Compressed Air Energy Storage Engineering and Economic Study

Final Report 10-09
December 2009

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Energy Research and
Development Authority

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Engineering and Economic Study

Final Report

Prepared for the

New York State
Energy Research and
Development Authority

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ABSTRACT AND KEY WORDS

Compressed Air Energy Storage (CAES) is a hybrid energy storage and generation concept that has many potential benefits especially when coupled with a wind energy generation facility. As wind energy generation continues to penetrate the grid at increasing levels, the inherent variability in the wind requires additional standby reserves to compensate for low wind energy production during peak load. As priorities have shifted to low carbon emitting generation options, wind/CAES plants have become more attractive compared to natural gas turbines that typically provide the standby reserves needed to buffer wind's variability, despite natural gas turbines' lower operational costs.

NYSERDA commissioned this study to determine the potential for CAES generation facilities in New York State (NYS) because of the pressure to find 25% of renewable generation resources to serve forecasted load in the State. The study examines four aspects of the CAES technologies that bear on its development in NYS, namely, the state of the technology and development costs, existence of suitable underground storage geologies, characteristics of the NY wind resources that would favor CAES siting, and lastly, the economic results that could be expected in the NYS energy market. It determines and describes at least 10 potentially suitable and cost-effective sites for large (over 100MW) CAES generation facilities in NYS. Recommendations are made for future research and development required to advance the technologies, especially adiabatic options. The report also prescribes more detailed economic assessments for any site which would include characterizing the hourly variability of the wind resource to define the opportunity to capture; store and export the wind energy; and the related economics, which depend on numerous factors such as volume of storage, locational energy pricing, operating parameters such as hours of charging/discharging, size of equipment, cost of fuel, energy and environmental policies, and others.

Keywords: energy storage; compressed air energy storage; CAES; wind energy; adiabatic; turbomachinery; CAES generation siting; New York State.

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EXECUTIVE SUMMARY

Compressed Air Energy Storage (CAES) is a hybrid energy storage and generation concept that has significant potential benefits to New York State (NYS), especially when coupled with wind energy generation facilities. As wind energy generation continues to penetrate the NY grid at increasing levels, the inherent unpredictable wind variability in MW output and ramping requires additional standby reserves, frequency regulation, and ramping to compensate for low wind power and energy production during peak-load time periods. As priorities have shifted to low carbon emitting generation options, CAES plants have become more attractive compared to natural gas turbines that typically provide the standby reserves, frequency regulation, and ramping needed to buffer wind's variability.

NYSERDA commissioned this study to determine the potential for CAES generation facilities in NYS because of the increasing pressure to find renewable generation resources to serve forecasted load in the State. Despite the fact that significant amounts of new wind power is forecasted to be developed in NYS, CAES is desired because of its controlled ability to act as a shock absorber and stabilize the transmission grid as new wind resources come on-line.

The study results herein present four aspects of the CAES technology that bear on its deployment in NYS, namely, the state of the technology and its development costs (both capital and operational costs), existence of suitable underground storage geologies in NYS, characteristics of the NYS wind resources that would favor CAES siting, and lastly, the economic results that could be expected in the NYS energy market. The study identifies and describes at least 10 potentially suitable and cost effective sites for large (over 100MW) CAES generation facilities in NYS. Recommendations are made for future research and development required to advance the technologies, especially the no-fuel, adiabatic CAES option. The report also prescribes more detailed economic assessments for any selected site, including a characterization of the hourly variability of the wind resource to define the opportunity to capture, store and use and/or export the wind energy at preferred on-peak time periods, and the related economics, which depend on numerous factors, including MWh's of storage, locational energy pricing, operating parameters such as hours of charging/discharging, size of equipment, cost of fuel, and energy and environmental policies.

The state of the CAES technology has developed significantly in theory and thermodynamic cycle options since the last constructed CAES plant was designed and built in Macintosh, Alabama, in 1991. The most significant design change has been to break up the long single-shaft design into two parts. The compression and expansion cycles are now independent and on different shafts, which offer higher reliability and lower costs. Also, the no-fuel adiabatic CAES cycle, which stores the heat of compression during the charging cycle to eliminate any fuel consumption during the discharge cycle, is now ready for component testing and then pilot scale testing. This process could entail either above-or below- ground air storage using a medium such as thermal oils, molten salt, rock, or ceramic materials to store compression cycle heat and then supply heat to the stored air before it expands and generates energy during the plants discharge cycle. Also, one new CAES thermodynamic cycle uses a standard simple cycle combustion turbine (CT), which serves as one of the power generation output sources for the overall CAES plant and a heat source to increase the temperature of air exiting the air store before it goes into separate turbo-expanders that also produce plant output power. One important aspect of this CT is that it eliminates the need of a customized high pressure combustor, which caused significant technical and reliability issues for the Alabama CAES plant. The turbo-expanders stand alone, as necessary, to produce spinning reserve, frequency regulation, and ramping ancillary services, thereby producing additional revenue streams for the overall CAES facility. As described fully in Chapter 5, the all-in per kW cost of a modern CAES design is lower than any other bulk storage electric generation concept.

In New York there exist several commercially viable CAES sites. The superior underground geology for CAES air storage is bedded salt caverns. There are salt formations across the western half of New York. From Syracuse, to the south and west tilts, a layer of salt that is found approximately 1200 feet below ground with a thickness of about 50 feet in the northern portion of the salt area, graduating to several thousand feet thick in the southern extreme at the border with Pennsylvania. NYSEG consulted with owners of commercial salt production facilities in this area and found that some of these salt facilities are very interested in participation in CAES plant demonstration projects. Additionally, mining operations in the Adirondack, Tug Hill Plateau, and Catskill Mountain areas have produced potentially developable underground air storage caverns. It should be noted, due to the nature of hard rock mining, mine shafts and vent shafts would need to be dewatered and sealed to prevent compressed air losses, adding to the cost of a CAES facility using such caverns. Abandoned oil and gas fields found in the western portion of the state also present opportunities for air storage applicable to CAES plants. (There is heavy competition between companies to use these reservoirs for natural gas storage.)

The study herein also assessed the advantages of partnering CAES facilities with wind resources, which are rapidly being developed in NYS. CAES possesses a unique feature that fits the NY wind profile, namely, that CAES uses off-peak power to charge the air storage cavern, which is usually when wind in NYS is most plentiful, and CAES discharges the compressed air during on-peak time periods, which is usually when wind is at a lull. In this way, it directly stores wind energy for discharge during peak load time periods. This not only benefits the wind farms, providing a large customer for its energy, but helps stabilize the transmission grid from the inherently unpredictable power fluctuations of wind generators. With this in mind, the best location of a CAES plant on the New York transmission system would be as close as possible to a large wind resource, if transmission constraints are not an issue during on-peak time periods. Co-locating a CAES plant with a wind farm, using a ring bus design configuration, is perhaps ideal because the transmission grid would never need to feel or compensate for the fluctuations of the wind generation resource. Using this approach, all of the wind farm output would be used to charge the CAES plant air storage system.

The economic assessments completed for this study compare the profitability levels of CAES plants in four geographic zones based on actual market conditions, including loads and hourly electric pricing and natural gas fuel pricing, using the actual prices that occurred in years 2001–2007. Conclusions from the economic modeling analyses indicate that CAES can be very profitable in New York, even given the environmental and policy concerns and issues that play into the energy storage market. It should be noted that the NYS regulatory treatment of utility-proposed CAES plants is an area recently under examination and could pose a substantial barrier to CAES development in NYS. Thus, this area of concern needs to be addressed as soon as possible. NYS policies should be created that allow utility CAES plant demonstrations to progress, which would provide real operational cost and benefit data to NYS policy makers.

1 INTRODUCTION

Energy storage can resolve many critical problems facing the electric transmission grid in New York State (NYS), including transmission congestion and the uncertainties related to the increased penetration of wind electric generation in NYS. NYS now has approximately 937 MW of wind plants in operation as of December 2008. Also, there is approximately 8,000 MW of wind power in the interconnection queue, including 1,200 MW of off-shore wind. The wind power output generally peaks during the night and is not reliably dispatchable, especially when it is most needed to serve on-peak loads on the system. Due to the variability of wind, the New York Independent System Operator (NYISO) is concerned with how the influx of new wind generation will impact the reserve and regulation requirements of the NY electric grid. One of the solutions is to use energy storage technologies to enable integration of intermittent and variable generation resources in the electric grid.

Many regulators and policy makers agree that energy storage can enable better integration of intermittent and variable renewable energy sources such as wind and can result in significant environmental and market benefits. However, these benefits are difficult to quantify because the benefits are divided among different stake holders such as generators, transmission owners and load, as which also are dependent upon site specific considerations. For example, an Energy Storage (ES) plant operator can buy off-peak coal or nuclear plant output, which can enable the coal or nuclear plant to run at full-load with a resulting lower heat rate and more efficient overall operation. This scenario would also preclude the coal plants from producing the higher SO_x and NO_x emission rates that would surely result if the plant throttled back for the night hours. An ES plant could opt to buy off the grid or complement a wind power resource, and achieve similar benefits. Similarly a strategically located energy storage plant can avoid the need for transmission system upgrades by storing off-peak-power to meet load requirements during on-peak hours. Recently, the NYISO has received various energy storage project applications. While reviewing these applications for interconnection, the ISO has had to create new rules for these storage projects and is also working on further changes to facilitate the integration of storage plants to provide ancillary services such as regulation and/or synchronous reserves.

Of all the large-scale energy storage options (i.e., with storage hours greater than 2 hours), Compressed Air Energy Storage (CAES) is the least capital intensive. Additionally, CAES plants have the longest cost-effective storage period of any bulk storage plant due to minimal losses, yet can provide quick recycling times, rapid ramp rates, and high-part load efficiency. It should be noted that a quick recycling time will be crucial in a distributed generation location so that the plant can be cycled daily.

A variety of electric energy storage systems have been evaluated in past research projects. The Sandia National Laboratories completed a life-cycle cost study for the USDOE in August 2003 on long- and short-term energy storage technologies, using in part results from past EPRI studies on energy storage options. Some of the technologies studied include battery storage, pumped hydro, flywheels, super-capacitors, superconducting magnetic energy storage, hydrogen fuel cells, hydrogen engines, and compressed air energy storage using both surface and underground air storage systems. Results of the study comparing CAES to eight other energy storage technologies are as follows:

1. CAES has the potential for the lowest levelized annual cost ($/kw-yr) due to the low cost of storage (per hour of discharge capability) and greater operational efficiency, both of which translate to lower operational costs
2. CAES has the lowest expected revenue requirements in cents/kwh – the amount a provider would have to charge for each kwh to cover all costs for operating and owning the system
3. CAES has the lowest annual anticipated cost for an eight-hour discharge system which included cost for O&M, electricity used, during the charging cycle, fuel requirements (if non-adiabatic CAES systems are used) and capital carrying charges

The basic design of a CAES plant uses off-peak electric power to fill and compress air in a storage vessel/cavern for use during on-peak hours by releasing the compressed air through a natural gas expansion turbine connected to a generator (see Figure 1 which shows the conceptual design of a conventional CAES plant). When the compressed air is released from the air store, it is heated and then expanded through an expansion turbine connected to an electric generator.

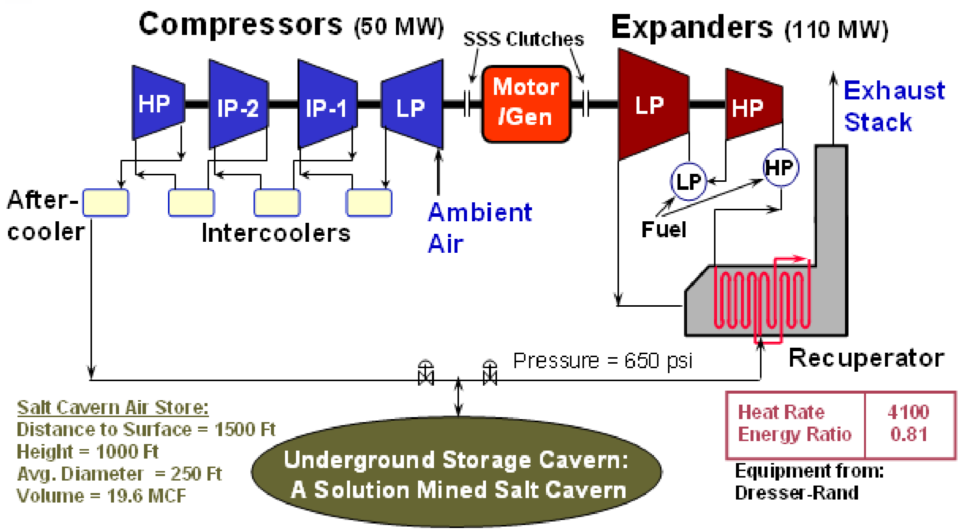

Figure 1: Schematic of Conventional CAES Plant (e.g., the McIntosh, Alabama CAES plant, 110MW-26 Hour)

Two conventional CAES plants using underground salt-storage caverns are currently in operation. The first is a 290-MW, four-hour plant that has been in operation in Huntorf, West Germany since December 1978. The first CAES plant built in the U.S., as described and illustrated above, is a 110-MW, 26- hour facility owned by Alabama Electric Cooperative (AEC) located in McIntosh, Alabama, which has been operating since June 1991. Both plants use solution-mined salt caverns for air storage and both have historically operated with reliability in the range of approximately 90 – 95 %.

The one major design difference between the German and Alabama plants is that the Alabaman plant has an exhaust gas heat exchanger (called a recuperator), which reduces the fuel use by 25% to heat the air after it comes out of the air storage cavern. The design and specification of the recuperator was based on a cost-benefit study performed by EPRI. Also, since the AEC CAES plant has excellent part load efficiency, the AEC operators often ran it at about 55% of its full power rating so that the plant could be used for up-ramp, down-ramp, and spinning reserve duty.

Objectives and Approach of the CAES Engineering and Economic Study

NYSEG led the project team to identify and assess sites in New York State that are potentially suitable for development of a CAES facility. To complete this study, three separate inquiries were initiated. NYSEG and EPRI focused on identifying the appropriate geology to enable underground compressed air storage. EPRI subcontracted the geologic literature search and inventory to PB-ESS and RESPEC. NYSEG performed site visits and interviews with geologists to confirm suitability. Additionally, NYSEG plotted locations of required energy infrastructure, i.e., high-voltage electric transmission lines and gas lines, to determine proximity to potential CAES sites. Customized Energy Services (CES) used historic data and forecasting models to evaluate possible economic advantages provided by potential CAES plants in various regions in the state. EPRI provided an assessment of various CAES designs and turbomachinery available for conventional and advanced designs of the air compression and power generation trains that comprise a CAES facility. Additionally, AWS Truewind provided an assessment of the wind resources in four representative portions of NYS to help determine potential for locating CAES in proximity of available renewable wind energy.

With the preliminary assessments under these studies completed, NYSEG, CES, and EPRI ranked the inventory of potential sites and determined its prime CAES site for further evaluation. The sites referenced to as Seneca CAES Plant site, received more detailed design assessments since it happened to be a site with an available underground solution mined salt cavern, on-site high pressure gas supply, and nearby (within 1 ½ miles) electric transmission lines with available transmission capacity to enable an approximately 150MW CAES plant to provide over 16 hours of electric energy and ancillary services into the NYISO Central Zone. For the Seneca CAES Plant and the size of its available cavern, CES, EPRI, NYSEG, and a NY-based major equipment vendor examined several possible CAES plant configurations to determine the optimal rate of charge and discharge, power output, and the resulting efficiencies. The study also assessed advantages in redundancy and reliability that multiple smaller compressor and expansion turbine units may have over CAES plants that use larger compressor and expansion turbine units. Economic impacts were determined for the plant at various size capacities, and it was determined that a larger plant capacity will result in better long-term economic payback even though upgrades to the existing transmission infrastructure will be required. In August 2009, the project team submitted an application for funding under the US DOE ARRA Smart Grid Demonstration grant program. An electronic and hard-copy of the full proposal was provided as a project deliverable under NYSERDA Contract 10467.

The ARRA proposal represents hundreds of hours of work by NYSEG, EPRI, CES, a major equipment vendor, construction and contract specialists, and other industry experts. The significance of the ARRA proposal is that it expands on the general information determined in the milestone reports and elaborates on the details of one potential CAES site using actual site-specific information. Very clear conclusions can be drawn with regard to the potential economic benefit to the transmission system as well as to the project developers. Together, this report and the ARRA proposal will provide invaluable assistance to NYSERDA who is charged with helping to develop energy storage in NY because of its potential environmental and transmission grid benefits.

2 OVERVIEW OF THE NY GEOLOGY SUITABLE FOR DEVELOPING CAES PROJECTS

Criteria for CAES Plant Siting

NYSEG set out to determine the initial research parameters to determine the presence of suitable CAES project sites in New York. The team determined that the following infrastructure is required. (If any of the infrastructure is not immediately available at the site, the team estimated that it may become cost prohibitive to construct extensions longer than approximately 20 mile)s:

- **Proximity to Natural Gas Transmission Lines (124 PSI or higher)**

A source of high pressure and adequate volume of natural gas should be present at the site. Natural gas is used in the conventional CAES expansion process as its combustion provides heat for the heat exchanger or recuperator to warm the air as it is released from the cavern prior to entering the turbo-expanders. The gas is usually run through a combustor or a combustion turbine. The required pipeline capacities and inlet pressures will be dependent upon the size and design of the combustion machinery. For adiabatic designs, gas lines will not be required; therefore, many more sites will be potentially developable.

- **Proximity to High Voltage (115Kv or above) Electric Transmission Lines**

Any CAES facility will require interconnection to a high voltage transmission line with adequate capacity and voltage to power the electric-drive compressors during off-peak hours and adequate available transmission capacity to accept energy as dispatched by the facility. One chief advantage of a CAES facility is its ability to "firm" electric energy provided by renewable energy sources, which is often variable and intermittent. Therefore, CAES sites that are interconnected to lines carrying such intermittent energy sources will directly provide that "firming" benefit.

- **Proximity to a Market for the Electricity (ISO Zone)**

As described in detail in Chapter 7, the profitability of CAES plants is largely a factor of how the facility is dispatched and the marginal price of electric power at its physical location in the NYISO market. Basically, the facility uses low-cost off-peak power to physically compress air into a storage cavern and therefore, stores the air's potential energy for release during periods of high marginal electric prices.

Suitable Geologic Structure for Air Storage

A review of literature and discussions with New York State Museum Geologist William Kelly (August 28, 2008 personal conversation) revealed that some opportunities indeed exist in NYS to store compressed air underground for use in a CAES facility. To determine the suitability of a geologic structure for compressed air storage, the following inter-related criteria need to be considered:

Volume

In order for a cavern to be economical to develop for air storage, it must meet a minimum volume. In general, the volume determines the length of time the air is available to do the work of generating electricity. Therefore, since CAES facilities will have a fixed cost for site development, equipment, control room, etc, regardless of the expected plant capacity, a larger volume will allow a higher return on investment. For the purpose of ranking the identified potential CAES sites, higher ranking was given to sites with larger potential air storage volume.

Porosity and Permeability

Porosity of a geologic formation can be expressed as a percentage of the volume of void space to the total volume of the solid. Porosity is measured from the inspection of either geophysical logs or from a pore analysis of core samples taken from the reservoir. Permeability is the capacity of a porous material to transmit fluids. It depends on factors of size, shape, uniformity, and connection between pore spaces.

Containment

Containment relates to the degree to which the air storage reservoir is trapped or isolated by cover rock or other geologic formations such as domes, traps, or anticlines. Ideally, none of the compressed air would be able to leak vertically or migrate laterally out of the storage vessel.

Pressure and depth

Pressure and depth to allow quick charging and discharging. An ideal cavern would be able to withstand a large pressure range, for example, a low pressure of approximately 400 psi to a high pressure of about 1600 psi. Even when the cavern is “emptied” and the compressed air has been discharged, the plant operator will maintain a minimum pressure to ensure the stability of the cavern and create a pressure "lock" to eliminate water leaking into the cavern. Caverns would ideally be located at sufficient depth to achieve a natural pressure due to the weight of the earth around the cavern. The natural pressure caused by the weight of the overburden is usually assumed to be 1 psi/foot of depth below surface. Therefore, if a cavern is located 1000 feet below the surface, it may be assumed that the ambient pressure in the cavern will equal approximately 1000 psi. It is vital to have a solid rock overburden layer sufficient to encase the pressure in the cavern below. To enable air to quickly charge the cavern, the subsurface storage medium should be flexible enough to expand as necessary to accept the flow of high pressure air without stress or cracking. With these pressure and flexibility requirements, it is obvious that not all geologic formations in New York may be suitable candidates for air storage.

Temperature

Temperature will be affected by the pressures applied to the cavern. As the air is pressurized, its temperature will rise. The subsurface storage medium will have to be able to endure temperature fluctuations. Additionally, where an adiabatic design is contemplated (no fuel is used to raise the temperature of the air as it exits the cavern, but rather the air is passed through a thermal storage area, which could be made up of a container of superheated rock or ceramic material), the thermal storage area would have to withstand an even higher temperature range.

Means of Brine Disposal

For salt solution-mined caverns, a source of freshwater for leaching the cavern and a suitable location and/or process for disposal of brine from the leaching process is required.

Figure 2 shows the extent of significant layers of salt minerals in New York. Historically, salt mining has been focused in this large area, which encompasses parts of Central and Western New York and all of New York's Southern Tier. The next map, Figure 3, shows high voltage electric lines and Figure 4 shows interstate pipelines in the State. Salt and other mining facilities are shown on Figure 5. The NYISO's forecast capacity of future wind power facilities is shown on Figure 6. Where the resources on these maps overlap will be the areas expected to present the best potential sites for CAES project development. To determine more precisely the locations possessing suitable geology, EPRI contracted a geologic investigation of the potential for compressed air storage caverns to PB-ESS and RESPEC, experts in geology. The results of this detailed geologic investigation are presented below. The entire report is enclosed as Appendix A.

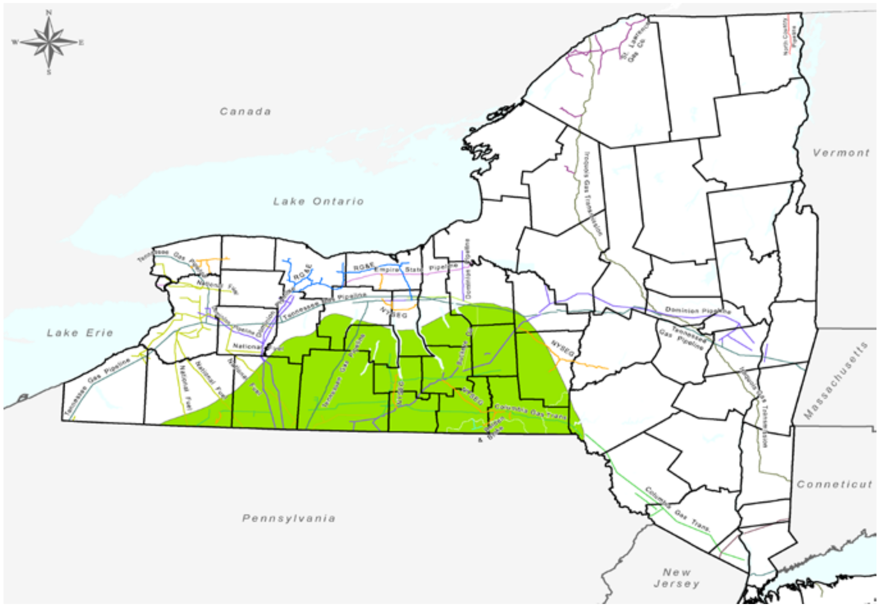

Figure 2: Area of Geologic Salt Formation

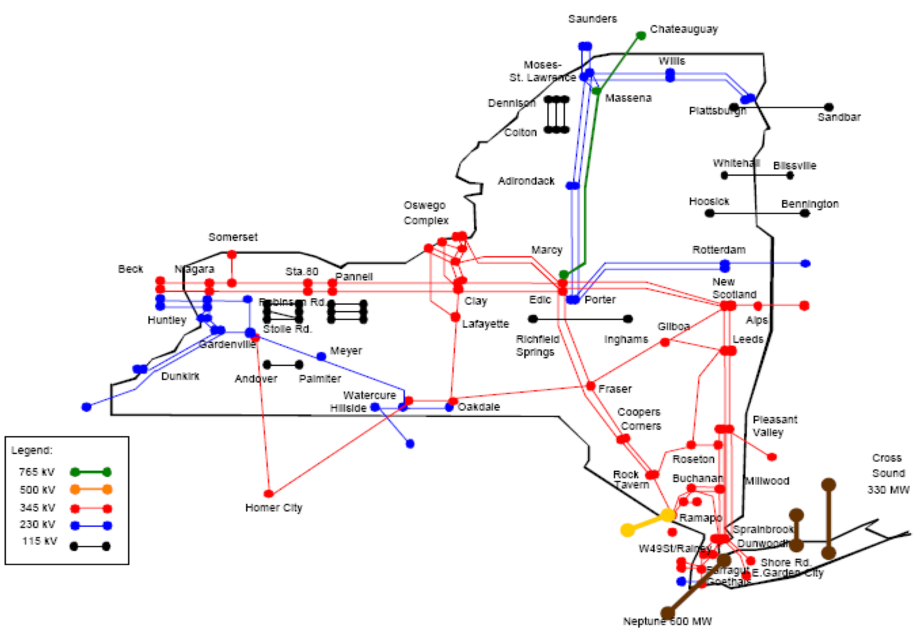

Figure 3: High Voltage Electric Lines

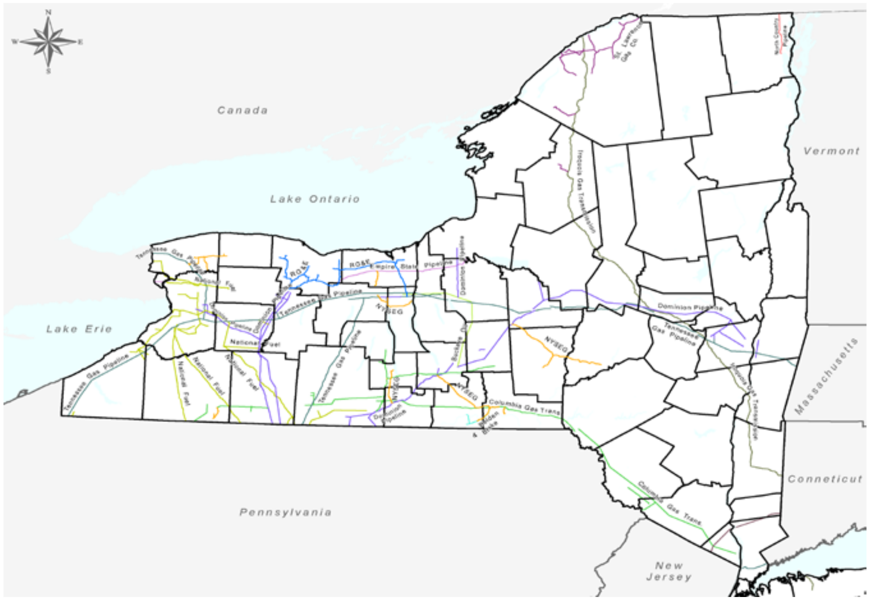

Figure 4: Natural Gas Transmission Lines

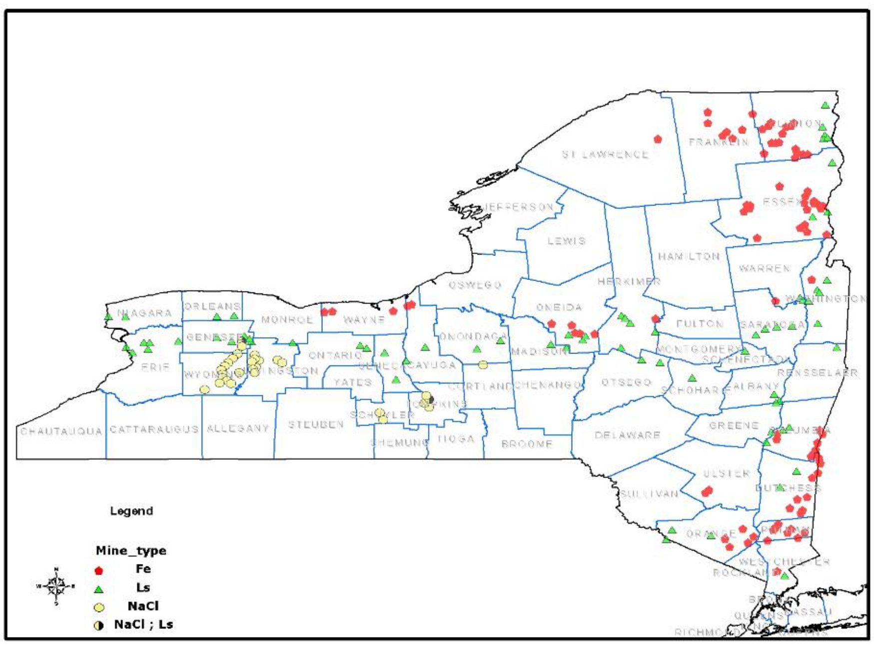

Figure 5: Mines in New York

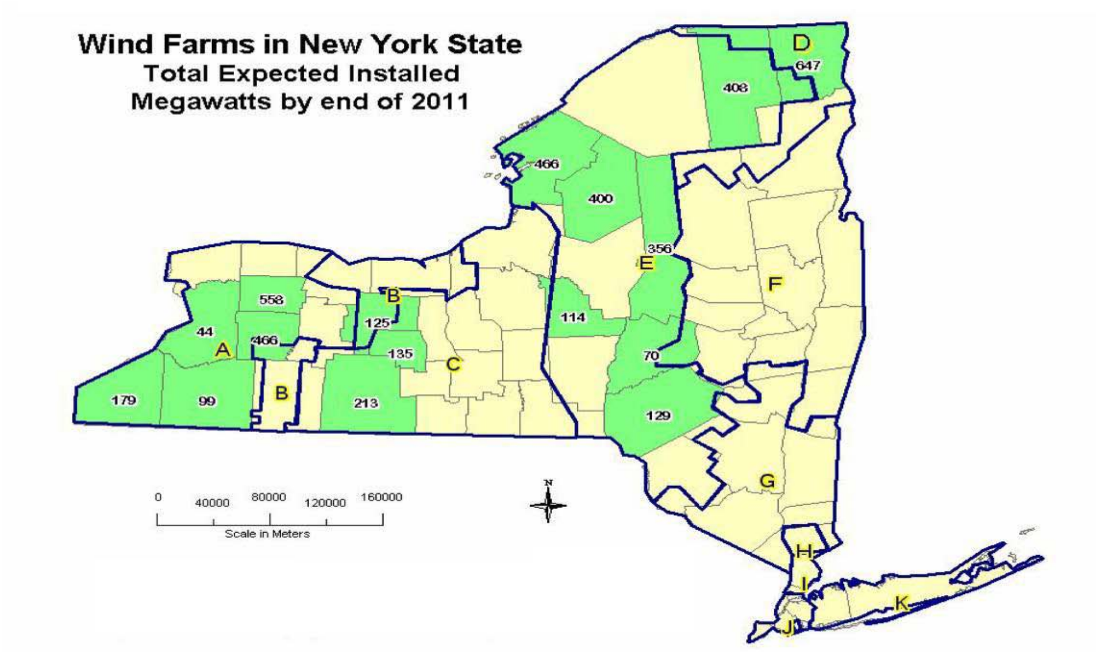

Figure 6: Total Expected Installed Wind Capacity by 2011. Source: NYISO

The types of storage locations that were considered are solution-mined salt caverns and room-and-pillar salt mines; reservoir storage fields; and existing underground non-salt mines, including those for limestone/dolostone, talc, gypsum, and other types of hard rock. Each of these general categories of candidate sites, as well as existing and historical facilities falling under each category, is described in the full report (See Appendix A), using currently available public information.

In general, existing salt caverns generated from solution mining or those caverns currently used for LPG or natural gas storage will require, as expected, modification for CAES use. Depending upon the size of the CAES plant, current casing strings will need to be analyzed for their flow characteristics, and if necessary, replaced to match the host utility CAES plant power and flow requirements. This is not unexpected since the original casing strings were designed for natural gas or propane, or other uses, and have diameters appropriate to the flow characteristics needed by the owner at the time of construction. In addition, these existing salt caverns have brine or other fluids in them, which will need to be addressed for CAES use. The costs for change of these existing salt caverns to CAES may or may not be less expensive than solution mining a new salt cavern for CAES, since the best choice has to be evaluated on a case-by-case basis and since the cost and time period for the solution mining operation will depend upon the MW power rating and duration of storage time for the CAES plant under consideration. The following table represents the Historic and Active Salt Mining Facilities in New York State. Map numbers are keyed to the Active and Historical Facilities map (Figure A-1) in Appendix A.

Table 1: Historic and Active Salt Facilities in New York

Historic Salt Facilities			
Solution Mining			
Map Number	**Facility Name**	**Map Number**	**Facility Name**
1	Ithaca	23	Lergy Salt Co
2	Ithaca	23	Castile Salt Co
3	Remington	24	Duncan Salt Co
4	Aurora	25	Perry Salt Co
5	Clifton Springs	26	Kerr Salt Co
6	Conesus	27	Bradley Salt Co
7	Livonia	28	Empire Salt Co
8	Dansville	29	Hawley Salt Co
9	Nunda	30	Guinlock Salt Co
10	Royal	31	Warsaw Salt Co
11	Lackawanna	32	Atlantic Salt Co
12	Leicester	33	Miller Salt Co
13	Genesee	34	Crystal Salt Co
14	Calcedonia	35	Pioneer Wolf Co

Historic Salt Facilities			
Solution Mining			
Map Number	**Facility Name**	**Map Number**	**Facility Name**
15	Pioneer	36	Globe Co
16	Crystal	37	Moulton Wolf Co
17	Rock Glen	38	Pearl Creek Salt Co
18	Worcester	39	Pavilion Salt Co
19	Bliss	40	Lehigh Salt Co
20	Batavia	41	Leroy Salt Co
21	York Salt Co	-	-
Room and Pillar			
Map Number	**Facility Name**	**Map Number**	**Facility Name**
1	Livonia Mine	4	Lehigh Mine
2	Sterling Mine	5	Morton Salt Milo Mine
3	Greigsville Mine	6	Retsof Mine

Active Salt Facilities			
Solution Mining			
Map Number	**Facility Name**	**Map Number**	**Facility Name**
1	Dale	4	Watkins Glen Village
2	Wyoming Village	5	Salt Point Brine
3	Silver Springs		

Room and Pillar			
Map Number	Facility Name	Map Number	Facility Name
1	Morton Salt Silver Springs	4	Retsof Mine
2	Cayuga Salt Mine	5	
3	Hampton Corners Mine		

The PB-ESS report also included an inventory and evaluation of the potential for other mines to be used for compressed air storage. Abandoned mines that are sufficiently deep (1,500-3,000 feet) may serve the needs for CAES vessels. Two potentially suitable salt mines, the Cargill Deicing Technology Cayuga Mine, and the Morton Salt Himrod Mine exist in central New York. The Gouverneur Talc Mine and two zinc mines operated by St. Lawrence Zinc also appear to have sufficient depth to be considered. These mines are located in the extreme northern part of the State. Shaft sealing is an issue that needs to be addressed properly to use these existing mines for the CAES application. The hard rock mines that were deemed to have sufficient depth to be considered as CAES vessels are listed in the table below.

Table 2: Hard Rock Mines in New York

	Hard Rock Mines		
Map Number	Operator	Mine Name	Commodity
1	Gold Bond Building Products	Clarence Center Plant	Gypsum
2	US Gypsum Co	Oakfield Mine	Gypsum
1	Gouverneur Talc Co Inc	#1 Mine	TALC
2	R. T. Vanderbilt Company Inc Gouverneur Talc Co Inc	#1 & #2 Mines	TALC

	Hard Rock Mines		
Map Number	**Operator**	**Mine Name**	**Commodity**
3	R. T. Vanderbilt Company Inc Gouverneur Talc Co Inc	#3 Mine	TALC
1	Zinc Corporation of America	Hyatt Mine	ZINC
2	Zinc Corporation of America	#4 Mine	ZINC
3	St. Lawrence Zinc Company LLC	Pierrepont Mine	ZINC
1	Wingdale Materials LLC	Wingdale Quarry	GRANITE
1	NYCO Minerals Inc	Willsboro Mine	Wollastonite

Depleted natural gas reservoirs would be suitable candidates for storage of compressed air if they possess adequate porosity, permeability, and thickness. Several depleted reservoirs in the south-central and western parts of the state have been converted to gas storage facilities. It was noted however that the proven gas reservoirs in the State tend to be relatively thin and/or have relatively low permeability outside of the known fields. These physical limitations have restricted their secondary uses for waste brine injection in support of salt cavern storage. Consequently, the physical limitations of the known gas reservoirs beyond the limits of the currently-used fields in New York may also restrict their use for CAES. The existing depleted natural gas storage reservoirs and their current uses are listed in the table below.

Table 3: Natural Gas Storage Reservoirs in New York

NG Storage Reservoir	
Map Number	**Facility**
1	Zoar

NG Storage Reservoir	
Map Number	**Facility**
2	Zoar
3	Holland
4	Bennington
5	Sheridan
6	Derby
7	Perrysburg
8	Lawtons
9	Colden
10	Collins
11	Zoar
12	Tuscarora
13	Limestone
14	Adrian Reef
15	Wycoff
16	N. Greenwood
17	Beech Hill
18	Quinlan Reef
19	Honeoye
20	Wayne-Dundee
21	Stagecoach
22	Stagecoach
23	Salt Point Storage

Table 4: Underground Liquid Propane Storage Facilities in New York

LPG Storage	
Map Number	**Facility**
1	TE Products Pipeline Co. LLC
2	Reading
3	Savona

The PB-ESS inventory report noted that there are two possible good regions of siliciclastic (sandstone) and carbonate (limestone and dolostone) formations for use as CAES reservoirs. These are the Queenston Formation and the Trenton-Black River graben reservoirs located in central New York. The Queenston Formation is a thick, but relatively low, permeability sandstone reservoir. Where geologic structure has provided enhanced secondary porosity, the Queenston may offer some potential for further consideration for CAES. The Trenton-Black River graben reservoirs are currently a high priority for natural gas production and/or for the CAES application. These reservoirs are relatively recent finds. These reservoirs, once depleted, are going to be prime candidates for natural gas storage or for the CAES application. CAES will have to compete economically against natural gas storage at these locations, on a case by case basis. Mapping and additional details on the geologic reservoirs are provided in the full report attached as Appendix A.

The conclusions provided by the PB-ESS study indicate that the type of underground vessel most conducive to use for compressed air storage varies according to geographic position within the State. Concluding that:

1. If operation of a CAES facility in the western part of New York is desired, development of specially designed caverns at the Morton Salt solution-mining facility at Silver Springs appears to be a viable option.
2. If operation of a CAES facility in the south-central part of New York is desired on a relatively short time frame, then the Cargill Deicing Technology Cayuga Mine and the Morton Salt Himrod Mine should be considered prime candidates. Development of

specially designed caverns at the Cargill Watkins Glen or US Salt Watkins Glen facilities also appear to be viable. The time frame for the development of new caverns at these sites depends on the capacity and hours of storage of the CAES plant under consideration.

3. Given the potential opportunity to look at use of inactive mine levels at the Cayuga Mine, the potential for geologic structure locally in the Queenston formation that could enhance its reservoir properties, and the proximity to electric transmission infrastructure, the Fir Tree Point Anticline in Lansing, Tompkins County, is an area worth further review as a means to address immediate need for a CAES in central New York and to further explore the viability of a thick, regional sandstone reservoir for the CAES application.
4. If CAES is desired in the northern part of the State, beyond the limits of salt deposits, then the St. Lawrence Zinc Mine, which was planned for closure at the end of 2008, should be approached. In addition, the Edwards Zinc Mine also appears to be sufficiently deep for CAES consideration.

In the last decade, natural gas exploration has boomed in New York, especially the Southern Tier with discovery and drilling in the Trenton–Black River formation and the more recent discovery of the vast Marcellus and Utica Shale natural gas resources. Geologists confirmed to the team members that the depleted wells of the Trenton–Black River may provide additional storage vessels for compressed air. In general, the Trenton-Black River wells are, more than 10,000 feet deep, and in many cases follow horizontal seams. Because of their depth and the volumes of gas extracted, they are likely to provide large volumes for potential air storage. Hundreds of brine wells exist in New York, a testament to the extensive long history of salt production in the State. Brine wells were created for the purpose of drawing out brine for evaporation into salt or for sale as a liquid for the chemical industry. These brine wells would vary in volume but sufficiently large wells may be found with further investigation or by contacting the well owner. Additionally, the project team found that brine transport pipelines exist in western NY counties, which would alleviate brine disposal environmental concerns related to creating or drying an existing solution-mined salt cavern. The table on the following page summarizes the geographic dispersion by county of the plugged and abandoned gas and/or oil wells sorted by total depth of well. The category of "plugged and abandoned" well type was selected because it may indicate that a well is available for re-use.

Table 5: Oil and Gas Wells in New York—Counties with Plugged and Abandoned Wells. Source: NYSDEC's searchable oil and gas database on NYSDEC's website, 2009.

	True Vertical Depth					
	5 to 12k feet	4 to 5k feet	3 to 4k feet	2 to 3k feet	1.5 to 2k feet	Total
County	# of Wells	# of Wells	# of Wells	# of Wells	# of Wells	# of Wells
Allegany	18	113	132	50	1133	1446
Broome	11	5	1			17
Cattaraugus	13	63	150	99	968	1293
Cayuga	7	4	11	3	17	42
Chautauqua	8	138	224	219	44	633
Chemung	9	3	10	9		31
Chenango	6		2	8	1	17
Cortland	6		1	4		11
Delaware	9	1				10
Erie	1	3	44	344	234	626
Genesee		5	3	10	72	90
Greene	1			1		2
Lewis					2	2
Livingston	4	1	5	20	40	70
Madison	3	3	5	5		16
Monroe			1			1
Montgomery					2	2
New York					2	2
Niagara			2	3	1	6
Oneida				2	1	3
Onondaga		4	4	7	10	25
Ontario	1	2	1	22	6	32
Orange	2			1		3
Orleans			2	11		13
Oswego				5		5
Otsego	4		3	2	4	13
Queens				4		4
Schoharie		1				1
Schuyler	16		6	34	62	118
Seneca	6	3		9	7	25
Steuben	32	79	66	13	13	203
Sullivan	2					2
Tioga	15	3	2			20
Tompkins	6		1	8	7	22
Ulster	4		1	1		6
Washington	1					1
Wayne		1	4			5
Westchester					1	1
Wyoming	20	3	38	116	104	281
Yates	16		3	9	3	31
Total	**221**	**435**	**722**	**1019**	**2734**	**5131**

Hard rock mine information literature searches were also conducted by the project team. The team identified mines additional to those identified by the PB-ESS study. The sources of data include an extensive database of abandoned, historic mines in New York provided by the NYS Geologist. The database includes maps, physical descriptions, survey plots, mine commodity, bore hole data if available, and landowner/contact names, which likely are no longer current. Six regions were selected for the hard rock mine study:

- Western foothills of the Adirondacks including the Tug Hill
- Eastern Adirondack Mountains
- Southeastern New York
- Central NY
- Finger Lakes
- Western New York

Listings of active and inactive hard rock mines shown by region are provided in Appendix B. Many mines are worthy of additional study for CAES storage if they are deep and available for development (several old mining areas, particularly in the Southeast of New York, are now within the boundaries of State or local parks or historic sites). Primarily, the deepest mines were the old iron mines in the Eastern Adirondack Mountains. The Republic Steel Iron Mines are being actively marketed for innovative re-use by the Clinton and Essex County economic development departments. Contact information is provided in the table. Many granite mines exist in New York however they were disqualified from consideration for CAES because many of the granite mines are surface quarries. Only the Wingdale mine, listed in the PB-ESS report, is listed as an underground granite mine.

Iron mines in the southeast part of New York are generally shallow. Usually, mining started at an exposed iron seam on the surface and progressed underground as mining followed the seam. Often, numerous shafts for egress and air flow were punctured into the mine shaft. Using a mine like this would require de-watering and plugging the shafts, and would still not provide adequate depth for compressed air storage. However, shallow mines may present suitable locations to investigate a novel, sealed pipe or concrete storage structure for small volumes of air storage.

Hard rock mines were not plentiful in the Central, Finger Lakes, or western parts of New York. Salt mines were plentiful, which were addressed previously. Conversely, in the Tughill area, numerous hard rock mines exist and are identified in the PB-ESS report.

Based upon the extensive data collection conducted relative to hard rock mines, suitable wells, geologic formations, and available volumes in existing storage caverns, the Table summarizes the estimates of the capacity in MWs and hours of storage from CAES plants if built in these locations. Most sites, especially active mines, are supported by power lines. Natural gas pipelines are present at some sites but are not an absolute requirement for CAES siting, i.e., if adiabatic designs are contemplated. Of course, detailed subsurface characterization would be required at any site. The list is ranked in order of feasibility and ease of construction, and secondarily by potential storage volume size.

Table 6: Potential CAES Sites in New York

Potential Site (Best Ranked First)	Town/County	Storage Capacity (Bcf)	CAES Capacity (MW)	CAES Capacity (hours)	Notes
Seneca Salt Storage area	Reading, Schuyler County	0.05	360	16	Active mining and storage area owned by Inergy, Inc. This site is the subject of the Energy East / NYSEG ARRA proposal.
Avoca Storage Cavern	Steuben County	6.7	Unknown	Unknown	Developed but unused solution mined storage cavern
Morton Salt—Silver Springs Field	Silver Springs, Wyoming County	Unknown	Unknown	Unknown	Active solution mine
Cargill Watkins Glen Plant	Watkins Glen, Schuyler County	Unknown	Unknown	Unknown	Active solution mine
St. Lawrence Zinc Mine	Fowler, St. Lawrence County	0.1	360	32	Owner interested in re-development

Potential Site (Best Ranked First)	Town/County	Storage Capacity (Bcf)	CAES Capacity (MW)	CAES Capacity (hours)	Notes
Morton Salt – Himrod	Himrod, Yates County	Unknown	Unknown	Unknown	Inactive room and pillar mine; modern era design and construction
Cargill Deicing Technology Cayuga Mine	Lansing, Tompkins County	Unknown	Unknown	Unknown	Active room and pillar mine
Retsof Salt Mine	York, Livingston County	Tests are underway to deter-mine available capacity	Unknown	Unknown	Abandoned and flooded; requires massive shaft sealing
Republic Steel Iron Mines	Essex and Clinton County	Unknown	Unknown	Unknown	2800 feet deep mines; actively being marketed by Clinton and Essex County IDAs
Lyon Mtn Iron Mine	Chateauguy, Clinton County	Unknown	Unknown	Unknown	200 to 2500 feet deep mines
Wingdale Quarry	Dover, Dutchess County	Unknown	Unknown	Unknown	Abandoned underground granite mine

3 OVERVIEW OF THE NY ENERGY MARKET

Introduction 1

The New York Independent System Operator (NYISO) is a not-for-profit corporation established in December 1998 to operate the State’s high voltage electric transmission system and administer the State’s wholesale electricity markets. The NYISO is a highly divested and complex marketplace featuring co-optimized energy and ancillary service market clearing systems. The system has a high utility generation divestiture rate (as part of the transition to competitive markets) which makes it one of the most divested markets in the nation. The NYISO’s market volume was nearly $9.5 billion in 2007. The NYISO has a unique challenge in that New York City, one of the world’s largest and most complex load pockets, is located within its area of control.

The NYISO Electricity Market includes markets for installed capacity, energy, ancillary services, and transmission congestion contracts. The energy and ancillary services markets establish prices that reflect the value of energy at each location on the network. They deliver significant benefits by coordinating the commitment and dispatch of generation to ensure that the lowest cost resources are started and dispatched each day to meet the systems demands at the lowest cost. There are six types of ancillary services in the NYISO Market, which include regulation and frequency control, 10-minute synchronous reserves, 10-minute non-synchronous reserves, 30-minute reserves, voltage support, and black start service.

The NYISO uses a two-settlement process for its energy market and certain ancillary services. The first is based on day-ahead bids, and the resulting schedule and pricing is determined by the NYISO Security Constrained Unit Commitment (SCUC) program. The second settlement is based on real-time bids, and the corresponding commitment and dispatch is determined by the Real Time System (RTS). NYISO completed a major market software upgrade called the Standard Market Design 2.0 (SMD-2) in 2005-2006, including changes to its ancillary service markets and the incorporation of a new demand curve for that market as well as three-part offers in real time for generators (start-up costs, minimum generation costs, and incremental energy costs).

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1 This section provides a brief overview of the NYISO Markets as related to the use of electric energy storage technologies as market resources. Specific information on the NYISO Markets and Market Design can be found on the NYISO website at www.nyiso.com.

Energy suppliers may sell directly into the energy market by providing an offer for their resources, or have a bilateral contract selling directly to the energy purchasers. Approximately 50% of the energy in New York State is traded through bilateral contracts outside of the NYISO market. Approximately 45% is traded in the NYISO Day-Ahead Market (DAM), and the remaining 5% is traded in the NYISO Real Time Market (RTM). Loads and other energy purchasers may be price takers, submit bids for supply at certain prices, or be a party to a bilateral contract securing energy directly from a supplier.

In selling or procuring energy in the NYISO Market, market participants should be aware of the risk associated with congestion charges across Zones and negotiate their contracts accordingly. Zones (shown in Table 7 and Figure 7) are regional areas that are determined by transmission district and interchange metering. NYISO wholesale electric prices are the same across a zone and differ between zones by transmission losses and congestion costs.

Table 7: NYISO Zones and SubZones

Location	Super Zone	Zone		Sub Zone
West	West of Central East	A	West	NMPC
				NYSEG
		B	Genesee	NMPC
				RG&E
		C	Central	NMPC
				NYSEG
		D	North	NMPC
				NYPA
				NYSEG
		E	Mohawk Valley	Cent. Hud
				NMPC
				NYSEG
East	East of Central East	F	Capital	NMPC
				NYSEG
		G	Hudson Valley	Cent. Hud
				Con Ed
				NYSEG
				O&R
		H	Milwood	Con Ed
				NYSEG
		I	Dunwoodie	Con Ed
	NYC or Con Ed	J	NYC	Con Ed
Long Island	Long Island	K	Long Island	LIPA

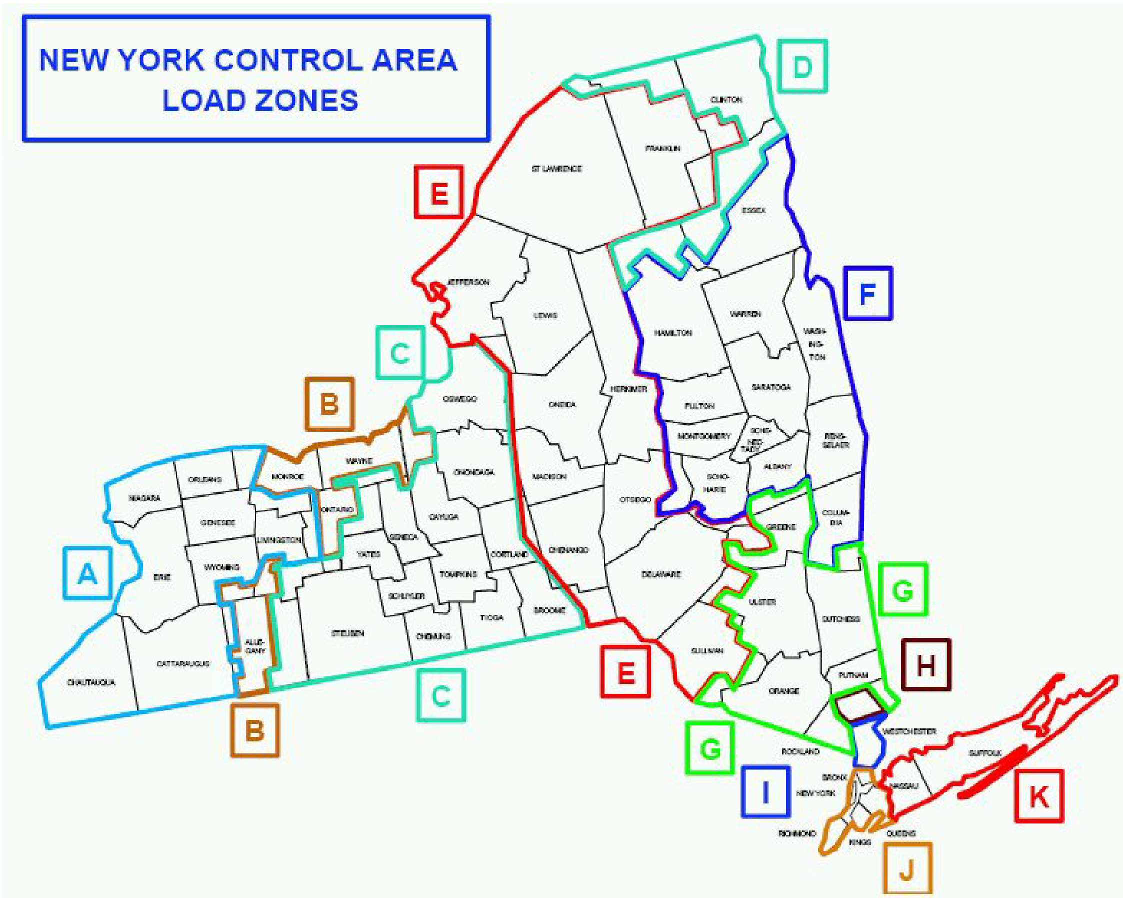


Figure 7: NYISO Control Area Load Zones. Source: NYISO

NYISO Transmission System

Figure 8 shows regions served by various transmission owners (TOs) under the New York Control Area (NYCA). These TOs include:

- New York Power Authority (NYPA)
- National Grid
- New York State Electric & Gas Corporation (NYSEG)
- Rochester Gas & Electric Corporation (RG&E)
- Central Hudson Gas & Electric Corporation

- Orange & Rockland Utilities, Inc.
- Consolidated Edison Co. (ConEd)
- Long Island Power Authority (LIPA)

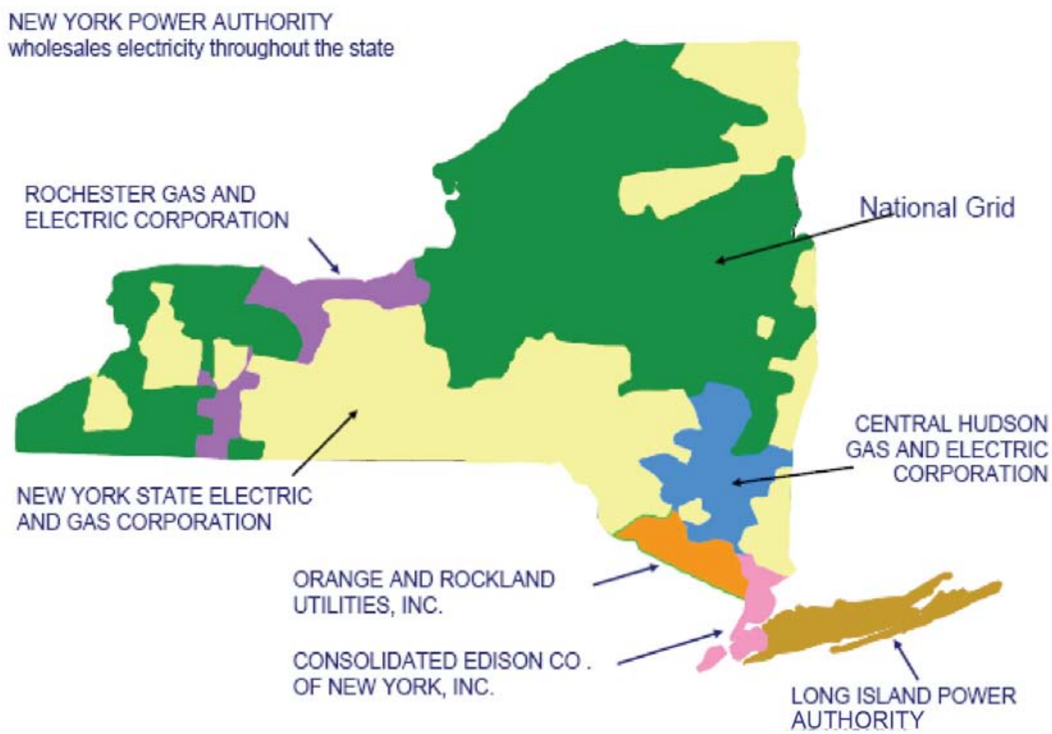


Figure 8: NYCA Transmission Owners. Source: NYISO

Figure 9 provides an overview of the major transmission facilities part of NY Transmission System. The total length of the transmission lines in NYISO is over 10,775 miles. Facilities with voltages from 69 kV up to 230 kV are referred to as High Voltage (HV); transmission facilities with voltages above 230 kV, e.g., 345 kV, 500 kV, and 765 kV, are referred to as Extra High Voltage (EHV). NYCA also includes two HVDC lines which include the 500 MW Neptune line and 330 MW Cross Sound Cable.

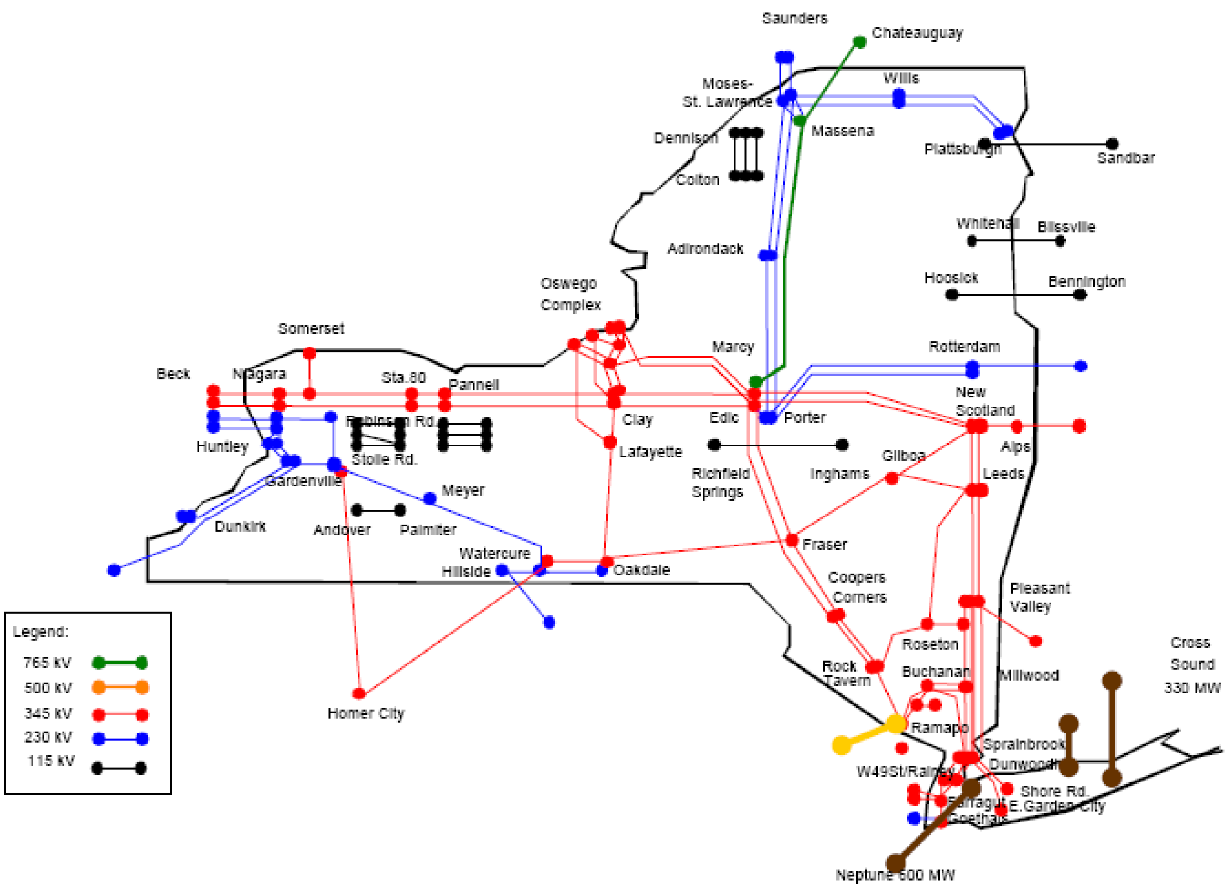


Figure 9: NY Transmission System. Source: NYISO

According to the NYISO state of the market report, the primary transmission constraints in New York occur at the following four locations as shown in Figure 10:

- The Central-East interface that separates eastern and western New York
- The transmission paths connecting the Capital region to the Hudson Valley

- The transmission interfaces into load pockets inside New York City
- The interfaces into Long Island

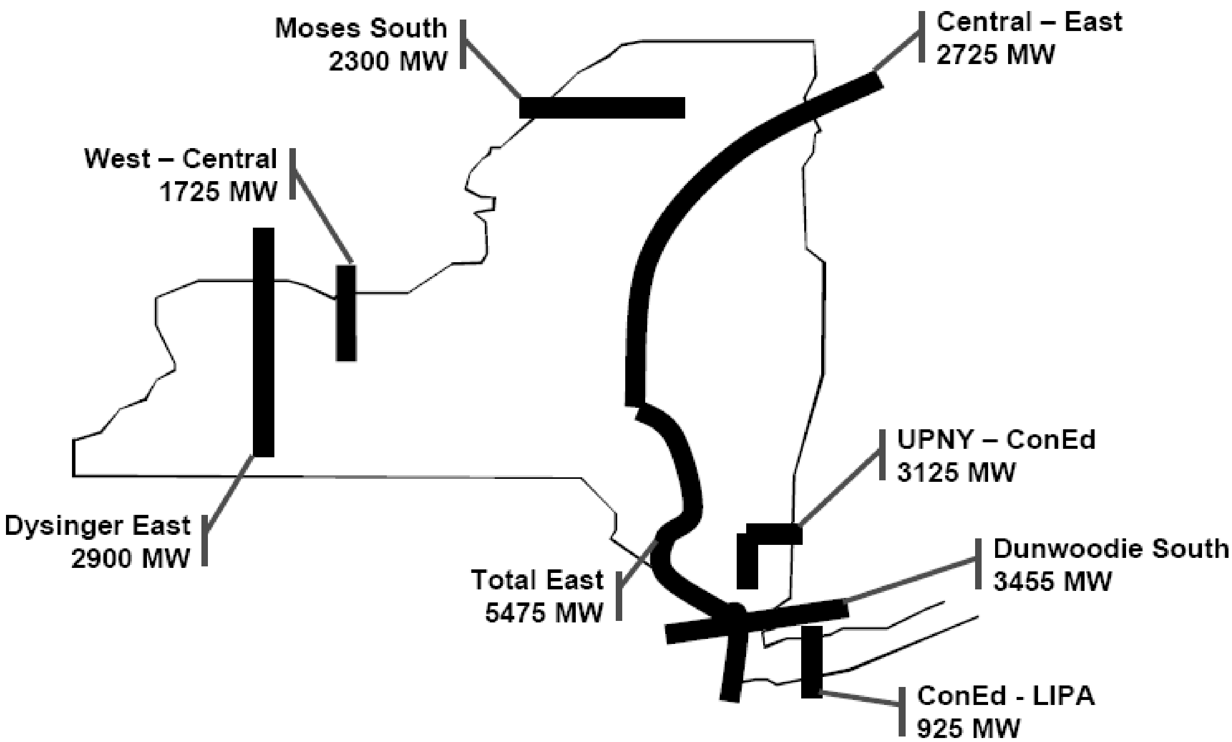


Figure 10: NY Transmission Interface Limits. Source: NYISO Market Overview Course

NYISO Generation

NY has more than 335 generation facilities including over 860 individual generators with almost 39 GW of installed capacity. Figure 11 shows the major generating facilities located within NYCA.

