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Energy Storage in the Golden State: An analysis of the regulatory and economic landscape.

Ryan Higgins

In partial fulfillment of a Bachelor of Arts Degree in Environmental Analysis,
2013/14 academic year, Pomona College, Claremont, California.

Readers:
Bowman Cutter
John Jurewitz

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List of Acronyms

- CA: California
- CAISO: California Independent System Operator
- CSI: California Solar Initiative
- CSP: Concentrated Solar Power
- CalPX: California Power Exchange
- CPUC: California Public Utilities Commission
- DES: Distributed Energy Storage
- DG: Distributed Generation
- ERCOT: Electric Reliability Council of Texas
- ESS: Energy Storage System
- FR: Flexible Resources
- IOU: Investor Owned Utility
- LESR: Limited Energy Storage Resource
- LSE: Load Serving Entity
- RES: Renewable Energy Resource
- RPS: Renewable Portfolio Standard
- TES: Thermal Energy Storage

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“The economic transmission of power without wires is of all-surpassing importance to man.

By its means he will gain complete mastery of the air, the sea and the desert.

It will enable him to dispense with the necessity of mining, pumping, transporting and burning fuel, and so do away with innumerable causes of sinful waste.

By its means, he will obtain at any place and in any desired amount, the energy of remote waterfalls—to drive his machinery, to construct his canals, tunnels and highways, to manufacture the materials of his want, his clothing and food, to heat and light his home—year in, year out, ever and ever, by day and by night.

It will make the living glorious sun his obedient, toiling slave.

It will bring peace and harmony on earth.”

Nikola Tesla, 1905.

Chapter 1: Introduction

The electricity grid as it currently exists – a vast network of electricity production and consumption nodes, connected by mammoth transmission wires – is a testament to one of the most fundamental properties of electricity: it is not a stock but a flow.

Electricity is energy, and traditionally societies have used high-energy density objects produced by the natural world as an intermediary means of storing energy until it was needed. Most recently, fossil fuels proved a very effective means of distributing this potential energy through a society, but have done so at a high cost to the environment.

Advances in energy technology have spurred nearly all of the great turning points in the history of humankind, with the advent of agriculture, horsepower and fossil fuels each ushering in their own new age and social structure. Now in the early years of the twenty-first century we find ourselves on the brink of another period of immense change; the fossil-fuel based society of the past two centuries must adapt to the reality of climate change and diminishing natural resources, or fall victim to its own insatiable appetite for energy. Fortunately our planet is well-endowed with a nearly inexhaustible energy source in the radiation provided by our sun, but the adaptation from our current dependence on fossil fuels will require massive improvements in the ways we obtain, deploy and consume the energy that fuels and sustains our society.

It is becoming increasingly clear that the use of fossil fuels must be phased out in favor of electricity. The Intergovernmental Panel on Climate Change (IPCC) has asserted that by the year 2050, carbon emissions must be brought to 80% below the 1990 level in order to reduce the likelihood of dangerous anthropogenic climate effects (Solomon, 2007). A recent report found that for California to achieve this goal, end-use energy consumption will need to be electrified, with electricity accounting for 55% of end-use energy in 2050, versus 15% today (Williams et al., 2012). Furthermore, this electricity will need to come from decarbonized suppliers, meaning that renewable resources will be the electricity generators of the future. This transition will make the ability to cheaply and efficiently store electricity an absolute necessity.

Electricity cannot truly be stored but must be either maintained chemically in a battery or converted to an alternate, storable, form of energy that can later be converted back to electricity for future use. Producers of electricity have never been able to effectively “bottle up” a unit of electricity and sell it to consumers in the manner that other commodities are sold in a conventional market. The commoditization of electricity necessitated the development of the grid, a system that would allow the electricity produced at fossil-fuel powered plants to make its way to end-users. The mammoth electricity transmission and distribution wires that crisscross all modern countries characterize the 20th century paradigm of energy use, which consisted of a centralized load serving entity coordinating the output of a number of large power plants, connected by massive transmission lines. The urgent need to begin using renewables to produce the massive amounts of energy consumed by our society, however, paired with rapid advances in the technology that will enable such a transformation, mean that this paradigm is under threat, along with the institutions that formed alongside it.

This paradigm shift will present major challenges to those responsible for maintaining a reliable electricity grid. The clean energy produced by intermittent renewables is highly desirable from an environmental standpoint, but it presents a major problem to utilities trying to match electricity supply with demand on the grid: it is not dispatchable. Resources like wind and solar generation produce energy only when the weather allows, while electricity consumers conduct their energy-intensive business in effective ignorance of where the electricity comes from. For an operator of the grid that needs to indiscriminately and instantaneously supply energy to end-users across the system, this presents a significant technical challenge, not to mention the economic issues that are associated with goods that cannot be stored.

At its very core the industry of creating and distributing energy is not a competitive one but has traditionally been treated as a “natural monopoly” over generation assets and distributional equipment, where utilities are allowed to own and operate transmission and distribution lines in order to provide electricity to consumers at a regulated price. Regulation means that consumers are protected from the exercise of excessive monopoly power, but is also a source of inefficiencies that would not exist in

a truly competitive market. In the electricity “market” as it currently exists, supply is limited and inelastic in the short run due to the formidable economic and regulatory barriers involved in the construction of a traditional, fossil-fuel powered power plant. Meanwhile it can be difficult to predict an electricity demand that is the result of the aggregated behavior of millions of consumers that are not quick to change their behavior based on price signals, although slightly more price elasticity has been demonstrated in the medium to long-run in California (Borenstein, 2009). Furthermore, the difficulties involved in tracking a unit of electricity as it travels through a physically complex grid with few capabilities of internal feedback make the principle of marginal cost pricing, an important feature of any competitive market, a virtual impossibility.

The development of energy storage systems (ESS) within this electricity grid, paired with the deployment of other “smart grid” technologies, could potentially address many of the technical and economic issues faced by the California energy sector. A “smarter” grid paired with effective price signals would incentivize electricity consumers to take more control over their electricity use, using energy storage and other load-shifting techniques to capitalize upon price differentials that would reflect the true cost of producing electricity at its time of use. Appropriate deployment of ESS could also eliminate the ease with which energy suppliers can exercise market power by decoupling supply and demand, allowing the grid itself to monitor and respond to market fluctuations. Lastly and perhaps most importantly in the context of California, storage has the potential to “smooth” and temporally shift the supply of electricity from RES, a service that will be of great value to the state as it moves towards lower-carbon energy sources.

California has traditionally been a leader in the United States in terms of environmental action; one of the boldest steps the state has taken towards sustainability in recent years has been the establishment of an aggressive Renewables Portfolio Standard (RPS). As the result of a series of legislative actions beginning in 2002, California now provides nearly 20% of its electricity from renewable resources, with mandatory targets to reach a 33% penetration level by the year 2020. Admirable as these efforts may be, they have been imposed on an electricity grid and an energy sector paradigm not accustomed to the difficulties of matching intermittent renewable

energy generation with inelastic electricity demand. As outlined in detail later in this report, the California ISO has identified several serious threats to grid stability and reliability that could develop as an increasing portion of our energy is supplied by intermittent RES. Basically, the output of renewable electricity resources like solar panels and wind turbines is intermittent and dependent upon natural cycles, while the electricity use habits of consumers are dictated more closely by their daily schedules. This means that while state policy continues to encourage massive amounts of private investment in newer and bigger renewable energy generation facilities it may become difficult to efficiently integrate into the grid all of the resulting renewable energy, due to an inability to store it until it is needed for use by consumers. In accordance with these issues, the state of California has instituted a series of regulatory and policy instruments intended to ensure that adequate electricity storage capacity is developed within the power grid over coming years.

On October 1st, 2013, a mandate was adopted by the California Public Utilities Commission (CPUC) requiring that 1.325 GW of energy storage capability be installed on the California electricity grid by 2024, through the actions of the state's three investor-owned utilities. While this is a bold first step towards mandated energy storage in the United States, it may be only the beginning for an energy storage industry in this state. It has been well established that energy storage would prove to be a useful asset on the California electrical grid, but the development of storage capacity past the requirements of the mandate will depend upon whether storage can be made *cost-effective*. Much of the value that storage creates is a public good: many storage applications allow the grid to operate more efficiently as a whole, but not necessarily in a way that can be monetized by any particular party. As a public good, these systemic benefits of storage capacity will be supplied sub-optimally in the absence of government intervention. The energy storage industry will accordingly be one that is strongly affected by the tides of change in technology, regulation and economics in the California energy market. This report will focus primarily on the intersection of the second two of these factors, largely leaving the technological questions to more well-informed parties while seeking to establish what regulatory and economic considerations might be undertaken to ensure that the road to deployment of

appropriate energy storage systems is made as clear as possible so that this technology can reach the socially efficient level on the California electricity grid.

Chapter 2 will assess the nature of the California electricity grid itself as the landscape upon which AB 2514 has been imposed. Electricity market institutions such as the system operator, energy exchange platform and utilities will be examined by virtue of their relationship to energy storage on the CA grid. An explanation of the issues posed by RES that necessitate the establishment of storage capability on the grid will be accompanied by an examination of the role each of these institutions will have to play in doing so.

