation is simply noted.



Wind Energy Curtailment Analysis

The ATC was not modeled as a linear function of the ERCOT load in the energy curtailment calculations.



INSTALLED WIND		CURTAILMENT WITHOUT CAES		CURTAILMENT WITH CAES		REDUCTION IN CURTAILMENT	
MW	MWh	%	MWh	%	MWh	%	MWh
1900	6,824,040	11.7	798,465	2.6	178,260	9.1	620,205
1800	6,464,880	9.0	579,833	1.0	67,100	7.9	512,733
1700	6,105,720	6.1	372,184	0	4,820	6.0	367,364
1600	5,746,560	3.1	177,709	0	0	3.1	177,709
1500	5,387,400	0	0	0	0	0	0

STUDY E: COMPLETION OF 345 KV TRANSMISSION LINE BETWEEN NORTH MCCAMEY AND ODESSA

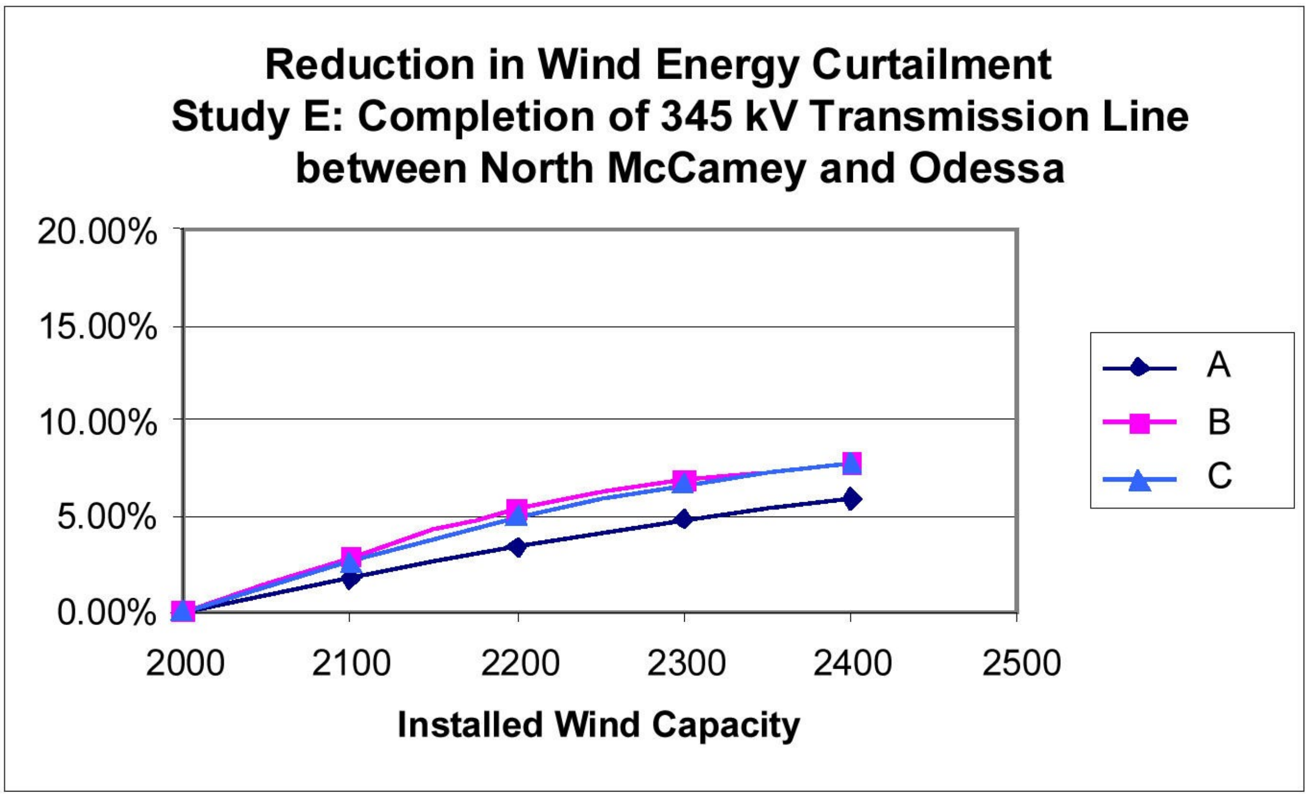
This study is the proposed transmission system as built out to 2008, which includes both 345 kV transmission lines.