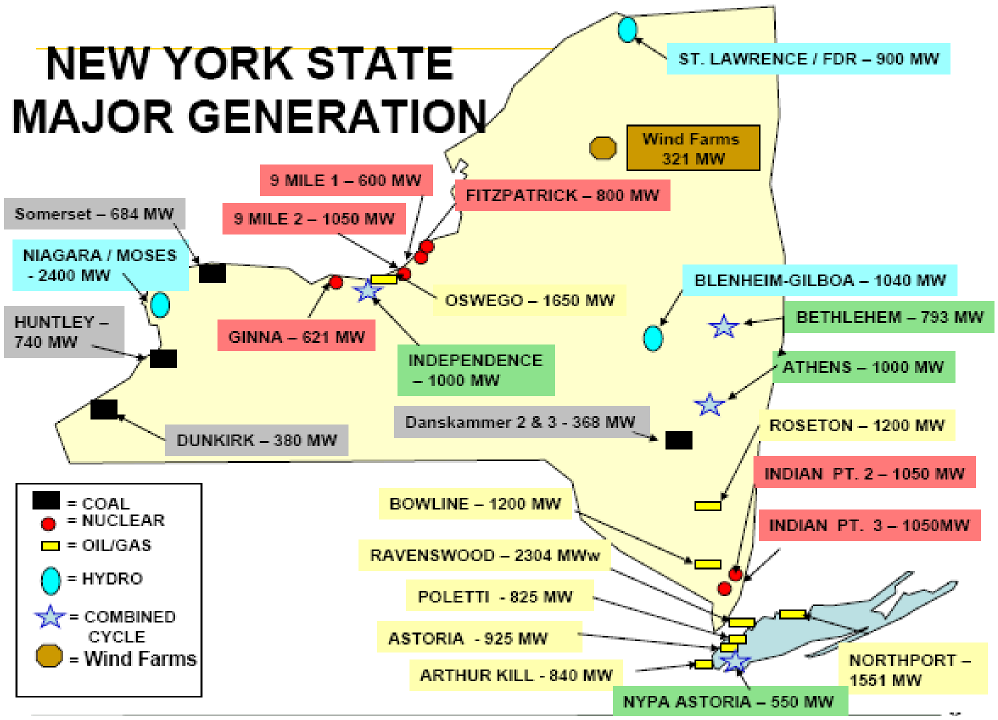


Figure 11: Major generating plants in NY. Source: NYISO Market Overview Course

Figure 12 shows the NYISO's installed generation capacity mix and actual generation fuel mix. As expected, the base load generating units using coal, nuclear, and hydro include a larger share in generation fuel mix.

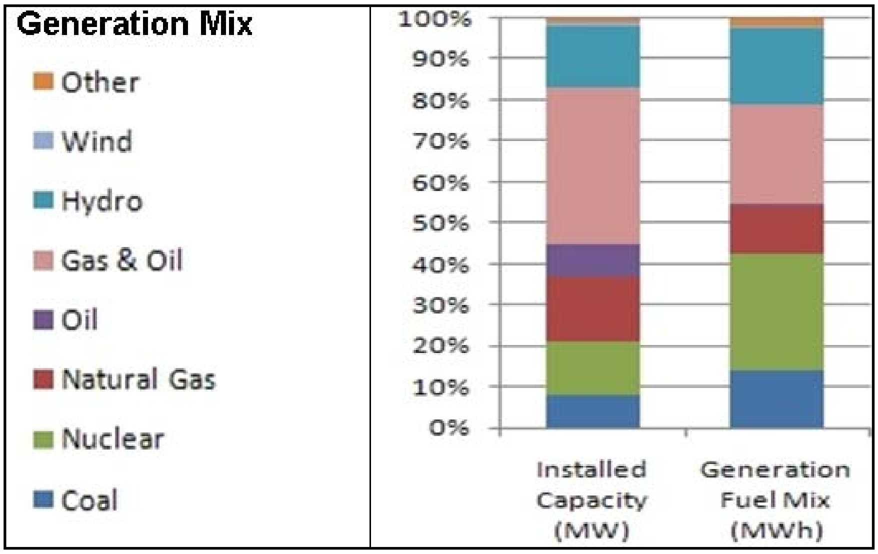


Figure 12: NYISO Generation Mix: Installed Capacity and Generation Fuel

Figure 13 shows the annual price duration curves for NYISO during 2005–2007. The figure also includes summary statistics that indicate the number of hours when the load weighted LMP in NYISO real time energy market was higher than \$100 / MWh and \$200/MWh.

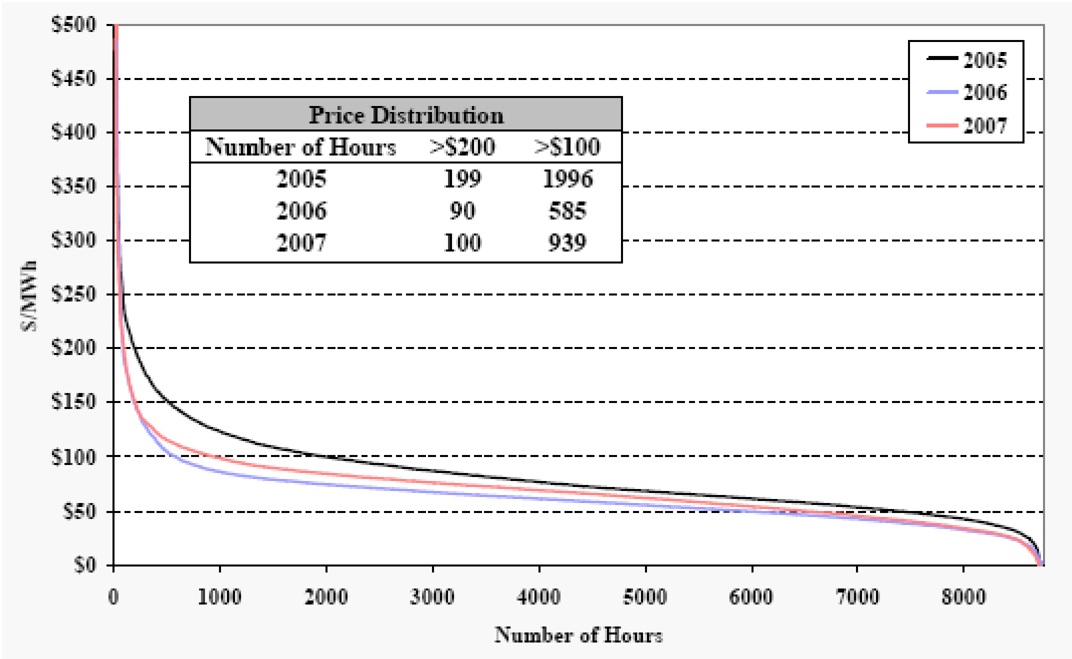


Figure 13: NYISO Real Time Price Duration Curves for 2005–2007. Source: NYISO State of the Market Report 2007)

The energy prices in 2005 are significantly higher than other years due to hurricanes Katrina and Rita in the fall of 2005.

__NYISO Load__

The forecast peak demand for the summer 2008 capability period was 33,809 MW. This forecast was approximately 362 MW (1.08%) higher than the forecast of 33,447 MW for the summer 2007 capability period, and 0.4% lower than the all-time New York Control Area (NYCA) seasonal peak of 33,939 MW, which occurred on August 2, 2006. Figure 14 shows the zonal peak loads for each of the 11 NYISO zones on August 2, 2006 and indicates that NYC and LI zones together accounted for more than 50% of the NYISO peak load.

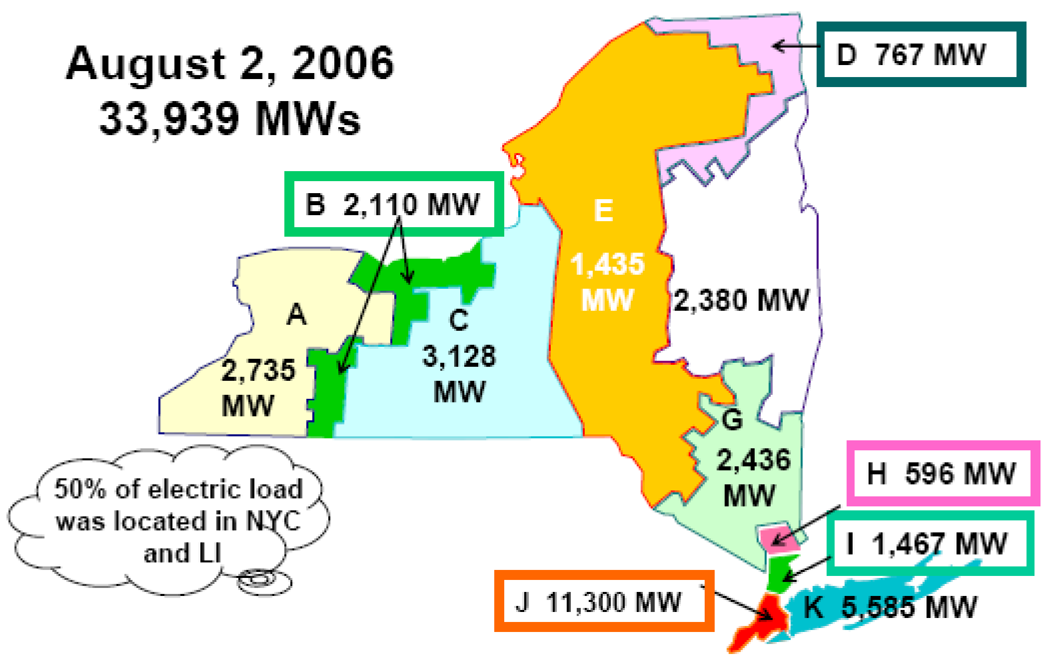


Figure 14: NYISO zonal peak loads during system peak. Source: NYISO—NYMOC Training Material

The Installed Capacity (ICAP) requirement for the 2008 summer period was 38,880 MW based on the NY State Reliability Council's (NYSRC) 15.0% Installed Reserve Margin (IRM) requirement. NYCA generation capacity for summer 2008 was 38,712 MW, and a net external capacity purchase of 2,802 MW was secured for the summer period. The combined capacity resources represented a 22.8% margin above the forecast peak demand of 33,809 MW.

Figure 15 shows the load duration curve for NYISO for 2005 through 2007. The figure also includes statistics on the number of hours when the total system load in NYISO was higher than 28GW, 30GW and 32GW.

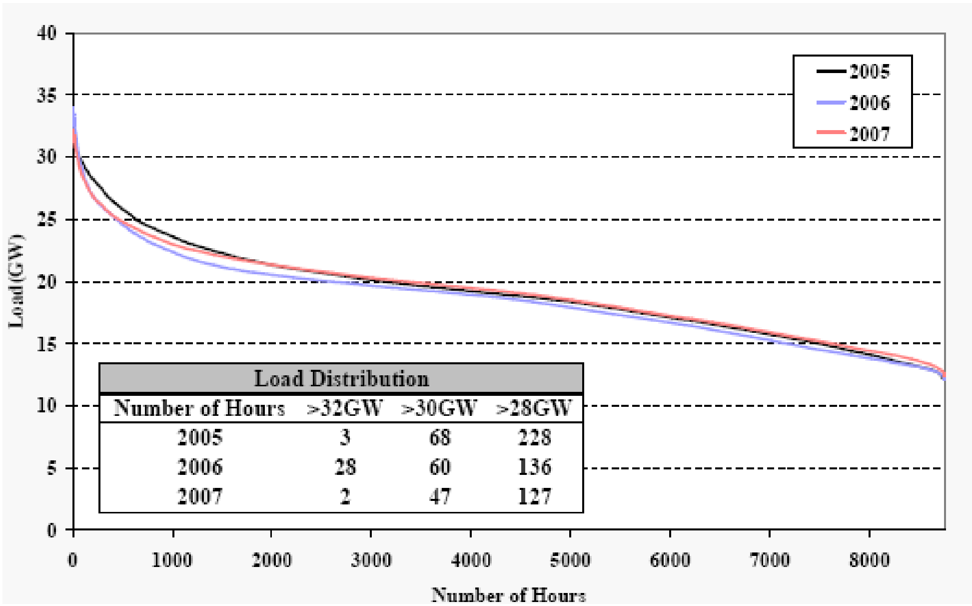


Figure 15: NYISO Load Duration Curves for Years 2005–2007. Source: NYISO State of the Market Report 2007

4 NYISO ENERGY MARKET

As mentioned earlier, NYISO operates a multi-settlement wholesale market system consisting of financially-binding day-ahead markets and real-time markets for energy and ancillary services. Through these markets, the NYISO commits generating resources, dispatches generation, procures ancillary services, schedules external transactions, and sets market-clearing prices based on supply offers and demand bids. The Real Time Commitment model (“RTC”) is primarily responsible for committing gas turbines and other quick-start resources that can start from an offline status and ramp to their maximum output within 10-minutes or 30 minutes of receiving an instruction. RTC also schedules external transactions for the next hour based on bids and offers submitted by participants. RTC executes every 15 minutes, looking across a two-and-a-half hour time horizon to determine whether it will be economic to start-up or shut-down generation.

Generating Capacity of 2 MW or higher can bid directly into the NYISO Markets. Generators can bid in increments of 0.1 MW and must be available for at least one hour. The NYISO has provided in its market design allowances for special resources that have limited electric energy output/reduction capability for short time periods and/or require a recharge period, such as some CAES cycles. These Energy Limited Resources (ELRs) are required to demonstrate the ability to operate for a minimum of four consecutive hours each day.

Regional distribution of energy prices

Based on statistical analysis of historical energy market results and transmission constraints, we have aggregated the 11 zones defined by NYISO into three regions (Figure 17 and Table 8). These regions are distinct in terms of geography and in energy price distribution. There is a clear similarity in the peak and off-peak prices in the zones in each region. This pattern is observed in all three periods used for this analysis: the complete year, the summer capabilities period, and the winter capabilities period.

Table 8: NYISO Zones and Regions used in this Analysis

Region	Zones
1. NY West	West (A), Genesee (B), Central (C), North (D) and Mohawk Valley (E)
2. NY East	Capital (F), Hudson Valley (G), Millwood (H) and Dunwoodie (I)
3. New York City	NYC (J) and Long Island (K)

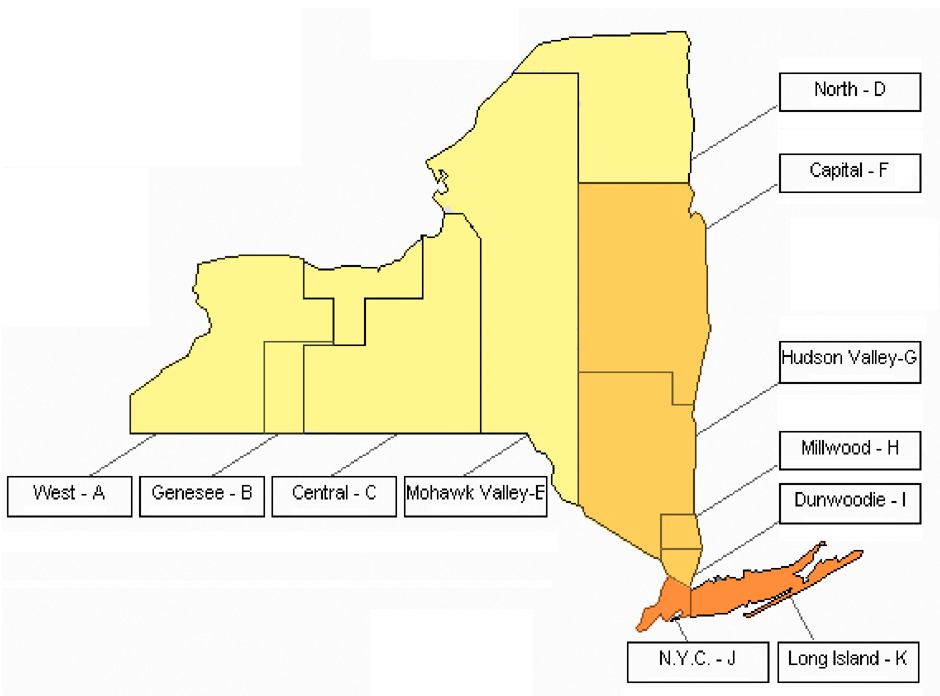


Figure 17: The 11 NYSO market zones grouped into three regions. Based on the NYISO LBMP Map © NYISO

Table 9: NYISO location-based marginal price distribution across zones for 2001–2007

		Peak ($/MWh)			Off-peak ($/MWh)		
Region	**Zone**	**All Year**	**Summer**	**Winter**	**All Year**	**Summer**	**Winter**
New York City	**Long Island**	$82.94	$80.19	$80.19	$59.69	$59.69	$59.70
	NYC	$79.73	$76.91	$76.91	$53.35	$53.35	$53.35
NY East	**Capital**	$65.32	$65.57	$65.57	$47.46	$47.46	$49.23
	Dunwoodie	$69.62	$67.05	$67.05	$48.40	$48.40	$49.48
	Hudson Valley	$68.06	$66.09	$66.09	$47.82	$47.82	$49.08
	Millwood	$68.98	$66.40	$66.40	$47.98	$47.98	$49.09
NY West	**Central**	$58.25	$57.74	$57.74	$42.18	$42.18	$43.23
	Genesee	$56.89	$56.29	$56.29	$40.62	$40.62	$41.68
	MH Valley	$60.09	$59.58	$59.58	$43.74	$43.74	$44.75
	North	$57.72	$57.64	$57.64	$42.78	$42.78	$43.86
	West	$54.32	$53.27	$53.27	$38.77	$38.77	$39.60

Table 9 lists the distribution of the mean location-based marginal price (LBMP) for different zones and seasons for the 2001–2007 period. For NYISO's operations, the peak period is defined as the hours between 7 am and 11 pm inclusive, prevailing Eastern Time, Monday through Friday, except for North American Electric Reliability Council (NERC)- defined holidays. The off-peak period is defined as the hours between 11 pm and 7 am, prevailing Eastern Time, Monday through Friday; all day Saturday and Sunday; and NERC-defined holidays. NYISO has defined the summer capability period as May 1 through October 31 and the winter capability period as November 1 through April 30.

Installed Capacity Market (ICAP)

The ICAP Market has been established to ensure that there is sufficient generation capacity to cover the capacity requirements determined by the NYISO. An ICAP resource can be a generator or load facility with access to the NYS transmission system. The resource must be capable of supplying generation or reducing load in the New York Control Area. ICAP market provides economic signals that supplement the signals provided by the NYISO's energy and operating reserve markets. If resources participate in the ICAP Market, they will receive revenue for making their resource available, and as a result, are required to offer the energy from the resource into the DAM. Energy storage systems capable of providing at least four hours of energy, are eligible to receive ICAP payments as part of Energy Limited Resources (ELR). Electric energy storage facilities can also receive ICAP revenues by participating in the Demand Response Program as Special Case Resource (ICAP-SCR). Thus any electric energy storage facility capable of providing four hours or more capacity can generate these additional revenues on top of the revenues received from energy and ancillary markets.

All Load Serving Entities (LSEs) must acquire sufficient ICAP to cover their load plus a reserve by self-scheduling, bilateral purchasing, or through one of the NYISO's forward procurement auctions. Any remaining obligations are settled against the NYISO's monthly spot auction where clearing prices are determined by a capacity demand curve. Currently, the capacity auctions have three distinct locations within New York: New York City, Long Island, and Rest-of-State. The locational requirements for New York City (Zone J) and Long Island (Zone K) require LSEs serving these areas to procure a certain percentage (80% and 99% respectively) of the regional peak load from resources within the individual zones (NYISO, 2005a). The clearing prices in New York City and Long Island are generally much higher than those in the Rest-of-State.

In 2008, the NYISO Market Monitor has indicated that long-term reliability concerns have risen in southeast New York (which includes Zones G through I), the portion of Rest-of-State (which includes Zones A through I) that is closest to New York City and Long Island. Based on the 2008 Comprehensive Reliability Plan (CRP), additional resources will likely be needed in southeast New York between 2013 and 2014. Furthermore, a recent analysis by the NYISO indicates that some capacity in Zones A through F will not be deliverable to southeast New York by 2012. This may require the NYISO to use non-market measures to reduce sales of capacity in Zones A to F because there is currently no mechanism in the capacity market for distinguishing the value of capacity located in Zones A to F from the value of capacity located in southeast New York. At the same time, the new Reliability Needs Assessment (RNA) issued periodically by NYISO, indicates that there are no additional requirements needed through the study period due to the State's 15x15 Energy Efficiency Portfolio Standard (EEPS).

Ancillary Services Markets

Ancillary Services support the transmission of real power and reactive power from resources to loads and are used to maintain the reliable operation of the power grid. The NYISO coordinates the provision of all Ancillary Services and directly arranges for its supplies that are not self-supplied. There are six types of Ancillary Services administered by the NYISO: Regulation and Frequency Response, three types of Operating Reserves (10-Minute Synchronous, 10-Minute Non-Spinning, and 30-Minute reserves), Voltage Support, and Black Start support.

NYISO uses a two-settlement system for Ancillary Services, which requires providers to meet their day ahead obligations in real time or purchased back from the ISO's Real-Time Market (RTM). NYISO implemented SMD-2/RTM in 2006, which included enhancements for the Ancillary Services markets.[2] NYISO co-optimizes regulation and operating reserves with energy in both the Day-Ahead and Real-Time Markets. The Ancillary Service market clearing prices are based on the marginal cost of the unit(s) providing the Ancillary Service to the system, which includes availability offer price and opportunity cost of not providing energy. NYISO also uses demand curves for Ancillary Services to reflect its value and energy in prices under scarcity conditions.

The following section provides an overview of each of the ancillary services markets:

- ***Regulation and Frequency Response Service*** provides a continuous balancing of supply with the system load requirements, in accordance with NERC criteria. This service is accomplished by committing online generators whose output is raised or lowered, usually in response to an Automatic Generation Control (AGC) signal, as necessary to follow moment-by-moment changes in load. Market participants use the revenues they

2 Source: NYISO State of the Market Report 2007

receive from providing these services to offset the charges paid to the NYISO for the service.

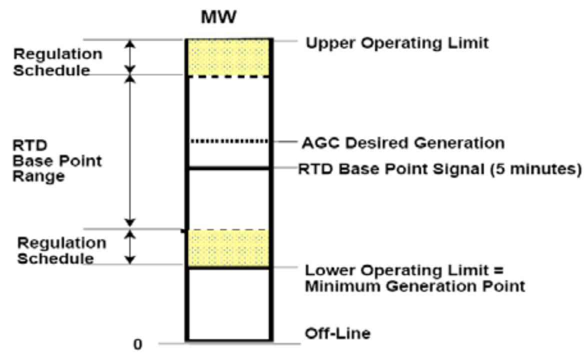


Figure 18: Generating Unit Operating Characteristics for regulation service. Source: NYISO

There are no locational requirements for regulation in NYISO and as a result, the Regulation Market Clearing Price (RMCP) is the same throughout the NYISO. The RMCP includes the availability bid and lost opportunity cost. The lost opportunity cost represents the difference between the LBMP and the energy offer provided by the marginal regulation unit. Under scarcity conditions, the NYISO uses a demand curve to set regulation prices for resources.

Table 10: NYISO Regulation Demand Curve

Regulation	**Demand Curve**
Need > 25MW to meet Target level	$300/MW
Need < 25MW to meet Target Level	$250/MW

The NYISO typically procures between 150-275 MW of regulation for each hour. The seasonal regulation requirements for each hour are listed in Table 11.

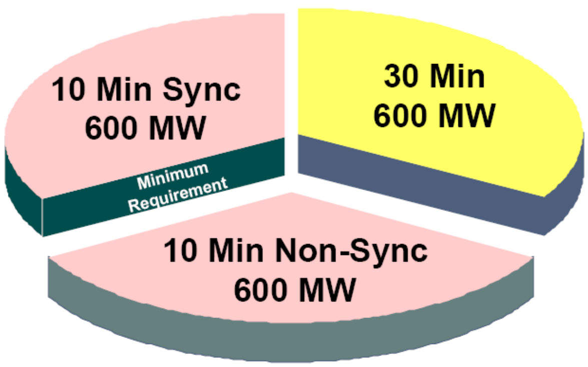
Table 11: NYISO Seasonal Regulation requirements (Range 150—275 MW) Source: NYISO

	April -May		June-August		September-October		November - March	
Hour Beg	Weekday	Sunday	Weekday	Sunday	Weekday	Sunday	Weekday	Sunday
0	150	150	175	175	180	160	190	160
1	150	150	175	175	180	160	190	160
2	150	150	175	175	180	160	190	160
3	150	150	175	175	180	160	190	160
4	150	150	175	175	180	160	190	160
5	175	150	200	175	250	160	250	160
6	275	150	275	175	275	160	275	160
7	275	150	275	175	275	160	275	160
8	275	150	275	175	275	160	275	160
9	200	160	250	160	260	180	250	180
10	175	175	240	175	250	210	250	210
11	150	150	210	175	210	160	210	160
12	150	150	175	175	180	160	180	160
13	150	150	175	175	180	160	180	160
14	150	150	175	175	180	160	180	160
15	175	150	175	175	190	160	190	160
16	200	175	250	230	250	230	275	230
17	200	200	250	250	250	250	275	250
18	200	200	250	250	250	250	275	250
19	200	200	250	250	250	250	250	250
20	200	200	250	250	250	250	250	250
21	200	200	250	250	250	250	250	250
22	175	175	225	225	240	225	240	225
23	150	150	175	175	190	175	190	175

The NYISO has a Regulation Revenue Adjustment charge which ensures regulation suppliers are properly compensated for regulating relative to the LBMP and their economic RTD base-point. The revenues from the regulation service are adjusted if the resource does not perform as expected. The NYISO has established a deviation tolerance, which is 3% of a unit's upper operating limit and defined by difference between maximum and minimum AGC basepoint as shown in Figure 18 above.

Resources under-generating and exceeding their deviation tolerance for five dispatch cycles (30 seconds), are penalized. Resources over-generating and exceeding their deviation tolerance for five dispatch cycles are not compensated for the additional generation. Resources over-generating, but within their deviation tolerance are paid for the over-generation.

Operating Reserve Services provides backup generation when there is an unexpected change in generation or transmission due to reaching a power system contingency and/or an equipment failure. The NYISO Reserves must be available in 10-minute spinning, 10-minute non-synchronous, and 30-minute reserves and are each separate products.



In each hour, the NYISO purchases approximately 1,800 MW of operating reserves. Of this 1,800 MW, at least 1,200 MW must be 10-minute reserves, and at least 600 MW must be spinning reserves.

Figure 19: NYCA Operating Reserve Requirements. Source: NYISO

Ten-minute spinning (or synchronous) reserves are held on generating units that are on-line and can provide additional output within 10-minutes as shown in Figure 20. Currently, the reliability rules only allow this type of a reserve to be provided by a generating source. There is a 2 MW minimum requirement and must be synchronized with the network. The resource must provide a full response in 10-minutes and be able to perform at the committed response for 30 minutes.

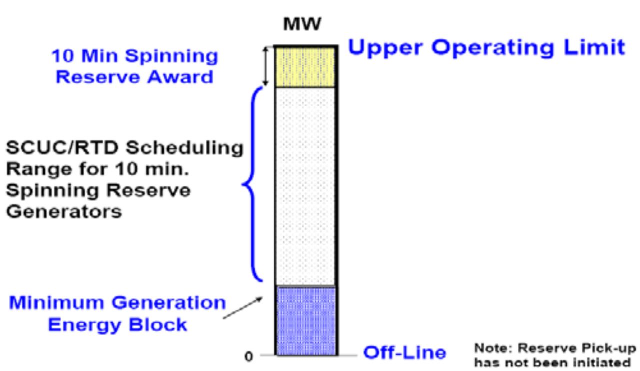


Figure 20: Spinning Reserve Bid

- **10-Minute non spinning reserve** can be used to supply 10-minute total resources, and are typically off-line gas turbines that can be turned on and produce electricity within 10-minutes. There is a 2 MW minimum requirement and it must be able to synchronize with the network and provide a full response in 10-minutes. Additionally, the unit must be able to perform at the committed response for 30 minutes.

- **30-minute operating reserves** may be supplied by any unit that can be ramped up in 30 minutes or that can be on-line and be producing within 30 minutes. All dispatchable (flexible) resources participate in the reserve market. There is a 2 MW minimum requirement and it must be able to synchronize with the network. The resource must provide a full response in 30 minutes and be able to perform at the committed response for at least one hour.

Reserves procurement is subject to locational requirements that ensure the reserves are located where they can respond to system contingencies. Of the required 1200 MW of total 10-minute reserves, 1,000 MW must be purchased east of the Central-East Interface.

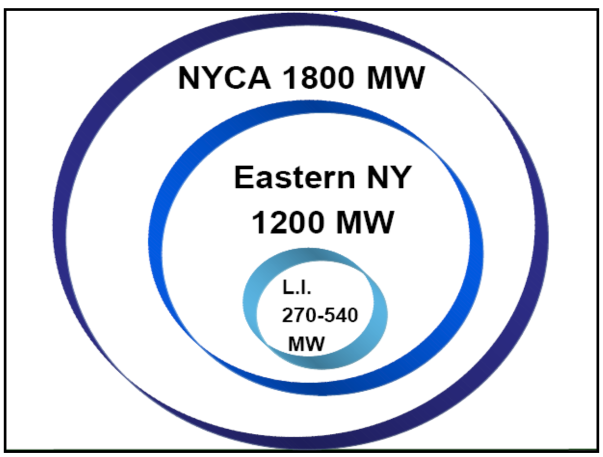


Figure 21: Nested Location Reserve Requirement

Table 12 shows the “NYISO Operating Reserve Requirements for the entire NY Control Area (NYCA), Eastern New York State, and Long Island.

Table 12: NYISO Operating Reserve Requirements. Source: NYISO

Reserve Product	NYCA	Eastern New York	Long Island
10 Minute Spinning Reserve	600 MW	300 MW	60 MW
10 Minute Total Reserve	1200 MW	1200 MW (1000 MW w/NE)	120 MW
30 Minute Reserve	1800 MW	1200 MW (1000 MW w/NE)	270 - 540 MW

The NYISO obtains 200 MW of 10-minute reserves through a reserve sharing agreement with New England. The NYISO procures at least 300 MW of 10-minute spinning reserves from the eastern portion of New York. It also procures at least 60 MW of 10-minute spinning, 120 MW of total 10-minute, and 540 MW of total reserves from within Long Island. The relative importance of each locational requirement is indicated by its demand curve value. The total 10-minute reserve requirement for New York currently has a demand curve value of $500/MWh, while the other locational requirements for eastern New York and Long Island have demand curve values of additional $25/MWh each as shown in Table 13.

Table 13: NYISO Reserve and Regulation Demand Curves. Source: NYISO

	NYCA	East	Long Island
Spinning 10 Minute Reserve	$500/MWh	$25/MWh	$25/MWh
Total 10 Minute Reserve	$150/MWh	$500/MWh	$25/MWh
30 Minute Reserve	200 MW @ $50/MWh 200 MW @ $100/MWh Remainder @ $200/MWh	$25/MWh	$300/MWh
Regulation	25 MW @ $250/MWh Remainder @ $300/MWh		

Voltage Support Services provide reactive power to maintain consistent voltage levels on the transmission system. Supply resources that have Automatic Voltage Control (AVR) and have successfully performed an annual MVAr test(s) to determine the total reactive power capability, can participate in the service and be paid a cost-based predetermined rate for the service. Suppliers are paid based on their capability whether they are called to provide the service or a portion of the service.

Black Start Service is reserved for certain generators identified by the NYISO which have the ability to start without any outside supply and are able to participate in the bulk power system restoration plan. Until recently, these resources were limited to a select number of the New York Power Authority's facilities. Currently, the NYISO has expanded this service to address providers of local Black Start and Restoration Services in the New York City Zone (Zone J). Other zones throughout the State may be considered in the future. Figure 22 provides an overview of the NYISO power restoration plan.

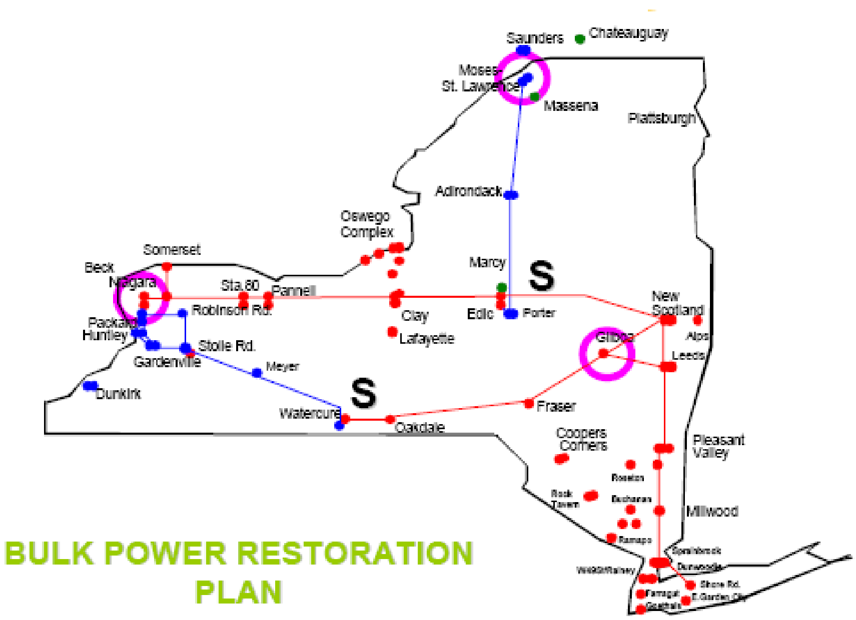


Figure 22: NYISO Power Restoration Plan. Source: NYISO

5 CAES PLANT TURBOMACHINERY DESIGN OPTIONS SUITABLE TO NEW YORK CONDITIONS

The approach used to investigate and present alternative CAES plant designs applicable in New York is to first present for the reader the capital and performance characteristics of the Alabama Electric Cooperative (AEC) CAES plant (see Table 14) as a reference plant. Next is to present some specific alternative CAES plant design options suitable for New York and compare these new CAES plant designs to the AEC plant, in terms of capital cost and operating performance parameters.

Table 14: Reference Plant Specifications From the Alabama Electric Cooperative (AEC) McIntosh CAES Plant

AEC McIntosh CAES Power Plant	
Plant Power Capacity (MW)	110
Storage Hours	26
Hours of Compression per Hour of Generation	1.6
Storage Geology	Salt
Storage Volume (million cubic feet)	19.6
Fuel	Gas
Compression Air Flow (lb/sec)	208
Expansion Air Flow (lb/sec)	340
Recuperator Cold Side Air In/Out Temp (F)	95/546
Recuperator Hot Side Gas In/Out Temp (F)	696/293
HP Expander Inlet Temperature (F)	1000
HP Expander inlet Pressure (psia)	620
LP Expander Inlet Temperature (F)	1600
LP Expander Inlet Pressure (psia)	218
Power Production Heat Rate (Btu/kWhr)	4100
Plant Charging Ratio (kWhr-In/kWhr-Out)	0.81

Today, two turbomachinery vendors offer equipment similar to that used in the AEC CAES plant; namely, Dresser Rand (module size = 135 MW) and Alstom (module size = 400 MW). Both vendors have put together a preferred CAES plant design that is rigid not only in the specified plant size but also in allowable operating air flows and pressures, which affect the air store depth and volume. These conditions may be met in New York but make it difficult to adjust the plant specifications to meet the needs of specific renewable plant capacities, modes of plant operation, and underground geologic formations in New York. Figure 1, in Chapter 1, displays the configuration, power and thermodynamic parameters of the conventional, reference case AEC CAES plant design option.

CAES PLANT DESIGN OPTIONS BASED ON STANDARD COMBUSTION TURBINE POWER BLOCKS

There is a strong interrelationship between a CAES plant design, the plant equipment specifications, vendor equipment chosen and the storage geology for each site being investigated. For example, the choice of the minimum inlet pressure to the expander determines the minimum storage pressure, sets the required air compressor discharge pressure, and impacts the efficiency of the overall CAES plant operating cycle. Also, the allowable storage pressures and the storage cost are dependent upon the storage geology. Thus, the CAES plant design, plant concept, and equipment specifications all must be "optimized" simultaneously with the economic and operating constraints imposed by the company attempting to build a CAES plant. In response to these needs and challenges, presented below are CAES plant design options that are able to provide variety and flexibility for CAES plant capacities and energy storage pressures. Using these design options will allow the user to improve the overall CAES plant performance and operating modes while reducing both the plant's capital costs and operating costs. These plant design options use existing technology by incorporating off-the-shelf gas turbines, compressors, and expanders into the overall plant design.[3]

The new CAES plant design options enable the CAES technology to have lower capital costs, shorter delivery times, and higher operational flexibility than those for the conventional AEC CAES plant design. The new CAES plant design options use a standard combustion turbine (CT)

3 One of the new CAES plant designs use a simple cycle combustion turbine module as a central element in the overall CAES plant design. These designs using a simple cycle CT are patented by Dr. Michael Nakhamkin, who is currently working for a subsidiary of PSE&G, called Energy Storage and Power, LLC, who is willing to negotiate a licensing agreement with any organization interested in building an advanced CAES plant using his designs.

engine as the only equipment which consumes fuel. The CT exhaust heat provides the heat energy input to the compressed air that is withdrawn from the storage system and expanded through a CAES expander in order to generate the CAES plant power output. There is no need for development and use of customized high pressure (HP) and low pressure (LP) combustors, which were a challenge during the AEC CAES project. The gas turbine vendors and equipment could be properly selected to optimize the CAES plant size and the operational performance of the plant, which would be chosen to best meet the specific needs of the New York grid (e.g., the MW size of the compressor and expander, the maximum storage hours for the plant, and the regulating rates, efficiency, and ramping characteristics of the overall plant.

A summary is presented below of the results of the CAES plant design options investigated in this project:

- The CAES-Air Injection (CAES-AI) design option is based on the injection of the stored and preheated air into a CT, thus providing an increase in the CT power output, due to the way the stored air is used. The CAES-AI design option is relatively simple and is expected to have the lowest specific CAES plant capital costs; particularly if it is based on an already existing operating CT at a New York utility. This design option is applicable to a variety of new or existing combustion turbines
- The CAES-AI/HP expander design option is the CAES-AI concept with an HP expander using preheated, stored, compressed air based on the high pressure difference between the stored air pressure and the pressure required for injection into the CT. As compared to CAES-AI concept, this concept has higher CAES power output
- The CAES-AI/Expander design option is the CAES-AI/HP design option with the following differences:
    - The expander operates between the stored air pressure and atmospheric pressure, with the extraction for air injected into CT
    - The expander inlet compressed air flow is a subject for optimization and not limited by the injection flow into the CT

  The CAES power for this concept is the CT power increase plus the expander power, both generated by the stored air.

- The CAES/Expander/Inlet Chilling design option is similar to CAES-AI/Expander design with the following differences:
  - o The expander is fed by the stored air preheated in the heat exchanger without an extraction of air injected into CT
  - o The expander is optimized to have its exhaust flow equal to the CT inlet flow, with an exhaust “chilled” temperature of about 10C to 15C (50F to 59F)
  - o The expander exhaust is injected into the CT inlet

  The CAES power for this design option is the expander power plus the CT power increase, due to the inlet temperature being lower than ambient temperature during on-peak time periods when the plant would be generating power.
- The CAES—Bottoming Cycle design option is based on an expander that is being fed by the stored compressed air preheated in the exhaust heat exchanger.

The above novel CAES plant design options use a standard, off-the-shelf CT, compressor, expander, motor, and heat exchanger. These components are offered by several vendors, and can be delivered as a packaged unit. It is envisioned that several smaller compressors could be used instead of a single large compressor, which would improve the plants reliability and allow for variations in storage-mode compressor power consumption during off-peak hours (e.g., from available but fluctuating wind turbine power during off-peak time periods).

The expanders in the CAES plant design options discussed earlier have relatively low inlet temperatures (below 538C/1000F), which allows for the use of existing standard expanders or back pressure steam turbine expander equipment to be used in the CAES plant. This will yield a reduced overall plant capital cost and reduced complexity for the overall CAES plant.

As cited in the discussions above, and to conduct a fair comparative analysis of the various CAES plant design options investigated, it is assumed herein that all the CAES plant design options will operate with the underground storage geology used in AEC’s 110 MW CAES plant (i.e., a solution mined salt cavern). Thus, the following air storage parameters are used in the comparative analysis that will be presented later:

- The storage geological formation is a salt dome
- The depth of the storage is 1500 ft (approximately 460m)

- The minimum storage pressure is approximately 40 bars (i.e., 580 psia)
- The maximum storage pressure is approximately 90 bars (i.e., 1305 psia)
- The storage volume for each concept was estimated on the relative basis based on the specific air consumption per kWh of peaking energy produced, and the associated costs were estimated based on the AEC's cavern cost being proportioned by the storage volume and airshaft diameter
- The ratio of the compression hours to generation hours is equal to two. This means that compressors have been sized for half of the CAES plant expander air flows
- The volume and costs for the above-ground air storage option for each design investigated is similarly estimated based on the relative specific air consumption per kWh of peaking energy produced and specific costs estimated

Of course, once the geologic parameters of a given New York site are available, and the compression versus generation hours ratio is determined, based on New York load shape characteristics, the comparative analysis described herein needs to be updated to be sure the best CAES plant design option is chosen (in performance of the economic evaluation as detailed in the next chapter, the optimum ratio of the compression hours to generation hours was determined to be equal to one, rather than two as designed and built in AEC's plant).

Performance Estimates of CAES Plant Options Based On Standard Combustion Turbine Power Blocks

This section presents performance characteristics of the CAES plant options based on a standard CT power block. Heat and mass balance estimates were developed using the GE-GATE Cycle modeling software. In order to produce performance estimates for each CAES plant design option, the CT used to do the calculations was a GE7241-FA combustion turbine, which is a common CT used by electric utilities today.

The section below provides specific performance characteristics for each considered CAES plant design option. The overall section concludes with a comparative analysis of the performance characteristics of all the considered CAES plant design options.

CAES-AI Concept

The schematic for the CAES-AI plant design option and its major performance characteristics are presented on Figure 23. Performance characteristics of the GE7241-FA CT at the same ambient conditions are presented on the Figure 24. The difference between the CAES-AI design power of 193MW (Figure 23) and the CT power of approximately 160MW (Figure 24) represents the CAES power of 33 MW generated by the stored air injected into CT. The table below summarizes the major performance characteristics of CAES-AI and the CT.

Table 15: Performance Characteristics of CAES-AI Option and the CT

	CAES-AI Plant Option Based on GE7241-FA CT	GE7241-FA CT (at 95F)
CT power, MW	160	160
CAES power, MW	33.3	NA
Total power, MW	193.1	160
Total heat rate, Btu/kWh	8394	10,600
Off-peak compressor power, MW	29.1	NA

The CAES-AI plant design option has the following major plant components:

- existing or new combustion turbine
- compressed air storage system
- multiple compressors, as appropriate, for compressed air energy storage charging during off-peak hours, using renewable sources whenever possible
- Heat recovery recuperator (HRR)
- Balance of Plant (BOP) equipment

The stored compressed air is preheated in the HRR, using the exhaust gas heat, and then is injected into an existing/new CT (at a pressure consistent with the combustion turbine compressor discharge pressure) for CT power augmentation for the CAES power generation cycle.

The key advantages of the CAES-AI plant design option is its simplicity, and it has the lowest specific capital costs ($/kW), particularly if an existing CT is used.

Because utility peak load requirements are most often met by a CT, operation of CTs and CAES plants would practically coincide. The total power of a CAES-AI plant consists of the CT power generated with the CT's heat rate and the incremental CAES power generated with approximately a 4000 Btu/kWh heat rate. The CAES power for this concept is 33.3 MW.

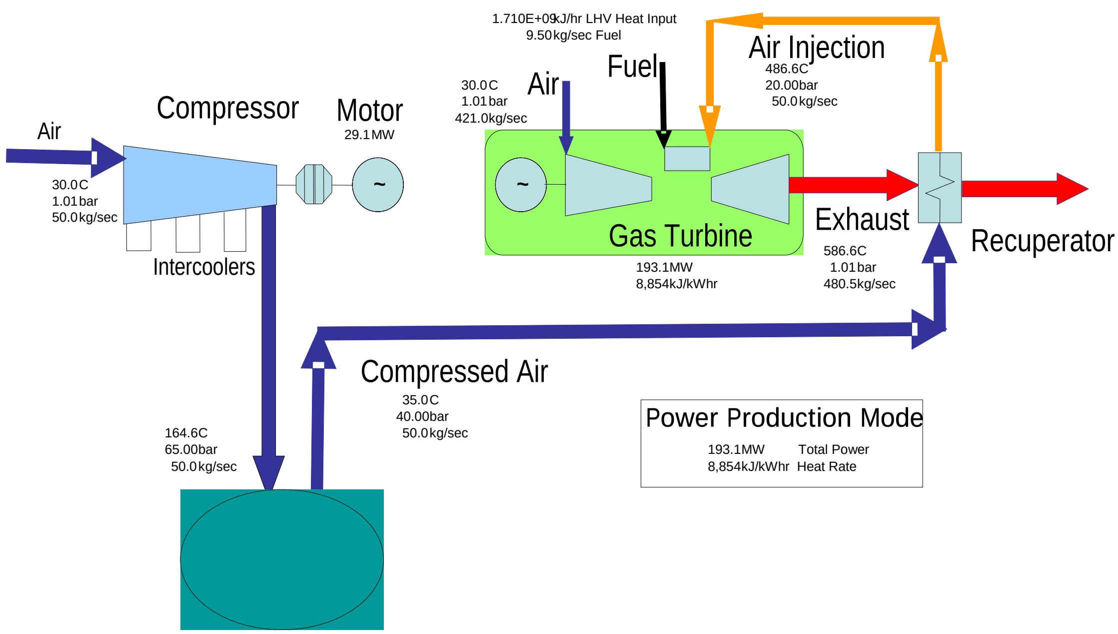


Figure 23: Schematic and Heat and Mass Balance for the CAES AI Plant Option

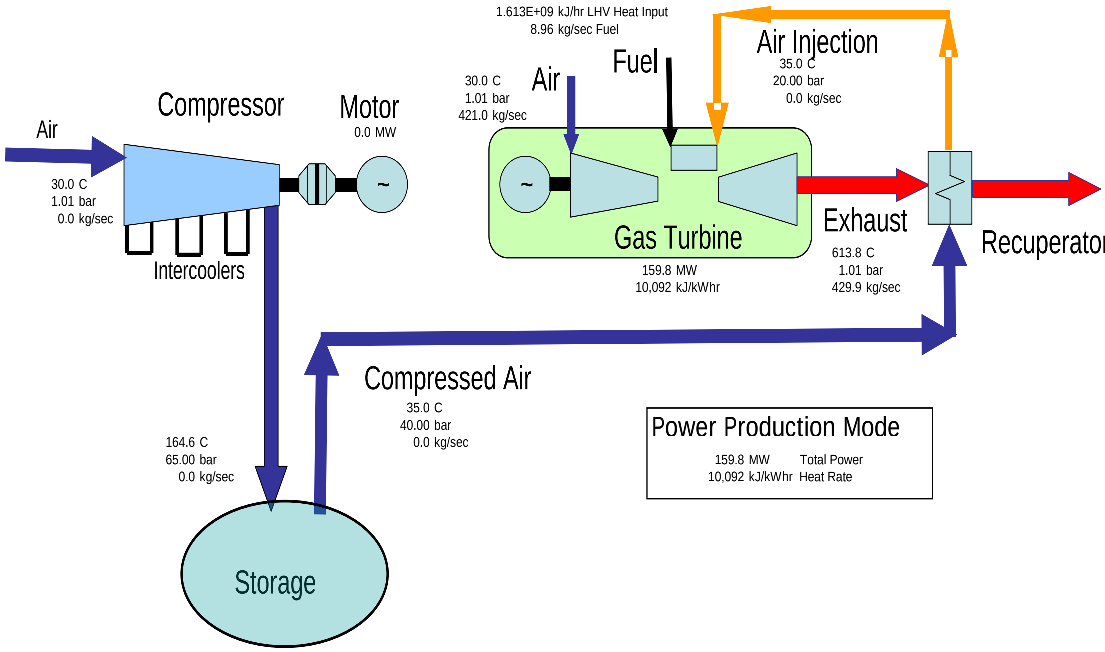


Figure 24: Schematic and Heat and Mass Balance for the CAES AI Plant Option Without Air Injection (Based on Performance of GE7241-FA-CT)

CAES-AI/HP Expander Concept

The schematic of the CAES-AI/HP Expander plant design option and its major performance characteristics are presented on Figure 25. The CAES-AI/HP Expander design has the same components as the CAES-AI plant option plus the high pressure expander sized for the maximum injection flow allowable by the CT. The stored compressed air is preheated in the HRR, using the exhaust gas heat, and then is directed into the HP expander using preheated stored compressed air with the pressure differences between a relatively high stored air pressure and the pressure required for air injection into the CT.

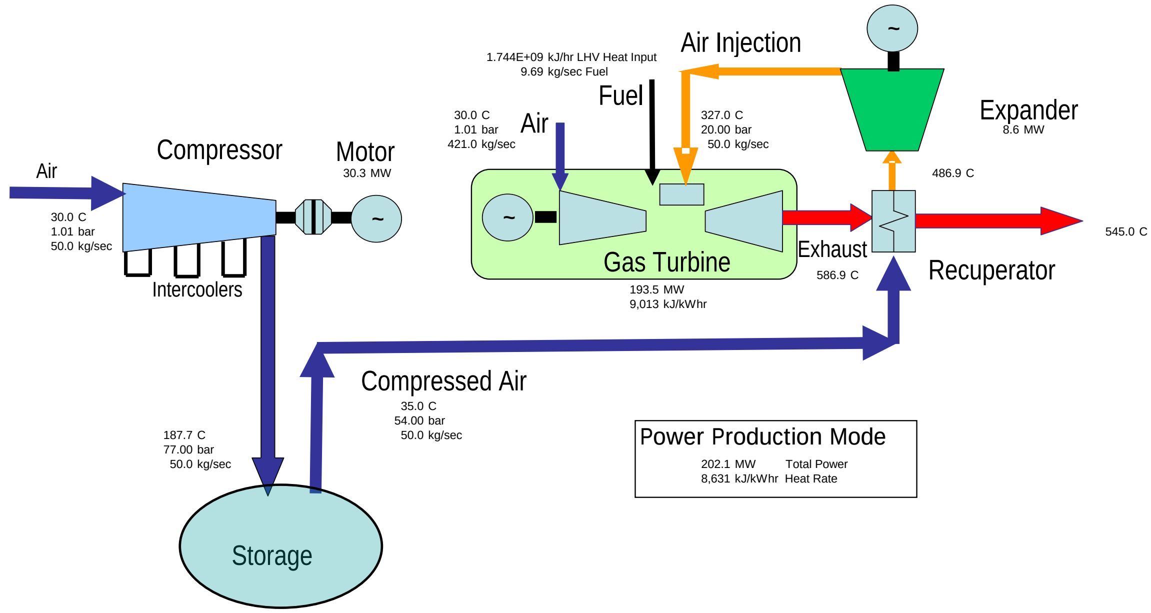


Figure 25: Schematic and Heat and Mass Balance for the CAES-AI/HP Expander Plant Option

The table below summarizes the major performance characteristics of CAES-AI/HP Expander design and the Combustion Turbine.

Table 16: Performance Characteristics of the CAES-AI/HP Expander Option and the CT

	CAES-AI/HP Expander Plant Option Based on GE7241-FA CT	GE7241-FA CT (at 95F)
CT power, MW	159.8	160
CAES power, MW	42.3	NA
Total power, MW	202.1	160
Total heat rate, Btu/kWh	8181	10600
Off-peak compressor power, MW	30.3	NA

CAES-AI/ Expander Concept

The schematic of the CAES-AI/Expander concept with its major performance characteristics are presented on Figure 26. The CAES-AI/HP Expander has the same components as the CAES-AI/HP Expander concept with the following differences:

- The expander operates between the stored compressed air and atmospheric pressures
- The expander has an extraction of air with parameters consistent with the air injection into the CT
- The expander inlet compressed air flow is a subject for optimization and not limited by the injection flow into the CT.

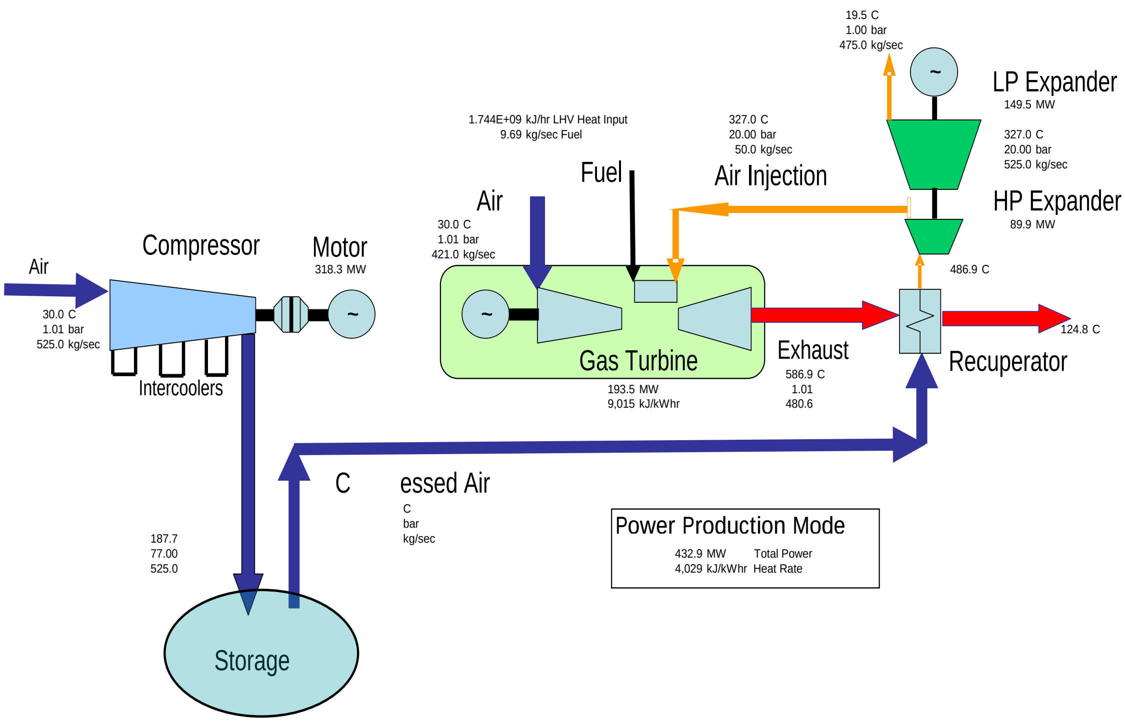


Figure 16: Schematic and Heat and Mass Balance for the CAES-AI/Expander Concept

The table below summarizes major performance characteristics of CAES-AI/Expander vs. Combustion Turbine.

Table 17: Performance Characteristics of CAES-AI/Expander Plant Option and the CT.

	CAES-AI/Expander Plant Option Based on GE7241-FA CT	GE7241-FA CT (at 95F)
CT power, MW	**159.8**	**160**
CAES power, MW	**273.1**	**NA**
Total power, MW	**432.9**	**160**
Total heat rate, Btu/kWh	**3819**	**10600**
Off-peak compressor power, MW	**318.3**	**NA**

CAES/Expander/Inlet Chilling Plant Design Option

The schematic of the CAES-AI/Expander/Inlet Chilling design with its major performance characteristics are presented on Figure 27. The CAES-AI/HP Expander has the same components as the CAES-AI/Expander concept with the following differences:

- The expander has no extraction for air injection into the CT
- The expander is optimized to have the exhaust flow equal to the CT inlet flow and the exhaust temperature of approximately 10°C to 15°C (50°F to 59°F)
- The expander exhaust is injected into the CT inlet

The CAES power for this design is the expander power plus the CT power increase, due to its inlet temperature being lower than ambient temperature.

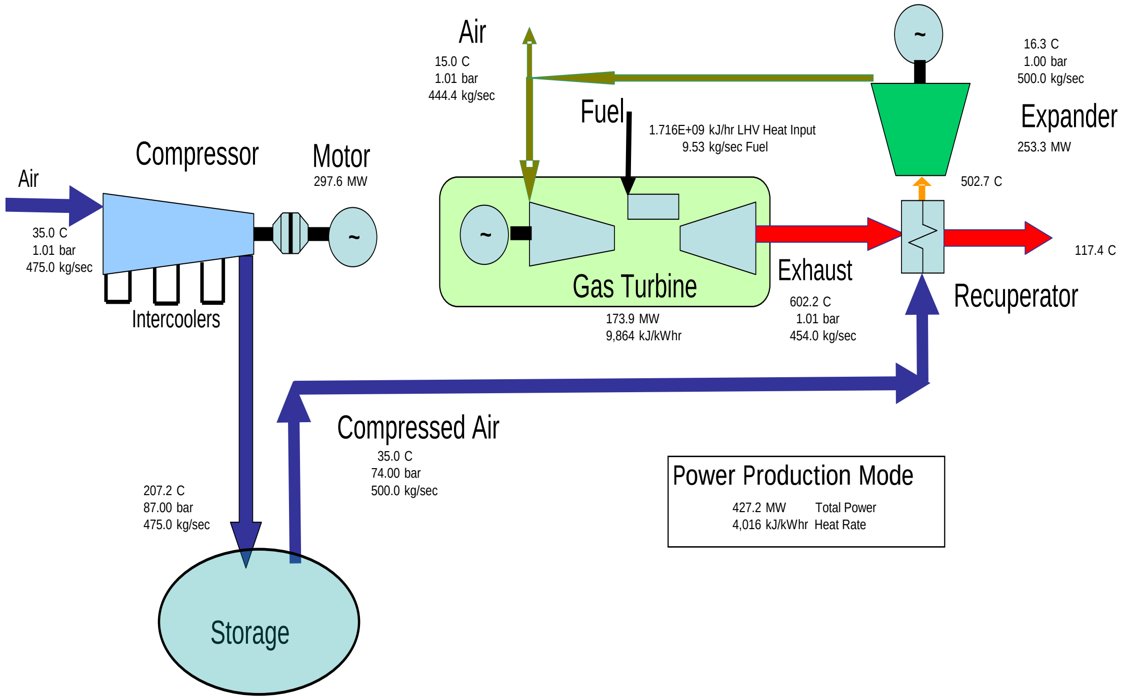


Figure 27: Schematic and Heat and Mass Balance for the CAES/Expander/Inlet Chilling Plant Option

The table below summarizes the major performance characteristics of CAES/Expander/Inlet Chilling design and a Combustion Turbine.

Table 18: Performance Characteristics of CAES/Expander/Inlet Chilling Design and the CT.

	CAES/Expander/Inlet Chilling Plant Option **Based on GE7241-FA CT**	**GE7241-FA CT (at 95F)**
CT power, MW	**159.8**	**160**
CAES power, MW	**267.4**	**NA**
Total power, MW	**427.2**	**160**
Total heat rate, Btu/kWh	**3811**	**10,600**
Off-peak compressor power, MW	**297.6**	**NA**

CAES/Expander Plant Option

The schematic of the CAES/Expander concept with major performance characteristics are presented on Figure 28. This concept practically has the same components as the CAES/Expander/Inlet Chilling concept with the following differences:

- The expander is not sized to meet the CT inlet flow requirements and therefore has some flexibility in its sizing
- The expander exhaust is not directed to the CT inlet

The CAES power is the expander power in the upper right corner of the figure below.

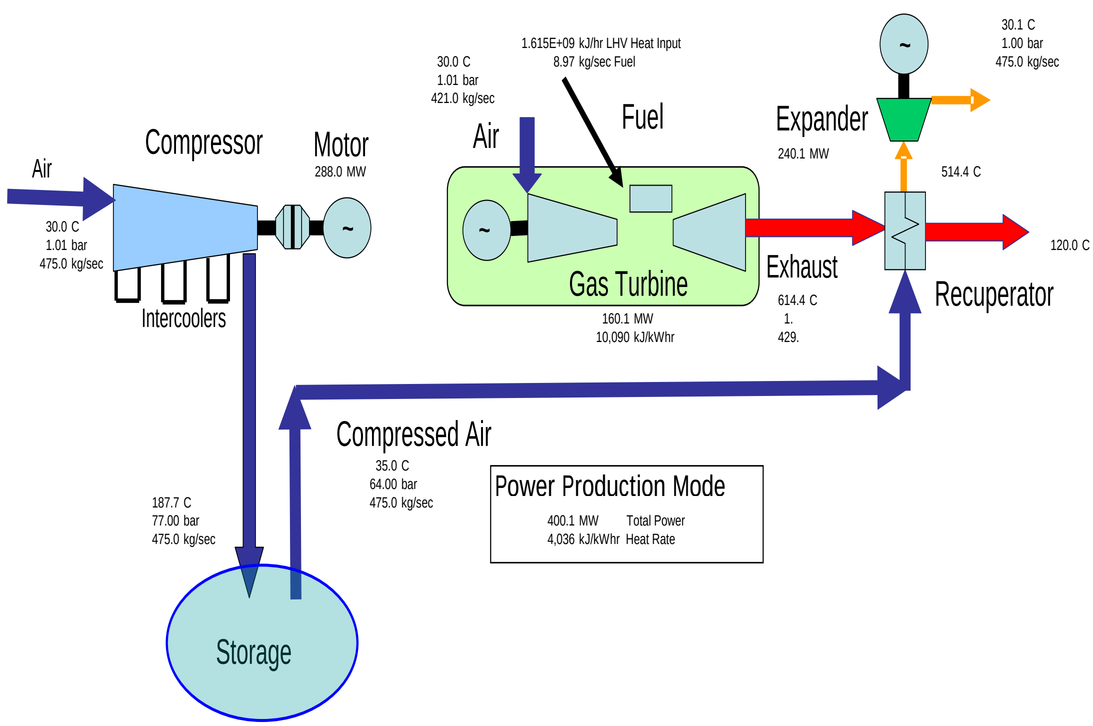


Figure 28: Schematic and Heat and Mass Balance for the CAES/Expander Plant Option

The table below summarizes the major performance characteristics of CAES/Expander design and a Combustion Turbine.

