

**BOTTLING RENEWABLE ENERGY**  
MARKET ASSESSMENT OF GRID-SCALE STORAGE  
FOR RENEWABLE INTEGRATION IN THE U.S.

Master of International Business Thesis  
**Submitted by Ravi Ashokkumar Manghani**  
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THE FLETCHER SCHOOL

TUFTS UNIVERSITY

## DEDICATION

TO THE LATEST AND BEST ADDITION IN MY LIFE –MY SON, ANAY

## ACKNOWLEDGMENTS

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## ABSTRACT

Grid-scale energy storage has received considerable attention in the recent years and global revenues are projected to increase from \$1.5 billion in 2010 to \$35.3 billion by 2020 (Pike Research 2010). In the U.S., energy storage finds multiple applications, driven by Renewable Integration, Peak Load Growth, Transmission Constraints and Smart Grid (Lin 2010). More renewable energy resources on the grid offer hand-in-glove opportunities for storage due to variable nature of renewable generation, which further burdens already inefficient grid operations. However, storage industry faces technical, economic and regulatory barriers, which will have to be overcome to encourage large-scale adoption.

This paper reviews the market opportunities, discusses the economics and barriers, and provides prescriptions for possible business models and policy recommendations.

## **Chapter 1: INTRODUCTION**

This paper will review the growth in the renewable energy sector in the United States and identify challenges in integrating renewable energy sources onto the grid. The paper will present energy storage as the possible solution to facilitate large scale adoption of renewable energy sources. Finally the paper will discuss business models that can provide ‘technology push’ and necessary policies that can encourage ‘market pull’ for energy storage solution. The primary motivation for this paper is to personally gain in-depth understanding of this industry.

Chapter 2 will give an overview of wind and solar renewable energy technologies, and also provide historic and projected growth of renewable energy resources on the U.S. grid.

Technological innovations and progressive energy policies will result in growth of renewable energy in the energy mix.

Chapter 3 will be about the structure of U.S. electricity grid and will provide the big picture of the complex electricity grid in the U.S. and introduce various energy services (generation, transmission, distribution, ancillary services, arbitrage, etc.) and different players (utilities, independent system operators, etc.).

With increasing renewable energy integrating these sources into the electricity grid poses unique challenges. Chapter 4 will take a systems approach to identify issues in efficiently balancing the load and generation, and conduct an analysis of costs involved in dealing with stability and reliability of the grid from a utility’s perspective.

Chapter 5 will begin with illustrating the role of grid-scale energy storage as an existing capable technology for various grid applications such as frequency regulation, arbitrage and backup

power among others. Role of technology, markets and policies will be discussed in making energy storage a competitive non-traditional asset in these applications compared to traditional fossil-fuel generation. Using the systems approach discussed in the previous chapter, cost-benefit analysis of energy storage in providing grid stability through effective integration of renewables will be conducted.

Chapter 6 will be the final chapter of this paper and will focus on applications where energy storage is cost competitive in facilitating renewable energy integration and recommend business models/scale-up strategies. The thesis will also provide suggestions for subsidies and other similar policy/market interventions that could make energy storage effective in areas where storage is close to being “on the money.”

## Chapter 2: RENEWABLE ENERGY GROWTH AND GOALS

### 2.1 Renewable Energy Growth

Renewable Energy is defined as energy from resources such as solar, wind, tidal, biomass and geothermal heat, which can be naturally replenished. In 2009, renewable energy made up 8 percent of total U.S. energy consumption and accounted for 12.2% of the net summer capacity (U.S. Energy Information Administration 2010).

Renewable energy technologies have been growing globally, and likewise in the United States. In the last 10 years, installed wind capacity has increased by 30% CAGR from 2.5 GW in 1999 to 35 GW in 2009. In spite of the global economic crisis, the installed wind capacity<sup>1</sup> grew by over 37% (and 9.5 GW) in 2009 (U.S. Department of Energy 2010). Solar photovoltaic (PV) has seen similar (and in many cases more spectacular) growth in the past decade. The U.S. solar PV market has grown 37% year-over-year from 2004-2009 (American Council On Renewable Energy (ACORE) 2010). 2009 was the fourth straight record year for solar installations (Ford 2010). Solar electric installations<sup>2</sup> grew 37% in 2009 to cumulative capacity of 2.1 GW (Resch 2010).

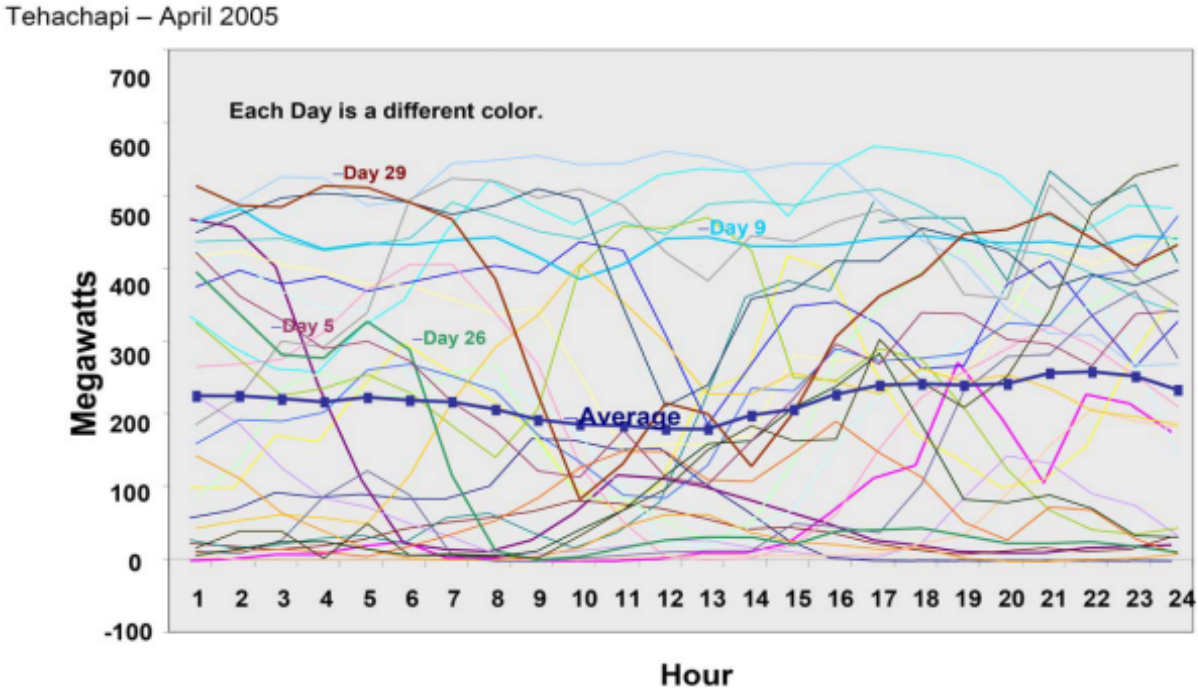
The U.S. Energy Information Administration (EIA) ( The U.S. Energy Information Administration (EIA) 2010) projects that in 2035 renewable resources will provide 17% of country's electricity generation, of which wind and solar will contribute 27%. Due to the immense potential of wind and solar in the coming years, focus of this paper will be on these two technologies. A more relevant reason for limiting the study to solar and wind is the variable

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<sup>1</sup> Wind generated electricity grew by 61% from 2007 to 2008 and by 28% between 2008 and 2009 in the U.S.

<sup>2</sup> Solar electric installations include both Photovoltaic (PV) and Concentrated Solar Panels (CSP)

nature of these resources. As illustrated in figure 1 (Cazalet 2008), addition of wind, creates more variability in the generation mix.



**Figure 1: Variability of wind resource in Tehachapi**

*Source: (Cazalet 2008)*

## 2.2 Wind

Winds are generated due to uneven heating of the earth's surface and atmosphere. Wind turbines capture wind's kinetic energy and convert it into electricity. The amount of energy produced is directly proportional to the cube of the wind speed. Wind turbines do not operate at very high or low speeds. Wind speed variations that cause uncertainty in wind power generation at different time scales lead to challenges in integrating wind power on to the grid as can be foreseen and will be discussed in chapter 4.

For the last few years, wind energy has been the fastest growing energy resource in terms of new installations in the U.S. In 2009 alone, (the financial crisis notwithstanding) the U.S. wind industry installed over 10 GW of new wind power making 2009 the best year ever for wind (American Wind Energy Association 2010). Wind installations contributed to 63.3% of all the new capacity additions in 2009 (U.S. Energy Information Administration 2010). These rising installations are all the more compelling because wind turbine costs and installed costs of wind power projects have been increasing for the last decade (U.S. Department of Energy 2010).

### **2.3 Solar**

Sun's energy can be converted into electricity using photovoltaic (PV) cells and concentrating solar power (CSP) plants. PV cells convert sunlight into electricity through photovoltaic effect. PV cells are pooled into panels and further into arrays of panels. Concentrating solar power systems focus sunlight and use the reflected sunlight to heat thermal fluids, which are used to generate electricity. As with wind, sunlight has temporal and spatial variations, which make solar energy an intermittent form of energy.

Like wind, solar installations have been increasing in the U.S., albeit did not have the same kind of initial base as wind. Solar electric capacity including PV and CSP crossed the 2 GW mark in 2009, compared to a modest 494 MW in 2000 (Solar Energy Industries Association 2010) with 481 MW new installations in 2009 alone. This phenomenal growth has been encouraged by sharp reduction in solar module and overall installation prices. Solar module prices have seen sustained drop with 36% lower prices in 2010 from 2001 (Solarbuzz 2011).

## 2.4 Renewable Energy Goals

Despite the recent ‘global recession,’ renewable energy technologies have seen significant interest in the past few years primarily due to climate change, energy security and economic development issues. Going forward, there are indications that renewable energy resources will continue to flourish. Although the U.S. does not have a federal renewable energy goal, the U.S. House of Representatives passed the American Clean Energy and Security Act of 2009 (Pew Center on Global Climate Change 2010) in June 2009 that aims to reduce GHG emissions by 17% below 2005 levels by 2020, 42% by 2030 and 83% by 2050 presumably with clean energy technologies and energy efficiency measures. The Senate Energy and Natural Resources Committee passed the American Clean Energy Leadership Act of 2009, which would have set national renewable energy standard goals. However, lacking bipartisan support, this bill or any other exhaustive climate legislation was brought to the Senate floor.

Many states, cities and towns have established renewable energy standards and policies. As of December 2010, twenty-nine states and the District of Columbia have progressive renewable energy portfolio standards (figure 2). California for example has a very ambitious 33% renewables by 2020 target. Wind and Solar are expected to effectively contribute 19 GW out of the total 71 GW generation capacity in order to meet the 33% goal by 2020 in the state of California (Hawkins 2008). As a result of individual state renewable portfolio standard (RPS) policies, renewables should continue to see significant growth rates.

According to the latest Annual Energy Outlook published by the U.S. Energy Information Administration ( The U.S. Energy Information Administration (EIA) 2010), solar and wind

capacity will grow from 540 MW and 25 GW in 2008 to 12.6 GW and 58 GW in 2035 respectively (figure 3).

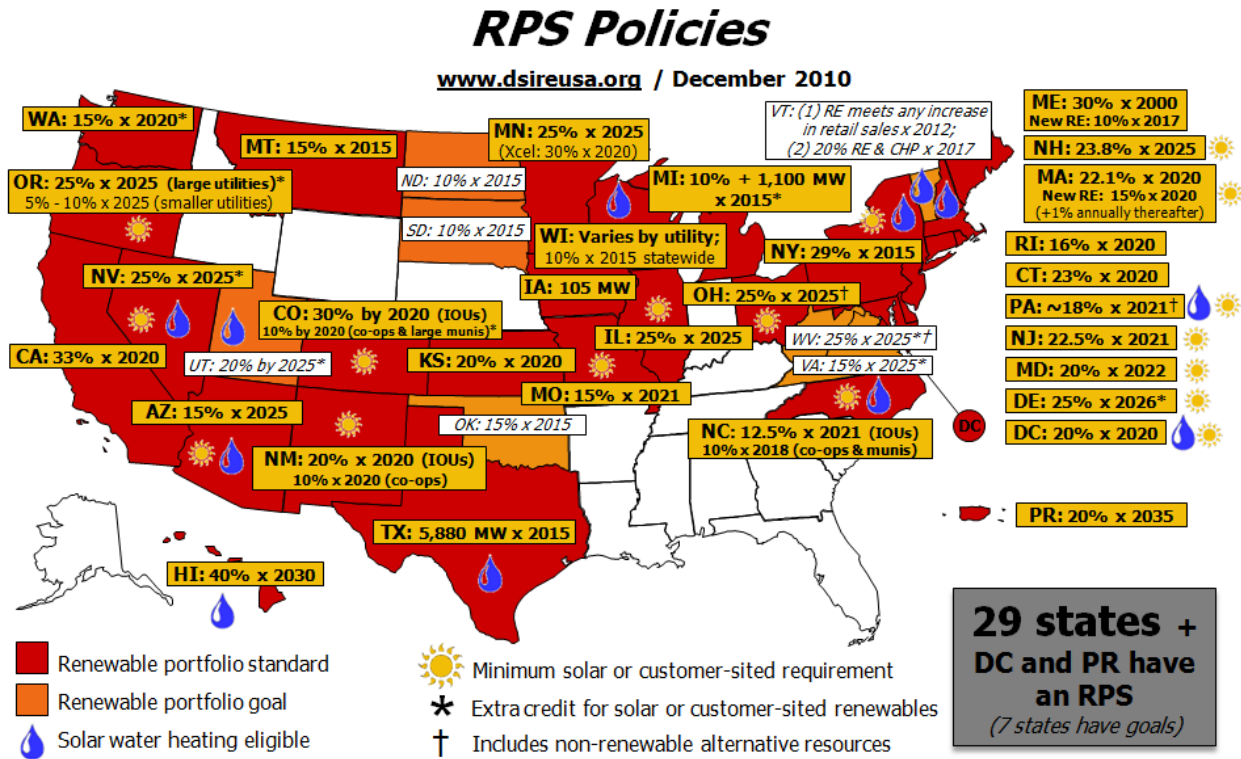
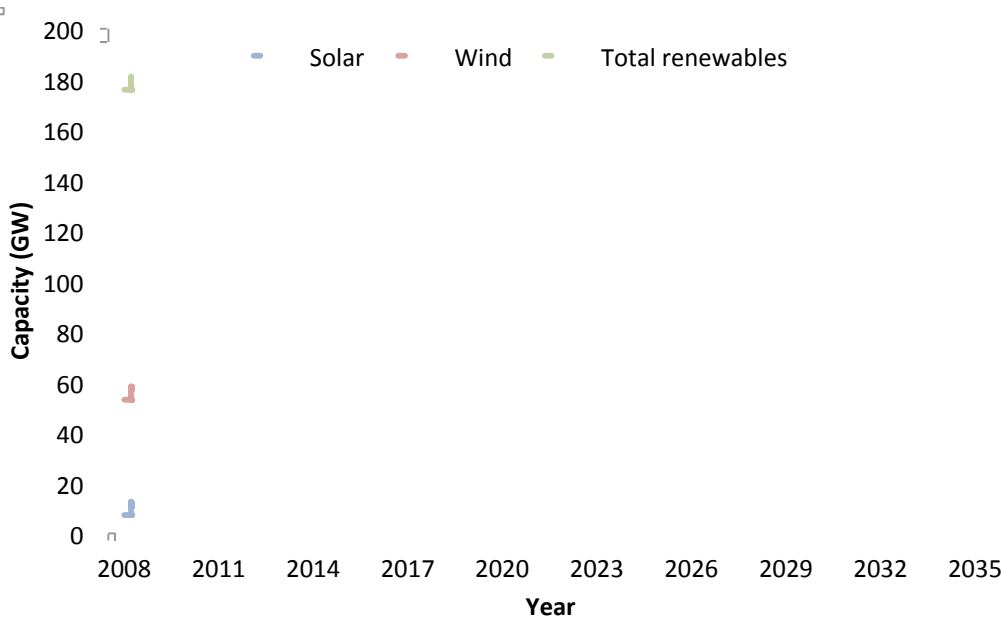


Figure 2: Individual State Renewable Portfolio Standards

Source: (DSIRE 2010)



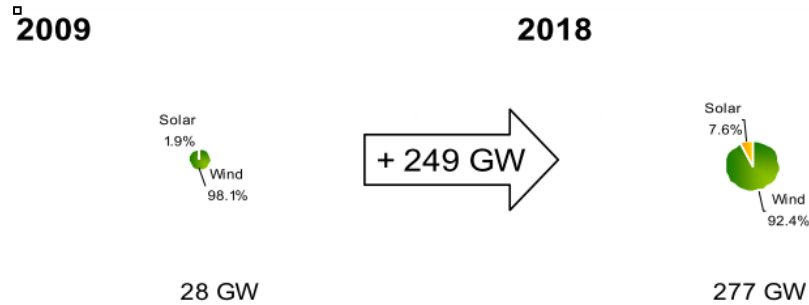
**Figure 3: Wind and Solar growth from EIA’s base case (2008-2035)**

*Source:* ( The U.S. Energy Information Administration (EIA) 2010)

The accelerated growth in wind till 2012 followed by a slower (yet steady) projection can be attributed to the scheduled expiration of production tax credits (PTC) federal subsidies at the end of 2012.