Transmission Capacity Analysis

The loss of the North McCamey - Odessa transmission line was the most severe contingency. The load flow cases required such extensive changes to incorporate the full 2000 MW wind, that full load flow analysis was not completed. The previous four load flow studies indicated little change to surrounding transmission with the modeling of the CAES compression or generation, as all additional wind is also modeled at the hub. In effect, one ends up modeling the wind and load at the same bus. As the West Regional Planning group was also modeling future wind installations directly to the hub, efforts were instead focused on the Wind Energy Curtailment Analysis for this configuration, assuming similar load flow results from the four previous studies (i.e. 400 MW compression allows 400 MW additional wind on the system, and 270 MW CAES generation lowers the wind capacity transfer by 270 MW.)

Wind Energy Curtailment Analysis

The ATC was not modeled as a linear function of the ERCOT load in the energy curtailment calculations.



INSTALLED WIND		CURTAILMENT WITHOUT CAES		CURTAILMENT WITH CAES		REDUCTION IN CURTAILMENT	
MW	MWh	%	MWh	%	MWh	%	MWh
2400	8,619,840	9.0	773,111	1.9	161,293	7.1	611,818
2300	8,260,680	6.8	562,439	0.7	60,942	6.1	501,497
2200	7,901,520	4.6	363,856	0	2,996	4.6	360,860
2100	7,542,360	2.3	175,101	0	0	2.3	175,101
2000	7,183,200	0	0	0	0	0	0

CURTAILMENT SUMMARY

Installed Wind (MW)	Study A 1000 MW 138 kV (Preliminary Analysis)		Study B Year 2006 138 kV System – without 345 kV		Study C Year 2006 138 kV System with SPS (n-0)		Study D 345 kV line between N. McCamey and Twin Buttes		Study E 345 kV line between N. McCamey and Odessa	
	Curtailment w/out CAES (%)	Curtailment with CAES (%)	Curtailment w/out CAES (%)	Curtailment with CAES (%)	Curtailment w/out CAES (%)	Curtailment with CAES (%)	Curtailment w/out CAES (%)	Curtailment with CAES (%)	Curtailment w/out CAES (%)	Curtailment with CAES (%)
800			0	0						
900			3.7	0						
1000	0	0	9.0	0	0	0				
1100	4.8	0	13.8	1.5	2.7	0				
1200	9.0	0.2	18.2	4.2	6.1	0				
1300	13.0	1.8	22.2	8.2	9.4	0.9				
1400	16.8	4.2			12.4	2.6				
1500					15.3	5.3	0	0		
1600							3.1	0		
1700							6.1	0		
1800							9.0	1.0		
1900							11.7	2.6		
2000									0	0
2100									2.3	0
2200									4.6	0
2300									6.8	0.7
2400									9.0	1.9

CAES ANNUAL OPERATING COSTS

For each of the curtailment reduction studies, an assessment was made of the variable costs associated with CAES plant operations. The costs primarily consist of fuel for regeneration of stored energy, operations and maintenance expense, and scheduling charges, classified as a transmission and distribution cost.

The table below presents a summary of the total CAES related operating costs for each of the curtailment reduction studies performed. The aggregate level of McCamey area wind generation capacity within each study is assumed to be 400 MW above the ATC.

	Study A	**Study B**	**Study C**	**Study D**	**Study E**
Installed Wind	1,400 MW	1200 MW	1,700 MW	1,900 MW	2,400 MW
CAES Operating Costs ($000s)					
$3.00 gas	14,295	13,709	13,679	14,002	13,814
$4.00 gas	17,962	17,227	17,189	17,594	17,358
$5.00 gas	21,630	20,744	20,699	21,186	20,903

A curtailment reduction calculator is being provided as an output of this study so that readers can perform their own valuation of the curtailment reduction benefits to compare to the costs of CAES.

