THE IMPACTS OF REGULATION, POLICY, ADVANCED TECHNOLOGIES, AND MARKET DYNAMICS ON THE DEPLOYMENT OF ENERGY STORAGE PROCESSES

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ABSTRACT

A number of factors are now coalescing which can be expected to lead to significant market opportunities for energy storage in the near term. These include, but are not limited to: government policy and regulatory initiatives; new requirements in wholesale electric markets, particularly related to the transmission and distribution of power; an increase in the percentage of intermittent power sources available (especially in certain regions of the US) leading to more significant requirements associated with, for example, frequency and voltage control; new larger megawatt-hour systems which can be utilized for dispatch during peak periods; the increased utilization of distributed energy systems; the impact of electric vehicle storage and the charging impact on the grid; and the possible integration of storage into smart grid platforms.

As the US energy delivery system changes to meet: changes in supply and demand patterns; changes in policy, as well as new and proposed regulations; requirements for increased efficiency; and capital and market constraints, it appears that energy storage can play an increasingly significant role. This paper focuses on each of the factors listed above and discusses how available and emerging technologies will impact each. The paper examines impacts associated with advanced battery systems, compressed air energy storage, pumped hydro, flywheels, and ultra-capacitors. With respect to battery storage, technologies such as advanced lead acid, sodium sulfur, lithium ion, and flow batteries are examined in detail, and technologies which should be favored, in the near term, for specific applications, are identified. In addition, the possibility and plausibility of “stacking” applications for specific technologies is addressed.

With respect to utility scale energy storage systems, a new and compelling interest has been emerging. Many applications, from substation and transmission upgrade deferral for utility-scale applications, to distributed energy storage for community-scale applications have now been identified, that are best solved by energy storage solutions of duration of 4 or more hours. However, near term focus by system developers for energy storage applications has been on power applications, those applications requiring (megawatt) MW scale power for only short periods of time, typically 15 to 45 minutes. Although there is significant interest in bulk energy storage for applications requiring MW scale power for 4 or more hours, currently there is only one turn-key system in the market that has demonstrated in the field that they can meet this requirement, and this supplier is backlogged for the next several years in filling current orders. Consequently, opportunity exists for new players in the bulk energy storage world.

What is really needed to continue the enabling of energy storage in the bulk storage arena are changes in regulatory policies and directives as they define generation, transmission, and distribution assets. This would occur by broadening the definition of what types of devices are included in each category. These changes in policy can lead to new rules and directives that define tariffs for the purchase of these services by the appropriate energy managers, including Independent Power Producers and the major Independent System Operators (ISO's) and Regional Transmission Organizations (RTO's) throughout the system. These changes could then direct downward to local utilities (rural and municipalities) that desire to employ bulk energy storage systems in their operations, but currently have no way to recover the cost of deploying these technologies. The definition of these new terms and conditions, in turn, would provide the necessary motivation to the bulk storage systems developers to make the appropriate financial and technical commitment to bring cost effective bulk storage turn-key solutions to the market. This would lead to a truly effective Smart Grid.

With respect to the aforementioned regulatory and policy initiatives necessary to spur the growth of storage utilization, both domestically and internationally, such regulation and policy initiatives continue to evolve. The paper examines federal and state initiatives, as well as initiatives abroad. With respect to the federal regulatory initiatives, the Federal Energy Regulatory Commission (FERC) has one regulation recently put into effect (FERC Order 1000), as well as Notices to Proposed Rulemaking (NOPRs) and Notices of Inquiry (NOIs), which can be expected to ultimately drive growth in the US market. With respect to state initiatives, California regulations (including AB2514)

have made California by far the leading market for storage in the US. With respect to China, storage is specifically mentioned in the 12th Five Year Plan as an important technological development in clean energy (although, primarily for electric vehicle applications). However, China's State Grid is conducting various test programs for different storage technologies as a precursor to policy design. The implications of the evolving policy and regulatory landscape, nationally and internationally, are addressed.