Other agencies such as the National Renewable Energy Laboratory (NREL) and the North American Electric Reliability Corporation (NERC) are more optimistic about wind and solar growth. NREL projects that all the RPS policies, even in absence of a federal policy, will result in 60 GW of wind by 2025 (compared to EIA’s estimate of 56 GW for 2025). While, NERC estimates 256 GW of wind installations and 21 GW of solar installations by 2018 (North American Electric Reliability Corporation 2009) (compared to EIA’s estimates of 53.5 GW and 10.5 GW respectively). NERC includes existing, planned and conceptual projects in their projections, though it is highly possible that not all planned or conceptual projects will go

offline. Hence, these projections ought to be considered upper bounds for wind and solar installations.



**Figure 4: Variable Generation Capacity Projections by NERC**

*Source:* (North American Electric Reliability Corporation 2009)

Renewable resources provide cleaner electricity without carbon emissions, stable electricity price and reduce U.S.'s reliance on foreign fuel sources. However, with more of these variable resources on a 'not-so' smart grid has its own set of challenges. The U.S. grid needs to undergo modifications in order to incorporate more renewables.

## Chapter 3: U.S. ELECTRICITY GRID AND RELATED MARKETS

### 3.1 The Big Picture

The United States (U.S.) electricity grid has grown in size over the decades into a complex network of power plants, and transmission and distribution lines that generate and carry over 10 billion kilowatt hours of electricity every day to over 140 million residential, commercial and industrial customers.

The electricity sector in the U.S. consists of three main operations: generation, transmission and distribution.

#### 3.1.1 Generation

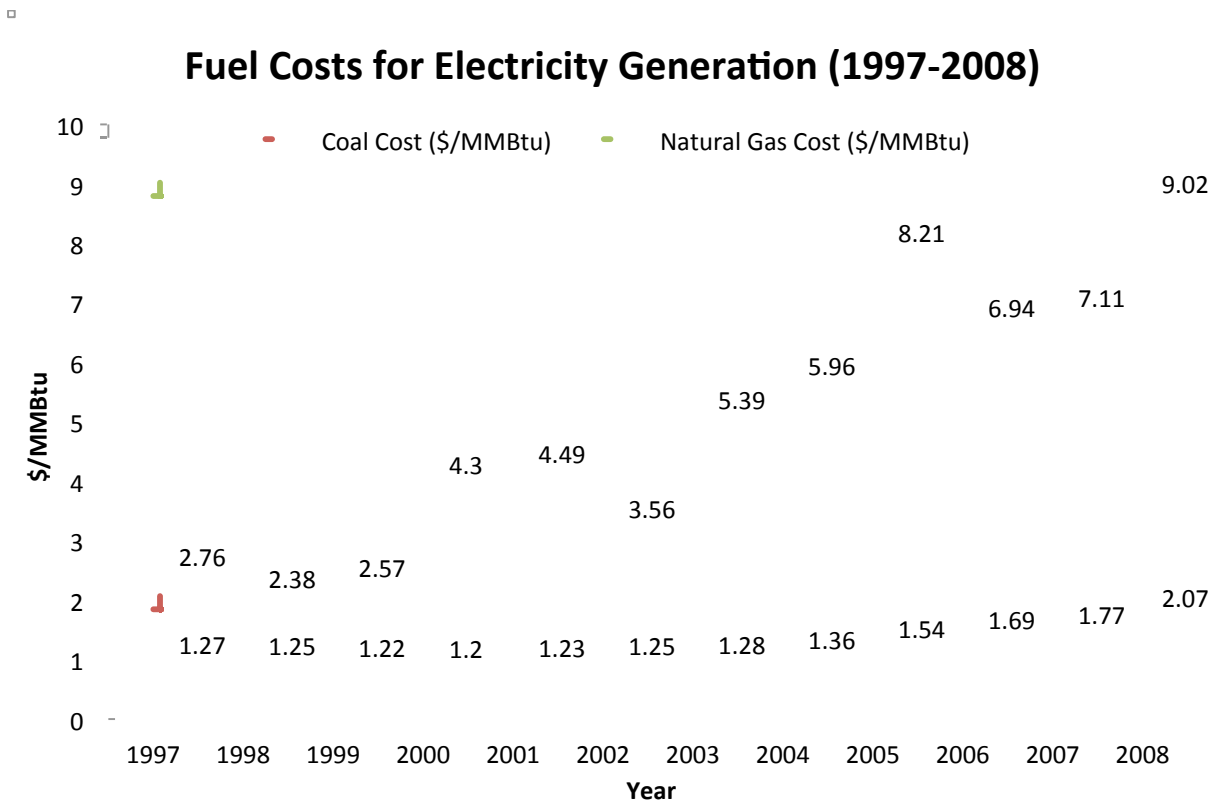
The total mix of generators is shown below in table 1.

Energy Source	Number of Generators	Generator Nameplate Capacity (MW)	Percentage
Coal	1,445	337,300	30.5%
Petroleum	3,768	63,655	5.8%
Natural Gas	5,467	454,611	41.2%
Other Gases	102	2,262	0.2%
Nuclear	104	106,147	9.6%
Hydroelectric Conventional	3,996	77,731	7.0%
Wind	494	24,980	2.3%
Solar Thermal and Photovoltaic	89	539	0.0%
Wood and Wood Derived Fuels	353	7,730	0.7%
Geothermal	228	3,281	0.3%
Other Biomass	1,412	4,854	0.4%
Pumped Storage	151	20,355	1.8%
Other	49	1,042	0.1%
<b>Total</b>	<b>17,658</b>	<b>1,104,486</b>	<b>100.0%</b>

**Table 1: Existing Capacity by Energy Source, 2008**

*Source:* (U.S. Energy Information Administration 2010)

Natural gas fired power plants lead with highest installed generation capacity with 5,467 generators and total nameplate capacity of 454,611 MW out of the total 1.1 TW installed capacity as of 2008 (U.S. Energy Information Administration 2010). Low natural gas prices and high electricity prices during 1999-2001 resulted in rise of natural gas-fired generation. Natural gas-fired combined-cycle plants produce electricity more efficiently than older coal and other fossil-fuel powered plants. However, due to lower coal-powered generation costs and price volatility compared to natural gas-powered generation, coal continues to be the fuel of choice for baseload electricity generation (figure 5). And even though the natural gas prices have dropped since 2008 resulting in fuel costs for generation to drop from \$9.02/MMBtu in 2008 to \$6.05/MMBtu in February 2010, coal still offers the lowest fuel cost among fossil fuels (EIA Monthly).



## Figure 5: Fuel Costs for Electricity Generation

Source: (U.S. Energy Information Administration 2010)

### 3.1.2 Transmission

A non-trivial reality about electricity, which makes the industry quite unique, is that for most part electricity cannot be stored, and has to be produced and consumed in real time. As a result, the supply and demand need to be monitored and balanced every second for reliable electricity supply.

The U.S. transmission system historically consisted of small local power plants supplying power to local customers on low-voltage power lines. Small interconnections existed between neighboring utilities primarily to increase reliability and sell excess electricity. This was the structure of the transmission system for most of last 100 years. Today, the electricity generated by 18,000 some generators is transmitted by a network of nearly 160,000 miles of high-voltage (>230kV) transmission lines. This change has taken place in the last few decades through consolidation of various utilities, construction and operation of larger power plants and increase in flow of electricity over larger distances.

The U.S. transmission system is made of three major interconnected systems:

- The Eastern Interconnected System
- The Western Interconnected System
- The Texas Interconnected System

These interconnected systems allow maintaining reliable supply across regions through coordination, planning and trading such that the overall production costs are kept low. The

overall responsibility of ensuring reliability of the interconnected transmission systems rests with the North American Electric Reliability Corporation (NERC).

The generation and transmission components are collectively called the bulk power system.

### **3.1.3 Distribution**

Local distribution systems carry electricity from substations and step-down transformers to consumers via low-voltage distribution lines and transformers. Distribution entities consist of investor-owned utilities, state and local government operated distribution utilities and rural cooperative utilities. In deregulated electric markets, distribution system support retail electricity markets (more about deregulation in section 3.2).

## **3.2 Deregulation**

For most part of the 20<sup>th</sup> century, the U.S. electricity sector consisted primarily of tightly regulated vertically integrated utilities providing generation, transmission and distribution in well-defined service territories. Until mid-1990s, utilities were the only users (through transmission and distribution) and state governments regulated these utilities primarily by setting retail prices that covered their capital and operating costs. The cost-based regulation provided no incentives for the utilities to promote operational efficiencies (Lien 2008).

In mid-1990s, there were a series of federal and state initiatives that aimed at restructuring the electricity market, which separated generation from transmission and distribution. In 1996, the Federal Electric Regulatory Commission (FERC) issued Orders 888 and 889 that allowed non-utilities to access and use transmission systems (Abraham 2002). This resulted in greater competition between generators and formation of wholesale electricity markets.



Source: (Energy Information Administration 2010)

Though the extent and rules of restructuring in each state vary, some of the primary elements of restructuring are unbundling of generation function from transmission and distribution entities, creation of Independent System Operators (ISOs) and wholesale markets and opportunity for retail competition all without completely losing oversight and control (Hogan 1998). As a result of restructuring, the competitive wholesale electric market structure can be described as consisting of generation companies, regulated transmission companies connected by interconnections and regulated distribution companies providing retail electricity to end-consumers (figure 7).

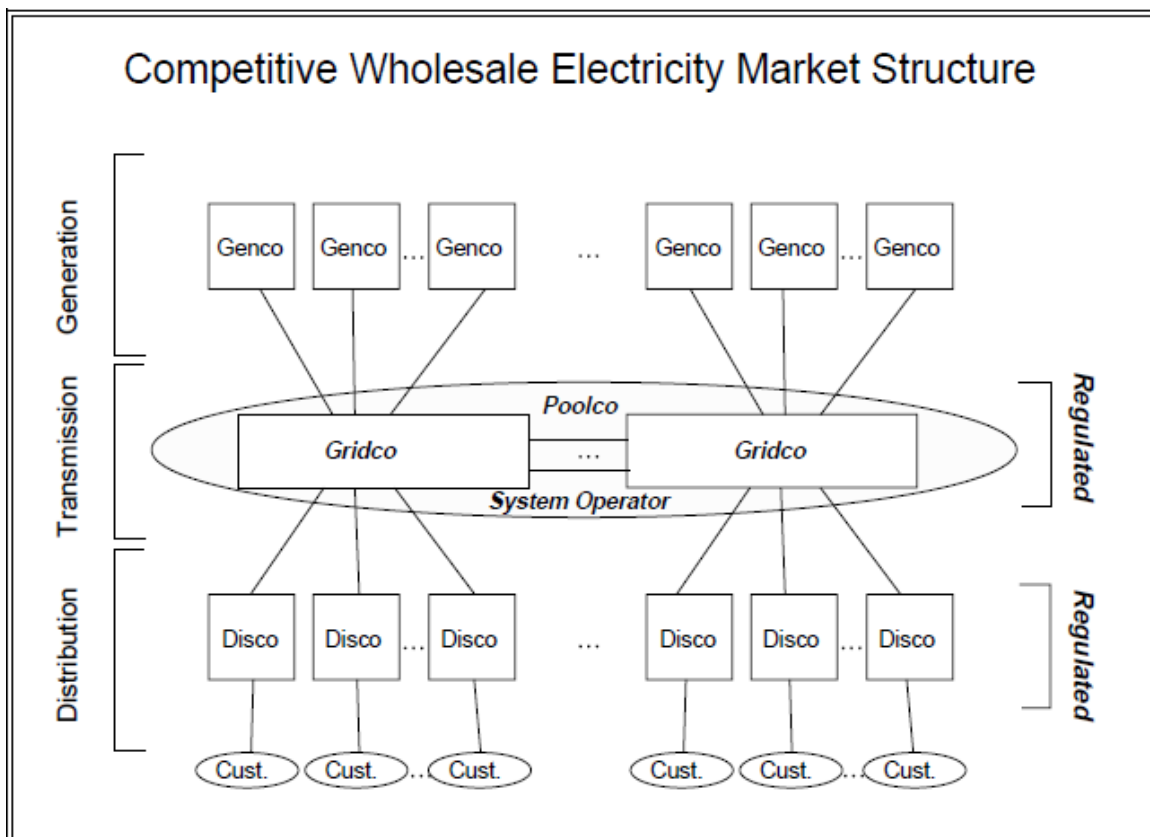


Figure 7: Competitive Wholesale Electricity Market Structure

Source: (Hogan 1998)

The presence of wholesale electricity markets in some states has significantly contributed to the growth of energy storage applications as we will see in chapter 5.

