New York State Energy Research and Development Authority

VPS Cycle with Steam Feasibility Study for Bulk Power Storage in New York City

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VPS Cycle with Steam Feasibility Study for Bulk Power Storage in New York City

Final Report

Prepared for:

New York State Energy Research and Development Authority

Albany, NY

Barry Liebowitz
Project Manager

Prepared by:

Expansion Energy LLC

Tarrytown, NY

David Vandor
Managing Director and Chief Technology Officer

and

Jeremy Dockter
Managing Director

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Notice

Abstract

The need for large-scale, multi-hour bulk power storage is growing in importance as increasing amounts of intermittent and fluctuating power from wind turbines, solar panels and other renewable sources are added to the grid. Large-scale, or utility-scale power storage systems also allow surplus off-peak power from baseload power plants (e.g., nuclear, coal-fired and gas-fired combined cycle plants) to be stored overnight and delivered during the peak demand period the following day. In addition, smaller multi-MW energy storage systems (i.e., 5 MW to 50 MW) may provide a means to add peak power capacity to constrained load pockets at high net efficiency while helping to upgrade and, in effect, to expand power distribution systems. This is especially relevant in and around NYC where few options exist and where upgrades are costly.

Expansion Energy LLC (XE), in collaboration with Consolidated Edison of New York (Con Ed) and equipment vendors including Dresser-Rand, Cameron Compression Systems, Chart Industries and others, with support by the New York State Energy Research and Development Authority (NYSERDA), assessed the feasibility of deploying XE’s patented Vandor’s Power Storage Cycle (VPS Cycle) power storage technology within Con Ed’s existing district steam system.

The VPS Cycle is a highly efficient utility-scale power storage system utilizing liquefied air as the storage medium and a heat source as part of the power release outflow stage. The feasibility study examined utilizing surplus steam produced by Con Ed as the heat source for the power outflow-from-storage in the Cycle. In addition to the steam cases examined, XE evaluated using natural gas to provide heat for the release of the stored energy in the system.

Key Words

Power storage / energy storage
Utility-scale power storage / utility-scale energy storage
Bulk power storage / bulk energy storage
Liquid air energy storage (LAES)
Round-trip efficiency (RTE)
Vandor’s Power Storage Cycle (VPS Cycle)
Base Case VPS Cycle
Steam Case VPS Cycle
Commercial-Scale VPS Cycle

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- NYSERDA
- Con Edison
- Process Engineering Associates
- Dresser-Rand
- Cameron
- York
- Trane
- Chart Industries
- Ebara
- CS&P Technologies
- ACD

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Summary

S.1 Background & Objectives

The need for large-scale, multi-hour bulk power storage is growing in importance as increasing amounts of intermittent and fluctuating power from wind turbines, solar panels and other renewable sources are added to the grid. Large-scale, or utility-scale, power storage systems also allow surplus off-peak power from baseload power plants (e.g., nuclear, coal-fired and gas-fired combined cycle plants) to be stored overnight and delivered during the peak demand period the following day. In addition, smaller multi-MW energy storage systems (i.e., 5 MW to 50 MW) may provide a means to add peak power capacity to constrained load pockets at high net efficiency while helping to upgrade and, in effect, to expand power distribution systems. This is especially relevant in and around New York City (NYC) where few options exist and where upgrades are costly.

For this study, Expansion Energy LLC (XE), in collaboration with Consolidated Edison of New York (Con Ed) and equipment vendors including Dresser-Rand, Cameron Compression Systems, Chart Industries and others, with support by the New York State Energy Research and Development Authority (NYSERDA), assessed the feasibility of deploying XE's patented Vandor's Power Storage Cycle (VPS Cycle) power storage technology within Con Ed's existing district steam system in NYC.

The VPS Cycle is a patented, highly efficient, utility-scale power storage system utilizing liquefied air as the storage medium and a heat source as part of the power release, or "outflow" stage. VPS is designed to operate on a daily cycle, storing energy during the overnight off-peak period and delivering 8-12 hours of power per day (at a constant release rate) during the grid's peak demand period. This feasibility study examined utilizing surplus steam produced by Con Ed as the heat source for the power outflow-from-storage in the Cycle. Con Ed provided XE with technical data regarding potential sites that might host VPS Cycle deployments. Con Ed also provided XE with insights as to the economics and regulatory hurdles associated with the deployment of utility-scale power storage systems. In addition to the steam cases examined, XE evaluated using natural gas to provide heat for the release of the stored energy in the system, referred to herein as the VPS Base Case.

Rotating equipment for the power inflow stage of the VPS Cycle includes a motor-driven air compressor array and heat exchangers to compress and cool the inflow air that is captured for storage, creating liquid air (L-Air). During the power outflow stage of the Cycle, the L-Air is first pressurized then released through a generator-loaded hot gas expander array. Cameron Industries assisted XE in evaluating the performance and costs of multi-stage integral gear air compressors. Dresser-Rand assisted XE in evaluating the performance and costs of hot gas expanders. Chart Industries provided performance and budget estimate assistance for L-Air storage tanks and cryogenic heat exchangers in the system. In addition, several makers of absorption chillers, cryogenic expanders and cryogenic liquid pumps provided performance and cost estimate support for these components.

The Base Case of the VPS Cycle is innovative in its use of recovered heat and cold to achieve very high thermal efficiencies during power outflow and a high projected round-trip efficiency (RTE) of greater than 95%. The VPS Cycle does not use toxic or exotic chemicals, such as those found in batteries, and does not need special geological conditions, such as those required by compressed air energy storage (CAES) systems.

Con Ed's existing steam generating and distribution system offers an opportunity to integrate the VPS Cycle with that system using steam as the thermal energy source for releasing energy stored by VPS, which results in achieving utility-scale power storage with no new fuel use and no new emissions. Under that concept, at any of Con Ed's four existing steam-generating plants the VPS Cycle would use available heat in the steam that is not now fully utilized, resulting in value-added use of Con Edison's steam assets and benefiting the region and the rate-payers.

If integrated with Con Edison's steam production system, the VPS Cycle would take steam produced by Con Edison's boilers at a maximum temperature of 800° F and approximately 850 psia, use a portion of the heat content of that steam in the power outflow mode of the VPS Cycle and return the steam to Con Ed at approximately 526°F and 845 psia. The 526°F is warmer than the minimum outflow temperature of 420 ° F, which is the quality required by the existing Con Ed steam distribution system.

In addition to the utility-scale (20 MW to 100s of MW) version of the VPS Cycle covered in this report, Expansion Energy has recently developed a smaller, simplified and lower-cost commercial-scale version of the VPS Cycle (4 MW to 20 MW) that will be pre-designed and 100% factory-manufactured, then delivered to the deployment site on skids, eliminating the need for on-site construction. This approach greatly increases the deployment potential (and market size) for VPS plants and would greatly increase the opportunities for VPS deployments in NYC. Commercial-Scale VPS plants are deployable at virtually any location that consumes at least 2 MW of power and has a natural gas grid connection. As such, Commercial-Scale VPS represents a potential paradigm shift in how energy is produced, delivered, stored and used worldwide. Like Utility-Scale VPS, Commercial-Scale VPS is designed to operate on a daily cycle, storing energy during the overnight off-peak period and delivering 8-12 hours of power per day at a constant release rate during the grid's peak demand period.

S.2 Scope of Work

The Scope of Work for NYSERDA contract #18814 included a set of nine tasks, each of which had several subtasks. Several of the originally identified tasks were revised during the study because of findings that were identified during the performance of the work. For example, the possibility of small-scale VPS Cycle deployments using lower-temperature, lower-pressure steam available at various distribution points in Con Ed’s system throughout New York City was deemed unfeasible early on during the study.

S.3 Findings

Expansion Energy’s assessments of its VPS Cycle power storage technology deployed in NYC—using either steam or natural gas as its thermal energy source—determined the following:

- The VPS Cycle is technically feasible for deployment and operation within Con Edison’s New York City metro service territory, either utilizing steam or natural gas as the thermal energy source for releasing the stored power. No significant technical barriers were identified that would prevent the successful deployment of VPS plants within the targeted region.
- Though the heat content of surplus steam from Con Edison’s NYC district heating systems is sufficient to allow one or more VPS plants to utilize it successfully, the heat content is only high enough to provide a modest amount of power to be sent out during the release (on-peak) stage of the VPS plant’s daily cycle.
- In contrast to utilizing steam, the use of natural gas in VPS’s release stage yields large amounts of net power output—nearly three times as much as when steam is used.
- The VPS “Base Case” utilizing natural gas as the thermal energy source generates excellent economic returns if a utility (e.g., Con Edison) is the owner of the VPS plant and that utility is able to monetize the majority of the value streams that a bulk power storage asset such as VPS provides. The approximately 45 MW Base Case VPS plant analyzed for this report is projected to yield a net present value (NPV) of approx. $218 million—available to be shared” by the VPS owner and other stakeholders in the total electrical system, including rate payers. This is on a VPS plant capital cost investment of about $100 million. In terms of absolute dollar value, rather than NPV, which discounts for the time value of money, the Base Case VPS plant would deliver approximately. $933 million of absolute value to the electrical system over a 25-year period—a value more than nine times the estimated capital cost of the VPS plant.
- A VPS plant utilizing steam, instead of natural gas, under the circumstances analyzed for this report would not likely generate a sufficient return to justify the investment under the assumptions used for this report. Special incentives from regulators or legislators would likely be required in order to induce a company to build and operate a VPS plant using steam. Special incentives could include accounting for the fact that the VPS plant could allow utilities or other electrical system stakeholders to avoid costs for other assets that power storage systems such as VPS could displace or defer.

S.4 Recommendations

The Base Case version of the VPS Cycle in or near New York City yields excellent economics, both for the owner of the VPS plant and for virtually all other stakeholders on the electrical system, including rate-payers—a total NPV of approximately $218 million. This VPS plant would serve the electrical system by delivering value from the majority of the approximately 20 storage value categories identified in this report and previously identified/quantified by NYSERDA; therefore, pursuing the development and operation of one or more VPS plants utilizing natural gas as the thermal energy source in or around New York City is highly recommended.

A VPS plant using steam is only financially viable if there are special incentives above and beyond any new incentives recommended in the following paragraphs available to induce a developer, most likely a utility, to own and operate the plant. That will come down to whether policy makers and regulators find it valuable enough to have a 100% green (no fossil fuel consumption) VPS plant and/or whether such a VPS plant would allow a sufficient amount of avoided costs to justify the VPS plant investment (i.e., by displacing or deferring the need to invest in other assets throughout the electrical grid).

Because the Base Case VPS Cycle analyzed for this study yields such positive economics for the electrical system on the whole, Expansion Energy has developed a series of recommendations (described more fully in the Conclusions and Recommendations section at the end of this report) to incentivize a New York utility owner to develop one or several VPS Cycle Base Case plants in or near New York City. Included in those recommendations is the petitioning of various state and federal regulators/policy makers, such as the New York Public Service Commission (PSC), the NY Legislature, the Federal Energy Regulatory Commission (FERC) and Congress to adopt policies and incentive frameworks that would stimulate investment in bulk power storage systems such as the VPS Cycle. One specific example of model legislation is California's AB 2514, which was passed into law in 2010 and is now being implemented by various stakeholders in California's electricity system. The main elements of California's AB 2514 would also benefit the electricity systems and rate-payers in New York City and New York State.

1 Background: The Base Case VPS Cycle

1.1 Stand-Alone Deployments Using Natural Gas Fuel as the Heat Source for the Outflow-from-Storage Mode

On October 26, 2010, the United States Patent and Trademark Office issued patent number 7,821,158 for a "System and Method for Liquid Air Production, Power Storage and Power Release" to David Vandor. A second patent, number 7,870,746, was issued on January 18, 2011; a third patent, number 8,020,404, was issued September 20, 2011; and a fourth patent, number 8,063,511, was issued on November 22, 2011. Patents have also been issued by the patent authorities of Canada and Japan. All six patents have been assigned to Expansion Energy LLC. Other Vandor's Power Storage (VPS) Cycle patents are pending internationally, all of which are assigned to Expansion Energy LLC.

The Base Case VPS Cycle can be divided into two distinct segments: Inflow-to-storage and Outflow-from-storage. Figure1 depicts the Inflow mode, and Figure 2 illustrates the Outflow mode.

Figure 1. VPS Cycle Inflow-to-Storage.

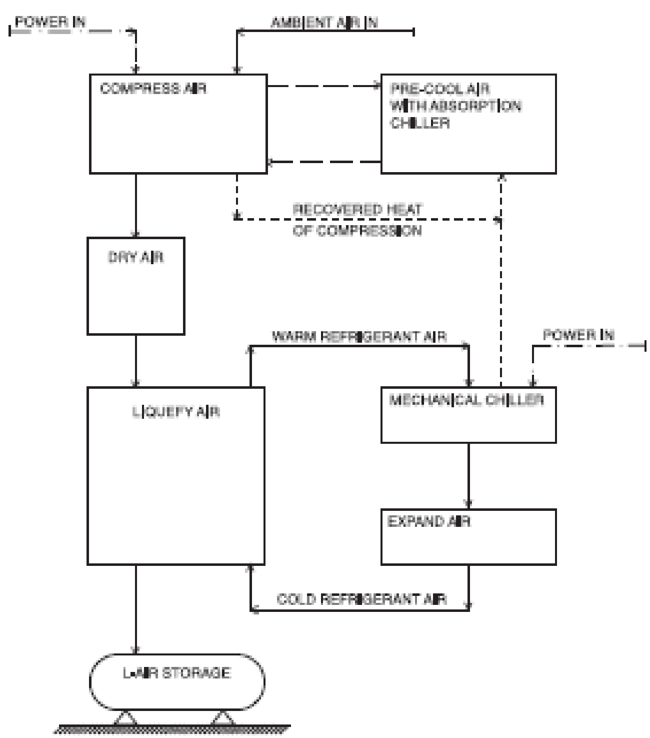
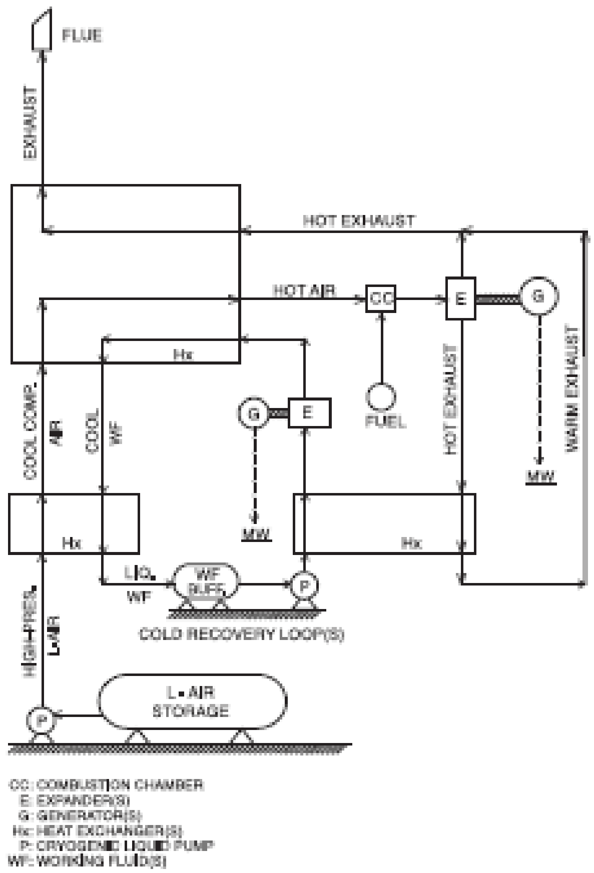


Figure 2. VPS Cycle Outflow-from-Storage.



A fundamental goal of the Base Case VPS Cycle is to utilize readily available, off-the-shelf equipment. Toward that end, XE worked with several prominent equipment makers to establish the performance parameters and budget estimates for the key components. The following are examples:

- The liquefier (HX-1), shown on Figure 1, was designed with the cooperation of Chart Industries, a premier supplier of brazed aluminum, plate fin, cryogenic heat exchangers.
- The six-stage air compressor, shown on Figure 1, was designed with the cooperation of Cameron compressors, whose integral gear compressor product line matches the requirements of the Inflow mode. Other makers, including MAN and GE have confirmed their ability to provide such compressors.
- The compressor-loaded cryogenic expander, shown on Figure 1, was vetted by ACD/Cosmodyne of CA, experts at designing and building cryogenic turbo equipment.
- The various hot gas expanders shown on Figure 2 were designed with the cooperation of Dresser-Rand, matching the D-R expander performance characteristics to the optimal VPS Outflow configuration.

- The Lithium Bromide Absorption Chiller (LiBAC) shown on Figure 1 was reviewed by several makers of such equipment, including York and Trane.

The configuration of components and the temperature and pressure values for each stream shown on the various process flow diagrams will require further optimizations by XE, its consulting engineer and the above-listed equipment providers. As such, the process flow diagrams are subject to change. The Cycle will undergo peer review by any potential licensee of the technology prior to any deployment. Figures 1 and 2 form the basis of the subject study; however, for the purpose of evaluating the use of Con Edison steam as the heat source for the power outflow mode, a revised version of Figure 2 needed to be completed. That proprietary document was provided to NYSERDA confidentially, along with confidential versions of the figures, which show a detailed inflow-to-storage process flow diagram and Figure 2, which shows a detailed outflow-from-storage process flow diagram.

1.2 General Principles Behind the VPS Cycle

The VPS Cycle aims to store a selected amount of liquid-air (L-Air), at optimal pressure and temperature conditions, over a specified inflow-to-storage period, with the least possible input of energy. This is achieved by the following:

- Establishing various pressure and temperature conditions for the stored air, all of which allow for storage in existing “off-the-shelf” cryogenic storage tanks, and all of which can be pumped to high pressure by cryogenic liquid pumps.
- Selecting an optimal balance between compression and refrigeration input to achieve the optimal L-Air storage conditions.
- Recovering waste heat of compression to produce free refrigeration (i.e., through the use of absorption chillers) that can be applied to each stage of compression, which reduces the total workload on the compressor motor.
- Utilizing low-grade refrigeration as a side load from the mechanical chiller that provides deep refrigeration to the compressed refrigerant air stream, prior to the expansion of that refrigerant air in a compressor-loaded cryogenic turbo-expander.

On the Outflow side, the Base Case of the VPS Cycle aims to produce the maximum possible power with the least possible burning of fuel, per the following techniques:

- Selecting the outflow pressure to which the released L-Air is pumped based on the maximum pressure tolerance and pressure letdown ratio capacity of standard “off the shelf” (Dresser-Rand) hot gas expanders.
- Recovering the refrigeration content of the stored L-Air (prior to vaporization and combustion) by using that refrigeration to condense several working fluids that are also expanded in hot gas expanders, at the maximum pressure, temperature and letdown ratio capacity for those secondary expanders.
- Using a portion of the waste heat from the expanded products of combustion (produced after pressurized natural gas (NG) is combusted in the presence of pumped-to-pressure and vaporized L-Air) to heat the working fluids that are used to produce additional power, where the working fluids are condensed by the “cold content” in the outbound L-Air.
- Using a portion of the waste heat available from the expanded products of combustion to pre-warm the vaporized (formerly) L-Air prior to its arrival at the combustion chamber.
- Burning the compressed NG + warm, high-pressure air mixture at an optimal rate to create enough high-grade heat (in Btus), allowing a portion of that heat to boil the working fluids and still yield a hot enough product of combustion to match the temperature capacity of the hot gas expanders.
- Expanding the hot, high-pressure products of combustion and at least one of the working fluids in a two-stage-with-reheat expander configuration, optimizing the performance characteristics of high-pressure expanders with cooler inlet temperatures and optimizing the performance characteristics of low-pressure expanders with hotter inlet temperatures, which result in the production of more power with less energy input.