1.0 Introduction

The ability to store energy, and deliver it as required, is certainly not a new phenomena (pumped hydro storage was first made available in Europe in the 1890s). However, there have been economic and technological advances in battery systems, as well as in flywheels, ultra-capacitors and compressed air storage systems, which has led to a dynamic wherein there is now a market for deployment of new storage systems, for some specific value propositions. In addition, regulatory and policy initiatives both at the federal and state level in the US, as well as in Europe and China, should lead to an ever increasing deployment of storage systems in the near term. It is therefore our belief that there will be a significant market for an array of storage systems, designed for specific applications, in the next few years.

At Hudson, we view any opportunity through the lens of the intersection of technology, policy and markets. We then invest when there is a dynamic indicating a favorable intersection for the specific technology and company being examined. In this paper, we view the field from the position of an agnostic with respect to particular technologies, but attempt to establish what we feel are value propositions based on the intersection of technology, policy and markets. We examine here both value propositions we believe may be sustainable at present, as well as those propositions which we feel will be sustainable later, when regulations and technologies still not available commercially (or available technologies which can be expected to make breakthroughs on cost reduction), are in place.

With respect to the regulatory framework, the examination presented here indicates that, aside from some instances in California, present energy storage regulations are still, by and large, not sufficient to drive significant growth in the US market. While the Federal Energy Regulatory Commission has established several Notices of Inquiry (NOIs) and Notices of Proposed Rulemaking (NOPRs) that will establish appropriate remuneration methods for grid system operators who chose to utilize available storage systems, until actual regulations are in place (which can take years) many value propositions will not be economically attractive. The paper describes in detail federal and state regulations and initiatives presently in place, and those which can be expected in the near future. Regulatory initiatives abroad are also discussed. The impact of these initiatives on specific value propositions is developed.

Of relevance to any discussion of storage, is the long term prospect of inexpensive natural gas, particularly in the U.S., dominated by our shale gas reserves. Any value proposition involving storage must be examined based on the understanding of whether processes utilizing abundant and inexpensive natural gas make more economic sense for the project envisioned. Without regulation and policy mandating storage, many, but perhaps not all, value propositions involving storage will not make economic sense when compared to, for example, simple or combined cycle gas turbine proposals. The impact of inexpensive natural gas on the increased utilization of energy storage is assessed.

2.0 Technologies

Currently, there exist a large number of utility scale energy storage technologies, ranging from traditional lead-acid batteries to seawater pumped hydro, some of which are well established, some of which are in the development stage, and some of which are in, or just emerging from, the laboratory. Each technology must be carefully investigated to determine its potential for use in specific utility scale energy storage applications. This is especially true when batteries designed for power applications are expected to be used, in addition, for energy applications, or when batteries designed for energy applications are expected to be used, in addition, for power applications. A brief description and operational status for the currently existing, utility scale energy storage technologies, is presented here. An assessment of their current readiness to support existing utility scale applications is enumerated in Section 3.0.

2.1 Traditional Lead-Acid Batteries

The most mature energy storage utility scale device in today's market is the traditional lead-acid battery, which is typically found in uninterruptable power supply (UPS) applications, which range from several kW for 15 minute applications to 2 MW for 30 second applications. Although these batteries are widely in use, many users have low levels of confidence in these systems, especially for utility scale applications, and are looking for alternative storage devices that may give better service life and reliability. Many of the lead-acid performance failures are driven by improper implementation and maintenance of these systems by both the system integrators and end users. When properly managed and integrated into a well designed system for a specific application though, lead-acid systems are currently the most cost effective energy storage devices on the market. Lead-acid batteries should therefore be considered a mature technology which, if properly managed, can operate successfully in a utility scale environment.

2.2 Nickel Cadmium Batteries

Nickel cadmium is a fully mature energy and a reliable storage technology. However, nickel cadmium batteries have limited deployment in utility scale applications (except for projects like the Green Valley 27 MW system in Alaska, which are unique utility scale projects). There is substantial resistance to further deployment for utility scale systems because of the recycling issues with the cadmium component. The relative cost for nickel cadmium based systems is also substantially higher than equivalent traditional lead-acid systems, another factor leading to their limited deployment in large scale applications. However, because of their superior performance in hostile environments, both hot and cold, the railroads use these batteries extensively in their mobile and stationary applications (although at typically lower power levels than that found in utility scale applications). Even given the limitations, nickel cadmium batteries should be considered a mature technology, and if properly managed, can operate successfully in a utility scale environment.