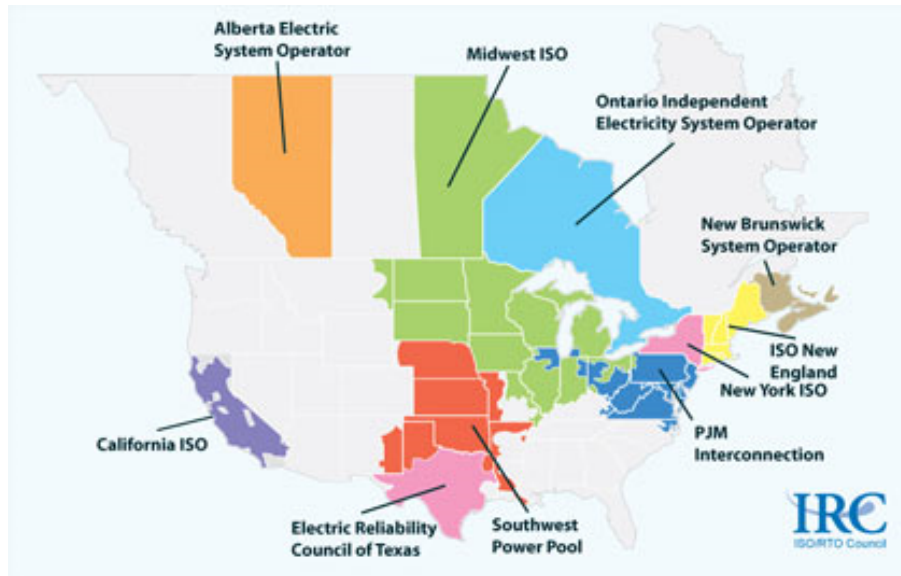
### 3.3 Services/Markets

Prior to the restructuring of the electricity sector, the industry was vertically integrated and utilities provided generation, transmission and distribution services to customers at closely regulated pricing based on cost of service. Restructuring established new wholesale spot energy markets, and to control and manage these markets non-profit Independent System Operators (ISOs) were created. The FERC Orders 888 and 889 resulted in formation of these ISOs,<sup>3</sup> as shown in figure 3. So far, the Northeast (NY-ISO and ISO-NE), Mid-Atlantic (PJM), most of Midwest (MISO), part of Southwest (SPP), Texas (ERCOT) and California (CAISO) have organized their markets to allow wholesale trading.<sup>4</sup> Currently, 10 ISOs/RTOs operate in North America (seven in the U.S. and three in Canada) covering about two-thirds of the U.S. population and over half of the Canadian population.

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<sup>3</sup> FERC also tends to call these as Regional Transmission Organizations (RTOs)

<sup>4</sup> NY-ISO – New York ISO; ISO-NE – ISO New England; PJM – Pennsylvania New Jersey and Maryland; MISO – Midwest ISO; SPP – Southwest Power Pool; ERCOT – Electric Reliability Council of Texas; CAISO – California ISO



**Figure 8: Map of North American Independent System Operators**

*Source:* (ISO/RTO Council 2010)

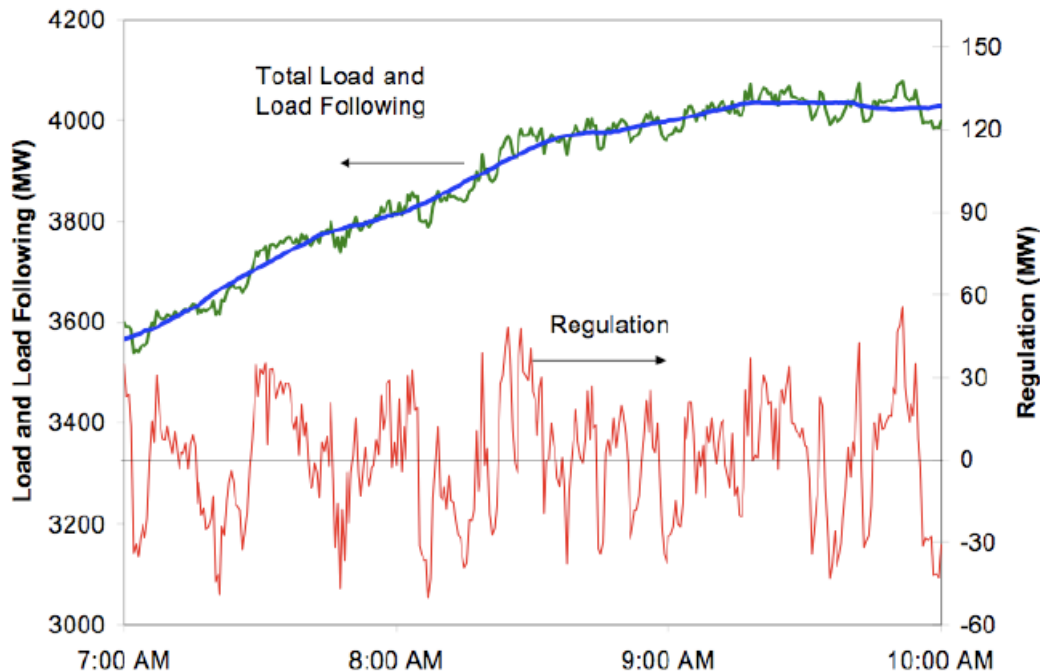
The ISOs are responsible for conducting market auctions and thereby manage the scheduling and dispatch of generation facilities and maintain reliable power supply. These auctions provide non-discriminatory access to transmission and operate the grid in an economically cost effective manner (Lien 2008). Since trades in these markets occur across states (at least for the Western and Eastern interconnections), the FERC oversees these markets (the ERCOT interconnection covers only the state of Texas and is not under FERC jurisdiction). In words of the ISO/RTO Council (an industry organization consisting of representatives of all North American ISOs/RTOs) in its 2009 State of Markets Report (ISO/RTO Council 2009):

*“Over the last decade, ISOs/RTOs have established real-time dispatch to meet regional electric demand (or, in some cases, have expanded existing real-time dispatch processes), established competitive wholesale electricity markets supported by this real-time dispatch, and developed effective regional transmission planning processes to support the reliable operation of the bulk power grid, all carried out on a non-discriminatory basis and in a cost-effective manner.”*

The wholesale electricity markets are further divided based on the type of service primarily into short-run and long-run markets. It is important to note that each ISO/RTO functions differently in terms of nature of these markets on the time scale, size as well as the rules to participate in these markets.

On the short-term dispatch scale, markets typically operate as Day Ahead Market (DAM) and Real Time Market (RTM). Through these markets, the ISOs provide reliable power supply to the users through careful and continuous balancing of supply and demand. In order to balance the supply with the load and maintain grid reliability at every instant, various electricity services are traded in these wholesale Day Ahead and Real Time markets. The reliability services provided in real-time by ISOs/RTOs include – outage coordination, generation scheduling, voltage management, ancillary services provision, and load forecasting.

Ancillary services are defined by Federal Electric Regulatory Commission (FERC) as those services necessary to support the delivery of electricity from seller to purchase while maintaining the integrity and reliability of the interconnected transmission system (Kirby 2004). The two most popular components (figure 9) are: frequency regulation and reserves. Frequency regulation is the ability to maintain frequency of the grid at constant value (60 Hz in the United States) as the supply and load fluctuate. Regulation is provided by generation sources that are on the grid and can increase (up regulation) or decrease (down regulation) power as needed. Storage is naturally suited for this application, as they provide better efficiency and rapid response compared to thermal generation.



**Figure 9: Regulation and Load following**

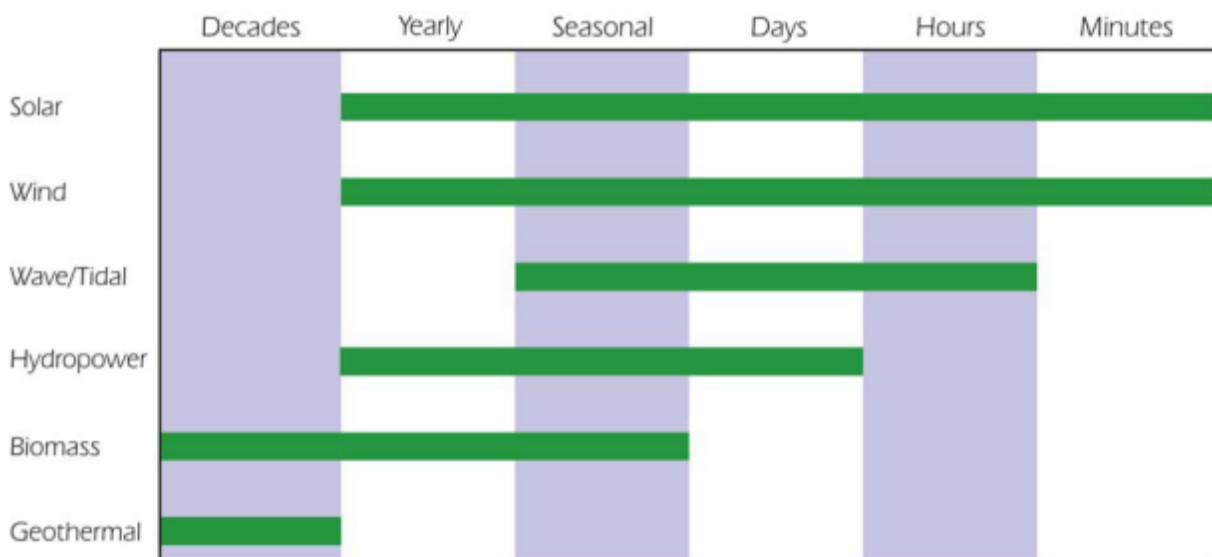
*Source: (Kirby 2004)*

Contingency reserves are the other category of energy services that can be traded in the open ancillary services markets. These reserves can be called upon when normal resources become unavailable (due to unscheduled outages, etc.). These reserves are further divided into three categories: spinning reserves, supplemental reserves and backup power. Spinning reserves are the first reserves to be used in case of shortfall. These reserves are online and usually operating below full output. Supplemental reserves consist of capacity that may not be online and are used once all spinning reserves are utilized. Conventional generators have to be online and operating at part-load to be used as reserve capacity. This results in uneconomic dispatch for these thermal reserves and also reduces the efficiency of these thermal plants (due to extra capital and O&M costs) (Denholm 2010).

So far I have painted a macro picture of the U.S. grid, without specifically addressing issues arising due to higher penetration of renewables. It should not be difficult to appreciate that growing renewables (with their distinctive characteristics) will raise challenges in managing such a complex power system (the grid) and will require not only innovations on the technology side but also further evolution of power markets and a fresh look at all four elements of the power sector – generation, transmission, distribution and consumption.

## Chapter 4: CHALLENGES WITH RENEWABLES

The challenges to renewable energy resources can be summed up in one word – “intermittent,” or perhaps two words “variable” and “uncertain.”<sup>5</sup> Both wind and solar are energy resources compared to other traditional resources that are capacity resources. Capacity resources can make themselves available when there is demand, whereas, wind and solar have their own ‘natural cycles (International Energy Agency 2005).’ As can be seen from figure 10, wind and solar require special attention compared to other renewable resources because the natural cycles span across different time spans, most importantly on minute scales.



**Figure 10: Natural Cycles of renewable resources**

*Source:* (International Energy Agency 2005)

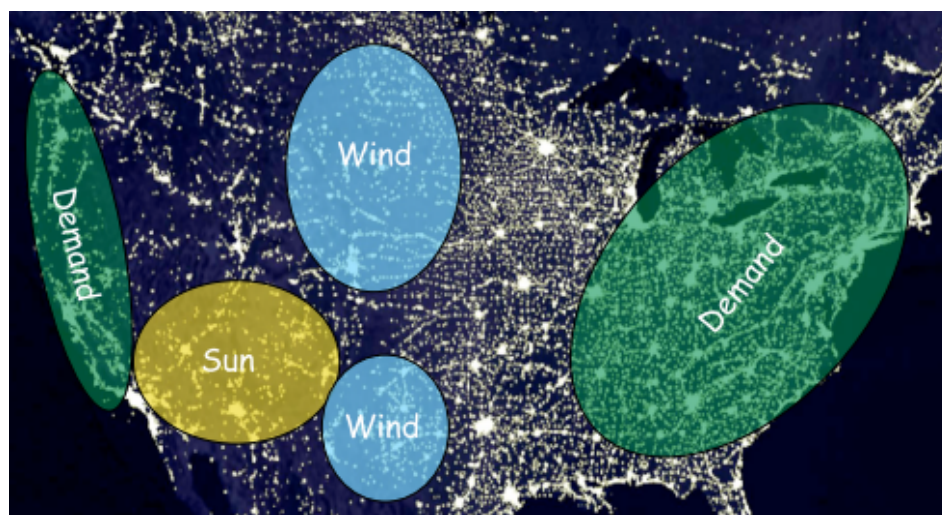
As more wind and solar penetrate into the U.S. grid, two major challenges arise, one due to location dependence and other because of the variable nature of these sources. The first challenge will require expansion of transmission lines from remote wind or solar resources to the

<sup>5</sup> Intermittent implies a typical “on-off” operation, however, wind and solar resources exhibit variability, and hence “variable” or perhaps “variable and uncertain” would be a correct description (Denholm 2010)

load centers. The second problem (and the focus of this paper) is integrating wind and solar resources that are inherently intermittent in nature onto the grid while maintaining its reliability. Wind and solar are what are known as “non-dispatchable” sources (U.S. Department of Energy 2008). Other conventional generators can be dispatched to meet demand responding to operators dispatch commands, while solar and wind resources provide power based on availability of sunlight and wind.

#### 4.1 Transmission Upgrade

In the U.S., wind and solar resources are abundant in regions that are remote from heavy load centers and also from existing transmission networks (figure 11). Most urban demand centers today receive their electricity from fossil-fuel powered plants using transmission lines through shorter distances. This poses important operational challenge of linking remote wind and solar resources with major load centers using a “locally-designed, built and maintained” grid ( APS Panel on Public Affairs 2010).



**Figure 11: Renewable resource regions and load centers**

*Source:* ( APS Panel on Public Affairs 2010)

Fully functional and robust transmission infrastructure is needed to link electricity generated by wind and solar resources to load centers and also smooth out variable generation. Further, transmission expansion is necessary to take advantage of geographic dispersion of renewable resources. The transmission lines will need to have adequate capacity to carry high amounts of renewable generated power along with baseload power generated from conventional generators and deal with congestion issues. For the grid to be truly robust the transmission system will need access to reserves to maintain power quality and reliability with variable generation such as solar and wind; more broadly speaking maintain the supply and demand balance. The time scales and magnitude of investments required to plan, site, commission and build new transmission infrastructure are usually much bigger than investment cycles for installation and operation of variable generation.

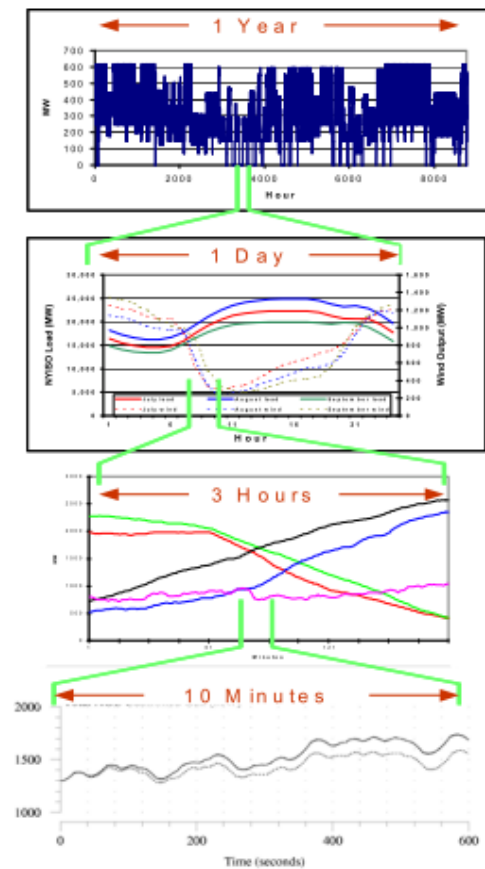
A whole different type of transmission upgrade will require greater level of coordination and communication with renewable generation resources for reliability, which include better interconnection standards.