The above outlined principles yield a Base Case VPS Cycle that offers the following significant benefits:

- Recovering the maximum power input (MWh) during the Outflow mode, yielding as close to 100% in Round-Trip Efficiency (RTE) as is practical.
- Achieving a high Thermal Efficiency (TE) because a large portion of the power output comes from the stored L-Air, which when derived from wind power, is produced with zero fuel use.
- Reducing fuel use and CO_2 emissions per MWh of power output because a significant portion of the power sent out is derived from zero emission wind power.

1.3 The Conceptual Framework for the Inflow-to-Storage Mode

The fundamental goal of the Base Case Inflow mode is to store 224,000 G of L-Air in storage tanks over a10-hour off-peak period (somewhat longer or shorter periods can be accommodated), with the lowest possible power (MW and MWh) input. XE selected 225,000 G of L-Air storage capacity as the Base Case with three shop-fabricated L-Air tanks, each holding 75,000 G. XE assumed that approximately 1,000 G would always remain in the tanks at the end of each Outflow mode.

Power input during the Inflow mode can come from any source adjacent to the VPS deployment or by “wheeling” from a distant source. Examples include wind power, baseload power, or power from landfill gas (LFG).

The Base Case assumes that during a 16-hour off-peak period, 10-hours of power input is available, continuously or in two or more time segments. For projects that want to store weekend power for weekday release, the total storage capacity may be larger.

At its core, the VPS Cycle Inflow mode is a finely tuned, novel L-Air production system that has the flexibility to produce high-density air at various temperatures and pressures. Less efficient and less flexible variations of L-Air production are commonly used at modern air separation plants, many-hundreds of which exist around the world today. Also, the VPS Cycle does not require that the L-Air be separated into its constituent gases, which lowers the total capital and operating costs relative to an equally sized air separation plant.

The main goal of the Inflow mode is to use as little energy (MW/MWh) as possible to fill up the nearly empty 225,000 G L-Air storage tanks. Even off-peak power has a cost. Also, we did not want to fill up the L-Air tanks very fast because that would require much larger equipment, even if the total MWh of input stayed the same.

In order to store 224,000 G of L-Air in 10 hours at the lowest possible MWh of power input, the Inflow mode had to achieve the optimal balance between the compression and refrigeration energy needed to liquefy the air, at the optimal storage pressure and temperature. Beyond that, the VPS Cycle's Inflow mode needed to recover the waste heat of compression, which is normally thrown away in inter- and after-coolers), and recycle that heat to produce "free" refrigeration and/or compression. Alternatively, the Cycle needed to recover the low-grade refrigeration available from a mechanical chiller that is used to provide high-grade refrigeration to the refrigerant air stream. That heat-/cold-recovery feature is the main

distinguishing thermodynamic feature of VPS when compared to Compressed Air Energy Storage (CAES) systems and most existing air separation plants. Standard CAES systems have no practical use for recovered heat of compression, requiring the disposal of millions of Btus through air compressor inter-coolers and after-coolers.

1.3.1 Process Flow Diagrams for the Inflow-to-Storage Mode

The figures submitted as confidential documents to NYSERDA are schematics of the main steps in producing the L-Air by compression and refrigeration. One shows the specific conditions at each stage of compression: the Lithium Bromide Absorption Chiller (LiBAC), where the heat of compression is converted to refrigeration; the mechanical chiller, where deeper refrigeration cools air used as a refrigerant; and the liquefier (HX-1), where refrigerated air is used to liquefy the process air that is produced for storage in the cryogenic storage tanks. Chart Industries (UK) has validated HX-1 and has provided XE with a budget estimate for that component. Chart has also provided us with budget estimates for the cryogenic storage tanks that will store the L-Air. The other confidential figure shows how the various streams get cooled in HX-3 by the counter-flowing cold water output of the LiBAC. (As mentioned above, an alternative design, also shown confidentially to NYSERDA, would eliminate the LiBAC and, instead, use a "side load" of available refrigeration from the mechanical chiller to cool the inter-stage air streams.)

As shown in Table 1 approximately 14.4 MW would be used to drive the main six-stage air compressor and approximately 0.9 MW would drive the Mechanical Chiller. Accounting for other power demand during inflow-to-storage, the total net power demand of the inflow mode is approximately 16.22 MW. Table 1, VPS Power In and Power Out tabulates the VPS Cycle's required power during the inflow-to-storage mode, as well as the gross and net power output during the outflow mode.

Table 1. VPS Power In and Power Out.

POWER USED DURING INFLOW	
	MW Used
Process Air & Recycle Compressor	14.40
Mechanical Chiller	0.90
Mole Sieve Heater	0.32
LiBAC Power	0.10
Fin-Fan Coolers	0.30
Cooling Tower, Pumps	0.10
Miscellaneous Power Demand	0.10
Total Power Demand	**16.22**
POWER PRODUCTION DURING OUTFLOW	
	MW Generated
E1 to G1, (Combustion Gas or Air)	8.12
E2 to G1, (Combustion Gas or Air)	10.43
W.F. 1, (CO2), E5 to G2	10.13
W.F. 2, (NH3), E3 to G2	7.56
W.F. 2, (NH3), E4 to G2	10.34
Sub Total (Gross Power Output)	**46.57**
	MW Used
Main L-Air Pump (3)	0.35
CO2 Pump	0.65
NG Fuel Comp. Motor	0.50
NH3 Pump	0.50
Total Deductions	**2.00**
Total (Net) Power Produced	**44.57**

A reading of Table 1 begins at point 1 where nighttime air at atmospheric pressure (14.7 psia) and at an approximate New York State annual average temperature of 53°F enters the main compressor. Subsequent points in the inflow process are numbered sequentially. The purpose of the air stream is shown next to each point, with "P" representing the process air that will end up as L-Air in storage and "R" representing the refrigerant air that is used to cool the process air. Because there is no chemical distinction between process air and refrigerant air, the two streams travel together for a portion of the Cycle, as indicated by those points with the designation "P+R." This is an important aspect of the patented VPS Cycle; a single compressor acts on the product stream (air) and on the refrigerant stream (also air), which streams move in a counter-flowing manner through the main heat exchanger where the refrigerant air liquefies the product air. XE calls this principle "like with like" because the product and refrigerant streams are the same, which yields significant benefits over other designs that use refrigerants other than air to liquefy the product air.

1.3.2 Molecular Sieve

After the first stage of compression (in C1) the process air moves through a molecular (or mole) sieve, where moisture and CO_2 are adsorbed in zeolite. Ordinary air contains approximately 400 parts per million (ppm) of CO_2 that cannot be left in the liquefaction process because the CO_2 would form ice crystals that would clog the heat exchangers. Saturated air also contains about 0.34% water by volume, which would also freeze up the heat exchangers and valves if it were not removed prior to chilling. The job of the mole sieve is to reduce the CO_2 and water content of the air down to less than 1 ppm for each air type.

The total flow rate through C1 includes an approximately 16% portion of air used to regenerate the mole sieve. In other words, the load on the compressor is about 16% higher than is required to compress the product air and refrigerant air because approximately 16% of the clean air that leaves the mole sieve is used to sweep the saturated vessels in the mole sieve, after which that sweep air is vented. The mole sieve is shown as a crosshatched diamond on the upper right portion of Figure 1. The position of the mole sieve relative to the outflow from C1 can be adjusted. For example, it can be placed further downstream at a point where the outflow from C1 has been cooled. Other design adjustments may include the temperature and pressure conditions for the inlet air and for the sweep air that regenerates the saturated vessel. It should be noted that the design of mole sieves, especially for air separation plants, is well understood by many suppliers of such equipment. The VPS Cycle offers no specific improvements to that commonly deployed technology.

The mole sieve is a multi-vessel device where at least one vessel is being regenerated while a clean vessel is adsorbing water and CO_2 from the air stream. The sweep air that is used to regenerate a saturated mole sieve vessel is further warmed to approximately 260°F, while the second vessel is removing CO_2 and moisture from the main stream of inlet air. For example, "UOP LLC, A Honeywell Company," reviewed the conditions shown on Figure 1 and advised XE as to design options for a mole sieve. Additionally, Chemical Design Inc., a New York based maker of such equipment, reviewed the conditions shown on Figure 1 and provided a budget estimate for a two-vessel design.

Warming of the sweep air may be achieved by heat exchange with a warmer heat source such as the lubricating oil in the mechanical chiller, which is a component in the inflow-to-storage mode that will be discussed below. Alternatively, electric heating may be used to warm the approximately 242°F sweep air to approximately 260°F, in order to facilitate the regeneration process. Figure 1 shows the electric warmer option; however, an optimized mole sieve configuration may result in other designs. In any event, a small portion of the air that went through C1 is used as sweep air and is vented to the atmosphere because it contains CO_2 and moisture, which would cause ice to form in the cryogenic heat exchangers if they were not removed from the process.

However, the heat content of that sweep air contributes to the energy input to the LiBAC by way of the heat exchanger labeled water heater. The sweep air vent releases air that has a slightly higher concentration of CO_2 and moisture than the ambient air that entered the Cycle. That released CO_2 is no more than what was contained in the ambient inlet process air in the first place; thus, the inflow mode yields no net emissions of CO_2 or anything else.

1.3.3 Lithium Bromide Absorption Chiller

As mentioned above, the heat of compression and other waste heat produced during the inflow-to-storage mode are recovered to drive a LiBAC, which acts as a “bottoming cycle” within the inflow mode, converting waste heat into low-grade refrigeration. Note that instead of inter- and after-coolers at each stage of compression, the water heater, the fin-fan coolers and the rest of the configuration together act as the substitute for standard inter- and after-coolers. This array is more effective in cooling the air streams before they re-enter the next stage of compression, cooling those streams down to 51°F. By contrast, standard inter- and after-coolers, using ambient air or cooling towers, would not be able to cool the air streams below approximately 75°F. Lowering the air stream by a further 24-degrees has a significant impact on the workload of the compressor and on the amount of power required to drive the compressor.

Returning to the air flow, the cleaned air leaves the mole sieve and moves through the water heater serving the LiBAC. After cooling by stream W1/W2, it returns to the second stage of compression (C2). After further compression in C2, the process air travels once again through the water heater, giving up a significant portion of the heat of compression to the water stream that is the heat source for the LiBAC. Not all of the heat of compression is useful. some low-grade heat is dissipated in fin-fan coolers; thus, the temperature of each air stream leaving and moving on to be further cooled is shown as 75°F. This represents the average annual nighttime temperature that can be achieved by air-cooled fin-fan coolers in New York State. (As noted above, were it not for the LiBAC and its supporting equipment, the 75°F would be the inlet temperature to each stage of compression, rather than the 51°F).

In earlier versions of VPS, an Ammonia Absorption Chiller (AAC) was considered instead of a LiBAC. Although AACs tend to achieve deeper refrigeration, they generally require warmer heat input. In the context of the VPS Cycle, an AAC may be an excellent choice for converting waste heat to useful refrigeration; however, for the purposes of this study, the LiBAC is a better choice because there are more makers of LiBAC equipment than AAC equipment, and because the Con Edison deployment will be in an indoor location where the storage of a significant amount of ammonia would not be practical. Furthermore, the use of low-grade refrigeration from the mechanical chiller as a free side-load can avoid the LiBAC, simplifying the Cycle and reducing the size of the equipment.

Returning to the air flow, the process air is joined by low-pressure refrigerant air for compression in C3. The combined air stream then gives up its heat of compression to the water heater, exiting after having been cooled in the fin-fan cooler. The “P+R” designation indicates that the air stream is a combined product and refrigerant stream.

After further cooling, that combined air stream returns, is compressed in C4 and is sent through a fin-fan cooler. It then exits and is sent directly for further cooling. It is not sent to the water heater because at 132°F it is not warm enough. The stream arrives, is compressed in C5 and is sent through the LiBAC water heater and a fin-fan cooler.

After additional cooling, that stream returns to, is compressed in C6 and is cooled in a fin-fan cooler, exiting. It is then sent for further cooling. A flow control valve separates the cooled P+R stream into a process stream and a refrigerant stream.

1.3.4 High-Grade Refrigeration

The VPS Cycle inflow-to-storage mode relies on several grades of refrigeration. As outlined above, the LiBAC converts waste heat into low-grade refrigeration that reduces the work of the main air compressor. After that, a mechanical chiller (shown on the bottom center of Figure 1) produces deeper-grade refrigeration, cooling the combined process and refrigerant air stream down to -40°F. That mechanical chiller is motor driven, like the main compressor, and absorbs a portion of the power input during the inflow mode.

The deepest grade refrigeration is provided by a compressor-loaded cryogenic expander, which is shown on Figure 1 as E1, with its compressor load as C7, to the left of the mechanical chiller. The refrigerant air enters E1 at -40°F and leaves at -256°F, which is cold enough to liquefy the process air in HX-1; thus, the VPS Cycle inflow mode relies on three successively lower grades of refrigeration provided by the LiBAC, the mechanical chiller and the compressor-loaded cryogenic expander.

Returning to the Cycle, the process stream at point 14 on Figure 1, at 50°F and 497.5 psia, enters HX-1 where it is liquefied by the refrigerant air stream. Before that liquefaction can occur, the refrigerant air stream (at point 15 on Figure 1) must be further compressed in C7, its heat of compression recovered in the water heater and cooled in the fin-fan cooler, and sent for further cooling. That refrigerant stream returns to Figure 1 at point 17 and enters the mechanical chiller for further cooling, exiting the mechanical chiller at -40°F and 1,200 psia.

The refrigerant air stream now enters cryogenic expander E1 where it is expanded from 1,200 psia to 75 psia. Because E1 is loaded by C7 and work is performed, the expansion process produces refrigeration. The refrigerant air stream leaves E1 at -256°F, which is cold enough to liquefy the counter-flowing 50°F process air in HX-1.

Returning to the mechanical chiller, the working fluid that is compressed and expanded in that device is shown as R-245A, but other refrigerants may also be suitable. The heat of compression that is produced in the mechanical chiller is shown as a virtual temperature to account for the heat in the R-245A and in the lubricating (lube) oil used by the mechanical chiller's compressor. As with the air streams, that waste heat is used to warm the water that drives the LiBAC and is returned to the chiller at approximately 73°F, lowering the chiller's work input.

1.3.5 L-Air Storage Conditions

Returning to HX-1, the process air exits the liquefier and enters the L-Air storage tank at 496.5 psia and at -230°F. The refrigerant air exits HX-1 at 40°F and 74 psia and is ready for another trip around the inflow process, joining fresh process air after point 6 before the combined air streams enter C3. The selection of the L-Air storage conditions (-230°F and 496.5 psia) represents one possible optimization where the storage pressure is higher than would be expected but where the storage temperature is warmer than would be expected for L-Air storage. At those conditions, the air is colder than its critical temperature and is at a higher pressure than its critical pressure. XE has coined and trademarked the term "Metacritical" to describe that phase, which is more like a dense fog than a liquid.

That temperature and pressure combination is well within the density range of L-Air where the fluid is pump-able; however, the somewhat “warmer than normal” L-Air temperature is achieved with significantly less energy input because for each degree drop in temperature a refrigeration process requires an exponential (not arithmetical) input of energy. On the other hand, the higher storage pressure requires a more expensive storage tank. The storage tank expense is a one-time occurrence and the energy input “costs” accrue over the life of the deployment. This means the optimum storage temperature and pressure conditions will favor warmer and higher-pressure conditions, as long as those conditions are within the pump-ability range of L-Air and as long as the selected storage pressure does not exceed the capacities of standard cryogenic storage tanks.

The conditions shown in the storage tank at the bottom left of Figure 1 are within the range of cryogenic storage tanks and can be efficiently pumped by cryogenic liquid pumps. Other conditions can be evaluated to find a different balance between energy input, storage tank availability and costs and the efficiency of the cryogenic liquid pump (on Figure 2) that will pump the stored L-Air to a higher pressure during the outflow mode.

1.3.6 Additional Comments

All of the temperatures and pressures are approximate and subject to optimizations and additional input from the makers of each component shown. Pressure drop through heat exchangers is accounted for and can be seen by the fact that the pressure of each stream is lower after its trip through a heat exchanger. The temperature approach of any two counter-flowing fluids in each heat exchanger is assumed to be no better than 10º F, which is an achievable standard for heat exchangers. The exception is HX-3, where the cooling stream (W1/W2) is water, which allows for an approach temperature of 8.2 degrees between the cold water and the outflow air streams. Table 1 lists the various power demand points on Figure 1, in addition to the compressor and mechanical chiller motors shown on Figure 1.

In summary, waste heat of compression from the main air compressor and from the mechanical chiller provide the energy used to drive the LiBAC. In turn, the refrigeration output of the LiBAC helps reduce the power demand of the compressor and the mechanical chiller by cooling the air and refrigerant streams that move, respectively, through those machines. As in the rest of the Cycle, the refrigeration of each stream increases its density, which reduces the amount of compression work needed to further increase the fluid’s density. In other words, the Cycle seeks an optimal balance between compression and refrigeration, where some of the refrigeration is derived from the waste heat of compression. In broad terms, that added degree of complexity saves approximately 20% in the required energy needed to store 274,000 gallons per day of L-Air.

As will be evident in subsequent sections of this report, that extra complexity (and extra capital cost) is worth the effort because the economics of the Cycle are more sensitive to energy input costs during inflow and the net energy output achieved during outflow, than to capital costs. Put another way, the VPS Cycle and all power storage designs are sensitive to the Round-Trip Efficiency (RTE) of the Cycle.

1.4 The Conceptual Framework for the Outflow-from-Storage Mode

The fundamental goal of the Base Case Outflow mode is to send 224,000 G of L-Air from the storage tanks (in 8-hours) to a combustion chamber (and after-burner), in which L-Air has been pumped to high enough pressure so that when it is burned with natural gas (NG), the product of combustion can be expanded (in two stages), driving a generator. Note that the pumping to pressure of a liquid (in this case L-Air) requires very little energy input because liquids are virtually incompressible. By storing L-Air, the VPS Cycle is "storing" compression, eliminating the front-end compressor normally found in gas turbines and eliminating the loss of some 60% of the turbine's output to the front-end compressor.

In effect, VPS separates the compression and expansion function of a simple cycle turbine, or Brayton Cycle), with the inflow mode providing the "compression" work (where refrigeration + compression equals increased density) and the outflow mode providing the expansion or power generation function. That separation of compression and expansion can be called a Deconstructed Brayton Cycle because over each 24-hour period all of the aspects of a standard Brayton Cycle gas turbine are performed, but those functions occur in different (optimal) time slots and in separated equipment that is optimized for each distinct function.

The delta between the storage pressure of the L-Air and the pressure at which the vaporized air arrives at the combustion chambers is bridged by a cryogenic liquid pump that pumps the L-Air to above 1,200 psia before it is vaporized. The pump uses only approximately 0.32 MW of power. As a result, the entire power output of the hot gas expander(s) can drive the generator.

In order to achieve the maximum possible power output (MWh) from the stored L-Air and the burned NG, the waste heat that remains after expansion must be put to good use, producing more power than the hot gas expanders alone. That waste heat recovery system is analogous to the steam cycle in a combined cycle power plant but uses non-water working fluids, which condense at colder temperatures than steam/water systems.