2.3 Advanced Lead Acid Batteries

A new lead acid battery variant is being introduced which overcomes many performance shortcomings of the traditional lead acid battery. The major change is the introduction of carbon materials in the negative grid. Three carbon based battery variations have been developed ranging from a pure carbon negative to different implementations of carbon in the negative grid. All these variations have very good cycling capability, substantially greater than traditional lead acid batteries. The pure carbon variety has very good high rate performance, but only limited energy capacity, making it a reasonably good power device for high rate applications. The active material impregnated variation is a reasonable compromise with good high rate performance but with limited energy capacity (although somewhat more capacity than the pure carbon negative). A third variation is a proprietary implementation that has excellent performance in both high rate capability and high capacity for long, deep discharges. Advanced lead-acid batteries should be considered a mature or maturing technology, which is expected to operate successfully in a utility scale environment.

2.4 Li-Ion Batteries

There are many electrochemical variations to the basic Li-ion battery that focus primarily on a target application. These batteries have excellent cycling performance capability. Most applications are of the power type; consequently, the design of the battery is in support of the power requirements, at the expense of energy capacity. Li-ion batteries operate very well at partial state of charge and have excellent cycling performance. Little actual field performance data has been made public so a determination of the level of successful operation experienced for a utility scale application is currently not possible. Li-ion batteries are to be considered a mature or maturing technology, which appears to have been successfully deployed in limited utility scale power applications.

2.5 Sodium Sulfur Batteries

Sodium sulfur is a relative newcomer to the energy storage industry and has been successfully commercialized. Although a very expensive alternative, all available systems that have been manufactured have been deployed. A current waiting period of several years is in place for new customers who have placed orders for systems. The system is available in an incremental size of 1 MW, 7 MWh for a base unit. Multiple units can be deployed to increase the power levels as needed. Typically deployed in energy applications, which take advantage of the 7 hour discharge at rated power, it can also be used in power applications, but with shorter life expectations. One drawback of the technology is that it must be maintained and operated at a temperature between 300 and 350 °C after initial startup. The one commercial manufacturer will allow the system to be cooled down and “frozen” after delivery under very carefully controlled conditions. Deviation from these conditions can result in permanent damage to the battery. Other firms are working on sodium sulfur technologies, and they may impact the field in the future. Sodium sulfur batteries are to be considered a mature technology that has been successfully deployed in utility scale power applications.

2.6 Flow Batteries

Although not a recent invention, flow batteries are beginning to enter the market, with their best performance currently being seen in small scale applications ranging from 5 kW to 250 kW, 2 to 4 hour discharge period. Because power capacity and energy capacity are decoupled, system designers have more flexibility in sizing the system for optimum footprint. There are currently two types of flow battery technologies in the market. The zinc-bromide technology is based on the plating (charging) and de-plating (discharging) of zinc metal in cell chambers. Energy is stored in the plated zinc and is recovered as a load is served in the de-plating process. Another type of flow battery is the redox technology in which all energy is stored in the electrolyte and the cell has no active role in the generation of electricity, other than to provide a location where the charged anolyte and catholyte can meet to exchange ions and generate a current (or discharged electrolytes can meet to restore them to a charged condition). One major advantage of a redox design is that self-discharge is practically non-existent and the system will remain at a high state of charge for an indefinite period. A drawback of the existing systems is the reliance on toxic or potentially toxic materials. Another technology that is often referred to as a flow technology is the metal-air battery where one of the electrodes is a metal, and the other is air. This technology has been extremely successful as a primary battery but has not yet been shown to successfully discharged and charged multiple times to support utility cycling applications. Zinc-air technology has the highest energy density compared to existing energy storage technologies Zinc bromide and redox batteries are to be considered maturing technologies. Metal air batteries are currently in the laboratory or demonstration stage but have garnered significant interest for potential utility scale applications.