The U.S. Department of Energy (DOE) recently conducted a study to examine costs, challenges and impacts of 20% wind generation in 2030 (U.S. Department of Energy 2008). As per the report:

*“If the considerable wind resources of the United States are to be utilized, a significant amount of new transmission will be required. Transmission must be recognized as a critical infrastructure element needed to enable regional delivery and trade of energy resources, much like the interstate highway system supports the nation’s transportation needs.”*

## 4.2 Intermittency/Variability

While the power system is capable of handling variability and uncertainty in load, higher penetration of renewables poses greater variability and uncertainty on different time scales. These time scales can be expressed in terms that correspond to grid operations: *Regulation* – second to minute scale, *Load-following* – minutes to hours, *Day-ahead Scheduling and Unit Commitment* – day scale and *Resource and Capacity Planning* – years (North American Electric Reliability Corporation 2009). Frequency Regulation and voltage stability become critical for short-term reliability, whereas load shifting is required to meet the ramping needs during shoulder hours (between peak and off-peak hours).

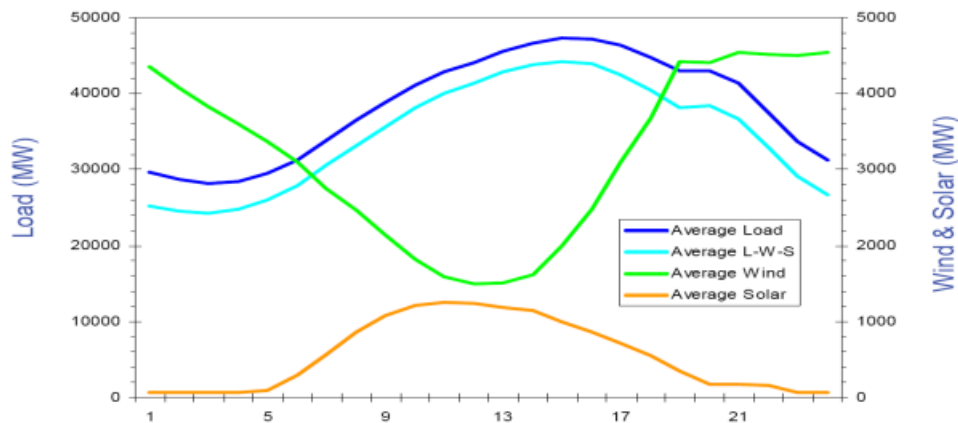


**Figure 12: Time Scales of Variability**

*Source:* (North American Electric Reliability Corporation 2009)

There are two aspects to the variable nature of renewable resources: ‘variability’ and ‘uncertainty.’ Variability is due to changes in the availability of the renewable fuel (such as diurnal and seasonal variability). Uncertainty stems from lack of predictability in knowing and/or accurately forecasting the timing and magnitude of this variability.

Average wind and solar profiles have characteristic diurnal patterns, with wind peaking late nights and early mornings; whereas solar power as expected peaks mid-day (figure 13). Wind peaks are out of phase with load, which adds to the challenge of balancing supply with demand.



**Figure 13: Daily Average for Wind and Solar Output**

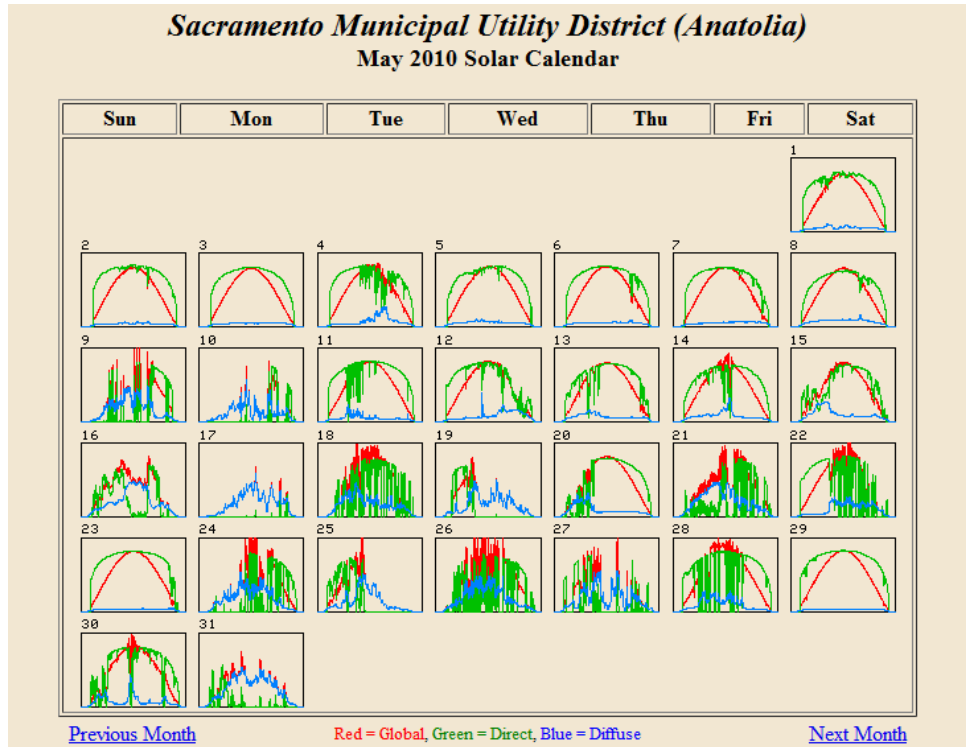
*Source:* (North American Electric Reliability Corporation 2009)

Figure 13 displays the annual average wind and solar power output in the state of California.

Then there is the issue of unpredictability in output on temporal (minute, hourly, daily and seasonal) and spatial scales.

Variability becomes evident when we look at solar irradiance data for Sacramento for the month of May (figure 14), where no two days were alike and had 22 partly or completely cloudy days in

the month (National Renewable Energy Laboratory 2010). Variability at multiple time scales coupled with unpredictability, makes forecasting a difficult task.



**Figure 14: Solar Irradiance Plot for Sacramento**

Source: (National Renewable Energy Laboratory 2010)

As mentioned, the different time scales (minutes, hours, daily and seasonal) require matching supply with demand to ascertain reliability of the grid. Demand is inherently variable as well; the difference between demand and renewable generation is predictability.

*“Demand can be anticipated to within a few percent based primarily on weather forecasts of temperature, humidity and precipitation, on demand history, and on anticipating major energy events such as the broadcast of television programs which a large expected viewing audience. Renewable generation depends primarily on specific weather characteristics such as wind for*

*wind generation and sunlight exposure for solar generation, which do not occur in regular patterns and are not correlated to diurnal patterns of demand. ( APS Panel on Public Affairs 2010)”*

## Chapter 5: ENERGY STORAGE SOLUTIONS FOR INTEGRATION

### 5.1 Technologies

Various solutions exist and continue to evolve to deal with current and forecasted levels of unpredictability in energy supply from renewables, including sophisticated forecasting, demand management, flexible energy markets, transmission interconnections, nodal transmission network, larger balancing areas and lastly energy storage. Energy storage industry has seen resurgence in recent years, being seen as a promising solution to the renewable energy integration problem. Energy storage opens up various benefits based on its location and characteristics. A range of possible applications are possible from 25-100 kW storage installed closer to loads (called Community Energy Storage<sup>6</sup>) to few hundred MW-few GW storage in form of pumped hydro and compressed air storage for bulk energy management. Analysis of various energy storage technologies can be narrowed down to few important parameters: capital cost (per kW and per kWh), storage power capacity, storage or discharge time, round trip efficiency and cycle life. Figure 15 shows applications for energy storage based on the storage time and capacity (Kluza 2009), and figure 16 shows some of the storage technologies based on their characteristics (Electricity Storage Association 2009).

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<sup>6</sup> Community Energy Storage is a small distributed energy storage unit connected to the secondary of transformers serving a few houses or small commercial loads (American Electric Power 2009)

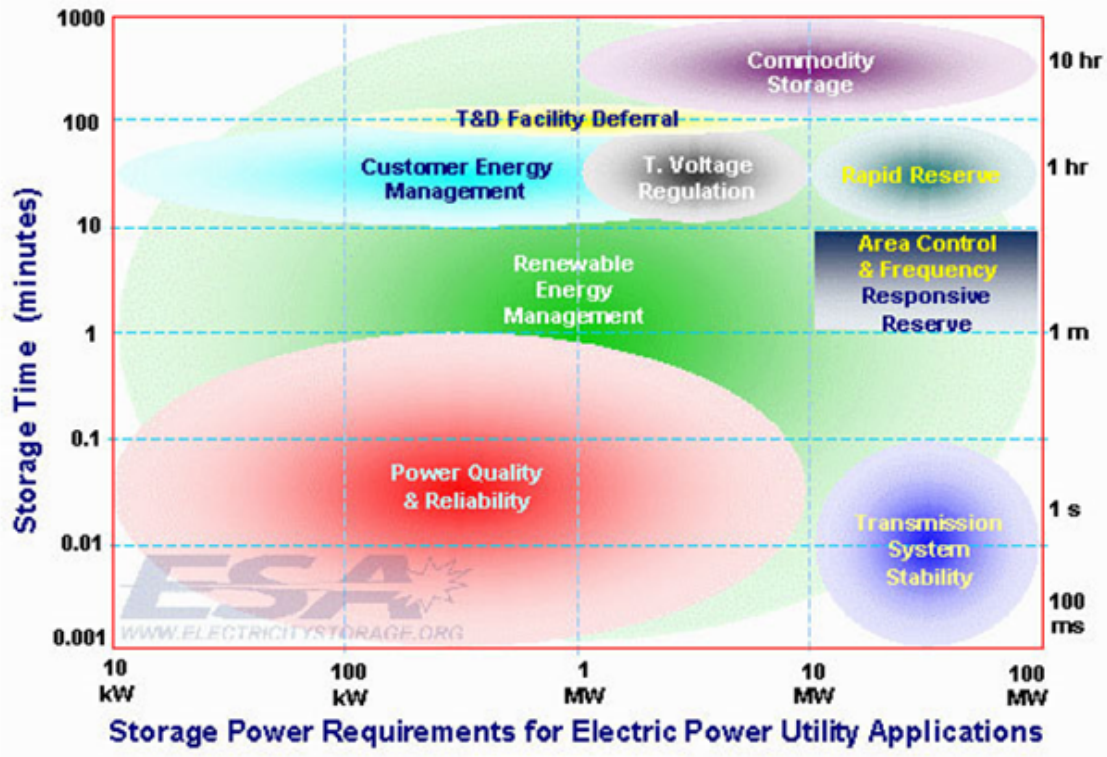


Figure 15: Storage Applications and requirements

Source: (Kluza 2009)

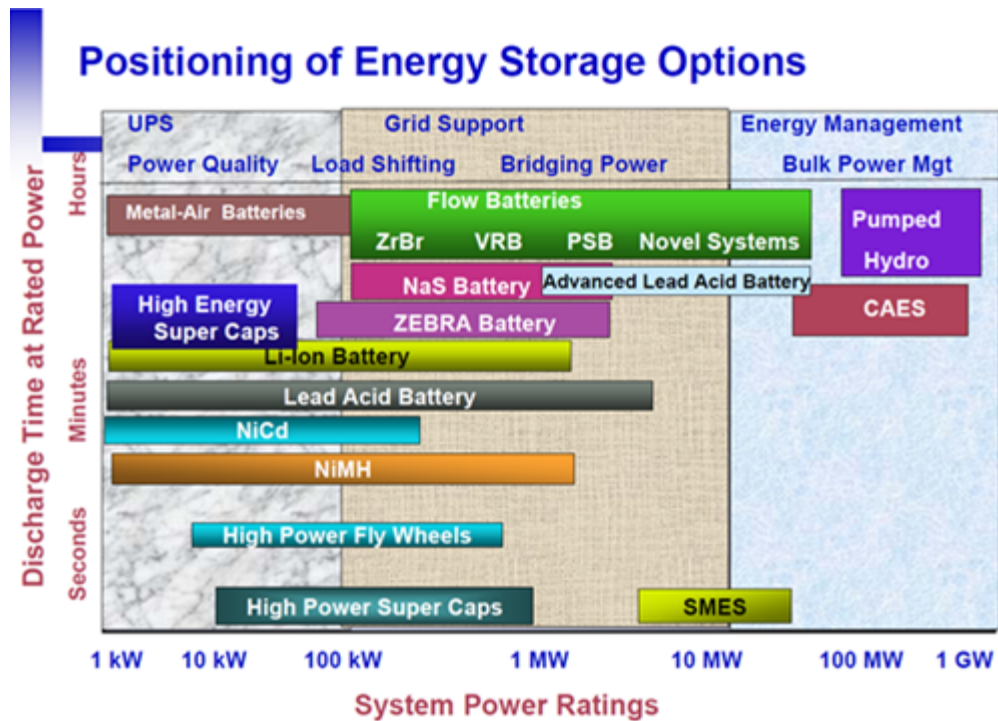


Figure 16: Energy Storage Technologies

Source: (Electricity Storage Association 2009)

There are a range of energy storage technologies that can be broken down primarily into – electrochemical technologies (i.e. batteries) and non-electrochemical technologies. Some of the relevant energy storage technologies are reviewed below. There are DOE sponsored and other studies and reports that provide a more comprehensive overview of all energy storage technologies.

### 5.1.1 Electrochemical Technologies

Electrochemical technologies rely on chemical reactions to release and flow electrons, leading to electric current. Electrochemical batteries consist of two electrodes – cathode and anode, and an electrolyte material. The two electrodes are connected to the electrolyte material that transports the ions between the two electrodes, while the electrons flow through the load. The different electrochemical technologies differ in the chemistry and choice of electrodes and electrolyte materials.

**Flow batteries:** Flow batteries are a class of batteries that are conceptually similar to fuel cells, as they consist of two different electrolytes flowing through each half of the cell separated by semi-permeable membrane (Electricity Storage Association 2009). The most common flow batteries use different redox states of Vanadium (called as Vanadium Redox Batteries) and electrolytes containing zinc and bromide ions (called as Zinc Bromide Batteries). Vanadium Redox was developed in 1980s, while ZnBr in 1970s. The interesting aspect of flow batteries is that their power and energy ratings can be independently controlled by area of the membrane (for power) and size of the electrolyte tank (for energy).

**Lead-acid batteries:** Lead-acid batteries have been around for a long time, especially in automotive and uninterrupted power supply applications. They consist of lead containing

electrodes with sulfuric acid electrolyte (Electricity Storage Association 2009). Recently there have been technological innovations in lead acid batteries that have led to the advent of *advanced* lead acid batteries. Advanced lead acid batteries have improved cycle life; cycle life has been one of the major disadvantages for lead acid batteries.