Equally important as waste heat recovery is the recovery of the cold content of the stored L-Air. Refrigeration is not thrown away. The L-Air, after being pumped to pressure, is not vaporized with ambient air or by the hot products of combustion. Rather, the cold content of the L-Air is used to condense the working fluid(s) that are expanded in a second set of generator-loaded hot gas expanders, much like in a steam cycle, but at colder temperatures. Those expanded working fluids are condensed by the outgoing L-Air, returning the working fluids to a liquid state and allowing them to be pumped to pressure, to be heated again, and to be expanded in a continuous loop.

As a bookkeeping matter, the working fluid condensation load is designed to match, as much as possible, the total available refrigeration in the 224,000 G of L-Air that is sent to the combustion chambers during the Outflow mode.

The total amounts of natural gas burned and the temperatures selected for the operation of the combustion chamber and after-burner are determined by the amount of heat needed to boil the working fluids relative to the refrigeration that can be applied to the working fluids to condense them. The combustion chamber(s) outflow temperatures are hotter than the inflow to the main hot gas expanders, allowing the hot products of combustion to heat the working fluids, and then allowing the products of combustion to be expanded in the main hot gas expanders.

1.4.1 Process Diagram for the Outflow-from-Storage Mode

The power outflow process begins by pumping the stored L-Air to pressure higher than its approximately 497 psia storage pressure and vaporizing it in a heat exchanger (HX-1) by a counter-flowing loop of CO_2, which causes the loop CO_2 to be liquefied. After the pressurized loop L-Air helps liquefy the counter-flowing CO_2 stream, and after the stored L-Air is vaporized, those two cold streams are sent to a Working Fluid Condenser (HX-3), where they are heated by warm expanded ammonia[1], which, in turn, is condensed by the cold air and CO_2 streams.

The vaporized CO_2 leaves HX-3 warm and is sent for super-heating to HX-6, after which it is expanded in E5, producing approximately 10.1 MW. The expanded and still warm CO_2 is used to pre-heat the outflow air in HX-2, which allows the CO_2 to return to its liquefier (HX-1) at ambient temperatures ready for condensation/liquefaction and a return trip along the path described above.

[1] Ammonia is a working fluid (refrigerant) that has a long history of use in refrigeration cycles; however, because of its toxicity in concentrated form and because of its flammability at high temperatures and in the presence of air, another working fluid will likely be selected for VPS Cycle deployments, especially for indoor deployments. Alternatives include R-245A and R-410A.

The expansion of the ammonia in E4 with re-heating in HX-5 and expansion in E3 produces an additional approximately 10.3 + 7.6 = 17.9 MW. Figure 2 shows E3, E4 and E5 on the same shaft, driving G2, which is a plausible arrangement but not the only possible configuration. The approximate total power output at G2 is 28.0 MW.

Meanwhile, the main outflow process air stream, having been vaporized in HX-1, warmed in the working fluid condenser (HX-3) and further warmed in HX-2, is sent at 1,712 psia to a combustion chamber, where it meets 1,712-psia NG and where the two streams are combusted. The 2,000º F product of combustion is used in HX-5 and HX-6 to warm the ammonia and CO_2, as outlined above, and then is sent to E1 for expansion, where it produces approximately 8.1 MW.

Leaving E1 at approximately 171 psia and 473º F, the products of combustion still contain enough oxygen to allow for a second round of combustion; therefore, the outflow from E1 is sent to an afterburner, where it is combusted again with more natural gas. The product of that second combustion is first sent to HX-5 and HX-6, for heat recovery, and then to E2, arriving at E2 at approximately 1,400º F and 162 psia. It is expanded in E2, producing approximately 10.4 MW. The approximate total power output at G1 is 8.1 + 10.4 = 18.5 MW.

The remaining heat in the expanded product of the second combustion is used as a supplemental heat source in HX-2 and HX-6. The low-pressure products of combustion (flue gas) leave the Cycle as cool as possible. Based on the current process design shown in Figure 2, the flue gas leaving the Cycle is estimated to be approximately 90°F at 15 psia. This feature of the design will require that the vents be of stainless steel to avoid any corrosion that might result from any liquefied acids that might be formed at such a relatively cool flue gas temperature.

The approximate total (gross) power output shown on Figure 2 is 28.0 + 18.5 = 46.5 MW. Various pumps and the NG compressor that delivers the fuel to the combustion chamber at the required pressure consume approximately 2.0 MW. The VPS Cycle’s net power output from 224,000 G of stored L-Air and approximately 158,500 SCF/H of NG is 44.5 MW, or 356 MWh over the eight-hour period required to nearly empty the L-Air storage tanks. A more detailed tabulation of the power generated during outflow and the power used to achieve the outflow mode is found in Table 1.

Note that the power output at G2 (28.08 MW) is significantly higher than the power output at G1 (18.5 MW)which reflects the balance between fuel-produced power at G1 and the release of stored power via heat- and cold-recovery at G2. As mentioned above, the Outflow mode of the Cycle is analogous to a combined cycle power plant; however, in the VPS Cycle, the heat recovery portion of the Cycle is much more productive than the steam portion of a combined cycle plant.

The purpose of the buffer tank in the CO_2 loop system is to allow the liquefied CO_2 to collect momentarily so a cryogenic pump can pump it to pressure.

At much larger scales, it may be prudent to have multiple trains for both the inflow and the outflow modes, which achieves a degree of redundancy and reduces the need for custom equipment. For example, if the equipment shown on Figure 2 were produced as one module, then a +/- 100-MW deployment would have two such modules. That approach may lower engineering and deployment costs, provide insurance against down time, and allow for better start up and turn down procedures.

We envision both Inflow and Outflow modes as operating automatically. As for safety concerns, the L-Air tank would be protected per applicable standards (including NFPA codes) and placed at an appropriate distance from the fuel stream, combustion chambers and electrical equipment. The VPS Cycle will be as safe as any air separation plant or combined cycle power plant.

1.5 Efficiency Analysis of the Base Case VPS Cycle

The energy/power inputs and outputs of the VPS Cycle are summarized in Table 2, which has been submitted to NYSERDA as a confidential document. The table is based on the conditions as illustrated on Figures 1 and 2, and per the energy inflow and outflow summary shown on Table 1. The base case assumes that the Cycle operates five days per week, with 10 off peak hours of daily inflow-to-storage and eight peak hours of outflow-from-storage. It also assumes an L-Air storage capacity of 225,000 gallons, where 1,000 gallons of L-Air remain in storage at the end of the outflow mode; therefore, 224,000 gallons of L-Air, or 1,368,800 lbs, are produced during the off-peak, night time inflow period and 224,000 gallons of L-Air are sent to the combustion chambers during the peak, daytime outflow period. Those flow rates translate to an outflow rate of 28,000 gallons per hour (or 171,100 lbs/h), and an inflow rate of 22,400 gallons per hour (or 136,880 lbs/h).

1.5.1 Time Slot Allocations

The top section of Table 2 tabulates one set of selected time slots allocated for the Cycle. Other time slot allocations can also be selected. For this analysis, eight hours of continuous power output was assumed and 10 hours of not necessarily continuous inflow-to-storage was assumed. The remaining 16 hours per day offer opportunities of selecting the optimal 10-hours for the inflow mode. That flexibility allows the operator of the VPS Cycle to seek the lowest possible cost off-peak power from various sources. Those 10 hours of inflow need not be continuous. If weekend inflow is deemed to be cost effective, then even greater flexibility is achieved. In some markets, an increased L-Air storage capacity may offer substantial flexibility as to when to purchase off-peak power. The extra cost of the supplemental storage capacity can be more than offset by the improved “purchasing power” of the operator of the VPS facility.

As shown on Table 1, the power required to fill the L-Air tanks is 16.22 MW (162.2 MWh). On an annual basis, the total power input from wind generation, for example, is 42,288 MWh, as shown on Table 2.

1.5.2 Energy Input

The next group of entries on Table 2 concern the energy input derived from the burning of the NG in the combustion chambers. During the eight hours of outflow, accounting for the two combustion chambers, approximately 161,289 standard cubic feet of NG per hour is burned, or approximately 147,579,435 Btu/h. Translating that energy input into an annual value and converting Btu/h into MWh yields an annual contribution of 90,187 MWh of power output from the NG. When that figure is added to the contribution of the annual wind power into the Cycle, the total annual energy input is 42,288 + 90,187 = 132,475 MWh. In other words, the Cycle receives 132,475 MWh of energy input, some of which arrives during off-peak periods (from wind turbines) and some of which arrives during the peak outflow period from the natural gas used as fuel. Other fuel sources can include landfill gas (LFG) and anaerobic digester gas (ADG).

The heat rate of the Cycle (in Btu/kWh) is the relationship between the total energy input derived from the NG (in Btu/h) and the net power output (in kW or MW). Heat rate is an efficiency measure commonly used by thermal power plants of all types. The lower the heat rate, the higher the energy conversion efficiency from thermal energy (Btus) to power (kW). As shown on Table 2, the heat rate is approximately 3,300 Btu/kWh, which reflects the fact that a portion of the power output is coming from the release of the stored energy in the air. Per note 4 on Table 2, that heat rate compares favorably to the heat rates kWh achieved by combined cycle power plants, which are (6,700 to 7,700 Btu/kWh). In other words, the VPS Cycle uses natural gas more efficiently than standard combined cycle power plants. This is in large measure because of the “free” energy input during outflow from the recovered energy in the stored L-Air.

As reported in several NYSERDA-sponsored studies, including the recent Seneca Lake proposal, the estimated heat rate of large-scale CAES deployments also using NG as the fuel during the outflow mode is 4,036 kJ/kWh or approximately 3,825 Btu/kWh. This means the VPS Cycle outflow mode uses NG more efficiently than CAES, mainly because VPS leverages more heat and cold recovery steps in the outflow mode, which is an option that is not available for CAES systems.

1.5.3 Power Output

Table 2 examines the gross and net power outflow values relative to the total power input value discussed in the previous paragraph. As shown on Table 1, the gross and net power output values for the Base Case are 46.5 MW and 44.5 MW, respectively, which yields about 92,000 MWh of annual power sales.

1.5.4 Thermal Efficiency

Table 2 tabulates the thermal efficiency (TE) of the VPS Cycle. TE is a ratio of the total power output relative to the total fuel input from the NG. Because the Cycle also received energy input from the wind, the total power output is higher than if the only power input source were the burning of NG; therefore, the TE value is above 100% and reaches approximately 103%. Thermal efficiency and heat rate are two ways of measuring the energy input delivered by the fuel compared to the energy output of the VPS Cycle.

1.5.5 Round-Trip Efficiency

Table 2 calculates the Round-Trip Efficiency (RTE) of the VPS Cycle. RTE is a measure of a cycle's ability to recover the energy stored during the inflow-to-storage period and is often viewed as the most significant metric for a power storage system. For example, if a pumped hydro system has 85% efficient pumps and 90% efficient turbines, no more than 75% of the energy input to the cycle can be recovered. In that case, a pumped hydro system would have an RTE of 75%.

In the context of power storage systems that burn fuel (NG), such as in CAES and in the VPS Cycle, the RTE can be calculated by subtracting the chemical contribution of the NG from the total power output, leaving the only other power source, for example, wind energy, which is (the mechanical energy, responsible for any power output that is above and beyond the output attributable to the NG. In that methodology, the remaining value can never be more than the total wind energy stored because a system cannot recover more power during the outflow mode than was stored during the inflow mode. If the NG use is very low and an RTE of 100% is attained/approached, then we can say that the cycle has a very high RTE and uses NG in a highly efficient manner.

Table 2 is an outline of XE's methodology for determining the Base Case RTE discussed here. The RTE calculations on the bottom of Table 2 compare the NG use of the VPS Cycle to the use of NG in the highest-efficiency, combined cycle power plants, which are approximately 60% efficient.

Table 2. Round-Trip Efficiency (RTE) Calculation Methodology.

Base Case Assumptions	
Storage	225,000 gallons of L-Air = 1,368,800 pounds of L-Air = 3 tanks, 75,000 gallons each
Inflow to Storage	10 hours per day times 5 days per week times 52.14 weeks per year
Outflow from Storage	8 hours per day times 5 days per week times 52.14 weeks per year
Energy Flow	
Inflow to Storage	16.22 MW x 10 hours = 162.2 MWh/day; **42,288 MWh/year**
Net Outflow from Storage	48.05 MW x 8 hours = 384.4 MWh/day; **100,212 MWh/year**
Natural Gas (NG) Used During Outflow	177,005 SCF/hr; 161,959,575 Btu/hr
Heat Rate of VPS Cycle	3,371 Btu/kWh
LHV Energy Content of NG	915 Btu/SCF (approximate)
Power Output Content of NG Used	MWh of power if NG is used in a highly efficient (60%) Combined-Cycle Power Plant: 59,804 MWh/year
Portion of Energy Output Attributable to Stored Energy	Total Power Output – Power Output Attributable to NG = Energy Recovered from Storage: 100,212 MWh – 59,804 MWh = 40,408 MWh
RTE = Recovered Output ÷ Inflow to Storage	40,408 ÷ 42,288 = **95.55%**

As shown in Table 2, the VPS Cycle achieves an RTE of more than 95%. Put another way, the VPS Cycle outflow mode recovers nearly all of the energy stored during the inflow period. After the contribution of the NG to the outflow mode is accounted for, based on its equivalent contribution in a combined cycle power plant, the remaining power output must be derived from the previous night's power input into the stored L-Air. That allocation can never be more than the MWh stored the night before, which requires the calculation to be "balanced" by the comparative rate at which the Cycle burns NG relative to the use of the same amount of NG in a combined cycle power plant.

The Cycle's very-high RTE does not suggest that there are no losses during outflow or inflow or that any portion of the Cycle is 100% efficient. RTE only examines the relationship between the total power output, the amount of NG used in the context of the power output that NG would achieve in a combined cycle power plant, and the amount of power used during the inflow mode.

The VPS Cycle's unmatched RTE is achieved by a deliberate design program inherent in the patented VPS Cycle. Because the Cycle operates across a wide range of temperatures (from 2,000 F during outflow to -230 during inflow), there are more opportunities for energy recovery from the heat of compression during inflow and from the refrigeration content of the L-Air during outflow.

In examining Table 2 and how the more than 95% RTE is achieved, it can be seen that the RTE is sensitive to the following values:

- The amount of wind power (MWh) required to fill up the L-Air storage tanks.
- The amount of NG used to facilitate the release of the stored power.
- The amount of total power (MWh) produced during the outflow mode.

For example, if the wind power input is low enough because of a very efficient inflow mode and the inflow mode still manages to put away the same 224,000 gallons of L-Air, then the RTE will likely be high because only a relatively small amount of power needs to be recovered during each outflow mode. In other words, a high-RTE cycle will produce more energy storage medium, such as air, with less energy input than a low-RTE system. That fact yields a fundamental distinction between VPS and CAES systems. Cavern storage of compressed air does not offer as many options for useful heat of compression recovery as VPS utilizes.

Similarly, if all other factors stay constant and the total power output is especially high because of a very efficient use of the available heat during the outflow mode, then the role of the NG used becomes relatively lower, which enhances the RTE calculation. A high-RTE cycle will produce more power during the outflow modes with less NG burned than a low-RTE system.

1.5.6 Other Comments on the Base Case VPS Cycle Efficiency

The VPS Cycle achieves its high RTE values because the inflow mode is designed to produce 224,000 gallons of L-Air with as little energy input (MWh) as possible within capital cost constraints. The Cycle achieves that goal by recovering the heat of compression and converting that waste energy into refrigeration, which cools the inlet streams to each compression stage. The cooling helps reduce the power demand of the compressor. Very little energy is dissipated in the fin-fan coolers and in the LiBAC cooling tower. Alternatively, the free, low-grade heat that is available from the mechanical chiller will also help cool the air to each compression stage, which increases the air's density and reduces the work of the compressor.

Similarly, during outflow, the VPS Cycle uses the available refrigeration content in the stored L-Air to condense two other working fluids, which are then boiled and expanded in generator-loaded expanders, fully utilizing, or recovering, the refrigeration content of the stored L-Air and the heat derived from the combustion of the air with the NG.

Moreover, the ability to locate VPS adjacent to the end-user of the power eliminates any power losses during the outflow mode and eliminates any issues related to grid congestion. Those two benefits, when added to the high RTE and TE of the Cycle, offer a system that is significantly superior to almost any CAES or other utility-scale power storage option.

The economic analysis of the VPS Cycle will examine the Cycle from two perspectives. At its core, the Outflow mode is the equivalent of a power production facility, but it does not send out power during low-value periods; therefore, the Outflow mode can be compared to the cost of a standard Combined Cycle Power Plant. The Inflow mode is an extra cost that allows VPS to achieve certain benefits that a standard Combined Cycle Power Plant cannot offer. The premium paid for the Inflow mode will be analyzed relative to the values it generates.

1.6 Budget Projection for the Base Case VPS Cycle

After close consultation with vendors of the key components utilized in the VPS Cycle and following careful review by Expansion Energy and its consultant engineers, XE determined that the total turnkey capital cost required to build a 44.5 MW VPS plant in New York City is approximately $100 million. As a turnkey estimate, this total cost includes all VPS equipment components, site preparation, grid interconnection, construction, contractor’s mark-up, engineering, program logic, plant commissioning, training, technology license fee and customary contingencies. A comprehensive itemized budget (proprietary) was provided confidentially to NYSERDA.

For numerous reasons, construction costs in New York City are substantially higher than in most other locations; therefore a VPS plant of this scale constructed in most other regions can be expected to cost significantly less than the estimated cost cited above.

1.7 A Smaller Alternative: Commercial-Scale VPS – 4 MW to 20 MW

In addition to the Utility-Scale (20 MW to 100s of MW) version of the VPS Cycle covered in this report, Expansion Energy recently developed a smaller, simplified and lower-cost Commercial-Scale version of the VPS Cycle(4 MW to 20 M).This version is pre-designed and 100% factory-manufactured, then delivered to the deployment site on skids, which eliminates the need for on-site construction. This approach greatly increases the deployment potential and market size for VPS plants. Commercial-Scale VPS plants are deployable at virtually any location that consumes at least 2 MW of power and has a natural gas grid connection. As such, Commercial-Scale VPS represents a potential paradigm shift in how energy is produced, delivered, stored and used worldwide.

Like Utility-Scale VPS, Commercial-Scale VPS is designed to operate on a daily cycle, storing energy during the overnight, off-peak period and delivering 8-12 hours of power per day at a constant release rate during the grid's peak demand period. There are certain key differences between the larger, Utility-Scale VPS and the smaller, modular Commercial-Scale VPS systems, which are summarized in Table 3.

Table 3. Utility-Scale VPS vs. Commercial-Scale VPS – Key Differences.