Chapter 3 will present an overview of energy storage as a concept, beginning with an introduction to key technologies but ultimately taking an application-specific approach to what storage technologies may be deployed, as well as where on the grid and for what purpose. This chapter will look at the opportunities that exist for the owners, operators and investors in storage technologies to monetize and recover the value that their investments create for the electricity grid and society as a whole, and will also explore areas where future value propositions may be created. Regulatory developments relevant to this issue will be introduced and examined by virtue of their potential to create a tangible marketplace for ESS technologies that provide many valuable services not recognized by the current regulatory paradigm and consequent market structure of modern electricity markets.

Chapter 4 will look towards the future of the California electricity grid and envision the impacts that the development of different types of storage technologies may have on the evolution of the way electricity is used and provided in California. Several scenarios will be developed to predict how technological change, regulatory measures, and general economic incentives may affect the nature and distribution of ESS that are deployed on the California electricity grid.

Chapter 5 will assess the scenarios created and conduct an analysis of how the development of an energy storage industry in California could provide value in addressing the grid issues associated with the state's ambitious renewable energy

goals. From this analysis, a conclusion will be drawn about how storage could best be cost-effectively used to create a more sustainable and reliable electricity grid for the state of California, and general policy recommendations will be made towards this end.

It is the aim of this report not to promote a specific technology or even an energy storage industry as a whole, but rather to shed some light on the effects that the development of such an industry could have on the California electricity market and the energy use paradigm that governs modern electricity grids worldwide. With the adoption of AB 2514, a grand experiment was set in motion that will benefit the entire world as California tests the uncharted technological, regulatory and economic territories of grid-scale energy storage capacity. It is a time of change in the electricity industry, and energy storage is a potentially transformative technology that could very well enable the shattering of an energy use paradigm that has held the world captive to fossil fuels for over a century.

Chapter 2: The California Electricity Market

2.1 Market Structure

Like the market for any good, the California electricity market exists fundamentally for the purpose of matching supply with demand. In most markets the laws of economics suffice to balance these two amounts, albeit with periods of scarcity and overabundance. The market for electricity differs in this characteristic due to the lack of storage capability – there are no “electricity warehouses”- and the ability to instantaneously match supply and demand is crucial. Failure to do so may result in planned or unplanned blackouts, or, in the extreme, damage to user equipment (AUS Consultants) or to the electricity grid itself. To borrow a metaphor from Peter Fox-Penner’s book Smart Power: Climate Change, the Smart Grid, and the Future of Electric Utilities, it is helpful to think of the electricity grid as a network of ponds that are all connected by channels of varying size. When electricity is generated in one area, it is analogous to releasing an amount of water into one of the ponds, with the excess water spreading through the network of channels as the water level is equalized across the system. Electricity consumers can be thought of as pipes drawing water from each of the ponds, each with a level of flow that fluctuates with energy use. The amount of water entering and exiting the network of ponds must be matched on a second-to-second basis or the water level will drop too low or overflow, interfering with the ability of the network to provide a reliable supply. Much of the complexity of the California electricity market is designated to simply matching supply and demand (in as socially efficient a manner as possible), which requires the cooperation of a variety of publicly and privately coordinated institutions.

Both the federal government and state governments are intimately involved in electricity regulation. The Federal Energy Regulatory Commission (FERC) regulates wholesale electricity transactions - transactions in which the purchaser does not “use” the electricity but instead sells the electricity to another party. In the 1980s, the FERC adopted “market-based” regulation of electricity transactions in wholesale markets. It is this market-based regulation that constitutes the “deregulation” of all wholesale power markets in the U.S. On the other hand, state regulatory commissions regulate retail electricity transactions. Any transaction in which the purchaser is an end-user of the

electricity is a retail transaction. About half the states in the U.S. have “deregulated” retail electricity markets by adopting some form of “retail competition” in which consumers can choose to purchase their electricity from various competitive retail providers. In most of these states, if a consumer chooses not to purchase power from a competitive retail supplier, the local utility is still required to provide consumers with electricity on a “default basis”, at prices regulated by the state utility commission.

California electricity markets are “deregulated” at both the wholesale and retail levels. Wholesale prices are determined in competitive markets subject to FERC market-based price regulation. Retail prices charged consumers by public utilities are subject to regulation by the CPUC, while the retail prices charged consumers by competitive retailers are unregulated. To enhance wholesale competition as a foundation for introducing retail competition, in 1996 the California legislature authorized two public-benefit, non-profit market institutions known as the California Power Exchange (CalPX) and the California Independent System Operator (CAISO). While it operated, the CalPX operated certain day-ahead and hour-ahead electricity markets. However, the CalPX was disbanded during the 2000-2001 California Power Crisis and its market-operating functions were taken over by the CAISO.

Today, the CAISO operates 24 hourly auction-based day-ahead markets as well as an hour-ahead day-of market that allows wholesale suppliers and purchasers of electricity to transact at market-clearing prices and quantities in each “zone” of the market (Kritikson, 2000). These CAISO auctions result in mutual financial commitments between buyers and sellers, which are the main determinants of the dispatch of generation by the CAISO. The CAISO also purchases certain “ancillary services” (AS) on a day-ahead and longer-term basis to assist it in operating the grid reliably. Suppliers in these AS markets agree to allow the CAISO to order them to undertake certain actions on a real-time basis for grid-balancing purposes. These adjustments are traditionally made through orders to dispatch traditional, fossil fuel-powered generation plants with the ability to quickly ramp production up and down.

Many of these plants are quick-start, simple-cycle gas turbine “peaking” plants. In the absence of electricity storage, additional plants such as these would likely have

to be built to enable the integration of large amounts of additional intermittent renewable generation. Finally, the CAISO attempts to balance the system on a moment-to-moment basis by operating 10-minute-ahead “real-time” markets during the day of actual grid operation. The real-time market is used to make last minute adjustments by a largely computerized system that monitors energy imbalances on the grid (Kritikson, 2000). Through these mechanisms, the CAISO balances the needs of around 30 million electricity users with the production capabilities of 671 power plants along 25,865 miles of transmission lines (Trabish, 2012), though an equally important role is played by electric utilities.

2.2 Utilities

Electric power utilities typically own and operate the distribution systems used to interconnect retail electricity consumers to the grid at large. Providing this delivery service necessarily places them in a commercial relationship with retail customers. These utilities also are the exclusive providers of electric energy to retail customers except in those states that have adopted retail competition. Even in these states, utilities typically serve a large portion of the retail energy market. In the early days of electric power, electric utilities were vertically integrated, regionally regulated monopoly companies that performed all retail services from the installation of light bulbs for customers to the generation and distribution of the electricity to power them (Fox-Penner, 2010). The role of utilities has evolved significantly since those early days, however, and even more extremely in California since the 1996 passage of AB 1890 and the consequent deregulation of the California electricity industry. Regulations prompting utility divestment of generation capacity (with some exceptions) have caused utilities to adopt a role more oriented toward electricity distribution and, recently, the provision of “energy services”, including energy efficiency measures and storage capacity.

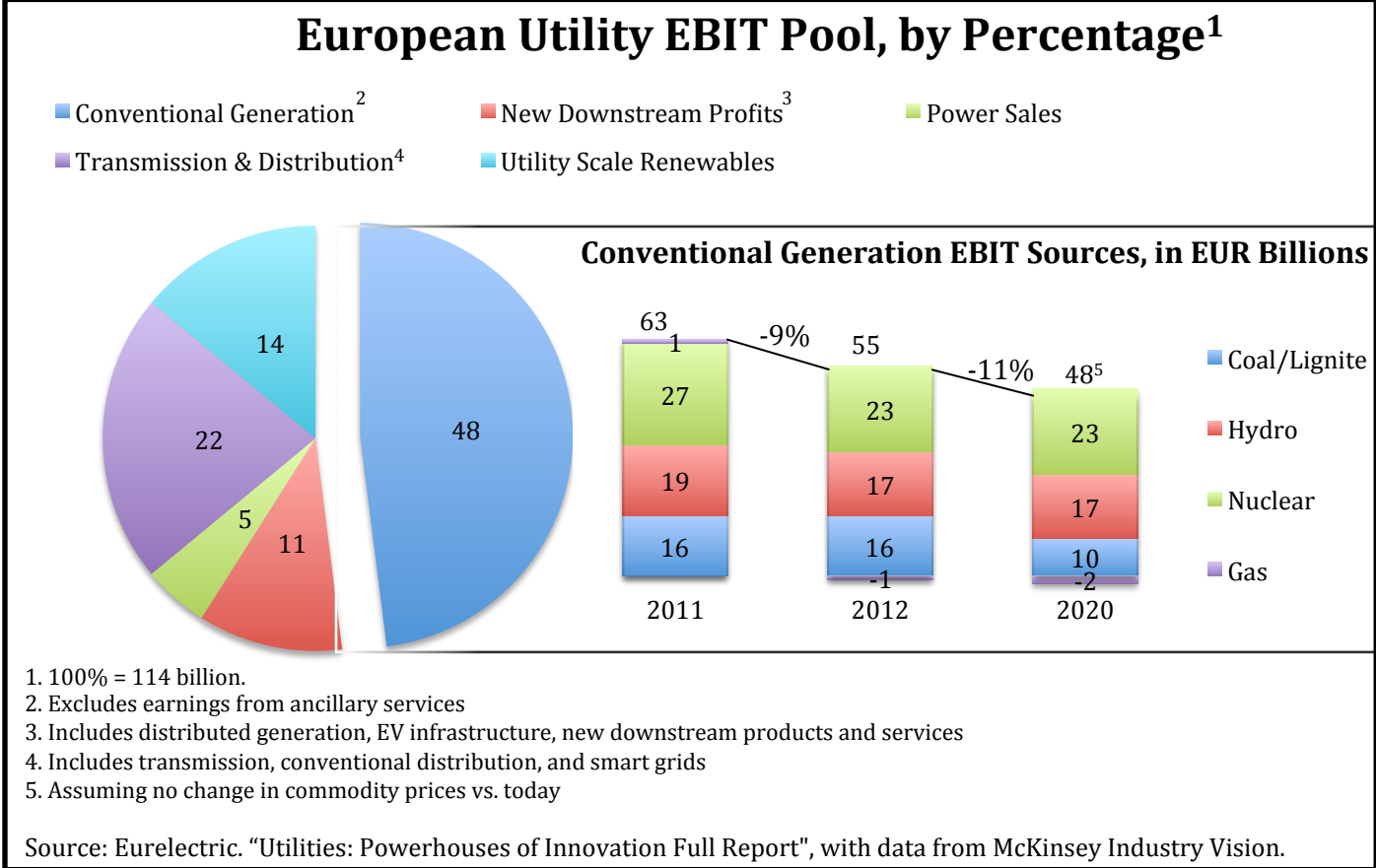
The three investor-owned utilities (IOUs) that serve California - Pacific Gas and Electric (PG&E), Southern California Edison and San Diego Gas and Electric (SDG&E) – own 70% of the California transmission system, while publicly-owned utilities (POUs) and other public agencies own the remaining 30% (Independent Energy Producers Association, n.d.). All electricity that is consumed in the state of California, even the