2.7 Flywheels

Flywheels have had a limited impact to date in the utility scale power market. Because of their limited energy storage capability at high power ratings, they have a very narrow application base that they can support. Flywheel subsystems are also perceived to be on the high end of the cost curve. However, they have the capability of moving from a full discharge operating mode, to a full charge operating mode in a matter of milliseconds, and can do that hundreds of thousands of times during their operational life (which is expected to be in excess of 20 years). There have been several recent successes in deploying MW scale flywheel systems to support the frequency regulation application. Because of the quickness at which the flywheel can go from full discharge to full charge, and all points in between, a 1 MW flywheel with no emissions, and with high efficiencies, has been touted to be able to displace up to 10 times the power generated by traditional regulation assets, i.e. a 10 MW gas turbine generator dedicated to frequency regulation that requires minutes to respond. Flywheels are to be considered a mature technology, which has been successfully deployed in utility scale power applications.

2.8 Super (or ultra) capacitors

Super capacitors are relatively new to the utility scale energy storage arena. They have an extremely low energy density, but very good power density, with the potential to be able to cycle millions of times during their lifetime. Used extensively in low power applications', scaling to utility scale applications has proven to be quite difficult. In addition, high costs of scaled-up systems have kept them out of high power, low energy applications in the utility power area. Until costs come down considerably, it is felt that super capacitors will not find a place in utility scale application support. Although a mature technology for small scale applications, it is to be considered that the technology is unlikely to be successfully deployed in utility scale power applications.

2.9 Thermal Storage

Thermal storage is available in both high temperature and low temperature systems. High temperature systems, typically using molten salts heated by solar collectors, have been deployed in several utility scale demonstrations. Because of the high capital costs for system deployment and problems with materials operating at such high temperatures, high temperature thermal storage has been slow in its adoption. Low temperature systems, typically using ice, are ideal for displacing traditional HVAC systems for large buildings. Water is frozen overnight, when electricity is at its lowest cost, and then used for air conditioning during the afternoons, when electricity is at its highest cost, eliminating the cost for operating an HVAC compressor during high cost periods.

High temperature thermal storage is a maturing technology that has been successfully deployed on a small scale in utility scale power applications. Low temperature thermal storage is a mature technology that has been successfully deployed in utility scale power applications.

2.10 Pumped Storage Hydro-Electricity (Pumped Hydro)

Pumped hydro accounts for most of the electric energy storage capacity currently deployed in the world. Where installed, it is used by the utilities to provide peaking power support during high demand periods. Storage is realized when water is pumped from a low level to a higher level, typically more than 100 feet in elevation, during the night when electricity cost is lowest. When needed, water is released from the high elevation through a turbine to the lower elevation releasing the stored energy to the grid. Although a proven and reasonably efficient method for storing electrical energy, difficulties in finding appropriate sites and permitting new sites has been next to impossible, primarily for environmental reasons. It has been decades since the last pumped hydro site was commissioned in the US. However, pumped hydro electric energy storage is a mature technology that has been successfully deployed in utility scale power applications.

2.11 Compressed Air Energy Storage (CAES)

There are two types of CAES systems: underground, in salt caverns or depleted natural gas fields, and above ground in high pressure air containment vessels. Underground CAES has been proven feasible with plants existing in Europe and the US, but finding appropriate sites is problematic, and the high capital investment need to build such plants has been difficult to procure. However, several demonstrations are pending in the US as more interest has been shown in deploying this energy storage technology. One major drawback is the round trip efficiency currently experienced. As air is compressed, energy is lost in the heat of compression. When stored in the cavern, energy is lost as the compressed air cools. During recovery of the stored energy, heat must be added to the compressed air to overcome the chill of expansion and provide sufficient energy to operate the compression stage of a gas turbine generator. Above ground CAES operates under the same principle and is typically built at a much smaller scale than underground CAES. Air is compressed and stored in a containment device, for example, a network of gas pipeline sections that make up a sealed containment vessel. One variation is the isothermal containerized CAES which is currently in development and demonstration. This design overcomes many of the efficiency issues related to below ground systems.

Underground CAES electric energy storage is considered a mature technology that has been successfully deployed in utility scale power applications. Above ground CAES electric energy storage is a developing technology that is currently considered laboratory scale.