Table 19: Performance Characteristics of CAES/Expander Plant option and the CT

	CAES/Expander Plant Option Based on GE7241-FA CT	**GE7241-FA CT (at 95F)**
CT power, MW	**159.8**	**160**
CAES power, MW	**240.2**	**NA**
Total power, MW	**400**	**160**
Total heat rate, Btu/kWh	**3826**	**10600**
Off-peak compressor power, MW	**288**	**NA**

Adiabatic Concept

A relatively new type of CAES plant design option not based on a CT power block will now be described; namely, the Adiabatic CAES plant design option, which uses no fuel to generate power, once off-peak electricity is used by the compressors to store the air. The schematic of the Adiabatic CAES plant option, and its major performance characteristics are presented on Figure 29. The adiabatic plant option is based on a conceptual design and principles presented in the EPRI report "Thermal Energy Storage for Advanced Compressed Air Energy Storage Plants," developed under EPRI project AP-5844.

This CAES plant option has the following components:

- Off-peak electricity is used to power the LP and HP compressors, with one intercooler and one aftercooler optimized to generate hot discharge compressed air that is stored and later used during the peak power generation cycle

- A thermal energy storage system is used to store the compressed air heat in the form of heated thermal oil (or possibly a pebble bed of sensible heat rock media)
- Heat exchangers are used to transfer the heat from the compressor discharges to the thermal store, and from the thermal store
- HP and LP Expanders use stored and preheated compressed air for the CAES power generation cycle

The major advantage of this concept is that it does not require any fuel during its generation cycle.

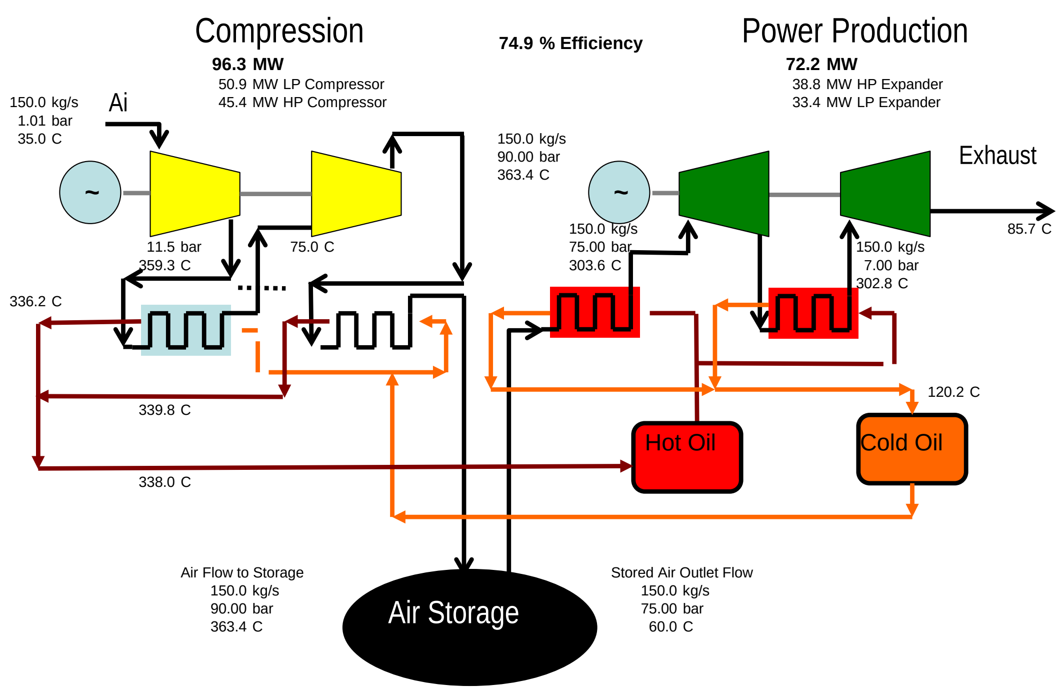


Figure 29: Schematic and Heat and Mass Balance for the CAES Adiabatic Plant Design Option

The table below summarizes the major performance characteristics of CAES Adiabatic plant option.

Table 20: Performance Characteristics of CAES Adiabatic Plant Option

	CAES Adiabatic Concept
CAES Power, MW	**72.2**
Total Heat Rate, Btu/kWh	**0**
Off-peak Compressor Power, MW	**96.3**

Capital Cost Estimates

The capital costs for each of the CAES plant design options analyzed in this project were estimated in 2007 dollars, based on a parametric approach equally applied to all designs. As guidance, the actual cost breakdown for the AEC's CAES plant was used, including the costs for the underground storage system and specific costs ($/kW) and proposals for similar turbomachinery for current CAES plant projects that are under development.

Capital cost estimates for each CAES plant design option were performed in three steps:

- Parametric estimates for the equipment costs were developed, based on specific parameters that resulted from the investigated design and its heat and mass balances
- Estimates for the material and labor costs for plant installation were developed
- Estimates for the underground storage system by proportioning the underground storage costs of the AEC's CAES plant to the design option analyzed were developed

For equipment pricing, the focus was on projects with comparable equipment parameters and scope of supply. The equipment and material costs were scaled to match the size and capacity for each CAES plant design option investigated. Due to the nature of the comparative capital cost estimates, certain site-specific optional equipment that could be equally applied to all designs (such as selective catalytic reduction equipment, buildings, and bridge cranes) were not specifically estimated and were accounted for by generic multipliers. Labor costs for engineering, installation, startup, and other services were estimated, based on median site.

The cost estimates of the underground store for all the analyzed CAES plant design options were based on the specific geological formation of the AEC 110 MW CAES plant; the air storage costs were prorated for each design investigated based on the air flow rates needed by that design.

In reality, it is known that actual plant costs will vary based on such items as the geographic location of the CAES plant, currency valuations, and competitive market conditions. For this study the costs are maintained consistent with the technology, and the overall costs provide sufficient information for a relative comparison of the selected CAES plant designs.

Capital Cost Estimate for Equipment

Capital costs for the following major components were estimated for each design option:

- Air compressors
- Turboexpander trains for the conventional and adiabatic designs
- Combustion turbine for each CAES plant design
- HP and LP turbo expanders
- Heat recovery recuperator
- Electric generators
- Associated balance-of-plant equipment
- Underground storage

The following is a brief description of the parametric approach applied to various plant components:

Air Compressor Package: The air compressor costs are based on actual quotations (by Ingersoll Rand and Cooper-Turbocompressor) and the compressor costs for the AEC's CAES project, which were prorated based on the air flow and discharge pressure for each design investigated. A specific cost of approximately $30/kg/h at 80 bar was used. The air compressor system configuration is assumed to be skid mounted for outdoor installation, with standard motor and control systems provided by the vendor. The air compressor is a standard centrifugal compressor design, with split casing and heavy-duty stainless steel impellers. The compressor lube oil system consists of an integral lube oil system and a water-cooled heat rejection system.

Turboexpander package: The turboexpander costs are based on a range of specific costs between $150/kW and $170/kW that were applied to the various CAES plant designs analyzed, based on experience. The turboexpander configuration is assumed to be skid mounted for outdoor installation, with a standard control system supplied by the vendor. The major components include:

- Turbine and enclosure
- Turbine electrical package/mechanical package
- Turbine generator starting/control and excitation skid
- Generator and generator transformer

Heat Recovery Unit: For each CAES plant design investigated, heat recovery units are priced based on calculated heat transfer surface area. Based on data obtained from experts involved in the recuperator design for the AEC CAES projects, ESPC used the unit rate of %15/sq.ft. for a 20 MJ/s heat exchanger at 40 bars rated pressure. The total cost is adjusted for size and pressure rating for each of the CAES plant design options investigated. The heat recovery unit is an extended surface type air-to-air heat exchanger designed to be installed in the exhaust gas duct of the plant. The unit has an all welded pressure part construction with tubes in a top-supported unit to provide for unrestricted downward thermal expansion. The unit will be shop fabricated and have heat transfer modules installed inside the shop fabricated casing sections, for one piece erection onto foundations in the field. A similar design approach is used for stand-alone air-to-air heat-exchangers.

Gas turbine package: For the CAES plant design options using the GE7241-FA combustion turbine power block, a common comparative capital cost analysis approach was used. The cost of the CT equipment package from the factory, including all auxiliaries, is estimated at approximately $220/kW based on past quotations and published data that does not include installation costs. The CT configuration will be skid mounted for outdoor installation, with standard control systems provided by the vendor. The major CT components include:

- Combustion turbine and enclosure
- Combustion turbine electrical package and mechanical package
- Combustion turbine starting and excitation skid
- Fuel gas metering equipment
- Generators and generator step-up transformers

Air Injection System: The CAES-AI plant options include the Air Injection (AI) power augmentation technology. The AI technology is currently an ESPC proprietary technology that has been validated on a GE 7241-FA Combustion Turbine at the US Broad River power plant. The technology is based on the injection of externally compressed air into the combustion turbine at any point upstream of combustors.

Compressed air storage: As it was mentioned above, the cost estimates for the underground storage for all the CAES plant design options were based on the specific geological formation used by the AEC 110 MW CAES plant; the air storage costs were prorated for each CAES plant design option investigated. The major data used in these analyses were:

- AEC cavern costs were approximately $7M
- 40% of the costs were allocated for the airshaft
- 60% of the costs were allocated to solution mining, to create the air volume required for 2600 MWh's of continuous CAES plant power output

Equipment Installation and Overall Construction Costs

Installation prices vary considerably depending on site location, labor unions, and local labor rates. In most cases special infrastructure "adders" are applied to the plant installation costs; e.g., for such items as the need for access roads, power transmission requirements, fuel gas pipeline extensions, training centers, and repair facilities, all of which can significantly increase the overall CAES plant cost. The pricing shown below are for a standard single fueled plant. Site and plant layout, installation, special subsoil design conditions, and "adders" can increase the price of the completed plant by as much as 80%. However, it can be reasonably assumed that such costs will affect all the CAES design options being considered on an equal prorated basis. In any case, it is prudent to evaluate possible site related costs which can make one technology design option significantly superior or inferior as compared to another plant design option.

Balance of Plant Equipment and Services: Standard auxiliary systems and controls, required to operate a plant design configuration are included in the cost estimates. The estimates also include services for plant engineering, construction management, and startup. The major items excluded are: plant licensing costs, permit costs, off-site roads, fuel pipeline, substation, fuel gas compressor and conditioning equipment, backup fuel, special tools, operational spares, consumables, and black start generator sets. Such items are site- or owner-specific optional equipment and are not part of a standard turnkey scope of equipment supply.

The cost estimates for the CAES plant design options investigated include the following balance-of-plant systems and services:

- AEC cavern costs were approximately $7M
- Plant engineering and design
- Equipment foundations and site civil works
- Piping systems, supports and insulation
- Chemical feed handling equipment
- Water treatment/waste water systems
- Motor control centers

- Plant control and monitoring equipment
- Electrical and control cablin
- Construction management and startup

A summary of the capital cost estimates for each CAES plant design option analyzed in this report is presented in Table 21. The combustion turbine used to produce the data in columns 3 through 7 was a GE Frame 7A CT. The costs are only to be viewed on a relative basis and not on an "absolute" cost basis. They are for a 10-hour underground salt based air storage system, or for a two-hour above-ground air storage system.

Table 21: Summary Cost Estimates of Second Generation CAES Plant Design Options

Study Case / Cost US$ x1000,s	CAES Conven-tional	CAES-AI no Expander	CAES-AI w. HP Expander	CAES-AI w. HP & LP Expander	CAES w. Expander	CAES w. Expander & Inlet Chilling	Adiabatic
Major Equipment Cost:							
Combustion Turbine	NA	38,000	38,000	38,000	38,000	38,000	NA
Air Compressor	9,000	3,200	3,400	23,000	21,000	22,000	9,000
Heat Exchangers	3,500	1,700	2,400	14,000	13,000	14,000	10,500
HP Expander	6,400	NA	2,400	16,000	35,000	35,000	8,000
LP Expander	14,900	NA	NA	24,000	NA	NA	7,000
Electrical & Controls	4,700	4,200	4,300	7,500	6,500	6,500	4,200
Total Major Equipment	38,500	47,100	50,500	122,500	113,500	115,500	38,700
Construction Cost:							
Materials	7,000	1,900	2,000	9,200	8,500	8,600	3,100
Labor	16,000	14,000	14,600	39,300	36,000	36,400	14,700
CAES Storage	8,000	3,000	3,000	19,000	18,000	18,000	6,000
Indirect Costs	10,500	10,700	11,400	29,000	26,800	27,300	9,600
Estimated Total Cost	**80,000**	**76,700**	**81,500**	**219,000**	**202,800**	**205,800**	**72,100**
Specific Capital Cost $/kW	**727**	**397**	**403**	**506**	**507**	**482**	**1,001**
Total Installed MW	**110**	**193**	**202**	**433**	**400**	**427**	**72**

Above-Ground Storage Air Storage Systems for CAES

Extensive feasibility studies were conducted focused on the development of man-made, above-ground storage systems. These efforts were primarily driven by two issues:

- To eliminate any geological restrictions for the location of a CAES plant
- To accommodate specific applications of low capacity CAES plants for renewable resources (e.g., wind power plants), distributed power generations or other load management/frequency regulation plants

Presented below is the analysis and results (based on past and present EPRI work) on the above-ground storage alternatives that can be used for CAES, including air storage using buried pressure vessels and concrete ring type pipes or piping used to transport natural gas. The studies identified that air stores using buried piping of 2–3 feet in diameter, located in specifically designed trenches (with proper isolation and cathodic protection), with a maximum pressure of approximately 1500 psia is the most cost-effective alternative (see EPRI's report: Transient Analysis of Hybrid Plants, WO 4481-02).

The volume and costs of the above-ground storage for each CAES plant design option could be relatively estimated based on established specific costs of approximately $50/kWh and applied to each design option analyzed based on its MW capacity and the air storage requirements.

6 IMPACT AND BENEFIT OF WIND RESOURCES ON CAES IN NY

Introduction

New York State Electric and Gas (NYSEG) contracted AWS Truewind (AWST) to provide a report evaluating Compressed Air Energy Storage (CAES) and its potential impact on wind power. This study will help determine the feasibility of using this technology as a means of managing energy flow during peak-use periods and the potential of mitigating the impacts on the transmission system due to wind power variability. This report presents the technology's state of development, relevant case studies, and an assessment of the possible future impact that CAES will have on the wind industry.

An assessment of the wind resource in four different regions within the State was also prepared and is included as Appendix C– Wind Assessment for New York State. Regions evaluated in the analysis included:

1. Sheldon and Wethersfield wind farms in Wyoming/Erie Counties
2. Lowville, Lewis County
3. South Corning, Steuben County
4. Jordanville in the Town of Warren, Herkimer County

Background

The generating capacity of wind energy facilities has grown rapidly in recent years; in 2008 alone, the U.S. wind industry added over 8,500 MW of generating capacity. As wind energy generation continues to penetrate the grid at increasing levels, the inherent variability in the wind requires additional standby reserves to compensate for low-wind energy production during peak load. These standby reserves are traditionally gas turbines, which have a low startup time and operational cost. However, the recent growth of the wind industry and national targets to reach upwards of 20% grid penetration may require additional options to offset the effects of wind’s variable output and supply a baseload generating capacity. Energy storage, particularly CAES, provides a possible solution to help address the challenges of increased grid penetration of wind energy.

CAES is a hybrid energy storage and generation concept that has many potential benefits when coupled with a wind energy generation facility. The system could convert off-peak or curtailed wind energy to compressed air for storage in an airtight underground reservoir. The stored air is then used to regenerate electricity when the plant is not curtailed or during peak time periods. A basic schematic of a wind/CAES system is given in Figure 30.

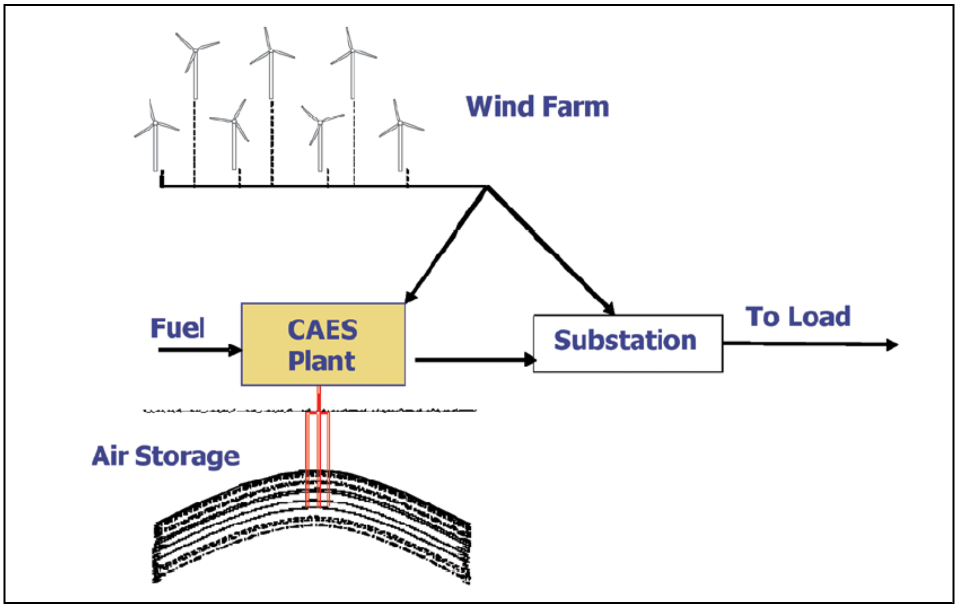


Figure 17: Schematic of a CAES System (Denholm)

This process initially attracted interest in the 1970s due to high gas prices and as a way to store low-cost baseload nuclear power during off-peak times. However, the technology did not catch on at the time and has gained renewed interest only recently. There are currently two installed CAES facilities: a 290 MW facility in Huntorf, Germany and a 110 MW facility in McIntosh, Alabama.

This technology may potentially allow wind energy to penetrate the grid at a higher percentage and, depending on available technology and suitable geology, may provide a low-cost solution for energy storage. CAES facilities can be developed in pre-existing geological formations and operate with less fuel than a traditional gas turbine. This creates the opportunity to manage on/off-peak energy and to possibly turn variable wind generation into a consistent baseload power source.

State of Development

Geology

In order to take advantage of a coupled wind/CAES facility, appropriate geologies must be located relatively close to regions with high wind energy potential. For power plants with greater than 100 MWh of storage, salt caverns and hard/porous rock formations are the most economical options; approximately 80% of the continental United States contains geological formations that may be suitable for CAES development (EPRI-DOE, 2003). As shown in Figure 31, these suitable geologies overlap well with high wind energy potential[4] regions in several areas. The main geologies in New York State that are suitable for CAES storage include bedded salt formations and aquifers.

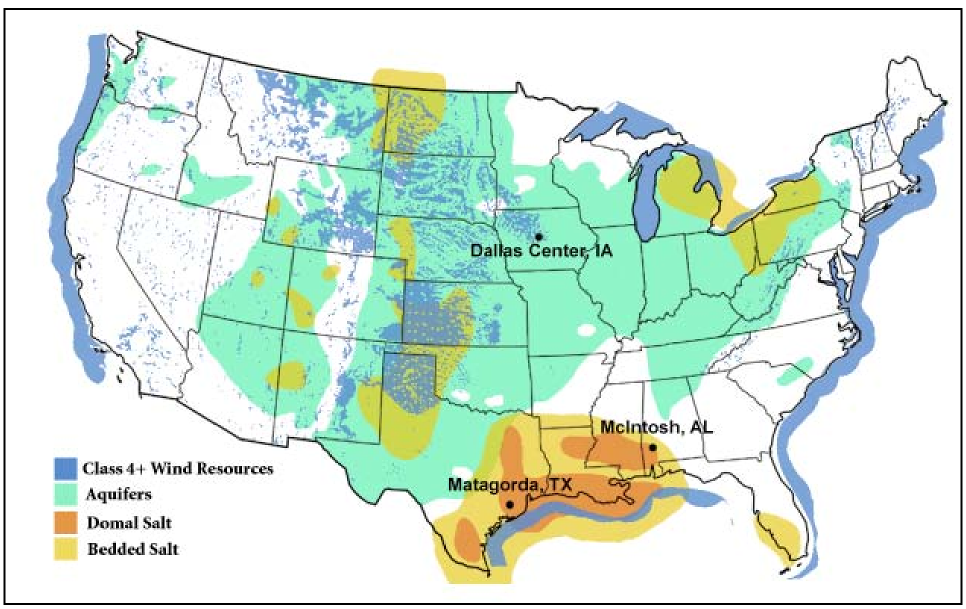


Figure 31: Locations of Suitable CAES Geology and High Quality Wind Resource (Succar, 2008)

4 The Class 4+ wind resource displayed in Figure 31 is defined as having a wind power density of greater than 400 W/m2 at 50 m (average annual wind speeds greater than ~7.0 m/s)

Domal salt formations appear to be the most feasible geology for CAES development. These formations can be solution mined using fresh water, which create large, airtight reservoirs with a crystalline outer wall. Assuming that there is a supply of fresh water and the resulting solution can be removed economically, the cost of solution mining a domal salt formation is relatively low compared to other geologies. The two existing CAES facilities use domal salt formations as their storage reservoirs.

Bedded salt formations may be significantly more difficult to develop for large-scale CAES reservoirs. Domal salt caverns tend to be tall and narrow with minimal roof spans, while bedded salt caverns are thinner and have a larger roof area to support. Salt bed formations also contain more impurities, which can affect the structural integrity of the reservoir (Succar, 2008).

Hard rock formations are another option for CAES development; new caverns can be excavated or existing mines can be used. Mining new caverns in hard rock formations is significantly more expensive than using existing mines. While it is possible to use hard rock for CAES development, it is unlikely that they will be used for large scale development, due to the much higher cost when compared to other geologies. As shown in Figure 32, there is significant overlap of potential mined storage and high quality wind resource for a wind/CAES plant.

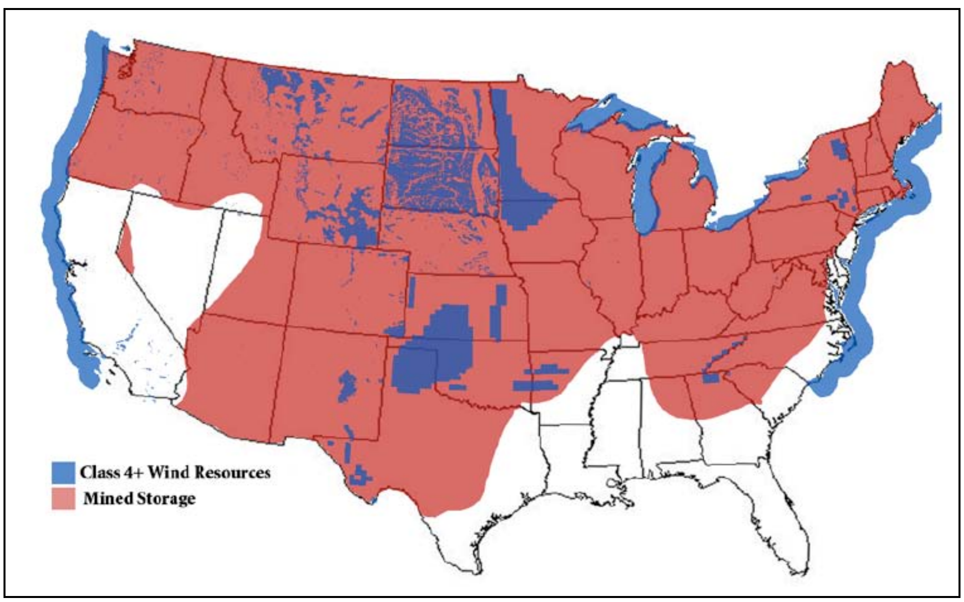


Figure 32: Locations of Mined Storage and High Quality Wind Resource (Succar, 2008)

Porous rock or aquifers may offer the most economical choice for large scale CAES development. These formations can also be found in high quality wind resource sites, further expanding their potential for CAES. While the two existing CAES facilities do not use porous rock as the storage medium, there has been a 25 MW porous rock test facility in Italy (Succar, 2008).

Estimated capital costs for the above geological formations are included in Table 22.

Table 22: Estimated Capital Costs for Varying Geologies. Source: EPRI-DOE, 2003

Geology	Capital Cost of Storage
Salt Cavern / Solution Mined	$1/kWh
Salt Cavern / Dry Mined	$10/kWh
Hard Rock / Excavated & Existing Mines	$30/kWh
Porous Rock / Aquifer	$0.10/kWh
Abandoned Limestone or Coalmines	$10/kWh

Through a study with EPRI and NYSERDA, several possible CAES development sites were evaluated within New York State. Based on a review of porous media, salt formations, and existing/new hard rock caverns, the study concluded that existing salt mines and porous media offer the most economical methods of underground storage in NYS (EPRI, 1994).

Technology

In simple terms, a typical CAES system will generate electricity by extracting the compressed air, heating the extracted air, and mixing/combusting with fuel using traditional gas turbine technology. A diagram of the basic components and steps used in this process is shown in Figure 33.

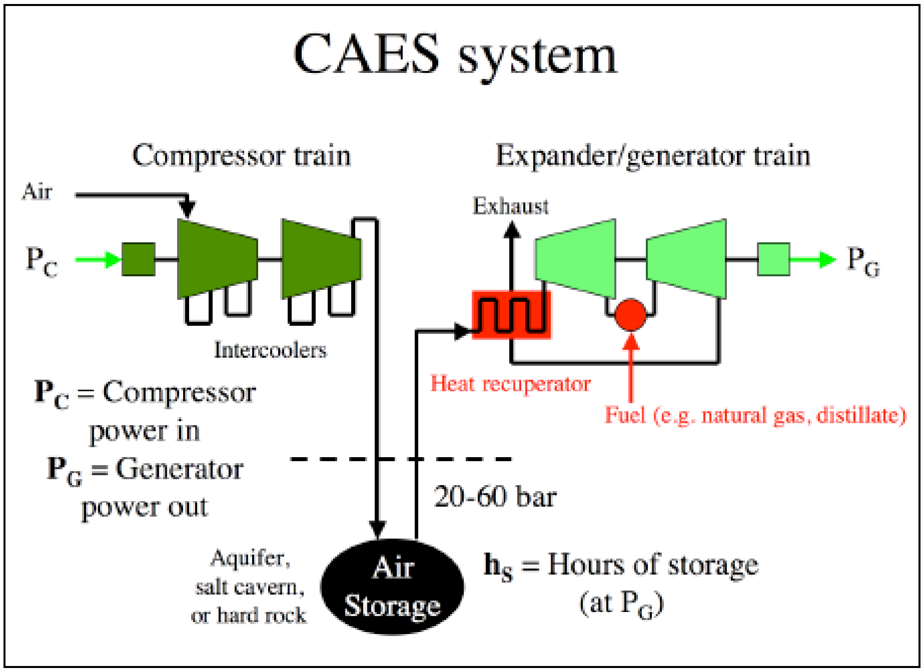


Figure 33: Typical CAES System Configuration (Succar, 2008)

When coupled with a wind power plant, excess energy is used to compress ambient air. During the compression process, intercoolers and an aftercooler are used to reduce the air temperature. This process increases the compression efficiency, decreases the required storage volume, and brings the air to a temperature closer to the temperature of the cavern walls, thus decreasing thermal stress in the storage reservoir.

During the expansion process, compressed air is extracted from the reservoir, mixed with fuel, and combusted. The combustion products expand and re-generate electricity, allowing the excess wind energy to be used during low wind energy generation periods. Typical CAES plants use fuel in the combustion process to increase the overall efficiency of the process and to ensure reliable operation. The amount of fuel needed in a CAES system is significantly lower than traditional turbines, since the air is already compressed from the storage reservoir. The combustion cycle of the process can use a variety of fuels, including hydrogen, natural gas, gasified biomass, and oil. A typical CAES system might consume 0.67 kWh of electricity in the compression phase and burn approximately 4,200 kJ of natural gas in the expansion to produce 1 kWh of regenerated electricity. When combined into a single performance metric, a typical CAES plant has round trip efficiencies in the range of 77–89% (Greenblatt, 2006).

As an alternative to using fuels in the expansion process, plants can be designed to operate adiabatically. In this configuration, thermal energy from the compression phase is stored and used to reheat the extracted air in the expansion phase. This process can reduce or entirely eliminate the need for additional fuel in the expansion process. However, this reduces the plants roundtrip efficiency to approximately 65% (EPRI-DOE, 2003).

A typical CAES plant will require approximately 2.4 x 10^7 m^3 per GW per week of storage. Hard rock caverns can be excavated to volumes of approximately 107 m^3, so multiple caverns would be required for a large scale CAES project. Assuming an aquifer that is 10 m thick and has a porosity of 0.2, a GW CAES plant with a week of storage would require approximately 12 km^2 of area (Greenblatt, 2006).

Existing/Proposed CAES Plants

As mentioned previously, there are currently two installed CAES systems and several others in the planning stages. The Huntorf plant near Bremen, Germany became the first operational CAES facility in 1978. The facility has two domal salt air caverns with a volume of 310,000 m^3 and a natural gas cavern with a volume of 300,000 m^3. The plant has a maximum capacity of 290 MW and approximately three to four hours of output at maximum capacity.

The plant serves as an emergency backup in case other power plants fail and as an option for peak load energy generation (Crotogino, 2001). More recently, the plant has been used to offset the variability of several wind energy facilities in Germany (EPRI-DOE, 2003). An aerial photograph of the Huntorf plant is shown in Figure 34.

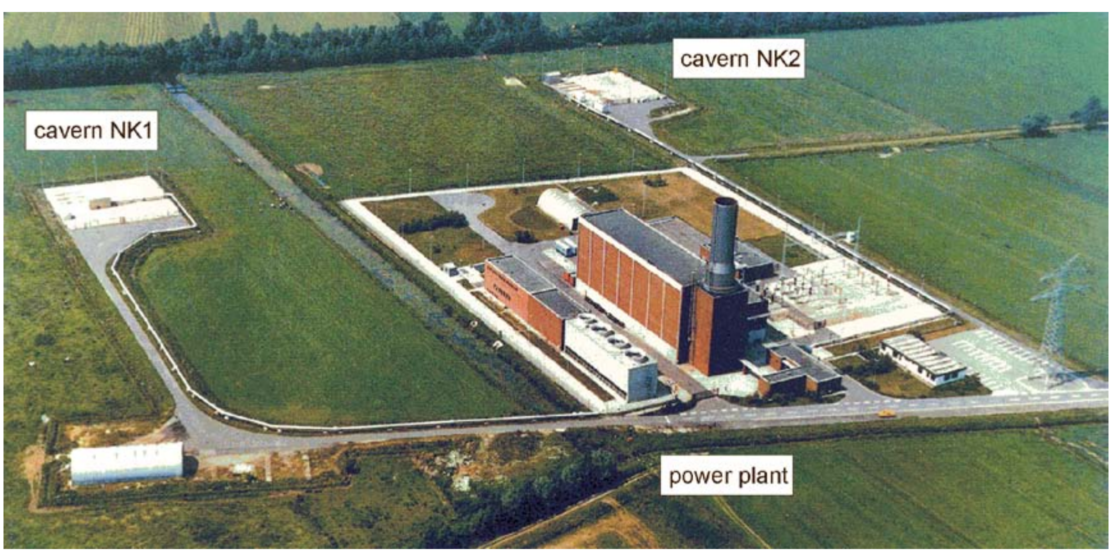


Figure 34: Aerial Photograph of the Huntorf Plant (Crotogino, 2001)

The second CAES plant is located in McIntosh Alabama and became operational in 1991. The plant uses a single domal salt cavern with a volume of approximately 560,000 m^3. The plant has a maximum capacity of 110 MW and was designed to supply approximately 26 hours of generation at maximum capacity. The plant also features a heat recuperator to pre-heat air in the expansion phase, reducing fuel consumption by approximately 22% at full capacity. The plant is used to generate peak power from off-peak storage and to provide generation reserves. An aerial photograph of the McIntosh plant is shown in Figure 35.

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Figure 35: Aerial Photograph of the McIntosh Plant (PowerSouth)

A summary of relevant information for the existing CAES plants is shown in Table 23.

Table 23: Existing CAES Plant Information. Source: EPRI-DOE, 2003

Characteristic	Huntorf Plant	McIntosh Plant
Amount Invested (2009 USD)	$139 million ($480/kWe)*	$54.1 million ($492/kWe)*
Commissioned	December 1978	June 1991
Rated Output	290 MW	110 MW (minimum 10 MW)
Storage Volume	310,000 m^3	560,000 m^3
Duration	3-4 Hours	26 Hours

Characteristic	Huntorf Plant	McIntosh Plant
Operating Pressure	20–43 bar	45-74 bar
Availability	90%	99%
Starting Reliability	99%	99%
Power Requirement	0.82 kW_{in} / kW_{out}	0.75 kW_{in} / kW_{out}
Normal Start	Eight Minutes	10–12 Minutes

* Figures adjusted to 2009 USD using US Bureau of Labor Statistics Inflation Estimates

There are currently plans for an 800-2,700 MW CAES facility in Norton, Ohio. The plant would use an existing limestone mine and would operate between pressures of 55-110 bar. A coupled wind/CAES plant is currently under development in Dallas Center, Iowa. The Iowa Stored Energy Park will feature a 268 MW CAES facility with a 75 MW wind plant over 100 miles away. The plant will be the first wind/CAES facility and the first CAES facility to use a porous rock (sandstone) storage medium (ISEP). The project will cost approximately $800/kW for a total cost of $214 million. There are also several studies and possible wind/CAES projects being explored in Texas.

Impact on Wind Energy

At wind power's current grid penetration levels, standby reserves are effectively used to mitigate the inherent variability of the wind resource. However, in order to reach increasing penetration levels, possibly with increasing fuel prices and carbon constrained emissions, alternative approaches may be needed to supplement wind energy. Compressed air energy storage (CAES) offers a potential solution to help manage energy flow during peak use periods and to create a reliable baseload power source, effectively mitigating the impacts on the transmission system due to wind power variability.

A wind/CAES system would have the ability to store energy when the wind plant is curtailed due to transmission congestion and during off-peak periods. This stored energy can then be used to regenerate electricity during peak load/price periods. Without a coupled energy storage system, the energy potential during curtailed periods would be lost. This approach may allow a more cost-effective means of selling electricity to the grid, since wind plant output does not usually correlate well with peak load; wind is usually strongest at night, while the load usually peaks in mid-day. This approach will have greater economic viability if the difference between on/off-peak electricity or fuel prices increase.

Additionally, CAES plants offer fast startup times and efficient part load operation, making them a natural fit to supplement variable wind energy generation. When coupled with an effective wind forecasting model, a wind/CAES system has the potential to offer reliable, consistent baseload power generation. High quality wind resource areas far from load centers could then be developed more economically, since the transmission lines would be operated at a higher capacity factor. A wind/CAES system has the potential to increase the long distance transmission line capacity factor from 36% to 90% (Mason, 2009). Furthermore, the use of CAES or other energy storage technology allows a greater penetration of wind energy on the grid. Coupled wind/storage systems would allow an upper limit on wind power grid penetration of approximately 80% (Greenblatt, 2006).

When compared to current baseload power sources, a wind/CAES facility may not currently compete in terms of total cost of energy. However, as fuel prices rise or as constraints on carbon emissions are implemented, wind/CAES systems will begin to compete with baseload power sources and other carbon reducing technologies (e.g. integrated gasification combined cycle with carbon capture and storage) (Succar, 2006). In the scenario of wind + backup as an alternative baseload power source, a coupled wind/CAES system has the potential to offer more attractive economics than a coupled wind/natural gas system. While the capital cost of a CAES facility is greater than a natural gas plant, a CAES facility will consume significantly less fuel, resulting in a retail price of energy approximately 25% less for the wind/CAES system. A wind/CAES system will lead to a reduction in natural gas consumption and CO_2 emissions of approximately 64% when compared to the wind/NG system (Mason, 2009).

While CAES may not currently compete with other technologies, several scenarios could increase the need or economic feasibility of a wind/CAES system, including the following:

- Electricity pricing volatility
- Carbon constraints or increased fossil fuel costs
- Increased penetration of renewable energy on the grid, leading to more curtailment

To date, there have only been two long-term operational CAES installations, neither of which were designed to supplement a wind generating facility. Additionally, these two projects were developed in domal salt formations, which are not typically found in high quality wind resource regions of the United States. Bedded salt, hard rock, and porous rock aquifers correlate better with these wind regions. While these geologies may be more available, bedded salt and hard rock formations appear to have more technical and economic challenges. Bedded salt caverns have structural issues and hard rock caverns are very expensive to mine. Porous rock aquifers may offer the most feasible option for wind/CAES development. These geologies occur in most of the continental United States and correlate well with high quality wind resource regions and appear to require the lowest capital cost investment. There has been one CAES test facility using a porous rock formation in Italy, but the short amount of time the facility was operational and the lack of a coupled wind plant make it difficult to determine the feasibility of a porous rock wind/CAES facility. The Iowa Stored Energy Park will feature a porous sandstone storage medium and will be coupled with a 75 MW wind plant. This project will provide a relevant case study to the industry that will help validate the real potential of a wind/CAES project.

As discussed, a coupled wind energy and CAES facility has the potential to mitigate the negative impacts of wind power's variability. A summary of potential benefits include:

- Management of energy flow during transmission curtailment and on/off-peak load periods
- Quick startup times and efficient part load operation
- Possible baseload power source that competes with traditional technology
- More efficient long distance transmission line capacity factors
- An increased upper limit of wind power grid penetration to ~80%

While there are many potential benefits of a wind/CAES facility, the technology is still in the initial stages of development and has not experienced widespread deployment. Potential barriers to a wind/CAES facility include the following:

- Suitable geologies in necessary region
- Operational experience in porous rock geologies
- Operational experience with varying operational strategies
- Political/economic climate

While additional research and experience with large scale wind/CAES systems is necessary for widespread deployment, they have many potential benefits to the transmission system, which will allow greater energy management and can mitigate the challenges of greater wind energy penetration into the grid.

Wind Assessment in New York State

The wind resource assessment for the selected regions within the State is included as a separate report (see Appendix C: Wind Assessment for New York State). For each region, a 12x24 matrix summarizing the average hourly wind speeds for each month and two graphs visualizing the variations are given. As shown in Appendix C, all four regions exhibit lower wind speeds during the day than at night. This characteristic reinforces the possibility of using a wind/CAES facility to store off-peak energy in New York State, which can then be used to regenerate electricity during peak load/price periods.

While the included wind resource analysis provides useful information for general trends and load matching, a more detailed analysis will be appropriate to further investigate a potential site and refine plant definition once the final selection has been identified. The capability for wind energy storage has its greatest value in being able to mitigate the volatility of an energy resource with high temporal variability. The true magnitude of these short-term fluctuations in wind energy is dampened when expressed as averages over extended periods of time. A more granular evaluation of the wind resource will serve to characterize the variability that exists within the wind resource, thus better defining the opportunity for energy capture, storage, and export using a CAES system. Therefore, it will be important to analyze hourly data for a continuous period of time to help determine the full potential that could be realized by the addition of a CAES plant.

7 ECONOMICS OF CAES IN NY

This section deals with the various factors that can affect economics of CAES projects including:

- CAES Design: energy ratio, power ratio, storage duration, ramp rate, and response time
- CAES Siting: Geological suitability, natural gas delivery & grid interconnection
- CAES Revenues & Costs: On-peak and off-peak energy prices, ancillary service revenues, interconnection costs, effect of changes in natural gas prices
- CAES Financing: Capital & real estate cost, construction & permitting period etc.

CAES Design Parameters

As explained in Chapter 5, there are various parameters that can be modified to choose an optimum CAES design based on geology as well as requirements. These factors include:

- Energy Ratio and Heat Rate
- Power Ratio
- Storage Duration
- Ramp rate and response time

For the various designs evaluated by EPRI, the energy ratio (electricity consumed / electricity delivered) of the CAES plant was 0.78. i.e. for generating 1 MWh of electricity from the CAES unit, the plant uses 0.78 MWh of electricity during off-peak hours for the compression cycle. CAES uses additional energy during expansion cycle by consuming natural gas. Heat rate of the plant indicates the amount of natural gas consumed for generating electricity. Heat rate of the CAES designs considered was approximately 4000 BTU / kWh.

Power ratio for the CAES unit refers to the size of the compressor to the output of the CAES plant. Power ratio of CAES plan can be easily modified by changing the size of the compressor unit, without affecting energy ratio and heat rate. The initial design evaluated by EPRI had a power ratio of approximately 0.5.

We developed a program to estimate the operational performance of this initial design. (Energy Ratio = 0.78, Heat Rate = 4000 and Power Ratio – 0.5). Figure 36 shows the results of this analysis conducted in NY West region (which has most suitable geological formations for CAES) during 2003-2007. This analysis tried to capture the optimal number of hours a CAES plant would operate each day such that the marginal revenue earned is more than the marginal operating cost considering the off-peak electricity cost and fuel price for natural gas. In most of the years, the CAES plant would have operated approximately for 1500 hours during the year, and on most of the days, the plant would have operated for four to five hours each day for discharging power during peak hours. At the same time there were some days when CAES plant would have operated for as high as eight to nine hours during a day. This information can be used in terms of selection of the geographical location, and determining the size of the cavern used for storing compressed air.

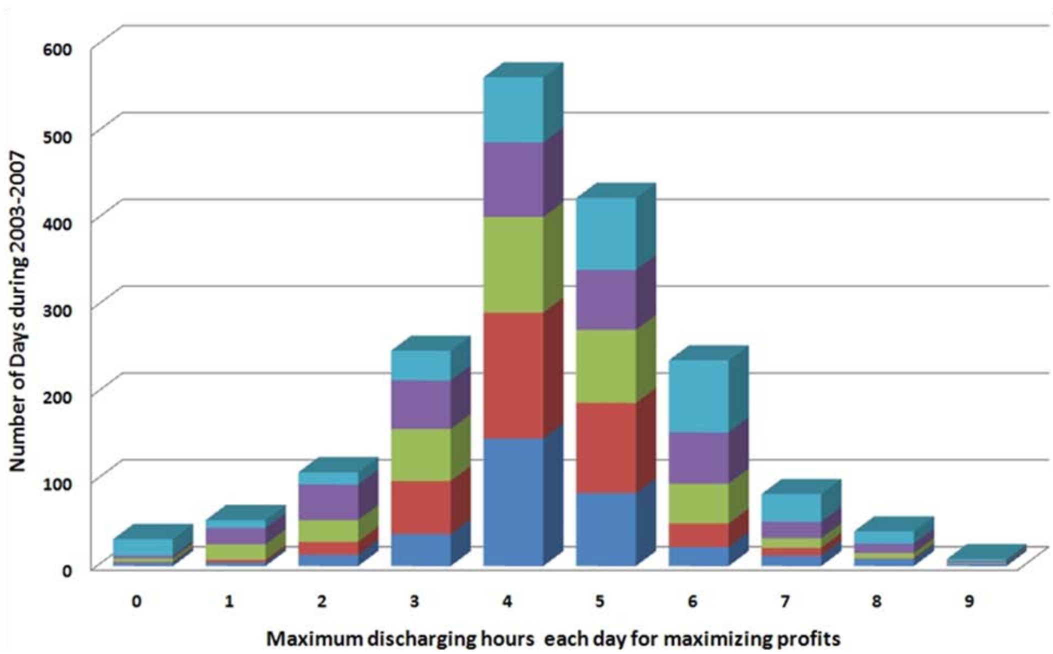

Figure 36: Anticipated operating hours for CAES unit with power ratio of 0.5 during 2003–2007

One way of increasing the usage of the CAES plant is by opting for a design with higher power ratio. Higher power ratio (by using a larger compressor) can help in increasing the number of operating hours by reducing the cost of charging, as a larger compressor will enable a CAES plant to compress air within shorter duration, thus benefiting from lower off-peak prices. This can be seen from Figure 37 and Figure 38, which display results of simulation conducted for CAES units with Power Ratio of 0.75 and 1.0 respectively. The figures show that CAES unit with power ratio of 0.75 will operate for six to seven hours a day on most of the days, and as much as 11 hours on some of the days. Increasing the power ratio further would result in increasing the usage further by allowing CAES unit to run as much as nine hours on most of the days. Figure 39 shows the same result by plotting the annual number of hours anticipated for all three designs during 2003–2007. This shows that by increasing the power ratio from 0.5 to 1.0, annual number of hours can be increased from approximately 1500 hours to almost 2400 hours. Of course the final choice of the design will have to take into account the additional cost of compressor, but this analysis clearly indicates that Power Ratio is one of the critical factors in determining operating hours for CAES facilities.

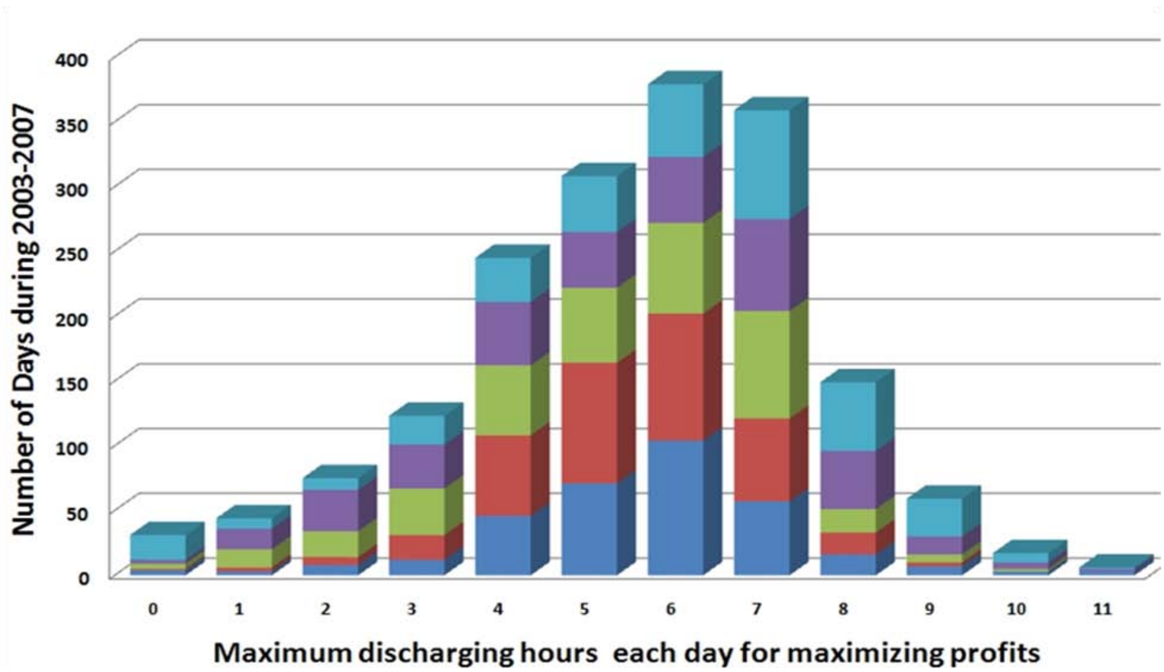

Figure 187: Anticipated operating hours for CAES unit with power ratio of 0.75 during 2003–2007

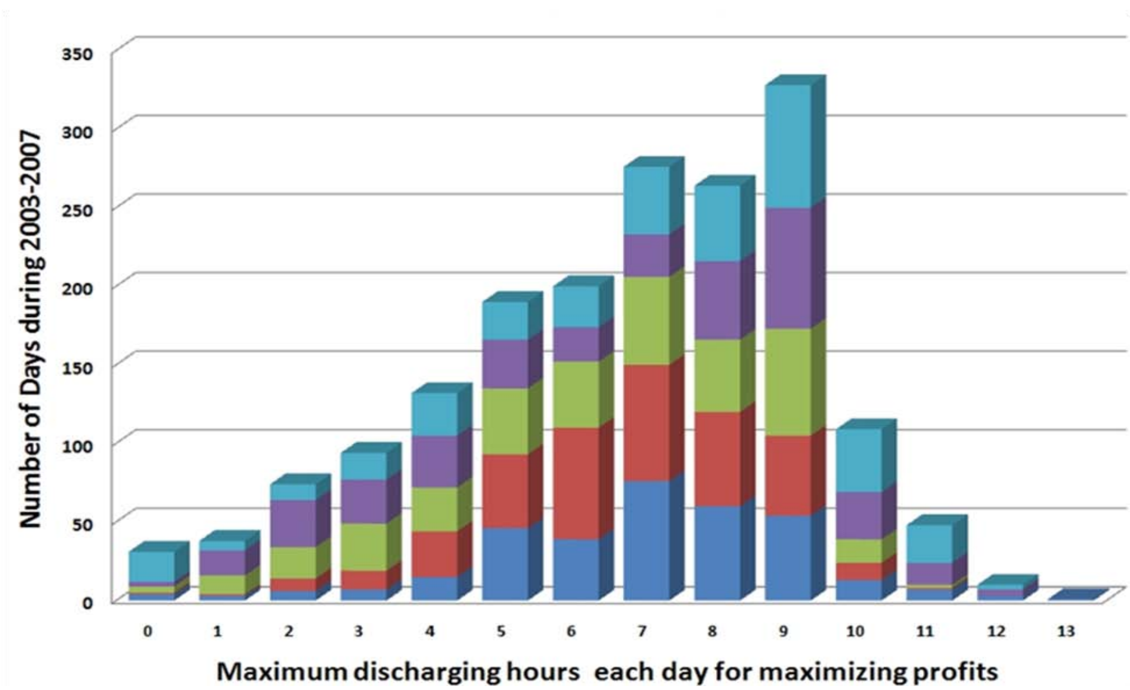

Figure 19: Anticipated operating hours for CAES unit with power ratio of 1.0 during 2003–2007

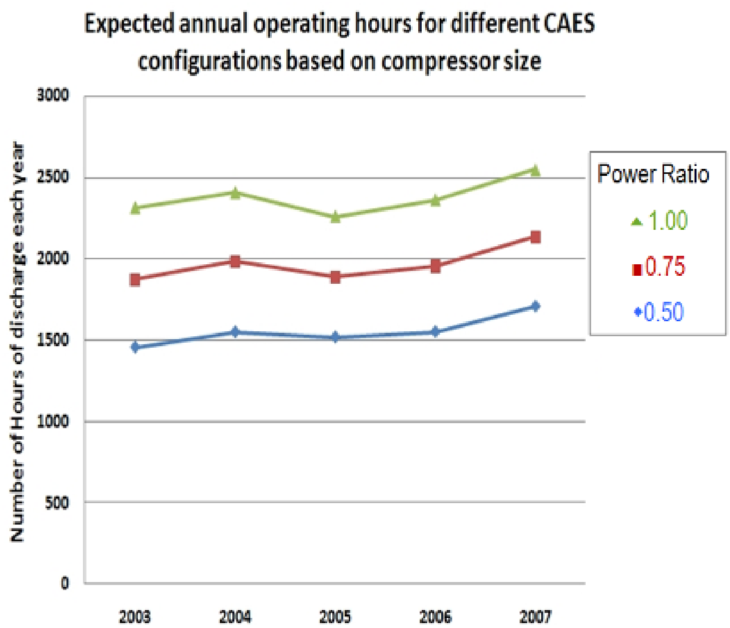

Figure 39: Anticipated annual operating hours for different power ratios during 2003–2007 with daily optimization

Some of the earlier CAES designs were developed with assumption that CAES plant needs larger storage capacity (24 hours or longer) so as to charge the cavern over weekends and discharge during peak hours throughout the week. Our analysis indicates that with the electricity markets, there are opportunities even on weekends for operating CAES plant. Figure 40 shows the average daily energy price curve for weekly, weekdays and weekends. The on-peak/off-peak price differential is lower on weekends, but there are at least few hours over weekends when it is economical for energy arbitrage.

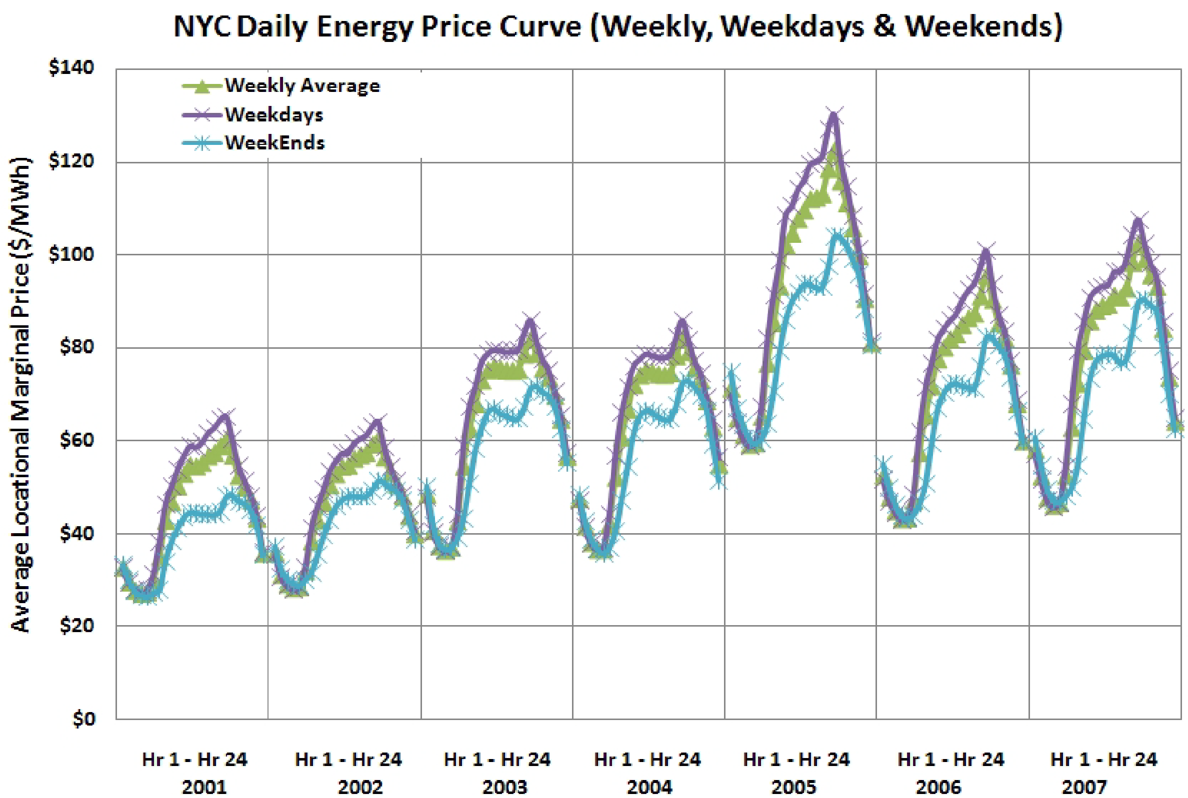

Figure 40: Average daily energy price curves for weeks, weekdays, and weekends in NYC zone during 2001–2007

Effect of storage capacity and optimization duration

Since daily energy prices fluctuate significantly day to day, the optimal operational period of CAES is also influenced by amount of storage capacity available. We tried to estimate this effect by running the simulations for a monthly cycle (i.e. instead of restricting operation of CAES unit on a daily cycle, allowing CAES plant to run compressor throughout the month whenever prices are low enough). By allowing the CAES plant to capture the variations in hourly energy prices over a monthly cycle, we anticipate that annual operating hours will further increase from approximately 2400 to 2500 (approximately 7% increase) as shown in Figure 41.

Although the increase in number of operating hours seems small, such change in operation from daily optimization to monthly optimization, can allow CAES unit to increase net revenues by almost 50% by capturing higher on-peak/off-peak differentials. Figure 42 shows that the net revenues per MW of installed capacity for CAES unit could have increased from approximately $90,000 to $130,000 during 2003–2007 by selecting a higher power ratio. At the same time, the monthly operation of CAES plant with power ratio of 1.0, could have resulted in net revenues of over $190,000 over the same period.

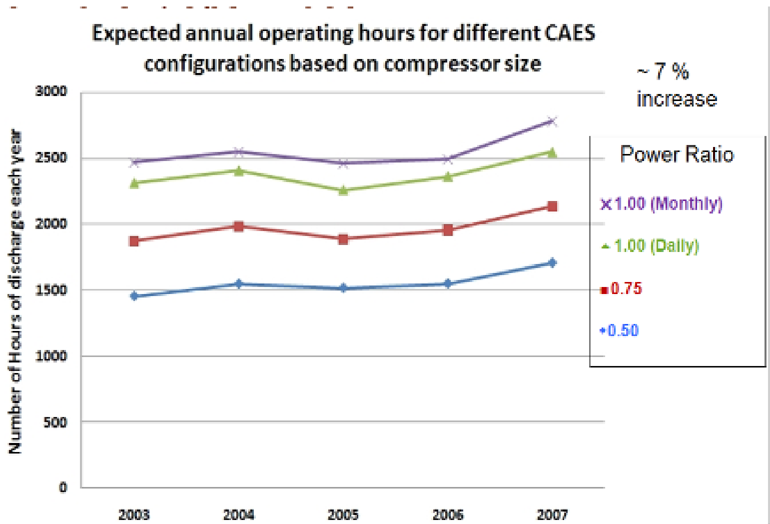

Figure 41: Increase in anticipated annual operating hours due to moving to monthly optimization from daily optimization

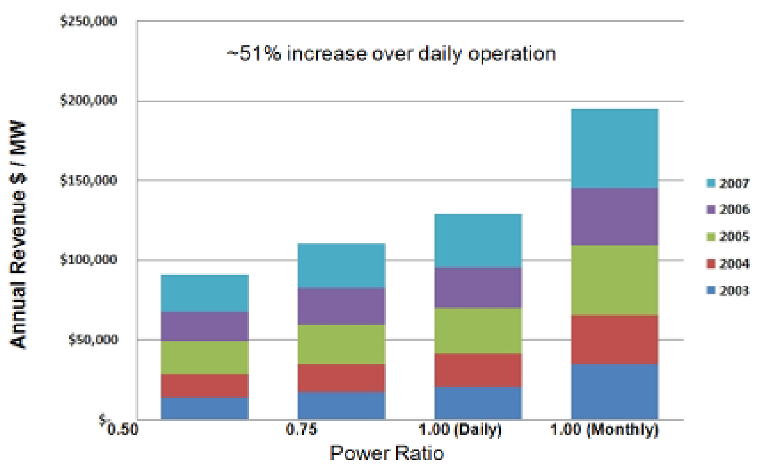

Figure 42: Expected net revenues from energy arbitrage for different power ratios with daily and monthly optimization

It is important to remember that the increase in net revenues is achieved mainly by the ability of capturing the peaks and valleys over a longer period, and not by substantial increase in operating hours.

Since the monthly operations result in substantial increase in net revenues, an obvious question is whether it is possible to attempt optimization of CAES operations over a seasonal period, assuming sufficient storage capacity is available.

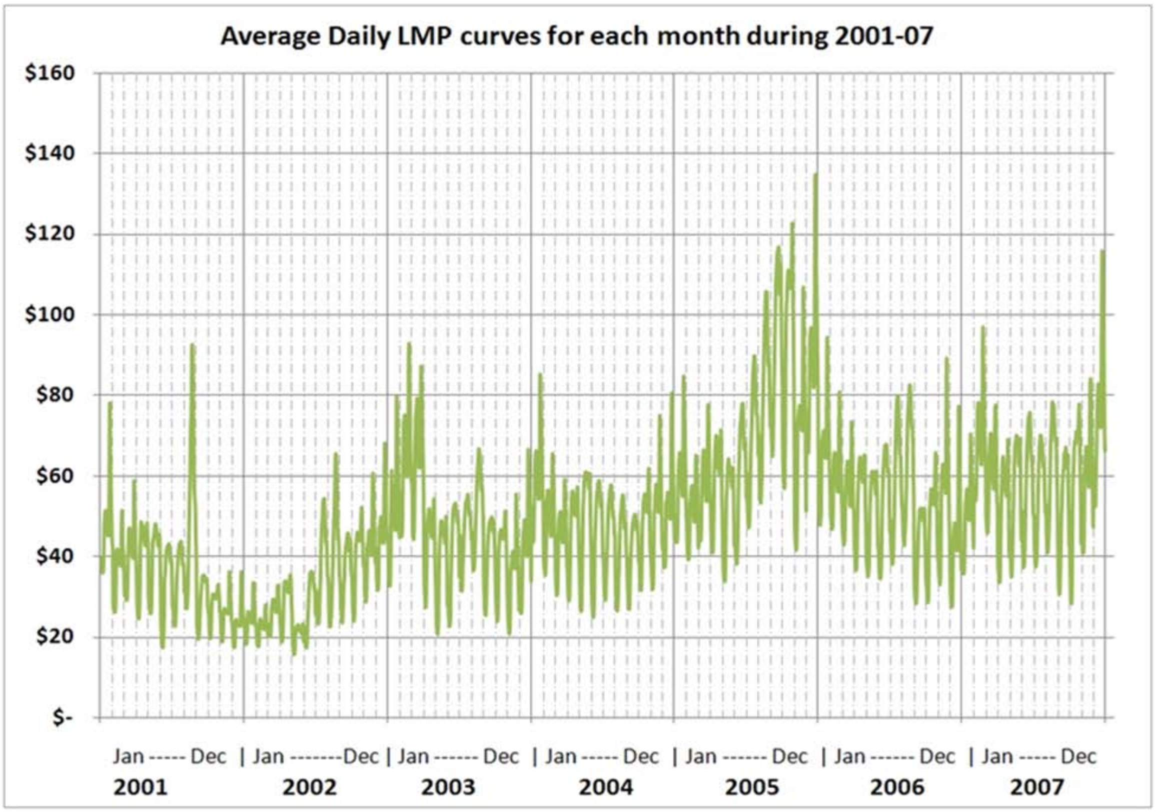

Figure 43: Average daily LMP curves for each month during 2001–2007

Figure 43 shows the distribution of the average daily energy price curve for each month during 2001–2007. This clearly indicates that even the peak price during certain months is lower than off-peak price in other periods. This supports the idea of seasonal optimization, but there are other factors that need to be considered. The economic feasibility of longer operation will be based on the cost of developing larger storage capacity and the increased revenue potential. At the same time, the bigger issue with operating CAES facility over longer duration is the ability to forecast period of charging and discharging. Typically load duration analysis would suggest that CAES facility would be charged during lower load periods in shoulder months for discharging during the peak load months during summer and winter. Practically there are lot more variables that influence the variation in energy prices, such as weather patterns and fuel prices. Figure 44 shows the results of this analysis. The blue-colored part indicates the period of the year when CAES facility would discharge, and the red-colored part indicates charging period. This indicates the large influence of weather patterns and fuel prices on distribution of charging and discharging periods.