***Lithium-ion batteries:*** Lithium-ion batteries have cathodes made of lithiated metal oxide and a graphite anode on support structure, while the electrolyte contains dissolved lithium salts (Electricity Storage Association 2009). Li-ion batteries became popular in portable battery market due to their high energy density (both in weight and volume basis), high efficiency and long cycle life. Due to these advantages, Li-ion batteries have also been preferred in plug-in hybrid and electric vehicles. However, their deployment on grid-scale storage has been constrained by their costs. There have been some demonstration projects using grid-scale Li-ion batteries. The AES Corporation after deploying 2 MW battery systems using Li-ion batteries in 2008 for providing ancillary services, installed 12 MW unit in Northern Chile in 2009. The leading grid-scale Li-ion battery manufacturers are A123 Systems, Altair Nanotechnologies and Saft.

***Sodium sulfur batteries:*** Sodium sulfur batteries consist of molten sodium at the positive electrode and molten sulfur at the negative electrode separated by ceramic electrolyte. The battery is maintained at 300 °C to keep sodium in liquid form and allow the reaction. Na-S batteries have been demonstrated at over 190 sites totaling more than 270 MW capacity, with the single largest installation in Northern Japan consisting of a 34 MW, 245 MWh unit for wind stabilization (Electricity Storage Association 2009). NGK Insulators, a publicly traded company in Japan is the only manufacturer of Na-S batteries in the world.

### 5.1.2 Non-electrochemical Technologies

**Compressed Air Energy Storage:** Compressed Air Energy Storage (CAES) compresses air using off-peak electricity and stores it into an underground cavity, typically mines or caverns formed in salt rocks (Electricity Storage Association 2009). At the time of generation, the pre-compressed air is used to run a gas turbine generator, consuming less than 40% of fuel compared to conventional gas turbines. There are two commercially operating CAES systems – Huntorf, Germany (290 MW, built in 1978) and McIntosh, Alabama (110 MW, built in 1991). *Adiabatic* CAES do not use fuel; instead store heat of compression in thermal oil, which is later used to heat air to expansion turbines (Intelligent Utility 2010).

**Flywheels:** Flywheels are mechanical devices that have a rotating cylindrical assembly (rotor) (Electricity Storage Association 2009). The rotor is accelerated to store energy in form of rotational energy and provides electricity when slowed down. To reduce drag/friction losses, rotors are encased on magnetically levitating bearings in vacuum. Flywheels are characterized by long operating life, little maintenance and high power density. Beacon Power has demonstration/pilot projects in CAISO (100 kW), NYISO (100 kW) and ISO-NE (3 MW) and is planning three 20 MW plants in PJM and NYISO (Beacon Power Corp 2010).

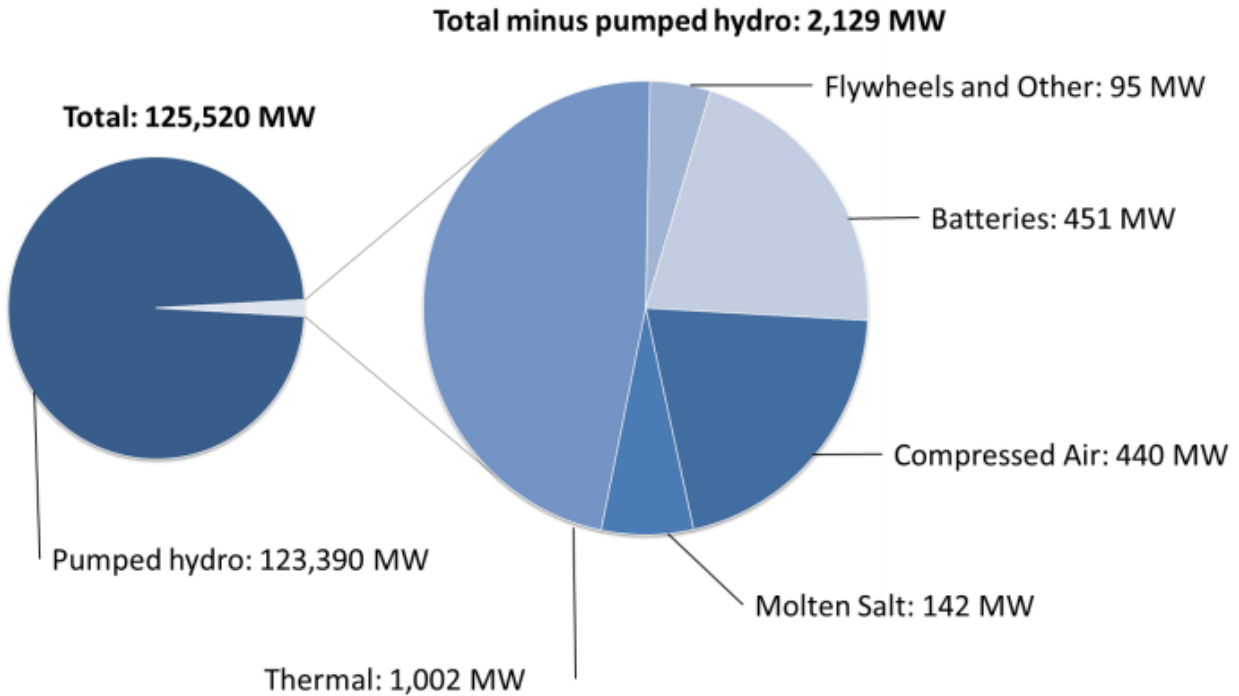
**Pumped Hydro:** Pumped hydro stores energy in form of potential energy by pumping water to higher altitude (uphill) when there is excess (or cheaper electricity). The water flow is reversed when electricity is needed. Pumped hydro is the most commonly used storage form with over 120 GW capacity worldwide (Lin 2010).

**Super-capacitors:** Capacitors store energy in electric field between electrodes and electrolyte. Super or ultra capacitors differ from ordinary capacitors in terms of higher energy density and

from batteries in very high cycle life. Super-capacitors are characterized by fast charge and discharge capability.

### 5.1.3 Technology Comparisons

Each storage technology has its own set of advantages and disadvantages, which has the storage industry competing in multiple applications based on favorable characteristics and limitations of these technologies. In terms of installations, pumped hydro has highest level of penetration with 123 GW of 125 GW total installed capacity (figure 17).



**Figure 17: Estimated Global Installed Storage Capacity**

*Source: (Lin 2010)*

Storage Technologies	Main Advantages (relative)	Disadvantages (Relative)	Power Application	Energy Application
Pumped Storage	High Capacity, Low Cost	Special Site Requirement		●
CAES	High Capacity, Low Cost	Special Site Requirement, Need Gas Fuel		●
Flow Batteries: PSB, VRB, ZnBr	High Capacity, Independent Power and Energy Ratings	Low Energy Density	◐	●
Metal-Air	Very High Energy Density	Electric Charging is Difficult		●
NaS	High Power & Energy Densities, High Efficiency	Production Cost, Safety Concerns (addressed in design)	●	●
Li-ion	High Power & Energy Densities, High Efficiency	High Production Cost, Requires Special Charging Circuit	●	○
Ni-Cd	High Power & Energy Densities, Efficiency		●	◐
Other Advanced Batteries	High Power & Energy Densities, High Efficiency	High Production Cost	●	○
Lead-Acid	Low Capital Cost	Limited Cycle Life when Deeply Discharged	●	○
Flywheels	High Power	Low Energy density	●	○
SMES, DSMES	High Power	Low Energy Density, High Production Cost	●	
E.C. Capacitors	Long Cycle Life, High Efficiency	Low Energy Density	●	◐

- Fully capable and reasonable
- ◐ Reasonable for this application
- Feasible but not quite practical or economical
- None Not feasible or economical

**Table 2: Storage Technologies Comparison**

*Source:* (Electricity Storage Association 2009)

As seen in figure 16, storage technologies can be classified based on storage power ratings into three categories: power quality, grid support and bulk energy/power management. Another way of classifying

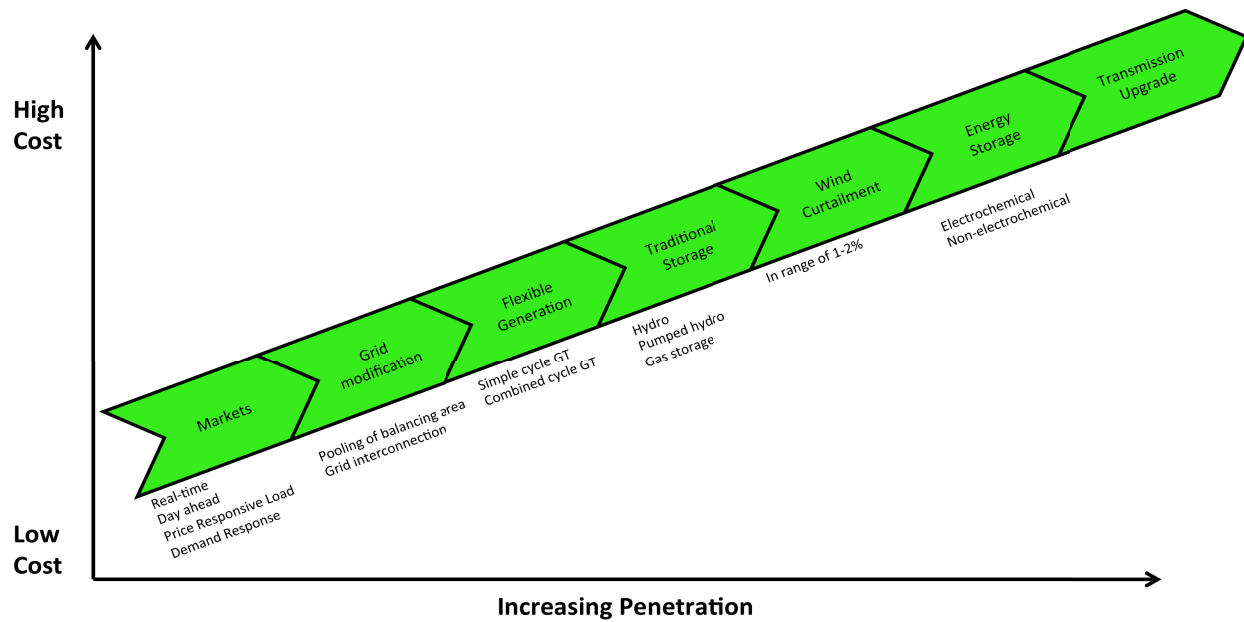
storage technologies is based on discharge duration. Technologies with fast discharge capabilities will fare well in power applications, whereas technologies with longer discharge times are well-suited for energy applications. A detailed comparison of relevant technologies is provided in table 2.

Apart from technological characteristics, storage adoption is greatly governed by market maturity (readiness of available markets). Needless to say, mature technologies have typically enjoyed high market potential; case in point – pumped hydro.

## **5.2 Non-storage solutions**

Energy storage is one of many solutions to accommodate renewable generation on the grid.

There are other supply and demand side technologies/solutions as can be seen in figure 18 (adapted from (Intelligent Utility 2010)). The renewable resource integration supply curve only provides qualitative assessment of the suite of solutions without any attempt to provide cost-benefit analysis of any of the solutions; slope of the curve is for illustrative purpose as well. Each solution has its own strengths but will be useful under limited conditions. As expected the cost of integrating renewables go up with higher penetration of renewables on the grid.



**Figure 18: Renewable Resources Integration Supply Curve**

*Adapted from: (Denholm 2010)*

Many of the current markets already have systems in place through their reserve requirements, real-time and day-ahead market rules, time-of-use pricing and other features to deal with limited renewable resources. These market requirements alone will not be sufficient with higher levels of renewables. Forecasting technologies are bound to improve as are the renewable technologies themselves, which will reduce the burden on real-time adjustments.

*“Forecasts must improve to accommodate the two most serious challenges in generation variability: up-ramps at times of low demand and down-ramps at times of high demand. In the former case conventional reserves may already be turned off, so that accommodating the up-ramp may require turning down base-load conventional generation or curtailing renewable generation. Both options are inefficient and expensive and may cause significant reliability issues. In the latter case, most conventional reserves may already be turned on, leaving few*

*options for compensating the power lost in the renewable down-ramp. ( APS Panel on Public Affairs 2010)”*

Apart from advancements in forecasting, demand response (or demand-supply management) and grid modifications (including widening of balancing areas and interconnection) seem to be promising solutions for low-to-moderate penetration.

### **5.2.1 Demand Response**

Demand response (DR), simply put, is curtailing demand during critical events such as peak demand, or market prices. The U.S. Department of Energy (Federal Energy Regulatory Commission 2009) defines DR as:

*“Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.”*

DR offers potential to reduce demand during excess demand or supply shortage, but does not work as effectively when there is excess supply (for example: windy days) or limited demand to begin with. Another drawback of DR is that end-consumers can be incentivized to curtail demand for short intervals, but longer disruption or curtailment of electricity consumption may not be possible (Pieper 2010). Also, with higher renewables, the frequency of DR events is expected to increase. Such frequent disruption of electricity use may not find enough buyers. Widespread DR adoption will require investments in advanced metering infrastructure, standards and communications technology. Some of the leading DR providers are: EnerNOC, Comverge,

OPower and some of the big names in communication and information technology – IBM, SAP, Cisco and Google to name a few.

### 5.2.2 Balancing Areas

The North American Electric Reliability Corporation (NERC) defines Balancing Area as: *“The collection of generation, transmission, and loads within the metered boundaries of the Balancing Authority.<sup>7</sup> The Balancing Authority maintains load-resource balance within this area. (North American Electric Reliability Corporation 2008)”*

Expanding a balancing area (BA) to include more loads and resources provides pooling effect and helps integrate variable renewable generation. Pooling of resources reduces the random variation and provides more reliability and flexibility.

*“Within a balancing area, as the level of variable generation increases, the variability when coupled with extreme events may not be manageable with the existing conventional generation resources within the balancing area alone. ( APS Panel on Public Affairs 2010)”*

Such an expansion of the transmission system can be done in two ways: virtual and physical. Virtual expansion obviously will be cheaper than physically having to expand and interconnect the grid. Plus, expansion of balancing area comes with its own set of challenges: amount of capital investments, political will to build more transmission lines, failure to mitigate certain variations (for instance diurnal variability), and diminishing returns of too large balancing areas.

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<sup>7</sup> Balancing Authority is the responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance, and supports Interconnection frequency in real time. (North American Electric Reliability Corporation 2008)

### 5.3 Storage Benefits

As can be seen from figures 15 and 16, energy storage has potential to provide multiple benefits and can be used for a variety of applications along the grid. At the same time, each storage technology has a range of benefits and applications in which it has competitive advantage over other storage technologies. For instance, Li-ion batteries that discharge in minutes and can store anywhere from few watts to a few megawatts find applications in renewable energy management and power quality/reliability applications. Compressed air storage on the other hand, is appropriate for reserves or commodity storage due to their long discharge times in hours and large capacity.