	Utility-Scale VPS	Commercial-Scale VPS
Scales	20 MW to 100s of MW	4 MW to 20 MW
Construction	Field-erected Site-constructed, like a power plant)	Factory-built Modular, manufactured appliance
Design / Engineering	Custom design/engineering New design for each VPS plant	Standardized design/engineering Each design pays dividends across dozens/hundreds of units
Application	Centralized/substation energy storage	Distributed energy storage End-user reduction of peak demand and power consumption; back-up/reliability
Customers	Utilities / Power Cooperatives Power Generators	Utilities/Power Cooperatives Power Generators Industrial Power Users Commercial Power Users Military
Competing Technologies	Pumped Hydro + CAES Each require scales > 100 MW	Virtually no competition 4-20 MW is too large for Batteries and too small for Pumped Hydro + CAES
Market Potential (# of plants)	Dozens or hundreds	Thousands
CAPEX per Plant	~ $100 million for 45 MW VPS plant	~ $20 million for 10 MW VPS plant

1.7.1 Utility-Scale VPS vs. Commercial-Scale VPS – Key Similarities

Despite the key differences between Utility-Scale VPS and Commercial-Scale VPS outlined above, Commercial-Scale VPS preserves the many important advantages that Utility-Scale VPS delivers, such as:

- A highly efficient distributed generation power plant with built in storage.
- Turns intermittent power sources (e.g., wind, solar) into firm power sources.
- Beneficial for storing base-load power (e.g., coal, nuclear, gas) off-peak.
- VPS components are 100% commercially available off-the-shelf.
- Round-trip efficiency (RTE) > 95%.
- 8 to 12+ hours of power release capacity—daily cycling at a constant release rate.
- Can be constructed virtually anywhere above-ground.
- Substantially reduces grid congestion if sited near high-demand, end-users/load centers.
- Ultra-high Btu conversion efficiency—Heat Rate = ~3,316 Btu/kWh vs. 6,660-7,700 for combined cycle plants.
- 10 times greater storage density than CAES and much higher RTE than CAES.
- VPS is 100% man made (no reliance on special geologic conditions/caverns), which is reliable, predictable, replicable.

1.7.2 Customers/End-Users for Commercial-Scale VPS

Whereas the target customers for Utility-Scale VPS plants are necessarily limited primarily to utilities, power cooperatives and power generators, the market for Commercial-Scale (4-20 MW) VPS plants includes, but is not limited to:

- Industrial facilities/factories/refineries.
- Utility – T&D "tight spots"/capacity upgrades.
- Military bases.
- Hospitals.
- Office parks/corporate campuses.
- Shopping centers.
- Airports & shipping ports.
- Wind farms & solar farms.
- Micro grids.
- University campuses.
- Data centers/server farms.
- Food processing/refrigerated warehouses.
- Mines & quarries.
- Other critical buildings/infrastructure.

1.7.3 VPS Integration with Gas-Fired Turbines—An Optimal Application

In addition to stand-alone Commercial-Scale VPS plants, another recent advancement of the VPS technology is the potential for Integration of VPS with existing simple-cycle, gas-fired power plants (e.g., peakers). In other words, existing simple-cycle power plants can be retrofitted with VPS technology to convert them into daily duty power storage assets, which makes them far more valuable assets than the occasionally used peakers that they are today. Hundreds of such peakers exist around the world and represent a large market opportunity.

1.7.4 Additional Benefit of Commercial-Scale VPS: Back-up Power

If access to grid power is interrupted for any reason, the prime mover of Commercial-Scale VPS plants (e.g., gas turbine or natural gas engine) can continue to generate power (1 MW to 4 MW, depending on the scale of that particular VPS plant) for an extended period (hours/days/weeks/months) even if no new liquid air is produced by the front end of the VPS plant. As long as the VPS plant's connection to the natural gas pipeline system is intact, each VPS plant will continue to have 10% to 20% of its rated power outflow capacity available as back-up generation. This may be particularly important in the New York City and Long Island markets, where the grid disruptions caused in 2012 by Hurricane Sandy have placed a new emphasis on grid reliability.

1.7.5 Targeted Licensees of the Commercial-Scale VPS Technology

Potential licensees of Commercial-Scale VPS technology include any of those listed in Section 2.6.2 (Customers/End-Users) in addition to manufacturers/vendors of energy equipment serving the markets for power generation, power storage or power distribution that may be interested in selling factory-built VPS plants to the market.

One particularly synergistic category of VPS end-users are the hundreds of air separation plants that exist worldwide, including in New York State, to make industrial gases such as oxygen, nitrogen and argon that operate 24/7 and face high "demand charges" and high peak-period energy consumption charges from power utilities. The front end, or power inflow-to-storage, portion of VPS plants resemble portions of air separation plants that already exist. Therefore, utilizing VPS at air separation plants would require only building/deploying the outflow-from-storage portion of a VPS plant, which would substantially reducing the capital cost, complexity and footprints of such deployments. Air separation plants are low-hanging fruit for VPS deployments because they deliver substantial and immediate value to the customer/host.

1.7.6 Economics/ROI for Commercial-Scale VPS Plants

Information from previously published NYSERDA reports on the value of energy storage suggest that the 25-year Present Value (PV) of energy storage assets that reduce an industrial customer's peak demand charges and peak power consumption charges may exceed $5,000/kW. This is far higher than the capital cost of VPS plants deployed at air separation plants (~$1,300/kW) or at other types of industrial facilities (~$2,000/kW); therefore the return-on-investment (ROI), or net present value (NPV) potential for Commercial-Scale VPS plants at many industrial facilities is extraordinarily high. There is also a high ROI pattern for utility owners of Commercial-Scale VPS plants in regions where power storage is in demand—either because of market need or government/regulatory policy.

1.7.7 Commercial-Scale VPS Conclusions

The recently designed Commercial-Scale VPS plants are smaller, simpler and lower-cost than Utility-Scale versions of VPS. Commercial-Scale VPS addresses an even broader and larger market than Utility-Scale deployments. These modular, standardized, factory-built appliances serve the large market for power storage at 4 MW to 20 MW. Today, at these scales, there is virtually no cost-effective technological solution, as these scales are generally too small for CAES and pumped hydro and too large for battery storage.

Using the same economic analysis methodology that was used for the Base Case Utility-Scale VPS plant that is the main subject of this report, Expansion Energy also analyzed the economics for Commercial-Scale VPS deployments. Results show that Commercial-Scale VPS plants generally deliver Net Present Values (NPV) of 2-3 times their turnkey capital cost, which is an extraordinarily high return-on-investment. This is true regardless of whether the owner of the Commercial-Scale VPS plant is an end-user (e.g., industrial power consumer) or a utility, as in the Base Case.

Commercial-Scale VPS represents a potential paradigm shift in how energy is produced, delivered, stored and used. Worldwide, virtually every facility that uses more than 2 MW of power from the electric grid and is served by a natural gas grid connection is a candidate site for a Commercial-Scale VPS plant. Each VPS deployment could eventually become part of a widespread network of cost-effective, low-emissions distributed storage and distributed generation assets. This would result in the combining of well-recognized economic and operational benefits of power storage and distributed generation, which are two of the most important trends in the power industry today.

2 Potential Deployments of Con Edison Steam Generating Plants

Prior to the execution of this contract, XE visited Con Edison's Hudson Avenue Steam Generating Station in Brooklyn, NY Subsequently, that plant has been shut down; therefore, its operating characteristics and site configuration will not be reported on or analyzed here, but that site may be considered for a VPS Cycle deployment at a future date. After the execution of this contract, XE visited and gathered data for the following three Con Edison steam generating facilities in Manhattan:

- West 59th Street Steam Generating Station.
- East 74th Street Steam Generating Station.
- East River (East 14th Street) Generating Station.

With regard to the fuel used at each facility, #6 oil has been used historically, but natural gas is increasingly used at each site, with natural gas likely becoming the exclusive fuel at some point in the future.

The maximum daily steam production rates for each facility are listed below. The minimum daily production varies from site to site and is dependent on the number of main boilers and the number of auxiliary boilers at each site. Seasonal variations in steam demand and the need to maintain the steam generating plants results in shutdowns during certain shoulder periods each year.

In April of 2011, XE prepared a Steam Information request to Con Edison, which is attached as Appendix A. David Vandor attended a meeting with Con Edison, Mr. Liebowitz, and James Foley of D-R to review progress to date, to establish steam conditions within the Con Edison system, and to select the West 59th Street Steam Generating Station as one model for the feasibility study.

2.1 West 59th Street Steam Generating Station

Steam data gathering was advanced during May 2011 with input from Con Edison that included a site visit to the W. 59th Street Steam Generating Station, where the on-site operating staff communicated to XE the steam conditions and operating logistics of the facility.

The following data and findings were collected during and after the May site visit to the West 59th Street Steam Generating Station.

1. **Space:** The southwest corner of the building, with an approximate 80’ by 100’ foot print, but not including the basement level, is an approximately 70’ high. This underutilized volume may be suitable for the deployment of the VPS Cycle equipment. The VPS Cycle installation will occur on multiple levels above the basement. For example, the first floor of that 80’ by 100’ area might contain the L-Air storage tanks and some heat exchangers; the second level might contain the inflow-to-storage compressor, chillers and additional heat exchangers; and a third level might contain the outflow-from-storage generator-loaded hot gas expanders, their related heat exchangers, program logic and connections to the steam and electric grids.

2. **Openings:** The largest loading dock at the site is located in the northwest corner of the building immediately adjacent to the space described above. That location will likely allow all of the L-Air storage tanks, the skidded compressor, chillers and generator-loaded expanders to be delivered to the site by over the road vehicles and maneuvered into their positions within the approximately 80’ by 100’ by 70’ volume that might be allocated to a VPS Cycle deployment. The services of an existing internal overhead crane will likely facilitate that process.

   The existing structural grid of the building limits the maneuvering room available and will constrain the absolute size and shape of any L-Air storage container or equipment skid that can be inserted into the building. In other words, the maximum dimensions of any single tank or skid may be limited to 60’ by 15’ by 12’, which will likely match the limits on road delivery of equipment.

3. **Steam Output:** The two main boilers, when operating, provide 1,000,000 lbs/h of steam at an approximate pressure of 850 psia and at approximately 750º F. Up to 100% of that steam output would be sent to the in house VPS Cycle during the daytime outflow mode, with VPS using a portion of the steam’s heat content and returning cooler steam to Con Edison’s distribution line at approximately 400 psia and at approximately 470º F. Those are the operating conditions of the local steam distribution system.

   The two main boilers do not run all year long. They tend to be off for maintenance and business reasons during the spring and fall shoulder periods. During those periods, the VPS outflow mode might rely on the three smaller package boilers (PBs) located in the same building. Those boilers each produce 120,000-lbs/hr of steam at 250 psia at approximately 400º F.

A question that stems from using PB steam is where would the quenched condensate from the used steam go at the end of the peak period power outflow mode? Although quenched condensate is normally sent to the NYC sewer system after a steam grid customer receives the steam, that option may not be available at this site. In that event, the Cycle would need to include water storage tanks that would hold the quenched condensate over-night until the next peak period power release, which would increase the need for space devoted to VPS. If that issue cannot be resolved, and if the PBs cannot serve the Cycle during the shoulder periods, then we can consider running the on-site simple-cycle gas turbine (GT) to produce some peak-period power from the GT. The waste heat from this process can be used as the shoulder period substitute for steam heat to release the stored L-Air. That option would need to be tested against emission permit constraints.

4. **Cold Water:** The VPS Cycle inflow mode uses a Lithium Bromide Absorption Chiller (LiBAC) to provide refrigeration used in several places in the Cycle. The LiBAC functions with water as a cooling medium that takes away low-grade heat that the LiBAC needs to dissipate. Normally, that cooling water can go to a cooling tower or to a set of fin-fan coolers, which rely on ambient air to dissipate the low-grade heat. Because the inflow mode is a nighttime function, and with NYC annual average nighttime temperatures at approximately 60º F, the fin-fan coolers will likely be the better solution than cooling towers.

   Instead of throwing away the low-grade heat carried by the cooling water, the Con Edison boilers can benefit from the pre-heated water that leaves the LiBAC. Every 10º F in extra heat in the water sent to the boiler will increase the efficiency of the boiler by approximately 1%.If VPS sends warm water to the boilers, it can replace that water from the city water supply, much like the Con Edison boilers now do, and benefit from the "refrigeration" content of the50º F to 60º F (depending on time of year) city water. In such an arrangement, the VPS LiBAC would be especially efficient, and the Con Edison boilers' efficiency might be improved by as much as 6%.

2.2 East 74th Street Steam Generating Station

XE visited Con Edison's East 74th Street Steam Generating Station and established the steam conditions and operating logistics. XE concluded that the site has room for a VPS Cycle deployment on the top floor and on a roof above. A summary of that meeting was distributed in June and an edited version follows.

The following data and findings were collected during and after the June site visit to the East 74th Street Steam Generating Station.

1. Maximum temperature of the steam produced: 800°F.

2. Standard pressure at which steam can be delivered to VPS Cycle: 850 psia.

3. Quantity of available steam: three main boilers, each with 450,000 lbs/hr, and six package boilers, each with 120,000 lbs/hr for a total capacity of 2,070,000 lbs/hr.

4. Return temperature and pressure required and quality of steam after it leaves the on-site VPS Cycle: 200 psia at a temperature equal to saturation plus 25°F, or approximately 425°F.

5. High-pressure steam is letdown (e.g. through expansion valves), with virtually no energy recovery system in place.

6. Room for VPS deployment: Ninth floor, south side room; approximately 100’ by 130’ plus the roof area above that room, but it likely requires structural reinforcement.

7. Establishing the energy value of steam in calculating Round-Trip Efficiency (RTE) of the VPS Cycle: XE and Con Edison discussed the concept of calculating the amount of heat energy (Btus) taken from the high-pressure steam before it is returned cooler and at a lower pressure to the steam distribution system, equating that amount of Btu transfer from the steam system to VPS with a natural gas equivalent, calculating the MW output of that amount of natural gas in a +/- 53% thermally efficient combined cycle power plant and assigning that value as the steam’s contribution to the total power output. If a steam-assisted VPS outflow produces 20 MW/h over eight hours (160 MWh) and requires the use of steam that, in its natural gas equivalent would have generated 4 MW/h (32 MWh), then only 128 MWh of the total output can be attributed to the stored energy. If the storage process required 15 MW/h over 10 hours (150 MWh), and only 128 MWh of the total power output can be assigned to the stored air, then the cycle will have an RTE of 85% because 128 MWh is 85% of the 150 MWh of stored energy.

   On a practical level, the existing pressure and temperature reduction process at East 74th Street recovers virtually no energy; therefore, if VPS were to be integrated into that system and would deliver the steam to the grid at the same conditions that are now in place, it can be argued that the steam’s contribution to VPS is zero because no extra energy was taken from it compared to the status quo. In that analysis, the RTE would approach 100% because of the recovered energy from the steam.

2.3 East River (East 14th Street) Steam Generating Station

Steam data gathering continued during July with input from Con Edison that included a site visit to the East River Steam Generating Station, where the steam conditions and operating logistics were established. The following data and findings were collected during and after the July site visit to the East River Steam Generating Station.

1. Maximum temperature of the steam produced: approximately 800°F.

2. High-pressure steam is letdown (e.g. through expansion valves) with no energy recovery system in place.

3. Standard pressure at which steam can be delivered to VPS Cycle: may be as high as 1,000 psia at the pressure letdown valve.

4. Quantity of available steam: as much as 5,700,000 pounds per hour total, but likely less than that at the pressure letdown valve(s); 5.1 million from high pressure boilers and 600,000 from package boilers.

5. Return temperature and pressure required and "quality" of steam after it leaves the VPS Cycle: 200 psia at a temperature equal to saturation plus 25°F, or approximately 425°F.

6. Room for VPS deployment: Approximately five empty silos formerly used to store coal, each approximately 20' in diameter and approximately 60' high, with access from above; compressors, expanders and heat exchangers would be arranged vertically in each silo, with manifolds above for piping and duct connections; L-Air storage tanks would be installed vertically.

7. Two simple cycle General Electric gas turbines (GTs) produce electricity, and the +/- 1,200°F exhaust produces steam for the Con Edison steam distribution system. Three steam-driven generators also produce electricity. The GTs' front-end compressors take in ambient air. The VPS Cycle can deliver -20°F air to the GTs in lieu of ambient air, which substantially improves the power output (and/or reducing the fuel use) of the GTs.

8. The pressure letdown devices used at East 14th Street do not recover any energy from pressure letdown step. As such, a VPS deployment at East 14th street would achieve a virtual 100% RTE because the outflow mode of the Cycle will yield significantly more energy than was used during the inflow mode to store the L-Air. The extra energy can be attributable to the now lost heat content of the steam that will be recovered in lieu of a pressure letdown valve.

The following summarizes the steam production values by the four boilers at the East 14th Street facility:

Unit 1: 1,500,000 lbs/hr at 520 psig, at 500°F, which can be directed to a pressure reducing station serving a 400 psig send-out main with 25 degrees of superheat or to a 200 psig send-out main with 25 degrees of superheat.

Unit 2: 1,500,000 lbs/hr at 520 psig, at 500°F, which can be directed to a pressure reducing station serving a 400 psig send-out main with 25ºsuperheat, or to a 200 psig send-out main with 25 degrees of superheat.

Unit 60: 1,000,000 lbs/hr at 400 psig, at 475°F, which can be directed to a pressure reducing station serving a 400 psig send-out main with 25º superheat or to a 200 psig send-out main with 25 deg superheat.

Unit 70: 1,100,000 lbs/hr at 400 psig, at 475°F, which can be directed to a pressure reducing station serving a 400 psig send-out main with 25º superheat or to a 200 psig send-out main with 25 deg superheat.

South Steam Station Package Boilers: five boilers each producing approximately 120,000 lbs/hr at 400 psig send-out main with 25º superheat.

The total steam output of the East 14th Street facility is 5,700,000 lbs/hr.

2.4 The Potential for VPS Cycle Deployments at Con Edison Steam Customer Sites

Based on the physical size and capital costs of small-scale VPS Cycle deployments and the need for economies of scale, XE concluded that distributed deployments of the VPS Cycle at individual commercial or institutional sites in Con Edison's service territory are not feasible. The size and weight of L-Air storage tanks and the other equipment, such as absorption chiller, mechanical chiller, air compressor, hot gas expanders, generators, heat exchangers will be too large to fit into the mechanical rooms of existing or future commercial buildings and cannot be cost-effectively located on roofs.

For example, a VPS Cycle deployment with a single 10,000-gallon L-Air storage tank using steam as the heat source during outflow would have a power output capacity of less than 1 MW or less than 8 MWh; however, that single L-Air tank would be the same size as a typical 10,000-gallon liquid delivery vehicle, say, 40' long and 8' in diameter, taking up more than 1,000 sq. ft, when accounting for buffer areas and access ways around the tank.

When the other major components are accounted for, the total space required for such a small installation (in MWhs) will be in excess of 10,000 sq. ft., which will be difficult to find in existing buildings. The weight of the equipment will be considerable, suggesting that deployment at a basement level would require less complex structural support than deployment at any other level, including on roofs. Access to basements in existing buildings is extremely limited, thwarting attempts to locate L-Air tanks and other large components at sub-surface levels.

The need to achieve economies of scale will likely require deployments with an output capacity of more than 5 MW (40 MWh), likely at least 10 MW (80 MWh) and possibly as much as 20 MW (160 MWh). Those scales are above the likely demand at any individual customer’s site and would require complex business and regulatory arrangements to allow the excess power output to be sold back into the grid.

In summary, XE concluded that the deployment of VPS Cycle power storage units at individual steam customer sites was not feasible, at least for the foreseeable future.

2.4.1 Power Recovery from Locally Distributed Steam

The maximum amount of steam that can be delivered to any site along the Con Edison steam grid is 84,000 lbs/h, and the maximum total amount of deliverable steam to the grid is 9,130,000 lbs/h.

XE has examined the possibility of deploying Organic Rankine Cycle (ORC) heat-to-power systems in a distributed manner, where each deployment would produce power that would not use the steam directly, as in a steam turbine, but would use the available heat in the steam. If each such deployment used 80,000 lbs/h of steam, up to 114 such deployments could theoretically be envisioned. If each deployment used the most efficient, commercially available ORC systems and produced as much as 4 MW of net power output, then a maximum of 456 MW of power could be produced within NYC, without any new fuel use or emissions.