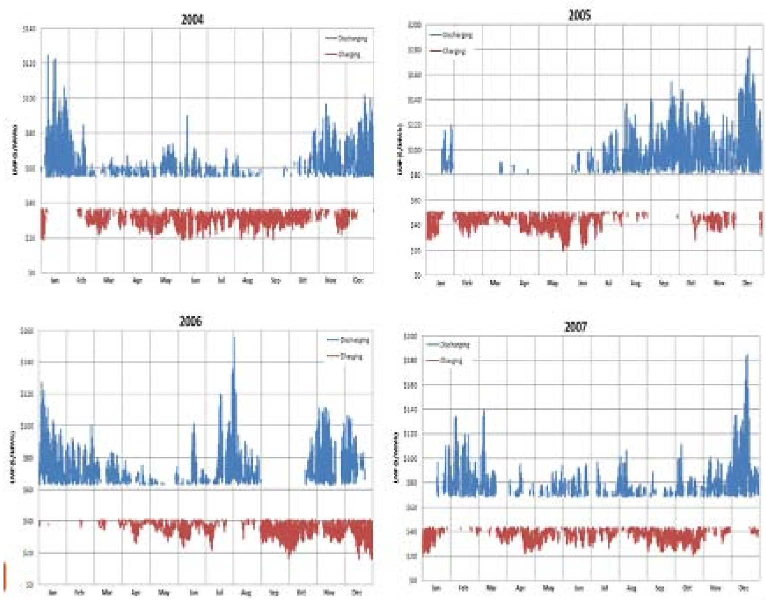

Figure 44: Ideal charging and discharging schedule for annual optimization during 2004–2007

During 2004, the winter period would have been an ideal period for discharging. During 2005, the discharging hours would have been grouped in the second half of the year. This was a result of the increase in fuel prices due to the severe hurricane season during 2005, which resulted in substantial increase in energy prices during the second half of 2005. The increased fuel prices in late 2005, continued to remain high in early 2006, and thus during 2006, CAES facility would have discharged during the early part of the year. The year 2006 also witnessed most of the regions experiencing highest loads during summer, which again would have resulted in discharging during summer months.

This suggests that practically, it would be difficult to operate CAES facilities on a seasonal basis, by ensuring that operators are able to charge the storage caverns sufficiently to meet the peak load during different seasons. Thus we believe that in most cases, CAES facilities would be operated on a daily or monthly optimization cycle.

Effect of location of CAES plant

As discussed in Chapter 3, various zones within NYISO exhibit significant differences in energy prices. These differences exist in both on-peak and off-peak prices. For NYISO's operations, the peak period is defined as the hours between 7 am and 11 pm inclusive, prevailing Eastern Time, Monday through Friday, except for North American Electric Reliability Council (NERC)- defined holidays. The off-peak period is defined as the hours between 11 pm and 7 am, prevailing Eastern Time, Monday through Friday; all day Saturday and Sunday and NERC-defined holidays.

1. Table 24 to

Table 29 show the summary of the statistical analysis of the zonal LBMP prices for 11 NYISO zones for different periods: the complete year, the summer capabilities period, and the winter capabilities period based on 2001–2007 data. NYISO has defined the summer capability period as May 1 through October 31 and the winter capability period as November 1 through April 30.

Table 24: Regional Distribution of Peak LBMP Prices ($/MWh) for 2001–2007

Region	Zone	2001	2002	2003	2004	2005	2006	2007
New York City	Long Island	$59.78	$57.48	$73.53	$72.23	$113.39	$100.68	$103.67
	NYC	$56.39	$55.43	$77.42	$76.41	$112.53	$86.07	$93.94
NY East	Capital	$49.45	$46.23	$60.23	$60.41	$89.98	$70.43	$80.57
	Dunwoodie	$52.65	$47.69	$61.82	$62.30	$95.83	$78.86	$88.28
	Hudson Valley	$51.97	$46.70	$61.26	$60.96	$92.85	$76.52	$86.27
	Millwood	$51.79	$46.80	$61.19	$61.48	$95.03	$78.50	$88.16
NY West	Central	$43.74	$38.85	$55.08	$55.72	$81.36	$63.57	$69.44
	Genesee	$42.25	$38.00	$54.33	$55.21	$79.88	$62.01	$66.58
	MH Valley	$44.91	$39.69	$56.79	$57.43	$83.85	$65.90	$72.13
	North	$43.29	$38.31	$55.10	$55.54	$80.63	$62.56	$68.63
	West	$41.48	$36.37	$51.47	$52.22	$76.07	$58.67	$63.97

Table 25: Regional Distribution of Peak LBMP Prices ($/MWh) for the Summer Capabilities Period 2001–2007

Region	Zone	2001	2002	2003	2004	2005	2006	2007
New York City	Long Island	$59.29	$66.51	$69.32	$72.28	$127.85	$105.91	$98.54
	NYC	$58.59	$63.69	$72.88	$73.80	$126.82	$89.71	$92.31
NY East	Capital	$50.60	$51.93	$55.44	$58.54	$97.24	$67.82	$74.08
	Dunwoodie	$55.35	$52.86	$59.00	$61.23	$107.06	$82.26	$87.40
	Hudson Valley	$54.52	$51.82	$57.85	$59.72	$102.89	$78.84	$84.50
	Millwood	$54.38	$52.02	$58.23	$60.48	$106.50	$81.89	$87.17
NY West	Central	$45.32	$41.80	$51.02	$53.68	$88.97	$62.98	$67.62
	Genesee	$43.95	$40.84	$50.40	$52.83	$87.46	$62.11	$64.95
	MH Valley	$46.60	$42.47	$52.52	$55.14	$91.49	$65.64	$70.50
	North	$44.92	$40.69	$50.76	$52.58	$87.41	$61.62	$66.72
	West	$43.53	$39.97	$47.57	$50.24	$84.21	$59.14	$62.90

Table 26: Regional Distribution of Peak LBMP Prices ($/MWh) for Winter Capabilities Period 2001–2007

Region	Zone	2001	2002	2003	2004	2005	2006	2007
New York City	Long Island	$60.29	$48.24	$77.84	$72.17	$98.82	$95.27	$108.93
	NYC	$54.13	$46.97	$82.07	$78.96	$98.12	$82.31	$95.60
NY East	Capital	$48.27	$40.38	$65.15	$62.23	$82.66	$73.12	$87.22
	Dunwoodie	$49.89	$42.39	$64.72	$63.34	$84.51	$75.35	$89.18
	Hudson Valley	$49.37	$41.46	$64.75	$62.17	$82.73	$74.13	$88.09
	Millwood	$49.14	$41.45	$64.22	$62.45	$83.47	$74.99	$89.17
NY West	Central	$42.12	$35.83	$59.23	$57.71	$73.69	$64.18	$71.31
	Genesee	$40.50	$35.09	$58.35	$57.53	$72.25	$61.91	$68.25
	MH Valley	$43.18	$36.84	$61.17	$59.67	$76.15	$66.17	$73.80
	North	$41.63	$35.87	$59.55	$58.42	$73.80	$63.52	$70.59
	West	$39.38	$32.69	$55.47	$54.14	$67.88	$58.18	$65.06

Table 27: Regional Distribution of Off-Peak LBMP Prices ($/MWh) 2001–2007

Region	Zone	2001	2002	2003	2004	2005	2006	2007
New York City	Long Island	$38.51	$39.42	$53.09	$54.89	$86.13	$73.50	$72.21
	NYC	$35.40	$37.92	$51.82	$51.33	$76.60	$57.72	$62.62
NY East	Capital	$32.71	$32.23	$43.87	$44.97	$66.62	$52.22	$59.55
	Dunwoodie	$33.09	$32.41	$44.18	$45.68	$68.90	$53.85	$60.66
	Hudson Valley	$33.03	$32.36	$44.04	$44.98	$67.06	$53.21	$60.05
	Millwood	$32.60	$32.00	$43.64	$45.14	$68.21	$53.62	$60.60
NY West	Central	$29.56	$28.20	$39.84	$41.02	$60.06	$46.43	$50.15
	Genesee	$28.48	$27.50	$39.17	$40.50	$58.46	$44.99	$45.25
	MH Valley	$30.57	$29.07	$41.31	$42.53	$62.42	$48.12	$52.17
	North	$30.11	$28.51	$40.60	$41.69	$61.20	$46.72	$50.59
	West	$28.07	$26.48	$37.06	$38.19	$55.26	$42.83	$43.48

Table 28: Regional Distribution of Off-Peak LBMP Prices ($/MWh) for Summer Capabilities Period 2001–2007

Region	Zone	2001	2002	2003	2004	2005	2006	2007
New York City	Long Island	$36.54	$42.76	$50.51	$56.06	$94.01	$70.84	$66.81
	NYC	$34.32	$41.40	$49.96	$50.18	$82.57	$56.45	$58.36
NY East	Capital	$31.17	$33.01	$40.44	$42.93	$70.62	$48.44	$53.25
	Dunwoodie	$32.08	$33.13	$41.17	$43.96	$73.89	$51.01	$56.00
	Hudson Valley	$31.93	$32.95	$40.93	$43.14	$71.42	$50.32	$55.31
	Millwood	$31.46	$32.70	$40.56	$43.42	$73.26	$50.76	$55.87
NY West	Central	$28.68	$27.87	$36.86	$38.61	$63.65	$44.62	$47.63
	Genesee	$27.63	$27.15	$36.36	$37.88	$61.84	$43.65	$42.45
	MH Valley	$29.70	$28.61	$38.26	$40.04	$66.28	$46.42	$49.89
	North	$29.28	$27.83	$37.59	$38.84	$65.01	$44.90	$48.40
	West	$27.38	$26.59	$34.32	$35.56	$59.11	$41.87	$40.74

Table 29: Regional Distribution of Off-Peak LBMP Prices ($/MWh) for Winter Capabilities Period 2001–2007

Region	Zone	2001	2002	2003	2004	2005	2006	2007
New York City	Long Island	$40.49	$36.05	$55.70	$53.67	$78.06	$76.18	$77.67
	NYC	$36.50	$34.40	$53.69	$52.54	$70.48	$58.99	$66.92
NY East	Capital	$34.27	$31.44	$47.34	$47.09	$62.51	$56.02	$65.92
	Dunwoodie	$34.11	$31.68	$47.23	$47.47	$63.78	$56.71	$65.36
	Hudson Valley	$34.14	$31.76	$47.19	$46.90	$62.58	$56.12	$64.84
	Millwood	$33.75	$31.30	$46.74	$46.93	$63.03	$56.49	$65.38
NY West	Central	$30.45	$28.54	$42.85	$43.53	$56.38	$48.25	$52.70
	Genesee	$29.33	$27.85	$42.02	$43.24	$54.99	$46.33	$48.08
	MH Valley	$31.45	$29.54	$44.41	$45.13	$58.46	$49.83	$54.48
	North	$30.95	$29.20	$43.65	$44.65	$57.29	$48.54	$52.80
	West	$28.76	$26.37	$39.84	$40.93	$51.32	$43.80	$46.25

Another way to visualize the differences in the locational energy prices is to compare daily price curves across different zones. Figure 45 shows the average daily LMP price curves for four representative zones. As shown in the previous tables, NYC and LI zones exhibit consistently highest energy prices, with NY Eastern region (represented by Hudson Valley) exhibiting higher prices than NY Western region (represented by Central Zone) in this figure.

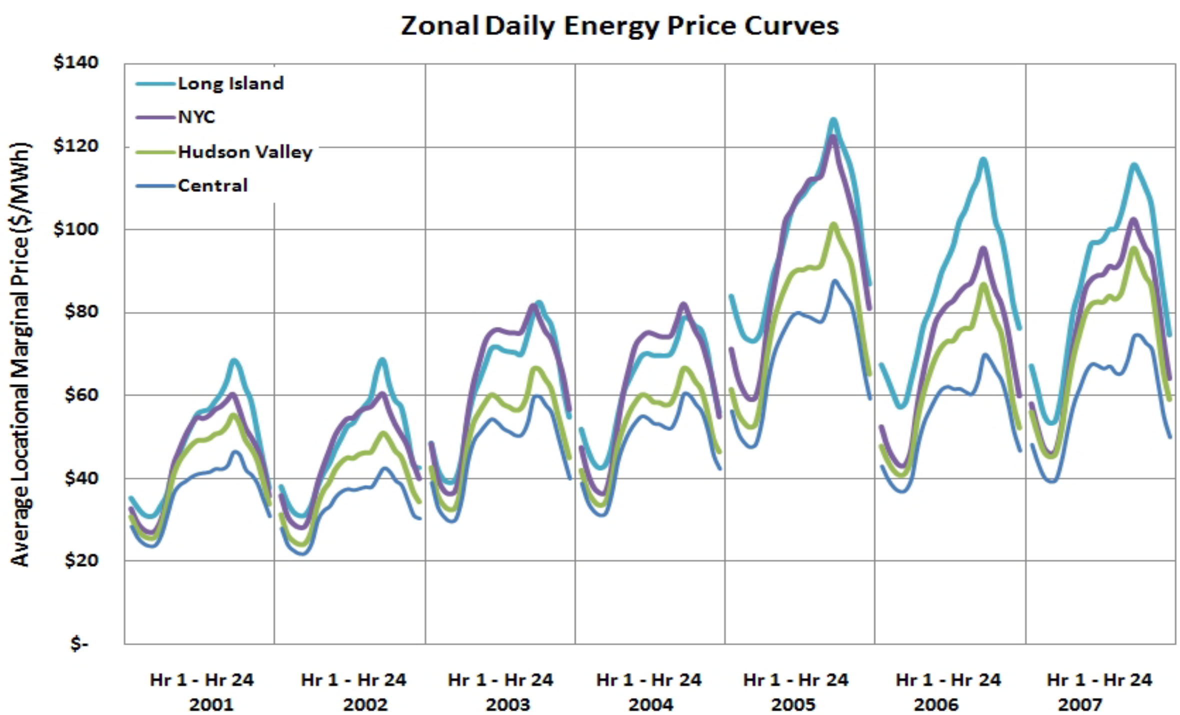

Figure 45: NYISO average daily LMP curves for various zones during 2001–2007

This price pattern results in increase in expected operating hours for CAES plants located in NY East and NYC region as compared to NY West region as shown in Figure 46. Our analysis suggests that a CAES plant that can operate for approximately 2400 hours per year in the western region, would be able to operate for almost 3000 hours in LI zone, and almost 3500 hours in NYC zone. The figure also suggests that NY East region also offers considerably better opportunities for CAES plants than NY West region.

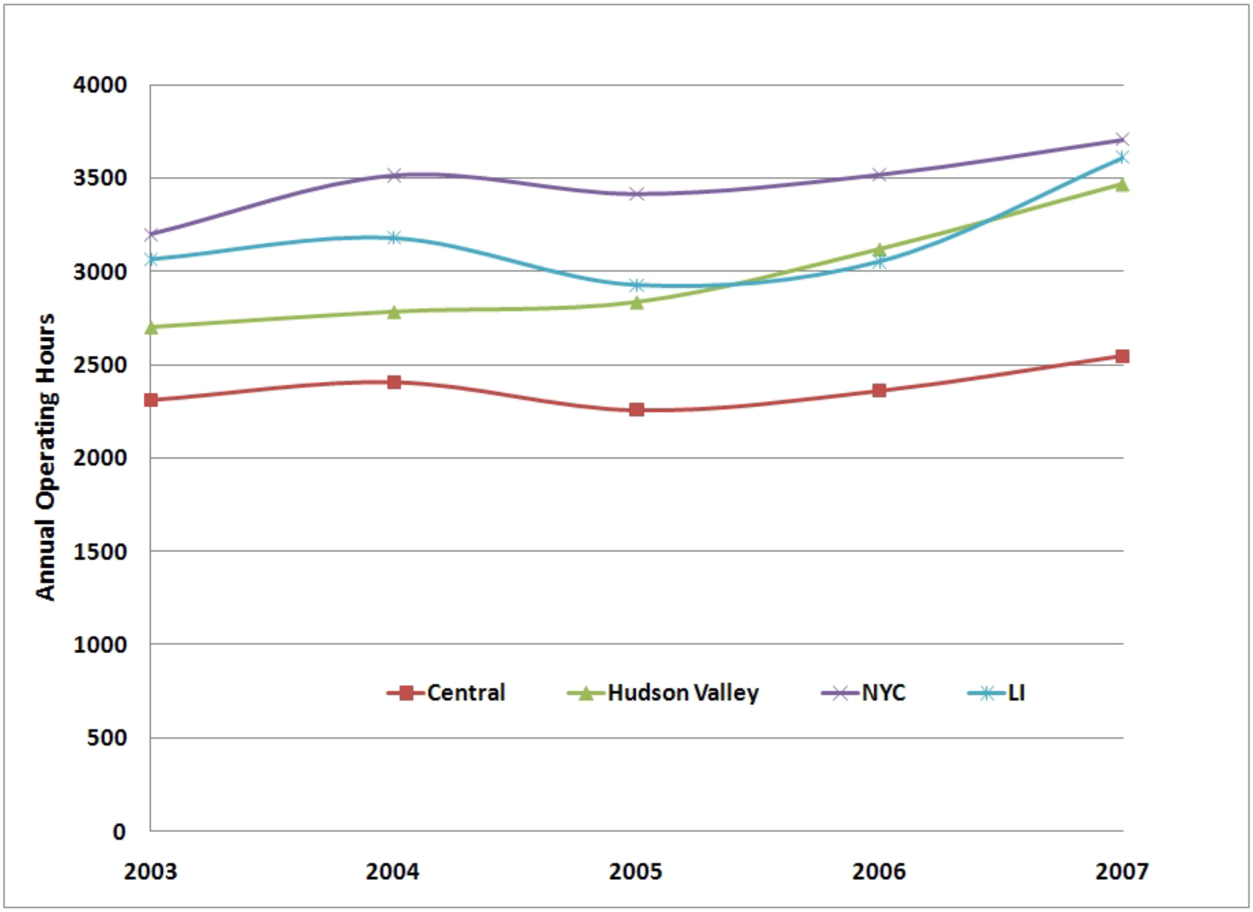

Figure 46: Anticipated annual operating hours for CAES unit with power ratio of 1.0 in different regions in NYISO

The increased operational hours also result in better net revenues for CAES units located in NY east and NYC region. Our analysis suggests that net revenues for a CAES plant located in NY east would have been almost double (approximately $250,000 / MW during 2003-2007) that of net revenues of a CAES plant located in NY west (approximately $130,000 / MW during same period). Both NYC and LI zones would have offered the highest revenue potential of almost $400,000 / MW for CAES plant during 2003-2007. These results are shown in Figure 47.

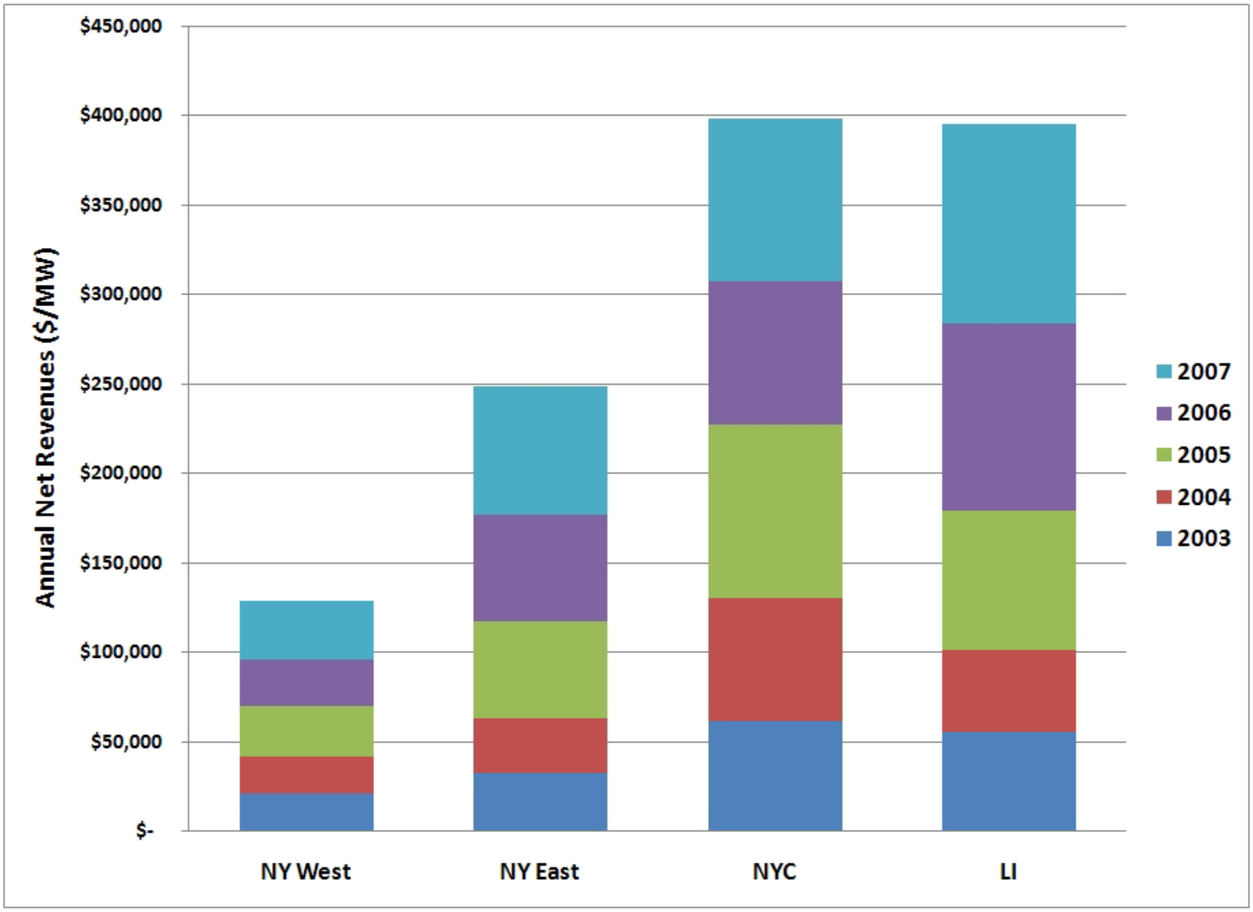

Figure 47: Anticipated annual net revenues from energy arbitrage in different regions in NYISO

Capacity market & Ancillary Service revenue

Most of the CAES facilities would also be eligible for receiving Capacity revenues through the ICAP markets in NYISO. Capacity markets provide an additional revenue stream for generation resources, to cover for any potential shortfall between annualized cost of new peaking units and the anticipated energy and ancillary service revenues.

Table 30: ICAP Revenues 2004-2007(NYISO, 2008)

	Minimum Market-clearing price ($/kW-Month)	Maximum Market-Clearing Price ($/kW-Month)
New York City	$5.60	$12.54
Rest of State	$1.58	$3.00

According to the NYISO State of the Market report for 2007, "in both 2006 and 2007, a significant amount of existing capacity did not clear in the capacity market due to high capacity offer prices. This conduct maintained capacity clearing prices in New York City near the cap for divested generation owners in the City. These prices are substantially higher than the prices that would have prevailed if all capacity had been sold, which raises significant competitive concerns. However, the New York ISO filed mitigation provisions to address these competitive concerns in October 2007 that were approved by the Commission in March 2008. These mitigation provisions and a merger condition imposed on Keyspan-Ravenswood has caused conduct in the capacity market to change significantly in 2008. In March 2008, virtually all of the capacity in New York City was sold, leading the New York City spot auction price to decrease by more than 80% from February to March 2008. The increased sales have continued into the summer months, dramatically reducing the clearing prices in New York City relative to the previous summer capability period."

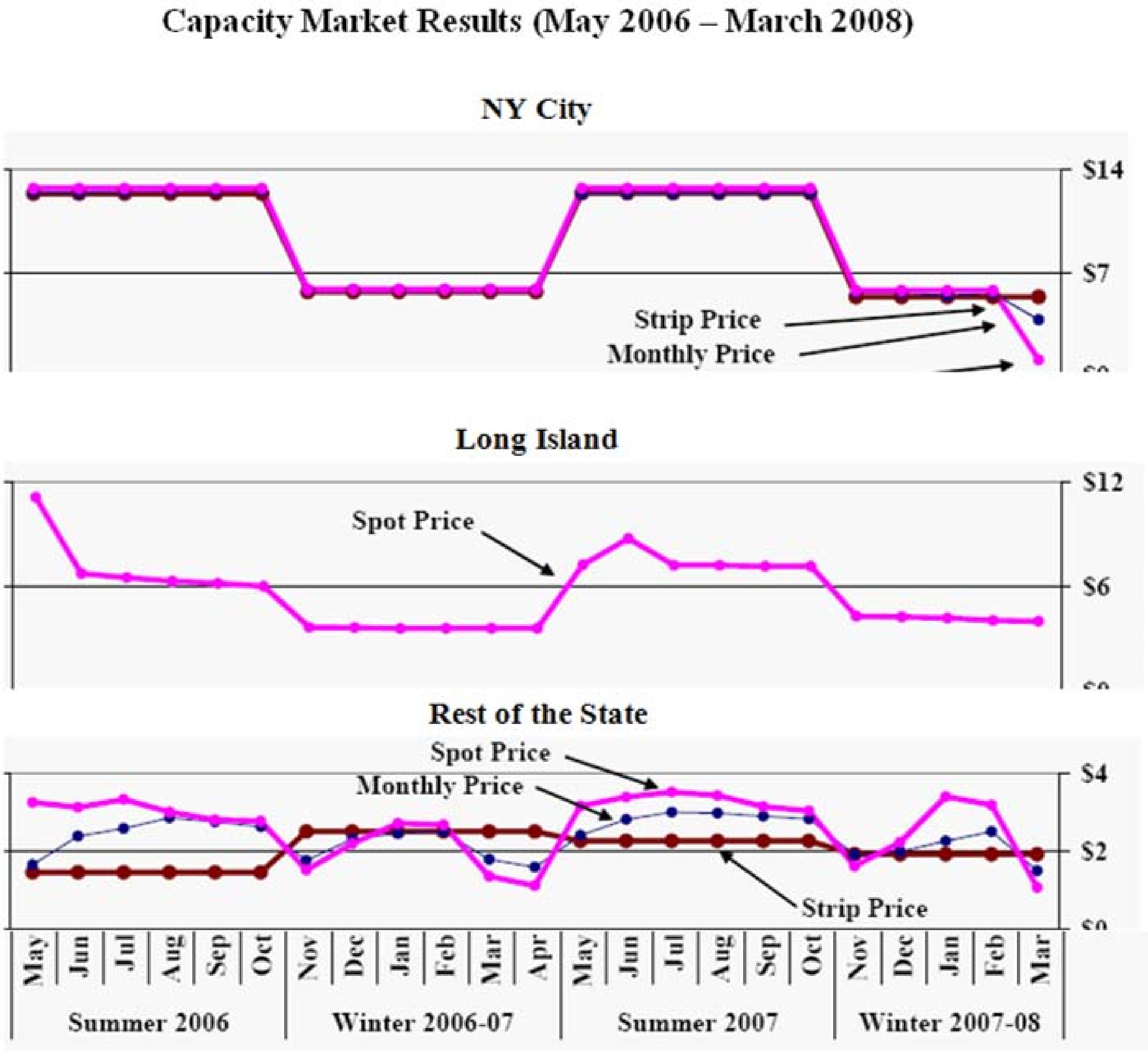

Figure 48: Capacity Market Results for NYC, LI, and Rest of the State (May 2006–March 2008). Source: NYISO State of the Market Report 2007

Regulation & Frequency Response

CAES resources can also participate in the regulation market if they have AGC capability within the NYCA. The price of regulation is set by a demand curve when shortages occur.

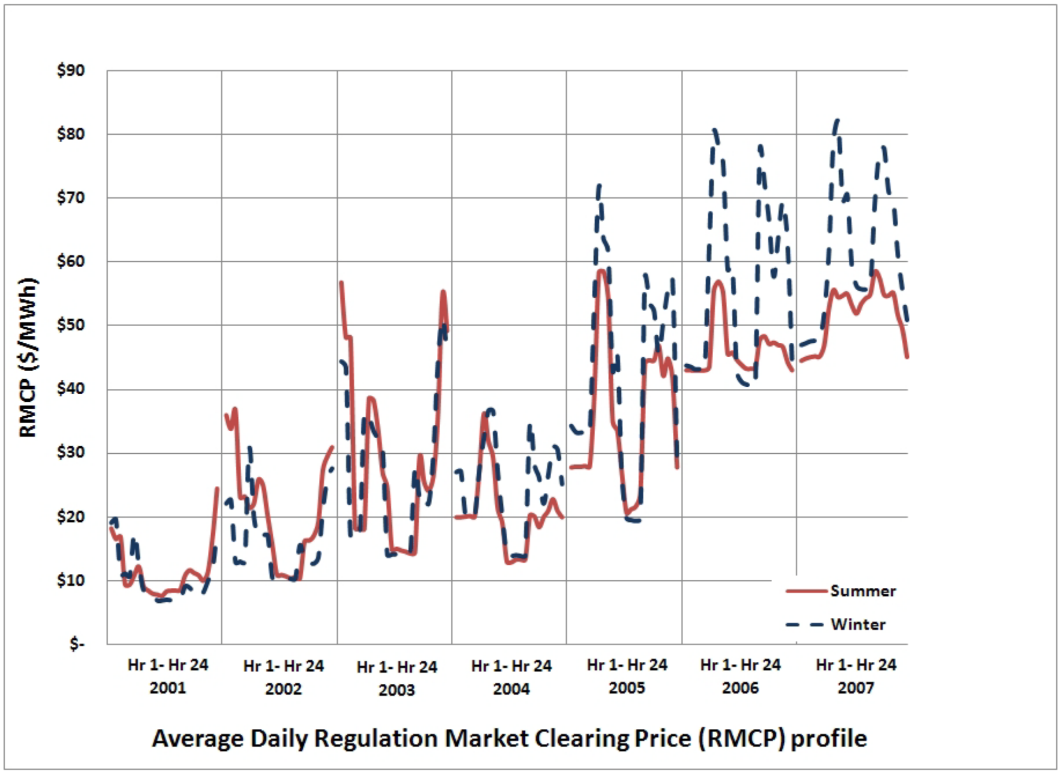

Figure 49: Average daily regulation market clearing price (RMCP) profiles for NYISO during 2001–2007

Figure shows the average daily regulation market-clearing price (RMCP) profiles for the years 2001–2007. These curves show the average RMCP price for each hour of the day during the year for the summer capabilities period and the winter capabilities period. During both the summer and winter capabilities periods, the regulation prices are higher than average during the morning pickup and evening drop-off hours, when the system load changes rapidly. In recent years the value of regulation during these peak periods has been significantly higher during the winter months than during the summer months due to higher fuel prices. Figure 50 shows the annual average price for regulation and spinning reserves for NYISO from 2001 to 2007.

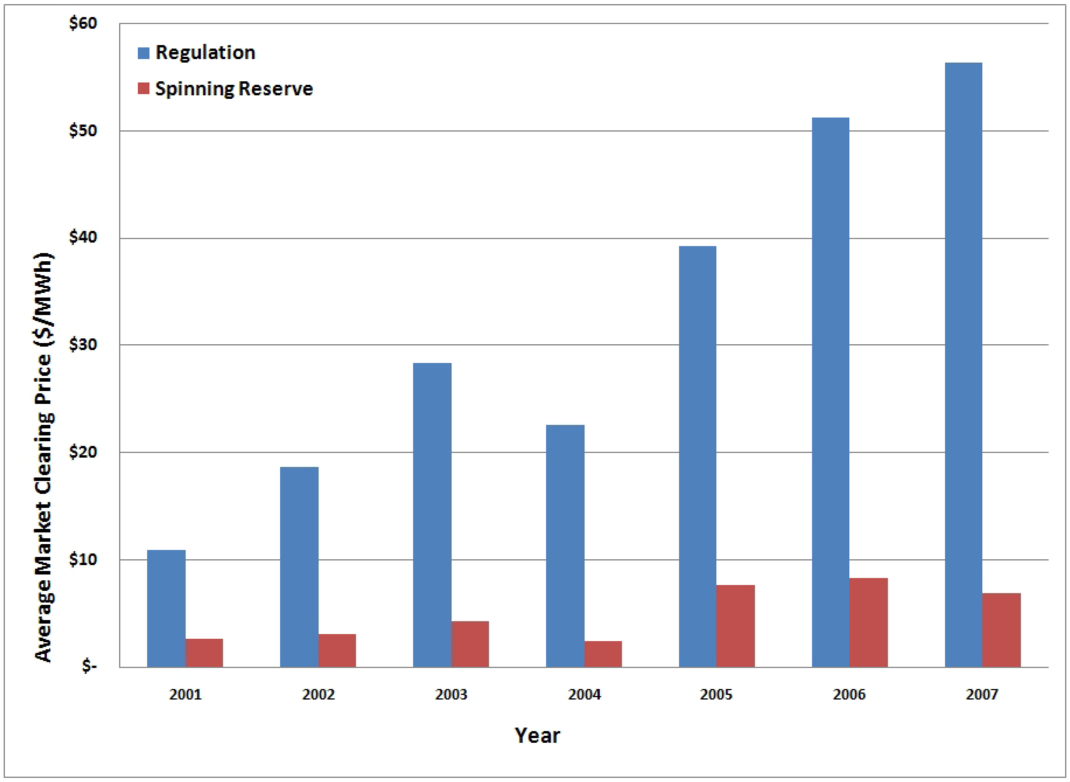

Figure 50: Annual average regulation and 10-minute spinning reserve prices for NYISO (2001–2007)

NYISO Market Monitor has observed following Regulation Offer Patterns in the 2007 State of the Market report:

- Higher offer prices beginning in September 2005 and further increases in 2007 have contributed to a rise in regulation clearing prices and expenses
- The rise in offers was not sufficient to warrant mitigation of regulation offers under the NYISO Tariff
- The effects of higher offer prices were partially offset by the entry in June 2006 of approximately 100 MW of low-priced offers from generators that did not previously offer regulation
- Due to limited participation in the regulation market, the ownership of resources that participate in the regulation market is relatively concentrated.

Figure 51 provides the summary of market monitor's analysis of NYISO ancillary service markets providing details of offered capacity in these markets for different range of offer prices.

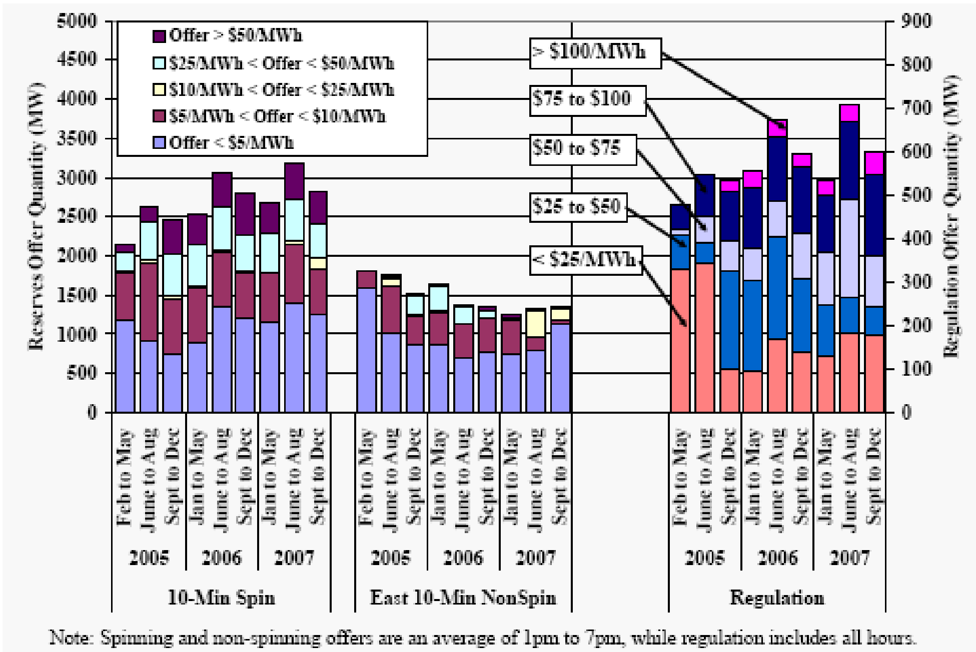

Figure 51: NYISO Ancillary Services: Offered MW and Prices (Source: NYISO State of the Market Report 2007)

Figures 52 through 54 show the average ancillary service market clearing daily price profiles for Regulation, 10-minute synchronized and 10-minute non-spinning reserves for annual, summer (May through October) and winter (November through April) capabilities period.

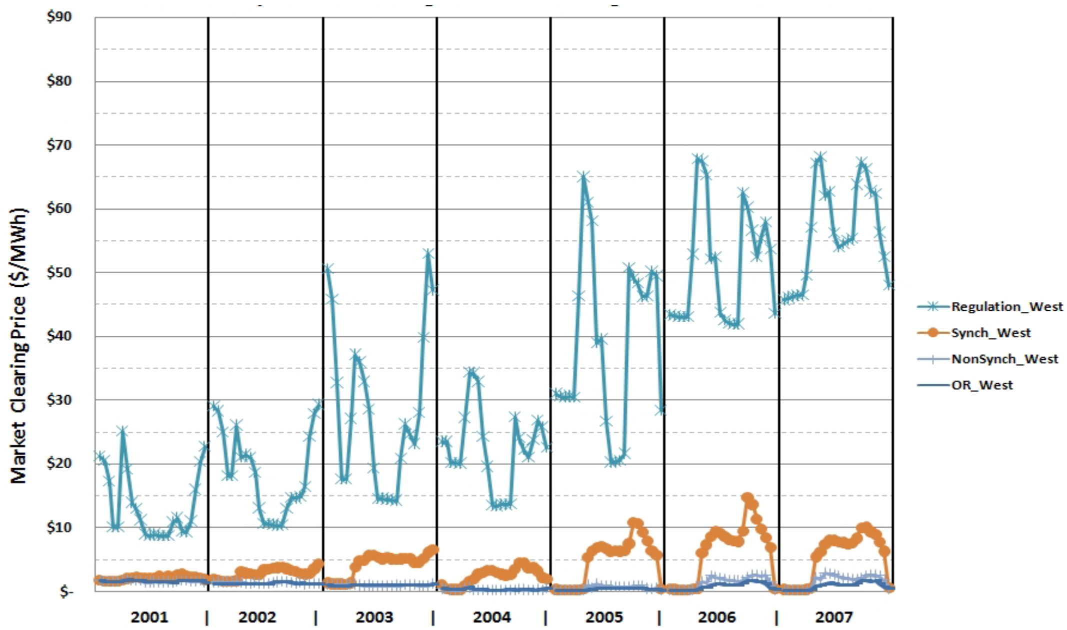

Figure 52: NYISO Ancillary Service Average Market Clearing Price Profiles—Annual

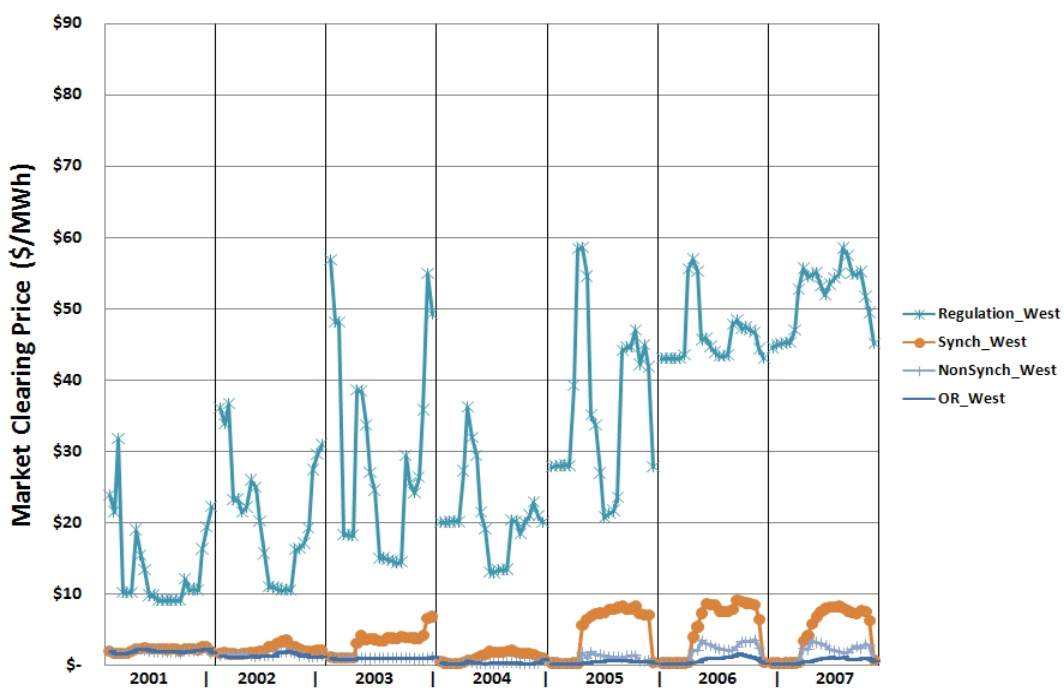

Figure 53: NYISO Ancillary Service Average Market Clearing Price Profiles—Summer

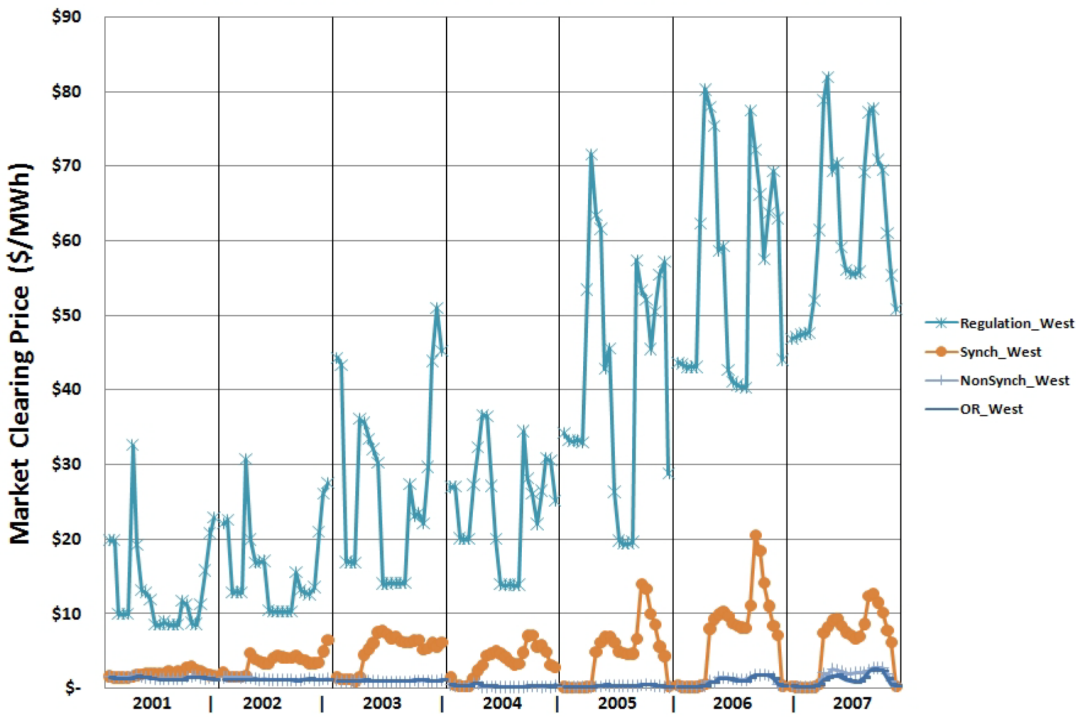

Figure 54: NYISO Ancillary Service Average Market Clearing Price Profiles—Winter

The following two figures summarize day-ahead and real-time clearing prices for the two most important reserve products in New York. Figure 55 shows 10-minute reserve prices in eastern New York, which are primarily based on the requirement to hold 1,000 MW of 10-minute reserves east of the Central-East Interface. This particular requirement is typically the most costly reserve requirement for the ISO to satisfy due to the relative scarcity of capacity in eastern New York.

Figure 56 shows 10-minute spinning reserve prices in western New York, which are primarily based on the requirement to hold 600 MW of 10-minute spinning reserves in New York. In both figures, average prices are shown by season and by hour of day. The market models use “demand curves” that place an economic value of $500/MWh on meeting each of these requirements.

Both figures show that average day-ahead prices are systematically higher or lower than average real-time prices under various circumstances. For instance, average real-time prices tend to be higher during the afternoon-peak, while average day-ahead prices tend to be higher at most other times.

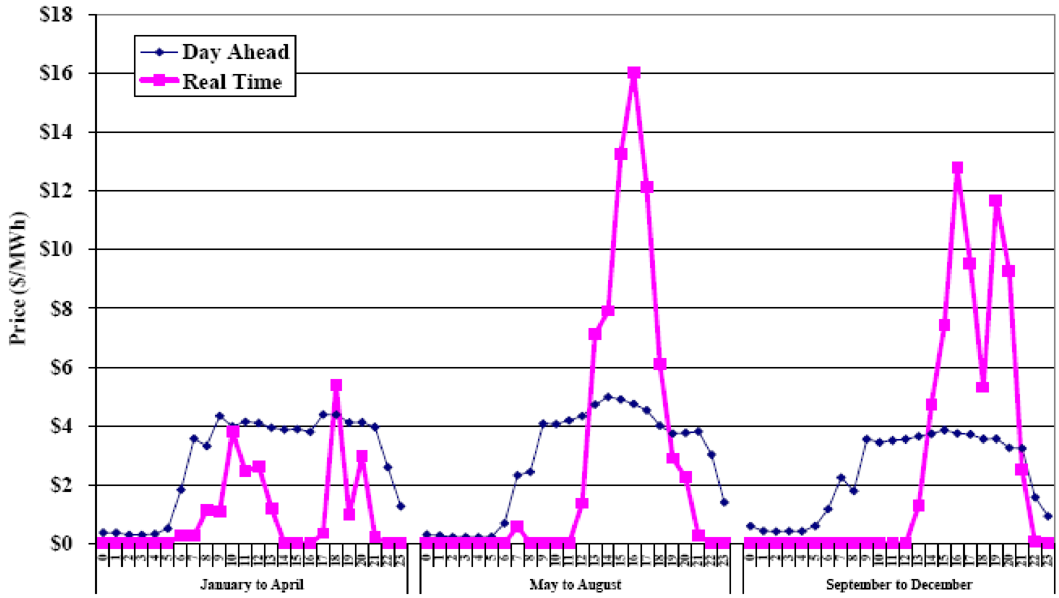

Figure 55: Day Ahead and Real Time 10-minute Synchronous Reserve Prices, Eastern NY 2007 (State of the Market Report)

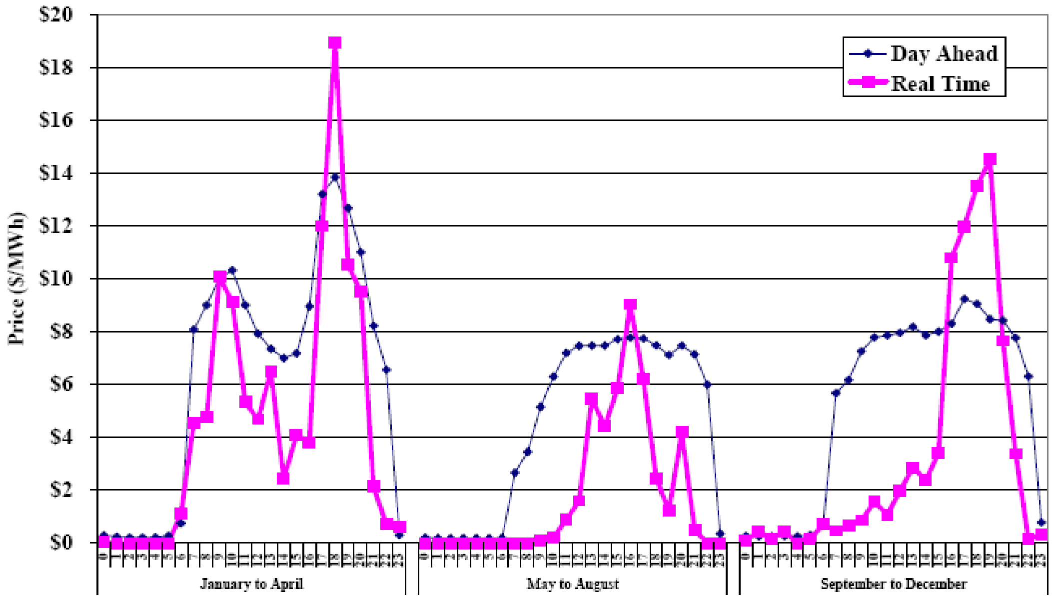

Figure 56: Day Ahead and Real Time 10-minute Synchronous Reserve Prices, Western NY 2007 (State of the Market Report)

Effect of natural gas price on CAES economics

Recent years have seen considerable volatility in the price of natural gas. Natural gas price fluctuations have a dual impact on CAES operations. On one side, increase in natural gas price, results in increase in operating cost for CAES units due to the amount of natural gas consumed during the expansion cycle. At the same time, natural gas price also affects the price of electricity, and thus, could result in changes in both on-peak revenues and off-peak costs.

Although natural gas-based units account for less than 30% of the installed capacity in NYISO, these units influence the market price for electricity for the majority of hours, as they are the marginal units supplying power during most of the year. Our simulations suggest that natural gas prices have greater impact on on-peak prices, than off-peak prices. Figure 57 shows the projected range for average revenues and costs for a CAES unit for a range of natural gas prices ($6/ MMBTU to $22/MMBTU).

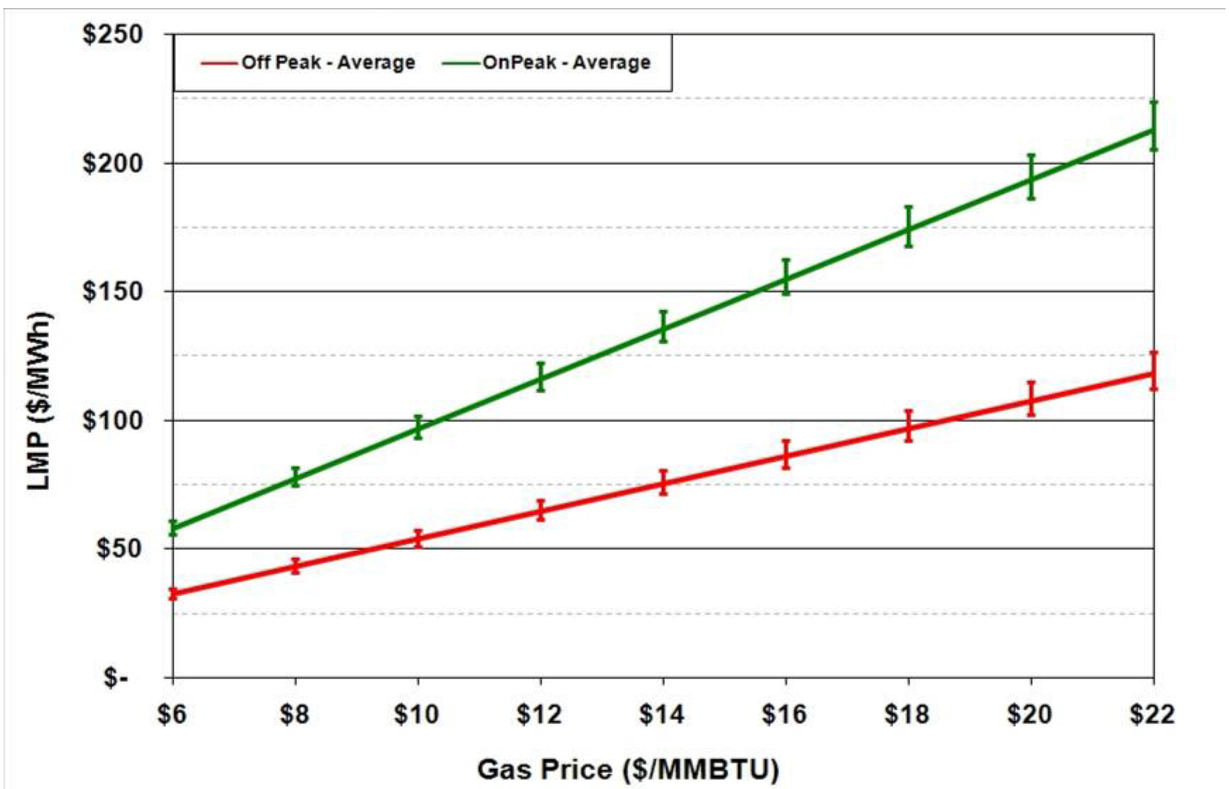

Figure 57: Impact of natural gas prices on on-peak and off-peak costs

Our analysis suggests that CAES units would earn higher net revenues in scenarios with higher natural gas prices, compared to lower natural gas price scenarios. This analysis is based on the assumption that there is no significant change in the supply mix for NYISO. One of the main factors that can influence this assumption is the increase in penetration of wind in NYISO.

Effect of Increased Wind Penetration

Energy storage can resolve many critical problems facing the electric transmission grid in New York State (NYS), including transmission congestion and the uncertainties related to the increased penetration of wind electric generation in NYS. NYS now has approximately 937 MW of wind plants in operation as of December 2008. Also, there is approximately 8,000 MW of wind power in the interconnection queue, including 1,200 MW of off-shore wind. The wind power output generally peaks during the night and is not reliably dispatchable, especially when it is most needed to serve on-peak loads on the system. Due to the intermittency and variability of wind, the New York Independent System Operator (NYISO) is concerned with how the influx of new wind generation will impact the reserve and regulation requirements of the NY electric grid. Wind generation variability could require additional power plants to run to provide energy ancillary services including regulation and synchronous reserve. This could add significant costs and complexities to the operation of the state-wide grid. NYISO is currently working on developing rules that would require wind resources to follow dispatch signals in support of system reliability concerns. So while wind energy is renewable, and emission-free, New York needs solutions to maximize the benefits of wind power to the grid and New York industrial, commercial, and domestic customers.

Not only is the NYISO concerned with load management, but the Regional Reliability Councils are also concerned. One of the solutions is to use energy storage technologies to enable integration of intermittent and variable generation resources in the electric grid. In fact, the US Department of Energy (DOE) Office of Electricity Delivery and Energy Reliability has created a “Modern Grid Initiative” to create an advanced US grid consisting of large numbers of diverse distributed generation and storage devices for the 21st century. The US DOE’s Modern Grid Initiative calls for technology solutions that enable distributed generation while ensuring power quality, cost-efficiency, and optimization of assets.

The New York Department of Public Service (NYDPS) has required the electric utilities in New York to obtain, at a minimum, 25% of its electric power supply from renewable sources by the year 2015. On January 7, 2009, Governor Paterson outlined in his State of the State address a plan for NYS that industry experts believe would increase the renewable power mandate by 5% to a total of 30% by 2015. The electric utilities in NY have taken action to acquire or contract for renewable energy for their customers, but will have to strive harder to meet the new planned goal, while controlling costs.

The following applications of CAES are described in the context of wind power.

- **Transmission Curtailment Reduction**

  Wind power generation is often located in remote areas which are poorly served by transmission and distribution systems. Occasionally, more power generation capacity is installed than the existing transmission system can service. As a result, operators are asked to curtail their production, which results in wasted energy or are required to invest in expanding the transmission capability. An energy storage plant, located close to the generation, allows the excess energy to be stored rather than wasted. This energy can then be delivered at times when the transmission system is not congested.

- **Time Shifting**

  Operators have limited control over the amount of power generated by wind turbines, since it depends on the wind available, and the wind available rarely matches the load requirement. This means that during periods of low demand, wind power must be curtailed, resulting in wasted energy which may not be available for sale during periods of high demand. In other situations, the generation from the wind in off-peak periods could back down generation to a point where the costs are increased due to units operating at minimum loads or reliability is risked because units are taken off line, but ultimately needed for On-Peak generation. Energy storage can be used to store energy generated during periods of low demand and deliver it during periods of high demand. When applied to wind generation, this application is sometimes called “firming and shaping” because it changes the power profile of the wind to allow greater control over dispatch. This can also help with system reliability in that greater margins may be needed as wind contributes more to the total resources available to the system.

- **Forecast Hedging**

  Sometimes wind energy is simply not available when it is needed, such as on windless days. In a deregulated market, depending on the settlement rules implemented, this can result in penalties for wind operators whose real-time generation falls short of the power bid for delivery. An energy storage system can act as a hedge against these penalties, by allowing operators to deliver the promised energy from the storage system and then replacing it on another day when power generation exceeds the contract for delivery.

- **Frequency Support**

  In an area with a great deal of wind generation, sudden shifts in wind patterns can lead to significant imbalances between generation and load, which in turn result in shifts in grid frequency. Such imbalances are usually handled by spinning reserve at the transmission level, but energy storage can provide prompt response to such imbalances without the emissions related to most conventional solutions.

- **Fluctuation Mitigation**

  The short-term variability associated with wind power has led in some cases to fluctuations with relatively short frequencies, from seconds to minutes. Energy storage has been proposed to mitigate these fluctuations[5]. However, these issues are directly addressed in many newer wind turbine designs, thus reducing the need for further equipment.

5 "Investigation into the Possible Use of Storage Batteries for Stabilization of Wind Power Generation," (Japanese), New Energy and Industrial Technology Development Organization (NEDO), Tokyo, Japan: February 2002. NEDO-NP-0004

8 ENVIRONMENTAL REGULATIONS AND PERMITTING

New York State Renewable Portfolio Standard

The New York Public Service Commission (PSC) adopted a Renewable Portfolio Standard (RPS) in September 2004. New York's RPS target is to have 25% of load met through renewable energy by 2013. Of this, 19% will be met by existing (2004) renewable generation. The remainder will be centrally procured by the New York State Energy Research and Development Authority (NYSERDA). As stated earlier, Governor Paterson has proposed a 5% increase in the 2015 RPS target.

The RPS program has two tiers of eligible resources – a Customer Sited Tier and a Main Tier. Resources eligible for the Customer Sited Tier are generally limited to the size of the load at the customer's meter and include fuel cells, solar, wind, and methane digesters. Resources eligible for the Main Tier include methane digesters, biomass, biofuels, fuel cells, hydro power, solar, ocean/tidal power, and wind power. NYSERDA can procure Main Tier RPS resources through auctions, contracts, or requests for proposal. The details of the most recent Main Tier request for proposals for the period beginning January 1, 2009 are contained in RFP 1168 on the NYSERDA web site: www.nyserda.org/rps/index.asp.

Compressed Air Energy Storage (CAES) is not listed as an RPS Main Tier Eligible Electric Generation Source in Appendix B Case 03-E-0188 of the April 2005 PSC Order.

Regional Greenhouse Gas Initiative

The Regional Greenhouse Gas Initiative (RGGI) is an effort by 10 northeastern states to implement a cap and trade system for CO_2 emissions. This program affects fossil fuel power plants with 25 MWs or greater generating capacity. RGGI seeks to first stabilize CO_2 levels during the first six years of the program (2009–2014) and then reduce them 2.5% per year for the four remaining years 2015–2018, resulting in 2018 CO_2 emissions at 2009 levels. Allowances will be auctioned off in a regional auction starting on September 25, 2008, and quarterly thereafter.

Section 10.3 of the RGGI Model Rule defines the eligible CO_2 emissions offset projects. Those projects include:landfill methane capture and destruction; reduction in emissions of sulfur hexafluoride; sequestration of carbon due to afforestation; reduction or avoidance of CO_2 emissions from natural gas, oil, or propane end-use combustion due to end use energy efficiency; and avoided methane emissions from agricultural manure management operations. CAES is not listed as an eligible CO_2 emissions offset project.

NYISO Permitting Process

Deliverability will be part of the NYISO's interconnection studies going forward. A generator can elect to study Energy Resource Interconnection Service (ERIS), Capacity Resource Interconnection Service (CRIS) or both at the time of the interconnection request but must finalize its decision when the Facilities Study Agreement is executed. Generators must elect CRIS to participate in the NYISO's Capacity Market. The deliverability test will be applied within each of New York's capacity regions – New York City, Long Island and Rest of State. To be deliverable, a generator must be deliverable throughout its relevant capacity region. The NYISO will determine within the context of the studies if any System Upgrade Facilities (SUFs) are required for a generator electing CRIS to be deliverable. The generator will be required to pay a portion or all of the cost for the SUF.

The NYISO is proposing formalizing the project tracking process for Developers to exchange information with the NYISO after the completion of the Facilities Study. The NYISO has provided a draft Process Map (shown in Figure 58) which details the steps in the Interconnection process, including contact information. In general, the process of becoming a NYISO generation market participation involves following process:

- Interconnection Planning Studies
  - Feasibility Study
  - System Reliability Impact Study
  - Facilities Study
- Legal
  - Feasibility Study Agreement
  - System Reliability Impact Study Agreement

- Facilities Study Agreements
- NYISO Interconnection Agreement

- Finance
  - The expander operates between the stored air pressure and atmospheric pressure, with the extraction for air injected into CT
  - Project Tracking
  - Registration

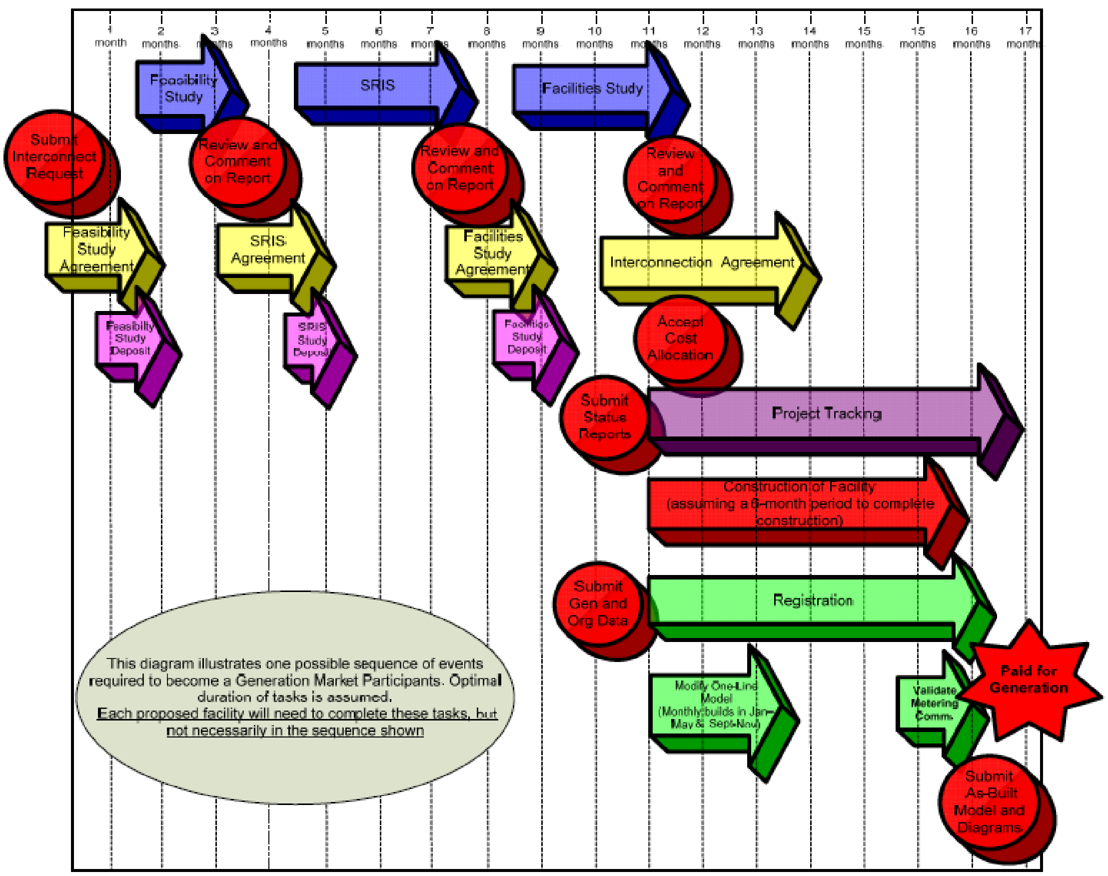

Figure 58: Steps for becoming NYISO Generation Market Participant (Source: NYISO)

Developers will be required to submit a bi-monthly Interconnection Project Status Report to both the NYISO and Transmission Owner after the completion of the Facilities Study throughout the development of the project. This report is to be submitted by the 15th of every odd numbered month. Pending comments received in the stakeholder process, the NYISO plans on implementing this reporting process in March 2009. The NYISO is in the beginning stages of discussing Queue Process Improvements in the stakeholder process. The intent of this is to streamline the interconnection process. There is no firm target date for completion.