electricity provided by competitive retailers, passes through these lines, which means that utilities are uniquely poised to monitor energy use and gather relevant data, a service that will prove essential to a state with the goal of pursuing a more efficient and sustainable electricity grid. The problem is that utilities' profits have traditionally been based on the "natural monopoly" they have over transmission capability and derived from volumetric electricity sales, providing an incentive to increase "throughput" of electricity through their wires even when doing so is perverse to the goal of energy efficiency (Kushler et al., 2006). This issue was confronted by California in the early 1980s through the "decoupling" of utility profits from volumetric energy sales, which were replaced through the periodic regulatory setting of a pre-determined revenue requirement. Moreover, to give utilities an affirmative incentive to encourage customers to adopt energy efficiency measures, they have been given performance-based rewards for progress towards energy efficiency goals (Kushler et al., 2006). Through such economic incentives, alongside the implementation of legislative mandates, the state of California aims to enlist utilities as major players in the campaign for a sustainable electricity market. Indeed, it should be the hope of utilities that they are included in the state's plan for the future, because as providers of a service (energy), they must respond to the changing demands of the society they serve. California no longer wants just cheap energy, but clean, reliable and efficient energy as well.

This trend is not isolated to California but is in fact indicative of a global shift in the utility industry. A recognition of the true costs of traditional electricity production combined with the advent of new, cleaner energy technologies have enabled a new energy use paradigm, in which utilities and other Load Serving Entities are expected not just to provide cheap electricity. Combined, these changes to the energy sector constitute not just a challenge to utility companies, but an existential threat that will require utilities to adapt or face becoming obsolete. The traditional profit streams of utilities are in decline as an increasing amount of emphasis is placed on efficiency over cheap energy. For evidence of this we can look to Europe, where renewables have already achieved market penetration levels comparable to those that California will soon reach, causing an "existential crisis" for utilities (The Economist, 2013). Figure 1 demonstrates how the earnings before tax & interest (EBIT) for European utility

countries has declined from 2011 to 2012, and projects further decline in earnings from conventional generation in particular, as the year 2020 approaches.

Figure 1: Declining value creation potential from conventional generation, the core profit pool in the European Utility Industry (2012).



In a move indicative of the change afoot in the utility industry, Germany’s second largest electric utility, RWE, recently announced plans to transform its business model, reinventing itself as a “renewable services provider” (Lacey, 2013). The company’s existential crisis came about as a result of plummeting profits, with recurrent net income falling by fully one third since 2010 (The Economist, 2013). Renewable energy and the changes to the electricity grid that will accompany them pose a significant threat to the conventional value streams of these companies, but at the same time present an opportunity for forward-looking industry players to benefit from capturing new profit opportunities as they come to exist. Energy storage is one sector in which utilities are currently evaluating the prospects for positive investment, and a promising one at that. A recent survey of 54 utility executives from 13 countries

across the globe found that although 23% saw energy storage as a potential threat to profits, 29% identified energy storage systems (ESS) as a development with the potential for revenue upside (St. John, 2013). Given their predominant position in the energy sector, it will be important that utilities see the potential value of energy storage and are made able to capitalize upon this value through proper regulatory measures.

2.3 Integration of Renewable Energy Resources

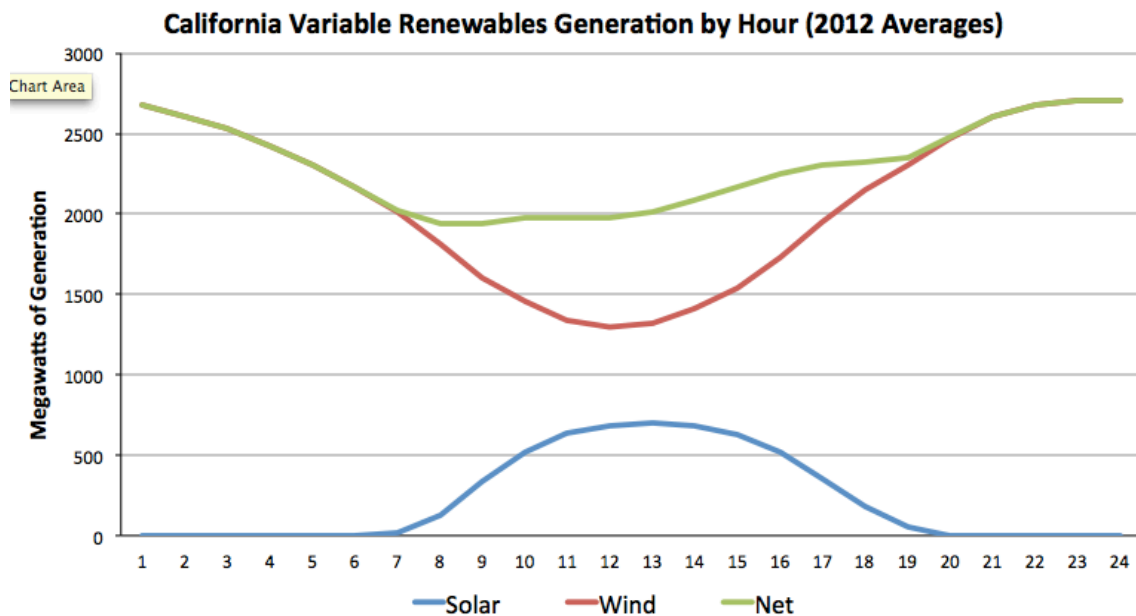
The California electricity market has been in the spotlight many times, but most recently much attention has been directed toward the state's Renewable Portfolio Standard, which currently mandates that by December 31st, 2020, one third of all energy retail sales in the state must be derived from renewable sources. This is a target that will likely increase, as the recently passed Assembly Bill (AB) 327 authorized the CPUC to establish even higher procurement goals for the future (DSIRE, 2013). The 2003 Energy Action Plan adopted by the CA energy agencies further strengthens the state's support for renewables by mandating a "loading order" that must be implemented by LSEs when participating in CAISO auctions, wherein cost-effective energy efficiency strategies must be the first method employed in meeting electricity demand, followed second by cost-effective renewable energy generations. Only after these two resources are fully utilized may conventional energy sources be employed in meeting load (Trabish, 2013).

This trend towards higher levels of electricity market penetration by renewable energy sources is consistent with the state's ultimate goal of carbon dioxide emissions reductions to 80% below 1990 levels by the year 2050 (Williams et al., 2012). It is also a trend that could threaten the reliability of the grid and the stability of electricity prices, necessitating a variety of technological and regulatory responses of which storage is one. The closure of the San Onofre Nuclear Generating Station will also have a significant impact on the availability of consistent, clean energy and further necessitate the implementation of load balancing and capacity resources such as storage on the California grid (Olson, 2013).

Load Shifting

Given the intermittent nature of renewable energy generation, there has been considerable discussion of the roles that energy storage could play in helping to “smooth” the supply of electricity from such sources. Indeed, this has been the most highly publicized and politicized argument in support of energy storage deployment in California, and will ultimately prove to be a technologically necessary one should intermittent RES achieve a high enough level of market penetration. Figure 2 displays the average hourly output from renewable energy sources in California over the course of a day. It can be seen how, when averaged over the course of a year, renewable energy generation follows a general pattern that declines during daytime hours as wind facilities, which produce the majority of their energy during nighttime hours, decline in output. It can be seen that as of 2012, wind and solar energy actually complement each other fairly well, with one balancing the output of the other to create an average net load that is fairly consistent on an hourly basis and that only dips by a maximum of 8000 megawatts (MW) over the course of the day. This could easily change as either solar or wind energy overtakes the other as the dominant RES on the California electricity grid.