A more conservative scenario can assume ten such ORC deployments at 4 MW each, yielding 40 MW of power output or 400 MWh if each site operated during a 10-hour peak daytime demand period.

Con Edison, NYSERDA and XE have examined available ORC designs by various entities. Some of those designs may be able to cost-effectively produce power from the recovered heat in the waste hot water that results from the use of the steam at each steam customer. That waste hot water is approximately 215°F and may be hot enough for productive power production in some ORC designs; however, a detailed analysis of how the 215°F waste hot water available at individual steam customers may be cost-effectively converted to recovered power is beyond the scope of this study, but it may be a suitable topic for follow up work by XE and/or others.

3 The VPS Cycle with Steam

In May of 2011, Expansion Energy LLC (XE) issued a consulting contract to Process Engineering Associates, LLC (PEA) to perform a thermodynamic analysis of the outflow-from-storage mode of the VPS Cycle, using available heat contained in steam produced at typical Con Edison steam generating plants in New York City. The consulting contract was issued by XE as part of the NYSERDA contract that is the subject of this report.

3.1 General Principles of the VPS Cycle with Steam

As in the Base Case VPS Cycle discussed above, the VPS Cycle with Steam aims to store a selected amount of L-Air, at optimal pressure and temperature conditions, over a specified inflow-to-storage period, with the least possible input of energy. For the purposes of this feasibility study, the analysis of possible deployments at Con Edison steam generating stations assumed that the amount of L-Air to be stored at each site was exactly the same as in the Base Case. This assumption allowed the analysis to focus entirely on the outflow-from-storage mode, assuming that the inflow-to-storage mode would be as described above for the Base Case.

On the Outflow side, the Base Case of the VPS Cycle aims to produce the maximum possible power with the least possible burning of fuel, per the following techniques:

- Select the outflow pressures to which the released L-Air is pumped, based on the maximum pressure tolerance and pressure letdown ratio capacity of standard off-the-shelf, Dresser-Rand hot gas expanders.
- Recover the refrigeration content of the stored L-Air prior to vaporization and combustion by using that refrigeration to condense several working fluids that are also expanded in hot gas expanders, at the maximum pressure, temperature, and letdown ratio capacity for those secondary expanders.
- Use a portion of the waste heat from the expanded products of combustion produced after pressurized NG is combusted in the presence of pumped-to-pressure and vaporized L-Air to heat the working fluids that are used to produce additional power. The working fluids are condensed by the cold content in the outbound L-Air.
- Use a portion of the waste heat available from the expanded products of combustion to pre-warm the vaporized former L-Air prior to its arrival at the combustion chamber.
- Burn the compressed NG and warm, high-pressure air mixture at an optimal rate to create enough heat (in Btus) and high-grade heat, allowing a portion of that heat to boil the working fluids and still yield a hot enough product of combustion to match the temperature capacity of the hot gas expanders.
- Expand the hot, high-pressure products of combustion and at least one of the working fluids in a two-stage-with-reheat configuration, optimizing the performance characteristics of high-pressure expanders with cooler inlet temperatures and low-pressure expanders with hotter inlet temperatures, which produces more power with less energy input.

As with the Base Case, the inflow mode for the VPS Cycle with Steam assumed that 224,000 G of L-Air would be stored in cryogenic storage tanks over a10-hour off-peak period with the lowest possible power (MW and MWh) input. Power input during the inflow can come from any source, such as wind, base-load, or LFG-to-kW, by wheeling.

The inflow-to-storage can occur during a 16-hour off-peak period, during which 10-hours of power input is available continuously or in two or more time segments. If weekend power is to be stored for weekday release, the total storage capacity may be larger.

3.2 Conceptual Framework for the Outflow-from-Storage Mode

Unlike in the Base Case outflow mode, the VPS Cycle with Steam does not have a natural gas combustion chamber where the pumped-to-pressure, vaporized, warmed air (formerly L-Air) is combusted with natural gas. Instead, available steam from the Con Edison steam generating facility is used to warm the L-Air and a second working fluid.

The warmed air leaves the Cycle after expansion and returns to the atmosphere from which it was produced the night before. Only a portion of the heat content of the steam generating boilers' output is used to warm the air and the secondary working fluid. The steam is returned to Con Edison somewhat cooler and at a slightly lower pressure, but it is still above the temperature and pressure standards of the steam distribution grid. The heat recovered from the steam generating boiler output is not now used by Con Edison and can be characterized as free energy.

In order to achieve the maximum possible power output (MWh) from the stored L-Air and the recovered heat from the steam, the waste heat that remains after the initial expansion of the air must be put to good use and produces more power than is available from a single pass through a hot gas expander. That waste heat recovery system is more fully described below.

Equally important as waste heat recovery is the recovery of the cold content of the stored L-Air. As in the Base Case, refrigeration is not thrown away. The cold content of the L-Air is used to condense a second working fluid in a closed loop that is expanded to generator-loaded hot gas expanders. The expanded working fluid is condensed by the outgoing L-Air, which returns the working fluids to a liquid state and allows them to be pumped to pressure, to be heated again and to be expanded in a continuous loop.

As a bookkeeping matter, the working fluid condensation load is designed to match, as much as possible, the total available refrigeration in the 224,000 G of L-Air that is sent to the combustion chambers during the Outflow mode. The total amount of steam needed for the Cycle is determined by the amount of heat needed to boil the air and the secondary working fluid relative to the refrigeration (stored in the L-Air) that can be applied to condense secondary working fluid. A more detailed description of the VPS with Steam Cycle follows.

3.3 VPS Cycle with Steam Process Flow Diagram and Process Description

XE's consultant, PEA, used a commercially available simulator program, Chemstations' CHEMCAD, to predict the steam usage and power output of the VPS Cycle outflow mode, where a specific amount of L-Air stored during an off-peak period would be the main working fluid (WF) during a peak period power generation mode. In addition to the L-Air quantities and storage conditions, XE provided PEA the estimated efficiencies of pumps and hot gas expanders, the inflow and outflow pressures and temperatures and maximum flow rate for the steam and a proposed process flow diagram. PEA then sought to maximize the energy produced by the generator-loaded expanders and to balance the WF and steam flow rates.

In addition to the stored L-Air, the VPS Cycle uses at least one other WF to help recover the cold content of the outflow air. PEA and XE collaborated on finding a refrigerant WF that is readily available, is in compliance with the Montreal Accord and has less safety concerns than Ammonia. The chosen refrigerant is R410a, which is a relatively new product that meets the above criteria. Other refrigerants may also be selected but were not analyzed.

3.3.1 Design Guidelines

XE provided initial design guidelines, which were amended during the study and settled with the following:

- High-Pressure Expander: 10:1 maximum expansion ratio, maximum inlet temperature 1,000°F, 85% efficiency.
- Low-Pressure Expanders: 10:1 maximum expansion ratio, maximum inlet temperature 1,400°F, 89% efficiency.
- Cryogenic Air-Pump: 87% efficiency.
- Refrigerant Pumps: 85% efficiency.
- Liquid Air: 171,100 Pounds/hr flow rate, from storage at -230°F, 496.5 PSIA.
- Refrigerant Approach Temperature: 5 °F.

- Vapor to Vapor Exchanger Approach Temperatures: 15 °F.
- Steam Inlet to VPS Cycle: 1,000,000 to more than 5,000,000 Pounds/hr maximum flow rate, depending on steam generating plant; 750°F to 800°F maximum inlet temperature, 850 PSIA maximum inlet pressure.
- Steam Outlet from VPS Cycle: At a temperature equal to saturation plus 25°F or a minimum outlet temperature of 425°F, at 200 PSIA minimum outlet pressure.

3.3.2 Process Description

A process flow diagram of the L-Air, R410a and steam moving through pumps, heat exchangers, and generator-loaded expanders was submitted to NYSERDA as a confidential document. The L-Air enters the process on the left side of the diagram at the arrow labeled Air Inlet, where the -230°F and 496.5 psia L-Air is pumped by pump 300 to 1,613 psia, which causes the L-Air to warm up to -221°F.

The high-pressure, slightly warmed air is now sent to heat exchanger (HX) 301 where a counter-flowing stream of R410a is condensed, which in turn warms the air to -65°F. The air then moves to HX 302 where a counter-flowing stream of R410a further warms the air to 47°F. The still high-pressure air moves to HX 303 where it is further warmed to approximately 189°F by a counter-flowing stream of low-pressure air.

The still high-pressure air then moves to HX 304 where it is warmed to 735°F by counter-flowing steam at 750°F. The now 735°F air at approximately 1,609 psia is sent to expander 1,which is generator loaded but with the PFD not illustrating the generator. The air is expanded to 160.9 psia (a 10:1 ratio), cooling it down to approximately 257°F. It is then sent to HX 306 where it is re-warmed to 735°F by 750°F steam and then expanded in expander 2 down to 16 psia, cooling it to approximately 234°F. Because the low-pressure air still contains valuable heat, it travels to heat exchanger 303 where it helps pre-warm the high-pressure air, as mentioned above. The low-pressure air leaves the process at approximately 70°F and 15 psia. The PFD illustrates that the path of the air is an open loop, with L-air entering at pump 100 and low-pressure, ambient temperature air leaving after HX 303.

By contrast, the path of the R410a is a closed loop, with no specific beginning or end point. The description of the R410a loop can begin at pump 308 where low-pressure (15.10 psia) liquid R410a, at approximately -60°F, is pumped to 1,711 psia, which causes the working fluid (WF) to be warmed to approximately -54°F. The high-pressure R410a moves on to HX 309 where it is warmed to approximately 26°F by counter-flowing low-pressure R410a at 100°F.

The high-pressure R410a is further warmed in HX 310 to 70°F and in HX 319 to approximately 288°F by counter-flowing R410a streams. The still high-pressure R410a meets a second high-pressure R410a stream at mixing valve 313 where the combined outflow from the valve is 1,708 psia at approximately 292°F. The combined high-pressure stream is warmed to 735°F by counter-flowing steam in HX 314 and is then sent to expander 3, leaving the expander at 181 psia and approximately 516°F.

The expanded R410a moves to valve 316 where the stream is separated into a portion that moves up on the PFD to HX 317, and where a portion moves down on the PFD to HX 312. Staying with the first portion that moves through HX 317, it is then expanded in expander 4, leaving the expander at approximately 18 psia and 523°F. That heat content is used in HX 319 and 309 to pre-warm counter-flowing R410a streams as discussed above. The stream moves on the HX 301 where it is condensed by counter-flowing cold air. The condensed R410A is then pumped by pump 308 and moves through the loop as discussed above.

Meanwhile the R410a portion that left valve 316 and was not sent to expander 4 moves to HX 312 where it warms a counter-flowing, high-pressure R410a stream and moves on to HX 310 where it gives up more heat to a counter-flowing R410a stream. It then arrives at HX 302 at 57°F and 179 psia where it is condensed by counter-flowing cold air. After condensation, or liquefaction, the moderate-pressure R410a is pumped to 1,711 psia in pump 311, which raises its temperature to approximately 72°F. The high-pressure R410a is warmed to approximately 300°F in HX 312 and is then sent to mixing valve 313 to join the other portion of the R410a loop and continue its trip as outlined above.

As can be seen on the PFD and as described above, 750°F steam at 850 psia is the heat source warming air in HX 306 and 304 and warming R410a in HX 314 and 317. For the sake of clarity, the PFD shows four steam paths, all collecting at valve 320 and leaving the VPS Cycle as Steam Out at approximately 526°F and 845 psia. In an actual deployment, a single steam stream would be split into four separate streams and then rejoined at valve 320. The steam is an open loop within the VPS Cycle outflow mode, entering at 750°F and 850 psia and leaving at 526°F and 845 psia. At that point, beyond valve 320, the steam is further de-pressurized and cooled before it enters the Con Edison steam distribution network.

In summary, the air open loop consists of:

- Pump 300 to increase the pressure to a suitable level for subsequent expansion in generator-loaded hot gas expanders 1 and 2.
- Low-pressure refrigerant condenser 301, where the cold content of the L-Air is used to condense low-pressure R410a.
- Moderate-pressure refrigerant condenser 302, where the cold content of the L-Air is used to condense moderate-pressure R410a.
- Interchanger 303 with the final expander discharge.
- Steam heater 304.
- High-pressure expander 1.
- Steam re-heater 306.
- Low-pressure expander 2.

The R410a closed loop consists of two sub-loops, which combine, separate and travel as follows:

- Low-pressure condenser 301.
- Pump 308.
- Low-pressure interchanger 309.
- High-pressure pre-cooler 310.
- Expander outlet interchanger 319.

Combines with High Pressure Loop

- Steam heater 314.
- High-pressure Expander 3.

Splits from High Pressure Loop

- Steam re-heater 317.
- Low-Pressure Expander 4.

The high-pressure loop:

- Pump 311.
- High-Pressure Expander outlet interchanger 312.

Combines with Low-Pressure Loop, (see above):

- High-pressure pre-cooler 310.
- High-pressure condenser 302.

The amount of refrigerant in the low-pressure loop was maximized because that loop has two expanders and, therefore, produces more power for each pound of refrigerant. The limitation on the low-pressure refrigerant is the amount of condensing that is available from the L-Air when a reasonable approach temperature is assumed. Once this amount was determined, the high-pressure loop was calculated to use the remaining cooling from the air.

3.4 Results

The calculations show that approximately 17.4 MW of gross power can be produced. Approximately 70% of the power is produced by the expansion of the L-Air, with the remaining 30% produced by the expansion of the R410a. That 30% is an essential aspect of the VPS Cycle because it puts to productive use the cold content of the L-Air, which helps condense the R410a, which, in turn, allows more of the heat content of the available steam to be used for power production.

The parasitic load from the pumps is approximately 0.7 MW, which yields a net power output of approximately 16.7 MW. The total L-Air available for release (224,000 gallons) will allow the Cycle to operate for eight hours and will yield 133.6 MWh of net power output.

The energy input to achieve the 16.7 MW of power output is derived from the off-peak energy input required to store the L-Air provided to PEA by XE as 16.2 MW over 10 hours, or 162 MWh, and from approximately 491,000 pounds per hour of steam delivered to the eight hours of power peak period power output. The heat content of the high-pressure steam that is normally reduced in pressure and temperature before send-out to the Con Edison steam distribution system can be considered free because no existing energy recovery systems are now in place between the high-pressure steam boilers and the steam distribution grid. This means the round-trip efficiency (RTE) of the VPS Cycle with Steam is 133.6 MWh of power output (calculated by PEA, per the above), divided by 162 MWh (as calculated by XE), which equals approximately 82.5%. That RTE is less than the RTE achievable for the Base Case VPS deployment discussed above, mainly because the available steam's temperature (its grade of heat) is lower than the grade of heat achieved by combusting natural gas, as in the Base Case.

Per the above process description and the PFD, the high-pressure steam's temperature is reduced from the initial 750°F to 526°F, and its pressure is reduced from 850 psia to 845 psia. This suggests that in addition to the VPS Cycle outflow mode, the steam that leaves VPS may contain enough recoverable energy before it enters the steam distribution grid to be useful in an Organic Rankine Cycle heat-to-power system, which was beyond the scope of this study.

4 Regulatory Constraints/Opportunities for Utility-Scale Power Storage Systems

4.1 Overview of Power Storage Policies – New York

Expansion Energy's meeting with staff of the New York State Public Service Commission (PSC) in June 2011 revealed that the PSC has not yet made any formal rulings regarding the issue of power production versus power release with regard to utility-scale bulk power storage systems such as the VPS Cycle. That appears to still be the case as of August 2012. As such, there is still some ambiguity within New York State regarding how bulk power storage facilities will be treated by the PSC (i.e., as generation versus storage).

Several years ago, New York State, with FERC approval, enacted regulation that provides a tariff for Limited Energy Storage Resources (LESRs) on the New York Independent System Operator (NYISO) system, but this is targeted toward short-term, distributed energy storage facilities such as flywheels, batteries and vehicle-to-grid technologies. In contrast to bulk power storage facilities, which are intended to provide large amounts of power for extended periods of time (e.g., multiple hours per day nearly every day), LESRs provide short-term regulation service by rapidly charging or discharging in response to regulation control signals. The LESR tariffs are only marginally instructive in providing a framework for how bulk power storage can be treated by NY regulators. Short-term regulation service is only one of the revenue streams that can be derived from bulk power storage systems; furthermore, not all types of regulation services are applicable for bulk storage systems.

The PSC currently does not place any road blocks against the deployment of bulk power storage systems on the grid within New York State, including in Con Edison's NYC steam service territory, which is the subject of this feasibility study. The PSC also has not enacted any programs or made any rulings that would specifically *encourage* the deployment of bulk power storage systems. The PSC staff interviewed by Expansion Energy supported the general view that strategically deployed bulk power storage systems can bring substantial enhancements and value to the overall grid—and to ratepayers, society and the environment—within the state. What is missing are PSC-approved programs that would assure an owner of such storage assets of having a reliable means of cost recovery, an investment return other than the indirect benefits of storage, (such as the deferral of capital programs to build out more generation and/or transmission/distribution infrastructure), and which would recognize the financial benefits of storage not only to the entire electrical system (generators, transmission system owners, ISOs, utilities, rate payers, etc.), but to society and the environment at large. This will become even more important as the percentage of power derived from intermittent renewable generation sources, most notably wind and solar, grows as a consequence of state and federal policies promoting the expansion of renewable power sources.

The major conundrum regarding deployment of bulk power storage systems appears to be that any type of storage that has an element of new electricity generation could be viewed by regulators as *production*, not storage. This may restrict regulated utilities, which are, in many respects, the most logical owners/operators of bulk power storage assets, from owning such assets and seeking cost recovery via a rate base. Utilities are in the best position to capture all of the value that bulk storage provides to the whole electrical system and to share that value with all stakeholders (rate payers, ISOs, transmission system operators, etc.). Any other type of owner (e.g., a merchant storage asset owner) would only be able to capture a portion of the total value that storage provides to the whole electrical system. Other stakeholders would essentially be "free-riders" subsidized by the merchant owner who would have few means of charging them. Perhaps more importantly, the few means of cost recovery and investment return available to a non-utility owner today may not be sufficient to economically justify an investment in bulk storage assets—despite the fact such systems could bring substantial value to the whole electrical system and could significantly exceed the cost of the storage assets.. Virtually all comprehensive published studies and policy papers on the topic of bulk power storage have reached this same conclusion, regardless of the state. For example, consider the following statements by the California Energy Storage Alliance[2] regarding policy in California relating to bulk power storage prior to the California Legislature's enactment of AB 2514 relating to power storage, which is discussed further in the sections that follow):

> Current market structure does not allow for the buyer of energy storage equipment to easily capture all the value streams provided by energy storage across the entire electric power system… The barrier is neither the availability of a reliable energy storage technology nor its cost; the barrier is the current accounting of disaggregated benefits in a regulated utility industry and the lack of clear policy direction to utilities that energy storage is a superior alternative to natural gas-fired peakers. Thus, while energy storage presents compelling social and economic benefits, California's current market structure has led to underinvestment [in storage].