3.0 Applications and Market Dynamics

There are seventeen fundamental utility applications, documented in recent publications by Sandia National Laboratories, which will be directly impacted by electrical energy storage in one form or another, especially as the smart grid gets fully implemented. They include integration with traditional generation sources and the integration with renewable energy generation resources. Sandwiched between these two groups are applications related to grid operations, grid infrastructure, and end user, all of which can be impacted by energy storage. A brief description of each, what is needed for each in energy storage capability, and how each can be supported by energy storage follows. Following this, an analysis of market dynamics related to the competitive atmosphere is presented.

Applications by Category

Category	Applications
Electric Supply	1. Electric Energy Time-Shift 2. Electric Supply Capacity
Grid Operations	3. Load Following 4. Area Regulation 5. Electric Supply Reserve Capacity 6. Transmission Support 7. Voltage Support
Grid Infrastructure	8. Transmission Congestion Relief 9. Transmission and Distribution Upgrade Deferral 10. Substation Onsite Power
End-User	11. Time-of-Use Energy Cost Management 12. Demand Charge Management 13. Electric Service Reliability 14. Electric Service Power Quality
Renewables Integration	15. Renewables Energy Time-Shift 16. Renewables Generation Capacity Firming 17. Wind Generation Grid Integration

3

3.1 Electric Supply

Electric Energy Time Shift

Energy storage systems charged slowly overnight with low cost electricity, could be dispatched the next day during peak load periods, to supplement generation capacity and minimize use of peaking plants, when loads approach critical peaks and additional capacity is required. This application requires an energy storage device with up to 4-6 hours of capacity at full power.

Electric Supply Capacity

Energy storage systems could cost effectively replace ageing peaking plants, eliminating inefficiencies and emissions from these plants. In addition, other ancillary services such as spinning reserve and frequency regulation could be provided when the energy storage system is not required for peaking support, giving a greater benefit than the traditional asset, which typically remains idle until it is called for peaking support.

3.2 Grid Operations

Load Following

This application requires an energy storage device capable of discharging up to 4-6 hours per day to provide load following support on a feeder or distribution system. It would be charged overnight when rates are at their lowest and discharged on a daily basis. The system could also provide demand side management benefits as well as other energy services.

Area Regulation

This application requires operating the energy storage device at a partial state of charge so that energy can be taken off the grid or put on the grid up to rated power as contracted for by the ISO. The storage device would be exposed to many shallow charge/discharge cycles each day. The capability to operate for long periods at partial state of charge without stressing the device is critical to the successful deployment of the storage technology. The energy content for the device requires full power discharges and/or discharges for periods of up to 15 minutes in duration.

Electric Supply Reserve Capacity

This application requires an energy storage device capable of delivering rated power on short notice for a 4-6 hour discharge, operating in much the same manner at spinning/ready reserve. A device of sufficient storage capacity could possibly be used in multiple applications, which would increase the operational value of the system when not called on for reserve services.

Transmission Support

This application requires an energy storage device capable of a 4-6 hour discharge at rated power. As it will be called on only a limited number of times a year to support transmission line overloads, it would be advantageous for the system to be able to be moved relatively easily to an alternative location, depending on the seasonal load profiles of the transmission support site. It may also be advantageous to relocate the system following completion of the original transmission system planned upgrade as conditions may dictate. When transmission support is not needed, the device could support other energy applications as available or could be reconfigured to support frequency regulation (if it is tolerant of the multiple daily cycling and high variable charge/discharge rates).

Voltage Support

This is a power application requirement that must be capable of operating in a 4-quadrant mode to provide both static and active VAR support. Most modern inverters and power conditioning systems are designed to have a 4-quadrant operating mode, so the desired power factor can be achieved quite readily. Most VAR support operations require little or no power from the storage device. In some applications, such as active VAR compensation where power is needed to be injected to provide damping for transmission/distribution line transients, power is provided by the storage device to inject energy to the line as needed.

3.3 Grid Infrastructure

All grid infrastructure applications require 4-6 hours of discharge at rated power.

Transmission Congestion Relief

Storage systems would be strategically located at sites where they would contribute the greatest relief to the congested transmission systems. Because of the variables in congestion points, and seasonal dependence on the severity of the congestion points, it would be advantageous to have an energy storage system easily transportable, as demands change at various locations.