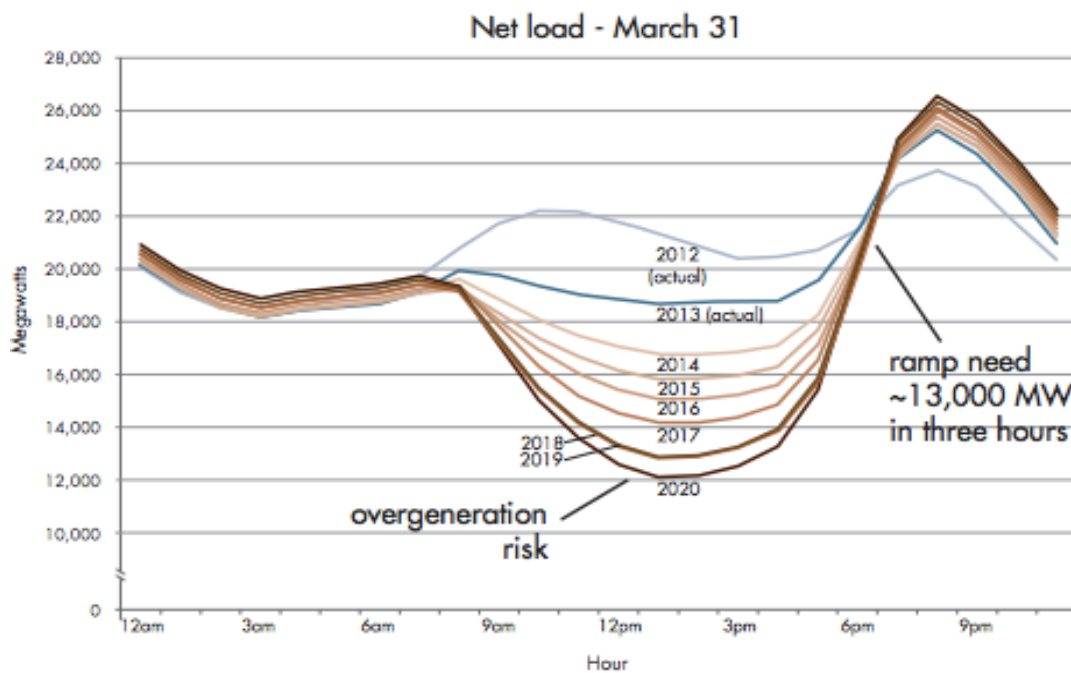
Figure 2: Average hourly output of Wind and Solar PV energy resources for 2012.



Source: CAISO website.

When discussed in reference to its role on the grid, renewable energy generation is treated as “negative load” rather than conventional generation due to its unpredictability and variability. This “negative load” allows the CAISO to lower the amount of traditional generation plants it dispatches during the day, when electricity demand is low and the amount of energy available from solar RES is high. A problem arises, however, when electricity demand skyrockets around 4 PM with people returning home from work and consuming energy, even as solar PV production is in decline and wind energy has not yet begun to supply much energy. Figure 3 was created by the CAISO to demonstrate the reality of this challenge and has been designated the “duck graph”. It illustrates the predicted net load for each hour of a typical day in March, for each year through 2020.

Figure 3: The Duck Graph



Source: CA ISO, 2013b.

The actual profiles of this day in March during 2012 and 2013 are not overly alarming, but the change seen between the net load profiles of these two years (created from real data, not projections) is more of a cause for concern. Even over the course of one year the required “ramping” capability – the ability to bring new sources of generation online quickly to meet net load – required to address this late-afternoon

net load swing nearly doubles from around 3,000 MW to almost 6,000. As is evident from the projections of future years in the graph, a considerable and increasing amount of strain will be placed on the grid operator to be able to address this swing in net load as the amount of energy produced by renewable energy sources grows. The current “duck graph” projections end with a need for 13,000 MW in around 3 hours, but the “neck” of the duck will only continue to grow with increasing penetration of renewables. In the years after 2020 we could be looking at a “giraffe” graph if steps are not taken to address this issue.

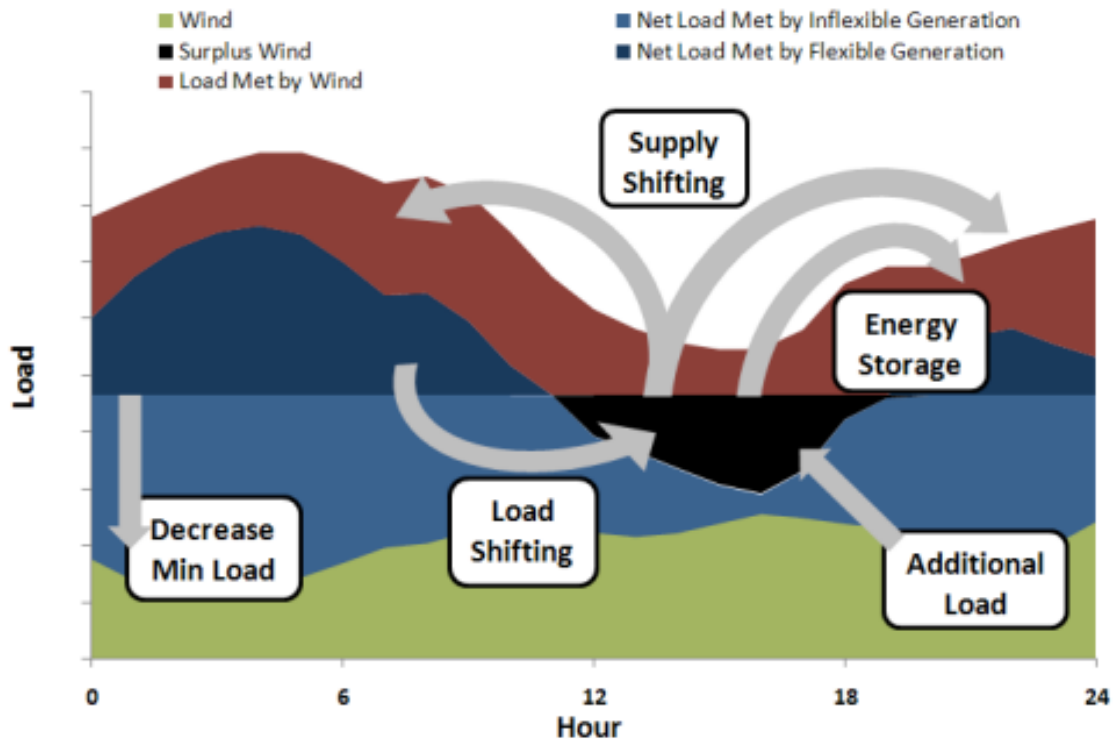
The reason for the immense swing illustrated in the duck graph is that unpredictable, intermittent resources have a very low “capacity value”, which is one of two main metrics that are used to assess the grid benefits of a generation facility. The other main metric, “energy value”, refers to the amount of energy that a facility will be able to supply to the grid at any given time, while the “capacity value” refers specifically to the amount of power a generation facility can reliably provide the grid at hours of peak demand. The reason “capacity value” is such an important metric is because it measures not only the amount of a facility’s energy that will be able to be sold at peak energy prices, but also because a high capacity value means that a generation facility has the capability of deferring investment of other forms of capacity i.e. traditional peaking plants.

A recent case study of California found that both wind and solar PV facilities saw their incremental capacity value decline significantly as renewable penetration levels increased, with the capacity value of additional solar PV decreasing by fully two thirds as the penetration of that technology approached 10% (Mills, 2013). The capacity value of wind is low even at low penetration levels due to the non-coincidence of wind energy generation with demand in that state of CA, but still declines by nearly 50% as wind approached a 10% market penetration level. The upshot of all of this is that with increasing levels of intermittent renewable generation that is non-coincident with peak demand in the state of CA, an increasing number of expensive, fossil fuel powered peaking plants will need to be constructed in the absence of energy storage.

ESS present a compelling solution to this problem due to several unique characteristics that make them far more effective than peaking plants in addressing these grid issues. The first and most basic feature that differentiates energy storage is its ability to act as both “load” and “generation” on the grid – at any given time, many ESS can either draw energy from, or provide energy to, the grid. This makes them economically compelling as a complement to renewable energy sources because they can absorb the excess or low-price energy created by VRES at off-peak hours, and then use that energy when the grid has higher levels of demand, either selling it back to the grid at higher prices or allowing ESS owners to avoid the need to purchase high-priced energy, opting to draw their energy from the ESS instead of the grid. Essentially, pairing intermittent RES with energy storage restores their capacity value.

Though electricity consumers engaging in such arbitrage would be doing so for their own good, there is a welfare effect associated with such behavior in electricity markets that comes in the form of lower electricity prices for all grid-connected consumers (Sioshansi, 2010). This is due largely to the elimination of the system need for expensive peaking plants and their high marginal cost energy as electricity demand that would typically prompt grid operators to bring peaking plants online is shifted to off-peak hours. This concept, known as Permanent Load Shifting (PLS), is illustrated in Figure 4 on the following page with a simplified example illustrating a wind-powered RES that overproduces during the day. This figure is only illustrative, and is not intended to serve as a representation of actual data.

Figure 4: Supply Shifting/Load Balancing Capabilities of Storage



Source: Denholm, 2010.