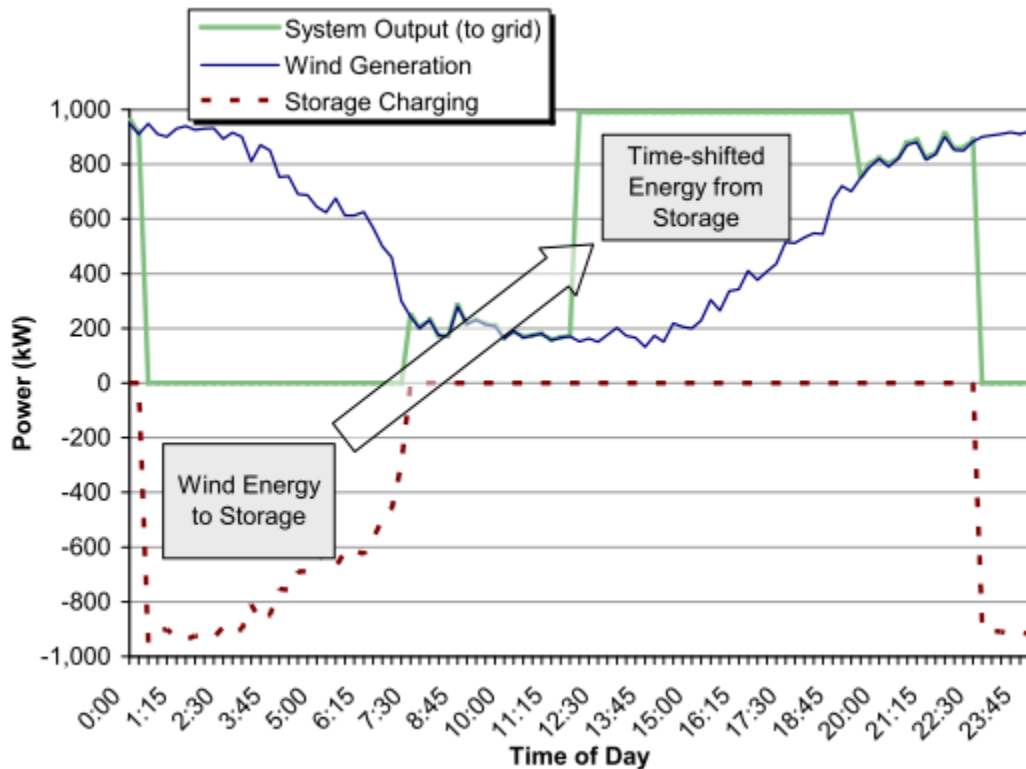
Apart from direct applications for renewables, storage will have a growing role to play in providing ancillary and other open market services with increasing renewable energy on the grid. With growing wind and solar, the overall need for these regulation and reserve services will increase (due to the need to balance more variable generation).

Storage applications that can complement renewable energy integration can be narrowed down to the following (Eyer 2010):

- 1) Renewable energy time-shifting
- 2) Renewables capacity firming
- 3) Grid integration

1) *Renewable energy time-shifting*: Wind tends to produce large amount of electric energy, when the energy has “low financial value,” – i.e. off-peak hours such as nights and weekends. Storage along with these renewable energy technologies can be used to store

energy when it is generated, and later used or sold by the storage discharge when the price is more favorable or demand is higher (figure 19). In case of solar and other renewables such as geothermal, the scope for time-shifting still exists but in a more traditional energy arbitrage sense.



**Figure 19: Wind Generation Time-Shifting**

*Source:* (Eyer 2010)

- 2) *Renewables capacity firming:* Renewables capacity firming in the simplest form is reducing the intermittent nature of the renewables to provide a more “constant” electricity supply. In essence, it is very similar to regulation services described earlier. Capacity firming allows the use of intermittent or variable renewable energy generation as a near constant source. There are some very obvious benefits as a result of near constant supply – use of traditional sources

to provide capacity firming and need for new transmission or distribution equipment are offset. More importantly, most conventional generation sources are not capable of ramping their output rapidly to make the demand see a constant supply. Storage can be used for both short-term variability (such as cloud passing over a region and reducing the output from a solar facility) and diurnal variability (insolation variation early morning and evenings). Firmer renewable capacity can reduce (or even preclude) the requirement for load following and transmission expansion especially during peak demand situations as the load sees ‘somewhat-to-very coincident’ supply (Eyer 2010).

3) *Grid integration*: As wind generation penetration levels increase, there will be growing number of issues for the grid that are unique to wind. Storage can play an important role in smooth integration of wind resources on the grid by providing the following important grid integration applications (Eyer 2010):

- Short-duration – reduce output volatility, improve power quality
- Long-duration – reduce output variability, transmission congestion relief, backup for unexpected wind generation shortfall, reduce minimum load violations.

## 5.4 Storage Economics

For most of the applications mentioned above (and other applications not associated with renewable sources), energy storage benefits are currently not explicitly rewarded. As a result, even though storage can provide these benefits, the industry has been unable to realize the economic potential of storage. Other issue with rightly valuating storage is the fact that storage could be used for multiple applications and in such situations the beneficiaries could be spread across the value chain. Moreover, the amount of benefit among the beneficiaries could vary as

well. Lastly, storage has benefits in form of payments to the owner/operator and also in terms of avoided costs. Again it is not trivial to separate these values and assign the appropriate monetary value to each benefit. Plus, in many applications, the lifetime economic benefits will largely depend on the actual utilization, which could vary depending on its interaction with load, weather, and grid capacity (Pieper 2010).

Storage in many cases would result in lower use of carbon intensive generation sources, or make their utilization more effective. Plus, in deferring transmission and distribution equipment installation/construction, storage can provide environmental benefits. There will be a need to put a price on carbon and environmental benefits offered through deferrals to truly value storage benefits.

In this paper, I take a very narrow approach to estimation of economic value of storage in the three renewable integration applications described in 5.3. However, more realistic and accurate estimates should apply a systems approach and calculate economic potential of storage as it provides multiple benefits along the value chain. For instance, storage used for diurnal time shifting for wind farms (application #1 in section 5.3) will essentially provide energy arbitrage benefits, and in real sense the total economic potential of such a storage system will be the sum of the economic value addition for both the applications. Similarly, storage providing capacity firming on a system-level will have same function as operating reserves and regulation resources.

There is whole another consideration for planned application synergies in order to make storage more economically viable. Storage applications which are compatible for combining benefits from two or more applications are not being considered in this paper, but there are several studies and reports that deal with application synergies. Such synergistic strategies should be

considered integral part of storage dialogue, as they are critical pieces to move the overall economic value proposition from red to black.

*Renewable energy time-shifting:* Simplest case for economic value in time-shifting is the arbitrage opportunity between renewable energy generated during off-peak hours stored and sold during on-peak hours (at on-peak price). Jim Eyer (Eyer 2010) calculates the energy price differential between on- and off-peak hours and multiplies by the amount of wind energy that a storage device could operationally time-shift per kW of wind generation to get the economic potential of time-shifting. The PV estimates over a 10-year period are listed in table 3 below.

*Renewables capacity firming:* Capacity firming as the name suggests is a capacity benefit. Each generator is assigned a capacity credit value based on the proportion of generator's capacity it can contribute when the demand is high. A fully dispatchable source such as a combustion turbine-based generator is allocated a capacity credit of 1, and all other generator resources are benchmarked to capacity credit value between 0 and 1 (Eyer 2010). The cost associated with capacity firming is based on this intrinsic capacity credit value, as additional generation capacity is needed during high demand hours to meet grid's reliability standards. Higher the capacity credit, lower is the firming requirement. Storage technologies can enhance the capacity credit of renewable resources. Storage resources can be charged using low-priced electricity from the grid (during off-peak hours) and discharged keeping the effective renewable source output stable. Thus, storage can find application in both distributed PV and bulk wind capacity firming (values tabulated in table 3).

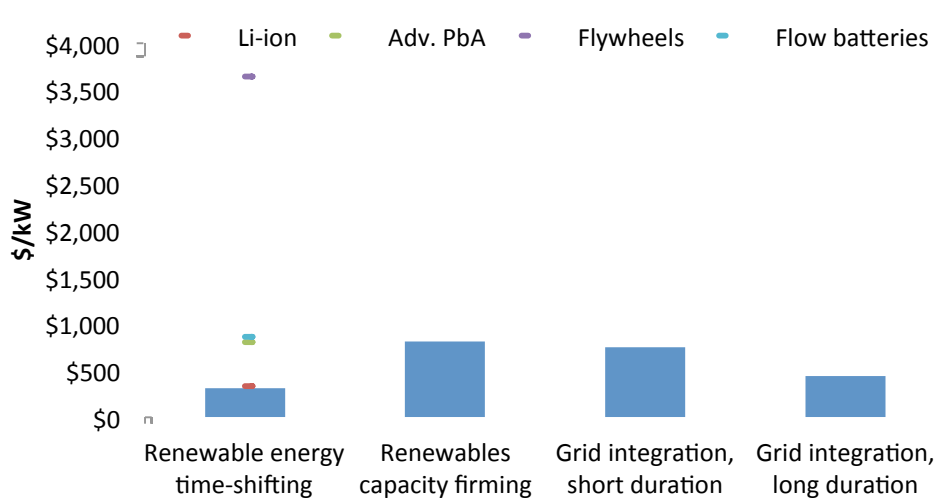
*Grid integration:* Grid integration economic value is the most difficult to compute, as it comprises of various sub-benefits as described in section 5.3. Traditionally, the short-term and

long-term applications spelled out above are served by building additional transmission lines on the grid. So the economic value offered by storage technologies is in the avoided costs of new transmission capacity.

Benefit Type	Benefit PV (\$/kW)	
	Low	High
Renewable energy time-shifting	233	389
Renewables capacity firming	709	915
Grid integration, short duration	500	1,000
Grid integration, long duration	100	782

**Table 3: Present Value Estimates of Storage Benefits**

*Source: (Eyer 2010)*



**Figure 20: Benefit PV and Storage Cost Comparison**

*Source: (Eyer 2010)*

## 5.5 Barriers

Energy storage technologies have seen a renewed interest fueled by four factors (Lin 2010):

Renewable Integration, Peak Load Growth, Transmission Constraints and Smart Grid. As with

any technological innovation, storage faces several barriers that hinder large-scale market

adoption. Whichever way we slice it, the main barriers fall under three main categories: technical, economic and market/regulatory.

### **5.5.1 Technical**

Energy storage technologies have recently received lot of attention and funding both from government (DOE) and private investors. However, most storage technologies are still in early (development) phases and require extended support for research, development and demonstration. In terms of technical maturity, pumped hydro storage has proven capability and seen wide scale adoption worldwide. Some of the newer technologies are yet to see same level of adoption, and not many commercial scale projects.

As part of their \$700 million commitment to storage through the Recovery Act, DOE supported 16 storage demonstration projects totaling \$185 million in 2009 (U.S. Department of Energy 2009). More such efforts will be needed to aid storage technologies overcome the “valleys of death.” Demonstration projects also serve the purpose of matching the right storage solutions with different applications based on their performance characteristics. Similar efforts are required at the other end of spectrum on more basic and applied research (on new materials, higher efficiency, longer cycle-life, etc.) through research institutions such as universities and national laboratories.

Technical challenges extend beyond storage units and include power electronics, interconnections and communication systems, which are integral in governing the success of storage applications.

### 5.5.2 Economic

Electricity is essentially a bulk commodity product. The only difference from traditional commodities is that until now it could not be readily stored and thus had to be consumed as it was generated, adding profound complexity to the supply demand dynamics. With the advent of advanced energy storage technologies, there is immense potential to alter the supply-demand equation. At a very basic level, the economics of storage relies on the electricity price differential.

Figure 20 summarizes the economic barriers facing rampant storage deployments. Many storage technologies have not achieved commercial scale economies and installed costs are still greater than their benefits over decades. It will be however, incorrect to assume that all storage applications in all geographic areas have lower than desired rate of return. Locations with special considerations such as island grids and congestion zones may offer higher economic value than the illustrated value in section 5.4 for some applications. Other aspects including state of deregulation, generation mix, installation siting (closer to load centers or renewable resources) and utility factors can all influence the exact economics. It is not far-fetched to say that even with current levels of storage capital costs there are niche markets where storage offers attractive returns as of today.

The biggest factor that can alter storage economics (apart from lowering installation and operating costs) is the ability to internalize and monetize storage applications which often spread over multiple benefits across multiple stakeholders. Ali Nourai and Chris Schafer (Nourai 2009) from American Electric Power claim that *“If utilities could monetize and add up all the available benefits of energy storage, it would pay for itself, many times over. With the relatively high cost*

*of current electricity storage technologies, the challenge for utilities today is to learn how to realize multiple values in the storage value stream.”*

### **5.5.3 Market/Regulatory**

The emergence of storage technologies has seen a lag when it comes to appropriate regulatory environment (R. V. Fioravanti 2009). Since storage during discharging can provide source of stored electricity, it is difficult to argue against storage being treated as a generation resource. On the other hand, since storage provides benefits such as reliability, power quality, congestion reduction and deferral of transmission and distribution investments, some may (rightly) treat storage as a transmission (or distribution) asset. In the deregulated states to promote competition, utilities cannot own generation assets, whereas generators do not operate transmission and distribution lines.

This leads to inconsistent treatment at the hands of state and federal regulators and cause uncertainty in minds of investors as there are different rules on mechanisms for cost recovery. Transmission investments are allowed additional equity boost in their rate base to recover costs, while renewable generation gets tax credits. In many applications, storage resources are not allowed to participate. For instance, CAISO and ERCOT have only recently initiated processes to allow energy storage resources to participate in ancillary services markets. Further, as stated in section 5.5.2 it is difficult to have regulations that measure multiple benefits as they are accrued across stakeholders.

By no means, am I suggesting here that these are the only reasons that energy storage has not been able to realize its potential. It is a known fact that, generally speaking, energy storage technologies currently are not as competitive compared to traditional natural gas or coal power

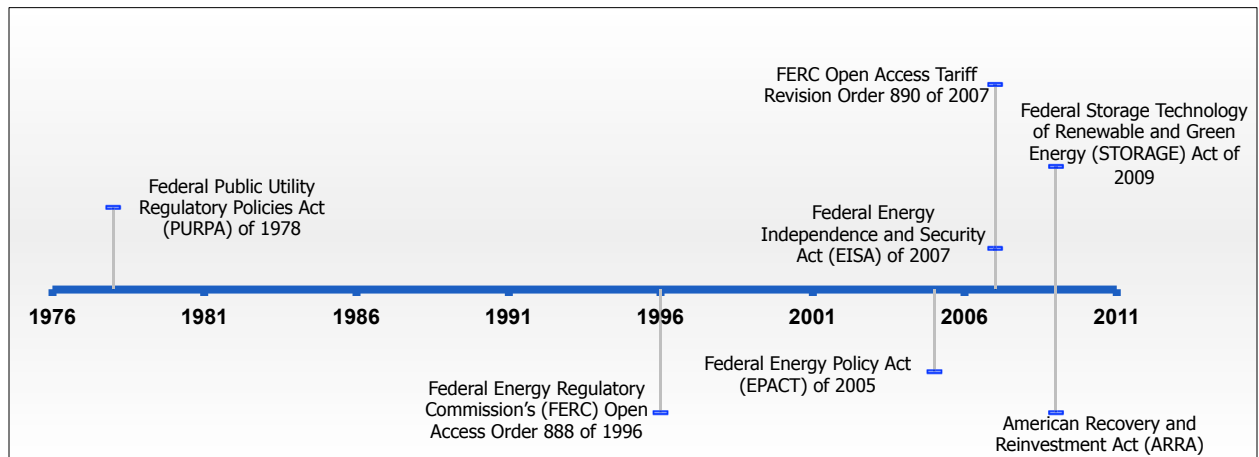
plants. In many cases, the lifecycle benefits may still be lower than the overall costs of some of these technologies. At the same time we have seen tremendous improvements in battery and other storage performance and costs. For instance, Li-ion battery costs have fallen 9% annually in the last decade (Pinner 2008).