The comments of the PSC staff interviewed by Expansion Energy support the value of bulk power storage to the overall system. The PSC's current position on bulk power storage seems to be that as long as the open market will pay for storage without inclusion in the rate base and a profit can be made from it, then it should be allowed to be built and integrated into the grid. Without a stronger and more predictable means of cost recovery and return-on-investment (plus the ability for regulated utilities to own such assets) supported by PSC rulings and/or other state-level policy, the deployment of bulk power storage systems is likely to be only a fraction of what it could be (and probably should be) considering dispatchable bulk power storage's overall value to the whole system. This situation argues for the PSC to adopt and/or promote more direct and robust financial/cost-recovery mechanisms and to allow regulated utilities to own

[2] California Energy Storage Alliance/Strategen. 2001. "Energy Storage – A Cheaper and Cleaner Alternative to Natural Gas-Fired Peaker Plants." Feb. 8.

energy storage assets, even if a portion of any such system could be deemed to be generation, in order to encourage the deployment of bulk power storage systems.

With respect to New York City, the PSC has stated that no new regulations are required for power storage systems to be deployed within the City, provided that such systems stand on their own economic merit in the open market (unless and until the PSC allows such systems to be rolled into a utility's rate base or allows other cost-recovery mechanisms). For now, power storage systems deployed in New York City must simply comply with the existing body of PSC regulations for resources on the grid.

With the exception of several large-scale pumped hydro energy storage systems and one Compressed Air Energy Storage (CAES) system that have been in service for decades, the promotion and deployment of bulk power storage systems is a relatively new phenomenon; therefore, few policy frameworks exist that can be used as regulatory models by New York State, especially for the treatment of storage as its own resource category (i.e., separate from generation). The few models that do exist are discussed below.

4.2 Overview of Power Storage Policies – Federal Level Frameworks

4.2.1 Federal Energy Regulatory Commission

The Federal Energy Regulatory Commission (FERC) has recognized the rate and reliability benefits of power storage facilities connected to the grid, as demonstrated by FERC's recent opening of the NYISO market for LESR assets as described above. Adding to this, on October 20, 2011, FERC issued a final ruling that will compensate energy storage-based resources that provide certain key reliability services on the electrical grid, particularly frequency regulation services. This ruling applies to all wholesale power market regions under FERC jurisdiction. While this ruling is a major step forward in providing market-based pricing that rewards not just the availability of, but also the speed of, storage that responds to short-term fluctuations in power frequency, it does not address the energy storage market segment that is most applicable to the VPS Cycle technology—specifically the "bulk" power storage market. This market can provide power for long durations and can allow for such important advances as time shift (i.e., storing power during off-peak periods and releasing it during on-peak periods) and for ongoing firming of intermittent renewable power sources. As such, FERC Order 755 is helpful, but it is not an ideal policy model from which to design appropriate bulk power storage policies.

4.2.2 Congress

At the Congressional level, Senate Bill S.1845,the "Storage Technology for Renewable and Green Energy Act" ("STORAGE" Act) of 2011, was introduced in November 2011 by Senators Wyden, Bingamen and

Collins; however, it has not yet cleared the Energy & Natural Resources Committee. Much like the large majority of bills in Congress at present, it appears to be stalled until at least after the November 2012 elections. In 2010, a similar bill was also introduced in both the House and the Senate with bi-partisan support, but it stalled in committee as well.

S.1815 would amend the Internal Revenue Code to[3]:

- Allow, through 2020, a 20% investment tax credit (ITC) of up to $40 million for investment in energy storage property that is directly connected to the electrical grid (i.e., a system of generators, transmission lines, and distribution facilities) and that is designed to receive, store, and convert energy to electricity; deliver it for sale; or use such energy to provide improved reliability or economic benefits to the grid.
- Make such property eligible for new clean renewable energy bond (CREB) financing.
- Allow a 30% investment tax credit of up to $1 million for business investment in on-site energy storage projects.
- Allow a 30% non-business energy property tax credit for the installation of energy storage equipment in a principal residence.

S.1845 would provide a powerful financial incentive to invest in energy storage projects/technologies of virtually all types, including bulk power storage; however, the bill has not yet been voted into law, and it is not yet clear whether it will ever be. Nonetheless, the bill seems to at least accept, by virtue of its broad definition of what qualifies as energy storage on the electrical grid, that storage technologies that have an element of power generation within them should still qualify as "storage" and not be lumped into, and regulated as, generation. In that respect, S. 1845 could serve as a regulatory precedent for the NY PSC.

4.3 Overview of Power Storage Policies – Frameworks from Other States

4.3.1 California - Legislation

In September 2010, California Assembly Bill AB 2514 was signed into law, which established California as the leading state in the US with regard to policy support for energy storage, including bulk power storage. This law relates specifically to the deployment of new grid-connected energy storage assets within the majority of California's electrical service territories and treats storage as its own resource category separate from generation.

AB 2514 includes a mix of mandates and incentives, and applies to both investor-owned utilities and publicly owned utilities. The law authorizes the California Public Utilities Commission (CPUC) to allow regulated investor-owned utilities to receive a rate-of-return for energy storage investments that is between

3 Congressional Research Service. 2012. http://www.govtrack.us/congress/bills/112/s1845

one-half and one percentage point higher than other asset classes. To comply with the law, utilities can either own energy storage assets or procure energy storage services from third parties or from customers.

AB 2514 acknowledges that:

> There are significant barriers to obtaining the benefits of energy storage systems, including inadequate evaluation of the use of energy storage to integrate renewable energy resources into the transmission and distribution grid through long-term electricity resource planning, lack of recognition of technological and marketplace advancements, and inadequate statutory and regulatory support.

In response, AB 2514 mandates the following:

> This bill would require the CPUC, by March 1, 2012, to open a proceeding to determine appropriate targets, if any, for each load-serving entity to procure viable and cost-effective energy storage systems and, by October 1, 2013, to adopt an energy storage system procurement target, if determined to be appropriate, to be achieved by each load-serving entity by December 31, 2015, and a 2nd target to be achieved by December 31, 2020. The bill would require the governing board of a local publicly owned electric utility, by March 1, 2012, to open a proceeding to determine appropriate targets, if any, for the utility to procure viable and cost-effective energy storage systems and, by October 1, 2014, to adopt an energy storage system procurement target, if determined to be appropriate, to be achieved by the utility by December 31, 2016, and a 2nd target to be achieved by December 31, 2021. The bill would require each load-serving entity and local publicly owned electric utility to report certain information to the CPUC, for a load-serving entity, or to the Energy Commission, for a local publicly owned electric utility. The bill would make other technical, nonsubstantive revisions to existing law. The bill would exempt from these requirements an electrical corporation that has 60,000 or fewer customers within California and a public utility district that receives all of its electricity pursuant to a preference right adopted and authorized by the United States Congress pursuant to a specified law.
>
> As part of [the initial CPUC] proceeding, the commission may consider a variety of possible policies to encourage the cost-effective deployment of energy storage systems [by load-serving entities], including refinement of existing procurement methods to properly value energy storage systems. [A substantially similar process applies to local publicly owned electric utilities.]

AB 2514 provides a specific definition of systems qualifying as energy storage for the purposes of complying with the law and provides for virtually any type of entity to be the owner of such energy storage systems:

(1) “Energy storage system” means commercially available technology that is capable of absorbing energy, storing it for a period of time, and thereafter dispatching the energy. An “energy storage system” may have any of the characteristics in paragraph (2), shall accomplish one of the purposes in paragraph (3), and shall meet at least one of the characteristics in paragraph (4).

(2) An “energy storage system” may have any of the following characteristics:

(a) Be either centralized or distributed.

(b) Be either owned by a load-serving entity or local publicly owned electric utility, a customer of a load-serving entity or local publicly owned electric utility, or a third party, or is jointly owned by two or more of the above.

(3) An “energy storage system” shall be cost effective and either reduce emissions of greenhouse gases, reduce demand for peak electrical generation, defer or substitute for an investment in generation, transmission, or distribution assets, or improve the reliable operation of the electrical transmission or distribution grid.

(4) An “energy storage system” shall do one or more of the following:

(a) Use mechanical, chemical, or thermal processes to store energy that was generated at one time for use at a later time.

(b) Store thermal energy for direct use for heating or cooling at a later time in a manner that avoids the need to use electricity at that later time.

(c) Use mechanical, chemical, or thermal processes to store energy generated from renewable resources for use at a later time.

(d) Use mechanical, chemical, or thermal processes to store energy generated from mechanical processes that would otherwise be wasted for delivery at a later time.

In adopting and evaluating appropriate energy storage system procurement targets and policies, AB 2514 instructs the CPUC to do all of the following:

> (a) Consider existing operational data and results of testing and trial pilot projects from existing energy storage facilities.
>
> (b) Consider available information from the California Independent System Operator derived from California Independent System Operator testing and evaluation procedures.
>
> (c) Consider the integration of energy storage technologies with other programs, including demand-side management or other means of achieving the purposes identified in Section 2837 that will result in the most efficient use of generation resources and cost-effective energy efficient grid integration and management.
>
> (d) Ensure that the energy storage system procurement targets and policies that are established are technologically viable and cost effective.

Regarding resource adequacy, AB 2514 provides the following:

> (a) An energy storage system may be used to meet the resource adequacy requirements established for a load-serving entity pursuant to Section 380 if it meets applicable standards.
>
> (b) An energy storage system may be used to meet the resource adequacy requirements established by a local publicly owned electric utility pursuant to Section 9620 if it meets applicable standards.

Cost-effectiveness is also addressed in AB 2514: “All procurement of energy storage systems by a load-serving entity or local publicly owned electric utility shall be cost effective.”

Among the most important elements of AB 2514 are its provisions relating to the mandated use of energy storage for integrating renewable energy into California’s overall power sources portfolio and for reducing the carbon footprint of its generation resources:

> Each electrical corporation's renewable energy procurement plan, prepared and approved pursuant to Article 16 (commencing with Section 399.11) of Chapter 2.3 of Part 1, shall require the utility to procure new energy storage systems that are appropriate to allow the electrical corporation to comply with the energy storage system procurement targets and policies adopted pursuant to Section 2836. The plan shall address the acquisition and use of energy storage systems in order to achieve the following purposes:
>
> (a) Integrate intermittent generation from eligible renewable energy resources into the reliable operation of the transmission and distribution grid.
>
> (b) Allow intermittent generation from eligible renewable energy resources to operate at or near full capacity.
>
> (c) Reduce the need for new fossil-fuel powered peaking generation facilities by using stored electricity to meet peak demand.
>
> (d) Reduce purchases of electricity generation sources with higher emissions of greenhouse gases.
>
> (e) Eliminate or reduce transmission and distribution losses, including increased losses during periods of congestion on the grid.
>
> (f) Reduce the demand for electricity during peak periods and achieve permanent load-shifting by using thermal storage to meet air-conditioning needs.
>
> (g) Avoid or delay investments in transmission and distribution system upgrades.
>
> (h) Use energy storage systems to provide the ancillary services otherwise provided by fossil-fueled generating facilities.

4.3.2 California – Rate Base

California has also been a leader by beginning to allow utilities to include the development and operation of energy storage assets within their rate base cases to the California Public Utilities Commission (PUC). In 2010, San Diego Gas & Electric (SDG&E) petitioned the PUC to allow the company to install and operate approximately 10 MW of electricity storage in 2011-2012, specifically to enable the further growth of intermittent renewable energy production, such as PV solar. Though relatively small in comparison to larger bulk storage systems, such as VPS, the petition creates a precedent regulatory action that allows utilities to earn a return on their investments in storage assets through a rate base recovery mechanism.

The total capital funding requested by SDG&E to be recovered through the rate base for these storage projects was $55 million—approximately $5,500/kW of storage capacity. The total amount of the request that was granted by the CA PUC has not yet been determined as of the date of this report.

Other states reportedly at various stages of considering energy storage assets for inclusion in their rate bases include Hawaii, Texas and New Jersey.[4,5]

4.3.3 Alabama

The only operating CAES plant in the US, located in McIntosh, AL, is owned by PowerSouth, a wholesale generator and transmission company that sells power to 20 local electric cooperatives and municipal electric systems. As such, the McIntosh plant is considered a generation asset under PowerSouth's business model; therefore the McIntosh plant is not a model for how such facilities are treated as storage, and not as generation, by regulators.

4.4 The Need for New Policies

There is a critical need for forward-looking states such as New York to create and promulgate their own regulatory frameworks for how bulk power storage assets, as opposed to generation assets, should be treated . The multiple, system-wide and society-wide benefits provided by bulk power storage indicate that policies/regulations in support of such storage assets should be enacted, including provisions for regulatory means for regulated utilities to own energy storage assets that may include some degree of what could be deemed new generation. California's recently enacted law, AB 2514, which promotes and mandates the utilization of viable energy storage systems, is one of the few policies existing in the US today that provides a model framework for the deployment of bulk power storage systems in New York. Even in the case of AB 2514, many of the details of that law remain to be determined by the future proceedings and rulings of the California Public Utilities Commission, as required by AB 2514. Alternative approaches and business models are proposed in Section 6 of this report.

4 US Dept. of Energy; 2012

5 Electricity Storage Association, 22nd Annual Meeting; May 2-4, 2012

5 Economic Viability Analysis & Alternative Power Storage Business Models

As indicated in Section 5, new business models will need to emerge in order to stimulate the development and operation of an optimal level of bulk power storage assets across New York and elsewhere. In particular, policy changes will need to allow for the owners of bulk power storage assets to capture the full value that such storage assets bring to the entire electrical system. Fortunately, deploying the best technologies in the areas of most critical need can result in total benefits and value of such magnitude that the owner of the storage assets can generate an attractive investment return while sharing the remainder of the total value resulting from such assets with other stakeholders within the electricity marketplace—i.e., with rate payers, ISOs, etc.

In order to demonstrate the economics, or value, of VPS Cycle deployments under a variety of scenarios relevant to this study, Expansion Energy developed a comprehensive VPS Economic Model using Microsoft Excel software, which was submitted to NYSERDA as a series of files, or scenarios. This tool is used to determine the total value of VPS deployments under any number of scenarios and how that value can be split between the asset owner and other stakeholders in the electrical system. The VPS Economic Model considers such factors as:

- The capital cost (CAPEX) to build a VPS Cycle plant at the scales analyzed by this study.
- The operating costs and overhead costs (OPEX) to run the VPS plant over a presumed lifetime of 25 years.
- The various categories of value from energy storage that VPS plants can deliver to the electrical grid and the potential revenues associated with such value categories, which could be captured by the owner of the VPS plant.
- The type of owner of the VPS plant (e.g., investor-owned utility, merchant project developer, etc.).
- The return on investment (ROI) for the VPS plant deployments analyzed by this study. ROI is analyzed both for the VPS plant's owner and for the electrical system on the whole (e.g., rate payers, ISOs, utilities, etc.).

The above factors were determined using information provided by Expansion Energy, Con Edison, NYSERDA, the California Energy Commission, and vendors of key equipment components utilized by VPS plants, and others.

5.1 Qualification and Quantification of Revenue Streams

As discussed earlier in this report, most bulk power storage systems, particularly those such as VPS that can be deployed near load centers, deliver a range of benefits to the electrical system. In fact, utilizing previously published NYSERDA reports, as well as select information from other reliable sources such as the California Energy Commission, Expansion Energy compiled 20 different value categories that bulk power storage systems can provide. They also can generate revenues for storage asset owners under appropriate policy frameworks for reimbursement/investment recovery. These 20 value categories are summarized and quantified in the table below.

Table 4: Power Storage Value Categories and $/kW Benefits

	Storage Value Category / Application	1-Year Unit Benefit ($/kW in 2014)	25-Year Unit Benefit (PV of $/kW 2014-2038)
1	Electric Energy: Buy Low (off-peak), Sell High (peak) ($/kW)	$61.23	$676.68
2	Electric Supply Capacity ($/kW)	$124.81	$1,379.40
3	Reduce Transmission Capacity Requirements ($/kW)	$15.45	$170.78
4	Reduce Transmission Congestion ($/kW)	$11.89	$131.37
5	Transmission & Distribution Upgrade Deferral/Displacement ($/kW)	$594.34	$594.34
6	Operating Reserve ($/kW)	$42.79	$472.94
7	Regulation and Frequency Response (Regulation) ($/kW)	$130.76	$1,445.09
8	Transmission Support ($/kW)	$28.53	$315.29
9	Electric Service Reliability ($/kW)	$59.43	$656.86
10	Electric Service Power Quality ($kW)	$118.87	$1,313.72
11	Electric Service Bill Reduction: Demand Charges ($/kW)	$178.30	$1,970.58
12	Electric Service Bill Reduction: Time-of-use Energy Prices ($/kW)	$273.40	$3,021.55
13	Renewable Electricity Production Time-shift ($/kW)	$137.89	$1,523.91
14	Renewables Capacity Firming ($/kW)	$53.49	$591.17
15	Federal Energy Storage Tax Credit ($/kW)	Not yet applicable	Not yet applicable
16	Carbon Credits ($kW)	Not yet applicable	Not yet applicable
17	Transmission & Distribution Line Losses: Energy ($/kW)	$49.92	$551.76
18	Transmission & Distribution Line Losses: Capacity ($/kW)	$19.02	$210.19
19	Goodwill / Public Relations ($/kW)	Not yet applicable	Not yet applicable
20	Avoided Need for "Peaker" Power Plants (levelized $/kW)	$269.31	$2,358.59
	TOTAL $ VALUE FROM ALL APPLICATIONS ($/kW)	**$2,169.43**	**$17,384.23**

The 20 value categories in Table 4were included in the VPS Economic Model for this study and provided the key data for projecting the revenue streams a VPS plant could draw from. Price, or revenue, for each value category is on a $/KW basis and refers to the KW output capacity of the storage system. Selection of the appropriate $/KW values for inclusion in the Economic Model is an important step in determining the investment potential of a storage system, including VPS. It is also important when determining the value of a storage asset to the electricity marketplace on the whole, including rate payers, ISOs, utilities, etc.

The source for nearly all of these 20 storage value categories is a previous NYSERDA report[6] published in March 2007. That study was also the source for the large majority of the corresponding $/KW values

6 NYSERDA. 2007. “Guide to Estimating Benefits and Market Potential for Electricity Storage in New York (With Emphasis on New York City,” NYSERDA Report 07-XX.

selected for use in the VPS Economic Model. $/KW values were increased to reflect a 2.5% annual rate of inflation. The 2007 NYSERDA study conducted an extensive analysis of the value of power storage category-by-category, ultimately ascribing in present value (PV) terms a $/KW value for each of the analyzed value streams . The fact that the 2007 study specifically focused on New York State, with emphasis on New York City, makes the selection of this data source for a VPS Economic Model focusing on NYC deployments even more appropriate.

Certain value categories presented in Table 4: Power Storage Value Categories and $/kW Benefits were not covered by NYSERDA's 2007 study. Expansion Energy relied on other credible sources of data for those categories, such as the California Energy Commission. Specific sources are identified for each value category in the VPS Economic Model spreadsheet.

It is important to note that not every value category is included in each VPS deployment scenario; moreover, not every type of storage system can capture each of these 20 value categories. Most systems can only capture a portion of them. As such, the Economic Model is designed to allow the user to select which value categories are applicable and appropriate for each deployment scenario. For example, in Table 5: Power Storage Value Categories Applicable for VPS Plants in NYC below, storage value categories that Expansion Energy, with input from Con Edison, determined would be applicable for a VPS plant located at certain locations and under certain circumstances (e.g., in areas of significant load growth) within or near New York City are highlighted in green).

Table 5. Power Storage Value Categories Applicable for VPS Plants in NYC.