APPENDICES

APPENDIX A

TRANSMISSION CAPACITY ANALYSIS FOR STUDY A: 1000 MW OF WIND GENERATION AND YEAR 2006 138 KV TRANSMISSION SYSTEM COMPLETED

Note: The Transmission Capacity Analysis for Study A is available upon request from the Texas State Energy Conservation Office.

APPENDIX B

TRANSMISSION CAPACITY ANALYSIS FOR STUDY B: YEAR 2006 138 KV TRANSMISSION SYSTEM WITHOUT 345 KV

Note: The Transmission Capacity Analysis for Study A is available upon request from the Texas State Energy Conservation Office.

APPENDIX C

TRANSMISSION CAPACITY ANALYSIS FOR STUDY C: YEAR 2006 138 KV TRANSMISSION SYSTEM WITH SPS (N-0)

Note: The Transmission Capacity Analysis for Study C is available upon request from the Texas State Energy Conservation Office.

APPENDIX D

TRANSMISSION CAPACITY ANALYSIS FOR STUDY D: COMPLETION OF 345 KV TRANSMISSION LINE BETWEEN NORTH MCCAMEY AND TWIN BUTTES

Note: The Transmission Capacity Analysis for Study D is available upon request from the Texas State Energy Conservation Office.

APPENDIX E

TRANSMISSION CAPACITY ANALYSIS FOR STUDY E: COMPLETION OF BOTH 345 KV TRANSMISSION LINES

Note: The Transmission Capacity Analysis for Study E is available upon request from the Texas State Energy Conservation Office.

APPENDIX F

WIND CURTAILMENT CALCULATOR

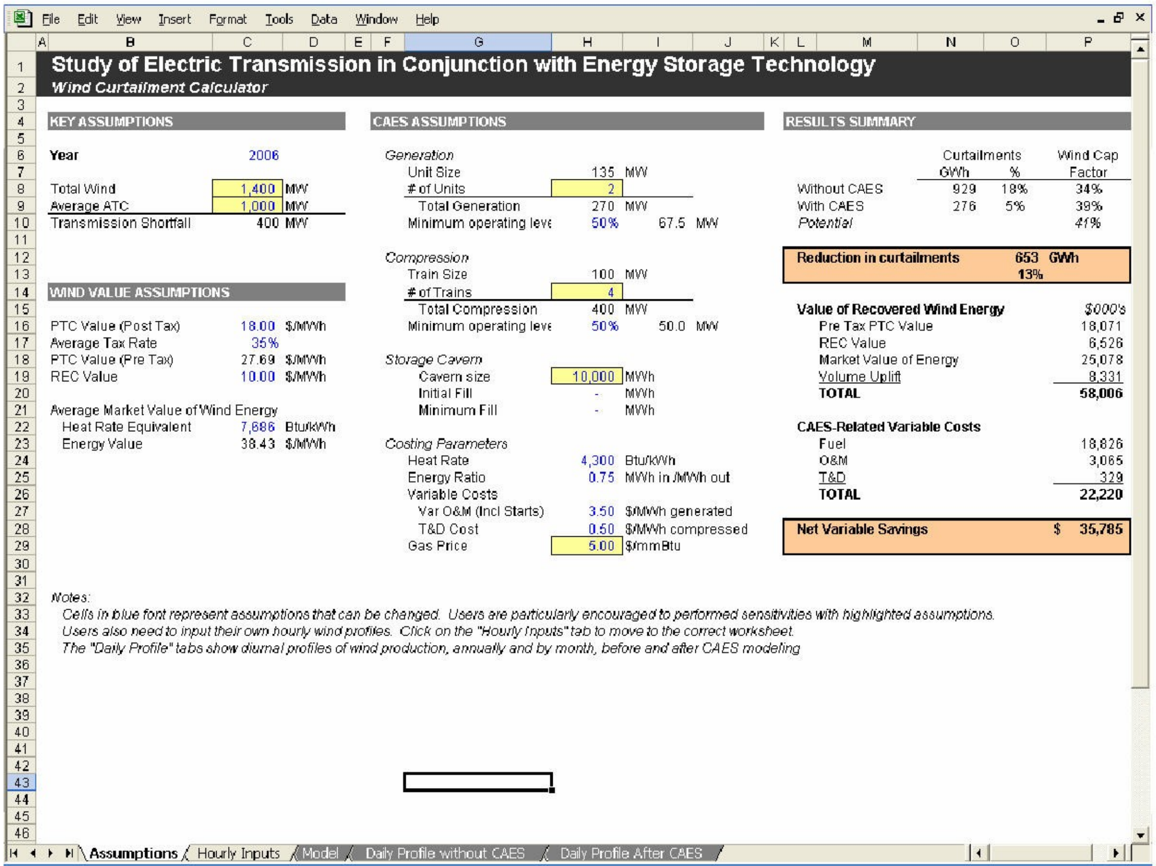
Note: The electronic version of the Wind and Storage Model Calculator is available upon request from the Texas State Energy Conservation Office.