9 CONCLUSIONS AND R&D OPPORTUNITIES TO DEPLOY CAES PLANTS IN NEW YORK

Our analysis indicates that NY offers suitable geology as well as required electric and gas infrastructure for building of CAES facilities. NYISO market design provides various opportunities to optimize CAES operations, but it is important for project developers to understand the various factors that can influence revenue potential as well as costs. The anticipated growth in share of wind in the supply mix of NYISO could improve the case for CAES projects in NY over the next decade.

The major R&D efforts associated with CAES in New York should be focused on verifying underground air storage formations, and conducting field tests to cycle air daily (following a CAES duty cycle) in at least two types of air reservoirs (namely, one for a depleted gas field and one for a depleted oil field). First, core samples should be acquired and investigated with respect to identifying any potential issues associated with the oxygen geochemistry in these formations. This can be done using standard autoclave systems on core samples taken from the depleted gas/oil sites, which can be obtained from the local State Geologic Survey, or if necessary, by drilling into the underground formation with a small bore drilling rig to obtain “clean” core samples for the needed geochemical investigations.

Analysis of specific characteristics for the new CAES plant design options, as well as for the no-fuel adiabatic CAES design option, was driven by a desire to lower plant costs and to simplify the overall plant equipment layout and connections, and use standard components and systems wherever possible. Even so, there are a number of R&D efforts required to ensure reliable and cost effective CAES plants for implementation in New York, where there is a growing renewable portion in the generation mix for the State.

Most, if not all of the R&D issues associated with the new CAES plant design options could be effectively addressed by demonstration projects with well thought-out test procedures to apply the demonstration projects results to a variety of CAES plant design options, differentiated by size and equipment module additions.

These demonstration projects could easily use existing old small capacity combustion turbines to reduce the capital costs and plant capacities of the demonstration plants. These projects would allow integrating various CAES plant configurations with the above-ground storage systems as well, with about 2 to 3 hours storage. Special hybrid designs could be provided to address various concepts including the adiabatic design, and to apply results of the demonstration project to a variety of applications.

The major characteristics of one of the new CAES plant design options is that they are based on a combustion turbine, and therefore a demonstration project could be based on any available existing combustion turbine that a New York utility is not using much, or is willing to contribute it to a CAES demonstration project. Also, the amount of air in the exhaust stream of this combustion turbine used in the demonstration project can be much smaller than all the exhaust air available, since all the demonstration project has to do is provide a proof of principle to the thermodynamic and performance characteristics expected. For example, the demonstration plant needs 1 MW to 5MW if it only uses a portion of the exhaust air for heating the stored air, or the demonstration plant could use all the exhaust air flow and produce 20 MW's to 100 MW's of output power, depending on the size of the combustion turbine the New York utility provides for the demonstration project.

Additionally, one of the biggest advantages of an adiabatic (no fuel) design option is the ability to eliminate the need for high-pressure gas transmission, which significantly increases the options for siting. Thermal storage media needs comparative study to determine cost efficiencies and durability in New York conditions.

The above R&D suggestions and others are summarized below, in recommended priority order:

- Work with New York utilities to identify potential CAES sites within their regions and verify underground geologic conditions applicable to CAES (e.g., perform core sample chemical analyses, and porosity, permeability and storage pressure and capacity investigations)

- Using a new or used CT from a New York host utility, build and test a CAES-CT demonstration plant. Depending on the amount of air flow directed from the CT exhaust, the CAES-CT plant could produce 5 MW's to 100 MW's of plant output
- Perform thermodynamic trade-off studies to choose a preferred CAES-CT plant design and determine the plant parameters appropriate to New York geologic site conditions and New York off-peak/on-peak renewable energy economic conditions
- Perform air storage cyclic field tests at one or more New York CAES sites and test CAES-CT combustor performance, using different air residence times in the storage reservoir, which will determine if chemical reactions in the air store could impact the plant's performance
- Design and build a prototype above-ground air store system, and perform field tests to determine corrosion or cyclic fatigue issues
- Develop a preferred no-fuel CAES plant design (i.e., the adiabatic CAES plant design option) and perform lab/field tests to determine the preferred thermal store materials that are best suited for New York conditions
- Analyze CAES plant design options based on using alternative fuels (e.g., biofuels, and hydrogen)
- Analyze adding a synchronous condenser feature to appropriate CAES-CT plant design options, since +/- VAR injection is needed in New York as more wind or other renewable generation plants are put into service (e.g., "excite" the compressor motor, the CT generator, and the expander generator to enable them to be used as synchronous condensers)

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Appendix A

Appendix A

INVESTIGATION OF POTENTIAL UNDERGROUND COMPRESSED AIR STORAGE LOCATIONS IN THE STATE OF NEW YORK

EPRI Report (From WO 066797)
Based on
PB-ESS/RESPC Topical Report RSI-2012

prepared for

EPRI NYSEG CAES Project Funded Via NYSERDA
EPRI Project Manager: Dr. Robert B. Schainker
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December 2008

INVESTIGATION OF POTENTIAL UNDERGROUND COMPRESSED AIR STORAGE LOCATIONS IN THE STATE OF NEW YORK

EPRI Report Based on
PB-ESS/RESPC Topical Report RSI-2012

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December 2008

EXECUTIVE SUMMARY

EPRI contracted PB Energy Storage Services, Inc. (PB ESS), who worked with RESPEC to prepare this report regarding potential locations for underground compressed air energy storage (CAES) throughout the state of New York. The objective of this study was to identify potential subsurface sites in the state of New York where compressed air can be injected, stored, and withdrawn for electrical power-generating purposes. The types of storage locations that were considered are solution-mined salt caverns and room-and-pillar salt mines; reservoir storage fields; and existing underground non-salt mines, including those for limestone/dolostone, talc, gypsum, and other types of hard rock. Each of these general categories of candidate sites, as well as existing and historical facilities falling under each category, is described in this report using currently available public information.

In general, existing salt caverns generated from solution mining or those caverns currently used for LPG or natural gas storage will require, as expected, modification for CAES use. Depending upon the size of the CAES plant, current casing strings will need to be analyzed for their flow characteristics and if necessary replaced to match the host utility CAES plant power and flow requirements. This is not unexpected since the original casing strings were designed for natural gas or propane or other uses and have diameters appropriate to the flow characteristics needed by the owner at the time of construction. In addition, these existing salt caverns have brine or other fluids in them, which will need to be addressed for CAES use. This too is not unexpected. The costs for change over of these existing salt caverns to CAES may or may not be less expensive than solution mining a new salt cavern for CAES, since the best choice has to be evaluated on a case-by-case basis since the cost and time period for the solution mining operation will depend upon the MW power rating and duration of storage time for the CAES plant under consideration.

Abandoned mines that are sufficiently deep (1,500–3,000 feet) may serve the needs for CAES vessels. Two potentially suitable salt mines, the Cargill Deicing Technology Cayuga Mine and the Morton Salt Himrod Mine, exist in central New York. The Gouverneur Talc Mine and two zinc mines operated by St. Lawrence Zinc also appear to have sufficient depth to be considered. These mines are located in the extreme northern part of the state. Shaft sealing is an issue that needs to be addressed properly to use these existing mines for the CAES application.

With few possible exceptions, the siliciclastic and carbonate reservoirs in New York State may be thin and/or may be insufficiently permeable to serve as viable CAES vessels. Where regions with good reservoir properties in New York State exist, many are presently in use for natural gas storage. Thus, these regions are attractive for CAES, but their use competes economically with natural gas storage.

Two possible good regions are the Queenston Formation and the Trenton-Black River graben reservoirs located in central New York. The Queenston Formation is a thick, but relatively low, permeability sandstone reservoir. Where geologic structure has potentially provided enhanced secondary porosity, the Queenston may offer some potential for further consideration for CAES. The Trenton-Black River graben reservoirs are currently a high priority for natural gas production and/or for the CAES application. These reservoirs are relatively recent finds. These reservoirs, once depleted, are going to be prime candidates for natural gas storage or for the CAES application. CAES will have to compete economically against natural gas storage at these locations, on a case by case basis.

Based upon the findings of this study, the type of facility most conducive to use for CAES varies according to geographic position within the state. The conclusions are as follows:

1. If operation of a CAES facility in the western part of New York is desired, development of specially designed caverns at the Morton Salt solution-mining facility at Silver Springs appears to be a viable option.

2. If operation of a CAES facility in the south-central part of the New York is desired on a relatively short time frame, then the Cargill Deicing Technology Cayuga Mine and the Morton Salt Himrod Mine should be considered prime candidates. Development of specially designed caverns at the Cargill Watkins Glen or U.S. Salt Watkins Glen facilities also appears to be viable. The time frame for the development of these sites depends on the MW capacity and the hours of storage of the CAES plant under consideration.

3. Given the potential opportunity to look at use of inactive mine levels at the Cayuga Mine, the potential for geologic structure locally in the Queenston Formation that could enhance its reservoir properties, and the proximity to the AES Cayuga power-generating station, the Fir Tree Point Anticline in Lansing, Tompkins County, is an area worth further consideration as a means to address immediate need for a CAES in central New York and to further explore the viability of a thick, regional sandstone reservoir for the CAES application.

4. If CAES is desired in the northern part of New York beyond the limits of salt deposits, then the Gouveneur Talc Mine, which was planned for closure at the end of 2008, should be approached. In addition, the St. Lawrence Zinc Number 2-4 Mine and the Edwards Zinc Mine also appear to be sufficiently deep for CAES consideration.

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1.0 INTRODUCTION

EPRI contracted PB Energy Storage Services, Inc. (PB ESS), who worked with RESPEC to prepare this report regarding potential locations for underground compressed air energy storage (CAES) throughout the state of New York. The objective of this study is to identify potential subsurface sites in the state of New York where compressed air can be injected, stored, and withdrawn for electrical power-generating purposes. The types of storage locations that have been considered are solution-mined salt caverns and room-and-pillar salt mines; reservoir storage fields; and existing underground non-salt mines, including those for limestone/dolostone, talc, gypsum, and other types of hard rock. Active and historical facilities are depicted on a statewide map illustrated in Figure A-1. Each of these general categories of candidate sites, as well as existing and historical facilities falling under each category, is described in more detail in this report. Where publicly available information exists, an estimate of the underground volume for air storage is provided along with each potential site.

2.0 SALT MINES AND CAVERNS

New York State possesses significant salt resources. The salt deposits are assigned to the Silurian-age Salina Group. A stratigraphic column for the New York portion of the Appalachian Basin showing the position of the Salina Group and other candidate reservoir formations for this study is provided in Figure 2-1.

The Salina Group exhibits considerable lateral variation in thickness and contains salt only in western and central parts of New York State. The Salina Group salts are also vertically interstratified with other rock types—mainly dolostone, anhydrite, and shale. Dolostone and shale comprise regionally thick and extensive members that separate three main evaporite units (i.e., salt and anhydrite) with the Appalachian Basin. Following Landes [1945] and Rickard [1969], the internal stratigraphic units for the Salina Group have been assigned letter designations with the A Unit at the base and the G Unit at the top (Figure 2-2). Unit B is best developed in western New York (Figure 2-3). Unit D is relatively thin but is laterally extensive. Unit F is best developed in southern and central New York. The thickness and lateral variability are further described below. In addition, historical and existing facilities exploiting each of the salt-bearing intervals are identified.

2.1 B-SALT

The B-Salts are situated within a “v-shaped” trough whose axis trends southwestward from Livingston County, New York, to Venango County, Pennsylvania (Figure 2-4). The trough extends northwestward from Venango County into northeastern Ohio. Near its northern limits in Livingston County, New York, the top of the B-Salt sequence resides at a subsurface elevation of about 110 feet above mean sea level (msl) (drilling depth of about 700 feet). Near its southern limits in Pennsylvania, the B-Salts decline in elevation to –5,400 feet msl (drilling depth of about 6,900 feet).

According to Rickard [1969], the B-Salts are thickest in New York along the axis of the depositional trough that extends southwesterly from Livingston County into northwestern Allegany County and eastern Cattaraugus County (see Figure 2-4). There, net B-Salt thickness is 50–100 feet. In the vicinity of the now-flooded Retsof Mine in Livingston County (where the B-Salt stratigraphy is well studied), the aggregate salt thickness is 75 feet.

There are six major beds that comprise the B-Salt sequence. The thickest bed (Retsof Bed) occurs at the top of the sequence and attains a thickness of 15 to 20 feet [Rickard, 1969; Jacoby, 1969]. Non-salt interbeds within the Salina B-Salt sequence range in thickness from less than 10 feet to about 35 feet. The thickest non-salt interbed separates the Retsof Bed from the remainder of the underlying B-Salt sequence.

Figure 2-1. Stratigraphic Column for the New York State Portion of the Appalachian Basin.

COMPOSITE PALEOZOIC STRATIGRAPHY FOR SOUTHWESTERN NEW YORK STATE

Period		Group	Unit	(rock type)*	Thickness	Reservoir Discussed In Text
Penn.		Pottsville	Olean	(ss, cgl)	25-30 m	
Miss.		Pocono	Knapp	(ss, cgl)	15-30 m	
Devonian	Upper	Conewango		(sh, ss, cgl)	215 m	
		Conneaut	Chadakoin	(sh, ss)	215 m	
		Canadaway	Undifferentiated	(sh, ss)	335-425 m	
			Perrysburg	(sh, ss)		
			Dunkirk	(sh)		
		West Falls	Java	(sh, ss)	115-380 m	
			Nunda	(sh, ss)		
			Rhinestreet	(sh)		
		Sonyea	Middlesex	(sh)	0-120 m	
		Genesee		(sh)	0-135 m	
	Middle		Tully	(ls)	0-15 m	
		Hamilton	Moscow	(sh)	60-185 m	
			Ludlowville	(sh)		
			Skaneateles	(sh)		
			Marcellus	(sh)		
			Onondaga	(ls)	10-70 m	•
	Lower	Tristates	Oriskany	(ss)	0-20 m	•
		Helderberg	Manlius	(ls, dol)	0-3 m	•
			Rondout	(ls, dol)		
Silurian	Upper		Akron	(dol)	0-5 m	
		Salina	Camillus	(sh, gypsum)	135-465 m	
			Syracuse	(dol, sh, salt)		
			Vernon	(sh, salt)		
		Lockport	Lockport	(dol)	45-75 m	•
		Clinton	Rochester	(sh)	40 m	
			Irondequoit	(ls)		
	Lower		Sodus	(sh)	25 m	
			Reynales	(ls)		
			Thorold	(ss)	1-2.5 m	
		Medina	Grimsby	(sh, ss)	25-45 m	•
			Whirlpool	(ss)	0-10 m	
Ordovician	Upper		Queenston	(ss, slt, sh)	335-455 m	•
			Oswego	(ss)		
			Lorraine	(ss, sh)	275-305 m	
			Utica	(sh)		
	Middle	Trenton-Black River	Trenton Group	(ls, dol, sh)	130-190 m	•
			Black River Group	(ls, dol)	70-170 m	
	Lower	Beekmantown	Tribes Hill	(ls)	0-170 m	
Cambrian	Upper		Little Falls	(dol)	0-105 m	
			Theresa/Galway	(dol)	175-410 m	
			Potsdam	(ss, dol)	0-450 m	•
Proterozoic			Gneiss, Marble, Quartzite			

* cgl = conglomerate ss = sandstone; slt = siltstone; sh = shale; ls = limestone; dol = dolomite

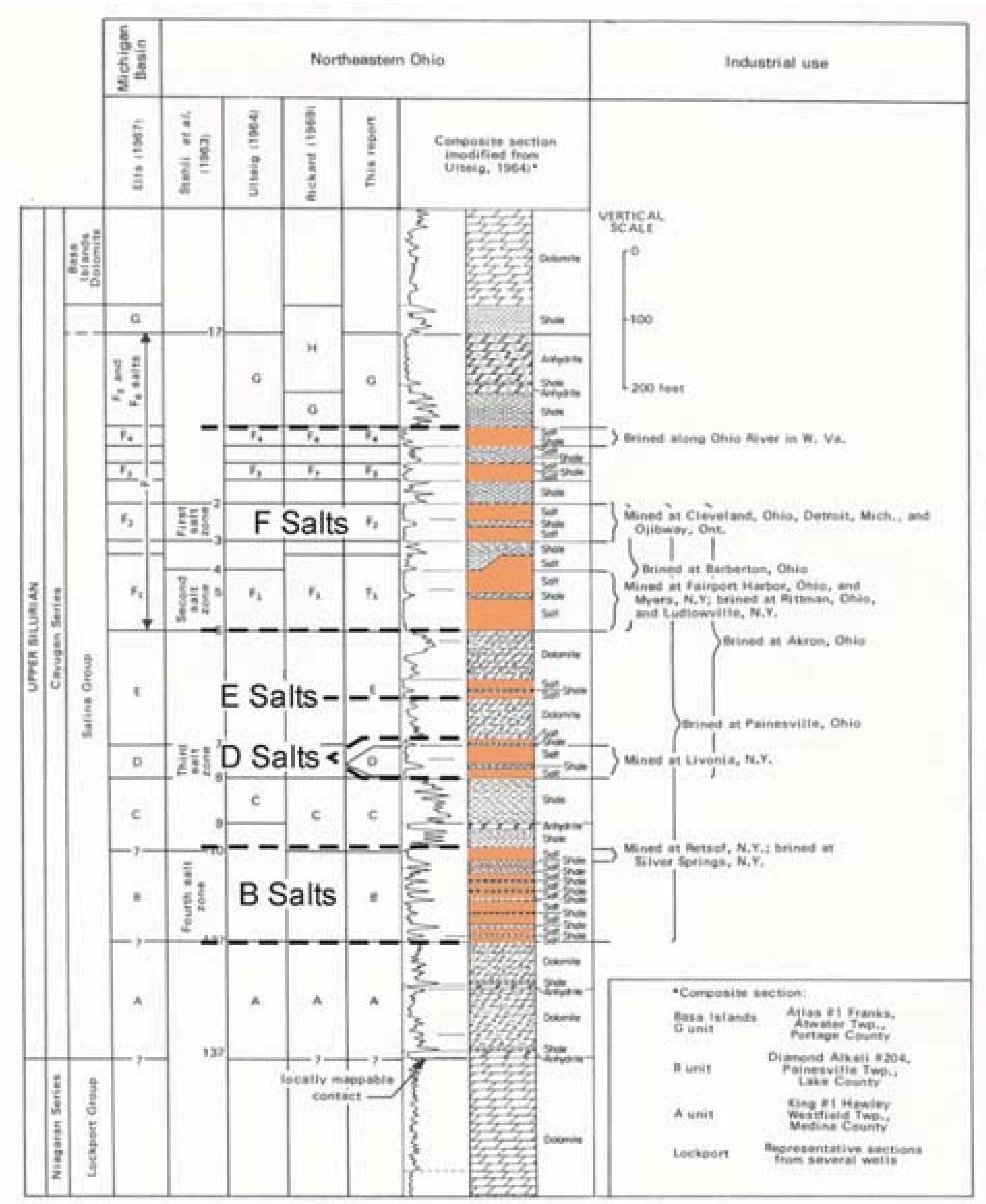


Figure 2-2. Stratigraphy of the Silurian Salina Group.

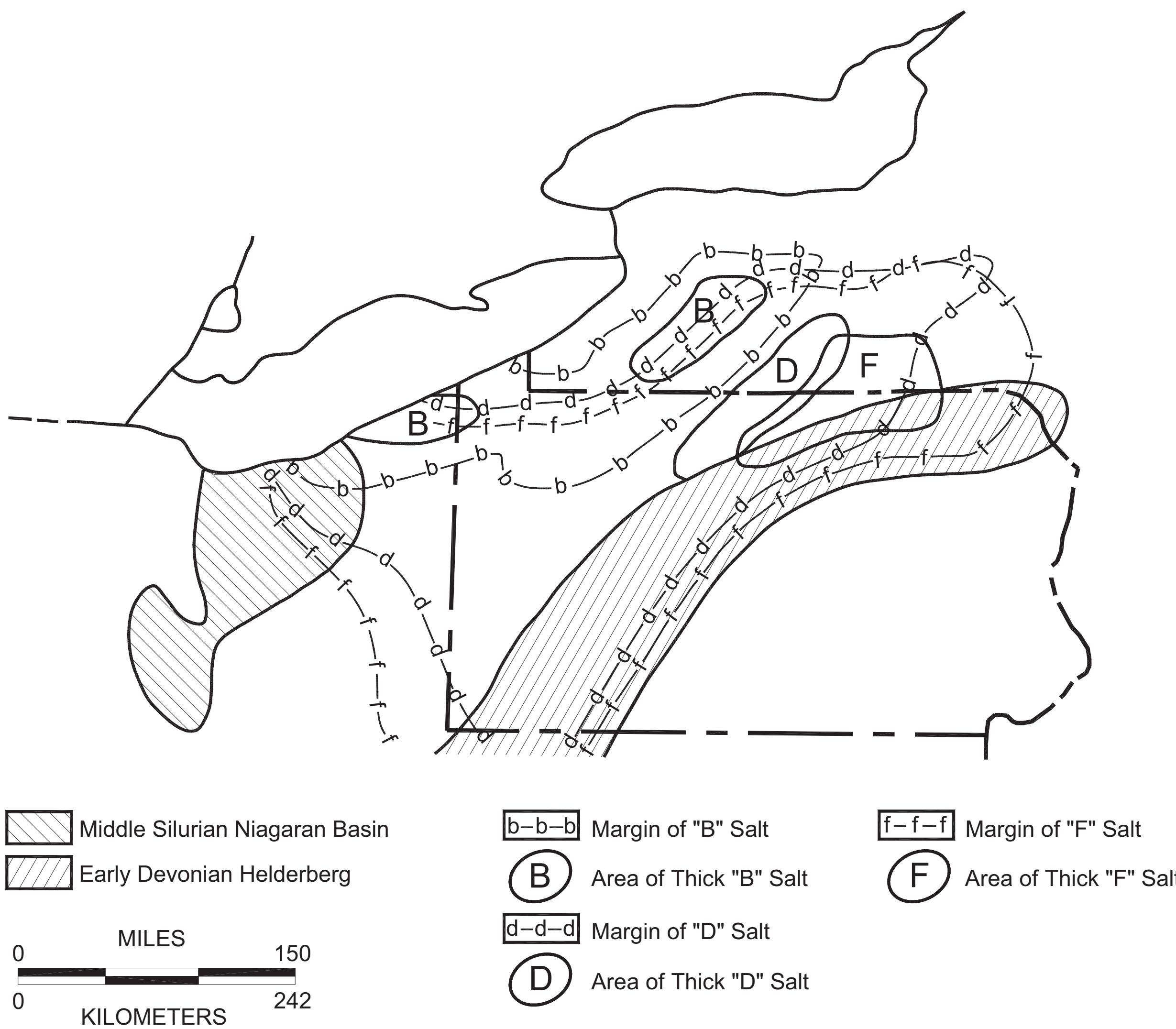


Figure 2-3. Lateral Trends in Salina Group Salt-Bearing Units (Mod.From Mesolella,1978).

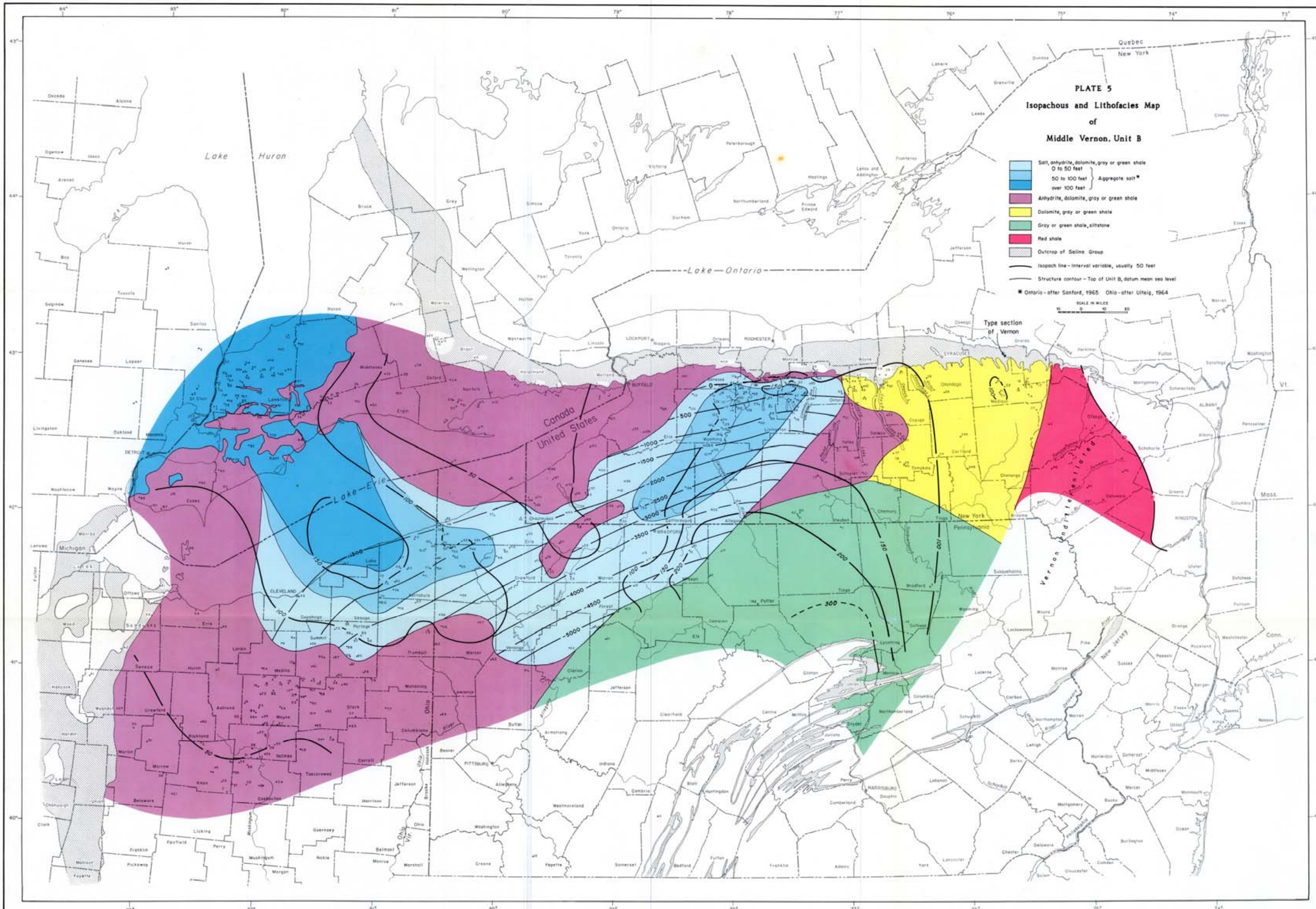


Figure 2-4. Unit B Facies and Thickness Trends (From Rickard [1969]).

2.1.1 Existing Facilities

There are presently three solution-mining operations that target the B-Salt in Wyoming County. In addition to the three current operations, as many as 13 other solution-mining facilities targeting the B-Salt operated historically in Wyoming, Genesee, and Livingston Counties.

There is presently one room-and-pillar salt mine operating in the B-Salt. Historically, as many as five room-and-pillar mines have operated in the B-Salt in Genesee and Livingston Counties. The locations of the active and historic solution mines and room-and-pillar mines are depicted on Figure A-1.

2.1.1.1 Solution Mines

The three solution mines that are currently active in the B-Salt are Morton Salt's Silver Springs field; Texas Brine's operations at the Wyoming field and the Dale field, in the town of Warsaw, that is currently operated by PB ESS under contract to Occidental Chemical (see Figure A-1). The New York State Department of Environmental Conservation (NYSDEC) [2006] report states that a total of 20.9 billion gallons of brine were produced by the five solution salt-mining facilities operational at that time. The three Wyoming County facilities would likely account for at least one-half of the cited production.

Based upon information contained on the Web site of the NYSDEC, the Silver Springs field currently has 12 operating wells of depths ranging from approximately 2,278 feet below ground surface (bgs) to 2,422 feet bgs. In 1998, there were 17 wells operating with 24 wells plugged at that time [New State Department of Environmental Conservation, 1998]. The Silver Springs plant, started in 1885, is the oldest of the three B-Salt solution-mining operations.

The PB ESS Dale field was started in 1970 and initially operated by Texas Brine. By 1998, there were 48 wells operating with 79 wells plugged [New York State Department of Environmental Conservation, 1998]. The current NYSDEC database contains information on 103 wells but there may be as many as 127 wells in the field. Well depths provided in the NYSDEC database range from 1,297 feet bgs to 1,600 feet bgs for 122 wells with one well drilled to 2,059 feet bgs.

The Wyoming field was started in 1984 and is operated by Texas Brine. In 1998, there were 45 operating wells with 11 reported to be plugged at that time [New York State Department of Environmental Conservation, 1998]. The current NYSDEC database contains information on 101 wells, but the facility may contain as many as 160–170 wells. Well depths provided in the NYSDEC database range from approximately 1,320 feet bgs to 1,950 feet bgs. A deep well, probably a test well for brine injection, was drilled to a depth of approximately 4,980 feet bgs at the Wyoming field.

In addition to the three currently active solution-mining operations, at least 13 other historic solution-mining facilities existed in Wyoming County with nine mines operating within the limits of the town of Warsaw [Werner, 1917; Judkins, 2003]. Combined annual production from all operating plants in any given year during the boom is loosely estimated at 50,000 to 100,000 tons. The historical operations are summarized in Table 2-1 and their locations are depicted on Figure A-1.

Short-lived solution-mining facilities targeting the B-Salt also operated in Genesee and Livingston Counties. In Genesse County, there were solution-mining operations at Leroy and Pavillion. In Livingston County, there were short-lived solution-mining operations, some of which exploited naturally artesian brine wells, at Piffard, Mount Morris, Lakeville, York, and Cuylerville. The historical operations in these counties are summarized in Table 2-2, and their locations are depicted on Figure A-1.

2.1.1.2 Room-and-Pillar Mines

Five room-and-pillar mines have operated in the B-Salt in Genesee and Livingston Counties. These room-and-pillar mines are the Lehigh, Greigsville, Sterling, Retsof, and American Rock Salt Mines. The Lehigh Mine ceased operation long ago and is likely to be at least partially brine filled. The Greigsville and Sterling Mines were acquired by the Retsof Mine and connected to that operation as it expanded. The Retsof Mine experienced a roof fall and water leak in 1994 and is now fully flooded. The American Rock Salt Mine, started in 1998, is currently the only active room-and-pillar salt mine operating in the B-Salt. The locations of the B-Salt mines are shown in Figure A-1.

The Retsof Mine was the first room-and-pillar salt mine to be operated in New York. It operated upon completion of its original 12×16-foot-diameter, 995-feet-deep shaft in 1895 until September 1995. A second shaft, the Fuller Shaft, was started ½ mile south of the original shaft in July 1921 [Kreidler, 1957].

In March 1994, a large section of roof rock in the southern portion of the mine collapsed, resulting in a water leak that ultimately flooded the mine. The collapse and flooding were attributed to anomalous deep subsurface hydrological conditions that provided for the naturally occurring artesian brine wells historically operated in the area.

At the time of the collapse, the Retsof Mine covered an area of approximately 6,000 acres, or 10 square miles. As the waterline advanced from the south, mining operations continued at the northern portion of the mine until its closure. The entire mine was flooded by December 1995.

Table 2-1. Historical Solution-Mining Operations in Wyoming County, New York (Page 1 of 3)

<table>
<tr><th>Location</th><th>Facility</th><th>Start Date</th><th>End Date</th><th>Owner</th><th>Aliases</th><th>No. of Wells</th><th>Depth (ft)</th><th>Salt (ft)</th><th>Capacity (bbl/d)[a]</th></tr>
<tr><td colspan="10">Wyoming County</td></tr>
<tr><td rowspan="3">1 Mile South Wyoming Village</td><td rowspan="3">Wyoming Valley Salt Company</td><td rowspan="3">1881</td><td rowspan="3">1883</td><td>Vacuum Oil Company (1878)</td><td>Pioneer Works</td><td>1</td><td>1,530</td><td>1,270–1,340</td><td></td></tr>
<tr><td>Standard Oil Company (1879)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Wyoming Valley Salt Co. (1879)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Wyoming Village</td><td>Globe Salt Company</td><td>1889</td><td><1888</td><td>Globe Salt Company (1883)</td><td></td><td>1</td><td>1,321</td><td>1,240–1,321</td><td>80</td></tr>
<tr><td rowspan="4">Town of Warsaw (North Side)</td><td rowspan="4">Warsaw Mining Company</td><td rowspan="4">1883</td><td rowspan="4">1906</td><td>Warsaw Mining Company (1881)</td><td>Warsaw Salt Mining Co.</td><td>6</td><td>1,658</td><td>1,572–1,658</td><td>800</td></tr>
<tr><td>John D. Wing (1883)</td><td>Warsaw Salt Mining Co.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>National Salt (1899)</td><td>Warsaw Dairy Salt Co.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>International Salt (1904)</td><td>Sixth Parcel</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">Saltvale</td><td rowspan="5">Crystal Salt Company</td><td rowspan="5">1883</td><td rowspan="5">>1917</td><td>Crystal Salt Company (1882)</td><td>Eureka Salt Co.</td><td>2</td><td>1,436</td><td>1,375–1,436</td><td></td></tr>
<tr><td>Imperial Crystal Salt Co. (1909)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Star and Crescent Salt Co. 1909)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Mr. Bumm (1910)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>International Salt (>1919)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Town of Warsaw (North Side)</td><td>Miller Salt Company</td><td>1885</td><td>>1886</td><td>Miller Salt Company (1885)</td><td></td><td>2</td><td>1,609</td><td>1,524–1,609</td><td>350</td></tr>
</table>

Table 2-1. Historical Solution-Mining Operations in Wyoming County, New York (Page 2 of 3)

Location	Facility	Start Date	End Date	Owner	Aliases	No. of Wells	Depth (ft)	Salt (ft)	Capacity (bbl/d) [a]
Town of Warsaw (East Side)	Gouinlock	1883	>1904	W. C. Guinlock (1883)		2	1,701	1,633	325
				National Salt (1899)	Eastern Block				
				International Salt (1904)	Fifth Parcel				
Town of Warsaw (West Side)	Guinlock & Humphrey	1883	<1917	Guinlock & Humphrey (1883)		2	1,879	1,837–1,879	325
				W. C. Guinlock (<1899)					
				National Salt (1899)	Western Block				
				International Salt (1904)	Fourth Parcel				
Town of Warsaw (South Side)	Empire Salt Company	1884	>1886	Empire Dairy Salt Company (1884)		4	1,960	1,890–1,960	1,100
				National Salt (1899)					
				International Salt (1904)	Second Parcel				
Town of Warsaw (Southwest Side)	Hawley Salt Company	1884	<1917	Hawley Salt Company (1884)		3	1,928		300
				National Salt (1899)					
				International Salt (1904)	Third Parcel				
Town of Covington (Near Pearl Creek)	Pearl Salt Company	1885–1886	<1899	Pearl Salt Company (1884)		2	1,194	1,157–1,194	300
				National Salt (1899)					
				International Salt (1904)	Seventh Parcel				
Village of Castile	Castile Salt Company	1884	<1899	Castile Salt Company (1884)		2	2,525	2,340–2,525	150
Village of Perry (Silver Lake Outlet)	Perry Salt Company	1887	1905	Perry Salt Company (1887)	Silver Lake Salt Co.	2+			
				National Salt (1899)					
				Iroquois Salt Co. (1902)					

Table 2-1. Historical Solution-Mining Operations in Wyoming County, New York (Page 3 of 3)

Location	Facility	Start Date	End Date	Owner	Aliases	No. of Wells	Depth (ft)	Salt (ft)	Capacity (bbl/d) [a]
Town of Warsaw (South Side)	Eldridge-Bradley Plant	1885	1904+	Eldridge Salt Company (1885)		5	2,039	1,975–2,039	600+
				Bradley Salt Company (1889)					
				National Salt (1889)	Yorkshire Plant				
				International Salt (1904)	Thirteenth Parcel				
Rock Glen Village	Rock Glen Salt Company	1886	>1919	A. Kerr, Bro. & Assoc. (1885)	Kerr Salt Co.	7	2,000		
				National Salt (1889)					
				American Electrolytic Co. (<1904)					
				Rock Glen Salt Co. (1906)					
				International Salt (<1919)					
Silver Springs	Morton Salt Company	1885	2008	Silver Springs Salt Co. (1883)	Silver Springs Factory	13+	2,300	2,200–2,300	
				Duncan Salt Co. (1885)					
				Worchester Salt Co. (1894)					
				Morton Salt Co. (<1957)					

(a) bbl/d = barrels per day.

Table 2-2. Historical Solution-Mining Operations in Genesee and Livingston Counties (Page 1 of 2)

Location	Facility	Start Date	End Date	Owner	Aliases	No. of Wells	Depth (ft)	Salt (ft)	Capacity (bbl/d) [a]
Genesee County									
Le Roy Village	American Chemical Company	1883	1884	American Chemical Co. (1883)	Lent Farm	1	615	590–615	100
3 Miles South of Le Roy	Le Roy Salt Company	1884	>1917	Le Roy Salt Company	Gilmore Farm	>8	878	838–878	600
				National Salt (1899)					
				Empire Salt Company (1901)					
				Le Roy Salt Company (1905)					
Pavillion Village	Pavillion Salt Company	1892	1899	Pavillion Salt Company (1891)		2	1,119	999–1,119	
				National Salt (1899)					
Livingston County									
Piffard	Livingston Salt Company	1884	1903	Livingston Salt Company (1883)		2	961	899–961	500
				Genesee Salt Company (<1903)					
				Alex Kerr, Bro. & Co. (1903)					
2 Miles North of Mount Morris	Lackawanna Salt Company	1885	<<1917	Lackawana Salt Company		2	1,350	1,258–1,350	
Piffard	Genesee Salt Company	1885	>1917	Genesee Salt Co. (1885)		5	708	Brine flow	1,200
				Alex Kerr, Bro. & Co.					
Mount Morris	Royal Salt Company	1885	<1917	Royal Salt Company (1885)		3	1,422	1,349–1,422	

Table 2-2. Historical Solution-Mining Operations in Genesee and Livingston Counties (Page 2 of 2)

Location	Facility	Start Date	End Date	Owner	Aliases	No. of Wells	Depth (ft)	Salt (ft)	Capacity (bbl/d)
Lakeville	Conesus Lake Salt & Mining Co.	1885	1885	Consesus Lake Salt & Mining Company (1885)		1	1,053	1,033–1,053	
York	York Salt Company	1884	<1917	York Salt Company (1884)		2	828	750–828	
Cuylerville	Leicester Salt & Mining Co.	1887	<1917	Leicester Salt & Mining Co. (1885)		2+	1,145	1,117–1,145	
				Phoenix Salt Co. (1892)					

(a) bbl/d = barrels per day.

In 1998, the American Rock Salt Mine was started at Hampton Corners, Livingston County (see Figure A-1). The initial production shaft was sunk to a depth of 1,433 feet bgs to access the B-Salt at this location. The NYSDEC reports a mine life of 9,000 acres with 672 acres currently permitted for operation. The American Rock Salt company Web site reports daily production rates of 10,000 to 18,000 tons.

The Lehigh Mine was the second mine in the state to be developed in the B-Salt. The mine's two 12×24-foot shafts were started in 1890 and completed in 1892. The shafts are 800 feet deep. The mine operated with a staff of 250 until the fall of 1894 when it was sold to Retsof. The mine facilities were decommissioned in 1905.

The Greigsville Mine was started in 1890 on a parcel ¾ mile north of Greigsville Station and only ½ mile west from the Retsof shaft. A single shaft, 22×11 feet in plan, was installed. The depth of the "Gray" shaft [Gowan et al., 1999] was not reported by Werner [1917], but the proximity of the Greigsville shaft to the Retsof shaft suggests a depth roughly between 1,400 and 1,500 feet. The Greigsville Mine operated for several years before it was purchased by Retsof and shuttered. The Greigsville Mine was eventually connected to the expanding Retsof Mine.

The shaft of the Sterling Salt Mine at Cuylerville was started in 1905 and completed in 1907. The "Barbara or B" shaft [Gowan et al., 1999] is 20 feet square and 1,100 feet deep [Werner, 1917]. The Sterling Mine was still independent of Retsof and still operating at the time that Werner published his history in 1917. Retsof acquired the rights to the Sterling Mine in 1930 [Kreidler, 1957] that may have already been closed because of market economics before that time. The Sterling Mine also was connected to the Retsof Mine in 1956 for ventilation and emergence egress purposes [Gowan et al., 1999].

2.1.2 LPG and Gas Storage Facilities

No liquefied petroleum gas (LPG) or natural gas storage facilities are known to exist in the B-Salt at this time. It should be noted, however, that Amoco Oil Company permitted and drilled two salt wells for storage at Gainesville, Wyoming County, in 1998. NYSDEC records indicate that these wells were to be leached to a capacity of 500 million barrels each with the brine going to the Morton Salt facility. The project was identified in New York State Department of Environmental Conservation [1998] as being delayed by economics and other factors. More recent NYSDEC records suggest that the wells were never leached into caverns and operated.

2.2 D-SALT

The D-Salts comprise the middle of the three main salt deposits in the Salina Group. Near their northern limits in Ontario County, New York, the top of the D-Salts resides at a subsurface elevation of about –400 feet msl (with a drilling depth of 1,500 feet).

Two to three salt beds comprise the D-Salt sequence. Although they are relatively thin, the D-Salts are pure and laterally persistent. In New York, discrete D-Salt bed thicknesses generally do not exceed 35 feet.

According to Rickard [1969], the D-Salts are thickest in a southwesterly trending region that extends from Schuyler County, New York, to Cameron County, Pennsylvania (Figure 2-5). Within this 160-kilometer-long by 45-kilometer-wide region, Rickard [1969] reports D-Salt aggregate thicknesses in excess of 80 feet. Surrounding the D-Salt depocenter is a broad region where aggregate D-Salt thicknesses reportedly range between 40 and 80 feet.

2.2.1 Existing Facilities

There are presently two solution-mining operations that exclusively target the D-Salt. However, existing solution-mining operations in Schuyler County that target shallower F-Salt may include some deeper wells that reach the D-Salt level.

There is one active room-and-pillar salt mine operating in the D-Salt. There is also one inactive room-and-pillar mine in the D-Salt that is likely to be at least partially brine filled. The locations of the active and historic solution mines and room-and-pillar mines are depicted on Figure A-1.

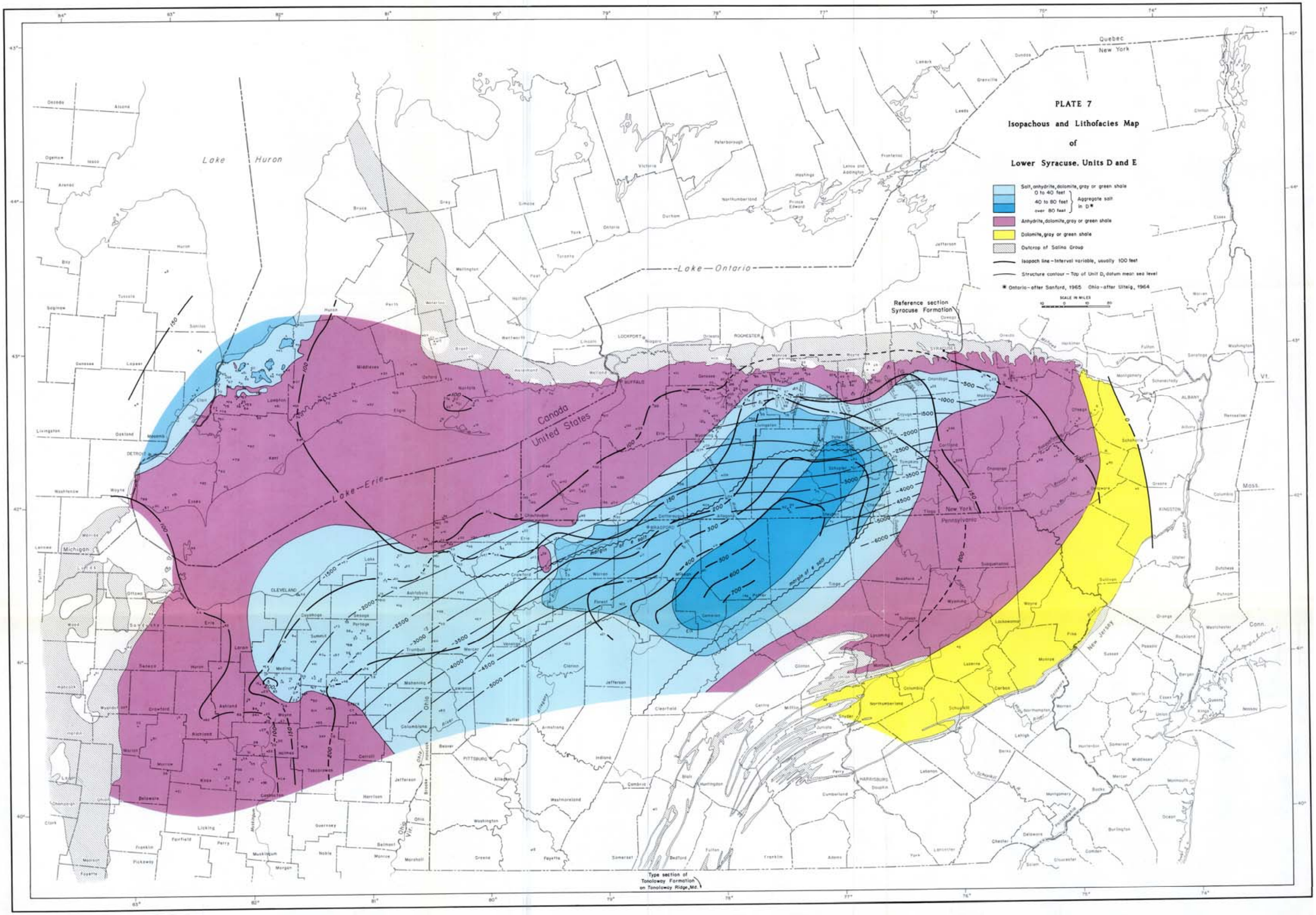
2.2.1.1 Solution Mines

There are no solution mines known to operate exclusively within the D-Salt at the present time. The two solution-mining operations in Watkins Glen that target the Salina F-Salt have some wells that are relatively deep and may tap the D-Salt. These operations are discussed further in Section 2.3.

2.2.1.2 Room-and-Pillar Mines

Two room-and-pillar mines have targeted the D-Salt in New York. They are the abandoned Livonia Mine in Livonia, Livingston County, and the active Cargill Deicing Technology Cayuga Mine in Lansing, Tompkins County. The locations of these mines are depicted on Figure A-1.

The Livonia Mine shaft was started during September 1890 at a location about ½ mile north of Livonia Station. The shaft was 14×24 feet and was completed to a depth of 1,432 feet



Unit D Facies and Thickness Trends (From Rickard [1969]).

in August 1892. Werner [1917] noted that the salts exposed in the Livonia Mine were white to pink, compared to the gray color of the salt in the nearby Retsof Mine. The mine operated for about 7 years before being purchased and shut down by the Retsof Mine. The surface facilities were fully decommissioned by 1908.

The Cayuga Mine is the deeper and larger of the two room-and-pillar salt mines presently operating in New York. The Cayuga Mine has been in operation since the 1920s but has only been extracting salt from the D-Salts since 1970. There are three shafts at the Cayuga Mine. The first shaft was started in 1917 by the Rock Salt Corporation which organized around 1915. Historical operations were in the stratigraphically higher F-Salts, so the early development of the mine is discussed in Section 3.2.

In 1970, the mine was acquired by Cargill Salt who has since operated it continuously at the 2,300-feet-deep, #6 salt level. The #6 salt bed is situated in the middle bed of the Salina D Unit. D-Salt extraction started on the east side of the lake between Portland Point and Myers Point (in the same area as the historical F-Salt workings) but now extends up and down the axis of Cayuga Lake from the shafts at estimated subsurface depths of roughly 2,000 to 2,300 feet. Cargill's deepest shaft is 12 feet in diameter with a shaft that extends from the bottom of the 2,300-foot level to the surface. According to Bement [2005], it was the largest single borehole in the world at the time it was constructed. As of 2005, the Cayuga Mine encompassed over 18,000 subterranean acres with a daily production rate of up to 10,000 tons per day. The NYSDEC reports a mine life of 13,147 acres with 9,260 acres currently permitted for operation.

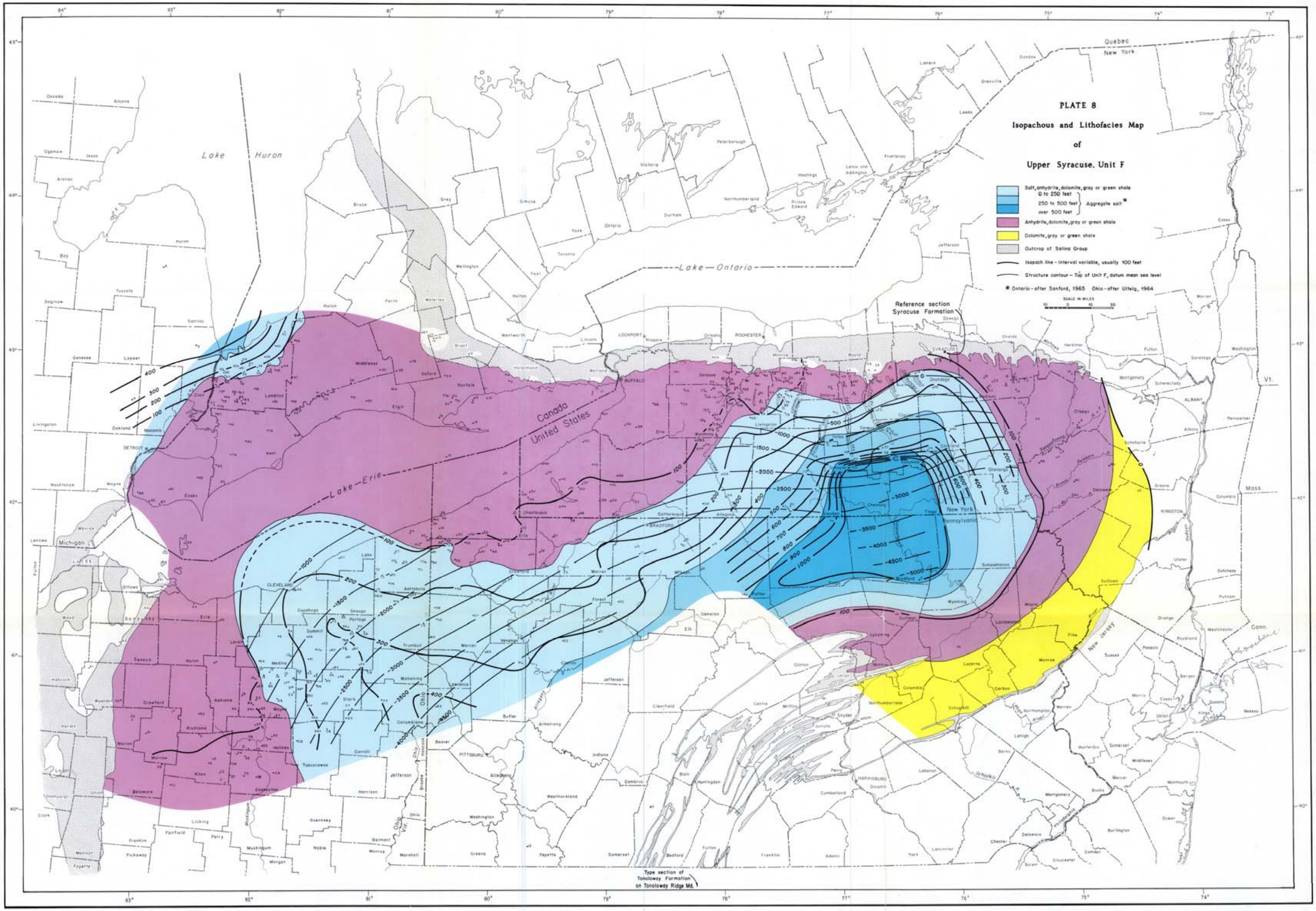
Cargill's room-and-pillar mine operations in New York, Ohio, and Louisiana have recently been reorganized and are now referred to as Cargill Deicing Technologies, Inc. facilities.

2.3 F-SALT

The F-Salt sequence is, by far, the thickest salt-bearing zone of the three in the Salina Group. The F-Salts range in elevation from a high near Syracuse in Onondaga County of 65 feet above msl [Rickard, 1969]. They occur as deep as about –2,600 feet msl in Sullivan County, Pennsylvania. The F-Salt, however, is also the most structurally complex of the Salina Group salt zones. The New York sections of the F-Salt sequence are intensely folded and faulted. Locally, the salt beds are also brecciated.

As shown in Figure 2-6, Rickard [1969] depicts a zone of F-Salt aggregate thickness in excess of 500 feet centered on Chemung and Tioga Counties in New York and Bradford County, Pennsylvania. Because of the substantial thicknesses attained by the F-Salts, the contour interval (250 feet) used by Rickard [1969] is large compared to the contour intervals used for the B-Salts (50 feet) and the D-Salts (40 feet). Although the salt beds commonly split locally into thinner discrete beds and secondary structure complicates the stratigraphic sections in north-central Pennsylvania and central New York, four major salt beds are generally recognized

[Rickard, 1969; Clifford, 1973]. In ascending order, these salt beds are designated F1 through F4.



Unit F Facies and Thickness Trends (From Rickard [1969

2.3.1 Existing Facilities

There are two active solution-mining operations, one inactive level in a deeper room-and-pillar mine, and five LPG/natural gas storage facilities currently known in the F-Salt. In addition, there are several historical solution-mining operations and one other room-and-pillar mine that operated in the Salina F in Schuyler and Tompkins Counties as well as the famous workings in the Syracuse area. The locations of these active and inactive mines and the hydrocarbon storage facilities are depicted on Figure A-1.

2.3.1.1 Solution Mines

Four major solution-mining operations that have targeted the F-Salt are the abandoned International Salt Myers Point facility, the active Cargill and U.S. Salt facilities in Watkins Glen, and the historical Syracuse/Tully Valley area operations. Small, short-lived solution-mining operations existed in Schuyler and Tompkins County as well are shown in Table 2-3.

The International Salt operation at Ludlowville contained at least 22 wells for which the NYSDEC database shows spudding dates of 1896 to 1958. Well depths ranged from approximately 1,500 feet to 2,200 feet bgs at the Ludlowville field. Operation of the Ludlowville field was initiated by the Cayuga Lake Salt Company as "The Cayuga Salt Works" with the first two wells completed in 1891 and 1892. The facility was acquired first by National Salt in 1899 and then by International Salt in 1904. International Salt operated the plant until 1962 [Bement, 2005].

The Cargill Salt operation in Watkins Glen consists of one field with about 27 wells ranging in depth from approximately 1,810 feet bgs to 2,784 feet bgs being represented in the current NYSDEC database. Approximately eight wells at the facility were permitted as "active" as of the end of 2007. The plant has been in operation since October 1899 when it was constructed by the Watkins Salt Company. Cargill is estimated to have assumed ownership of the operation during the early 1980s.

The U.S. Salt operation in Watkins Glen consists of one field with at least 44 wells ranging in depth from 1,874 feet bgs to 2,936 feet bgs. The first well at "The Glen Salt Works" was started in February 1893 by the Glen Salt Company. The plant was operational by 1894 and came into the possession of International Salt in 1904. International Salt and its successor, AKZO Nobel Salt, operated the plant until 1994 when it was acquired by U.S. Salt. NYSDEC records indicate that there are six currently active permitted wells.

Table 2-3. Historical Solution-Mining Operations in Schyler and Tompkins Counties

Location	Facility	Start Date	End Date	Owner	Aliases	No. of Wells	Depth (ft)	Salt (ft)	Capacity (bbl/d)
Schuyler County									
West of Watkins Village	Glen Salt Works	1894	Still Active	Glen Salt Company (1893)		3	1,927	1,841–1,927	1,000
				National Salt (1899)					
				International Salt (1904)					
				AKZO Salt (1968)					
				U.S. Salt (1994)					
East of Watkins Village	Watkins Salt Company	1899	Still Active	Watkins Salt Company (1898)		4	1,800		1,200
				Cargill (1980s)					
Watkins (Eastern Limits)	Union Plant	1899	<<1917	Seneca Lake Salt Co. (1899)		2			
				Union Salt Co. (1902)					
Tompkins County									
Ludlowville Village	Cayuga Salt Works	1891	1962	Cayuga Lake Salt Co. (1891)		22			800
				National Salt (1899)					
				International Salt (1904)					
Ithaca	Ithaca Salt Company	1896	<1917	Ithaca Salt Company (1896)		2	2,490+	2,240+	800
				National Salt (1899)					
				International Salt (1904)					
Ithaca	Remington Salt Company	1902	>1917	Remington Salt Company (1900)		3	2,200	2,100–2,200	

The most famous and historical solution-mining operations in the F-Salt are those in the Syracuse area of Onondaga County. The earliest operations in the area, extending back to colonial times, were from salt springs situated in close proximity to Onondaga Lake. Repeated efforts to find rock salt in that area closest to Syracuse proved futile.

More relevant to considerations for CAES are the wells at Tully, about 17 miles south of Syracuse, where rock salt was confirmed as early as 1888. The Solvay Process Company had installed 41 wells, approximately 1,200 feet deep, in the salt as early as 1896 [Newland, 1919]. As of 1986, more than 120 wells had been drilled on the west and east sides of the Tully Valley. The current NYSDEC database for the Tully fields contains reference to 162 wells. Four wells that were completed during 1971–1985 show LCP Chemicals as the permit holder. These wells appear to be the most recent ones drilled at Tully and range in depth between 1,350 feet bgs and 1,426 feet bgs. The four LCP Chemicals wells were plugged and abandoned during 1995, apparently marking the end of brine production at these historical fields.

The remaining 158 Tully Valley wells listed in the NYSDEC database were completed during 1889 and 1976 and show Allied Signal as the permit holder. These wells appear to include the original Solvay Process wells and range in depth between 911 feet bgs and 2,133 feet bgs. These wells are all plugged and abandoned.

At the end of the 96-year period of brine production from the Tully fields, more than 96.2 million tons of salt were extracted from the four beds comprising the Salina F sequence [Kappel, 2000].

2.3.1.2 Room-and-Pillar Mines

The two room-and-pillar mines that have targeted the F-Salts are the abandoned Morton Salt Mine in the Village of Himrod and the abandoned upper levels of the active Cargill Deicing Technology Cayuga Mine. The Morton Mine began operations in late 1971 to early 1972. Based on information in PB ESS files, the Morton Mine is approximately 2,050 feet deep. At the time of its construction, the mine was believed to have a workable capacity of approximately 2.5 million tons per year. By October 1974, the mine covered an area of approximately ½ square mile. The volume of the mine is believed to be about 13.5 million barrels, based on information in PB ESS files. The Morton Mine closed on May 18, 1976. The NYSDEC currently regulates less than 5 acres and states that 50 acres have been reclaimed.

The Cayuga Mine has been in operation since the 1920s. Whereas the mine currently extracts D-Salt from beneath Cayuga Lake, the operations before 1970 were in the F-Salts beneath the eastern lake shore. The first shaft at Cayuga was started in 1917 by the Rock Salt Corporation, that organized around 1915. The shaft was completed in 1918 but was not yet equipped for production at the time that Newland [1919] provided his description. Bement [2005] reports that by 1918, the shaft had been advanced to the 1,500-foot level (i.e., the #1 Salt or 457-meter level referred to by Prucha [1968]), but the salt at the top of the F Unit was of poor quality.

The mine was acquired by the newly formed Cayuga Rock Salt Company in 1921 [Bement, 2005]. Cayuga Rock Salt advanced the shaft downward to the 2,000-foot level to tap the #4 Salt bed at the base of the Salina F (i.e., the 609-meter level of Prucha [1968]). This level was mined successfully between 1925 and 1968. Mine workings at the #4 level followed complex geologic structure which ultimately rendered mining too difficult to maintain profitability by the end of the 1960s. It was at that point that the facility was acquired by Cargill who began operations in the D-Salts within which there is considerably less complicated structure associated with the relatively tabular salt body [Goodman and Plumeau, 2004].

2.3.1.3 LPG/Gas Storage Facilities

Based upon information gleaned from the NYSDEC Web site, there are four LPG storage facilities and one natural gas storage field which utilize F-Salts. These facilities are the Seneca Lake Storage and New York State Electric and Gas (NYSEG) operations both in Watkins Glen, Schuyler County; the New York LP Gas Storage and TE Products Pipeline in Harford, Cortland County; and Inergy Midstream in Bath, Steuben County. The locations of these facilities are shown in Figure A-1.

The Seneca Lake Storage and NYSEG natural gas storage facilities are located in the Salt Point Storage Field in the town of Reading, Schuyler County. The Seneca Lake Storage operation has one well permitted whose total depth of 2,308 feet was reached in December 1997. The NYSDEC database does not indicate that this well is yet active for storage.

The NYSEG natural gas storage facility contains three wells. Well depths range from approximately 2,040 feet bgs to 2,650 feet bgs. All three NYSEG wells are listed as active by the NYSDEC and their 1998 annual report references a total capacity of the three wells to be 2.340 billion cubic feet (Bcf).

New York LP Gas Storage and Texas Eastern (TE) Products Pipeline facilities are located in the Harford Mills Field in the town of Harford, Cortland County. New York LP Gas Storage appears to have had a single well that was drilled in 1954 and reached a total depth of 3,305 feet. This well was plugged and abandoned in March 2002. No information on cavern size is provided in the NYSDEC database. The TE Products Pipeline facility contains two wells with depths of approximately 3,218 feet bgs and 3,400 feet bgs, respectively. Information in PB ESS files suggests that the combined volume of these two caverns is about 0.5 million barrels. NYSDEC [1998] reported the capacity of the two caverns at Harford Mills to be 25,000 million gallons.