	Storage Value Category / Application	1-Year Unit Benefit ($/kW in 2014)	25-Year Unit Benefit (PV of $/kW 2014-2038)
1	Electric Energy: Buy Low (off-peak), Sell High (peak) ($/kW)	$61.23	$676.68
2	Electric Supply Capacity ($/kW)	$124.81	$1,379.40
3	Reduce Transmission Capacity Requirements ($/kW)	$15.45	$170.78
4	Reduce Transmission Congestion ($/kW)	$11.89	$131.37
5	Transmission & Distribution Upgrade Deferral/Displacement ($/kW)	$594.34	$594.34
6	Operating Reserve ($/kW)	$42.79	$472.94
7	Regulation and Frequency Response (Regulation) ($/kW)	$130.76	$1,445.09
8	Transmission Support ($/kW)	$28.53	$315.29
9	Electric Service Reliability ($/kW)	$59.43	$656.86
10	Electric Service Power Quality ($kW)	$118.87	$1,313.72
11	Electric Service Bill Reduction: Demand Charges ($/kW)	$178.30	$1,970.58
12	Electric Service Bill Reduction: Time-of-use Energy Prices ($/kW)	$273.40	$3,021.55
13	Renewable Electricity Production Time-shift ($/kW)	$137.89	$1,523.91
14	Renewables Capacity Firming ($/kW)	$53.49	$591.17
15	Federal Energy Storage Tax Credit ($/kW)	Not yet applicable	Not yet applicable
16	Carbon Credits ($kW)	Not yet applicable	Not yet applicable
17	Transmission & Distribution Line Losses: Energy ($/kW)	$49.92	$551.76
18	Transmission & Distribution Line Losses: Capacity ($/kW)	$19.02	$210.19
19	Goodwill / Public Relations ($/kW)	Not yet applicable	Not yet applicable
20	Avoided Need for "Peaker" Power Plants (levelized $/kW)	$269.31	$2,358.59
	TOTAL $ VALUE FROM ALL APPLICATIONS ($/kW)	**$2,169.43**	**$17,384.23**

Once the appropriate storage value categories and their corresponding $/KW numbers were selected and other key assumptions were determined, that information was used by the Economic Model to generate a total Net Present Value (NPV) for each VPS deployment scenario analyzed. The total NPV generated by the Economic Model includes the benefits of the VPS deployment to the entire electrical system and further determines the percentage of that total NPV that would need to accrue to owner of the VPS plant in order to induce them to build, own and operate the project. Both CAPEX and OPEX were included in the analysis.

The sections that follow show results from the VPS Economic Model for a number of scenarios applicable to this study. A version of the VPS Economic Model for each of these scenarios was also provided to NYSERDA as an Excel spreadsheet. The tabulated results of a series of sensitivity analyses for each of these scenarios is also presented in subsequent sections of this report. The specific scenarios examined are:

1. A Base Case VPS plant owned by an Investor-Owned Utility with 44.5 MW of output that utilizes natural gas as the source of thermal energy during the power outflow stage.
2. A Base Case VPS plant owned by a Merchant Storage Developer with 44.5 MW of output that utilizes natural gas as the source of thermal energy during the power outflow stage.
3. A Steam Case VPS plant owned by an Investor-Owned Utility with 17.06 MW of output that utilizes surplus district steam from Con Edison as the source of thermal energy during the power outflow stage.
4. A Steam Case VPS plant owned by a Merchant Storage Developer with 17.06 MW of output that utilizes surplus district steam from Con Edison as the source of thermal energy during the power outflow stage.

5.2 Economic Analysis of the Base Case VPS Cycle

Expansion Energy considers its Base Case VPS Cycle plant constructed and operating in or near New York City to have the following characteristics regardless of the type of entity that owns the plant:

- 44.5 MW power outflow capacity.
- 16.22 MW power inflow rate.
- Utilization of natural gas as the thermal energy source to release the power stored by VPS's inflow cycle; 3.62 Mcf of gas consumed per MWh of power outflow.
- Eight hours of power release per day, operating 350 days per year.
- 25-year plant lifetime.
- Total VPS plant CAPEX of $97,500,000.
- Two-year construction period.
- 10% NPV discount rate.

These factors were utilized as key assumptions in the Base Case of VPS Economic Model. Additional assumptions for each scenario under study are also listed in the scenario summaries below as well as in the Key Assumptions worksheet within each Economic Model spreadsheet provided to NYSERDA.

The sections that follow demonstrate the economic characteristics of a Base Case VPS plant deployed in or near New York City under two different types of owners (i.e., two separate scenarios):

- A regulated Investor-Owned Utility ("IOU") owner.
- A Merchant (non-regulated entity) owner.

5.2.1 Base Case Scenario #1: Investor-Owned Utility (IOU) as VPS Plant Owner

Compared to other types of owners, IOUs, which are typically regulated entities and deliver electricity to end-users, are likely in the best position, to capture the full value of a VPS plant deployment if they are allowed by regulatory agencies to charge their customers enough in rates or to use other cost recovery mechanisms, and they are able to "share" a portion that total value with other stakeholders in the electrical system.

The table below shows the storage value categories, highlighted in green, that are assumed to be applicable for a Base Case VPS plant that is owned by an IOU and deployed in or near New York City . It also shows the corresponding value (in $/kW of capacity) for each category and the total value of all categories together.

Table 6. Storage Values for Base Case VPS Deployment in NYC – IOU Owner.

	Storage Value Category / Application	1-Year Unit Benefit ($/kW in 2014)	25-Year Unit Benefit (PV of $/kW 2014-2038)
1	Electric Energy: Buy Low (off-peak), Sell High (peak) ($/kW)	$61.23	$676.68
2	Electric Supply Capacity ($/kW)	$124.81	$1,379.40
3	Reduce Transmission Capacity Requirements ($/kW)	$15.45	$170.78
4	Reduce Transmission Congestion ($/kW)	$11.89	$131.37
5	Transmission & Distribution Upgrade Deferral/Displacement ($/kW)	$594.34	$594.34
6	Operating Reserve ($/kW)	$42.79	$472.94
7	Regulation and Frequency Response (Regulation) ($/kW)		
8	Transmission Support ($/kW)		
9	Electric Service Reliability ($/kW)	$59.43	$656.86
10	Electric Service Power Quality ($kW)		
11	Electric Service Bill Reduction: Demand Charges ($/kW)		
12	Electric Service Bill Reduction: Time-of-use Energy Prices ($/kW)		
13	Renewable Electricity Production Time-shift ($/kW)	$137.89	$1,523.91
14	Renewables Capacity Firming ($/kW)	$53.49	$591.17
15	Federal Energy Storage Tax Credit ($/kW)		
16	Carbon Credits ($kW)		
17	Transmission & Distribution Line Losses: Energy ($/kW)	$49.92	$551.76
18	Transmission & Distribution Line Losses: Capacity ($/kW)	$19.02	$210.19
19	Goodwill / Public Relations ($/kW)		
20	Avoided Need for "Peaker" Power Plants (levelized $/kW)	$269.31	$2,358.59
	TOTAL $ VALUE FROM ALL APPLICATIONS ($/kW)	**$1,439.58**	**$9,318.01**

Utilizing the NPV of all applicable storage values for the 25-year expected plant lifetime, under the assumptions modeled, the Base Case VPS plant would yield the following economic results, which would be available to be shared among the various stakeholders in the overall electrical system:

Table 7. NPV of Base Case VPS Plant Deployed in NYC – IOU Owner.

NPV: 25-Year Project Lifetime; Pre-Tax

Start Date =	2012
Commercial Operations Date =	2014
Base Year for NPV Calculation =	2014

	2012	2013	2014
VPS Plant Total Capital Cost			($97,500,000)
Interest During Construction (capitalized)			($14,127,750)
Present Value of VPS Plant Operating Costs			($76,609,561)
Present Value of VPS Plant Overhead Costs			($8,150,736)
Present Value of VPS Application Benefits			$414,651,311
Net Present Value of VPS Plant	**$0**	**$0**	**$218,263,264**

A VPS plant deployed under this scenario would deliver net benefits of more than $218 million to the electrical system on a net present value basis. In terms of absolute dollar value, rather than NPV, which discounts for the time value of money, the Base Case VPS plant would deliver approximately. $933 million of absolute value to the electrical system over a 25-year period. This is a value nearly 10 times the estimated capital cost of the VPS plant. Also, the VPS plant would break even for the total electrical system, not just its owner, within approximately two years following completion of construction.

Significantly, for this deployment scenario, the total $/KW of value delivered in Year 1 alone is approximately 2/3 of the total cost to build the VPS plant. The VPS plant could deliver $1,440/KW in value and would cost approximately $2,191/KW to build (CAPEX); therefore, approximately 2/3 of the total capital cost of the VPS plant in this scenario could be recovered in just one year, if policy mechanisms are in place to allow the owner of the VPS plant to capture the total value that the VPS plant brings to the electrical grid on the whole. This is an extraordinarily high rate of cost recovery, which demonstrates the high value of VPS plants deployed in well-chosen locations.

It is also significant to note that the cost of VPS Cycle plant constructed in or near New York City is not likely to cost substantially more than a simple-cycle gas-fired power plant, such as those used commonly as peaker plants. According to detailed California Energy Commission study7 from 2009, a simple-cycle gas-fired power plant constructed in a heavily populated area can cost as much as $1,578/kW of generation capacity. A VPS Cycle plant of the same output capacity constructed in NYC is estimated to cost approximately $2,191/kW of capacity—but also brings the major additional benefits of power storage in addition to power generation. Moreover, a VPS plant has substantially better operating efficiencies (i.e., Btu-to-power conversion efficiency) than a simple-cycle gas-fired plant, or even a combined-cycle power plant, and will cost significantly less to operate in terms of fuel consumption per kWh produced.

5.2.2 Sharing of Value

In terms of how much of the total value of a VPS plant (deployed in this scenario, and each additional scenario analyzed) would be needed to induce its construction and ownership by an IOU, and in terms of how much value would be "left over" for the other stakeholders in the electrical system, it is assumed that:

- Con Edison's standard regulated annual rate-of-return of 11% IRR is allowed.[8]
- New York State adopts a storage incentive structure similar to that of California law AB 2514, which allows IOUs to receive up to an additional 1% annual rate-of-return on top of the standard allowed rate-of-return.
- The resulting total annual rate-of-return allowed for IOU-owned power storage projects in New York State is 12%.
- Con Edison funds the VPS plant with 100% equity capital (no debt).[9]

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7 California Energy Commission. 2009. "Comparative Cost of California Central Station Electricity Generation Technologies"; "High Case" chosen due to high costs of NYC construction.

8 Source: Con Edison, 2012

9 In practice, debt capital may be used for a substantial portion of a VPS plant's capital cost; however, large energy projects are often first analyzed "unlevered", so the level of debt ("leverage") does not "distort" a project's intrinsic value. Further, whether debt would be available for a technology at VPS's stage of commercialization is not predictable.

Under these assumptions, the VPS Economic Model for the Base Case deployment shows the following split of value would occur:

Table 8: Value Split for VPS Base Case – IOU Owner

Recipient of Value	% Share of Value	NPV
IOU (Con Edison)	32.8%	$71,590,350
Other Stakeholders/Ratepayers	67.2%	$146,672,914

5.2.3 Base Case Scenario #2: Merchant VPS Plant Owner

In contrast to IOU-owned VPS plants, Merchant-owned VPS plants would typically only be able to charge the market for a limited range of the value categories that VPS can deliver to the overall electrical system. A Merchant VPS plant can be viewed as similar to a Merchant-owned gas-fired power plant, such as aa plant owned by an independent power producer (IPP), in that it would earn a return on its investment by selling storage and power to the market on the basis of what the open market is willing to pay for it. As such, the value categories within the VPS Economic Model that are applicable to a Merchant-owned VPS plant are more limited than in the case of an Investor-Owned Utility owner, as shown in the table below, because the market currently has no incentive to reward an investment in storage other than in such categories. The rows highlighted green in Table 9 are the value categories that could reasonably be assumed to be applicable and monetizable for a Merchant-owned plant.

Table 9. Storage Values for Base Case VPS Deployment in NYC – Merchant Owner.

	Storage Value Category / Application	1-Year Unit Benefit ($/kW in 2014)	25-Year Unit Benefit (PV of $/kW 2014-2038)
1	Electric Energy: Buy Low (off-peak), Sell High (peak) ($/kW)	$61.23	$676.68
2	Electric Supply Capacity ($/kW)	$124.81	$1,379.40
3	Reduce Transmission Capacity Requirements ($/kW)		
4	Reduce Transmission Congestion ($/kW)		
5	Transmission & Distribution Upgrade Deferral/Displacement ($/kW)		
6	Operating Reserve ($/kW)	$42.79	$472.94
7	Regulation and Frequency Response (Regulation) ($/kW)		
8	Transmission Support ($/kW)		
9	Electric Service Reliability ($/kW)		
10	Electric Service Power Quality ($kW)		
11	Electric Service Bill Reduction: Demand Charges ($/kW)		
12	Electric Service Bill Reduction: Time-of-use Energy Prices ($/kW)		
13	Renewable Electricity Production Time-shift ($/kW)	$137.89	$1,523.91
14	Renewables Capacity Firming ($/kW)	$53.49	$591.17
15	Federal Energy Storage Tax Credit ($/kW)		
16	Carbon Credits ($kW)		
17	Transmission & Distribution Line Losses: Energy ($/kW)		
18	Transmission & Distribution Line Losses: Capacity ($/kW)		
19	Goodwill / Public Relations ($/kW)		
20	Avoided Need for "Peaker" Power Plants (levelized $/kW)		
	TOTAL $ VALUE FROM ALL APPLICATIONS ($/kW)	**$420.21**	**$4,644.10**

It is very important to note that the Merchant VPS plant deployment analyzed here, if deployed in the same location and under the same circumstances, delivers exactly the same value to the total electrical system as the IOU-owned VPS plant presented in the scenario analyzed above; however, in the Merchant case, the Merchant's investment is subsidizing the system overall by not allowing the Merchant to participate financially in any of the other categories of value that its investment has delivered to the electrical system on the whole, including to the ratepayers. Just as importantly, if not being able to participate financially in the other applicable storage value categories prevents the Merchant owner from receiving an adequate rate-of-return on its investment, which is likely in many circumstances), the VPS plant would never be built and the benefits to the total electrical system would never be realized. That likelihood is demonstrated with the analyses of this section.

Utilizing the NPV of all the storage values reasonably applicable for a Merchant plant for the 25-year expected plant lifetime, under the assumptions modeled, the Merchant-owned Base Case VPS plant would yield the following economic results for the Merchant owner:

Table 10. NPV for Base Case VPS Plant Deployed in NYC – Merchant Owner.

NPV: 25-Year Project Lifetime; Pre-Tax

Start Date =	2012
Commercial Operations Date =	2014
Base Year for NPV Calculation =	2014

	2012	2013	2014
VPS Plant Total Capital Cost			($97,500,000)
Interest During Construction (capitalized)			($14,127,750)
Present Value of VPS Plant Operating Costs			($76,609,561)
Present Value of VPS Plant Overhead Costs			($8,150,736)
Present Value of VPS Application Benefits			$206,662,634
Net Present Value of VPS Plant	**$0**	**$0**	**$10,274,587**

A VPS plant deployed under this scenario would deliver net financial benefits of a modest $10 million to the Merchant owner, on a net present value basis. This is the case because without a regulatory system that allows a Merchant owner to capture more of the value delivered to the total electrical system by power storage projects, the economic returns are dramatically reduced as compared the IOU-owned case presented in the previous section. In this scenario, the VPS plant would not break even for the Merchant owner until 10 years following completion of construction.

Though a positive NPV of any sort would in theory incentivize a Merchant to invest in a VPS plant project, or any other type of project, in reality, it would not likely be sufficient to induce a Merchant owner to build a VPS plant. This is particularly true because the VPS Cycle is a technology that is still in its commercialization stage; therefore the perceived risk of such a project would likely be too high to be justified by a modest NPV of approximately $10 million.

In addition, the applicable storage value categories deemed to be monetizable (highlighted in Table 9: Storage Values for Base Case VPS Deployment in NYC – Merchant Owner) are somewhat generous in this scenario, as it is assumed that the Merchant owner will get full credit for the Renewable Electricity Production Time-shift and Renewables Capacity Firming categories. In reality, this would only be true where an off-taker, or contracted customer, for the VPS plant would be willing to assign all of the value associated with storing renewable energy to the Merchant owner. It also assumes that there is a strong mandate or incentive structure in place to promote the generation of renewable power, which may or may not be the case.

If the Renewable Electricity Production Time-shift and Renewables Capacity Firming categories are removed from applicable categories for a Merchant owner, the following is the result:

Table 11. Storage Values for Base Case VPS Deployment in NYC – Merchant-Owner, No Renewables.

	Storage Value Category / Application	1-Year Unit Benefit ($/kW in 2014)	25-Year Unit Benefit (PV of $/kW 2014-2038)
1	Electric Energy: Buy Low (off-peak), Sell High (peak) ($/kW)	$61.23	$676.68
2	Electric Supply Capacity ($/kW)	$124.81	$1,379.40
3	Reduce Transmission Capacity Requirements ($/kW)		
4	Reduce Transmission Congestion ($/kW)		
5	Transmission & Distribution Upgrade Deferral/Displacement ($/kW)		
6	Operating Reserve ($/kW)	$42.79	$472.94
7	Regulation and Frequency Response (Regulation) ($/kW)		
8	Transmission Support ($/kW)		
9	Electric Service Reliability ($/kW)		
10	Electric Service Power Quality ($kW)		
11	Electric Service Bill Reduction: Demand Charges ($/kW)		
12	Electric Service Bill Reduction: Time-of-use Energy Prices ($/kW)		
13	Renewable Electricity Production Time-shift ($/kW)		
14	Renewables Capacity Firming ($/kW)		
15	Federal Energy Storage Tax Credit ($/kW)		
16	Carbon Credits ($kW)		
17	Transmission & Distribution Line Losses: Energy ($/kW)		
18	Transmission & Distribution Line Losses: Capacity ($/kW)		
19	Goodwill / Public Relations ($/kW)		
20	Avoided Need for "Peaker" Power Plants (levelized $/kW)		
	TOTAL $ VALUE FROM ALL APPLICATIONS ($/kW)	**$228.83**	**$2,529.02**

Utilizing the NPV of only the above applicable storage values (no renewables) for the 25-year expected plant lifetime, under the assumptions modeled, the Merchant-owned Base Case VPS plant would yield the following economic results for the Merchant owner:

Table 12. NPV for Base Case VPS Plant Deployed in NYC – Merchant Owner, No Renewables.

NPV: 25-Year Project Lifetime Pre-Tax

Start Date =	2012
Commercial Operations Date =	2014
Base Year for NPV Calculaiton =	2014

	2012	2013	2014
VPS Plant Total Capital Cost			($97,500,000)
Interest During Construction (capitalized)			($14,127,750)
Present Value of VPS Plant Operating Costs			($76,609,561)
Present Value of VPS Plant Overhead Costs			($8,150,736)
Present Value of VPS Application Benefits			$112,541,374

A VPS plant deployed under this scenario (no renewables) would deliver net financial benefits of negative $84 million to the Merchant owner on a net present value basis. This scenario also yields a negative IRR for the Merchant owner and never breaks even throughout the 25-year project lifetime; therefore, under this scenario, the Merchant owner has no financial motivation to invest in and build/operate a VPS plant.

5.2.4 Sensitivity Analysis for the Base Case

The two main costs that can most affect the economic performance of a VPS plant are:

- The total capital cost (CAPEX) to construct the VPS plant.
- The price of the thermal energy source required for VPS's power release stage.