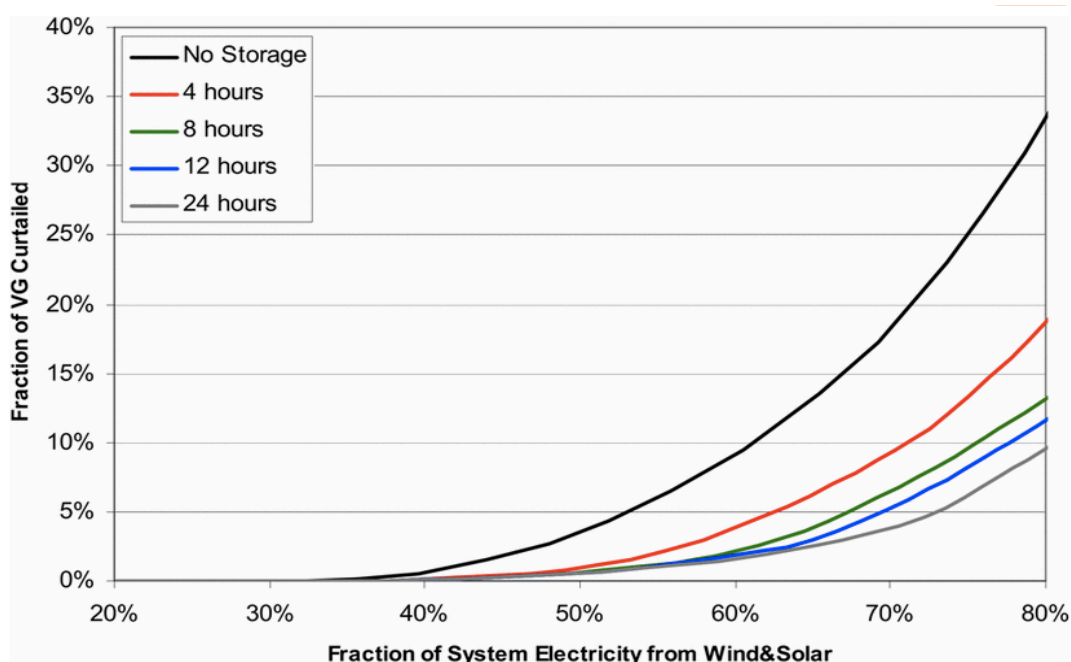
In this graph of a hypothetical electrical system with high penetration of intermittent wind generation, it can be seen that surplus wind energy is being produced between hours 12 and 18, when net load decreases due to dwindling electricity demand. Placing ESS on the grid would open up the possibility of “absorbing” this excess energy and using it to offset the need for additional generation capacity, in the form of flexible thermal generation (FTG), later in the day. In assessing which grid assets to employ in meeting peak load, the industry typically evaluates alternate strategies using Levelized Cost of Energy (LCOE), which ranks technologies by their cost per unit of energy provided over an entire lifecycle, as a metric. From this point of view, this practice makes sense only if the cost of installing sufficient ESS to achieve this is less than the combined cost of installing and operating FTG, which would be largely dependent on natural gas prices and carbon prices. In light of CA’s aggressive RPS and the massive social need to reduce carbon emissions, however, another factor needs to be taken into account; the potential curtailment of RES. Without storage, this “surplus” wind

energy would not even be produced, as intermittent RES would be ordered to curtail their generation so as not to overload the grid with too much electricity.

Renewables Integration

Even today on the CA electricity grid, energy that could be produced at an incredibly low marginal economic and social cost is turned down due to the fact that basically, the grid cannot absorb it. The Tehachapi region in CA is one area where the utility operating the wind energy generation facility has to practice curtailment around 6-8% of the time due to congestion of local transmission lines (Fink et al., 2009). Curtailment of RES remains an exception on today's electricity grid, but it has been demonstrated that curtailment levels increase in a non-linear fashion with increasing penetration of intermittent RES, as shown by Figure 5 below.

Figure 5: Simulated Curtailment of Variable Generation as a Function of Storage in ERCOT.



Source: Denholm, 2012.

In this simulation of the Electric Reliability Council of Texas (ERCOT) grid, significant curtailment does not begin until around 50% of the energy used by the grid

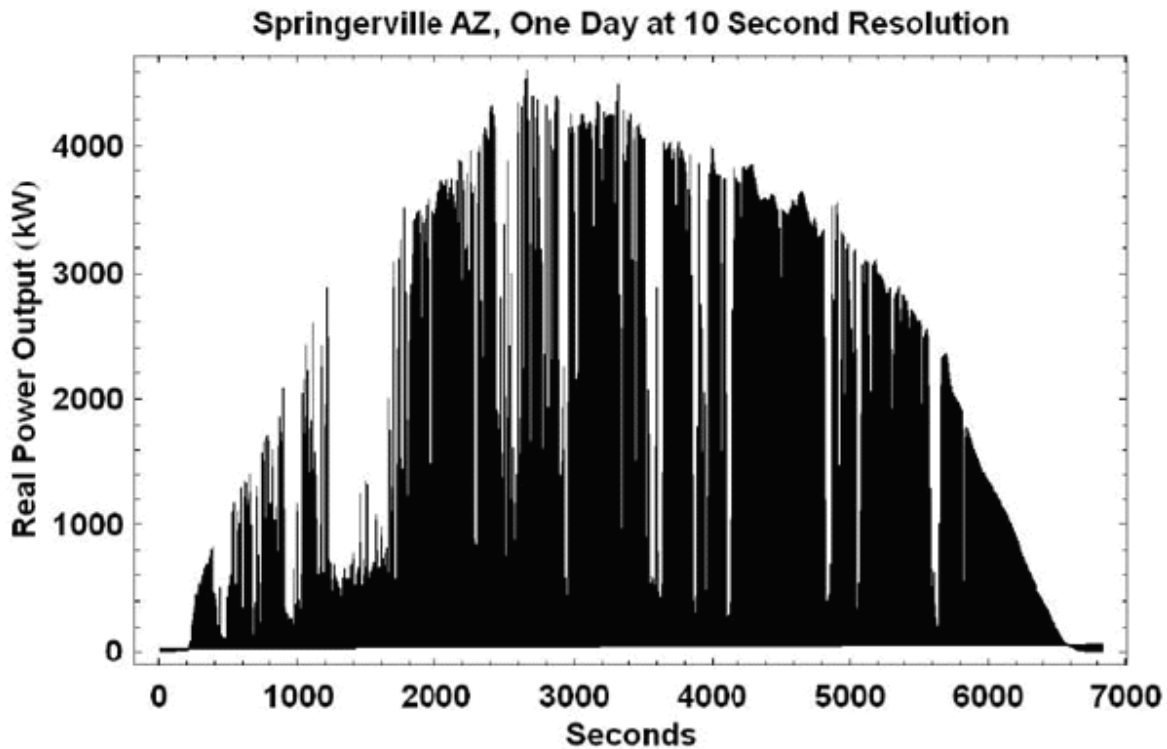
is produced from wind and solar generation, but increases very steeply after that point without storage capacity. This causes the LCOE of RES to increase equally quickly, due to the fact that LCOE is inversely proportional to capacity factor in a generation facility with zero marginal operational costs (Denholm, 2012). This is consistent with findings that on the CA electricity grid, solar PV and concentrated solar power (CSP) facilities would experience substantially greater curtailment without storage capabilities than with them as penetration levels approach 15-20% for each technology (Mills, 2013). It is important to note that while significant curtailment does not begin until fairly high levels of penetration are reached, without ESS the diminution of the value of RES energy begins far earlier than curtailment because a portion of the energy they produce must be sold during low-price periods.

For CSP in particular, it was found that while without storage, 7% and 48% of energy produced at these penetration levels would have to be curtailed or sold at low prices, respectively, the ability to store this energy for 6 hours would essentially mitigate curtailment while keeping energy sold at low prices below 2% (Mills, 2013). This is an especially promising value proposition because CSP, which operates by harnessing solar heat to create steam, is naturally a very good candidate for the installation of a thermal energy storage (TES) system. TES has the potential to make CSP more dispatchable an energy resource than either wind or solar PV, which would significantly raise its capacity value over that of other intermittent RES (Madaeni et al., 2011).

Ancillary Services

The final, and most pressing issue that an RPS poses to the California electricity grid is an increase in short-term variability of electricity output with increasingly intermittent RES. While the average, long term patterns that VRES follow (see Figure 2) are fairly predictable, the variability of these resources on a daily, hourly, and even second to second basis can be extreme. Figure 6 on the following page illustrates the real-time variability seen in the output of a solar PV facility in Arizona.

Figure 6: Real Time Variability in output of Solar Electricity Generation Facility in Arizona



Source: Apt & Curtright, 2008

Although you can see that the general outline of the output from this one day at a solar generation facility in Arizona follows a similar shape as the annual averages displayed in Figure 6, it can also be seen that the actual real-time output of the facility can vary from peak to nearly zero in a matter of minutes or less. As an increasingly large percentage of our electricity is derived from RES this creates a need to obtain “flexible resources”— those that can switch very quickly from acting as a neutral or even positive load on the grid to acting as a supplier of energy— to account for this problem. To return to the pond analogy, these are the resources that allow the system operator to keep the “water level” even on a second-to-second basis, despite potentially large fluctuations in the real-time inputs to the system. A 2010 California Energy Commission study found that the 33% penetration level targeted by 2020 could cause “extreme” degradation of the performance of the CA electricity grid without investing in mitigation technologies such as flexible resources (KEMA, 2010).