The Inergy facility appears to be the largest in terms of number of wells. The facility, formerly owned by Bath Petroleum, operates from the Savona Field located in the town of Bath, Steuben County. The facility has permits for 12 active wells ranging in depth from approximately 3,100 feet bgs to 3,600 feet bgs. Information in PB ESS files on this facility dates back to 1993 when there were five active wells (plus one inactive well) with a total estimated volume of about 1 million barrels. This facility, first developed in the mid-1950s, underwent significant expansion with six additional wells drilled during 1992–1995. In 1998, the NYSDEC reported the total storage capacity of the facility to be 50.045 million gallons.

3.0 NATURAL GAS RESERVOIRS

Both siliciclastic (sandstone) and carbonate (limestone, dolostone) formations exist in New York that are either known to be, or are potentially, reservoir-grade in terms of their permeability, porosity, and thickness. Several depleted reservoirs in the south-central and western parts of the state have been converted to gas storage facilities. It should be noted, however, that the proven gas reservoirs in New York State tend to be relatively thin and/or relatively low permeability outside of the known fields. These physical limitations have restricted their secondary uses for waste brine injection in support of salt cavern storage. Consequently, the physical limitations of the known gas reservoirs beyond the limits of the currently-used fields in New York State may also restrict their use for CAES.

Each of the siliciclastic and carbonate reservoirs that have been converted is depicted on Figure A-1, and its stratigraphic position is shown in Figure 2-1. The candidate siliciclastic and carbonate reservoirs are described below.

3.1 SILICICLASTIC RESERVOIRS

The siliciclastic reservoirs are presented in ascending stratigraphic order. They include the Cambrian Potsdam Sandstone, the Ordovician Queenston Formation, the Silurian Medina Group, and the Devonian Oriskany Sandstone. Each of these reservoirs is discussed in more detail below.

3.1.1 Potsdam

The Upper Cambrian Potsdam Formation is fine- to coarse-grained quartz arenite to arkosic and dolomitic sandstone and sandy dolostone that underlies western New York in a belt between the Niagara River and Utica. The Potsdam Formation overlies Grenville crystalline rocks and is overlain by the Upper Cambrian Theresa Formation which consists of sandy, fossiliferous, and silty dolostone. Diagenesis of the Theresa Formation has formed some impermeable intervals that may serve as seals for the underlying higher porosity and more permeable Potsdam sandstones [Kolkas and Friedman, 2007]. The Potsdam Formation is laterally equivalent to the Mount Simon Formation in Ohio and Illinois Basins.

There is no significant commercial gas production from the Potsdam Formation in New York, but there are gas shows from about eight wells that were drilled in the late 1890s in the Utica, New York, area. There are fewer than about 30 modern wells through the Potsdam Formation in New York, but those well logs show variable but good porosity [Robinson, 1998].

The Potsdam Formation was identified as a target for brine disposal and gas storage [Kolkas and Friedman, 2007] and possibly for carbon sequestration by the Reservoir Characterization

Group of the New York State Museum. The relatively high salinity of the Potsdam pore waters limits the potential for solubility storage of CO_2, but there is potential for between 0.5 and 30 percent volumetric storage of CO_2 if the in situ fluids could be displaced.

3.1.1.1 Thickness

The Potsdam Formation ranges from zero feet at the post-Knox unconformity near the southern shore of Lake Ontario to nearly 1,500 feet at the Pennsylvania border [Harris and Baronoski, 1996]. The pinchout of the Potsdam in the north where it is overlain by less permeable strata (Theresa Formation and Middle Ordovician units) forms a stratigraphic trap that is the lowest risk Cambrian target for future gas exploration in New York. This target area extends for about 50 kilometers along the southern shore of Lake Ontario and has an estimated 460 Bcf of recoverable gas resources. This target area is shown on Figure A-1.

3.1.1.2 Permeability

Permeability data for the Potsdam Formation in New York are sparse but studies of the Mount Simon Formation in the Illinois Basin show permeability of 100 to 200 millidarcies (mD) at depths of about 2,000 feet to about 10 mD at depths of nearly 4,500 feet [Frailey et al., 2004]. Depths to the Potsdam Formation in New York range from about 2,000 to 5,000 feet, and so by analogy with the Mount Simon Formation, permeability of the Potsdam Formation may be expected to range from about 100 to less than 10 mD.

3.1.1.3 Porosity

Porosity data for the Potsdam Formation and other Cambrian reservoirs in New York are sparse in the published literature (most likely owing to the absence of commercial production). Porosity (based on well log data) for a Potsdam/Theresa producing field in Oxford County of southern Ontario ranges from 3.5 to 22 percent with an average of 9.5 percent [Harris and Baronoski, 1996].

3.1.1.4 Gas Storage Facilities

There are presently no known natural gas storage facilities in the Potsdam Formation.

3.1.2 Queenston

The Upper Ordovician Queenston Formation is a thick sequence of maroon shales, siltstones, and fine-grained sandstones. The Queenston Formation is a natural gas reservoir in central New York where it contains several hundred feet of predominantly white, pink, and red sandstone. Where sandstone is the predominant lithology in central New York, the formation also has the potential to serve as a brine injection target. Farther west, the Queenston contains too much shale to possess the required permeability to serve as a gas reservoir, a brine injection target, or a CAES candidate [Goodman, 2005a; 2005b].

It remains unclear whether or not primary intragranular porosity in the eastern Queenston sandstones is sufficient to yield economical quantities of gas or to serve as a storage reservoir. Some geoscientists believe that secondary (fracture) porosity is required. For example, Ryder [1995] observes that fracturing associated with basement block faulting is a key variable affecting permeability trends. Several of the larger gas fields in New York are crossed by northeast-trending fracture systems. These larger fields are located in Cayuga County and Seneca County. Nonetheless, the formation produces at least small amounts of gas and is capable of accepting brine elsewhere to the south of those counties. It is not clear whether or not the apparent permeability of the Queenston sandstones in other areas is related to primary porosity or secondary porosity.

3.1.2.1 Thickness

The Queenston Formation is likely to be greater than 700 feet thick in the area where it is sandstone-dominated, but the top 100–300 feet are likely to exhibit the reservoir-grade qualities that offer potential for brine injection or CAES. Lateral variation in sandstone/shale ratios indicates that the potential for the Queenston to serve as a CAES target increases from west to east.

3.1.2.2 Porosity

Reported porosity for the Queenston ranges from 2 to 13 percent with averages between about 4 and 11 percent [Saroff, 1988; Ward, 1988].

3.1.2.3 Permeability

The Queenston has relatively low permeability. Reported permeability for the Queenston ranges from <0.1 mD to 5 mD with averages between about 0.016 mD and 0.2 mD [Lugert et al., 2005; Ehgartner et al., 2005].

3.1.2.4 Gas Storage Facilities

There are presently no known natural gas storage facilities in the Queenston Formation.

3.1.3 Medina Group

The Silurian Medina Group is an interval of sandstone, siltstone, and shale that outcrops across western New York on the Lake Ontario Plain and reaches depths between about 3,000 to 4,000 feet along the Pennsylvania border.

Natural gas production from the Medina Group has been long lasting and has taken place over a broad area of western New York and adjacent states. The earliest known drilling for Medina Group gas was conducted by the Buffalo Gas Light Company in 1872. As of 1983, the

Medina Group in New York yielded a total of 440 Bcf of gas from approximately 4,900 wells [McCormac et al., 1996].

The producing units in the Medina Group are the Whirlpool and Grimsby sandstones. The Whirlpool consists of white to light-gray to red, fine to very fine, quartz sandstone. The lower part of the Whirlpool was deposited in braided fluvial systems and the upper part was deposited in a wave-dominated near-shore marine environment. The Grimsby is a white to gray to red, medium to very-fine grained, quartz sandstone deposited in deltaic to shallow marine environments. Because of the complex lateral and vertical interplay of depositional environments for these units, they are characterized by discontinuous and isolated sandstone bodies, resulting in strong reservoir heterogeneity [McCormac et al., 1996].

3.1.3.1 Thickness

The Medina Group ranges in total thickness from less than 100 feet to about 225 feet. The producing sandstones range from 3 to 50 feet thick with an average thickness of 23 feet.

3.1.3.2 Porosity

Porosity in the Medina Group reservoir sandstones in the New York-Pennsylvania-Ohio region ranges from 2 to 23 percent with an average of 7.8 percent. For a producing field in Chatauqua County, New York, porosity is reported to range from 1.5 to 11.2 percent with an average of 6.3 percent. Porosity in the Medina producing zones is mostly secondary, formed by dissolution of feldspars and calcite cement. Porosity is greatest along major surface lineaments which depict deep-seated fractures and/or faults. These structures provided fluid pathways which promoted development of the secondary porosity [McCormac et al., 1996].

3.1.3.3 Permeability

Average permeability for the Medina reservoir sandstones in the New York-Pennsylvania-Ohio region ranges from 0.1 to 40 mD. Most reported values are less than 0.1 mD and rare reservoir samples show permeability as high as 200 mD. The average permeability reported for a producing field in Chatauqua County, New York, is 3.4 mD [McCormac et al., 1996].

3.1.3.4 Gas Storage Facilities

Several natural gas storage facilities have been developed in Medina Group sandstones. The locations of the fields hosting the storage facilities are shown in Figure A-1. These facilities include National Fuel operations in Perrysburg, Cattaraugus County (40 wells, 3,850 Bcf in 1998); Hanover, Chautauqua County (Nashville and Sheridan fields, 97 wells, 12,230 Bcf in 1998); and Bennington, Wyoming County (64 wells, 5,000 Bcf in 1998). Both National Fuel and Iroquois Gas Corporation operate storage facilities using the Medina Group in the Erie County towns of Collins, North Collins, Marilla, Colden, Aurora, Holland, Boston, Eden, and Evans. The operations as of 1998 occurred in five discrete fields of varying total capacity (Colden Field, 166 wells, 16,220 Bcf; Collins field, 47 wells, 5,880 Bcf; Derby field, 14 wells, 0.250 Bcf; Holland field, 26 wells, 2,600 Bcf; and Lawtons field, 31 wells, 2,470 Bcf).

Honeoye Storage Corporation stores gas in the Medina Group in the towns of Bristol and Richmond in Ontario County. The Honeoye field has 39 wells with a total capacity of 8,713 Bcf [New York State Department of Environmental Conservation, 1998]. Information on specific wells included in these fields is available from a database maintained by NYSDEC.

3.1.4 Oriskany Sandstone

The Lower Devonian Oriskany Sandstone is a white to light-gray and gray-brown, well-sorted, fine- to medium-grained, quartz sandstone [Patchen and Harper, 1996]. Calcium carbonate is the predominant cement in the Oriskany Sandstone—in places, comprising 50 percent of the bulk mineralogy. Silica cement is less common, comprising up to about 15 percent of the bulk mineralogy. The Oriskany Sandstone is present beneath the southern tier of New York and is absent (pinches out) in westernmost New York and in a narrow east-west trending zone located about 50 kilometers north of the Pennsylvania border [Patchen and Harper, 1996].

Gas production from the Oriskany in New York occurs from a combination of structural and stratigraphic traps [Patchen and Harper, 1996; Harper and Patchen, 1996]. In this area, Silurian salt-cored structures are superimposed on the wedge-shaped sandstone bodies which are thinning northward toward the pinchout areas. In the pinchout areas, the wedge of Oriskany Sandstone is trapped between relatively impermeable Lower and Middle Devonian shales and carbonates. Where affected by salt deformation, these wedges of reservoir sandstone are folded into small-scale anticlines and dome structures. Available literature indicates that fracturing is an important factor that enhances permeability in each of the types of Oriskany reservoir-trap combinations.

3.1.4.1 Thickness

The Oriskany Sandstone generally is in the 0–30 foot range, but there are one or two regions in south-central New York where the thickness exceeds 50 feet, based upon published formation isopach maps.

3.1.4.2 Porosity

Generally, the typical porosity range for the sandstone facies (there are carbonate-rich units in some areas) across the region is 5–12 percent [Patchen and Harper, 1996]. Although correlated log profiles were generated along the trends of major regional anticlines, no zones of enhanced porosity associated with secondary structure were detected.

3.1.4.3 Permeability

Literature references cite regional permeability for the Oriskany Sandstone to range from 0.01 mD to nearly 30 mD. The high permeability end of the range is interpreted to be controlled by intense fracturing and/or dissolution of carbonate cement.

3.1.4.4 Gas Storage Facilities

Based upon information gleaned from the NYSDEC Web site and New York State Department of Environmental Conservation [1998], there are ten natural gas storage facilities that utilize the Oriskany Sandstone. These facilities are as follows: Beech Hill field, 41 wells, 23,000 Bcf; West Independence field, 32 wells, 11,800 Bcf; East Independence field, 11 wells, 6,400 Bcf; Limestone field, 14 wells, 19,800 Bcf; and Tuscarora field, 8 wells, 6,300 Bcf—all operated by National Fuel Gas. In addition, the Woodhull field, 51 wells, 35,904 Bcf, is operated by Dominion Transmission, Inc.; the Wayne-Dundee, Wayne, and Troupsburg fields operated by Columbia Gas Transmission Corporation, Home Gas Company, and Wyckoff Gas Storage, respectively. The locations of these fields are provided in Figure A-1.

3.2 CARBONATE RESERVOIRS

The carbonate reservoirs are presented in ascending stratigraphic order. They include the Ordovician Trenton-Black River, the Silurian Lockport Group, the Devonian Helderberg Group and the Devonian Onondaga Limestone. Each of these reservoirs is discussed in more detail below.

3.2.1 Trenton-Black River

The Middle Ordovician Trenton-Black River Group is a significant commercial gas play in the southern tier of New York. The top of the Trenton is at depths of about 3,400–3,500 feet with gas-producing zones at depths of about 4,000–4,200 feet [Nuttall, 1996]. The Black River Group consists of light-medium brown to gray, burrow-mottled, stylolitic mudstone and is gradational through a 10-foot-thick zone with the overlying Trenton Limestone [Patchen et al., 2005]. The Trenton Limestone consists of thinly laminated mudstone-wackestone tidal flat facies, skeletal grainstone-packstone shoal facies, and nodular skeletal wackestone-packstone facies [Nuttall, 1996; Patchen et al., 2005; Smith, 2006].

Trenton deposition occurred across a low-relief platform or carbonate ramp that was part of a platform-to-basin system extending eastward across western New York [Patchen et al., 2005]. The Trenton interval is thickest in the central part of the southern tier region of New York where it becomes more argillaceous in its upper portion and has a more gradational contact with the overlying Utica Shale farther east. The Trenton producing fields in south-central New York are largely located along the platform margin (transition zone between the platform and basin) where muddy dolowackestones and dolomudstones form the main reservoir rocks.

Trenton-Black River Group gas reservoirs occur in hydrothermal and brecciated dolomite along steeply dipping faults (mostly identified as strike-slip faults) and at fault intersections [Patchen et al., 2005; Smith, 2006]. Deep-seated faults that were active during Ordovician time provided pathways for hydrothermal fluids which caused dolomitization and formation of secondary porosity (vugs, breccia) in the Trenton-Black River carbonates along the fault zones. Gas production from the Trenton-Black River Group is, therefore, strongly fault controlled. These fractured and dolomitized reservoirs are generally kilometers in length but only hundreds of meters in width (following fault trends). Many of the reservoirs occur in structural lows associated with pull-apart or transtension along strike-slip faults [Patchen et al., 2005]. The Reservoir Characterization Group at the New York State Museum estimates that hydrothermal dolomite reservoirs in the Trenton-Black River Group occur across a much wider area of New York than is currently producing today. After depletion, the Trenton-Black River reservoirs have high potential as storage reservoirs for gas, compressed air, brines, or CO_2 (carbon sequestration). The limiting factor will be the narrow zones of permeability restricted to zones of hydrothermal alteration along faults.

3.2.1.1 Thickness

The average thickness of the Trenton-Black River Group interval is 250 feet and ranges from about 30 to 800 feet. The hydrothermally altered dolomite intervals that form the main producing zones are on the order of 50 to 100 feet thick.

3.2.1.2 Porosity

The spread of porosity values for the producing zones documented in the literature ranges from near zero to greater than 25 percent [Nuttall, 1996]. The average porosity is cited to be 7 percent. Porosity is dominantly vugs, channels, and molds in dolomudstones and dolowackestones [Smith, 2006]. The porosity formed by dissolution of dolomite and calcite and was enhanced by fracturing and brecciation.

3.2.1.3 Permeability

Permeability values in the 0.05–10,000 mD range with an average of 60 mD reported in the literature for the Trenton-Black River hydrothermally altered dolomite [Nuttall, 1996; Patchen et al., 2005; Smith, 2006]. Permeability is strongly controlled by fracturing along fault zones. The highest permeabilities occur along fault zones where hydrothermal fluids have formed secondary porosity and where there is good fracture permeability. Outside of fault zones, the Trenton-Black River Group is generally tight, having low permeabilities.

3.2.1.4 Gas Storage Facilities

There are presently no known natural gas storage facilities in the Trenton-Black River graben reservoirs.

3.2.2 Lockport Group

The Lockport Group consists of erosionally resistant dolostones. These hard rocks form the Niagara Escarpment, a prominent ridge along the northern edge of the east-west-trending outcrop belt across western New York.

Lockport Group strata in New York have been penetrated by exploratory wells for oil and gas. The majority of the gas production is situated farther west in Ohio, however. In that region, the sequence contains a high percentage of porous, dolomitized, crinoidal grainstone. Across western New York, the dolostones of the Lockport Group generally become finer-grained in an eastward direction. There also appears to be an increase in the argillaceous content of the carbonates to the east along the outcrop belt. Both the eastward decrease in carbonate grain size and the increase in argillaceous content likely result in a decrease in the permeability of the strata below that required for reservoir status. For example, one well in the Lockport Group at Geneva, New York, was abandoned after producing only 100,000 thousand cubic feet (mcf) of gas [Noger et al., 1996].

3.2.2.1 Thickness

The Lockport Dolomite is about 100 feet thick with pay zones that range in thickness between about 10 and 20 feet [Noger et al., 1996].

3.2.2.2 Porosity

Average porosity in the Lockport producing zones (patch reef and grainstone lithologies) ranges from 3.4 to 14 percent and is typically 8 to 10 percent. Minimum porosity is 1 percent and maximum reported porosity is 37 percent [Noger et al., 1996].

3.2.2.3 Permeability

The average permeability for the producing zones of the Lockport ranges from <1 to 50.6 mD [Noger et al., 1996].

3.2.2.4 Gas Storage Facilities

There are presently no known natural gas storage facilities in the Lockport Group.

3.2.3 Helderberg Group

The Helderberg Group carbonates occupy a stratigraphic position above the Silurian Salina Group and below the Oriskany Sandstone. These Helderberg carbonates are typically well-cemented even where an appreciable thickness of the stratigraphic unit is preserved. Still, there is one natural gas storage facility in New York State that utilizes Helderberg Group strata.

3.2.3.1 Thickness

The Helderberg Group is erosionally truncated along a line trending southwest from the outcrop belt in north-central Seneca County to the southwestern corner of Allegany County. From that zero line, the thickness of the Helderberg Group increases in a southeasterly direction to a maximum of near 400 feet in southern Sullivan County [Oliver et al., 1971].

3.2.3.2 Porosity

RESPEC was unable to locate porosity data for the Helderberg Group carbonates in New York State.

3.2.3.3 Permeability

RESPEC was unable to locate permeability data for the Helderberg Group carbonates in New York State.

3.2.3.4 Gas Storage Facilities

Based upon information gleaned from the NYSDEC Web site, there is one natural gas storage facility that utilizes the Helderberg Group carbonates. This facility is the Stagecoach field operated by Central New York Oil and Gas Company in Owego, Tioga County. The 12 wells in the Stagecoach field range from approximately 5,400 feet bgs to approximately 8,000 feet bgs. The location of the Stagecoach field is shown in Figure A-1.

3.2.4 Onondaga Limestone

The Middle Devonian Onondaga Limestone includes a northeast-trending belt of reefs across central New York which form commercial gas plays. The stratigraphy of the Onondaga includes, in ascending order, the Edgecliff Member, Nedrow Member, Moorehouse Member, and Seneca Member [Oliver, 1954]. Gas production is from the Edgecliff Member which, in New York, consists of light-gray, coarse, fossiliferous limestone with pinnacle reefs [Van Tyne, 1996]. The Nedrow and Moorehouse Members are medium-gray, fossiliferous, cherty limestone and the Seneca Member is massive, shaley, dark-gray limestone [Van Tyne, 1996].

Cumulative gas production from the Onondaga ranges from 700,000 to 7,100,000 mcf in Steuben County, New York [Van Tyne, 1996]. Depths to the producing zone in Steuben County ranges from about 3,200 to 4,500 feet; the variation in depth to the producing zone is because of the differences in pinnacle reef thickness within the Onondaga.

3.2.4.1 Thickness

Based on gas wells in Steuben County, New York, the Onondaga Limestone has an average thickness of about 168 feet with a range from 115 to 203 feet [Van Tyne, 1996].

3.2.4.2 Porosity

New data are available for the petrophysical characteristics of the Onondaga. Based on core from one gas well in Steuben County, New York, a reef in the Onondaga has an average porosity of 5.8 percent ranging from less than 3 percent in the lower portion to 11 percent in the upper portion [Van Tyne, 1996].

3.2.4.3 Permeability

Few data are available for the petrophysical characteristics of the Onondaga. Based on a core from one gas well in Steuben County, New York, a reef in the Onondaga has an average permeability of 22.9 mD with a range from 0.1 mD in the lower portion to 608 mD in the upper portion [Van Tyne, 1996].

3.2.4.4 Gas Storage Facilities

Based upon information gleaned from the NYSDEC Web site, there are three natural gas storage facilities that utilize the Onondaga Limestone. These facilities are as follows: Quinlan Reef in Olean, Cattaraugus County, operated by Dominion Transmission, Inc.; the Zoar Reef in Collins, Erie County, operated by National Fuel Gas Supply Corporation; and the Adrian Reef in Canisteo, Steuben County, operated by Steuben Gas Storage Company. The three fields incorporate approximately 40 wells with depths ranging from approximately 1,660 feet bgs to approximately 5,300 feet bgs. The locations of the Onondaga fields are shown in Figure A-1.

4.0 HARD ROCK MINES

For purposes of this report, the term "hard rock mine" is intended to refer to all mines that are not in halite (rock salt). Thus although gypsum is certainly not a hard mineral on the hardness scale, gypsum mines are included in this section of the report as a type of hard mine. Other types of mines included in this section are those for limestone/dolostone, zinc, talc, granite, and lead.

4.1 LIMESTONE/DOLOSTONE MINES

There are 113 limestone and 27 dolostone mines and quarries currently permitted for operation in New York State. The NYSDEC Web site indicates none of the current mines have underground acreage associated with their operations.

Review of information on early mining operations in New York State [Newland, 1919] indicates underground mining of limestone occurred in the Kingston area (i.e., near Rondout) and in Schoharie County (i.e., at or near the Howe caverns). Most of these historic mines ceased operation before 1900. Consequently, information on these and other locations is limited, and additional research is required to determine the locations, size, and conditions of these historical mine locations.

4.2 GYPSUM MINES

Based upon information gleaned from the NYSDEC Web site, there are two recently active gypsum mines in New York State. The mines are located in the towns of Clarence Center and Oakfield. Gold Bond Building Products currently owns the Clarence Center Mine, which has an estimated mine life of 17 acres, with zero acres currently permitted. The Oakfield Mine is owned by U.S. Gypsum Company with an estimated mine life of 15 acres—none of which is currently permitted. This mine has been operated by U.S. Gypsum since approximately 1903 [Newland, 1919].

In addition to the U.S. Gypsum facility, at least two other mines were operating in the Oakfield area in the late nineteenth and early twentieth century. These mines may have been incorporated into the current U.S. Gyspsum operation. Newland [1919] refers to subsurface mining operations by Empire Gypsum Company and Lycoming Calcining Company in the town of Wheatland. Additionally, a third mine appears to have been owned by Ebsary Gypsum Company in nearby Wheatland Center. However, information on these historical locations is limited and additional research is required to determine the locations, size, nature (i.e., surface or subsurface mines), and conditions.

Given the proximity of the gypsum mines to the Salina Group outcrop belt, they are shallow subsurface facilities. It is unlikely that the mines have extended appreciably more than 100 feet bgs. At this subsurface depth, the gypsum deposits begin to grade back into the precursor anhydrite beds [Newland, 1929]. This zone of the mineralogic transition is generally demarcated by the foot of the Onondaga Limestone Escarpment, which marks the southern limit of the Salina Group outcrop belt.

4.3 GOUVERNEUR TALC MINE

Based upon information gleaned from the NYSDEC Web site, there are three separate talc mines owned by R. T. Vanderbilt Company, Inc. Governeur Talc Division, in Gouverneur, New York. Two of the mines may be surface pits, but the third is designated Mine #1 (underground). The Mine #1 location is shown in Figure A-1. This underground mine is likely to be the historic mine operated by Gouverneur Talc before the company's acquisition by Vanderbilt in 1948. The NYSDEC reports 19 current permitted acres, with no mine life left and 5 acres reclaimed, with a regulated acreage range of 10–20 acres.

Roe [1975] describes the Gouverneur Talc mine as the largest underground talc mine in North America. The mine has a 1,100-foot-deep shaft carrying a 6-ton skip. Open stope mining is practiced, and hard rock mining methods are employed because of the hardness of the ore. Ore processing is performed underground via a crusher installed at the 700-foot level in the mine. NYSDEC conveyed that this mine is presently deeper, somewhere on the order of 1,500–1,800 feet deep.

R. T. Vanderbilt Company announced its decision in January 2008 to discontinue talc production at its Gouverneur facility by the end of 2008. According to a company statement, the market for talc has dropped steadily over the years while business costs have continued to increase. While R. T. Vanderbilt Company has been processing talc at Gouverneur since 1948, it has become a relatively small part of the company's operations overall—representing less than 7 percent of total revenue in 2007. The production volume of talc at the company's Gouverneur facility has dropped from over 200,000 tons in 1988 to approximately 80,000 tons today.

Gouverneur Talc also operates a wollastonite mine (the Diana Mine) that NYSDEC indicates has an underground component to it. NYSDEC reports that the underground portion only goes down 400–500 feet.

Review of available histories on early talc mining references the existence of numerous underground talc mines within the Edwards District of Saint Lawrence County with talc depths around 350 feet bgs. However, information on these historic locations reviewed as part of this study is limited, and additional research is required to determine the locations, size, nature (i.e., surface or subsurface mines), and conditions of these historic mine locations.

4.4 GRANITE MINE

Based upon information gleaned from the NYSDEC Web site, there are 26 granite mines currently permitted in New York State, with one mine listed as having underground acreage. The Winddale Quarry Mine, located in Dover, is listed as having 60 acres of currently permitted mine with 288 acres of mine life.

4.5 ZINC MINE

Based upon information gleaned from the NYSDEC Web site, four zinc mines are currently permitted in New York. Three of these mines are listed has having underground acreage. Two of the active mines (Number 4 Mine and Pierrepont Mine) are owned by St. Lawrenece Zinc Company. The Number 4 Mine is currently permitted for 432 acres with a mine life of 1,124 acres listed. The Number 4 Mine is linked to St. Lawrence Zinc's Number 2 Mine underground and is reported to be 3,700 feet deep. The Pierrepont Mine has no acres currently permitted with a mine life of 243 acres listed. The Pierrepont Mine is reported by the NYSDEC to be about 1,100 feet deep.

The remaining two mines (Hyatt Mine and Edwards Mine) are owned by Zinc Corporation of America. The Hyatt Mine has no acres currently permitted with a mine life of 74 listed. According to the NYSDEC, the Hyatt Mine is about 1,000 feet deep. The Edwards Mine has been closed since 1970. NYSDEC reports its depth to be 5,000 feet. Its shaft is presently sealed.

In addition to these recent and current mining operations, review of New York State Museum Bulletins indicated historical zinc mining not only in St. Lawrence County (i.e., the location of the currently mining operations), but also in southeastern New York in the Shawangunk Mountain range of Ulster and Sullivin Counties. However, information on these historic locations is limited and additional research is required to determine the locations, size, nature (i.e., surface or subsurface mines), and conditions of these historic mine locations.

4.6 LEAD MINES

No lead mines are currently permitted by the NYSDEC. However, review of New York State bulletins and other sources indicates lead may have been mined in New York State during the nineteenth century. However, information on these historic locations is limited and additional research is required to determine the locations, size, nature (i.e., surface or subsurface mines), and conditions of these historic mine locations.

4.7 IRON MINES

Iron, like lead, is no longer actively mined in New York; however, based on historical data, iron was mined across most of the eastern portion of the state from as early as the 1750, with efforts in the Adirondack region beginning in the early 1800s. At least two subsurface mines were operated by the Witherbee, Sherman Company, and the Port Hennery Iron Ore Company existed in the Mineville area of the Adirondacks. However, information on these historic locations is limited and additional research is required to determine the locations, size, nature (i.e., surface or subsurface mines), and conditions of these historic mine locations.

5.0 EVALUATION CRITERIA

To evaluate the above-described salt-related facilities, reservoirs, and subsurface mines for their suitability for CAES, RESPEC requested from PB ESS engineers and geoscientists some basic selection criteria. The most important requirement expressed by PB ESS was for the CAES "vessel" to be compatible with estimated peak operational pressures in the 800–1,300 psi range. Assuming maximum air pressures in the range of 0.75–0.8 psi/foot, PB ESS conveyed to RESPEC that subsurface void space should generally be in the 1,500–3,000-foot-depth range, with 1,500–2,000 feet ideal, given other operational considerations. PB ESS advised RESPEC to eliminate from further consideration those mines and storage facilities at subsurface depths less than 1,000 feet.

RESPEC further inquired as to the minimum required size for a subsurface "vessel" needed for CAES. PB ESS advised RESPEC that a capacity of 1.5–2.0 million barrels at 2,000 feet would be needed for a viable CAES project. PB ESS further advised us that many salt caverns in the United States fall within the 2–4 million barrel range.

Finally, PB ESS opined that high deliverability is important for CAES. A value of 462 million cubic feet per day was cited as a per-turbine requirement for CAES. A final criterion considered by RESPEC was the economical feasibility of CAES in a competitive site usage climate. RESPEC attempted to determine whether or not CAES was an economically attractive alternative to a candidate facility's current or planned use.

6.0 CANDIDATE SALT UNIT AND RESERVOIR PERFORMANCE AGAINST DESIGN CRITERIA

Utilizing the criteria provided by PB ESS, RESPEC evaluated each of the potential candidate salt-related facilities and reservoirs.

6.1 SALT-RELATED FACILITIES

The major issues to contend with regarding use of existing salt caverns for CAES are casing modifications, brine disposal, and competition against current use. The major issues to contend with regarding use of existing room-and-pillar salt mines are subsurface depth and shaft integrity/sealing.

6.1.1 Salt Caverns

Existing caverns, whether solution-mining caverns or hydrocarbon storage caverns, would require modifications to casing strings for CAES. It is generally assumed that existing casing strings in wells at both historical and active facilities are too small in diameter to meet the deliverability demands of CAES.

It should also be noted that modification of casing strings for LPG and/or natural gas storage caverns would require evacuation of product from the existing caverns. Such purging could be expensive and potentially hazardous because of explosion risks.

Brine in existing caverns will require disposal. New York State geology does not appear to provide viable deep subsurface brine injection targets. The inability to manage waste brine has been a major barrier to further development of hydrocarbon storage in salt in New York. That being said, brine disposal will also hamper development of newly designed caverns specifically for CAES unless the brine can be provided to a current salt producer at a rate and in a manner that are economically viable to that producer.

Enthusiasm among current operators for conversion of existing LPG and/or natural gas storage caverns to CAES use is not likely to be high because of current energy demands/economics. The inability to readily expand existing hydrocarbon storage facilities or to develop new ones because of the lack of brine disposal potential in New York State places a premium on the storage space presently available. It may be difficult for CAES to compete against current LPG and natural gas storage uses for the current cavern space in the state.

Development of new, specially designed caverns at an existing solution-mining facility appears to be a viable long-term option. Currently, many existing caverns and galleries at the current and historical solution-mining operations do not appear to be suitable for conversion to

CAES. Thus a CAES operator would have to conduct an engineering/economic feasibility evaluation in consultation with a salt producer to develop a new, specially designed cavern in a manner that is compatible with the current operation. This option, however, is a long-term approach, because it could require 10–15 years of mining before the cavern would be of sufficient size for CAES. Consequently, development of new, specially designed caverns does not address an immediate need for a CAES vessel.

In the western part of the state, B-Salt is the target at the PB ESS Dale field, the Texas Brine Wyoming field, and the Morton Salt Silver Springs plant. Of these three, the Morton Salt plant would appear to be the most viable candidate for future development of CAES. The Dale and Wyoming fields are situated relatively close to the Clarendon-Linden Fault System. The caverns at Dale and Wyoming are also relatively shallow as compared to the salt depths at Morton. Historically, increased seismicity has been associated with injection of brine under pressure at Dale [Fletcher and Sykes, 1977]. Consequently, injection of compressed air at the pressures necessary in the relatively shallow salt interval at these facilities will raise concern on the part of facility operators, state regulators and the local communities for potential reactivation of naturally occurring faults and an associated increase in earthquake activity.

In the central part of the state, F-Salt is the target at the Cargill Watkins Glen plant at the U.S. Salt Watkins Glen plant. The F-Salt sequence is relatively thick at Watkins Glen compared to the B-Salt sequence in western New York. A thicker salt sequence would provide more flexibility on the depth and size of any specially designed caverns for CAES at these facilities should either operator express an interest.

6.1.2 Salt Mines

Room-and-pillar salt mines offer the advantage of relatively large subsurface void space without the need for solution mining and associated brine disposal. However, it is likely that several of the abandoned mines are brine filled. Furthermore, the main issue associated with use of room-and-pillar mines for CAES is going to be shaft sealing.

The abandoned mines at Lehigh, Retsof, Livonia, are known, or are likely, to be brine-filled. Brine disposal will be an issue. Because of the known or anticipated large volumes of brine, these mines are not considered prime candidates. It should also be noted that the Lehigh Mine was constructed with two shafts, and the mine is only 800 feet deep. The Livonia Mine is between 1,432 feet and 1,462 feet deep, so its suitability for CAES is marginal on the basis of depth, notwithstanding the expressed concern regarding the anticipated brine volumes in the mine.

The active American Rock Salt Mine is a relatively new, single-level mine in the Retsof Bed (Salina B) and, as such, the operator is unlikely to be interested in CAES on the operating level. In essence, RESPEC anticipates that the operator would not feel comfortable that there is sufficient room in the mine to provide safe separation between its employees supporting the on-going operation and a CAES facility.

The inactive Morton Salt Mine at Himrod is of a modern era design and construction. Consequently, the shaft has the potential to remain in very good condition and may not have the significant brine seepage issues that the historical mine shafts are likely to have experienced.

Based on information in PB ESS files, the Morton Mine is approximately 2,050 feet deep. By October 1974 the mine covered an area of approximately one-half square mile. The volume of the mine is believed to be about 13.5 million barrels based on information in PB ESS files. On the basis of its size, depth, and anticipated lack of a significant brine seepage problem, the Morton Mine appears to be a viable candidate for CAES.

The active Cargill Deicing Technology Cayuga Mine is a multilevel mine with abandoned shallower levels and considerable volume. The proximity of the Cayuga Mine to the AES Cayuga power-generating station also suggests ease of access to the grid. There may be an interest on the part of this operator to consider CAES on one of the shallower, inactive levels if duel use of the facility can be done safely. Isolation of the CAES chamber from the shafts will be the major engineering issue. There are presently three shafts at Cayuga. The shallowest level is at about 1,500-foot depth and is believed to be accessed only by one shaft. Given the vertical separation from the ongoing operation, this shallow "457-m" level may prove to be the acceptable candidate for CAES from the current operator's perspective.

6.2 NATURAL GAS RESERVOIRS

With two possible exceptions, the reservoirs in New York are likely to lack the thickness and permeability to serve effectively as CAES vessels based upon their poor performance for brine disposal. The possible exceptions are (1) a single brine injection well targeting the Queenston Formation in Steuben County that can accept high rates of flow for short durations and (2) Trenton-Black River graben reservoirs. These possible exceptions are not proven, however. Given further investigation, these two possible exceptions may not perform well against the CAES evaluation criteria provided by PB ESS.

6.2.1 Siliciclastic Reservoirs

The siliciclastic reservoirs considered for CAES in this study are the Cambrian Potsdam Sandstone, the Ordovician Queenston Formation, the Silurian Medina Group, and the Devonian Oriskany Sandstone.

6.2.1.1 Potsdam Sandstone

The Potsdam Sandstone appears to be insufficiently permeable to accept brine where previously attempted in Steuben County. Its poor performance for brine disposal does not bode well for its suitability for CAES. Furthermore, there are no current hydrocarbon storage facilities in the Potsdam Sandstone in New York. This fact further discounts its viability as a CAES candidate.

6.2.1.2 Queenston Formation

The Queenston Formation is generally considered to be too impermeable for brine disposal. However, the Inergy Midstream LPG (former Bath Petroleum) storage facility at Bath has a Queenston brine disposal well that can accept high rates of brine for short periods [Ehgartner et al., 2005]. This characteristic may indicate local suitability for CAES.

In addition, the Queenston Formation maintains a fairly thick sandstone section northward and eastward from the Savona area toward the active gas fields in the Auburn area. This stretch is untested for Queenston permeability, but the formation may exhibit suitable properties where geologic structure has enhanced secondary porosity. One such area is beneath the Fir Tree Point Anticline in close proximity to the Cargill Deicing Technology Cayuga Mine. Seismic reflection data (available for lease) indicate deep-seated structure that affects the Queenston and enhances the prospects for porosity and permeability development. The proximity of this area to the AES Cayuga power-generating station also suggests ease of access to the grid.

6.2.1.3 Medina Group

The Medina Group has been the main gas-producing reservoir in western New York. Although locally permeable sandstone bodies occur within the Medina Group, it is generally considered to be a low permeability, nonconventional reservoir. .

Several gas storage facilities have been developed in Medina Group sandstones. These facilities include National Fuel operations in Perrysburg, Cattaraugus County; Hanover, Chautauqua County; and Bennington, Wyoming County. Both National Fuel and Iroquois Gas Corporation operate storage facilities using the Medina Group in the Erie County towns of Collins, North Collins, Marilla, Colden, Aurora, Holland, Boston, Eden, and Evans. Honeoye Storage Corporation stores gas in the Medina Group in the towns of Bristol and Richmond in Ontario County. Therefore, additional research could be performed using very specific, quantified CAES criteria to determine if the permeable sandstone zones within the Medina could be demonstrated to be viable for CAES.

6.2.1.4 Oriskany Sandstone

Oriskany Sandstone production is waning, and the depleted gas fields located in Cattaraugus, Allegany, Steuben, Schuyler, Yates, and Chemung Counties are currently used for gas storage. Given the increased demand for natural gas in the region, conversion of existing gas storage facilities in the Oriskany to CAES is not likely to be of interest to the current operators.

Outside the known fields, the Oriskany is generally too thin and too impermeable to be considered viable for brine disposal. Based upon the poor performance potential of the formation for brine disposal, the Oriskany is not considered a highly viable candidate for CAES.

6.2.2 Carbonate Reservoirs

The carbonate reservoirs considered for CAES in this study are the Ordovician Trenton-Black River grabens, the Silurian Lockport Group, the Devonian Helderberg Group, and the Devonian Onondaga Limestone.

6.2.2.1 Trenton-Black River

The active Trenton-Black River reservoirs located in the south-central part of the state, after depletion, have tremendous potential as gas storage reservoirs, and the operators producing these fields are very aware of this value. It would likely be cost prohibitive to buy into one of these depleted wells or fields to develop one for CAES because of the interest in their future use as a conventional gas storage reservoir.

6.2.2.2 Lockport Group

There are no active gas fields or operating gas storage facilities in the Lockport Group. In the western part of the state where the formation is likely to be more permeable, the porosity is likely to be brine-filled instead of gas-filled. Because of the absence of major gas accumulation in the Lockport Group, there is relatively little data available on its reservoir properties within New York. The Lockport Group does comprise the "Newburg" reservoir in north-central Ohio, however, but the Lockport Group remains unproven for its potential to serve as a reservoir for CAES in New York.

6.2.2.3 Helderberg Group

The Helderberg Group strata are thickest in the southeastern part of the state. One natural gas storage facility in southern Tioga County utilizes the Helderberg Group as a reservoir. RESPEC anticipates that local structural geologic conditions have enhanced the fracture permeability at that location. It is unclear, however, whether or not comparable fracture permeability exists elsewhere. The well-cemented nature of these carbonates would suggest that they are not a viable CAES candidate in the absence of structurally controlled secondary permeability.

6.2.2.4 Onondaga Limestone

There are localized reef accumulations that have been productive gas reservoirs. Several of these depleted reef reservoirs have also been converted to gas storage facilities. These may have some potential to serve as CAES vessels.

6.3 HARD ROCK MINES

The various "hard rock" (i.e., non-salt) mines included in this section include those for limestone/dolostone, zinc, talc, granite, and lead.

6.3.1 Limestone/Dolostone Mines

Limestone/dolostone mines operate mostly as open quarries in New York, but historically "natural cement" operations went underground in the Lower Hudson Valley near Kingston. Most of these operations were not active after 1900, but some of the mine cavities are still open. Given their shallow subsurface disposition, these historical subsurface limestone/dolostone mines are excluded as viable candidates as CAES reservoirs.

6.3.2 Gypsum Mines

All subsurface gypsum mines operated in western New York. These mines are typically shallow—on the order of 100 feet bgs. Their shallow depths preclude them from consideration as viable CAES reservoirs—regardless of their volume.

6.3.3 Gouverneur Talc Mine

The Gouverneur Talc Mine is a potential candidate for CAES if such a facility were deemed desirable in the far north of the state. The mine is closing at the end of 2008, and the mine is reported to have a working level as deep as 1,500–1,800 feet. The mine, which is advanced through the hard, low permeability, high strength metamorphic rock in this part of the state, may be a viable candidate as a reservoir for CAES.

6.3.4 Granite Mine

RESPEC is still researching information on a subsurface granite mine in the eastern part of the state. This mine is likely to be a shallow subsurface operation, and as such, is not considered to be a suitable candidate for CAES.

6.3.5 Zinc Mine

St. Lawrence Zinc's Number 2-4 Mine and the Edwards Mine both have very deep mining levels that could potentially serve as CAES reservoirs. More information is required on the volume of the various mining levels in these facilities to further evaluate their viability as CAES candidates. That information is best obtained from mining plans that are presently not part of the readily available public record.

6.3.6 Lead Mines

Historical lead mines located in the eastern part of the state are likely to be shallow subsurface facilities and as such, are not likely to be viable candidates for CAES.

7.0 CONCLUSIONS AND RECOMMENDATIONS

PB ESS contracted RESPEC to prepare this report regarding potential locations for underground CAES throughout the state of New York. The objective of this study was to identify potential subsurface sites in the state of New York where compressed air can be injected, stored, and withdrawn for electrical power-generating purposes. The types of storage locations that were considered are solution-mined salt caverns and room-and-pillar salt mines; reservoir storage fields; and existing underground non-salt mines, including those for limestone/dolostone, talc, gypsum and other types of hard rock. Each of these general categories of candidate sites, as well as existing and historical facilities falling under each category, is described in this report using currently available public information.

In general, existing salt caverns generated from solution mining or those caverns currently used for LPG or natural gas storage are much larger than needed for CAES and will require modification for CAES use since they were designed and build for a different use. Casing strings will likely have to be replaced to support the flow requirements for CAES. Also, since existing salt caverns are currently being used to store salt brine or other fluids, these materials will have to be removed to support a CAES plant. Thus, in general, depending on cost trade-offs, it needs to be determined on a site by site analysis, whether to use an existing salt cavern or create a specially designed caverns at a current solution-mining operation.

Abandoned mines that are sufficiently deep (1,500–3,000 feet) may also be used for the CAES application. Two potentially suitable salt mines that exist in central New York are the Cargill Deicing Technology Cayuga Mine and the Morton Salt Himrod Mine. Also, the Gouverneur Talc Mine and two zinc mines operated by St. Lawrence Zinc appear to have sufficient depth to be considered. These mines are located in the extreme northern part of the state. It should be noted an issue to contend with regarding use of room-and-pillar salt mines or the zinc mines will be to perform the necessary shaft sealing of these mines, which should be able to be performed with a cost specific to each site.

With few possible exceptions, the siliciclastic and carbonate reservoirs in New York State may be too thin and/or not sufficiently permeable for CAES application, depending on the plant size. Where the reservoir properties do look good in New York State, most of such reservoirs are presently in use for natural gas storage.

Two good geologic formations are the Queenston Formation and the Trenton-Black River graben reservoirs located in central New York. The Queenston Formation is a thick, but relatively low, permeability sandstone reservoir. Where geologic structure has potentially provided enhanced secondary porosity, the Queenston may offer some potential for further consideration for CAES. The Trenton-Black River graben reservoirs are currently a high priority for natural gas production. These reservoirs are relatively recent finds. These reservoirs, once depleted, are going to be prime candidates for natural gas storage or for CAES application. Thus, CAES will have to compete economically against natural gas storage at these geologically attractive regions.

Based upon the findings of this study, the type of facility most conducive to use for CAES varies according to geographic position within the state. The conclusions are as follows:

1. If operation of a CAES facility in the western part of New York is desired, development of specially designed caverns at the Morton Salt solution-mining facility at Silver Springs appears to be a good option.
2. If operation of a CAES facility in the south-central part of the New York is desired on a relatively short time frame, then the Cargill Deicing Technology Cayuga Mine and the Morton Salt Himrod Mine should be considered prime candidates. Development of specially designed caverns at the Cargill Watkins Glen or U.S. Salt Watkins Glen facilities appears to be a viable option.
3. Given the potential opportunity to look at use of inactive mine levels at the Cayuga Mine, the potential for geologic structure locally in the Queenston Formation that could enhance its reservoir properties, and the proximity to the AES Cayuga power generating station, the Fir Tree Point Anticline in Lansing, Tompkins County, is an area worth further consideration as a means to deploy CAES in central New York and to further explore the viability of a thick, regional sandstone reservoir for CAES.
4. If CAES is desired in the northern part of New York beyond the limits of salt deposits, then the Gouveneur Talc Mine, which is was scheduled for closure at the end of 2008, should be approached. In addition, the St. Lawrence Zinc Number 2-4 Mine, and the Edwards Zinc Mine also appear to be sufficiently deep for further consideration for CAES.

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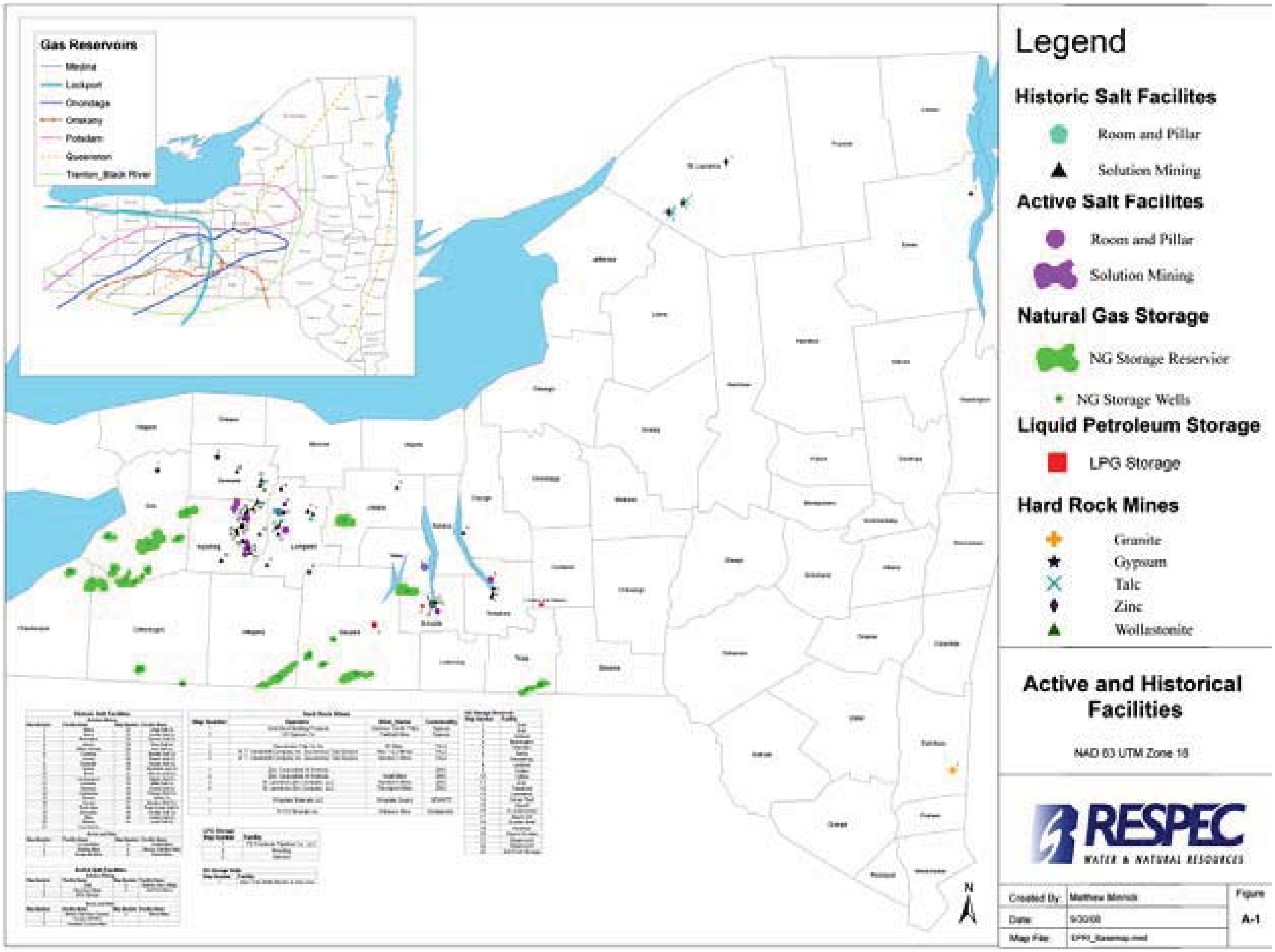
APPENDIX A

ACTIVE AND HISTORICAL SALT SOLUTION MINES, ROOM-AND-PILLAR SALT MINES, SALT CAVERN GAS STORAGE FACILITIES, AND HARD ROCK MINES



Gas Reservoirs
Medina
Lockport
Onondaga
Oriskany
Potsdam
Queenston
Trenton_Black River
Legend
Historic Salt Facilites
Room and Pillar
Solution Mining
Active Salt Facilites
Room and Pillar
Solution Mining
Natural Gas Storage
NG Storage Reservior
NG Storage Wells
Liquid Petroleum Storage
LPG Storage
Hard Rock Mines
Granite
Gypsum
Talc
Zinc
Wollastonite
Active and Historical Facilities
NAD 83 UTM Zone 18
RESPEC
WATER & NATURAL RESOURCES
Created By: Matthew Minnick
Date: 9/30/08
Map File:
Figure
A-1

Appendix A Tables (Embedded in Map)

Historic Salt Facilities			
Solution Mining			
Map Number	**Facility Name**	**Map Number**	**Facility name**
1	Ithaca	23	Lergy Salt Co
2	Ithaca	23	Castile Salt Co
3	Remington	24	Duncan Salt Co
4	Aurora	25	Perry Salt Co
5	Clifton Springs	26	Kerr Salt Co
6	Coesus	27	Bradley Salt Co
7	Livonia	28	Empire Salt Co
8	Dansville	29	Hawley Salt Co
9	Nunda	30	Gouinlock and Co
10	Royal	31	Warsaw Salt Co
11	Lackawanna	32	Atlantic Salt Co
12	Leicester	33	Miller Salt Co
13	Genesse	34	Crystal Salt Co
14	Calcedonia	35	Pioneer Wolf Co
15	Pioneer	36	Globe Co
16	Crystal	37	Moulton Wolf Co
17	Rock Glen	38	Pearl Creek Salt Co
18	Worcester	39	Pavilian Salt Co
19	Bliss	40	Lehigh Salt Co
20	Batavia	41	Leroy Salt Co
21	York Salt Co	-	-
	Room and Pillar		
Map Number	**Facility Name**	**Map Number**	**Facility Name**
1	Livonia Mine	4	Lehigh Mine
2	Sterling Mine	5	Morton Salt Milo Mine
3	Greigsville Mine	6	Retsof Mine

Active Salt Facilities			
	Solution Mining		
Map Number	**Facility Name**	**Map Number**	**Facility Name**
1	Dale	4	Watkins Glen Village
2	Wyoming Village	5	Salt Point Brine
3	Silver Springs		
Room and Pillar			
Map Number	**Facility Name**	**Map Number**	**Facility Name**
1	Morton Salt Silver Springs	4	Retsof Mine
2	Cayuga Salt Mine	5	
3	Hampton Corners Mine		

	Hard Rock Mines		
Map Number	**Operator**	**Mine Name**	**Commodity**
1	Gold Bond Building Products	Clarence Center Plant	Gypsum
2	US Gypsum Co	Oakfield Mine	Gypsum
1	Gouverneur Talc Co Inc	#1 Mine	TALC
2	R. T. Vanderbilt Company Inc Gouverneur Talc Co Inc	Nos 1 & 2 Mines	TALC
3	R. T. Vanderbilt Company Inc Gouverneur Talc Co Inc	Number 3 Mine	TALC
1	Zinc Corporation of America	Hyatt Mine	ZINC
2	Zinc Corporation of America	Number 4 Mine	ZINC
3	St. Lawrence Zinc Company LLC	Pierrepont Mine	ZINC
	St. Lawrence Zinc Company LLC		ZINC
1	Wingdale Materials LLC	Wingdale Quarry	GRANITE
1	NYCO Minerals Inc	Willsboro Mine	Wollastonite

NG Storage Reservoir	
Map Number	**Facility**
1	Zoar
2	Zoar
3	Holland
4	Bennington
5	Sheridan
6	Derby
7	Perrysburg
8	Lawtons
9	Colden
10	Collins
11	Zoar
12	Tuscarora
13	Limestone
14	Adrian Reef
15	Wycoff
16	N. Greenwood
17	Beech Hill
18	Quinlan Reef
19	Honeoye
20	Wayne-Dundee
21	Stagecoach
22	Stagecoach
23	Salt Point Storage

Appendix B

INACTIVE MINES IN SELECT REGIONS

ID	Mine name	County	Region	Lat	Long	Type	Commodity	Company	Year	Notes concerning attachments in Database
FE004a	81 EXPLORATION	CLINTON	Eastern Andirondacks	N44-42-18	W73-56-46	UNDERGROUND	IRON	REPUBLIC STEEL CORP	1946	Paul Tromblee is site manager for old Republic Steel iron mines in Clinton and Essesx counties. Ptromblee@nycap.rr.com; office phone is 518 942-7783. Interested in redevelopment/reuse of mine for energy projects. Don B. shaft (owned by Rhodia Inc) would be the most logical re-entry point to the closed mines. Depth was 2800 feet when concluded mining. All shafts filled w/ water currently. Fred Ellerbusch is Rhodia Inc mine engineer for Mineville mines at 609 - 860- 3671. Kay Spafford owns the Harmony shaft and is marketing it for re-use. Phone: 518 461-6147. Essex County IDA: 518 873-9114.
FE004a	81 MINE		Eastern Andirondacks	N44-42-18	W73-57-08	UNDERGROUND	IRON	REPUBLIC STEEL CORP	0	
FE004a	81 ORE SHOOT		Eastern Andirondacks	N44-42-18	W73-56-46	UNDERGROUND	IRON	REPUBLIC STEEL CORP	1947	
FE001f	ARNOLD HILL		Eastern Andirondacks	N44-29-07	W73-37-00	UNDERGROUND	IRON	REPUBLIC STEEL CORP	0	
FE002	BOWEN-SIGNOR		Eastern Andirondacks	N44-36-00	W73-48-11	UNDERGROUND	IRON	UNKNOWN	0	
FE004	CHATEAUGAY MINE		Eastern Andirondacks	N44-43-21	W73-54-28	UNDERGROUND	IRON	REPUBLIC STEEL CORP	0	
	JACKSON HILL		Eastern Andirondacks	N44-28-37	W73-40-02	UNDERGROUND	IRON	REPUBLIC STEEL CORP	0	
	LOCATION MAP		Eastern Andirondacks	N44-27-49	W73-40-26	UNDERGROUND	IRON	REPUBLIC STEEL CORP	0	
FE004	LYON MTN MAGNETITE DEPOSITS		Eastern Andirondacks	N44-43-21	W73-54-28	UNDERGROUND	IRON	REPUBLIC STEEL CORP	0	
FE001a	PALMER HILL MINE		Eastern Andirondacks	N44-27-49	W73-40-26	UNDERGROUND	IRON	REPUBLIC STEEL CORP	0	
GPH02	CROWN POINT GRAPHITE CO MINE	ESSEX	Eastern Andirondacks	N43-53-43	W73-34-50	UNDERGROUND	GRAPHITE	UNKNOWN	1918	PRIVATE DOMAIN
FE015a	21 BONANZA-JOKER MINE		Eastern Andirondacks	N44-05-17	W73-31-34	UNDERGROUND	IRON	REPUBLIC STEEL CORP	1960	ADIRONDACK DIST
FE015c	CHEEVER MINES		Eastern Andirondacks	N44-04-41	W73-26-43	UNDERGROUND	IRON	REPUBLIC STEEL CORP	1910	SHOWS VARIOUS SECTIONS:LOCATION FROM MILS
FE015b	FISHER HILL (Mineville)		Eastern Andirondacks	N44-06-38	W73-31-32	UNDERGROUND	IRON	REPUBLIC STEEL CORP	0	
	OLIVER IRON MINE-FILE NO 8N042		Eastern Andirondacks	N43-56-51	W73-26-10	UNDERGROUND	IRON	OLIVER IRON MNG CO	0	
FE001a	PALMER HILL		Eastern Andirondacks	N44-05-33	W73-31-33	UNDERGROUND	IRON	PERU STEEL	0	SHOWING LOCATION OF D. D. H 70 & 71
	PERU STEEL & IRON		Eastern Andirondacks	N44-05-33	W73-31-33	UNDERGROUND	IRON	PERU STEEL	0	SECTION NO. 12:CENTRAL LOCATION
	PORT HENRY MINE		Eastern Andirondacks	N44-02-32	W73-27-08	UNDERGROUND	IRON	REPUBLIC STEEL CORP	1978	LEVEL MAP BLOCK 230:1950 FEET BELOW LAKE CHAMPLAIN
	PROPERTY MAP		Eastern Andirondacks	N44-04-10	W73-28-36	UNDERGROUND	IRON	REPUBLIC STEEL CORP	1907	SHOWS PORT HENRY IRON ORE BED:PEASE, G.B. PROPERTY
	SHERMAN MINE		Eastern Andirondacks	N44-06-54	W73-31-31	UNDERGROUND	IRON	REPUBLIC STEEL CORP	1927	LOCATION FROM MILS
FE013	SKIFF MOUNTAIN MINE		Eastern Andirondacks	N43-53-11	W73-35-36	UNDERGROUND	IRON	REPUBLIC STEEL CORP.	1921	CROWN POINT DIST.
FE015f	WELTCH SHAFT		Eastern Andirondacks	N44-05-17	W73-31-34	UNDERGROUND	IRON	UNKNOWN	1964	PRIVATE DOMAIN
	WITHERBEE		Eastern Andirondacks	N44-05-33	W73-30-48	UNDERGROUND	IRON	REPUBLIC STEEL CORP	0	
WOL01?	INTERPACE		Eastern Andirondacks	N44-21-23	W73-23-38	UNDERGROUND	WOLLASTONITE	INTERPACE CORP	1976	
GPH10	LAKESIDE	WARREN	Eastern Andirondacks	N43-44-44	W73-29-50	UNDERGROUND	GRAPHITE	UNKNOWN	1918	PRIVATE DOMAIN
	BENSON MAIN PIT	ST. LAWRENCE	Tug Hill Plateau	N44-10-27	W75-00-45	UNDERGROUND	IRON	BENSON MAIN PIT	1968	SEC D 3+30
	CHAUMONT TAILINGS		Tug Hill Plateau	N44-10-27	W75-00-45	UNDERGROUND	IRON	BENSON MINES INC	1977	
ZN05	BALMAT NO 3		Tug Hill Plateau	N0-00-00	W187-29-19	UNDERGROUND	IRON	ST JOE RESOURCES	1984	
PYR02?	ANNA & STELLA MINES-FILE NO 8M60		Tug Hill Plateau	N0-00-00	W187-29-19	UNDERGROUND	IRON	ST LAWRENCE PYRITES COI	1912	AT DEKALB JUNCTION
TLC02?	NEWTON FALLS		Tug Hill Plateau	N44-10-27	W75-00-45	UNDERGROUND	IRON	UNKNOWN	1968	LOOKING NORTH
PB07	DOWNING ARCHIE FARM PPT		Tug Hill Plateau	N44-25-14	W75-32-47	UNDERGROUND	LEAD	UNKNOWN	1952	PRIVATE DOMAIN-MINE NAME ALSO HAS MACOMB
PB07	GORDON O H FARM PROSPECT-MACOM		Tug Hill Plateau	N44-22-28	W75-43-18	UNDERGROUND	LEAD	UNKNOWN	1952	PRIVATE DOMAIN
PB09	JONES DEPOSIT-MACOMB DISTRICT		Tug Hill Plateau	N44-25-30	W75-32-25	UNDERGROUND	LEAD	UNKNOWN	1952	PRIVATE DOMAIN
PB10	MACOMB		Tug Hill Plateau	N44-25-14	W75-32-25	UNDERGROUND	LEAD	UNKNOWN	1952	PRIVATE DOMAIN-MINE ALSO KNOWN AS BROWN MINE
PYR06	STILES MINE		Tug Hill Plateau	N44-26-21	W75-20-21	UNDERGROUND	PYRITES	UNKNOWN	0	PRIVATE DOMAIN
TLC01	CARBOLA TALC LEVEL 1-4- FILE 8N0		Tug Hill Plateau	N43-26-06	W75-27-26	UNDERGROUND	TALC	CARBOLA CHEMICAL CO	1944	
ZN02	HYATT		Tug Hill Plateau	N44-18-15	W75-18-26	UNDERGROUND	TALC	GOUVERNEUR TALC CO	1977	EST FROM GOUVERNEUR TALC CO INC INFO
TLC08	ARNOLD		Tug Hill Plateau	N44-16-05	W75-23-41	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	1977	
ZN03	BALMAT		Tug Hill Plateau	N44-15-00	W75-24-03	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	0	EST FROM MILS INFO
ZN07	EDWARDS		Tug Hill Plateau	N0-00-00	W187-29-19	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	0	MAP SHOWS COUNTER VERTICAL WILLIAMS CRANE & BROWN
TLC14	FREEMAN NO 2 1/2		Tug Hill Plateau	N44-18-15	W75-18-26	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	1977	EST FROM GOUVERNEUR TALC CO INC INFO
TLC12	GOUVERNEUR TALC NO 1		Tug Hill Plateau	N44-15-31	W75-28-34	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	1977	EST FROM GOUVERNEUR TALC CO INC INFO:MAP LEGEND
TLC13	GOUVERNEUR TALC NO 3		Tug Hill Plateau	N44-18-32	W75-18-26	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	1977	EST FROM GOUVERNEUR TALC CO INC INFO & MAP LEGEND
TLC09	JOHNSON		Tug Hill Plateau	N44-16-21	W75-22-11	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	1977	EST FROM GOUVERNEUR TALC CO INC INFO
TLC18	ONTARIO		Tug Hill Plateau	N44-16-38	W75-21-26	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	1977	EST FROM GOUVERNEUR TALC CO INC INFO
TLC10	WIGHT		Tug Hill Plateau	N44-15-16	W75-24-03	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	1977	LOCATION FROM GOUVERNEUR TALC CO INC