Transmission and Distribution Upgrade Deferral

Typically, deferral would be scheduled for 1 to 3 years, depending on projected load growth. For this reason, it is essential that the energy storage system be relatively transportable so it could be moved to a new site at the end of the deferral period, as set by the utility planners. In the case of sub-station upgrade deferral operations, it might also be very advantageous to be able to move the energy storage system from a summer peaking site to a winter peaking site as seasonal loads vary.

Substation Onsite Power

Substations require on-site power when grid power is lost, in order have power available for switching components and substation communication and control systems, so that the substation is properly prepared for the return of the grid. These loads vary substantially from substation to substation so a standard off-the-shelf energy storage system may not be the best approach for many sites. There are over 100,000 such sites in the US.

3.4 End User

All of these applications could be supported with the same, well designed, cost effective energy storage system. There is currently no system available which could be considered off-the-shelf for these applications.

Time-of-Use Energy Cost Management

With the onset of the smart grid and accompanying smart meters, end users may soon be faced with Time-of-Day rates that vary with electricity supply and demand. Conservation is one approach to control costs, but when power is consumed as needed, it may come at a premium cost. Energy storage systems designed around the domestic and small business requirements would provide peaking power during the high-rate periods and keep end users electricity bills under control. Storage capacity on the order of 2-6 hours is needed to support this application.

Demand Charge Management

Large businesses and industrial power consumers already face the issue of demand charges for the high 15-minute load interval experienced during the month. Energy storage designed to offset the peak demand at a predetermined load point would give customers better control of their energy costs. Storage capacity on the order of 4-6 hours is needed to support this application.

Electric Service Reliability

In the US during the past year, power service was interrupted to millions of customers due to natural causes. The cost of these interruptions is not only an inconvenience to the end user but is sometimes a serious danger. Energy storage, and a good plan for energy conservation, would benefit the end user by providing power during these outages. Storage capacity would differ from end user to end user because of loads and ability to purchase desired capacity but, with proper planning, a system could be designed at a reasonable cost to cover an extended outage.

Electric Service Power Quality

Momentary interruptions of several seconds to several minutes are not uncommon on the US grid, especially in certain parts of the country. Energy storage could be used to carry the end user loads during these minor power interruptions and short outages, and clocks would keep time, and essentials, which depend on a reliable electric service, would not be interrupted.

3.5 Renewables Integration

Renewables Energy Time-Shift

Time shift is not generally related to providing a fixed power for a specific period of time, but is oriented to moving photovoltaic (PV) or wind power from one part of the production day to another. For PV, morning loads are typically oversupplied as the PV output ramps up; afternoon loads are typically undersupplied as PV output ramps down. The value of the energy in the afternoon is generally much higher than in other parts of the day. Consequently, PV power has a higher value in the afternoon when energy is stored early in the morning and is dispatched from the energy storage device in the afternoon. This application requires an energy storage device with up to 2-4 hours of capacity at full power. For wind, nights provide the highest output but the lowest return. Storing at night and delivering during the day provides a better revenue profile. This application requires an energy storage device with 6-8 hours of capacity at full load.

Renewables Generation Capacity Firming

This is very similar to Energy Time Shift but with a somewhat different purpose. For PV, for example, output power does not match peaking afternoon loads but is typically decreasing as loads increase. By employing an energy storage system that is charged slowly overnight with low cost electricity and then dispatched as PV power is dropping in the late afternoon, this would firm power through the end of the peak load period. This extended power output leads to high value power being extended beyond the normal PV production day. This application requires an energy storage device with up to 2-4 hours of capacity at full power.

Wind Generation Grid Integration

Because wind variations can substantially reduce power output from a wind farm, large ramping transients are generated that must be managed by the utility through its regulation capacity on the grid at any given time. If ramping is not limited to a rate manageable by the regulation resource, instability is introduced to the grid that could possible lead to voltage collapse. Consequently, ramp rates must be controlled within a specified tolerance. Typically this is done with a smoothing battery that provides the capability to absorb excess generated power or to dispatch fill-in power at the specified ramp rate, to maintain grid stability. This is a power application requiring many shallow cycles at typically high currents.