Many energy storage technologies fit this description, both for their ability to both withdraw and supply energy to the grid, effectively doubling their regulation capabilities (Lin, 2011), and for their comparative advantage in speed – most batteries can provide instantaneous power to the grid at speeds on the order of a few milliseconds (Divya & Østergaard, 2009). There already exists a commercial market for such services – known as the Ancillary Services (AS) market in California. As our energy sources become increasingly intermittent, these markets will only expand as a reflection of the grid’s need for load balancing resources; AS markets will be discussed in detail in section 3.4.

In sum, an increasing level of RES on the California grid presents a range of issues to grid operators, utilities, and ultimately anyone who relies on the CA electricity grid. Some of these concerns are more immediate than others. Lower-cost substitutes for ESS may exist up to a certain point of market penetration, but although studies have found that with “low levels of VRES [variable renewable energy sources] penetration in a strong grid, electricity storage is not crucial” (Beaudin et al., 2010), they have also concluded that storage becomes increasingly important for grid stability as RES levels increase. As an expert contact on SoCal Edison’s special projects management team put it, ESS application may not be essential even at the 33% market penetration level targeted by the RPS, but it will become increasingly important and feasible as penetration levels reach 40-50%, and “that is the direction the state is heading” (SoCal Edison, Personal communication, October 2013).

Chapter 3: Energy Storage

The previous chapter entailed a description of the technical, regulatory and economic landscape of the California electricity market into which energy storage technologies will be propelled by Assembly Bill 2514. More specifically, AB 2514 will promote the deployment of “energy storage systems” (ESS), defined as “commercially available technology that is capable of absorbing energy, storing it for a period of time, and thereafter dispatching the energy” (AB 2514). The bill, passed in 2010, also authorized the California Public Utilities Commission to begin proceedings towards establishing an acceptable target for the procurement of such technologies by the state’s IOUs. This broad definition of ESS was intended to “embrace a mix of ownership models and contribute to a diverse portfolio that can encourage competition, innovation, partnerships, and affordability” (CPUC, 2013).

3.1 Assembly Bill 2514

On October 17, 2013 the CPUC established a procurement goal of 1.325 GW by the year 2020 for the three IOUs, further directing Community Choice Aggregators and Electric Service Providers (ESPs - i.e., competitive retailers) to acquire the equivalent of 1% of their generation by the same date. Table 1 on the following page outlines the procurement goals set for IOUs, which shares the same basic structure as the regulations currently in development that will guide procurement for publicly owned utilities (POUs). In the relevant press release, the CPUC established three main goals as underlying their decision to incentivize the development of energy storage capacity in California (CPUC, 2013):

- 1) Optimization of the grid, including peak reduction, contribution to reliability needs, or deferment of transmission and distribution upgrade investments

- 2) Integration of renewable energy

- 3) Reduction of greenhouse gas emissions to 80 percent below 1990 levels by 2050, per California’s goals

Table 1: California ISO Energy Storage Procurement Goals, by MW of Capacity.

Year	2014	2016	2018	2020	Total
Southern California Edison					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal					
SCE	90	120	160	210	580
Pacific Gas and Electric					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal PG&E	90	120	160	210	580
San Diego Gas & Electric					
Transmission	10	15	22	33	80
Distribution	7	10	15	23	55
Customer	3	5	8	14	30
Subtotal SDG&E	20	30	45	70	165
Total					
All 3 utilities	200	270	365	490	1,325

Data from California Public Utilities Commission. 2013

Each of these three goals also identifies a broad category of value for any ESS that can address these present and future grid adaptation issues.

The mandate allows for flexibility in that an IOU may defer up to 80% of target storage capacity to a later installment period, if they demonstrate that the mandated amount is not operationally or economically viable for them during the stated period. This will be helpful to IOUs in allowing them to procure storage capacity cost-effectively as it becomes technologically available, but the flexibility is limited. The bill also includes an absolute installation deadline of 2024, meaning that by this year there will be fully 1.325 GW of installed energy storage capacity on the California electricity grid. This is an exciting development given the potential for energy storage to be a “game changer” for the California electricity grid, yet AB 2514 will be only the beginning for the energy storage industry in this state.

The flexibility of the mandate, along with its emphasis on cost-effectiveness, means that despite the hard procurement goals, even under the mandate energy storage will only be deployed where the technology is an economically viable choice. For example, in deploying their portion of the ESS technology under the mandate, SoCal Edison has stated that they will use an application-specific approach in which they identify the most promising value streams for storage and match these niche applications with the most cost-effective, appropriate ESS technology (Rittershausen and McDonough, 2011). What this means is that energy storage regulation and deployment should be viewed as a way to fulfill a need of the electricity grid, rather than as a means of promoting a certain technology. If alternative means of addressing these issues are more cost-effective, they should be deployed before ESS.

3.2 Application Categories

Section 2.3 identified several significant challenges that will confront the CA electricity grid in coming years, that energy storage has the potential to address. Some of these categories were permanent load shifting, the need for more flexible resources with quick ramping capabilities, and the goal of achieving the state’s RPS and GHG emissions goals as efficiently as possible. Most uses of ESS fall into one of these broad categories, but there are several other distinctions that are important to recognize regarding the deployment and use of ESS, as they will largely impact the

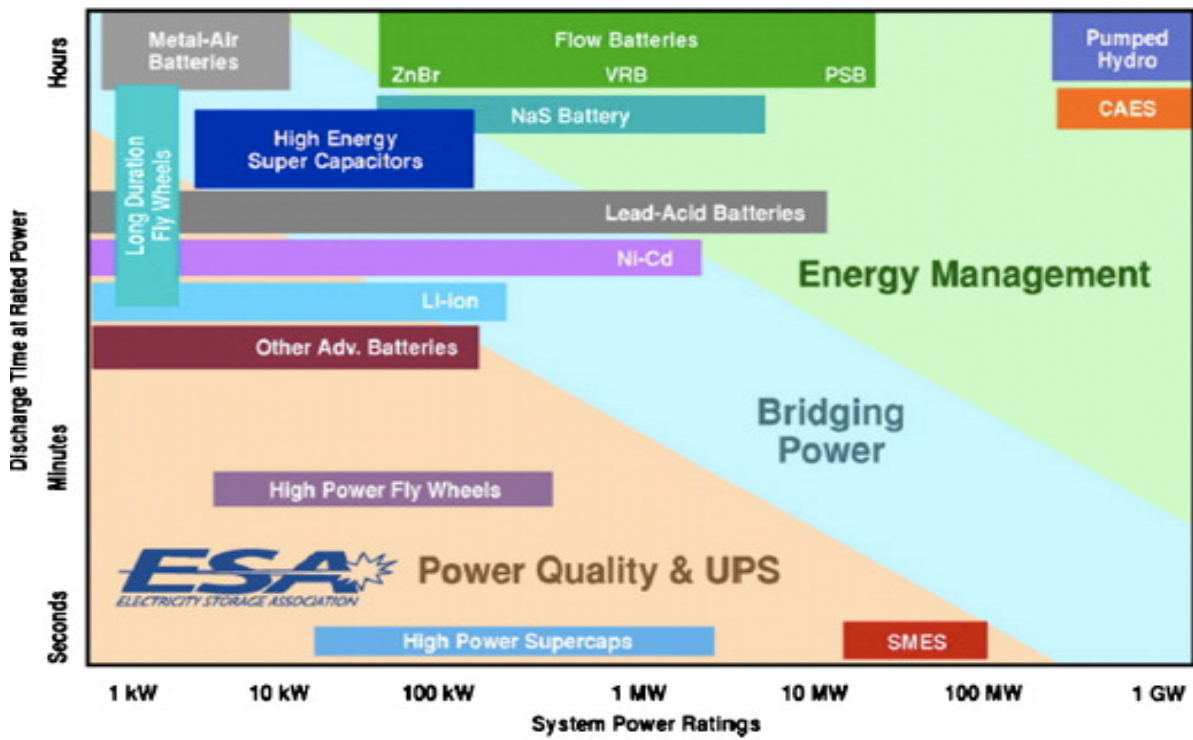
ability of ESS to be properly remunerated and will have implications for the structural future of CA's electricity grid.

System Security Vs. System Adequacy

Most of the value to be derived from energy storage technologies is a result of their ability to make the electricity grid more flexible in the face of a shifting regulatory and technological environment, thereby increasing the overall reliability of the grid. The National Energy Research Council (NERC) has defined system reliability as "the degree to which the performance of the elements of the technical system results in power being delivered to consumers within accepted standards and in the amount desired", and identified two distinguishable aspects of grid reliability. These are system security, which relates to the ability of the system to withstand contingencies, and adequacy, which refers to the ability of grid operators to consistently meet the aggregate power and electricity demand of all consumers (Oren, 2005).