TLC04	WINTERGREEN		Tug Hill Plateau	N44-18-15	W75-19-11	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	1977	EST FROM GOUVERNEUR TALC CO INC INFO
TLC06	WOODCOCK		Tug Hill Plateau	N44-15-32	W75-24-03	UNDERGROUND	TALC	GOUVERNEUR TALC CO INC	1977	LOCATION EST FROM GOUVERNEUR TALC CO INFO
TLC14	FREEMAN NO 2 1/2		Tug Hill Plateau	N44-18-15	W75-18-26	UNDERGROUND	TALC	INTERNATI	1977	EST FROM GOUVERNEUR TALC CO INC INFO
TLC14	INTERNATIONAL PULP NO 2 1/2 MINE		Tug Hill Plateau	N44-17-42	W75-22-34	UNDERGROUND	TALC	INTERNATI	0	ALSO ON EDWARDS QUAD
TLC08	ARNOLD MINE-FILE NO 8N075		Tug Hill Plateau	N44-16-05	W75-23-41	UNDERGROUND	TALC	LOOMIS TALC CORP	0	
TLC07	DOMINION		Tug Hill Plateau	N44-15-49	W75-23-18	UNDERGROUND	TALC	UNKNOWN	1919	PRIVATE DOMAIN
TLC02?	EAST ANTHONY-NEWTON PROSPECTS 8		Tug Hill Plateau	N0-00-00	W187-29-19	UNDERGROUND	TALC	UNKNOWN	1945	
TLC16	INTERNATIONAL NO 4 FILE NO 8N078		Tug Hill Plateau	N44-23-42	W185-47-19	UNDERGROUND	TALC	UNKNOWN	1945	
TLC14, 15,	INTERNATIONAL PULP CO SHAFT		Tug Hill Plateau	N44-18-15	W75-18-48	UNDERGROUND	TALC	UNKNOWN	1919	PRIVATE DOMAIN
TLC01	NATURAL BRIDGE TALC-FILE NO 8N03		Tug Hill Plateau	N44-06-04	W75-28-29	UNDERGROUND	TALC	UNKNOWN	1944	
TLC05	U S TALC CO SHAFT		Tug Hill Plateau	N44-18-32	W75-19-11	UNDERGROUND	TALC	UNKNOWN	1919	PRIVATE DOMAIN
TLC04	UNIFORM FIBROUS TALC CO SHAFT		Tug Hill Plateau	N44-18-15	W75-19-11	UNDERGROUND	TALC	UNKNOWN	1919	PRIVATE DOMAIN
FE011a? F	MORGAN OR PARDEE	**JEFFERSON**	Tug Hill Plateau	N44-14-57	W75-34-34	UNDERGROUND	IRON	UNKNOWN	1944	PRIVATE DOMAIN
	SHARON LIMONITE MINE-FILE NO 8N0	**DUTCHESS**	Southeast NY	N0-00-00	W187-29-19	UNDERGROUND	LIMESTONE	UNKNOWN	0	
FE040	BULL MINE	**ORANGE**	Southeast NY	N41-21-58	W74-11-56	UNDERGROUND	IRON	PARROT IRON ORE CO	0	
FE039	FOREST OF DEAN MINE		Southeast NY	N41-19-59	W74-00-51	UNDERGROUND	IRON	FOREST OF DEAN IRON ORE	1939	WITHIN WEST POINT MILITARY RESERVE
	GOSHEN QUARRY-FILE NO 8N136		Southeast NY	N0-00-00	W187-29-19	UNDERGROUND	IRON	DUTCHESS QUARRY & SUPF	1977	NO TOPO AVAILABLE
FE044	RANIER HILL PROSPECT		Southeast NY	N41-22-30	W74-11-34	UNDERGROUND	IRON	UNKNOWN	1944	PRIVATE DOMAIN
FE042	SCOTT		Southeast NY	N41-11-59	W74-14-55	UNDERGROUND	IRON	RAMAPO ORE CO	0	
	SNYDER		Southeast NY	N0-00-00	W187-29-19	UNDERGROUND	IRON	ALAN WOOD STEEL	1914	
FE042a	COOK-SCOTT MINE		Southeast NY	N41-12-31	W74-12-46	UNDERGROUND	LEAD/ZINC	UNKNOWN	0	
	NEW YORK MINE		Southeast NY	N41-33-10	W74-34-49	UNDERGROUND	LEAD/ZINC	ELLENVILLE ZINC CO	0	CENTRAL LOCATION-ULSTER SULLIVAN & ORANGE COUNTIES
FE049a	CROTON MAGNETIC IRON MINE-8BX054	**PUTNAM**	Southeast NY	N41-23-48	W73-36-45	UNDERGROUND	IRON	UNKNOWN	1942	EST AT BREWSTER
FE050	MAHOPAC MINE		Southeast NY	N41-23-54	W73-46-04	UNDERGROUND	IRON	LAKE MA	0	
FE049b	THEALL		Southeast NY	N41-21-56	W73-38-56	UNDERGROUND	IRON	CROTON MAGNETIC IRON M	1891	
ZN09	SHAWANGUNK MINE	**SULLIVAN**	Southeast NY	N41-18-24	W74-04-49	UNDERGROUND	LEAD	ST NICHOLAS ZINC CO	0	
	NEW YORK MINES		Southeast NY	N41-33-10	W74-34-49	UNDERGROUND	LEAD/ZINC	UNKNOWN	0	CENTRAL LOCATION-ULSTER SULLIVAN & ORANGE COUNTIES
ZN09	SHAWANGUNK		Southeast NY	N41-38-34	W74-31-11	UNDERGROUND	LEAD/ZINC	ST NICHOLAS ZINC CO	1944	
ZN09	SUMMITVILLE MINE		Southeast NY	N41-38-34	W74-31-11	UNDERGROUND	LEAD/ZINC	ST NICHOLAS ZINC CO	0	
	WAWARSING PIT-FILE NO 8N137	**ULSTER**	Southeast NY	N0-00-00	W187-29-19	UNDERGROUND	IRON	DUTCHESS QUARRY & SUPF	1977	NO TOPO AVAILABLE
ZN11 or PE	ULSTER MINE		Southeast NY	N41-39-53	W74-25-46	UNDERGROUND	LEAD	UNKNOWN	1948	
	NEW YORK MINES		Southeast NY	N41-33-10	W74-34-49	UNDERGROUND	LEAD/ZINC	UNKNOWN	0	CENTRAL LOCATION-ULSTER SULLIVAN & ORANGE COUNTIES
	LUDLOWVILLE SALT REFINERY	**TOMPKINS**	Finger Lakes	N42-32-18	W76-33-09	UNDERGROUND	BRINE	UNKNOWN	0	PRIVATE DOMAIN

CAYUGA JUNCTION QUARRY	**CAYUGA**	Finger Lakes	N52-51-54	W76-42-06	UNKNOWN	GYPSUM	UNKNOWN		PRIVATE DOMAIN
CROSS ROADS STATION QUARRY		Finger Lakes	N42-52-43	W76-40-39	UNKNOWN	GYPSUM	UNKNOWN		PRIVATE DOMAIN
HIBISCUS POINT QUARRY		Finger Lakes	N52-51-21	W76-42-27	UNKNOWN	GYPSUM	UNKNOWN		PRIVATE DOMAIN
DOLOMITE PRODUCTS GYPSUM MINE	**MONROE**	Western NY	N43-00-18	W77-48-35	UNDERGROUND	GYPSUM	DOLOMITE PRODUCTS CO IN	1943	
EBSARY GYPSUM MINE FILE NO 8N065		Western NY	N0-00-00	W187-29-19	UNDERGROUND	GYPSUM	EBSARY GYPSUM CO	0	LEGEND STATES AT WHEATLAND
DOLOMITE PRODUCTS GYPSUM MINE		Western NY	N43-00-18	W77-48-35	UNDERGROUND	GYPSUM	LYCOMI	1943	
ABANDONED GYPSUM WORKINGS		Western NY	N43-01-19	W77-51-12	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
ABANDONED GYPSUM WORKINGS		Western NY	N42-59-25	W77-51-51	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
CONSOL WHEATLAND PLASTER SHAFT		Western NY	N43-00-01	W77-49-40	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
EMPIRE GYPSUM CO		Western NY	N43-00-36	W77-47-29	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
GARBUTT GYPSUM CO SHAFT		Western NY	N43-00-18	W77-48-35	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
LYCOMING CALCINING CO		Western NY	N43-00-35	W77-48-13	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
MCVANE FARM ADIT		Western NY	N43-01-25	W77-47-31	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
MONARCH PLASTER SHAFT & CRUSHER		Western NY	N43-00-17	W77-49-19	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
ROGERS M FARM GYPSUM DEPOSIT		Western NY	N43-01-07	W77-48-37	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
UNNAMED ADIT		Western NY	N43-00-17	W77-49-41	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
RETSOF MINE	**LIVINGSTON**	Western NY	N42-49-56	W77-52-53	UNDERGROUND	SALT	INTERNATIONAL SALT	1986	LOCATED IN RETSOF, NY
AMERICAN GYPSUM CO SHAFT	**GENESEE**	Western NY	N43-02-03	W78-27-55	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
STANDARD PLASTER CO ABND WKGS		Western NY	N43-01-59	W78-25-20	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
UNNAMED SHAFT		Western NY	N43-04-15	W78-18-15	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
UNNAMED SHAFT		Western NY	N43-04-00	W78-19-00	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
UNNAMED SHAFT		Western NY	N43-04-15	W78-17-53	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN
UNNAMED SHAFTS		Western NY	N43-04-16	W78-18-59	UNDERGROUND	GYPSUM	UNKNOWN	1919	PRIVATE DOMAIN

Appendix C

463 New Karner Road
Albany, NY 12205

Voice: 518-213-0044
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Email: jperry@awstruewind.com

TO: Lisa Hoffman, NYSEG
FROM: Mark Grammatico, Meteorologist
CC: Jim Perry, Project Manager
DATE: 3 December 2009
RE: Virtual Met Mast – Wind Assessment for New York State

Introduction

AWS Truewind was retained by NYSEG to produce a virtual met mast for four regions in New York State. The project areas included in the study were provided by NYSEG as being representative of the wind regime for that region. The virtual met masts are roughly located in South Corning (Steuben County), Lowville (Lewis County), Jordanville (Herkimer County), and portions of Erie and Wyoming County. The project locations are shown in Figure 1(A-D) and the virtual met mast coordinates are included in Table 1.

Table 1. Virtual Met Mast Coordinates

Virtual Met Mast Location	Site Coordinates Lat/Long
South Corning	42.189 N, -76.982 W
Lowville	43.770 N, -75.588 W
Jordanville	42.942 N, -74.887 W
Wyoming/Erie	42.683 N, -78.246 W

Wind Data

The mean wind speeds at the virtual met mast locations are estimated to be between 6.12 m/s (South Corning) and 6.45 m/s (Wyoming/Erie) at an 80 m hub height. The mean wind resource is based on the simulated wind speed time series from the ***windTrends®*** dataset. Figure 2(A-D) contains 12x24 speed matrices that provide a representative long-term monthly and diurnal estimate of the wind speeds for each virtual met mast location. AWS Truewind recommends that all modeled wind resource estimates be verified with on-site measurements.

The Weibull function is an analytical curve that describes the wind speed frequency distribution, or number of observations in specific wind speed ranges. Its two adjustable parameters allow a good fit to a wide range of actual distributions. *A* is a scale parameter related to the mean wind speed while *k* is dependent on the width of the distribution. Values of *k* typically range from 1 to 3.5, the higher values indicating a narrower distribution. We determined that the Weibull distributions that best fit the modeled 80-m frequency distributions have a scale parameter (A) between 7.12 –7.42 and a shape parameter (k) between 2.39 and 2.47. These values are indicative of a moderately variable wind resource, with few high wind events. Figure 3(A-D) includes the predicted annual wind speed frequency distributions and fitted Weibull curves for each location.

Figure 4(A-D) shows the monthly mean wind speed distribution at each virtual met mast location. The highest wind speeds are observed in the fall and winter and the lowest wind speeds observed in summer. The peak is consistent with normal seasonal conditions resulting from strong atmospheric temperature and pressure gradients in the region. The range of variation in the monthly speeds at these locations is estimated to be between 1.9 m/s (South Corning) and 2.4 m/s (Lowville).

Figure 5(A-D) shows the diurnal mean wind speed distributions for each season and on an annual average basis, while Table 3 presents these values in tabular format. The distributions show that the highest wind speeds generally occur during the overnight hours. This is because the absence of solar heating and associated convective mixing at night produces a shallow boundary layer, which is often capped by high winds. The effects of local convective winds are greater during the warmer months when winds are light and solar heating is strong. This leads to a more dramatic difference between wind speeds during daylight and nighttime hours. The range of variation in the annual hourly speeds across the four regions is roughly between 1.8 m/s (Wyoming/Erie, Lowville) and 1.9 m/s (Jordanville, South Corning).

Local Climate

We also estimated local meteorological variables as part of the virtual met mast. The average wind speed, air temperature, air pressure, and air density at the site are presented in Table 2. Figures 6 and 7 show the estimated monthly mean air temperature and density for the virtual met mast locations.

Table 2. New York State Meteorological Variables

Variable	South Corning	Lowville	Jordanville	Wyoming/Erie
Mean Wind Speed (m/s)	6.12	6.38	6.15	6.45
Air Temperature (°C)	6.77	6.06	6.42	6.16
Air Pressure (mb)	938.4	942.3	942.7	931.7
Air Density (kg/m^3)	1.170	1.178	1.177	1.164

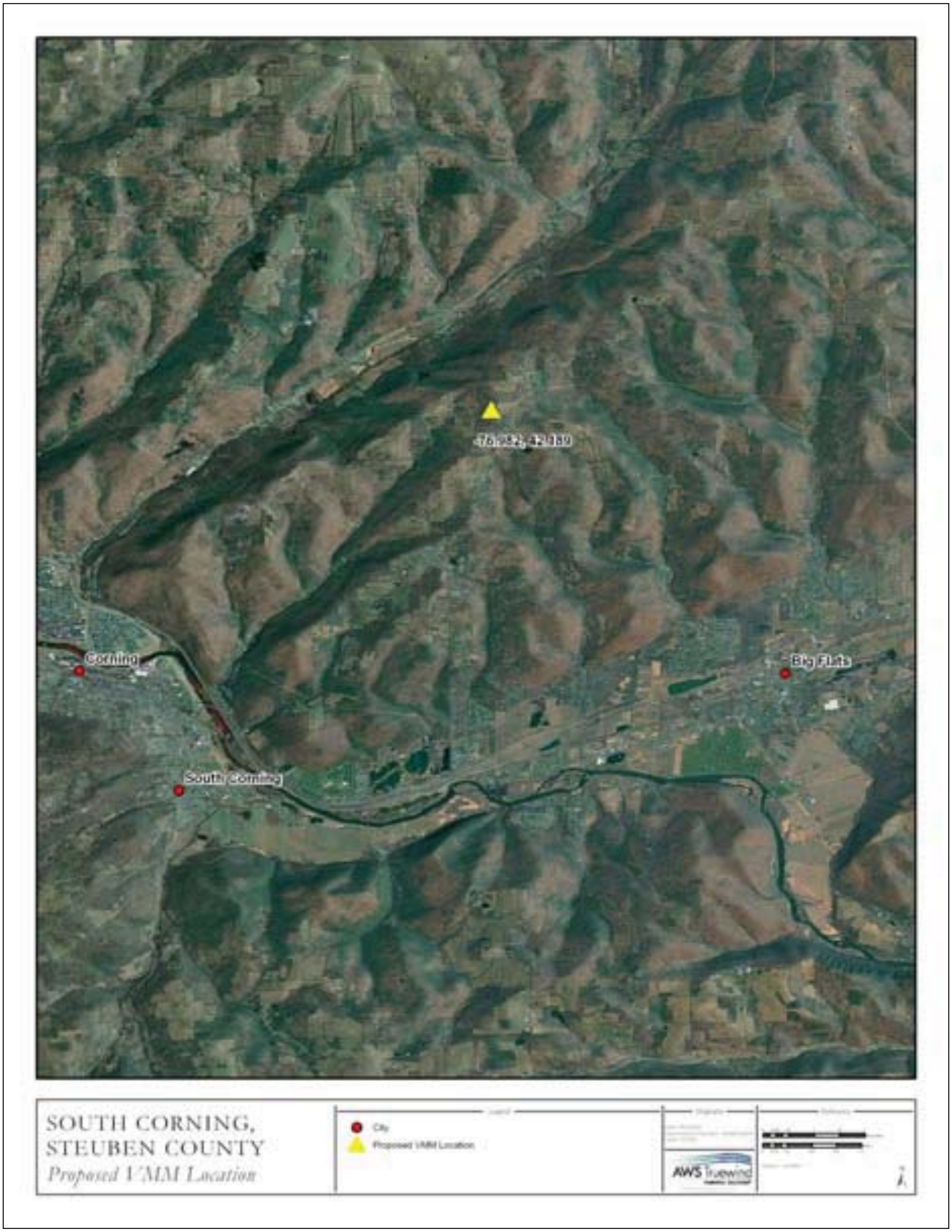


Figure 1A. South Corning Project Area

Figure 1B. Lowville Project Area

Figure 1C. Jordanville Project Area

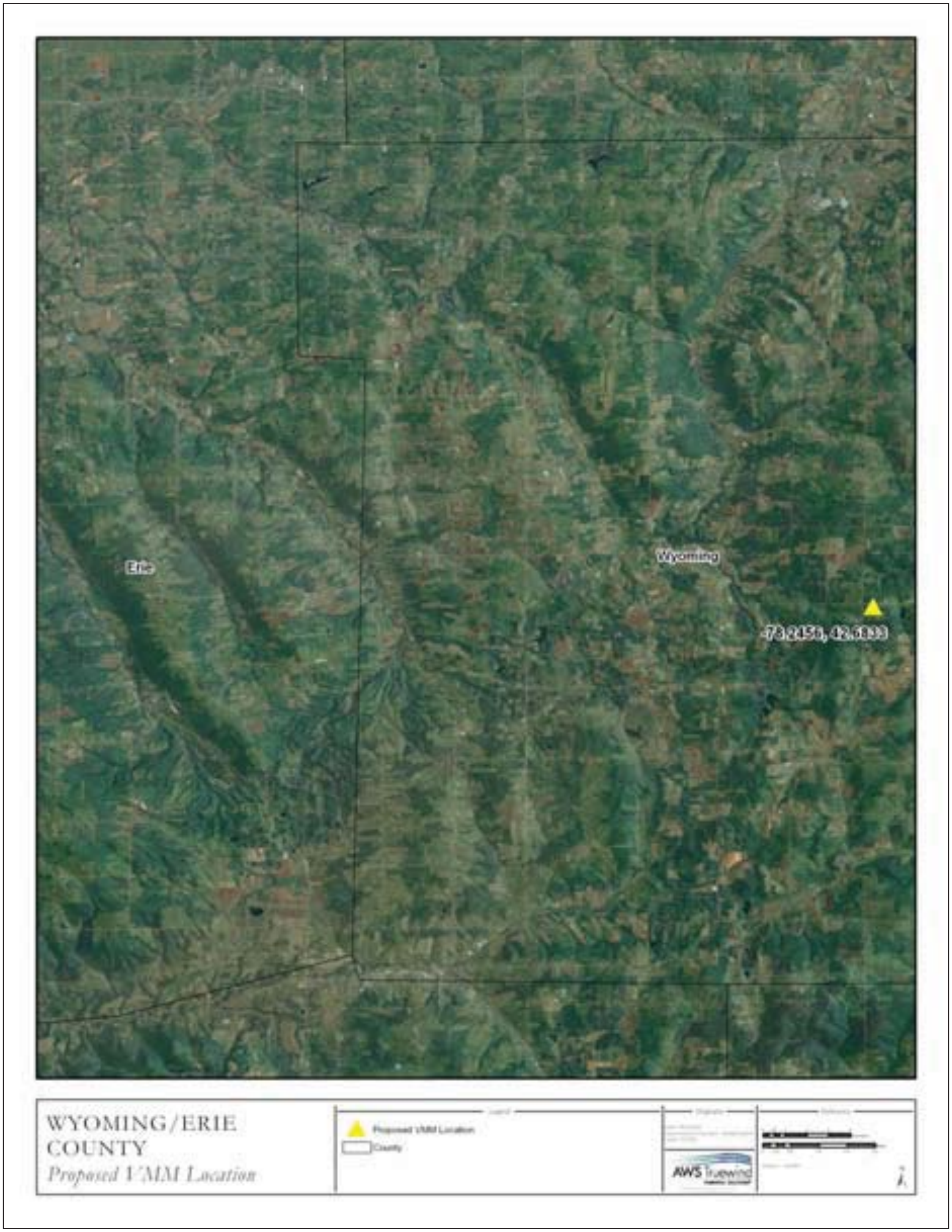


Figure 1D. Wyoming/Erie Project Area

Hour	Month												Average
(LST)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(m/s)
0	7.7	7.1	7.3	7.0	6.8	7.0	6.7	6.4	6.4	7.4	7.1	7.4	7.02
1	7.9	7.6	7.3	7.0	6.9	7.2	6.8	6.2	6.6	7.5	7.2	7.5	7.15
2	7.5	7.8	7.3	7.1	7.1	7.0	6.6	6.0	6.8	7.3	7.1	7.4	7.07
3	7.4	7.6	7.1	7.0	7.2	6.8	6.5	6.2	6.8	7.2	7.5	7.4	7.06
4	7.4	7.5	6.8	6.8	7.3	6.8	6.4	6.4	7.0	7.3	7.6	7.2	7.03
5	7.1	7.4	6.7	6.8	7.3	6.6	6.1	6.6	7.1	7.2	7.6	7.1	6.94
6	6.9	7.6	6.7	6.5	7.0	6.0	5.5	6.5	7.0	7.2	7.5	7.0	6.78
7	6.8	7.7	7.1	6.5	5.8	4.5	4.4	5.4	6.7	7.3	7.5	7.2	6.40
8	6.8	7.3	6.6	5.8	5.5	4.0	3.9	4.5	5.7	6.2	7.2	7.0	5.87
9	6.9	6.8	6.2	5.1	5.2	3.5	3.4	3.5	4.7	5.2	6.9	6.8	5.34
10	6.8	6.6	5.7	4.9	5.0	3.7	3.9	3.4	4.9	4.6	6.3	6.8	5.22
11	6.8	6.1	6.0	4.8	5.1	4.1	4.1	3.7	4.8	4.5	6.1	6.4	5.21
12	6.9	5.8	6.3	5.0	5.2	4.3	4.5	3.8	4.8	4.7	5.8	6.1	5.26
13	6.7	5.9	6.5	5.2	5.4	4.5	4.6	3.9	5.1	5.0	6.0	6.2	5.42
14	6.5	5.9	6.5	5.4	5.0	4.6	4.6	4.0	5.1	5.1	5.9	6.0	5.38
15	6.4	5.7	6.4	5.7	5.2	4.4	4.4	4.1	5.0	5.1	5.9	6.2	5.37
16	6.5	5.8	6.3	5.9	5.0	4.2	4.2	4.0	5.0	5.2	6.1	6.3	5.38
17	6.5	6.0	6.3	6.0	5.2	4.0	4.2	3.9	5.1	5.4	6.2	6.3	5.41
18	6.7	6.0	6.4	6.0	5.2	4.1	4.3	4.3	5.2	6.1	6.4	6.7	5.60
19	7.0	6.2	6.6	6.2	5.3	4.7	4.7	5.1	5.7	7.1	6.4	6.9	6.00
20	7.1	6.1	6.8	6.3	5.8	5.3	5.2	5.4	5.8	7.1	6.4	6.9	6.17
21	7.2	6.0	7.0	6.4	6.2	5.8	5.7	5.6	5.8	7.0	6.5	6.9	6.35
22	7.2	6.4	7.3	6.8	6.6	6.6	6.1	5.9	5.9	7.4	6.5	7.2	6.67
23	7.5	6.6	7.5	6.8	6.8	6.9	6.1	6.2	6.2	7.5	7.0	7.3	6.87
Average (m/s)	7.00	6.65	6.69	6.12	5.96	5.28	5.12	5.05	5.81	6.31	6.69	6.84	Overall 6.12

Figure 2A. South Corning Long Term Monthly and Diurnal Mean Wind Speed Estimate

Hour (LST)	Month												Average (m/s)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
0	7.5	7.9	7.3	7.3	7.1	6.8	6.7	6.4	7.2	7.6	7.1	7.8	7.22
1	7.5	7.7	7.1	7.1	7.3	6.8	6.7	6.2	7.1	7.5	7.1	7.7	7.14
2	7.4	7.5	6.9	7.0	7.3	6.4	6.6	6.1	6.9	7.5	7.0	7.4	7.00
3	7.4	7.3	7.0	7.0	7.5	6.3	6.7	6.0	6.9	7.4	7.3	7.5	7.03
4	7.6	7.1	7.2	6.9	7.6	6.4	6.7	6.3	6.9	7.4	7.6	7.6	7.10
5	7.5	6.9	7.3	6.9	7.5	6.3	6.4	6.3	7.2	7.1	7.8	7.5	7.06
6	7.4	6.6	7.3	6.9	7.0	5.6	5.7	6.2	7.3	6.9	8.0	7.5	6.86
7	7.3	6.4	7.1	6.7	5.7	4.5	4.3	5.0	6.9	6.7	8.1	7.6	6.35
8	6.9	5.9	6.8	5.9	5.4	4.4	4.1	4.3	5.6	6.0	7.7	7.6	5.88
9	6.5	5.3	6.5	5.0	5.1	4.3	3.9	3.6	4.3	5.3	7.3	7.7	5.40
10	6.3	5.3	6.5	5.0	5.1	4.6	4.4	4.1	4.5	5.1	6.9	7.7	5.47
11	6.2	5.5	6.6	5.1	5.4	4.8	4.8	4.5	5.0	5.3	6.6	7.4	5.61
12	6.5	5.8	6.7	5.2	5.6	4.8	5.2	4.5	4.9	5.6	6.2	7.2	5.69
13	6.8	6.3	7.1	5.4	6.0	5.0	5.4	4.4	5.3	5.9	6.1	6.9	5.89
14	6.8	6.6	7.1	5.3	5.9	5.1	5.5	4.3	5.2	6.0	6.2	6.7	5.90
15	6.7	6.9	6.9	5.6	5.9	5.2	5.6	4.2	5.2	6.2	6.4	6.8	5.95
16	6.8	6.9	6.9	5.5	6.0	5.3	5.5	4.2	5.2	6.4	6.5	6.8	5.98
17	7.0	7.2	7.0	5.4	5.9	5.1	5.2	4.4	5.2	6.5	6.9	6.8	6.03
18	7.2	7.6	7.0	5.4	5.9	4.9	5.1	4.6	5.6	6.6	7.0	6.8	6.14
19	7.2	8.0	7.1	5.4	6.0	4.9	5.2	4.9	6.5	6.9	7.3	6.8	6.35
20	7.1	8.1	7.2	5.8	6.2	5.4	5.6	4.9	6.7	6.8	7.2	7.3	6.52
21	6.9	8.2	7.3	6.2	6.4	5.9	5.9	5.0	6.9	6.8	7.2	7.9	6.69
22	7.0	8.1	7.2	6.3	6.3	6.3	6.6	5.6	7.4	7.1	7.1	7.9	6.89
23	7.2	8.0	7.1	6.7	6.6	6.7	6.5	6.1	7.4	7.3	7.2	7.8	7.05
Average (m/s)	7.02	6.97	7.01	6.04	6.28	5.48	5.60	5.09	6.13	6.58	7.08	7.37	Overall 6.38

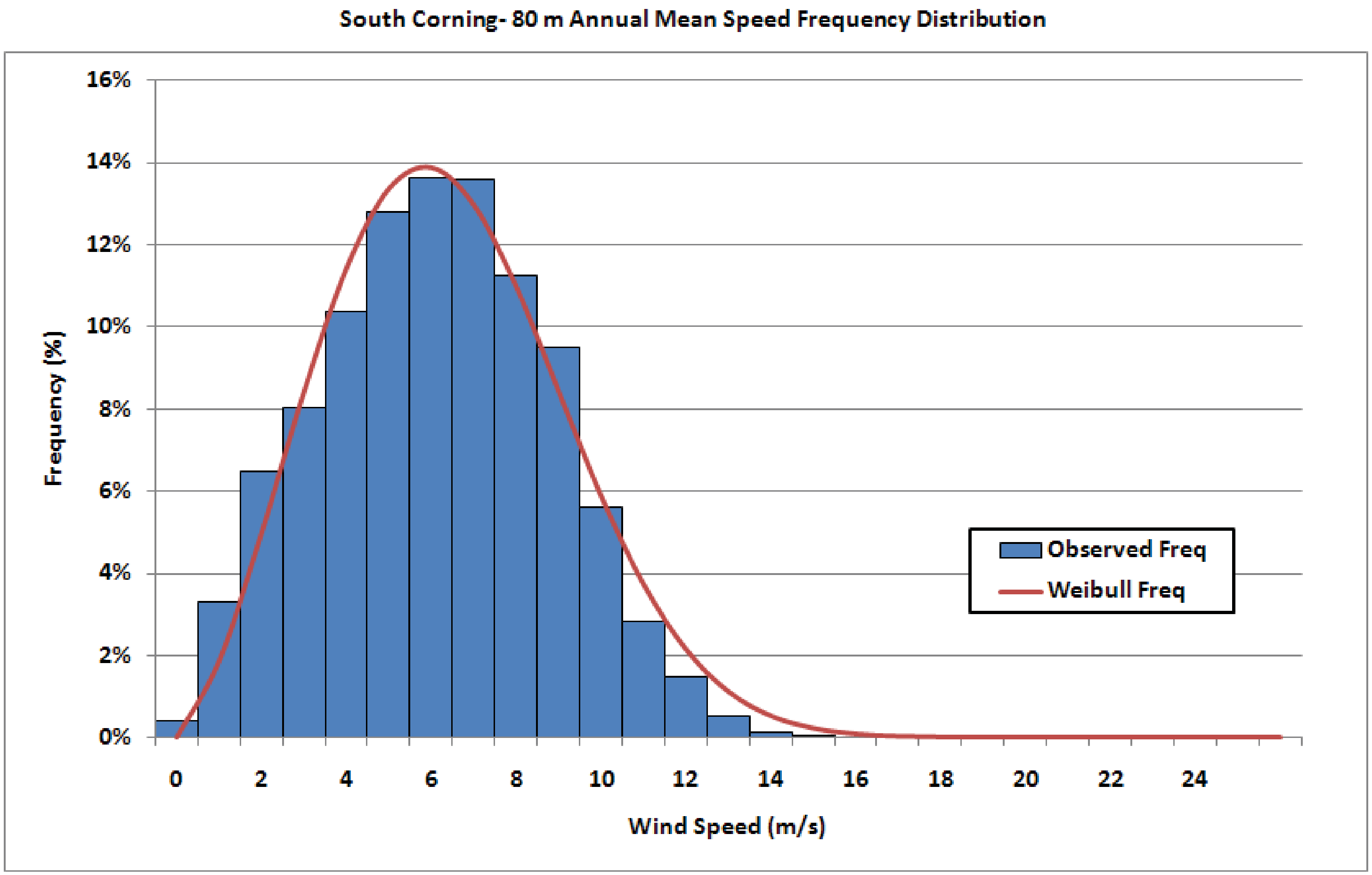
Figure 2B. Lowville Long Term Monthly and Diurnal Mean Wind Speed Estimate

Hour (LST)	Month												Average (m/s)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
0	8.0	7.5	6.7	6.6	6.9	6.7	6.6	6.6	7.4	7.3	7.0	7.7	7.09
1	8.0	7.5	6.9	6.7	6.8	6.6	6.4	6.5	7.1	7.3	7.2	7.8	7.07
2	7.9	7.4	7.0	6.6	6.8	6.5	6.2	6.1	6.6	7.1	7.2	7.6	6.90
3	7.9	7.6	6.9	6.8	6.8	6.5	6.2	5.8	6.3	7.1	7.2	7.8	6.91
4	7.8	7.5	6.9	7.0	6.8	6.6	6.2	5.8	6.3	6.9	7.2	7.9	6.91
5	7.5	7.4	6.7	6.7	6.5	6.6	6.0	5.6	6.5	6.9	7.2	7.6	6.77
6	7.4	7.2	6.5	6.6	6.0	5.3	5.2	5.2	6.3	6.8	7.2	7.4	6.42
7	7.7	7.4	6.4	6.4	4.9	4.2	3.7	4.0	5.8	7.0	7.3	7.5	6.01
8	7.5	7.1	5.9	5.8	4.4	4.3	3.8	3.6	4.7	5.9	6.9	7.2	5.59
9	7.3	6.8	5.4	5.3	3.9	4.4	3.9	3.1	3.6	4.8	6.6	6.9	5.16
10	7.0	6.7	5.4	5.1	4.3	4.7	4.2	3.6	3.9	5.1	6.0	6.7	5.22
11	6.8	6.5	5.5	5.1	4.3	4.8	4.6	3.9	4.2	5.5	6.0	6.4	5.28
12	6.7	6.4	5.7	5.3	4.9	4.7	4.8	4.1	4.2	5.5	6.0	6.1	5.36
13	6.5	6.3	6.0	5.3	5.3	4.5	4.9	4.3	4.5	5.8	5.9	6.2	5.45
14	6.4	6.1	6.2	5.1	5.4	4.2	4.9	4.1	4.5	5.9	6.1	6.2	5.43
15	6.3	6.1	6.5	5.5	5.6	4.2	4.8	4.4	4.6	6.1	6.1	6.2	5.53
16	6.3	6.2	6.7	5.7	5.4	4.3	4.7	4.5	4.6	6.1	6.2	6.5	5.59
17	6.4	6.4	6.8	5.9	5.5	4.4	4.5	4.6	4.7	6.3	6.7	6.6	5.72
18	6.3	6.7	6.9	6.0	5.8	4.2	4.6	4.7	5.4	7.1	7.0	7.0	5.99
19	6.5	7.0	7.1	6.1	6.2	4.5	5.0	5.2	6.6	7.8	7.1	7.3	6.37
20	6.7	7.0	7.1	6.3	6.6	4.9	5.6	5.2	6.6	7.4	7.0	7.4	6.48
21	6.9	6.9	7.1	6.5	6.9	5.3	6.3	5.3	6.7	7.0	6.9	7.4	6.58
22	7.1	6.9	7.0	6.3	7.3	5.9	6.6	5.8	7.2	7.0	6.7	7.3	6.76
23	7.7	7.1	6.8	6.6	7.0	6.3	6.5	6.6	7.3	7.1	6.8	7.4	6.93
Average (m/s)	7.10	6.91	6.52	6.05	5.85	5.18	5.26	4.94	5.65	6.53	6.72	7.09	Overall 6.15

Figure 2C. Jordanville Long Term Monthly and Diurnal Mean Wind Speed Estimate

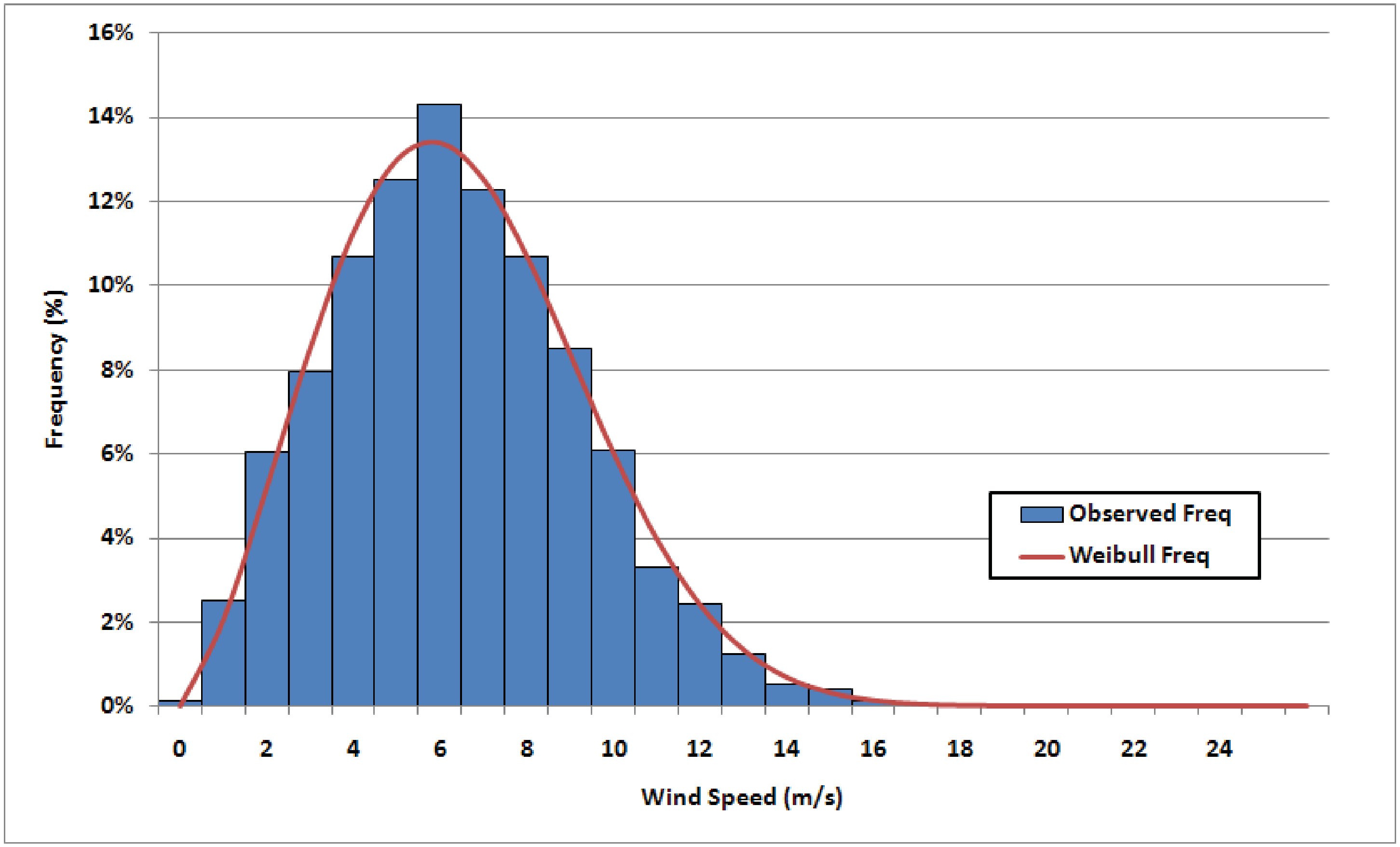
Hour	Month												Average
(LST)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(m/s)
0	8.0	8.6	7.6	6.9	7.3	7.3	6.5	7.1	7.3	7.4	7.3	8.0	7.44
1	7.8	8.5	7.7	6.9	7.4	7.2	6.4	6.9	7.1	7.6	7.7	8.1	7.44
2	7.7	8.2	7.5	6.8	7.0	7.2	6.4	6.6	6.6	7.5	7.6	8.0	7.25
3	7.7	8.0	7.3	6.9	7.1	7.3	6.3	6.4	6.5	7.5	7.5	8.1	7.20
4	7.8	7.6	7.4	7.1	7.0	7.1	6.3	6.2	7.0	7.4	7.6	8.0	7.20
5	7.7	7.4	7.3	7.1	6.9	6.8	6.3	5.9	7.0	7.1	7.4	7.7	7.04
6	7.6	7.1	7.0	6.9	6.4	5.9	5.6	5.5	6.7	7.2	7.5	7.5	6.75
7	7.7	6.8	7.2	6.5	5.7	4.7	4.2	4.3	6.4	7.4	7.5	7.6	6.33
8	7.6	6.5	6.9	6.0	5.6	4.6	4.2	4.0	5.3	6.5	7.4	7.5	6.00
9	7.5	6.1	6.6	5.4	5.6	4.5	4.3	3.7	4.3	5.6	7.3	7.4	5.68
10	7.1	6.1	6.3	5.4	5.4	4.7	4.7	4.0	4.5	6.0	6.9	7.4	5.71
11	6.6	6.1	6.3	5.3	5.8	4.8	4.8	4.1	4.6	6.2	6.9	6.9	5.69
12	6.4	6.1	6.5	5.2	5.8	4.8	4.9	4.2	4.8	6.2	6.8	6.4	5.67
13	6.5	6.3	6.7	5.2	5.9	4.7	5.0	4.5	4.8	6.3	6.9	6.4	5.76
14	6.6	6.4	6.6	5.4	5.7	4.4	5.0	4.3	4.8	6.3	6.7	6.3	5.73
15	6.8	6.5	6.8	5.6	5.6	4.2	5.0	4.5	4.9	6.5	6.6	6.4	5.78
16	7.0	6.6	6.9	5.6	5.3	3.8	4.6	4.5	5.0	6.6	6.8	6.8	5.79
17	7.1	6.7	6.9	5.7	5.3	3.5	4.3	4.3	5.1	6.8	6.8	6.8	5.77
18	7.3	7.2	6.9	5.9	5.4	3.5	4.2	4.8	5.7	7.1	6.7	7.1	5.97
19	7.4	7.9	7.1	6.2	6.0	3.9	4.5	5.2	6.7	7.9	6.9	7.5	6.45
20	7.5	8.1	7.4	6.6	6.2	4.5	5.5	5.7	6.8	7.6	6.9	7.6	6.69
21	7.6	8.3	7.6	7.1	6.3	5.0	6.4	6.1	6.9	7.4	6.9	7.6	6.93
22	8.1	8.6	7.7	7.1	6.4	5.6	6.5	6.7	7.4	7.2	7.0	7.7	7.16
23	8.1	8.5	7.8	7.1	6.8	6.2	6.5	7.2	7.6	7.3	7.4	7.8	7.36
Average (m/s)	7.37	7.26	7.08	6.26	6.16	5.25	5.35	5.27	5.99	6.94	7.13	7.36	Overall 6.45

Figure 2D. Wyoming/Erie County Long Term Monthly and Diurnal Mean Wind Speed Estimate



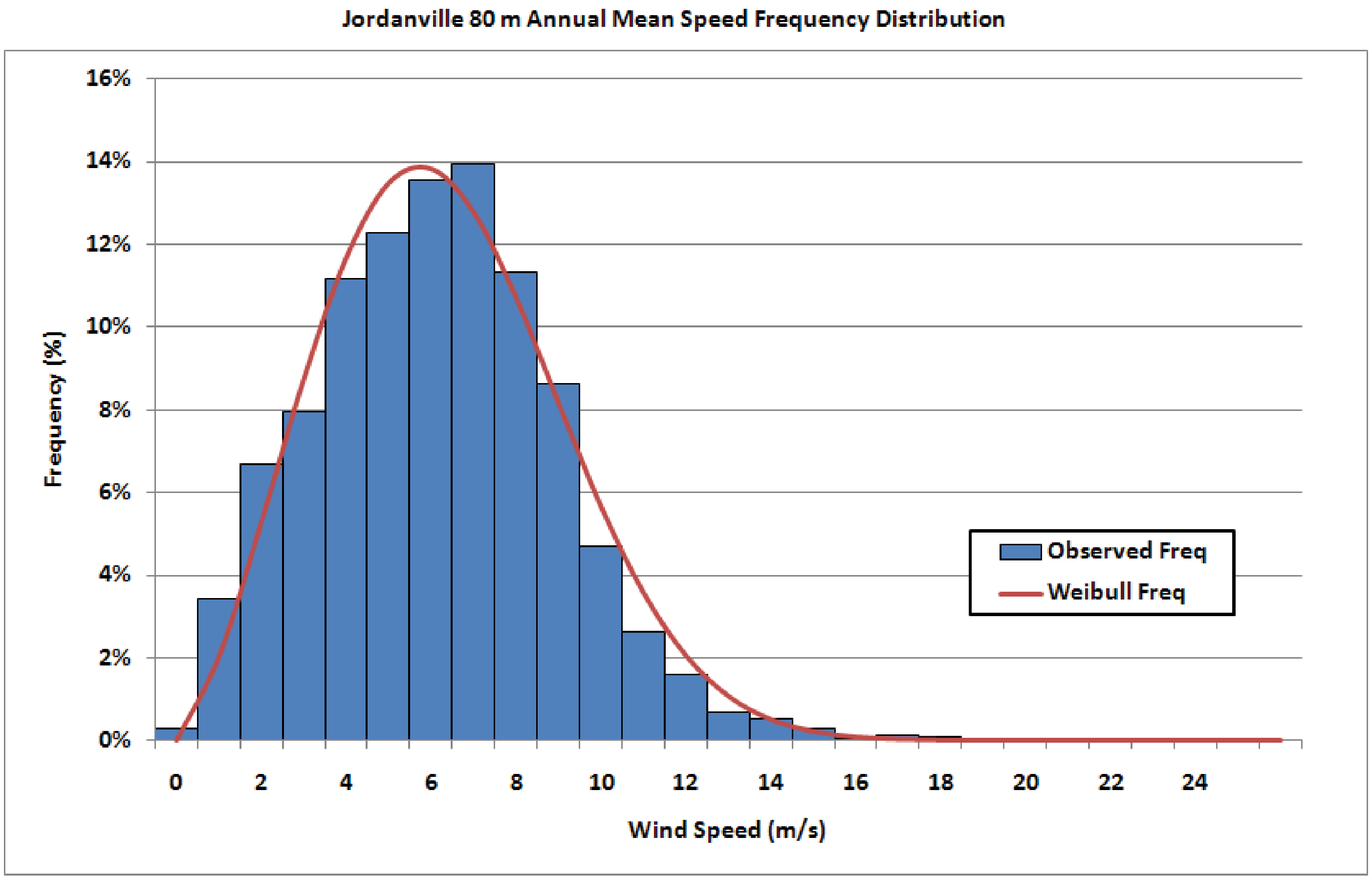
Speed Bin	Frequency
0	0.4%
1	3.3%
2	6.5%
3	8.0%
4	10.4%
5	12.8%
6	13.6%
7	13.6%
8	11.3%
9	9.5%
10	5.6%
11	2.8%
12	1.5%
13	0.5%
14	0.1%
15	0.1%
16	0.0%
17	0.0%
18	0.0%
19	0.0%
20	0.0%
21	0.0%
22	0.0%
23	0.0%
24	0.0%
25	0.0%
>25	0.0%

Figure 3A. South Corning Annual Mean Wind Speed Frequency Distribution and Fitted Weibull Curve



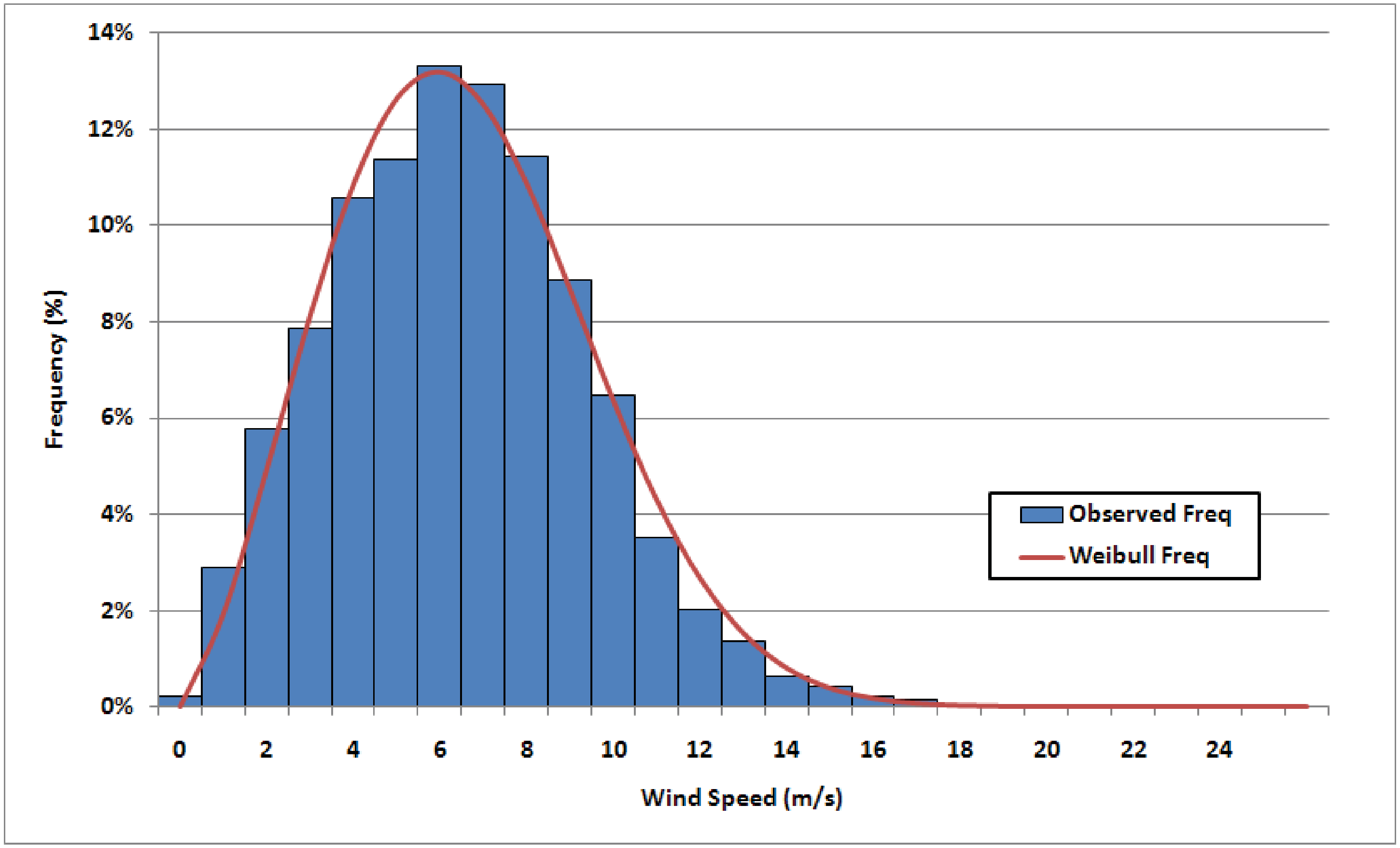
Speed Bin	Frequency
0	0.1%
1	2.5%
2	6.1%
3	8.0%
4	10.7%
5	12.5%
6	14.3%
7	12.3%
8	10.7%
9	8.5%
10	6.1%
11	3.3%
12	2.4%
13	1.2%
14	0.5%
15	0.4%
16	0.1%
17	0.1%
18	0.0%
19	0.0%
20	0.0%
21	0.0%
22	0.0%
23	0.0%
24	0.0%
25	0.0%
>25	0.0%

Figure 3B. Lowville Annual Mean Wind Speed Frequency Distribution and Fitted Weibull Curve



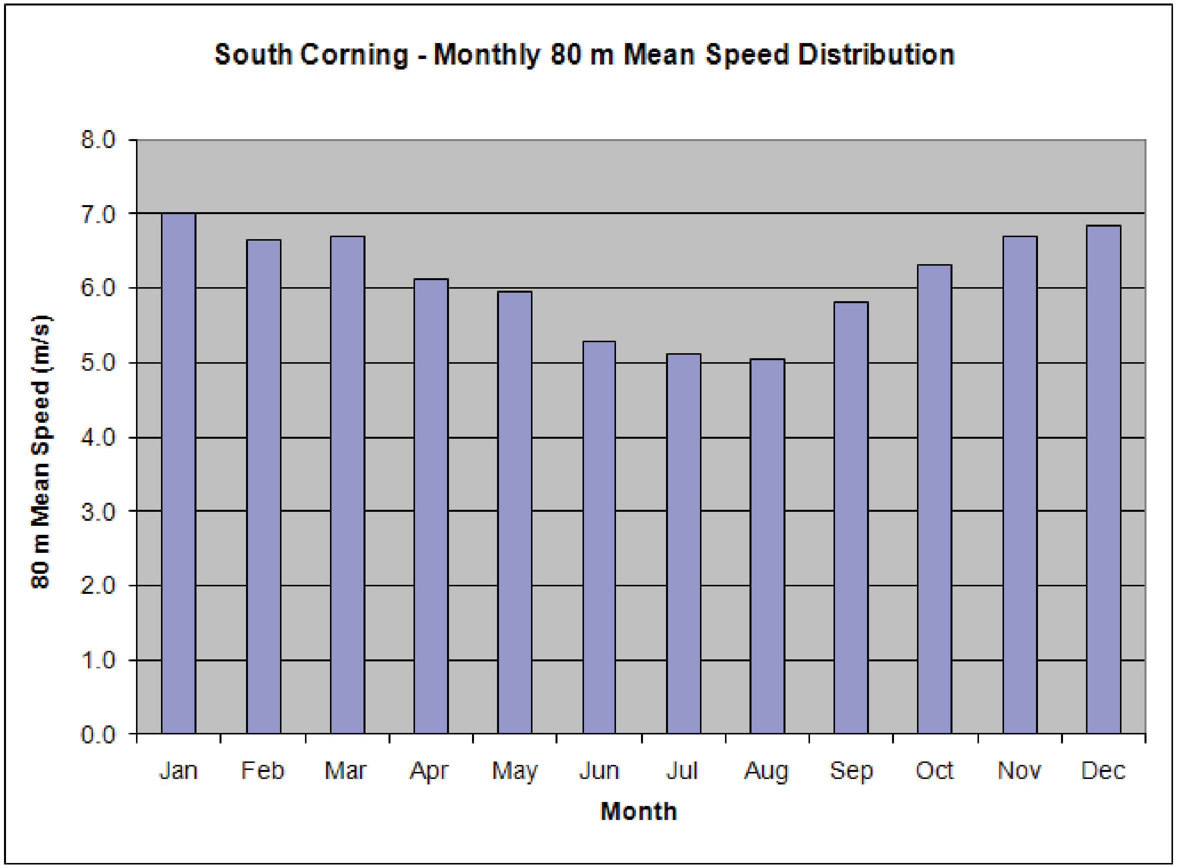
Speed Bin	Frequency
0	0.3%
1	3.4%
2	6.7%
3	8.0%
4	11.2%
5	12.3%
6	13.5%
7	13.9%
8	11.3%
9	8.6%
10	4.7%
11	2.6%
12	1.6%
13	0.7%
14	0.5%
15	0.3%
16	0.1%
17	0.1%
18	0.1%
19	0.0%
20	0.0%
21	0.0%
22	0.0%
23	0.0%
24	0.0%
25	0.0%
>25	0.0%

Figure 3C. Jordanville Annual Mean Wind Speed Frequency Distribution and Fitted Weibull Curve



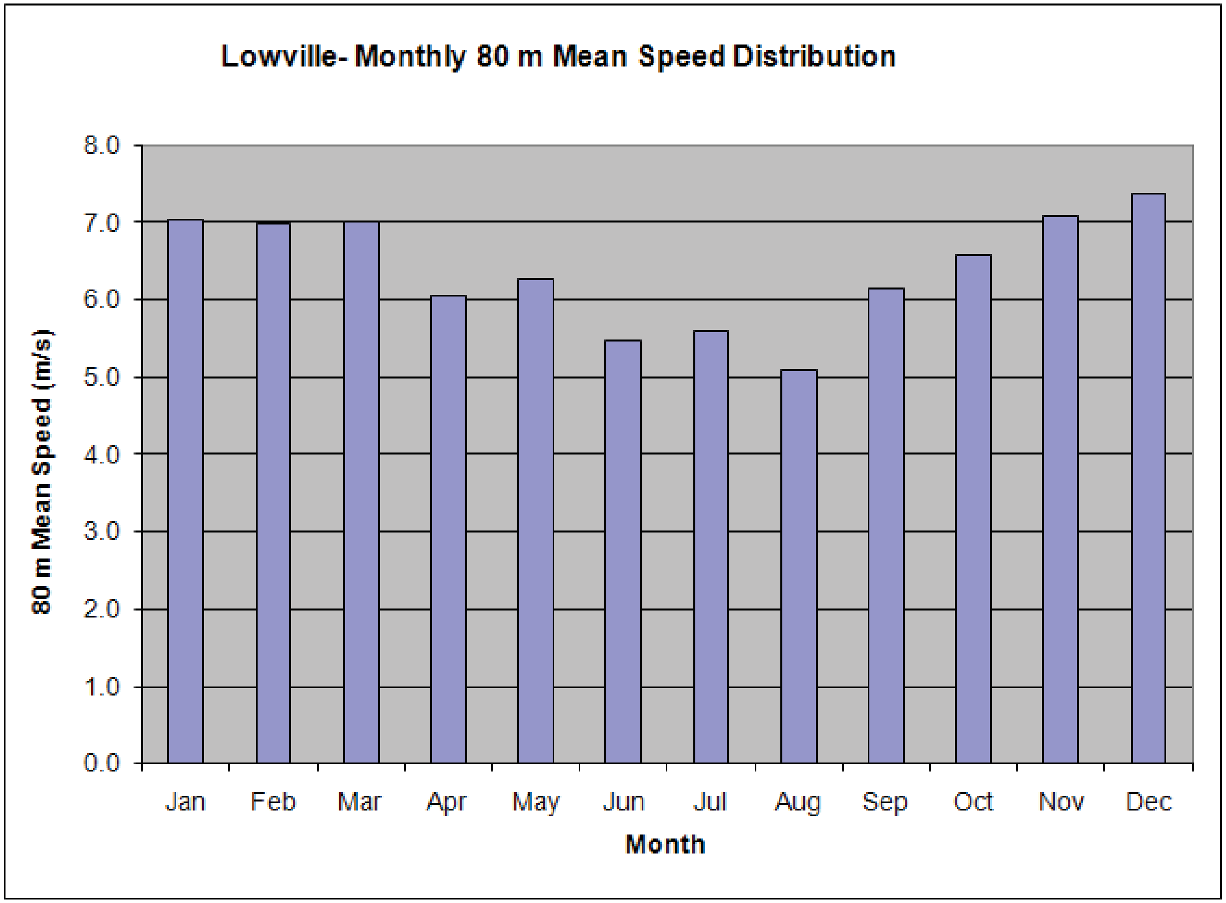
Speed Bin	Frequency
0	0.2%
1	2.9%
2	5.8%
3	7.9%
4	10.6%
5	11.4%
6	13.3%
7	12.9%
8	11.4%
9	8.9%
10	6.5%
11	3.5%
12	2.0%
13	1.4%
14	0.6%
15	0.4%
16	0.2%
17	0.1%
18	0.0%
19	0.0%
20	0.0%
21	0.0%
22	0.0%
23	0.0%
24	0.0%
25	0.0%
>25	0.0%

Figure 3D. Wyoming/Erie County Annual Mean Wind Speed Frequency Distribution and Fitted Weibull Curve



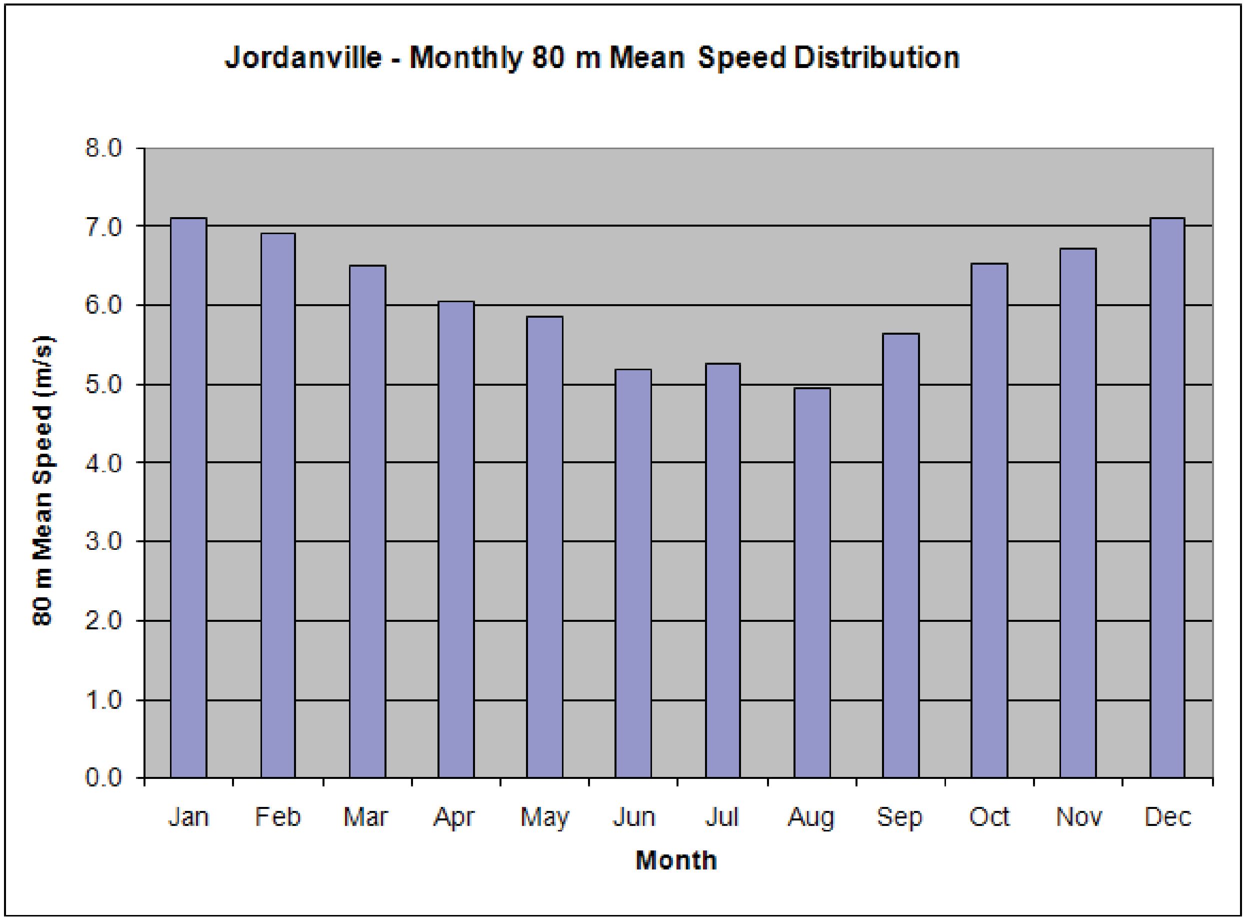
Month	80 m Mean Speed
Jan	7.00
Feb	6.65
Mar	6.69
Apr	6.12
May	5.96
Jun	5.28
Jul	5.12
Aug	5.05
Sep	5.81
Oct	6.31
Nov	6.69
Dec	6.84