There is also another component to wind integration, as noted in above. Time shifting, much like that of PV time shifting, is necessary when substantial wind power is being generated and loads are minimal. Storing the excess wind power in these conditions would eliminate spilled power and lost power that is typically curtailed during high wind, light load conditions. This application requires an energy storage device with up to 6-8 hours, perhaps even more, with capacity at full power.

3.6 Market Dynamics

At present, the major competition to storage in the U.S. is natural gas fired generation (either simple cycle gas turbines, or combined cycle plants, referred to as CCGT). The natural gas resource of the U.S. has been greatly augmented by the ability to extract shale gas inexpensively, and by the discovery of additional large shale gas deposits, such as the Marcellus Shale, which is located in Pennsylvania, Ohio and New York (at or near area where significant gas utilization is located). There is increased scrutiny of the techniques associated with extraction, but barring some catastrophic event, it is expected that natural gas will stay relatively inexpensive, even as gas replaces retiring coal fired generation. The available resource in the US has been estimated by the Potential Gas Committee as 2100 trillion cubic feet (tcf). In addition, shale gas is not only a U.S. phenomenon. Significant reserve of both shale oil and gas exist in Canada. Even in Great Britain, a firm recently reported a find of approximately 200 tcf of shale gas. This is to be compared to the previous total estimate of gas reserves in Great Britain of 2 tcf. It is also expected that significant reserves will be found elsewhere, including in China.

Given the amount available, it can be expected that natural gas will remain inexpensive in the U.S. for years. As an example of the inexpensive cost of production of electricity from natural gas, a CCGT plant with an electrical efficiency of approximately 50%, using $4.50/MMBTU gas, can produce electricity at a levelized cost (LCOE) of about $.06/kwh. In an unregulated atmosphere, there may be few applications and projects, at present, where storage can compete with gas generation. The challenge is therefore clear for storage- reduce cost and wait for FERC, etc. to regulate the requirement for storage (see Section 4). Such regulations like First/Fast, described in Section 4 below, should significantly increase the use of storage. In the meantime it is incumbent on storage providers to reduce cost in the near term.

At present, energy storage costs are somewhat prohibitive, and it has been reported that potential buyers do not see a realistic return on their investment at current prices, except in a few very specific situations. However, when technologies expand to full commercial scale production, as has been observed with the development and deployment of, for example, S&C Electric's Pure Wave UPS device, costs may be expected to decline by as much as a factor of 5, for many energy storage technologies. In power applications, current costs for turn-key systems are in the $1,700/kW range and costs per kWh are very high, but the focus is on power, not energy, so it is meaningless to comment on the cost per kWh for power devices. In energy applications, current costs for turn-key systems are in the $2,500 to $4,500/kW range and costs per kWh range from $250/kWh to $700/kWh, depending on the energy storage technology. Potentially, because no exotic materials are used in flow battery energy storage technologies, one can expect to see turn-key costs to fall to the $1,200/kW and $100/kWh range. Most other technologies currently out of the laboratory (most presently in demonstration programs) expect to see a reduction in overall costs as deployment expands. The actual cost reductions required can only be determined on a case by case basis, considering the wide variety of potential applications, and the competitive atmosphere.

It is also to be understood that many new and promising energy storage technologies are still at laboratory scale and these are not expected to make an impact on the current market for at least 5 to 10 years. Historically, development periods for energy storage technologies run from 15 to 25 years from concept development to deployment, as observed in the sodium sulfur development and commercialization effort.

Clearly, given the low cost of storage's major competition, the expansion of storage will depend on both the reduction in cost and the regulatory atmosphere. In the next section, regulations presently in place and those expected in the near term, which can impact greatly on the expansion of storage in the U.S. and abroad, are described.

4.0 Regulatory Framework

Given the present cost structure of utility scale storage, and the relatively inexpensive cost of natural gas in the U.S., regulations which put in place monetary formulae for utilizing and/or specifying storage, are the most important components to spur the growth of the storage industry. While there are a few value propositions where storage can compete at present with the other available methods for meeting power and energy requirements, most of the seventeen sectors described in Section 3 will benefit significantly, and yield cost effective solutions, when expected federal and regional regulations are enacted. A review of present and expected regulations, both federal and regional, are described here, as well as a review of expectations internationally.