Storage technologies are often classified by energy capacity and power capacity, and these characteristics will play a large part in determining which of the two grid reliability categories a technology may prove useful for at the grid scale. Figure 7 on the following page provides a comparison of the different extant storage technologies by rated power and discharge time at that power level, as well as providing some examples of use categories that technologies with certain characteristics might fulfill, along the top of the graph. Technologies that lie near the bottom of the graph are known as Limited Energy Storage Resources (LESR) as they can provide power at their rated capacity for only a short amount of time, such as seconds or minutes at most. LESRs such as flywheels and certain batteries are more applicable to the provision of grid security, and are valued mainly for their ability to provide ancillary services. The technologies listed farther up the graph, notably CAES, Flow Batteries and Metal-Air Batteries, have longer charge and discharge cycles and are able to provide electricity to the grid for longer periods of time, but often at the cost of flexibility. These resources provide adequacy to the grid by increasing the capacity value of RES, and are valued primarily for their ability to permanently shift broader, more predictable energy usage patterns and allow ESS owners to take advantage of temporal differentiation in electricity prices.

Figure 7: Power and Energy Capacities of ESS Technologies, with Applications.



Source: <www.energystorage.org>

Security and adequacy are two distinct grid characteristics that require the implementation of correspondingly distinct technologies to achieve. Both of these are services that will be essential to the CAISO and the CA electricity grid in general as our electricity is obtained from increasingly intermittent resources like wind and solar generation facilities.

Locations within the Grid

Another important classification category, and one that the CPUC in fact identified and accounted for in their mandate, is the location of storage capacity on the grid. The three categories identified by the CPUC are transmission-connected, distribution-connected and storage that is located with end-users; this report will add a fourth category, that of generation-owned and sited (this falls under transmission-connected in the mandate, but the distinction is significant enough to warrant a fourth category). Although the CPUC has established targets for each category provided for in AB 2514 (see Table 1), the ultimate location and ownership of energy storage facilities beyond

the mandate will be determined more significantly by the characteristics of the technologies that become competitive as the energy storage industry grows and the influence of regulation. Certain operational features of successful technologies, including but not limited to safety, durability and energy capacity, will also have a strong influence on the outcomes of this category. This category is especially intriguing because the location of storage, along with who owns and operates it, will play a major role in determining whether energy storage technology is deployed as just another part of a centralized, utility owned electricity grid, or as a truly disruptive technology that challenges the current energy use paradigm.

Use Category

There are a variety of recognized value propositions for electricity grid services that storage can fulfill. Which specific application a facility will be applied to will depend largely on the previous two categories. The likely uses of storage, by location along the grid, are displayed in Table 2.

Table 2: Likely Use Categories of Storage, by Location.

	Adequacy/Capacity	Security/Flexibility
Transmission and Distribution	Line and Transformer Deferral, Load Shifting (Peaking Plant Deferral, Renewable Penetration)	Stability, Ancillary Services (Frequency Regulation, Spinning Reserve)
End-Use	Load Shifting/Peak Load Reduction, Energy Arbitrage	Power Quality/Reliability, Distributed Generation & Smart Grid Support Reserves
Generation	Increased Value of Generation/ MWh (Dispatchability), Spinning Reserve, Capacity Deferral, Load Balancing,	Voltage/Frequency Regulation.

The use cases listed here are the most potentially valuable discrete value streams of an ESS, and therefore the most likely uses of an energy storage system should it be introduced to the grid under the ownership structure of a party looking to maximize profit. Many of the benefits of energy storage are the most valuable when provided to the electricity grid as a whole (Denholm, 2012), and Section 3.5 will examine these systemic effects of storage. These use cases were developed

considering technical feasibility, the accessibility of the relevant markets to certain parties, and the incentive structures guiding players at various locations on the grid. The realization of these use cases depends upon, in addition to the two variables listed here, ownership category (which will influence the operational incentives of any given ESS) and the market avenues that are created for proper remuneration of each use. These will be examined in Section 3.4.

3.3 Technology

It is important to this analysis to conduct a review of the state of energy storage technologies and their attributes, in order to more effectively match them with appropriate applications on the grid. Storage technologies can be implemented at three basic levels: bulk storage, grid-scale storage and distributed energy storage (DES). These can be generally classified as facilities that provide storage at the Gigawatt (GW), Megawatt (MW), and Kilowatt (kW) scale. This report will focus on grid-scale technologies, but will also review the potential for bulk storage as well as for the aggregation of large amounts of distributed end-use storage.

The only form of storage with any prominence in electricity grids as they currently exist is bulk storage, in the form of pumped hydroelectric storage (PHS). The 120 GW of PHS that is currently installed accounts for 97% of global installed energy storage capacity, and is equivalent to approximately 3% of the world's total installed generation capacity (Beaudin et al., 2010). This report will avoid PHS, both because it is largely excluded from the counting towards procurement targets under the AB 2514 mandate, and due to the fact that mounting concerns over the environmental impact of reservoirs may limit the feasibility of such projects in the future (Yang & Jackson, 2011), especially in the state of California.

Energy storage systems comprise a wide range of technologies with many different characteristics. These subtleties can make a “uniform comparison of storage technologies (for example on a \$/kW or \$/kWh basis) difficult and often of limited use” (Sioshansi et al., 2012). For this reason I will discuss the likely technologies in context, as opposed to attempting to judge them across one unilateral criteria. There are numerous functional distinctions that can be drawn for energy storage technologies.

Several of those most important in determining the nature and impact of storage deployment in the state of California will be employed in this report. The following is a brief review of four of the most promising technologies, identified in the California Senate's analysis of AB 2514 as likely to have an impact on the electricity grid as a result of their ability to provide valuable services to the grid (Senate Rules Committee, 2010). The basic metrics most relevant to this analysis have been identified for each technology, while the advantages and disadvantages of each technology have been identified. The primary metrics identified include:

Ramping: The amount of time that an ESS takes to go from zero power output to full power output. Quick ramping is the main feature of a "flexible" system and has many advantages over traditional generation.

Duration: How long an ESS can provide power at its rated capacity. This will determine whether an ESS is more relevant to grid capacity or security.

Efficiency: Indicates the energy loss involved with electricity conversion into and back from each ESS. Will be especially important for technologies attempting to take advantage of price differentials.

Longevity: The length of an ESS life cycle has been identified as having important implications for both its economic (CPUC, 2010) and its energetic (Bahnard et al., 2013) justifications. A longer life cycle means a more useful technology.

Cost/kWh: This metric looks at the LCOE of energy an ESS can provide. Although this is not necessarily the best measure of life time cost for ESS, which often concentrate on power, rather than energy, capacity, it is important because it is the metric commonly used in the energy industry and is the one that will be used to compare ESS will against other grid assets.

Several other important, but harder to quantify for inclusion in the table, considerations looked at include safety and locational restrictions such as energy density – technologies that require a large land area to store energy will be at a disadvantage to technologies that can do so in a compact way, especially for uses nearer to end-users. See Appendix 2 for a more complete listing of extant storage technologies and their metrics.

Compressed Air Energy Storage (CAES) Systems

CAES systems employ off-peak power to pump air into a container, typically an underground salt cavern or similar geologic formation, where it is stored as potential energy until needed. When excess power is needed for the grid at peak hours the air is released and heated, passing through the turbine of an engine that converts the energy back to electricity for use on the grid (Chen et al., 2013). These systems can go from zero to full capacity of power output in 5-12 minutes - a quicker ramp rate than traditional gas-fired peaking plants – and typically have a high energy capacity, making them good candidates for meeting peak load. CAES also have large energy capacity and can provide energy to the grid for extended durations, making it a good option for PLS as well. These systems are somewhat limited in that they need to be placed in a location with a suitable area for placing the compressed air (such as old mine shafts) and also must have access to natural gas pipelines and electricity transmission.

Advantages: Economy of scale is created allowing low capital costs /kWh.

Disadvantages: Low energy density for aboveground CAES. Below-ground CAES require specific geographical features.

Ramping	Duration	Efficiency	Longevity	Cost (\$/kWh)
5-12 minutes.	8-20 hours.	60-80%	>13,000	60-125

Flywheel Energy Storage (FES)

Flywheels are an LESR that convert electricity to maintainable kinetic energy to allow for conversion back to electricity when needed at peak hours. These systems consist of disks rotating on ball bearings, and a generator that can convert the angular momentum of the desks into electricity and back. FES can store energy at relatively high efficiency for short periods of time, but are also subject to high rates of self-discharge due to frictional losses over longer periods (Rastler, 2010).

Advantages: High efficiency, very responsive/flexible resource. Long lifecycle equates to lower capital costs per kW provided.

Disadvantages: Low energy density, inability to provide power for long durations. Very high initial capital costs.

Ramping	Duration	Efficiency	Longevity	Cost/kWh
<4 milliseconds	1 hour or less.	93%	>100,000	7800-8800

Thermal Energy Storage (TES)

TES systems use off-peak energy to create thermal energy that is then stored in a medium until it can be used either as thermal energy or for conversion back to electricity. These systems have the advantages of simplicity, safety and the ability to alter the air conditioning patterns of buildings, which the CPUC estimates account for more than 40-50% of a buildings' peak electricity demand on hot days ("Ice Bear Energy Storage System"). One of the most promising TES systems employs air conditioning systems that create large amounts of ice during the middle of the night, a period of very low electricity demand, and then use this ice to cool entire buildings during the day without the contemporaneous use of electricity. By taking advantage of a diurnal effect and creating the coolant (ice) at night when thermal energy efficiency is high, as opposed to during the day when it is hotter and thermal efficiency is lower, such systems are able not only to shift a building's AC energy usage but also to reduce it, making the "effective efficiency" of these systems as compared to conventional AC units greater than 1 (Ice Energy).

Advantages: High efficiency, low levelized costs.