As such, Expansion Energy ran a series of scenarios in the VPS Economic Model and changed these two variables in the Key Assumptions to construct the sensitivity analysis matrices presented below: one for the IOU-Owner case, and one for the Merchant-Owner case. Natural gas is the assumed thermal energy source in terms of $/MMBtu. All other assumptions within the Economic Model remained the same as in the standard Base Case model. Results are shown in terms of NPV within the matrix cells.

5.2.4.1 Base Case Scenario #1: Investor-Owned Utility as VPS Plant Owner

As shown in the matrix below, an IOU-owned VPS plant yields excellent financial performance under any realistic cost scenario, provided that the plant is able to generate the revenue streams discussed in Section 6.1 (e.g., through cost-recovery allowances from regulators). This indicates IOU-owned VPS plants deployed in or near New York City ,as modeled for this scenario, are not particularly sensitive to capital costs or its main operating costs.

Table 13. VPS Sensitivity Analysis – NPVs from Various CAPEX & Gas Costs – IOU.

	CAPEX				
	$75 MM	**$85 MM**	**$97.5 MM**	**$110 MM**	**$125 MM**
Gas = $4	$256 MM	$244 MM	$229 MM	$214 MM	$196 MM
Gas = $5	$250 MM	$239 MM	$223 MM	$208 MM	$190 MM
Gas = $6	$245 MM	$233 MM	$218 MM	$203 MM	$185 MM
Gas = $8	$235 MM	$223 MM	$208 MM	$193 MM	$175 MM
Gas = $10	$224 MM	$213 MM	$197 MM	$182 MM	$164 MM

The VPS plant under this scenario, and most others, is even less sensitive to overhead costs, such as labor, land, insurance, etc., which represent a small percentage of total costs. Even doubling the overhead costs assumed in the Base Case scenario only drops the NPV from $218 million to $204 million, which is still a very attractive return on investment.

Naturally, a substantial drop in the price of off-peak power and/or a substantial rise in the price of on-peak power would materially raise the NPV of a storage asset like the VPS plant via the Buy-Low, Sell-High storage value category included in the VPS Economic Model.; That is somewhat unlikely to occur in the foreseeable future, as the off-peak vs. on-peak “deltas” used in this analysis were based on a four-year historical average, which can be reasonably assumed to have smoothed out the effects of any anomalies in the data from a single period. There is little reason to believe that sustained major increases or decreases in that pricing delta will occur in the coming years.

5.2.4.2 Base Case Scenario #2: Merchant VPS Plant Owner

As shown in the matrix below, a Merchant-owned VPS plant under the circumstances studied here can be quite sensitive to either capital costs or the main operating costs. Merchant-owned VPS plants with a CAPEX above the Base Case amount will have a hard time earning a positive NPV moreover, a VPS plant facing natural gas costs above the $6/MMBtu delivered price assumed in the Base Case are detrimental to the project's NPV in all cases except where there would be a substantially lower CAPEX than in the Base Case. Of course, this sensitivity is largely a function of the quite limited revenue streams that a Merchant plant could generate, as discussed in Section 6.2.3, without changes to the current regulatory treatment of storage, which at present offers little or no incentive in terms of cost recovery or other mechanisms.

Table 14. VPS Sensitivity Analysis – NPVs from Various CAPEX & Gas Costs – Merchant.

	CAPEX				
	$75 MM	**$85 MM**	**$97.5 MM**	**$110 MM**	**$125 MM**
Gas = $4	$48 MM	$36 MM	$21 MM	$6 MM	($12 MM)
Gas = $5	$42 MM	$30 MM	$15 MM	$500 K	($18 MM)
Gas = $6	$37 MM	$25 MM	$10 MM	($5 MM)	($23 MM)
Gas = $8	$27 MM	$15 MM	($135 K)	($15 MM)	($33 MM)
Gas = $10	$16 MM	$4 MM	($11 MM)	($26 MM)	($43 MM)

Notably, a Merchant-owned VPS plant under this scenario, and most others, is also sensitive to overhead costs, such as labor, land, insurance, etc despite the fact that overhead costs represent a small percentage of total costs. For example, doubling the overhead costs yields a *negative* $4 million NPV for a Merchant owner in this scenario.

5.3 Economic Analysis of the VPS Cycle Using Steam

Expansion Energy modeled a Steam Case VPS Cycle plant constructed and operating in or near New York City with the following characteristics, regardless of the type of entity that owns the plant. These characteristics are based on a detailed technical analysis with input from Expansion Energy, Con Edison and a range of suppliers of key components of a VPS plant:

- 17.06 MW power outflow capacity.
- 16.22 MW power inflow rate.
- Utilization of surplus steam heat from Con Edison's district heating system as the thermal energy source to release the power stored by VPS's inflow cycle. 500,000 pounds of steam is consumed per MWh of power outflow.
- Surplus steam heat is available at no charge to the VPS plant owner.
- eight hours of power release per day, operating 350 days per year.
- 25-year plant lifetime.
- Total VPS plant CAPEX of $97,500,000.
- Two-year construction period.
- 10% NPV discount rate.

As with the Base Case discussed previously, the above factors were utilized as key assumptions in a Steam Case version of the VPS Economic Model. Results of that economic analysis follow.

5.3.1 Steam Case Scenario #1: Investor-Owned Utility as VPS Plant Owner

As with the Base Case scenario, an IOU, in this case Con Edison, would likely be in the best position, as opposed to other types of owners, to capture the full value of a VPS plant using steam as the thermal energy source. This is due to its potential to capture value from numerous categories of value, particularly those identified and highlighted in green in the table below. (Note that the applicable value categories for an IOU-owned VPS plant using steam are exactly the same as the applicable value categories for a Base Case IOU-owned VPS plant—i.e., using natural gas as the thermal energy source).

Table 15. Storage Values for Steam Case VPS Deployment in NYC – IOU-Owner

	Storage Value Category / Application	1-Year Unit Benefit ($/kW in 2014)	25-Year Unit Benefit (PV of $/kW 2014-2038)
1	Electric Energy: Buy Low (off-peak), Sell High (peak) ($/kW)	$61.23	$676.68
2	Electric Supply Capacity ($/kW)	$124.81	$1,379.40
3	Reduce Transmission Capacity Requirements ($/kW)	$15.45	$170.78
4	Reduce Transmission Congestion ($/kW)	$11.89	$131.37
5	Transmission & Distribution Upgrade Deferral/Displacement ($/kW)	$594.34	$594.34
6	Operating Reserve ($/kW)	$42.79	$472.94
7	Regulation and Frequency Response (Regulation) ($/kW)		
8	Transmission Support ($/kW)		
9	Electric Service Reliability ($/kW)	$59.43	$656.86
10	Electric Service Power Quality ($kW)		
11	Electric Service Bill Reduction: Demand Charges ($/kW)		
12	Electric Service Bill Reduction: Time-of-use Energy Prices ($/kW)		
13	Renewable Electricity Production Time-shift ($/kW)	$137.89	$1,523.91
14	Renewables Capacity Firming ($/kW)	$53.49	$591.17
15	Federal Energy Storage Tax Credit ($/kW)		
16	Carbon Credits ($kW)		
17	Transmission & Distribution Line Losses: Energy ($/kW)	$49.92	$551.76
18	Transmission & Distribution Line Losses: Capacity ($/kW)	$19.02	$210.19
19	Goodwill / Public Relations ($/kW)		
20	Avoided Need for "Peaker" Power Plants (levelized $/kW)	$269.31	$2,358.59
	TOTAL $ VALUE FROM ALL APPLICATIONS ($/kW)	**$1,439.58**	**$9,318.01**

Utilizing the NPV of all applicable storage values for the 25-year expected plant lifetime, under the assumptions modeled, the Steam Case VPS plant would yield the following economic results:

Table 16. NPV for Steam Case VPS Deployment in NYC – IOU-Owner

NPV: 25-Year Project Lifetime; Pre-Tax

Start Date =	2012
Commercial Operations Date =	2014
Base Year for NPV Calculaiton =	2014

	2012	2013	2014
VPS Plant Total Capital Cost			($97,500,000)
Interest During Construction (capitalized)			($14,127,750)
Present Value of VPS Plant Operating Costs			($50,354,011)
Present Value of VPS Plant Overhead Costs			($8,150,736)
Present Value of VPS Application Benefits			$158,965,199
Net Present Value of VPS Plant	**$0**	**$0**	**($11,167,298)**

A VPS plant deployed under this scenario would deliver net benefits of negative $11 million to the electrical system on a net present value basis, even though in terms of absolute dollar value rather than NPV, which discounts for the "time value of money"), the Base Case VPS plant would deliver approximately $208 million of absolute value to the electrical system over a 25-year period. Break-even would not occur for the IOU until 10 years following construction; moreover, even if 100% of all of the value available to capture would be assigned to the IOU, with none left to share with the other stakeholders in the electrical system, the IRR generated would only be 11.2%. This falls below the 12% threshold required by the IOU, as demonstrated previously in the Base Case IOU-Owner scenario discussed in a previous section.

Without special incentives from regulators, even beyond adopting new mechanisms for IOUs to capture and monetize the many values associated with power storage, the IOU would have only marginal financial motivation to invest in and build/operate a VPS plant that utilizes steam in the manner assumed for this study.

5.3.2 Steam Case Scenario #2: Merchant VPS Plant Owner

For reasons described throughout this report, an IOU is almost always in the best position to capture the full value of a bulk power storage system such as a VPS Cycle plant, and the storage value categories that a Merchant owner could monetize are limited. As such, an IOU-owned plant can be considered the best case scenario, particularly in financial terms, for deploying a VPS plant, whether it relies on natural gas or steam as its thermal energy source. Since even the IOU-owner in the Steam Case cannot generate a sufficient return to justify investment in a VPS plant, a Merchant owner in the Steam Case would produce even less attractive economic results, particularly as measured by financial returns to the Merchant investor. Because of that factor, the VPS Economic Model was not run for the Steam Case with a Merchant owner, and no such results are presented here, as there would be a substantially negative NPV in such scenario.

5.3.3 Sensitivity Analysis for the VPS Cycle Using Steam

As with the Base Case, Expansion Energy performed a sensitivity analysis for the Steam Case where an IOU is the owner of the VPS plant. Note that because the VPS plant uses no natural gas in the Steam Case, and because it is assumed that the surplus steam heat is available for free, natural gas costs were not used in the Steam Case sensitivity analysis. Instead, a doubling of overhead costs, which includes everything except insurance charges, was used for one variable in the sensitivity analysis. The other variable used was project CAPEX, just as in the Base Case.

5.3.3.1 Base Case Scenario #1: Investor-Owned Utility as VPS Plant Owner

Table 17. VPS Sensitivity Analysis – NPVs from Various CAPEX & Gas Costs – IOU.

	CAPEX				
	$75 MM	**$85 MM**	**$97.5 MM**	**$110 MM**	**$125 MM**
Overhead Costs Same as Base Case	$16 MM	$4 MM	($11 MM)	($26 MM)	($44 MM)
Overhead Costs = 2X Base Case	($3 MM)	($15 MM)	($30 MM)	($45 MM)	($63 MM)

As can be seen in the matrix above, an IOU-owned VPS plant using steam and operating in or near NYC could only be justified economically if the total project CAPEX were to decrease substantially to no more than approximately t $85 MM. Even in that circumstance, the project would be quite sensitive to any increases in overhead costs, making it somewhat risky to proceed with constructing and operating such a plant except under the strictest and most reliable conditions; that is, unless regulators were to increase incentives and/or cost-recovery mechanisms available to the VPS plant owner.

5.3.3.2 Base Case Scenario #2: Merchant VPS Plant Owner

Since even the IOU-owner in the Steam Case cannot generate a sufficient return to justify investment in a VPS plant under most circumstances studied for this report, a Merchant-owner in the Steam Case would produce even less attractive economic results for a Merchant owner. Due to this factor, the VPS Economic Model was not run for the Steam Case with a Merchant owner, and, by extension, no sensitivity analysis was performed. The Merchant-owner Steam Case is deemed to be economically unfeasible in every realistic scenario.

6 Conclusions and Recommendations

6.1 Conclusions

Expansion Energy determined the following with respect to the objectives of NYSERDA PON 1670 through its assessments of its VPS Cycle power storage technology deployed in New York City using either steam or natural gas as its thermal energy source: :

- The VPS Cycle is technically feasible for deployment and operation within Con Edison's New York City metro service territory, utilizing either steam or natural gas as the thermal energy source for releasing the stored power. No significant technical barriers were identified that would prevent the successful deployment of VPS plants within the targeted region.
- Though the heat content of surplus steam from Con Edison's NYC district heating systems is sufficient to allow one of more VPS plants to utilize it successfully, the heat content is only high enough to provide a modest amount of power to be sent out during the release, on-peak, stage of the VPS plant's daily cycle.
- In contrast to utilizing steam, the use of natural gas in VPS's release stage yields large amounts of net power output nearly three times as much as when steam is used.
- The VPS Base Case utilizing natural gas as the thermal energy source generates excellent economic returns if a utility (e.g., Con Edison) is the owner of the VPS plant and that utility is able to monetize the majority of the value streams that a bulk power storage asset like VPS provides. The approximately 45 MW Base Case VPS plant analyzed for this report is projected to yield a NPV of approximately $218 million, which is available to be shared by the VPS owner and other stakeholders in the total electrical system, including rate payers. This is on a VPS plant capital cost estimated at approximately $98 million.
- In spite of the excellent financial returns that a VPS plant owned by a utility can deliver under a well-designed incentive structure from regulators, a merchant VPS plant would probably not be in a good position to extract and monetize value from all of the relevant categories of value that storage provides. The merchant owner would not likely be able to participate in the same cost recovery mechanism as a regulated utility (if policy changes are adopted). As such, the economic returns to a merchant owner, though not to the rest of the stakeholders in the electrical system, are far lower than for a utility owner—only about $10 MM in NPV terms. Though this NPV is a positive value, it is not likely large enough on a $98 million capital cost to justify the merchant investor taking the risk of building and operating a VPS plant.
- A VPS plant utilizing steam under the circumstances analyzed for this report would not likely generate a sufficient return to justify an investment by any owner under the assumptions used for this report. Under such conditions, the VPS plant would yield a *negative* $11 million for a utility owner. Special incentives from regulators or legislators would likely be required in order to induce a company to build and operate a VPS plant using steam. Special incentives could include accounting for the fact that the VPS plant could allow utilities or other electrical system stakeholders to avoid costs for other assets that power storage systems such as VPS could displace or defer.

6.2 Recommendations

The Base Case version of the VPS Cycle in or near New York City yields excellent economics, both for the owner of the VPS plant and for the electrical system on the whole a total NPV of approx. $218 million. A plant such as this would serve the electrical system by delivering value from the majority of the approximately 20 storage value categories identified in this report. It is quite worth pursuing the development and operation of one or more VPS plants that use natural gas as its thermal energy source in or around New York City.

A VPS plant using steam is only financially viable if there are special incentives available, above and beyond any new incentives recommended in the following paragraphs, to induce a developer, most likely a utility, to own and operate the plant. That will come down to whether policy makers and regulators find it valuable enough to have a 100% green, or no fossil fuel consumption, VPS plant and/or whether such a VPS plant would allow a sufficient amount of avoided costs to justify the VPS plant investment by displacing or deferring the need to invest in other assets throughout the electrical grid).

Because the VPS Base Case analyzed for this study yields such positive economics for the electrical system on the whole and for all stakeholders, the following actions are recommended to incentivize a utility owner, most likely Con Edison, to develop one or several VPS plants using natural gas in or near New York City. Note that most of these recommendations are policy-related rather than technical or financial in nature.

- Petition the NY Public Service Commission (PSC) to adopt rules: (i) recognizing that storage assets are separate and distinct from generation assets, even if storage assets include some element that may look like generation, as is the case with VPS; and (ii) that allow regulated utilities such as Con Edison to build, own and operate such storage facilities because utilities are in the best position to capture and deliver value from the many storage value streams and to share that value with the total electrical system.
- Petition the NY PSC to: (i) recognize the quantified value of each of the storage value categories identified in this report that are applicable to a VPS plant owned by a utility; (ii)allow Con Edison and other utilities to collect, or monetize the portion of such quantified values that would allow the utility to generate its regulated rate-of-return in addition to any additional economic incentive that may be allowed in order to stimulate investment in storage assets. NYSERDA’s previous studies quantifying the value of storage across numerous value categories, which was also used for this report, would be an excellent source for such economic values.
- Petition the NY PSC, and NY Legislature, as necessary, to allow bulk power storage assets to be included in utilities’ rate bases to provide an assured mechanism of cost recovery.
- Petition the NY Legislature to pass legislation that provides significant inducements for developers, including regulated utilities, to build and operate bulk storage assets to support the electrical grid in numerous ways as described throughout this report. California’s new law, AB 2514, could serve as model legislation for New York to have a head start in drafting the appropriate bill(s).
- Petition the FERC and the NY PSC to provide incentives for bulk power storage assets similar to those available for transmission assets today.

- Petition the FERC to classify bulk power storage as a separate asset class that provides unique benefits to the total electrical system.
- Support the passage in Congress of Senate bill S.1845 ("STORAGE Act"), which would provide a 20% investment tax credit for grid-connected power storage assets.
- Coordinate with Con Edison, the Coalition for the Advancement of Renewable Energy through Bulk Storage (CAREBS) and others to persuade the policy-makers listed above to adopt such changes.
- If a sufficient number of the policy changes recommended above appear likely to occur, commence a more detailed Phase II level of investigation for deploying one or more VPS plants in Con Edison's service territory or in other areas near New York City and build on the results of this study.

Appendix A – Steam Information Request for Con Edison

To: Ed Ecock, Anthony Barna – Con Edison

From: David Vandor – Expansion Energy LLC

Re: Steam Conditions for VPS Cycle Feasibility Study

Date: April 4, 2011

In preparation for our meeting of 4/26, and as part of our efforts, per NYSERDA contract #11814, to evaluate the feasibility of deploying one or more VPS Cycle's in NYC; please provide Expansion Energy with responses to the steam-related questions below.

A) At a Steam Generating Facility, such as in Brooklyn or on the west-side of Manhattan:

1. What is the standard maximum temperature of the steam produced? 600 F?
2. What is the standard pressure at which that steam can be delivered to an adjacent VPS Cycle deployment?
3. Do the temperatures and pressures vary seasonally or within each daily cycle? If so, by what amount?
4. What is the typical quantity (in any unit) of hot steam available at a Steam Generating Facility?
5. What are the temperature (420 F?), pressure and "quality" conditions required by Con Edison for the returned steam from the VPS Cycle to the steam distribution system? (By "quality" we mean vapor percentage.)

B) At a Typical Steam Customer's Site:

6. What is the standard maximum temperature of the delivered steam? 400 F?
7. What is the standard pressure of the delivered steam?
8. Do the temperatures and pressures vary seasonally or within each daily cycle?
9. What is the typical quantity (in any unit) of available steam?
10. What is the maximum temperature of the wastewater that can be disposed into the NYC sewer system?
11. What are the typical uses for steam by customers of Con Edison's steam network, by approximate % of customers? (The total may be more than 100% if some customers have multiple uses for the steam.)

a) Winter heating? ______%

b) Summer air conditioning? ______%

c) Hot water production? ______%

d) Industrial processes? ______%

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New York State Energy Research and Development Authority

17 Columbia Circle
Albany, New York 12203-6399

toll free: 866 NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

State of New York
Andrew M. Cuomo, Governor

VPS Cycle with Steam Feasibility Study for Bulk Power Storage in New York City

Final Report
May 2013

New York State Energy Research and Development Authority
Richard L. Kauffman, Chairman | John B. Rhodes, President and CEO