WIND CURTAILMENT CALCULATOR

The Wind Curtailment Calculator has been provided as an output of this study so that interested parties may perform curtailment reduction analyses with their own wind profiles and estimates of future transmission capacity.

The spreadsheet entitled "Curtailment Reduction Calculator.xls" is a model consisting of 5 worksheets. The first two sheets "Assumptions" and "Hourly Inputs" are the ones in which users can modify certain assumptions.

"Assumptions" Worksheet



This sheet is the main control for the calculator. In this sheet, there are sections for various categories of assumptions. This sheet also includes a summary of key results.

Data items in blue font can be changed by the user. Some of these variables have been highlighted in yellow. These highlighted assumptions are the main data items for users to change in order to perform any desired analyses.

Key Assumptions

The key assumptions consist of *Year*, *Total Wind*, and *Average ATC*. *Year* is the year for which the analysis is being done. This is only provided as a convenience and has no impact on the calculations. Note that this model does not make adjustments for leap year or daylight savings time. *Total Wind* is the level of McCamey area wind generation capacity that is to be analyzed. Note that the actual hourly profile for the wind needs to be input in the "Hourly Inputs" worksheet. ATC is the average available transfer capacity for the planned transmission system in the study year. If the user desires to use an ATC that is not constant for all hours of the year, then an 8760 data set can be pasted into the "Hourly Inputs" worksheet.

Wind Value Assumptions

These variables are needed for the model to calculate the value of wind energy that would otherwise have been curtailed. The starting assumption for REC value is based on discussions with market players on current values for

RECs. The starting assumption for *Heat Rate Equivalent* for the average market value of wind energy is based on analysis of ERCOT's OOME down payments in year 2002 for curtailed wind energy.

CAES Assumptions

In this section, users can manipulate the configuration and operating parameters of the CAES plant to determine the impact on curtailment reduction and associated cost/benefits. The configuration of the CAES plant can be adjusted by specifying a different number of units for either compression or generation or by changing the energy storage capacity of the storage cavern. Users can also adjust assumptions that affect operating costs associated with the use of a CAES plant, including gas price. For the sake of ease of use, a single gas price is assumed to apply for the entire year.