Nationally, the Federal Energy Regulatory Commission (FERC) recently has enacted Order 1000, related to transmission planning and cost allocation. This rule requires a transmission planning process to be developed in each region, with several implications for storage. These include preferential treatment to transmission expansion that accommodates renewables and a procedure which creates a more economically viable market for utilizing storage in renewable's firming.

In addition, FERC has developed several Notices of Inquiry (NOIs) and Notices to Proposed Rulemaking (NOPRs), which establish appropriate remuneration methods for grid system operators when using storage. These include: the NOPR First/Fast, which provides uniform pay-for-performance compensation for frequency regulation, including compensation for ramping speed; the NOPR for Variable Energy Resources (VERs), whereby public utility transmission providers will receive appropriate remuneration from VERs, as well as customers, for providing ancillary services to the grid; and the NOI for promoting transmission investment through pricing reform, which could provide subsidies for transmission and distribution upgrades provided by storage. Unfortunately, it is expected that final FERC Orders related to these are as much as 2 years away.

With respect to the Independent System Operators (ISOs), a number, including CAISO, ERCOT, PJM, NYISO, ISO-NE and MISO, have established rules and rights for storage providers. Some have proposed tariff schedules related to storage provided ancillary services. Unfortunately, at present, the system wide problem is that there are either no performance based payments or the prices paid for ancillary services are, in most cases, too low for storage providers.

While individual states, including Texas, Hawaii, New York and Colorado, are considering statewide regulations, the most ambitious statewide program for storage is in California. Regulations favoring storage include: SB412, the State Generation Incentive Program, which provides $2.00/W for advanced energy storage systems in customer side applications; AB2514, the Energy Storage Bill, which requires the California Public Utility Commission (CPUC) to adopt storage procurement targets to be achieved by each load serving entity by 2015; SBX1-2, the California Renewable Performance Standard, which specifies storage to meet demand when renewable are insufficient for frequency regulation and reserve capacity; and the CAISO proposed demand response tariff, which can lead to frequency regulation performance based payments.

In Europe, Germany has the most developed program to incentivize storage. While there are no direct subsidies for storage, the 2011 amendment to the Renewable Energy Sources Act can have a significant impact on storage utilization, especially related to the interconnection of stranded renewable power resources to the grid. Utilities having to meet power reliability standards will need to pay attention to providing firming and reserve capacity, creating an attractive market for storage.

In China, the 12th Five Year Plan mentions storage as an important technological development for clean energy, but the focus is on transportation scale storage. However, with the increased emphasis on renewables (there is a goal of 70 GW of wind in the 12th Five Year Plan), there will be a need for providing both ancillary and dispatch services. Recognizing this, the State Grid has initiated several grid storage demonstration projects to test out various storage technologies. While these projects show a commitment to exploring opportunities, the time scale for significant implementation is expected to be significant.

5.0 **Conclusions**

In this paper we have attempted to describe the landscape for energy storage expansion based on analyzing available technologies, within the framework of market dynamics and regulatory developments. The following represents our conclusions:

1. Available storage technologies continue to be refined, both to increase efficiency and life cycle and to reduce cost. A significant number are either at a scale deemed commercial, or at a demonstration scale.
2. There are at least seventeen defined value propositions for storage.
3. The proliferation of renewable power production yields significant value propositions for a number of these technologies.
4. While the regulatory framework in the U.S. and overseas does not, at present, favor the proliferation of storage, a significant number of proposed regulations making storage economically attractive, are expected to be enacted in the near term.
5. The major competition for storage continues to be natural gas fired generation, and with the low cost of gas expected to continue in the near term, it will be necessary for providers of storage technologies to find methods to reduce costs, as they reach commercial scale. While this is expected to occur, the real key will be the expansion of a regulatory framework favoring storage.
6. While there are only a few distinct value propositions which make economic sense at present, the near term regulatory atmosphere, and the expected cost reductions as technologies drive to scale, will make storage far more attractive.
7. Based on these conclusions, the expectation is that in the next few years, (assuming regulations favoring storage are finally established as law), that the storage industry will see a hugely significant expansion. This is expected even in the competitive atmosphere of low cost natural gas.