Apart from the cost effectiveness of energy storage technologies, the factors mentioned above have contributed to slower adoption of storage for renewable energy integration. The rest of the paper will review the policies that have enabled emergence of storage so far, look at policies that are currently being considered at federal and state or regional levels, recommend certain policy interventions and prescribe business models that can push the market in the “right direction” making storage “on the money.”

## **5.6 Policy Incentives**

### **5.6.1 Timeline of Federal Policies**

The seeds for progressive policies encouraging renewable energy technologies date back to the Federal Public Utility Regulatory Policies Act (PURPA) of 1978. According to the Department of Energy’s Energy Information Agency (Zucchet 1995), “The single most important factor in the development of a commercial renewable energy market was the passage of the Public Utility Regulatory Policies Act (PURPA) in 1978. Among other things, PURPA encouraged the development of small-scale electric power plants, especially those fueled by renewable resources. The renewables industry responded to such incentives by growing rapidly, gaining experience, improving technologies and reliability, and lowering costs.”



**Figure 21: Enabling Policies for Energy Storage**

*Adapted from: (Vartanian 2008)*

FERC’s Open Access Order 888 of 1996 further strengthens competition by providing framework for new market participants to access the electricity market and unbundling several energy services including frequency regulation, spinning and supplemental reserves, voltage control and imbalance services (Vartanian 2008). It opened the doors for non-traditional market participants to trade in the day ahead and real time markets for ancillary services. However, it was not until the FERC Order 890 in 2007 that non-traditional energy resources such as energy storage and demand response could participate in FERC jurisdictional markets.

The Federal Energy Policy Act (EPACT) of 2005 and the Federal Energy Independence and Security Act (EISA) of 2007 have been instrumental in paving the way for smart grid framework, development and implementation (Vartanian 2008).

Arguably the biggest shot in the arm for energy storage has been provided by the American Recovery and Reinvestment Act (ARRA) of 2009 or the ‘stimulus funding.’ Out of the \$787 billion approved for stimulus package, \$84.8 billion has been earmarked for energy, transportation and climate change related projects, of which \$32.7 billion have been grants for

energy through the Department of Energy (Pew Center on Global Climate Change 2009). \$4.5 billion have been utilized and approved specifically for electric grid modernization. There are storage related projects in other categories through vehicle programs and Advanced Research Project Agency – Energy (ARPA-E). From the \$4.5 billion for smart grid and efficient electrical transmission, \$700 million have been marked for energy storage demonstration projects, of which \$620 million were awarded in November 2009 towards 16 regional smart grid demonstration projects and 16 utility-scale energy storage demonstration projects (U.S. Department of Energy 2009).

In May 2009, the Federal Storage Technology of Renewable and Green Energy (STORAGE) Act of 2009 was introduced in the Senate (GovTrack 2009). With the busy senate calendar and midterm elections, it is unlikely that this bill, which very aptly has been called the STORAGE Act, will be put into law anytime in the coming months. This bill proposes providing energy investment credit for energy storage property connected to the grid or onsite storage. Those projects that are connected to the electric grid receive a 20% credit, and those on residential, commercial, and industrial properties receive a 30% credit (S. 1091 Storage Act Frequently Asked Questions 2009). The bill imposes a minimum capacity requirement for both categories: systems on residential, commercial or industrial properties must have equivalent capacity of 20 kilowatt-hours or more and ability to discharge at least 5 kilowatts of electricity for 4 hours, while storage connected to the grid must have the capacity of 2 megawatt-hours or more and ability to provide 500 kilowatts of electricity for 4 hours. There is an overarching requirement that qualifying energy storage property or onsite energy storage must be used to reduce peak electricity requirements on the grid or to store electricity from intermittent renewable energy

resources. In addition, the bill would enable utility energy storage to be paid by clean energy bonds.

Before I move to analyzing specific policy approaches that will be needed in the future (including the above mentioned STORAGE Act), I would like to illustrate that even when federal level guidelines exist there are difficulties in structuring right policies at the regional level. The case in point is the FERC Order 890 that allows for open access i.e. competitive participation of energy storage in FERC jurisdictional wholesale electricity markets.

### **5.6.2 FERC Order 890**

On February 16, 2007, FERC issued the Order 890, which seeks to promote greater competition in the electricity markets and strengthen the reliability of grid (Vartanian 2008). As a result of this Order, all ISOs are mandated to change their market tariffs to allow non-generation resources to provide frequency regulation.

Even in the FERC jurisdictional markets that have been mandated to change their market tariffs to encourage non-generation resources, this movement has been slow and inconsistent. The current status of ancillary markets (as of early 2010) in terms of readiness for energy storage is summarized in table 4 (Judson 2009).

<b>Grid Operator</b>	<b>Readiness for ES</b>
<b>NY-ISO</b>	Tailored market rules approved by stakeholders. Market Open for Storage (LESRs). Tariff approved by FERC on May 15, 2009.
<b>PJM</b>	Open. Developing better regulation dispatch signals
<b>ISO-NE</b>	Pilot program approved and operational. Permanent rules expected to be developed in 6-12 months.
<b>CAISO</b>	Stakeholder process developing tailored market rules for ES resources, proposed 40 MW pilot. Expect higher price for fast response.
<b>MISO</b>	Filed tariffs for ES in May '08, approved Dec '08. Opened in June 2009. New Tariff for Storage, expect to implement January 1, 2010

**Table 4: Readiness for energy storage in FERC regulated markets for ancillary services**

As can be seen from the table, some of the ISOs have had a better record and longer history with energy storage technologies than the others. Even among these ISOs, the market rules and tariffs are different.

The ISO-New England has a “mileage” payment scheme, under which resources that spend more time providing regulation services get paid more. This works in favor of energy storage technologies as they are fast to provide regulation services, compared to natural gas peaking plants that have a slower ramp rate (Helman 2009). On the other hand, the same ISO does not reimburse energy storage for opportunity costs as it does to traditional generators (natural gas plants). As a result, natural gas plants have the advantage of getting two streams of revenue for providing regulation services – regulation services through market clearing price and the opportunity costs of these plants not being available for other services when providing regulation.

The New York ISO was considering a rule change that would mandate a response rate of higher than 90% from regulation resources, which would work against flywheels and other fast discharging energy storage technologies (Walawalkar 2008).

PJM Interconnection, which is the world's largest electricity market providing over 160 GW capacity to over 50 million people in thirteen Mid - Atlantic States and the District of Columbia (Walawalkar 2008). PJM like ISO-NE provides opportunity costs payments to traditional generators for regulation services. PJM has also developed better dispatch signals such that energy storage technologies will be better suited to provide quick regulation services (Judson 2009).

MISO has decoupled capacity from energy for frequency regulation services. It does not have any minimum energy requirement for non-traditional providers (Judson 2009). As a result, flywheels and other fast responding energy storage technologies can be included much more readily to provide regulation services. Other ISOs typically have a capacity requirement for a certain minimum duration (CAISO – 1 hour).

It can be seen from the above discussion, that even though the FERC issued the Order 890 that allowed non-traditional resources such as energy storage to compete in the ancillary services markets, it takes time to incorporate rules and tariffs for new technologies such as storage. Plus, there are inherent advantages to the incumbents (in this case through opportunity payments).

All this while, I have talked about ancillary services in the deregulated markets. It should be noted that ancillary services are needed in the regulated markets as well. However, in these markets, it is the responsibility of the vertically integrated utility to provide reliable power supply across its service area.

### 5.6.3 Analysis of current policies in discussion

In order to understand how right policies are needed to promote energy storage technologies in renewable energy integration, I will compare three currently discussed policies (bills) aimed to enable energy storage. It is interesting to note that two of these bills are currently in discussion at state level, while the STORAGE Act is a federal bill. Both the state-level bills are from the State of California. One big reason why California is seriously discussing energy storage is because it also has the most ambitious renewable energy goal among all states. The three policies in question are:

#### 5.6.3.1 The STORAGE Act of 2009

The STORAGE act (GovTrack 2009) provides traditional investment tax credit (ITC) for energy storage technology installations at different levels. It will provide tax credits for developers, and also to individual residential, commercial and industrial entities. More so, individual installations will receive a higher tax credit of 30%, compared to developers that could earn 20% credit.

An investment tax credit offsets initial investment risk in capital heavy projects by reducing taxes for qualified tax payers who make the capital investments. This provides an economic incentive for such capital intensive projects.

In words of Senator Ron Wyden of Oregon (Wyden 2009) – *“The bill will base the tax credit on the amount of energy stored, not the type of technology used. The goal is not to pick winners and losers, but to offer a broad range of incentives to foster innovation and installation. By providing tax incentives, the bill will create demand for renewable energy storage technologies.”*

A similar bill was introduced in the U.S. Senate called the Storage Technology of Renewable and Green Energy Act of 2010, or simply Storage 2010 (GovTrack 2010). The bill could potentially provide up to \$1.5 billion in federal tax credits. Storage 2010 will provide 20% ITC of up to \$30 million for storage systems connected to the grid, 30% tax credit of up to \$1 billion to businesses and 30% to homeowners for on-site storage projects.

While, an ITC promotes investment, it does not encourage optimal utilization of such installations. Storage services will still have to be promoted by providing necessary market for stored electricity. Also, as it is obvious from the discussion so far, value of storage service depends on the location, type of renewable technology and weather, it is premature to provide a flat tax credit.

#### ***5.6.3.2 California Assembly Bill 2514***

The California Assembly Bill 2514 (Skinner 2010) requires electrical corporations and locally owned utilities to create energy storage systems by introducing a mandate. As per the bill, the state should have 2.25 percent of their peak loads with energy storage by 2014 and 5 percent by 2020. As per some estimates, the bill if passed could result in 3.4 GW of storage capacity in California in next 10 years from current levels of 1.5 GW (8.5 percent annual increase).

Recently, California passed and signed into law a watered down version of AB 2514 that did not set mandates for storage, but set a future date to consider establishing storage targets to be met by 2015 and 2020 (Wesoff 2010).

Like RPS for renewable energy technologies, a mandate for energy storage has the same benefits including reduced risk by guarantying demand, specific amount of storage is assured and above

all is simple to implement (Komor, The Renewable Portfolio Standard 2004). However, it also comes with similar drawbacks – not supporting more promising but currently high-priced technologies, plus it is a regulation which by itself creates a market but does not define market rules.

### ***5.6.3.3 California Assembly Bill 44***

The California Assembly Bill 44 (Blakeslee 2008) proposes that an investment made by an electrical corporation on energy storage systems should receive an increase of half of one percent to one percent in the rate of return on investment similar to investments made on generation using renewable energy resources.

This bill involves the state public utility commission and proposes preferential rate making for energy storage, similar to renewable resources. This approach is very similar to feed in tariff provided for renewable energy technologies in various countries including Germany and China. The only difference being that increased rate of return is not a figure picked out of thin air. Like feed in tariffs, it has similar pros such as costs to ratepayers, low revenue uncertainty and effective in increasing storage technology installations, and cons such as create “standard costs,” is not a “market mechanism” and is political process (Komor, Feed-in Laws: Crude, Effective, Outdated but Not Dead 2004).

Storage applications intersect across the electricity value chain (figure 22) and involve various stakeholders. The key stakeholders in the value chain are: electricity end users, utilities, merchant storage project owners, aggregators, wind farm or solar plant project owners, and storage equipment and service providers. Then there are other societal and institutional stakeholders such as rate-payers, federal and state regulators, and independent system operators.

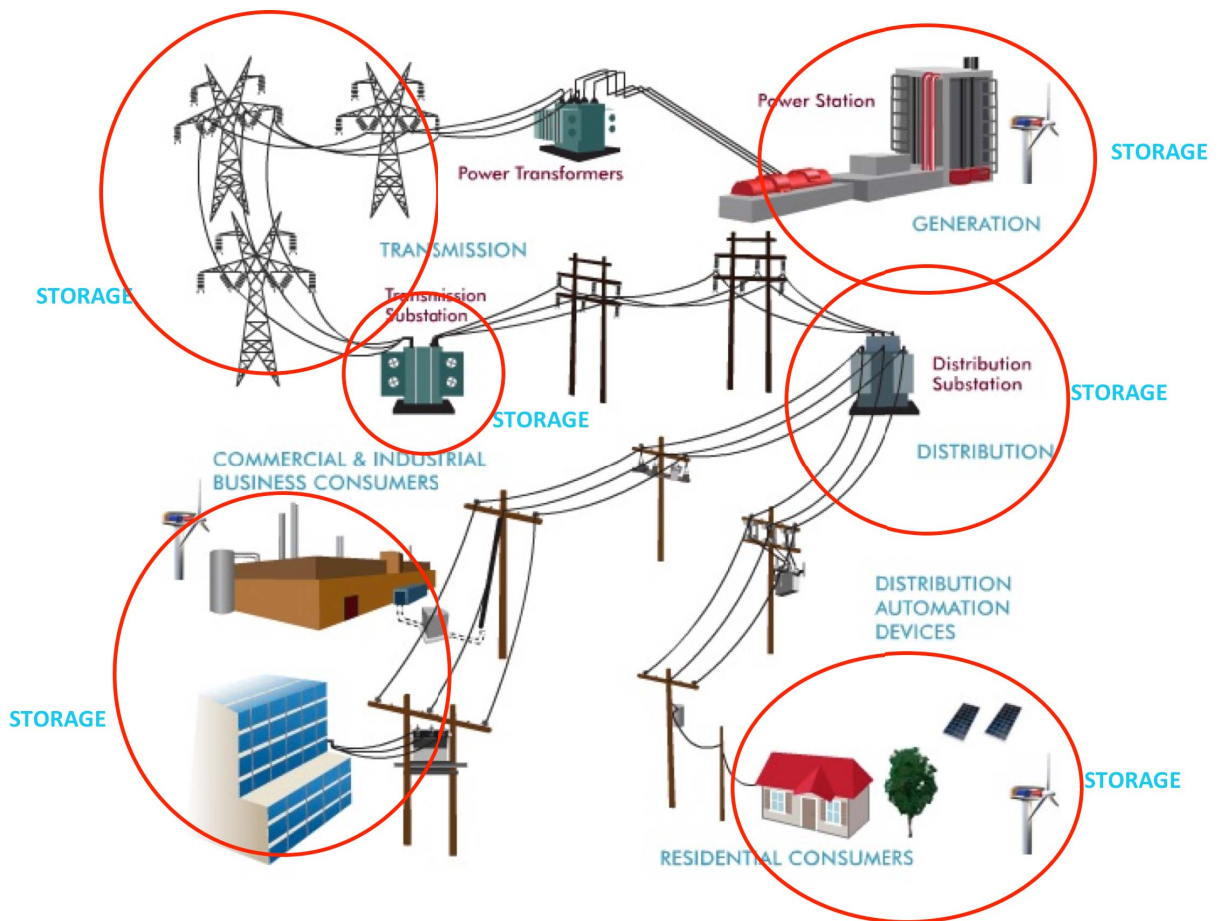


Figure 22: Electricity Value Chain

Adapted from: (Oncor 2011)

Historically utilities have been known to be conservative and risk-averse organizations. It is only in the last two decades has there been a (slow) movement towards deregulation in the U.S.