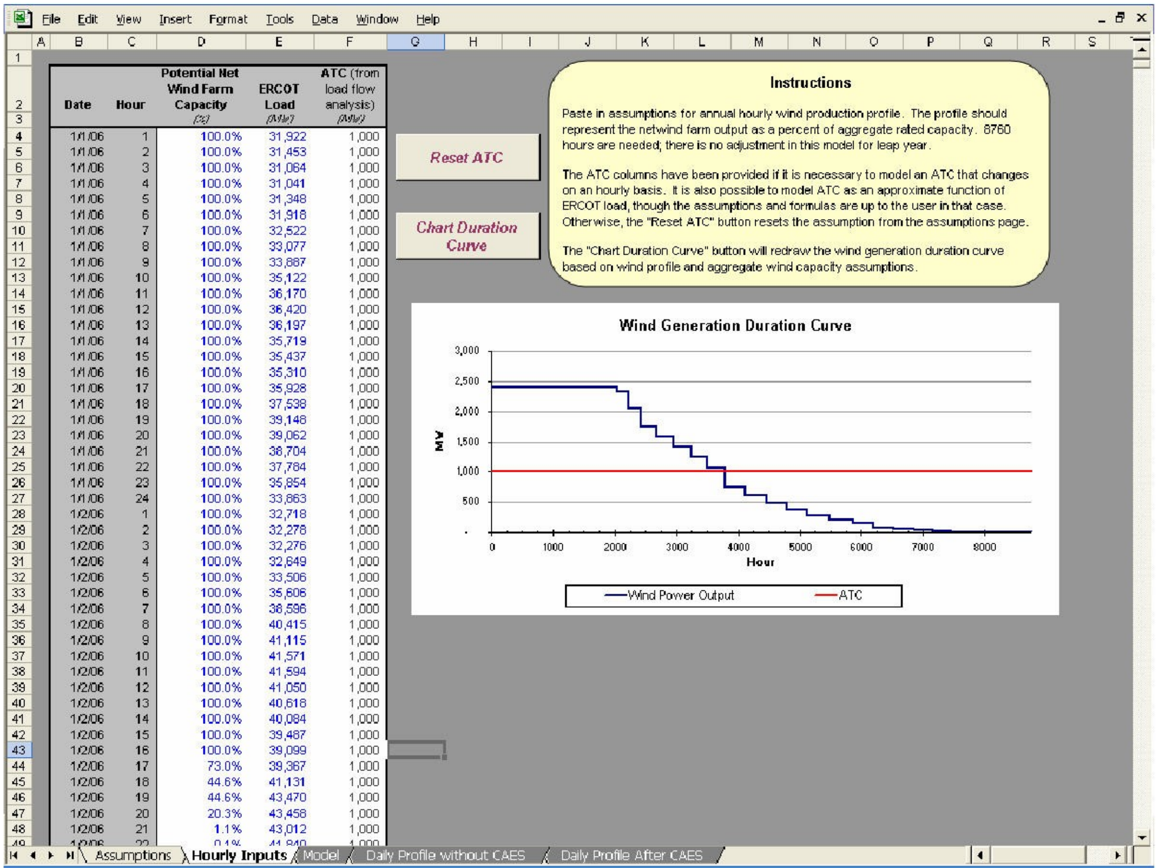
Results Summary

This section shows the difference in curtailments of wind energy with and without the use of a CAES facility. The curtailment reduction is shown as both an energy number in gigawatt-hours, and also as a percent of potential annual wind energy generation.

This section calculates the net curtailment reduction value from use of a CAES plant. This value is calculated as the difference between the value of the recovered wind energy and any storage-related operating costs.

The only benefits that are quantified are those associated with curtailment reduction. Therefore, other values from the use of a CAES plant, such as firming and shaping of wind energy, would have to be calculated in a different model.

"Hourly Inputs" Worksheet



This sheet enables the user to input an hourly data series that defines a typical wind generation profile as a percent of total wind capacity. The profile that is developed by the user should be intended to represent the average wind profile of all McCamey area wind generation resources, and it should also represent net, rather than gross output.

If desired, users may also input a data series for transmission capacity that varies during the year. For convenience, a data column has been added for ERCOT load, since it may be desirable to use a formula that approximates McCamey area ATC as a function of ERCOT load.

Clicking the button, *Reset ATC,* will overwrite any data or formulas that may have been input into the ATC data column. By clicking the button, *Chart Duration Curve,* users can update the wind generation duration curve in order to get a visual representation of the wind profile being used in the calculator.

"Model" Worksheet

Access to this worksheet has been provided for the convenience of the user, though there are no inputs in this sheet that require the user's attention. This worksheet shows the hourly model used to calculate curtailments with and without energy storage. A monthly summary is shown at the top of the worksheet, though users will need to use the scroll bars to see all of the information.

"Daily Profile…" Worksheets

The two worksheets show the typical diurnal wind energy production profile for the assumptions and wind profile provided by the user. The "Daily Profile Without CAES" worksheet shows the wind energy production profile after curtailment for the level of wind assumed by the user, using the assumptions for ATC to calculate curtailments. The graph also shows the potential profile, assuming that the level of transmission had been sufficient to allow maximum generation of wind energy with no curtailments. "Daily Profile After CAES" worksheet shows the impact of storage on the wind production profile. Three profiles are shown. The first is what wind production would have looked like without curtailments, the second is what the wind production profile would look like after accounting for the effects of energy storage. The third profile is the net energy production delivered to the grid, after subtracting the energy put into storage and adding the electricity regeneration from stored energy.