Figure 4A. South Corning Monthly Mean Wind Speed Distribution



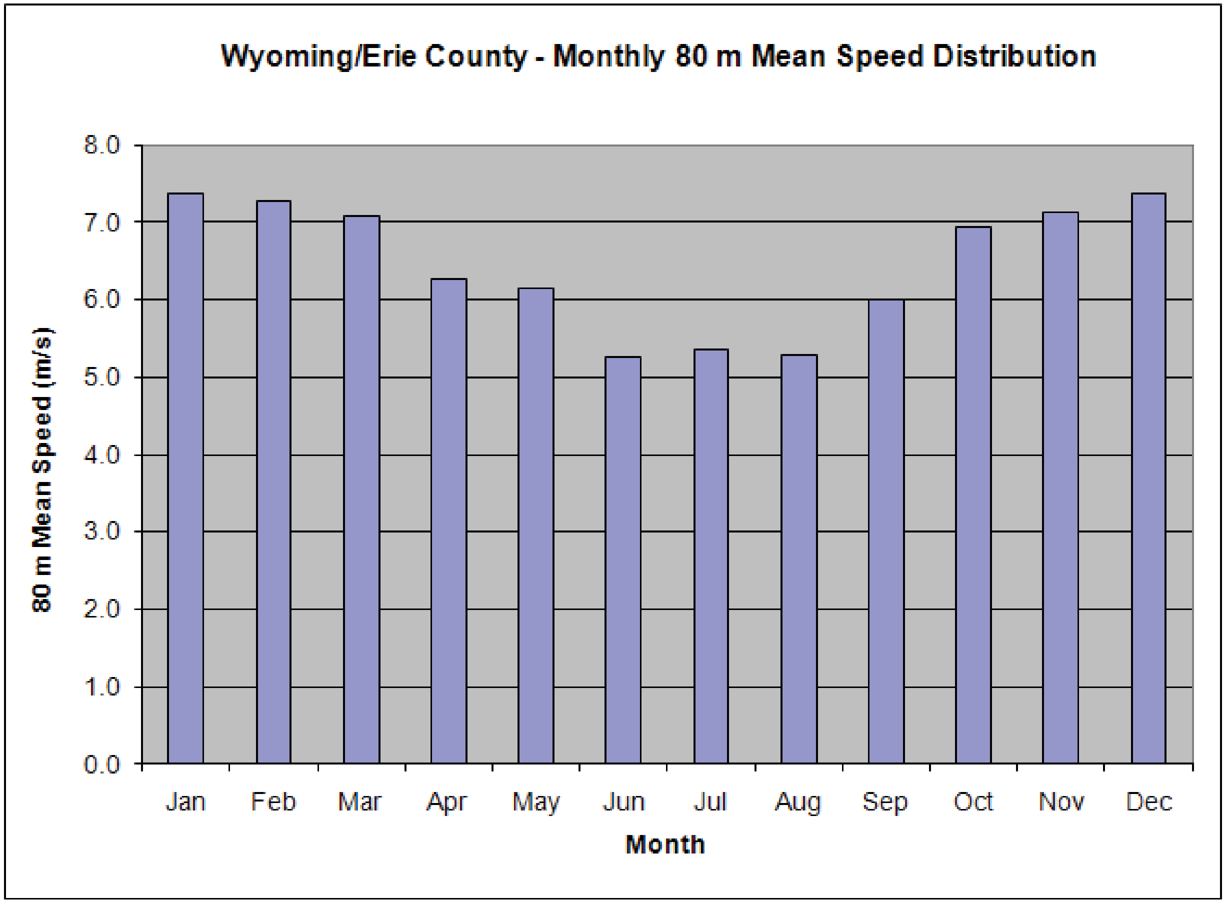
Month	80 m Mean Speed
Jan	7.02
Feb	6.97
Mar	7.01
Apr	6.04
May	6.28
Jun	5.48
Jul	5.60
Aug	5.09
Sep	6.13
Oct	6.58
Nov	7.08
Dec	7.37

Figure 4B. Lowville Monthly Mean Wind Speed Distribution



Month	80 m Mean Speed
Jan	7.10
Feb	6.91
Mar	6.52
Apr	6.05
May	5.85
Jun	5.18
Jul	5.26
Aug	4.94
Sep	5.65
Oct	6.53
Nov	6.72
Dec	7.09

Figure 4C. Jordanville Monthly Mean Wind Speed Distribution



Month	80 m Mean Speed
Jan	7.37
Feb	7.26
Mar	7.08
Apr	6.26
May	6.16
Jun	5.25
Jul	5.35
Aug	5.27
Sep	5.99
Oct	6.94
Nov	7.13
Dec	7.36

Figure 4D. Wyoming/Erie County Monthly Mean Wind Speed Distribution

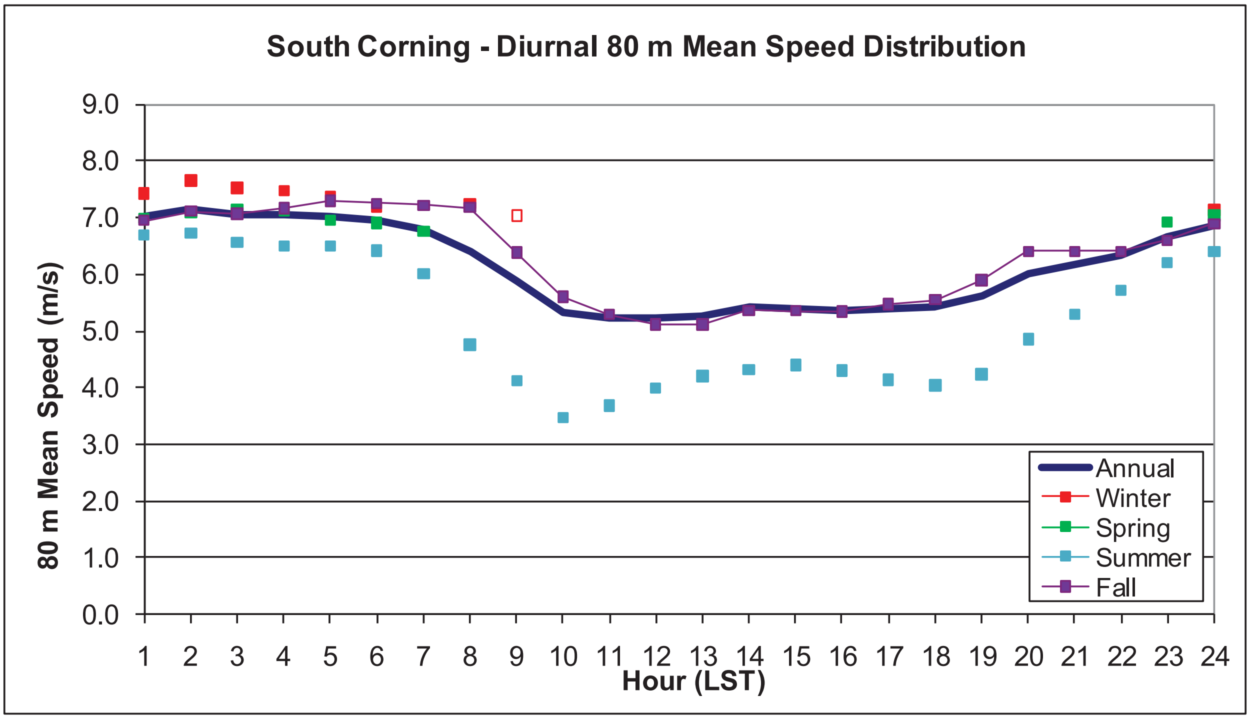


Figure 5A. South Corning Diurnal Wind Speed Distribution

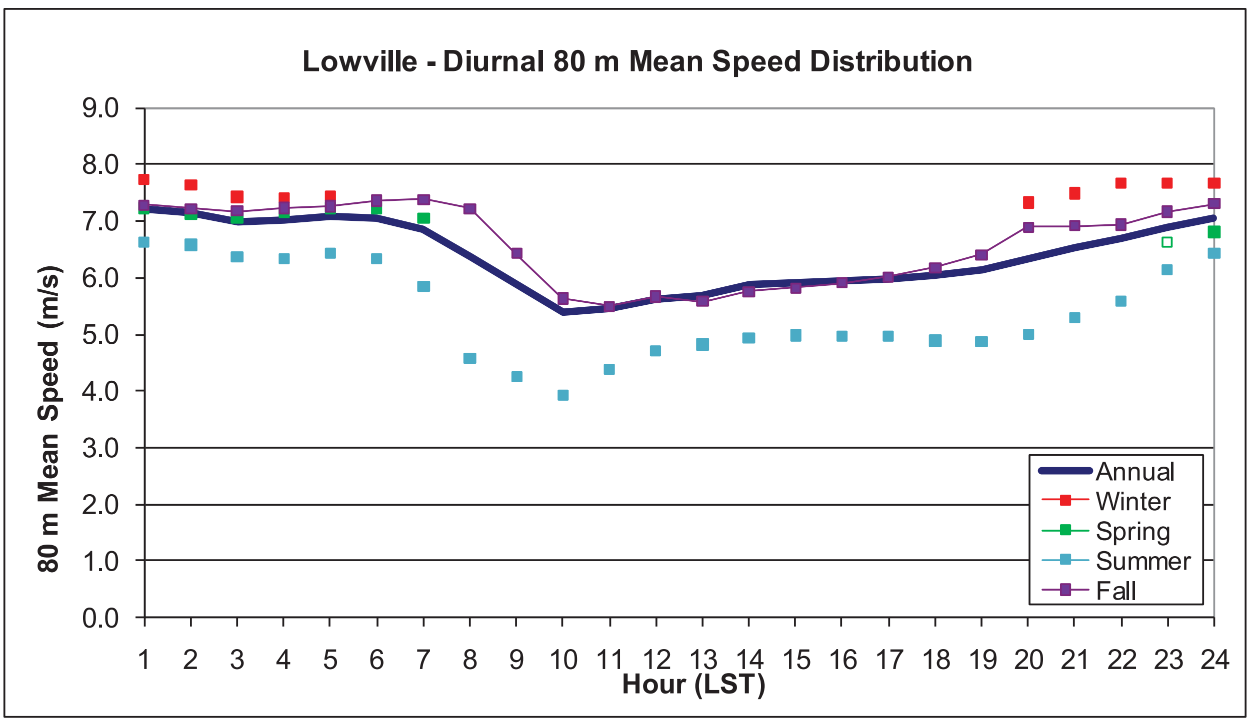


Figure 5B. Lowville Diurnal Wind Speed Distribution

AWS Truewind

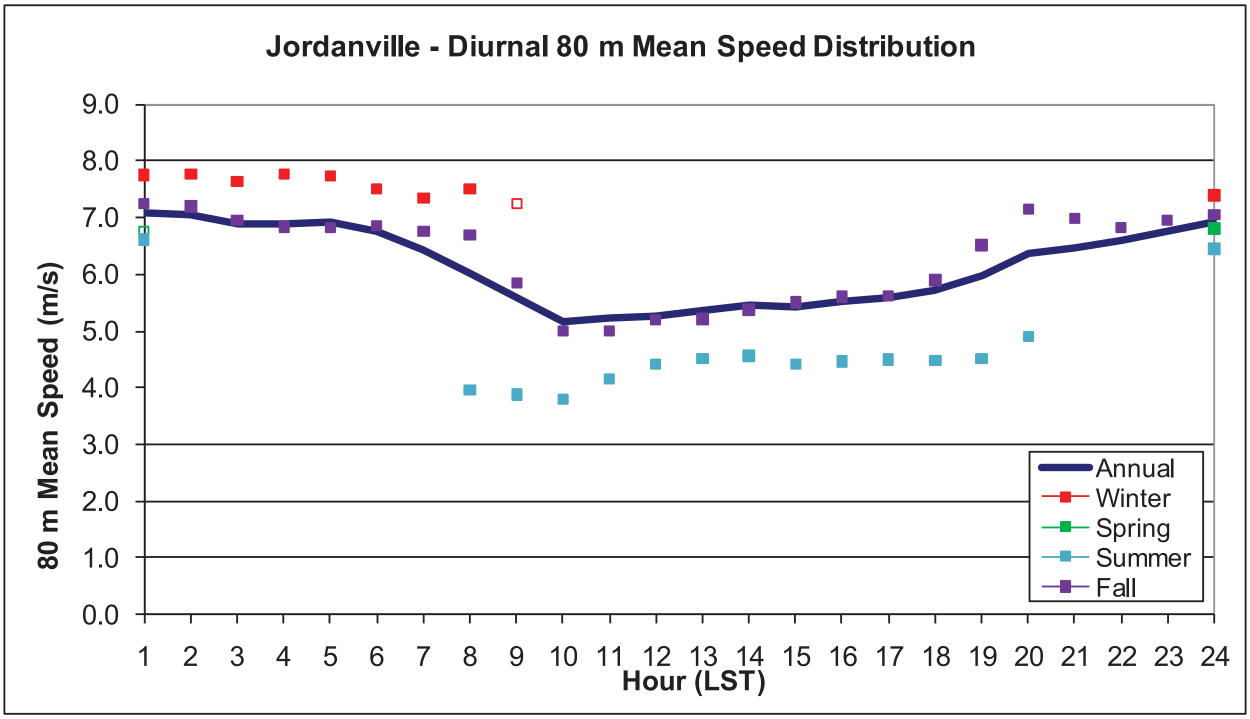


Figure 5C. Jordanville Diurnal Wind Speed Distribution

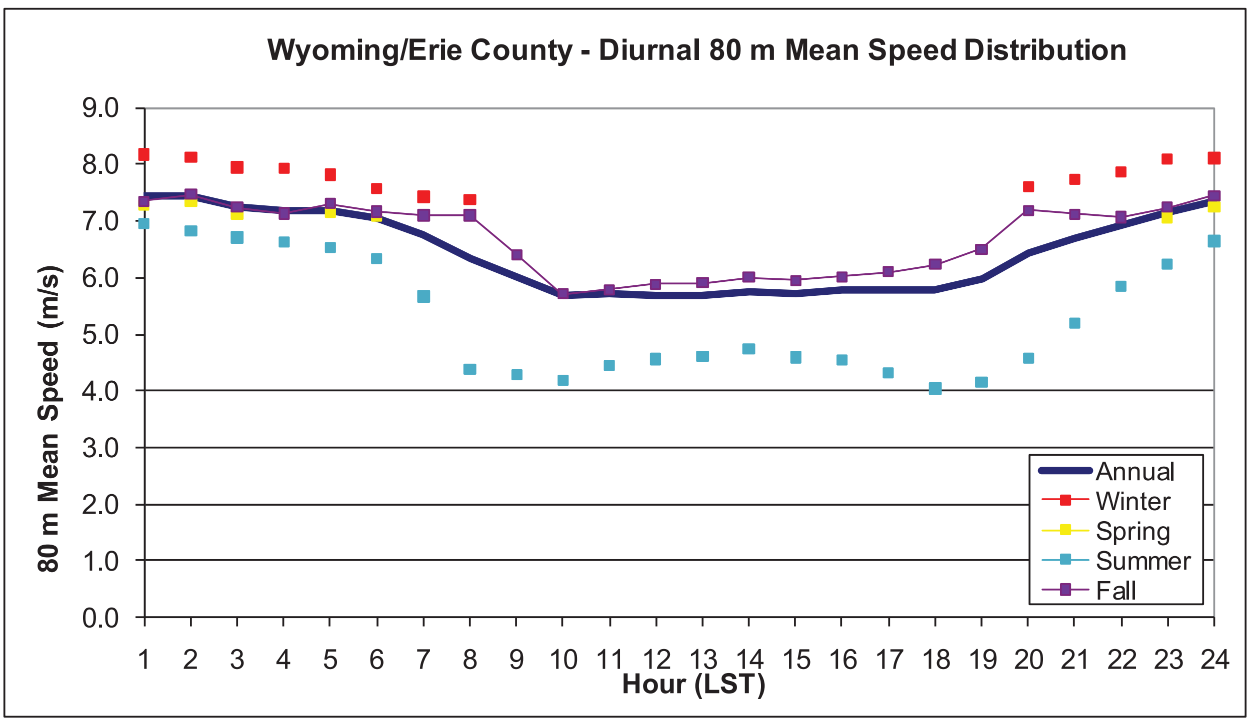


Figure 5D. Wyoming/Erie County Diurnal Wind Speed Distribution

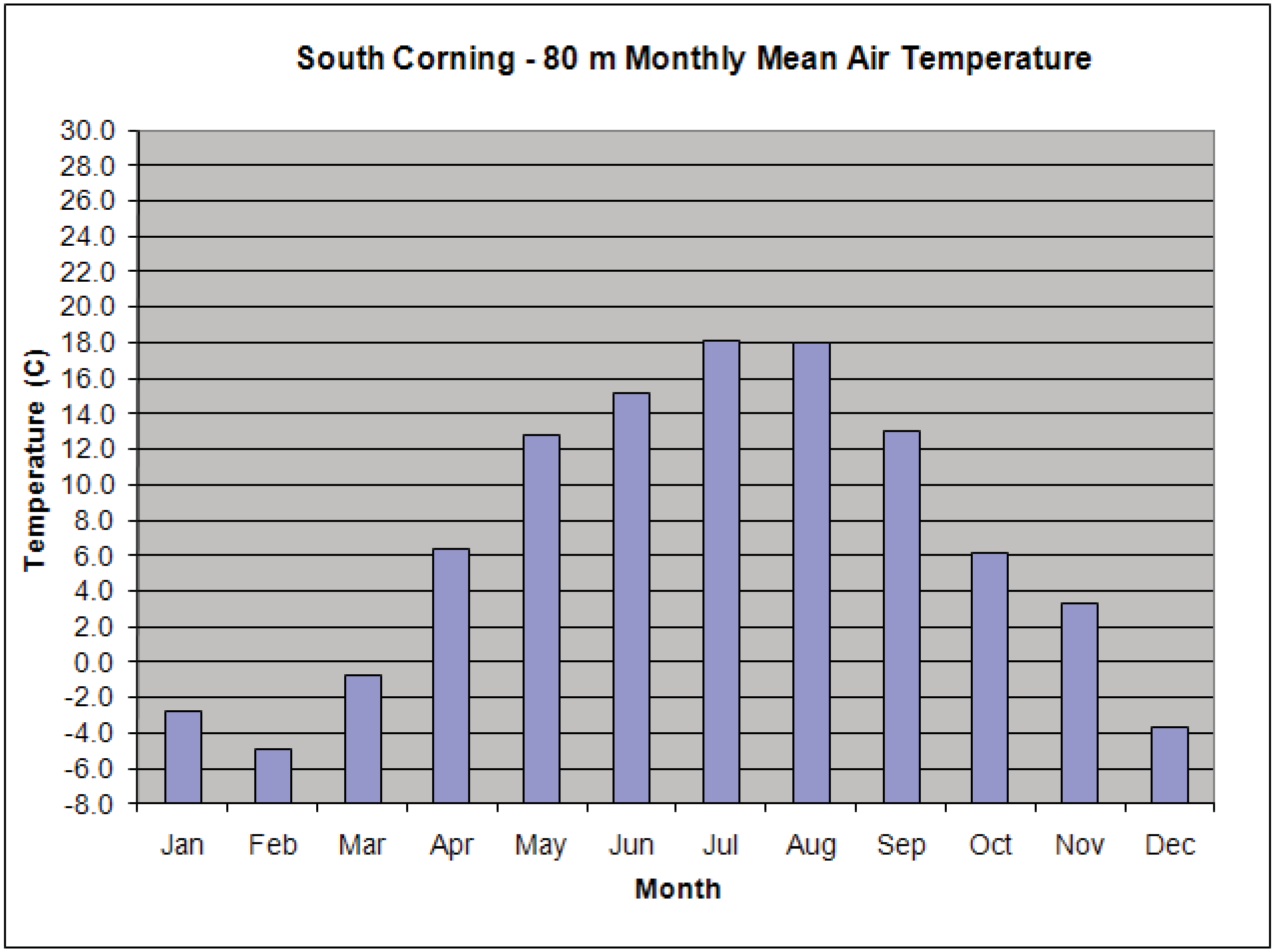
Table 3. Diurnal Wind Speed Distributions by Season

Hour (LST)	South Corning 80 m Mean Speed				
	Annual	Winter	Spring	Summer	Fall
0	7.02	7.43	7.00	6.69	6.95
1	7.15	7.66	7.08	6.74	7.12
2	7.07	7.52	7.14	6.56	7.07
3	7.06	7.47	7.11	6.49	7.16
4	7.03	7.38	6.96	6.51	7.30
5	6.94	7.19	6.91	6.42	7.26
6	6.78	7.16	6.75	6.00	7.22
7	6.40	7.25	6.47	4.76	7.17
8	5.87	7.04	5.98	4.12	6.39
9	5.34	6.82	5.49	3.48	5.60
10	5.22	6.70	5.23	3.68	5.29
11	5.21	6.47	5.29	3.99	5.11
12	5.26	6.24	5.49	4.21	5.11
13	5.42	6.27	5.71	4.32	5.36
14	5.38	6.14	5.64	4.40	5.35
15	5.37	6.09	5.75	4.30	5.34
16	5.38	6.19	5.72	4.13	5.47
17	5.41	6.26	5.83	4.04	5.55
18	5.60	6.45	5.84	4.23	5.90
19	6.00	6.68	6.03	4.86	6.41
20	6.17	6.70	6.27	5.29	6.41
21	6.35	6.72	6.51	5.72	6.41
22	6.67	6.96	6.91	6.21	6.60
23	6.87	7.13	7.03	6.40	6.89

Hour (LST)	Lowville 80 m Mean Speed				
	Annual	Winter	Spring	Summer	Fall
0	7.22	7.74	7.23	6.64	7.29
1	7.14	7.63	7.14	6.58	7.22
2	7.00	7.43	7.05	6.37	7.17
3	7.03	7.42	7.15	6.33	7.23
4	7.10	7.45	7.24	6.43	7.27
5	7.06	7.31	7.24	6.33	7.37
6	6.86	7.18	7.05	5.84	7.38
7	6.35	7.11	6.51	4.59	7.22
8	5.88	6.80	6.03	4.25	6.43
9	5.40	6.50	5.54	3.92	5.63
10	5.47	6.43	5.56	4.37	5.50
11	5.61	6.36	5.69	4.71	5.67
12	5.69	6.53	5.83	4.82	5.58
13	5.89	6.69	6.18	4.94	5.75
14	5.90	6.67	6.11	4.99	5.82
15	5.95	6.82	6.13	4.98	5.90
16	5.98	6.82	6.13	4.97	6.02
17	6.03	6.99	6.08	4.89	6.18
18	6.14	7.22	6.10	4.87	6.41
19	6.35	7.33	6.21	5.01	6.90
20	6.52	7.50	6.41	5.30	6.92
21	6.69	7.67	6.61	5.60	6.94
22	6.89	7.66	6.63	6.15	7.17
23	7.05	7.68	6.81	6.43	7.31

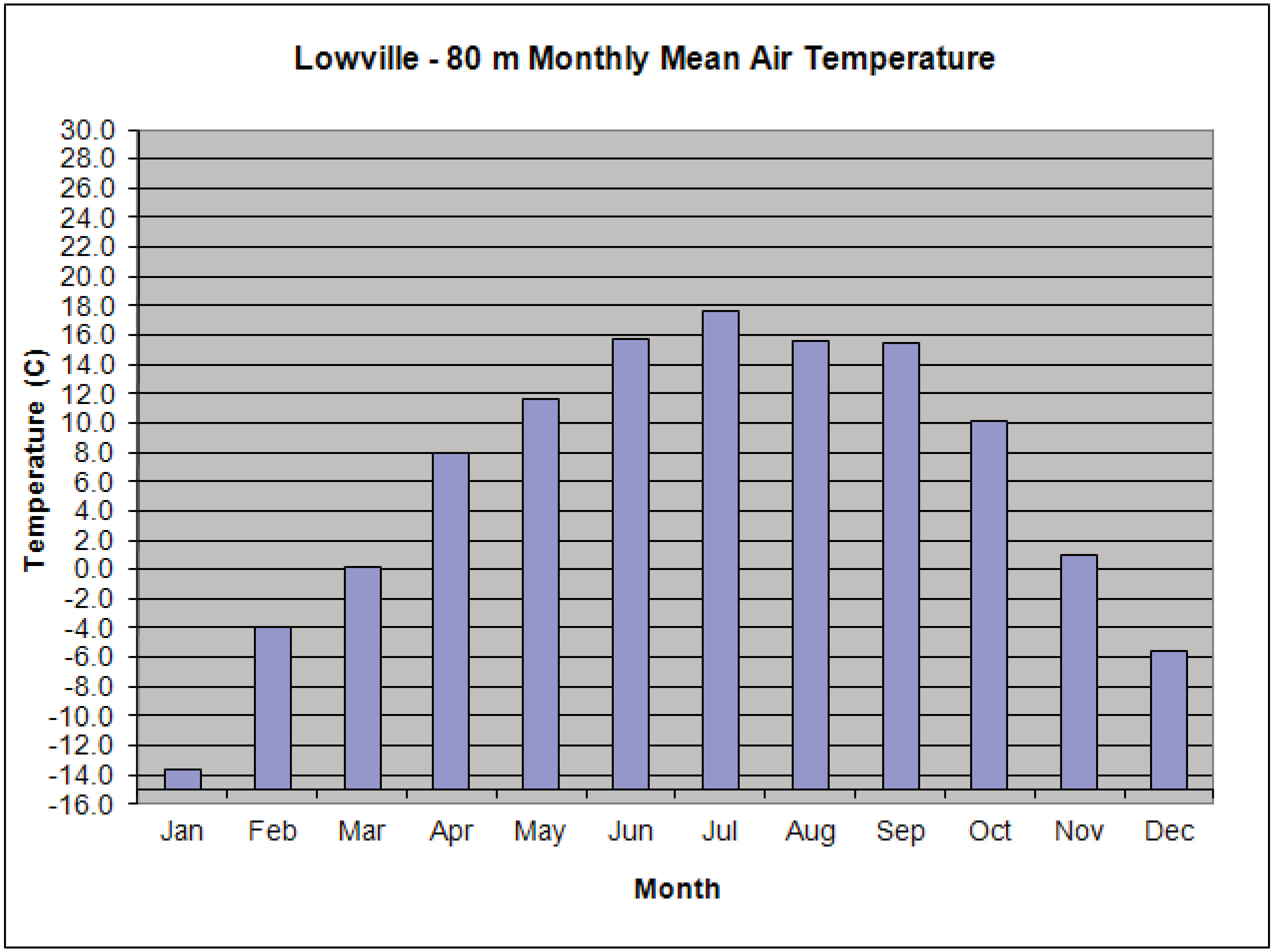
Hour (LST)	Jordanville 80 m Mean Speed				
	Annual	Winter	Spring	Summer	Fall
0	7.09	7.75	6.76	6.61	7.25
1	7.07	7.78	6.77	6.52	7.20
2	6.90	7.63	6.78	6.26	6.96
3	6.91	7.78	6.86	6.16	6.84
4	6.91	7.73	6.89	6.21	6.83
5	6.77	7.51	6.66	6.07	6.87
6	6.42	7.36	6.36	5.22	6.77
7	6.01	7.51	5.91	3.96	6.70
8	5.59	7.25	5.39	3.88	5.86
9	5.16	6.99	4.88	3.80	5.01
10	5.22	6.80	4.96	4.15	5.00
11	5.28	6.57	4.95	4.42	5.19
12	5.36	6.42	5.31	4.51	5.21
13	5.45	6.35	5.52	4.56	5.37
14	5.43	6.24	5.58	4.40	5.50
15	5.53	6.20	5.84	4.46	5.60
16	5.59	6.32	5.93	4.49	5.62
17	5.72	6.46	6.06	4.48	5.90
18	5.99	6.66	6.26	4.51	6.52
19	6.37	6.95	6.48	4.90	7.15
20	6.48	7.00	6.66	5.26	6.99
21	6.58	7.04	6.83	5.62	6.83
22	6.76	7.10	6.88	6.09	6.96
23	6.93	7.39	6.81	6.45	7.05

Hour (LST)	Wyoming/Erie County 80 m Mean Speed				
	Annual	Winter	Spring	Summer	Fall
0	7.44	8.18	7.29	6.95	7.36
1	7.44	8.13	7.36	6.83	7.47
2	7.25	7.95	7.11	6.72	7.24
3	7.20	7.94	7.09	6.63	7.14
4	7.20	7.82	7.14	6.53	7.31
5	7.04	7.58	7.09	6.35	7.17
6	6.75	7.43	6.80	5.66	7.11
7	6.33	7.38	6.46	4.38	7.10
8	6.00	7.18	6.16	4.28	6.40
9	5.68	6.99	5.85	4.18	5.71
10	5.71	6.87	5.71	4.45	5.79
11	5.69	6.52	5.79	4.56	5.89
12	5.67	6.33	5.82	4.62	5.90
13	5.76	6.40	5.93	4.73	6.00
14	5.73	6.46	5.92	4.59	5.95
15	5.78	6.56	5.99	4.54	6.01
16	5.79	6.80	5.95	4.33	6.10
17	5.77	6.86	5.95	4.04	6.24
18	5.97	7.19	6.03	4.16	6.50
19	6.45	7.61	6.46	4.57	7.18
20	6.69	7.73	6.72	5.20	7.13
21	6.93	7.86	6.98	5.84	7.07
22	7.16	8.10	7.07	6.25	7.24
23	7.36	8.12	7.24	6.64	7.45



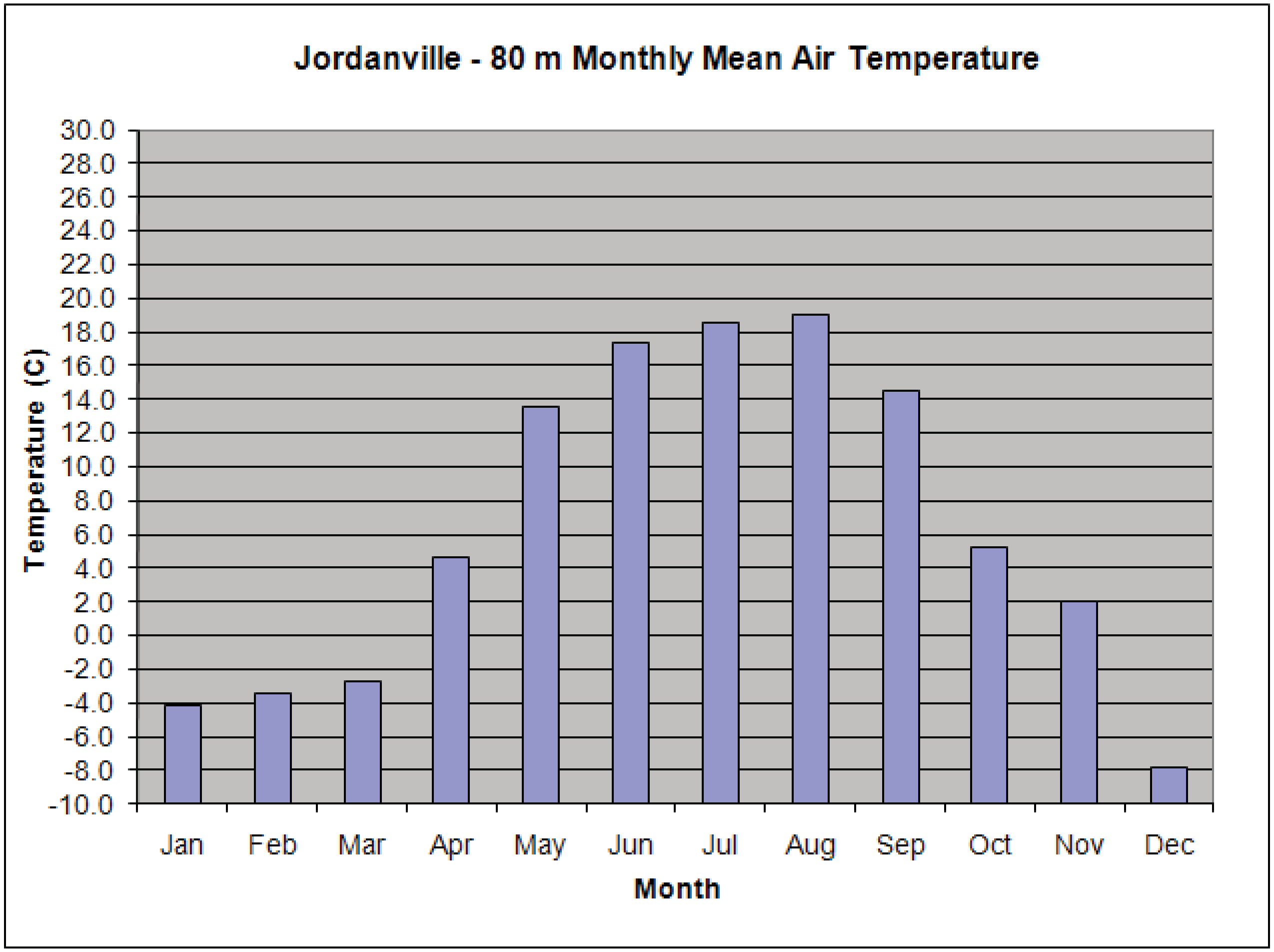
Month	Temperature
Jan	-2.77
Feb	-4.88
Mar	-0.79
Apr	6.40
May	12.74
Jun	15.18
Jul	18.14
Aug	17.95
Sep	13.02
Oct	6.14
Nov	3.36
Dec	-3.63

Figure 6A. South Corning Monthly Mean Air Temperature



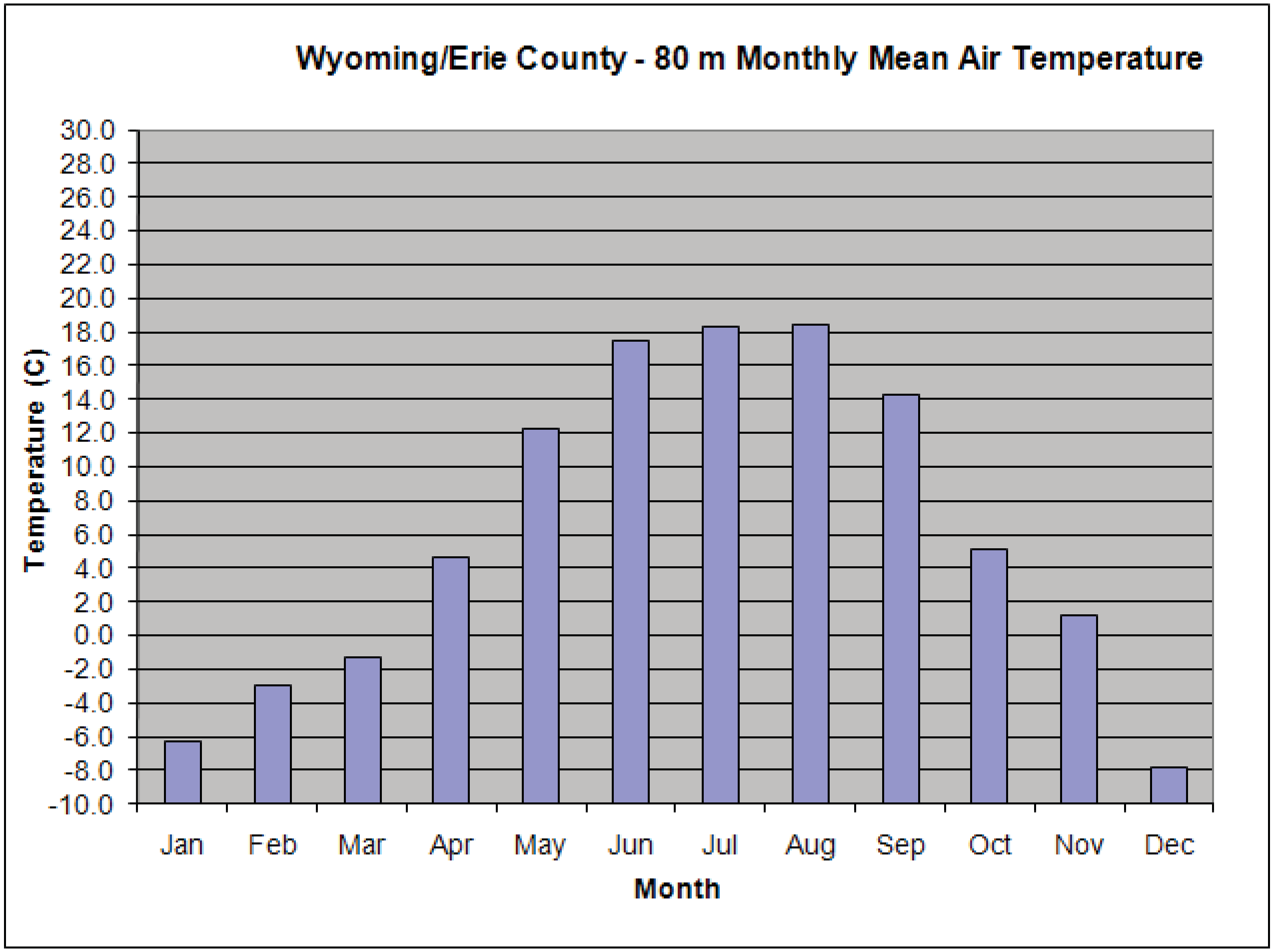
Month	Temperature
Jan	-13.62
Feb	-3.99
Mar	0.20
Apr	8.01
May	11.58
Jun	15.76
Jul	17.63
Aug	15.66
Sep	15.42
Oct	10.19
Nov	0.95
Dec	-5.58

Figure 6B. Lowville Monthly Mean Air Temperature



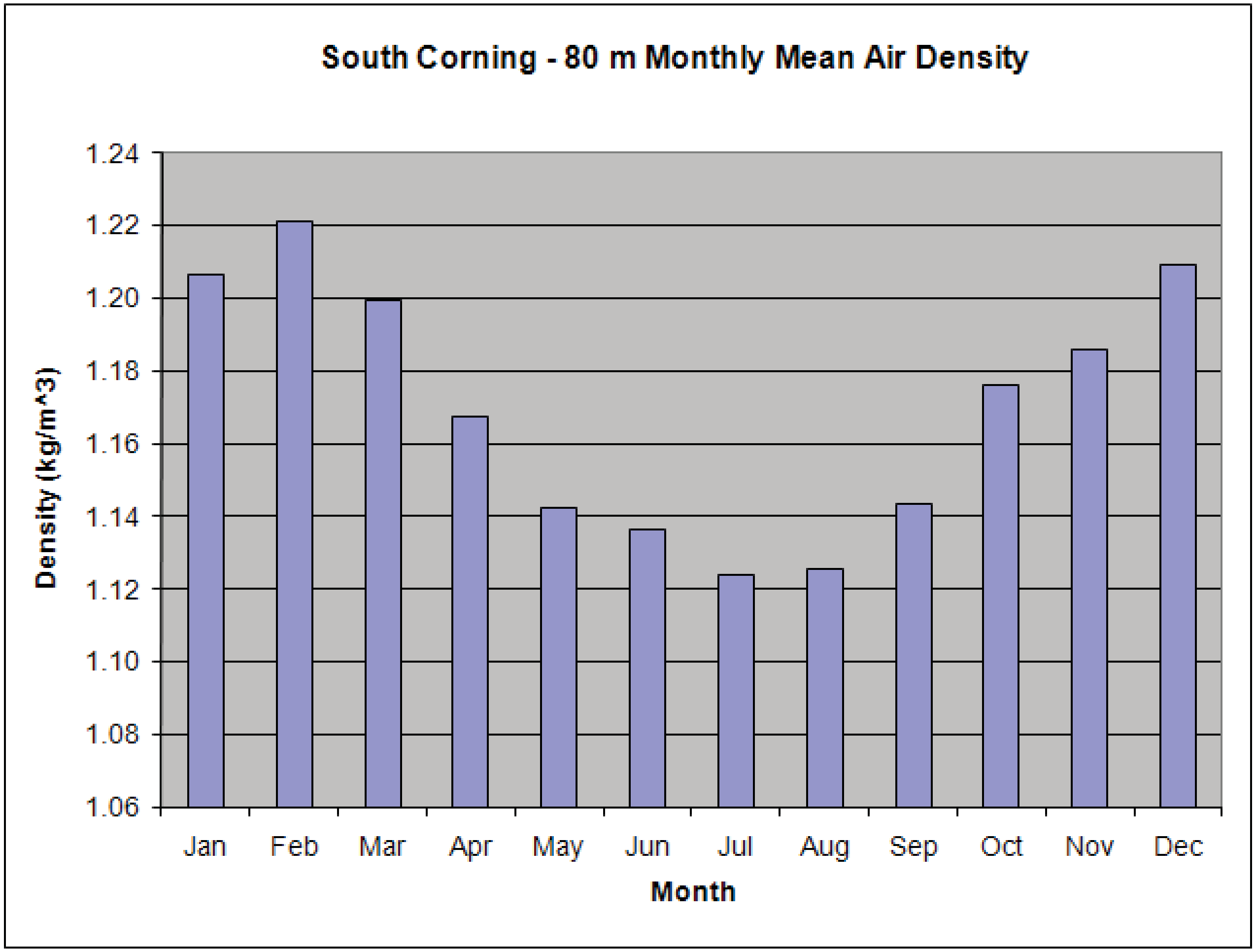
Month	Temperature
Jan	-4.17
Feb	-3.38
Mar	-2.68
Apr	4.70
May	13.56
Jun	17.33
Jul	18.58
Aug	19.01
Sep	14.45
Oct	5.19
Nov	2.03
Dec	-7.85

Figure 6C. Jordanville Monthly Mean Air Temperature



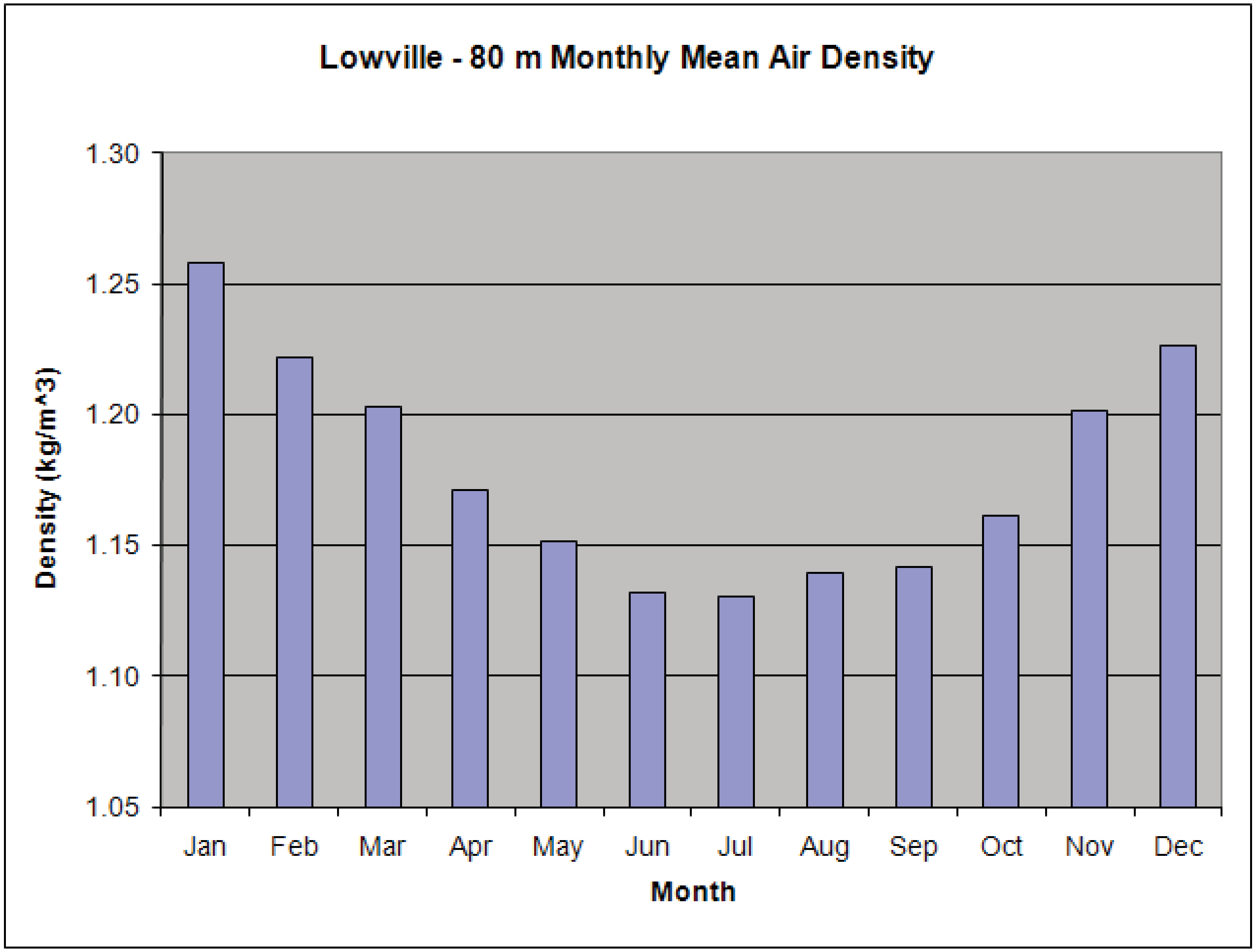
Month	Temperature
Jan	-6.31
Feb	-2.93
Mar	-1.33
Apr	4.68
May	12.21
Jun	17.47
Jul	18.34
Aug	18.43
Sep	14.31
Oct	5.10
Nov	1.23
Dec	-7.86

Figure 6D. Wyoming/Erie County Monthly Mean Air Temperature



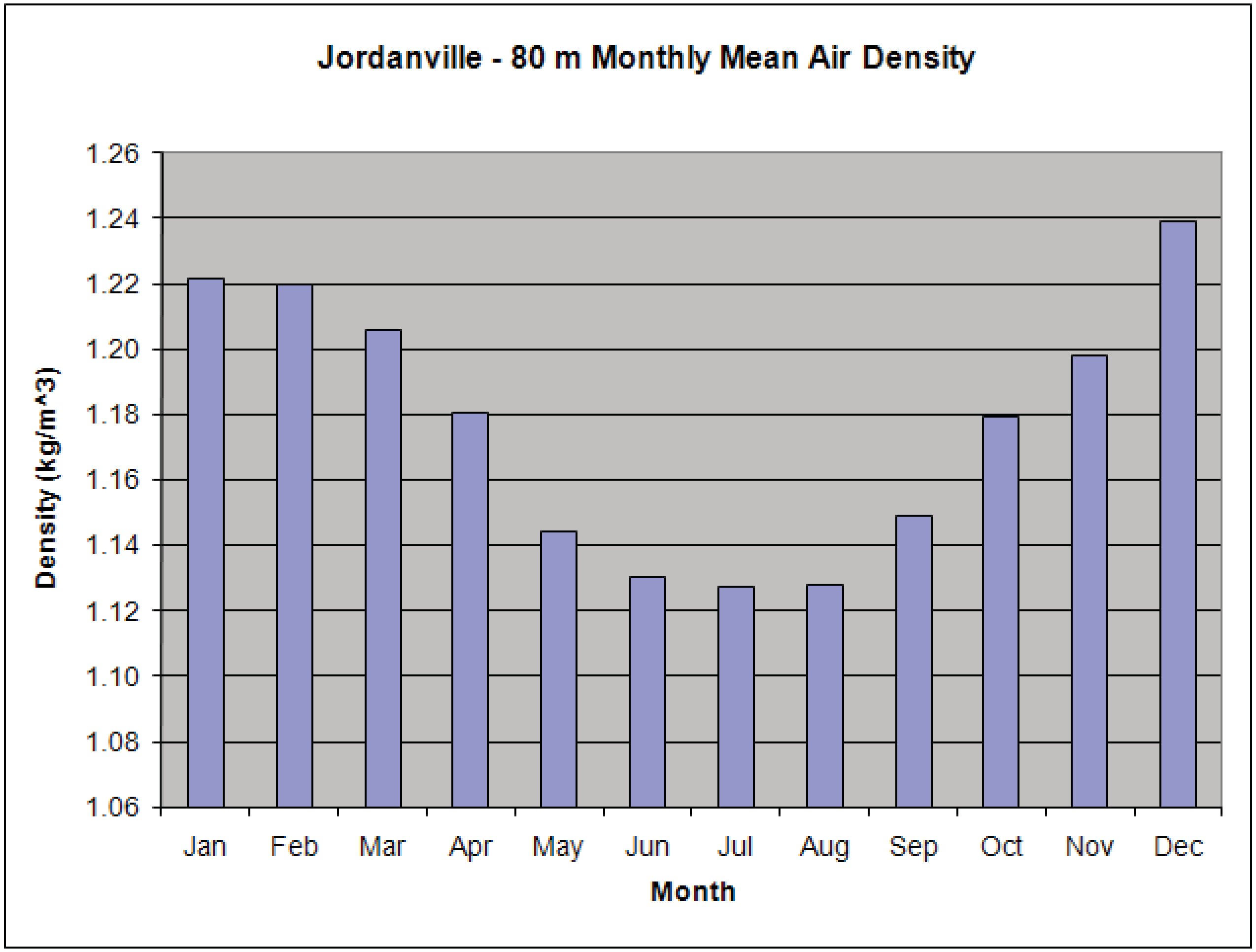
Month	Density
Jan	1.206
Feb	1.221
Mar	1.199
Apr	1.168
May	1.142
Jun	1.136
Jul	1.124
Aug	1.126
Sep	1.143
Oct	1.176
Nov	1.186
Dec	1.209

Figure 7A. South Corning Monthly Mean Air Density



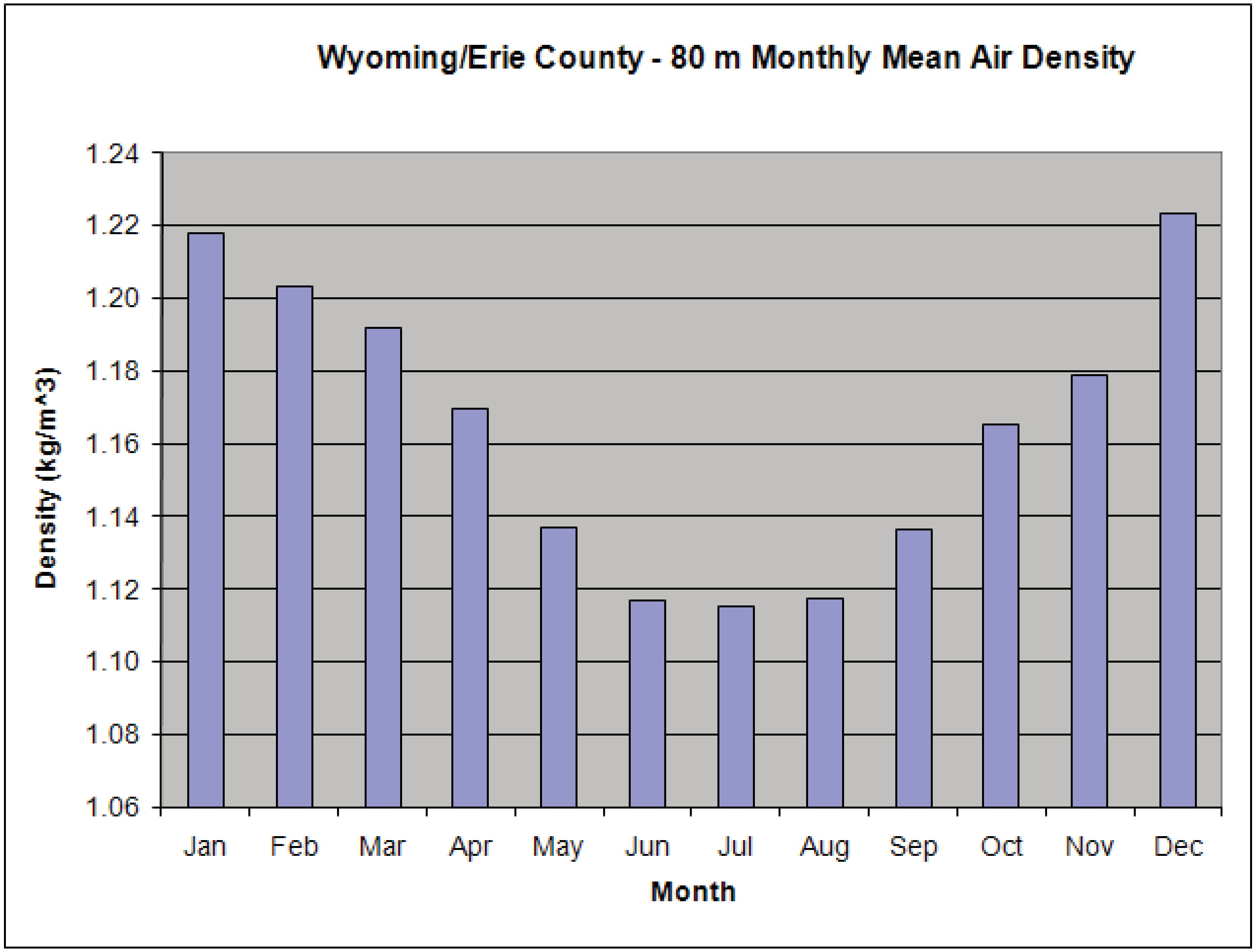
Month	Density
Jan	1.258
Feb	1.222
Mar	1.203
Apr	1.171
May	1.152
Jun	1.132
Jul	1.131
Aug	1.139
Sep	1.142
Oct	1.161
Nov	1.201
Dec	1.226

Figure 7B. Lowville Monthly Mean Air Density



Month	Density
Jan	1.222
Feb	1.220
Mar	1.206
Apr	1.181
May	1.144
Jun	1.130
Jul	1.127
Aug	1.128
Sep	1.149
Oct	1.179
Nov	1.198
Dec	1.239

Figure 7C. Jordanville Monthly Mean Air Density



Month	Density
Jan	1.218
Feb	1.203
Mar	1.192
Apr	1.170
May	1.137
Jun	1.117
Jul	1.115
Aug	1.117
Sep	1.136
Oct	1.165
Nov	1.179
Dec	1.223

Figure 7D. Wyoming/Erie CountyMonthly Mean Air Density

Methodology

Virtual met masts are created using the ***MesoMap***® system developed by AWS Truewind to map the wind resources of large regions at a high level of detail and accuracy. MesoMap accomplishes this by combining a state-of-the-art numerical weather model for simulating regional (mesoscale) weather patterns with a wind flow model responsive to local (microscale) terrain and surface conditions. Using weather data collected from weather balloons, satellites, and meteorological stations as its main inputs, MesoMap does not require wind data to make reasonably accurate predictions. However such data are still required to confirm the wind resource at any particular location before major investments are made in a wind project. In the past five years, MesoMap has been applied in over 30 countries on four continents. In North America alone, MesoMap has been used to map all of the United States and Canada and several states of Mexico. The typical error margin is 5-7%, depending on the complexity of the terrain and the size of the region.

Description

The MesoMap system has three main components: models, databases, and computer systems. These components are described below.

Models

At the core of the MesoMap system is MASS (Mesoscale Atmospheric Simulation System), a numerical weather model that has been developed over the past 20 years by AWS Truewind's partner MESO, Inc., both as a research tool and to provide commercial weather forecasting services.[1] MASS simulates the fundamental physics of the atmosphere including conservation of mass, momentum, and energy, as well as the moisture phases, and it contains a turbulent kinetic energy module that accounts for the effects of viscosity and thermal stability on wind shear. A dynamic model, MASS simulates the evolution of atmospheric conditions in time steps as short as a few seconds. This creates great computational demands, especially when running at high resolution. Hence MASS is usually coupled to a simpler but much faster program, WindMap, a mass-conserving wind flow model developed by AWS Truewind.[2] Depending on the size and complexity of the region and requirements of the client, WindMap is used to improve the spatial resolution of the MASS simulations to account for the local effects of terrain and surface roughness variations.

Data Sources

MASS uses a variety of online, global, geophysical and meteorological databases. The main meteorological inputs are reanalysis data, rawinsonde data, and land surface measurements. The reanalysis database – the most important – is a gridded historical data set produced by the US

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[1] Manobianco, J., J. W. Zack and G.E. Taylor, 1996: Workstation-based real-time mesoscale modeling designed for weather support to operations at the Kennedy Space Center and Cape Canaveral Air Station. Bull. Amer. Meteor. Soc., 77, 653-672. Embedded equations are described in Zack, J., et al., 1995: MASS Version 5.6 Reference Manual. MESO, Inc., Troy, NY.

[2] Brower, M.C., 1999: Validation of the WindMap Model and Development of MesoMap, Proc. of Windpower 1999, American Wind Energy Association, Washington, DC.

National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR).[3] The data provide a snapshot of atmospheric conditions around the word at all levels of the atmosphere in intervals of six hours. Along with rawinsonde and surface data, the reanalysis data establish the initial conditions as well as lateral boundary conditions for the MASS runs. The MASS model itself determines the evolution of atmospheric conditions within the region based on the interactions among different elements in the atmosphere and between the atmosphere and the surface. The reanalysis data are on a relatively coarse grid (about 210 km spacing). To avoid generating noise at the boundaries that can result from large jumps in grid cell size, MASS is run in several nested grids of successfully finer mesh size, each taking as input the output of the previous nest, until the desired grid scale is reached. The outermost grid typically extends several thousand kilometers.

The main geophysical inputs are elevation, land cover, vegetation greenness (normalized differential vegetation index, or NDVI), soil moisture, and sea-surface temperatures. The elevation data used by MASS are from the Shuttle Radar Topographical Mission 30 Arc-Second Data Set (SRTM30), which was produced in an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA).[4] The land cover data are from the satellite-based Moderate Resolution Imaging Spectro-radiometer (MODIS) data set.[5] The NDVI data were derived from a predecessor of MODIS, the satellite-based Advanced Very High Resolution Radiometer (AVHRR).[6] The nominal spatial resolution of all of these data sets is 1 km.

Maps of much higher resolution than 1 km can be produced either by MASS or by WindMap if the necessary topographical and land cover data are available. In the past year, 3 arc-second SRTM data have been released for most of the world except the polar regions. These data provide highly accurate elevations on a 90 m horizontal grid (30 m in the United States). A data set called GeoCover, from EarthSat, offers high-quality land cover classifications on a 28 m grid for most of the world.[7] The WindMap model automatically adjusts for differences in elevation and surface roughness between the mesoscale and microscale.

Computer and Storage Systems

The MesoMap system requires a very powerful set of computers and storage systems to produce detailed wind resource maps in a reasonable amount of time. To meet this need AWS Truewind has created a distributed processing network consisting of about 130 Pentium II processors and 10 terabytes of hard disk storage. Since each day simulated by a processor is entirely independent of other days, a project can be run on this system up to 130 times faster than would

[3] Robert Kistler et al., The NCEP/NCAR Reanalysis, Bulletin of the American Meteorological Society (2001).
[4] For more information, see http://www2.jpl.nasa.gov/srtm/.
[5] See http://edcdaac.usgs.gov/modis/mod12q1.asp.
[6] See http://edcwww.cr.usgs.gov/products/landcover/glcc.html.
[7] See http://www.mdafederal.com/geocover/geocoverlc.

be possible with any single processor. To put it another way, a typical MesoMap project that would take two years to run on a single processor can be completed in about a week.

The Modeling Process

The MesoMap system creates wind resource information in several steps. First, the MASS model simulates weather conditions over 366 days selected from a 15-year period. The days are chosen through a stratified random sampling scheme so that each month and season is represented equally in the sample; only the year is randomized. Each simulation generates wind and other weather variables (including temperature, pressure, moisture, turbulent kinetic energy, and heat flux) in three dimensions throughout the model domain, and the information is stored at hourly intervals. This information can be used to create virtual met mast hourly time series data.

When the mesoscale runs are finished, the results are summarized in files, which are then input into the WindMap program for the final mapping stage.

Once completed, the maps and data can be compared with land and ocean surface wind measurements, and if significant discrepancies are observed, the wind maps can be adjusted. The most common sources of validation data are tall towers instrumented for wind energy assessment and standard meteorological stations. The validation is usually carried out in the following steps:

1. Station locations are verified and adjusted, if necessary, by comparing the quoted elevations and station descriptions against the elevation and land cover maps. Where there are obvious errors in position, the stations are moved to the nearest point with the correct elevation and surface characteristics.
2. The observed mean speed and power are adjusted to the long-term climate norm and then extrapolated to the map height using the power law. Often, for the tall towers, little or no extrapolation is needed. Where multi-level data are available, the observed mean wind shear exponent is used. Where measurements were taken at a single height, the wind shear is estimated from available information concerning the station location and surroundings.
3. The predicted and measured/extrapolated speeds are compared, and the map bias (map speed minus measured/extrapolated speed) is calculated for each point. If there are enough towers, the mean bias and standard deviation of the biases is calculated. (It is important to note that the bias and standard deviation may reflect errors in the data as well as the map.)
4. If we detect a pattern of bias, the maps are adjusted to reduce or eliminate the discrepancy.

The MesoMap system has been validated in this fashion using data from well over 1000 stations worldwide. We have found the typical standard error, after accounting for uncertainty in the data, to be 5-7% of the mean speed at a height of 50 m.

For a virtual met mast, the final wind speed data are scaled to match the final speeds from the WindMap simulation.

<u>Factors Affecting Accuracy</u>

In our experience, the most important sources of error in the wind resource estimates produced by MesoMap are the following:

- Finite grid scale of the simulations
- Errors in assumed surface properties such as roughness
- Errors in the topographical and land cover data bases

The finite grid scale of the simulations results in a smoothing of terrain features such as mountains and valleys. For example, a mountain ridge that is 2000 m above sea level may appear to the model to be only 1600 m high. Where the flow is forced over the terrain, this smoothing can result in an underestimation of the mean wind speed or power at the ridge top. Where the mountains block the flow, on the other hand, the smoothing can result in an overestimation of the resource, as the model understates the blocking effect. The problem of finite grid scale can be solved by increasing the spatial resolution of the simulations, but at a cost in computer processing and storage.

While topographic data are usually reliable, errors in the size and location of terrain features nonetheless occur from time to time. Errors in the land cover data are more common, and usually result from the misclassification of aerial or satellite imagery. Wherever possible, AWS Truewind uses the most accurate and detailed land cover databases.

Assuming the land cover types are correctly identified, there remains uncertainty in the surface properties that should be assigned to each type, and especially the vegetation height and roughness. A forest, for example, may consist of a variety of trees of varying heights and density, leaf characteristics, and other features affecting surface roughness. An area designated as cropland may be devoid of trees, or it may be broken up into fields separated by windbreaks. Uncertainties such as these can be resolved only by visiting the region and verifying firsthand the land cover data.

Disclaimer

Statistical analysis and validation studies have determined the standard error for annual wind speeds produced by the Virtual Met Mast to be approximately 5 - 7%. However, when the data are stratified by shorter time scales (i.e. monthly), this error may be slightly higher as an anomalously high or low diurnal (24-hour) wind speed time series for a particular site may have a greater effect on smaller averaging periods. The 366-day hourly time series generated by MesoMap for the Virtual Met Mast are not contiguous from one day to the next and should not be considered to be representative of a continual sequence of ambient weather.

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