Electricity sector is unique in many respects characterized by high capital costs, bulk commodity nature of electricity, regulation and oversight, need for reliability and affordability, and need for long term planning and correspondingly long lock in. Apart from these long-established characteristics, there have been interesting developments that have provided impetus for emerging technologies such as demand response, renewable energy, smart grid and storage.

All these factors combined with multiple benefits offered by storage across multiple stakeholders present a whole range of business possibilities. Some of these business models are discussed here. It is worth reiterating that storage players should focus on maximizing multiple revenue streams as currently single application economics are favorable only in niche markets.

1) *Project financed developer*: This would be a typical special purpose project financed entity, which is fairly common in the electric sector. The developer would own the storage assets and rely on multiple year commitment from a wind-farm or solar facility owner for providing renewable energy integration service (in form of firmer capacity or time-shift). The wind or solar developer in return would achieve more lucrative power purchase agreements (PPAs) or capacity credits for offering a higher valued firmer capacity. A slight variation of this model could have the renewable energy developer owning the storage technology to provide in-house firmer and/or time-shifted renewable energy supply.

This business model could pose challenges to the asset owner in form of uncertainty in obtaining reliable PPAs or exposure to huge capital investments. Project financing does alleviate some of the risks by taking the investments off the sponsor's balance sheets.

2) *Storage equipment supplier*: Energy storage technologies require manufacturing capabilities and companies with the intellectual property could acquire technical and manufacturing knowhow to essentially function as storage manufacturers. This business model though of a conventional manufacturing outfit deserves a special mention because of the capital intensive nature of the business and potential customers. In many cases, customers would be utilities. As mentioned earlier, their risk averseness makes dealing with them tricky. A123 Systems and Altair Nanotechnologies are both lithium-ion battery manufacturers who supply grid-scale batteries to a utility, AES Corporation. AES has adopted different strategy with each vendor, having itself invested \$3 million in Altair Nano (Altair Nano 2007) and signed an exclusivity contract with A123 Systems. Such strategic alliances with key customers (or even suppliers) could improve risk coverage.

A123 Systems with its new Li-ion technology initially targeted power tools sector as its beachhead market to gain manufacturing expertise, product development, customer confidence and investor support, before venturing into the larger grid-scale storage. There are lessons to be learned about how to approach market development when in this sector.

3) *Vertically integrated storage service provider*: Beacon Power, a Massachusetts based flywheel manufacturer does not just manufactures flywheel systems, it also builds, owns and operates storage facilities in Massachusetts and New York (under construction). This vertically integrated approach can be capital intensive, but can also serve as an effective market entry strategy (Beacon Power Corp 2010). The build-own-operate model provides proof of concept to interested potential customers and thereby gaining their buy-in. It does so at the cost of additional balance-sheet risk and operational liability.

4) *Storage built- owned-operated by utilities*: Storage benefits cross the realm of transmission and distribution applications, for this reason utilities have invested in storage particularly pumped hydro) in the past and continue to do so. Pumped hydro offers economies of scale and is a commercially proven technology. From a risk to returns perspective it fits the utilities' conservative approach. For the same reasons, Sodium-Sulfur and CAES have received attention from some utilities. Utilities have started to invest in distributed energy storage systems (DESS) installed at substation level (few to tens of MW). With growing renewables, especially distributed PV, and interest in plug-in hybrid electric vehicles (PHEV), there has been some attention to the other end of storage size spectrum – Community Energy Storage (CES) systems, which are typically in the range of tens of kilowatts power and tens of kilowatt-hours of capacity, and can be installed in backyards. Utilities such as American Electric Power (AEP) and Duke Energy have taken leadership in developing standards for CES. CES provide utilities with more superior control of power quality and reliability issues at a much micro-level (due to no transmission losses) and with advanced metering infrastructure, could play a big role in smart grid implementation (Nourai 2009). CES offers utilities strategic advantages as utilities can bundle different services and possibly monetize them (which has been one of the biggest barriers to storage deployment), plus keeps independent storage developers out as utilities get to control customer-owned distributed renewable generation.

As we have seen there are multiple avenues for entering the grid-scale storage industry (just within the renewables integration sub-industry) based on technology capabilities, risk appetite and ability to access revenue streams. The risk appetite and access to multiple revenue streams of

the discussed business models/opportunities for a given technology can be illustrated in a 2X2 matrix as shown in figure 23.

Multiple Value Streams	High		Storage owned by utilities
		Storage service provider	Storage equipment vendor
	Low	Project financed developer	
		High	Low
		Risk Exposure	

**Figure 23: Risk-returns Matrix for Storage Business Models**

### 6.2 Policy Recommendations

As we have seen in the earlier chapter, there have been policies both in place and under consideration that are treating energy storage as an important technology to improve large scale

integration of renewable resources. However, since energy storage is relatively immature technology it has only recently received this kind of attention from policy makers.

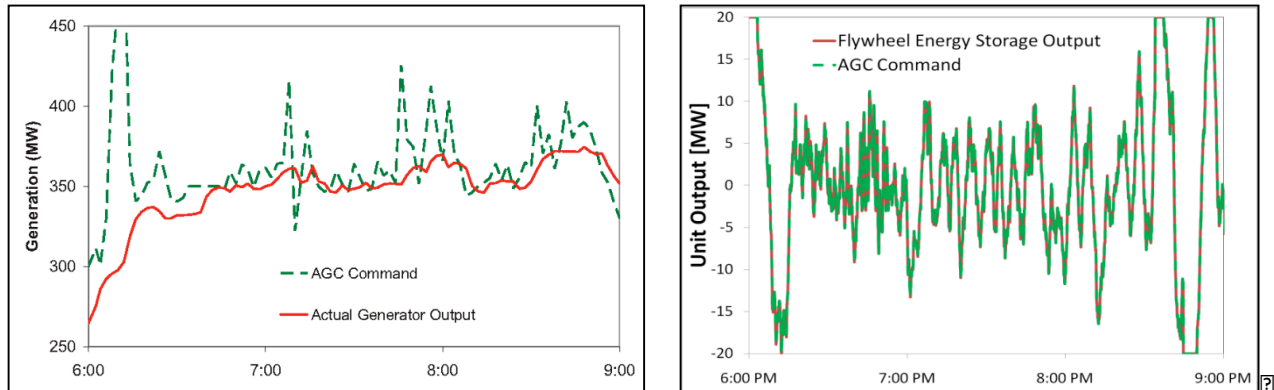
Most of the policies discussed so far have components that have the potential of promoting energy storage technologies. But none of them have ALL the required elements to push storage in the market or create sufficient demand pull. Essentially there are two main pillars that are required: recognizing all energy storage benefits (i.e. creating the pie) and removing market barriers so as to monetize the benefits (i.e. splitting the pie). A third obvious pillar is to promote technology innovations by providing early funding to enable technologies navigate through the “cradle of death” and “valley of death.”

Yang and Williams (Yang 2009) classify necessary policy options as:

- Supply-push policies such as investment in research, development and demonstration to overcome “valley of death,” loan guarantees for pre-commercial projects and encouragement for private sector participation.
- Demand-pull policies that augment financial benefits through incentives such as PTCs, feed-in-tariffs and creation of special storage markets.
- Regulation and planning that includes storage as integral piece in the national transmission plan and recognize storage as transmission upgrade.

Energy storage functions differently from traditional fossil-fuel based generation. These differences are not trivial. Hence it is important understand how to value these differences. As can be seen in figure 24, storage (flywheels in this case) can provide instantaneous regulation

service (right side image), whereas, traditional generator moves very slowly, and does not provide instantaneous signal (left side image).



**Figure 24: Speed of regulation service – traditional generation versus storage**

*Source:* (Judson 2009)

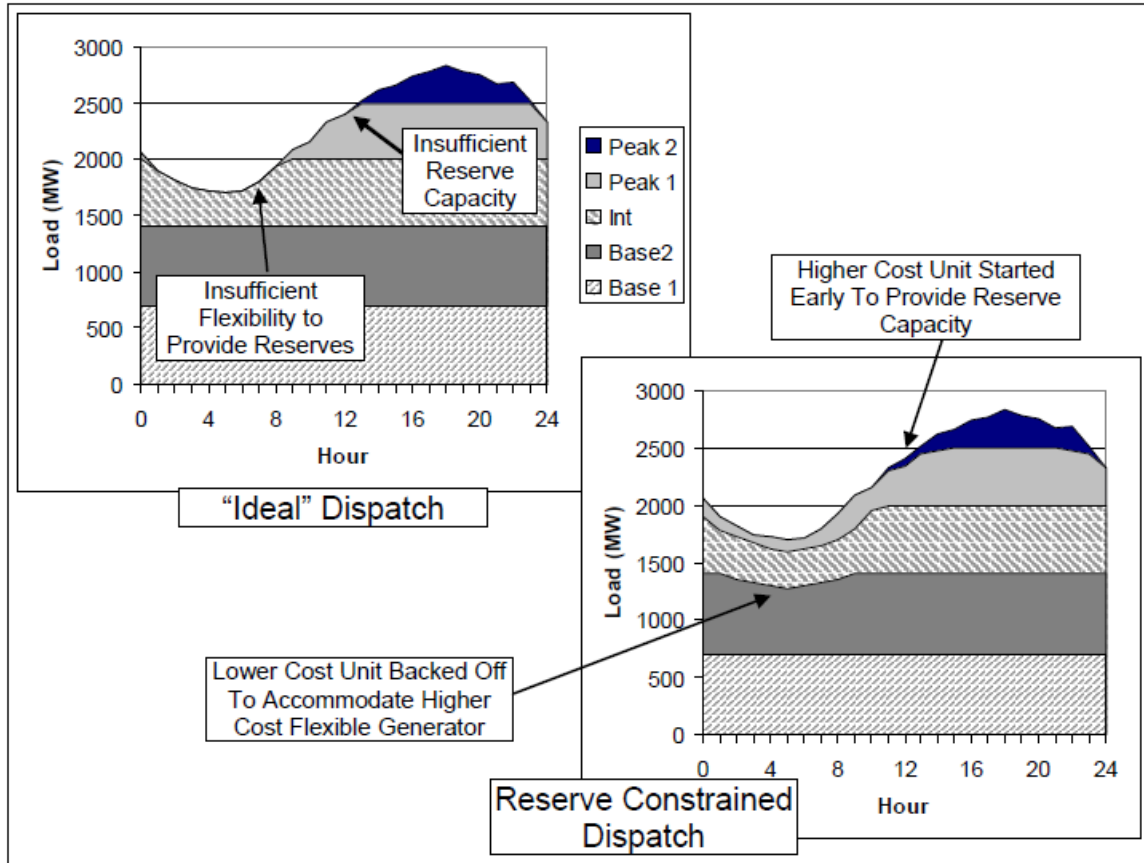
As a result of the fast regulation offered, storage can provide better capacity utilization.

According to a study done at PNNL, fast response energy storage technologies can reduce the amount of regulation procurement by up to 40% in CAISO (Makarov 2008). Policies thus need to acknowledge and value this fast service in light of reduced asset requirement and better utilization.

On the other hand, rapid ancillary response required from traditional generation assets forces partially loaded power plants – leading to increased costs, inefficient operations and uneconomic dispatch (figure 25). Whereas, these assets would be more efficient if only used for base load.

The inefficient operations also result in higher emission intensity. Talking about emissions, use of combustion turbine as backups for wind turbines results in reduced CO<sub>2</sub> savings by about 22% and expected NO<sub>x</sub> savings by about 70% (Katzenstein 2009). KEMA studies have shown that energy storage storing energy from renewable sources when used for frequency regulation can

reduce CO<sub>2</sub> emissions by 70% (R. a. Fioravanti 2006). Currently, there is no carbon price in the U.S.; however, environmental benefits of storage are clearly important.



**Figure 25: Ideal versus Uneconomic dispatch**

*Source:* (Denholm 2010)

In many situations, energy storage can also provide other benefits (apart from time- shifting and capacity firming) such as transmission and distribution asset deferrals, voltage regulation, power stability and reliability and back-up power. Currently, no policies that assign monetary value for these services exist. For storage to be truly economically feasible there needs to be a framework that can fairly value these multiple value streams and compensate these storage services.

Of the policies discussed earlier, California's Assembly Bill 44 manages to address some of these issues. It provides preferential treatment through higher rate of return. Calculation of the premium should include all the recognized benefits.

The second pillar relates to creating right market rules that reduce the barriers to operating energy storage, so that storage benefits can be monetized. Many system operators have taken the leaf from FERC Order 890 and are moving towards right market rules. But this movement has been slow.

Lastly, there is an underlying issue with energy storage as it competes with and provides benefits of generation, transmission and distribution assets. Hence, there needs to be a special asset categorization of energy storage. If such an asset class can be defined, it will be easier to implement some of the policies mentioned in this paper as rules can be written keeping the special nature of storage technologies in mind.

## Chapter 7: CONCLUSION

The aging U.S. electricity grid faces more variable and uncertain generation in form of renewable resources. State renewable mandates and standards, falling installation costs and growing concern for the environment assure higher level of variable renewables in the coming years. Current mechanisms and markets could potentially fail to incorporate aggressive renewable installations, which call for solutions to facilitate renewable energy integration. Storage with its ability to act as buffer between electricity supply and demand is one such solution.

Various storage technologies with different characteristics offer applications across different time scales and capacities. Benefits that enable more renewables on the grid include: renewable time-shifting, renewable capacity firming and other grid integration benefits such as improved power quality, reduced volatility and variability, emergency back-up, and transmission congestion relief.

In spite of all the excitement seen by the energy storage industry (including the first post financial meltdown big name IPO in A123), there still exist multiple barriers on economic, technical and regulatory fronts to propel more storage installations in the U.S. As of today only some storage technologies make economic sense, that too in specific applications.

Some of the key barriers are: high cost of capital; number of players across which benefits accrue; limited financial backing for pre-commercialized technologies; lack of clear rules that monetize and internalize storage benefits (enjoyed by transmission investments); no tax credits, tariffs or markets (like Renewable Energy Certificates) unlike renewable resources; and inconsistent regulatory treatment.

Policy recommendations needed to address key barriers include supply-side policies (investments in research, development and demonstration of pre-commercialized technologies), demand-pull policies (tax credits, storage specific markets) and long-term planning (consistent treatment of storage recognizing storage benefits in line with transmission investments).

Growth in storage space continues to offer new business opportunities across the value chain and to various players – utilities, technology suppliers, project developers, service providers and aggregators.

## APPENDIX: INTERVIEWS AND CONVERSATIONS

I would like to acknowledge all the following individuals for their precious time and invaluable insights into the exciting energy storage industry. Names marked with asterisks were interviewed in a structured or semi-formal manner. Others have provided with their expert opinion during innumerable water cooler conversations.

Michael Avidan\*, PG&E

Sean Becker, SparkPlug Power

Kelly Sims-Gallagher, Fletcher School

Tod Hynes, XL Hybrids (and MIT)

Robb Jetty\*, Recurrent Energy

Colette Lamontagne\*, Navigant Consulting

Janet Lin, MIT Sloan

David MacMillan\*, MegaWatt Storage Farms

Phil Martin, EnerNOC

Forgan McIntosh, MIT Sloan

Ali Nourai\*, American Electric Power (now KEMA)

Rich Silkman\*, GridSolar

Carlo Tursi, MIT Sloan

Charlie Vartanian\*, A123 Systems

Rahul Walawalkar\*, Customized Energy Solutions

ChrisWalti, MIT Sloan

John Wood, Ecoult

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