Disadvantages: Only applicable for certain uses (primarily AC), does not truly store electricity but rather shifts usage. Heat loss makes energy storage for periods longer than daily cycle unfeasible.

Ramping	Duration	Efficiency	Longevity	Cost/kWh
N/A	6 hours	80-99% (>100% counting diurnal effect)	25 years.	Low.

Battery Storage Systems

Battery systems encompass a wide range of technologies that employ an equally wide variety of chemical processes to maintain electricity within a container for a period of time, allowing it to be discharged as needed. Other than the use of chemical reactions to store energy there are few unifying characteristics for these technologies, but several promising battery technologies are identified here.

Flow Batteries

Flow batteries consist of two tanks of electrolyte solution, each with an electrode and a circulation system that pushes the electrolytes into a central unit where they are separated by a membrane. As electrolytes flow through the system they undergo reduction and oxidation (redox), which allows them to store or provide electricity, respectively. A recent study showed that flow batteries have a lot of potential to be a cost-effective storage option, but required “technical validation of performance and durability at smaller scale” (Rastler et al., 2012).

Advantages: While power capacity is limited by the size of the membrane, the energy storage capacity (duration at rated power capacity) can be increased by increasing the volumes of the two electrolytes and is thus theoretically limitless (Leung et al., 2012). Modularity also means that rated power can also be increased relatively easily, meaning it may be possible to lower costs by creating economies of scale in the future. Full discharge possible without damage to system.

Disadvantages: Low energy density, requires large area. High levelized cost for commercially available technologies. Commercially available technologies undergo damage with cycling.

Ramping	Duration	Efficiency	Longevity	Cost/kWh
Seconds.	4-5 hrs. (for commercially available)	65-70%	Theoretically limitless, but currently low.	> 500 kWh

Metal-Air Batteries

Metal-Air batteries have several advantages over traditional batteries; their fundamental ingredients are plentiful and inexpensive, they involve no toxic components and they have the potential to store energy for comparatively long periods of time. While not commercially proven, these systems were found by a survey of emerging storage technologies to have significant potential to provide storage services with at the “lowest projected [capital] costs” (Rastler et al., 2012). Though this technology is only on the brink of commercial grid-scale deployment, the following are the projected characteristics of a new Zinc-Air battery developed by Eos Energy Storage (Eos Energy Storage, 2013). These batteries are being deployed by utilities worldwide for the first time during 2014, and as such have not been truly tested, but these numbers can be considered those of a competitive, and nearly commercially available metal-air battery.

Advantages: Safety, Modularity, Low levelized costs.

Disadvantages: Not a high efficiency. Long life-cycle technologies not yet commercially proven.

Ramping	Duration	Efficiency	Longevity	Cost/kWh
Immediate	4-6 hours.	75%	>10,000	160

Li-Ion Batteries

Li-ion batteries have a long history of use in consumer electronics where they are valued for their high energy density and relatively low weight, with approximately 10-12 GWh installed globally (Rastler, 2010). This commercial maturity provides a market advantage; this technology is positioned to be the primary battery system for electric and plug-in hybrid vehicles, and could prove applicable for grid uses with duration needs less than 4 hours.

Advantages: High Efficiency. High energy density.

Disadvantages: Limited lifespan. Safety Concerns (Fire). High levelized costs.

Ramping	Duration	Efficiency	Longevity	Cost/MWh
20 milliseconds	15 min. – 4hrs.	90%	Info not currently available	900 - 6200

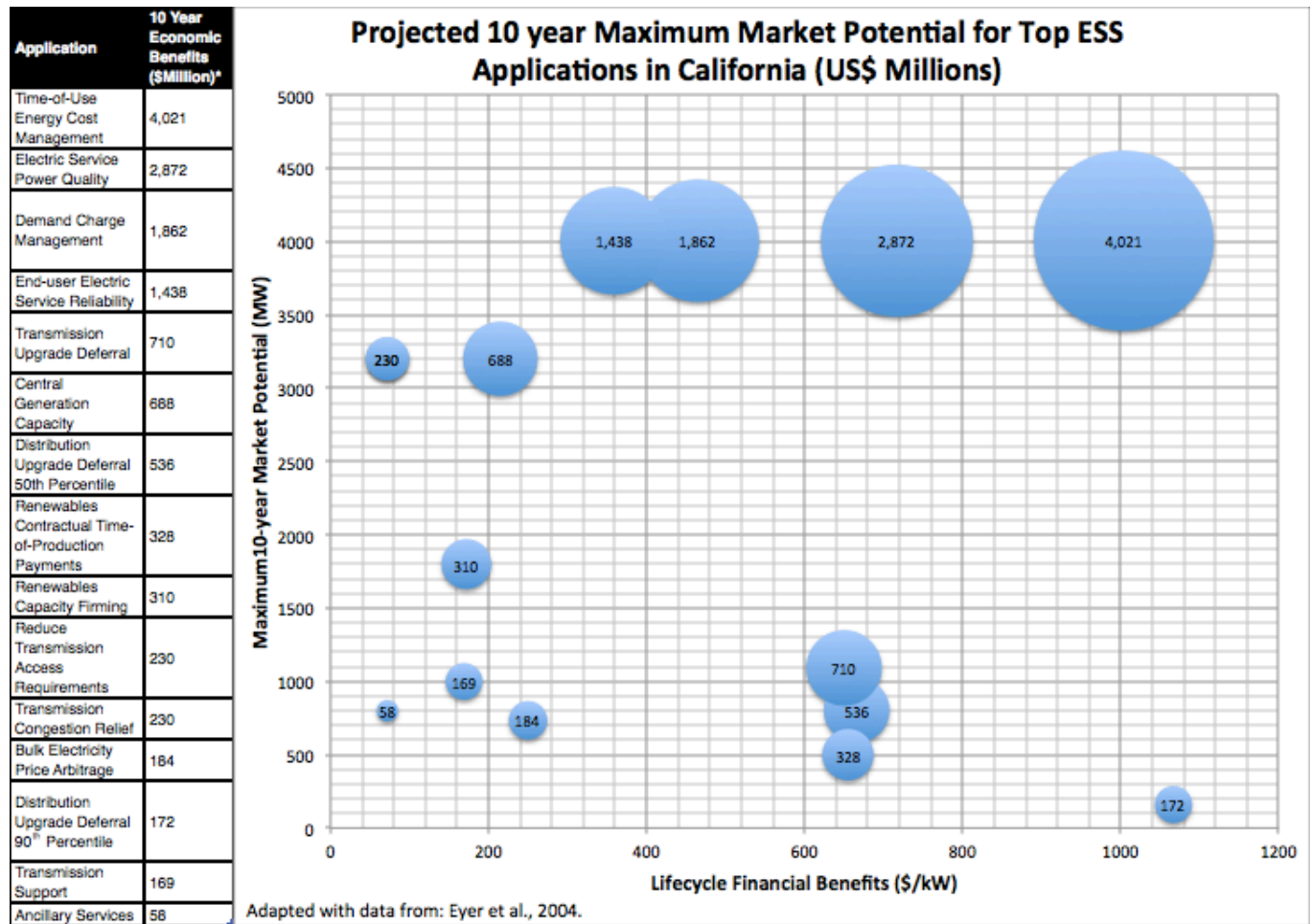
Battery systems currently take a back seat to other energy storage applications, largely due to safety and cost-effectiveness concerns, but rapid advances in battery technology will make them formidable competitors in the energy storage field in coming years.

In actually procuring and installing storage capability, utilities and commercial investors alike will weigh the costs of each technology against the attainable value streams for each application to determine whether or not they will be a cost-effective deployment. These value streams are subject to and dependent upon both the regulatory treatment of storage and market developments. Considerable uncertainty exists in both of these areas, and could serve as a barrier to investment in storage technologies.

3.4 Value Recovery/Mean of Monetization

The main factor governing if and how storage becomes an independent and transformative industry is an economic one; storage facilities will not be installed if there are not sufficient prospects for owners and investors to recover the value that they create. Though energy storage provides an array of benefits to the grid, much of the value created by an ESS may be difficult for potential investors to monetize and profit from. This could prove a substantial impediment to investment in energy storage technologies. A medley of factors including but not limited to ownership, regulatory developments and electricity prices will influence the potential for investors in storage capacity to obtain the financial compensation needed to make the project cost-effective (OEERE, 2011). Figure 8 on the following page illustrates the projected market size for the key potential value streams of an energy storage industry. This graph clearly illustrates that the potential for value creation exists for a prospective energy storage sector. However, the means for recovery of that value may not yet exist under the current electricity market structure in California.

Figure 8: Projected Size of Market Potential for CA Energy Storage Industry, by \$/kW.



There are two main obstacles to the realization of the value created by energy storage; the first reason for this is the fact that many of the services provided by storage – decreased likelihood of blackouts, generally lower electricity prices, etc. – can be classified as public goods. If the electricity industry in CA remained a vertically-integrated system owned and operated by utilities, this would not be an issue as these overarching entities would be able to internalize most of the benefits provided by storage to the system as a whole, by virtue of their position. In a deregulated, market-operated electricity market, however, such goods are plagued by monetization issues such as the free-rider problem, and often will not be produced at socially efficient levels. The right amount of grid-connected energy storage can provide a plethora of indirect benefits, but parties will not invest in this level of storage if they cannot realize value from it. This is one argument for utility ownership of a certain amount of the energy storage capacity on the grid; due to their relationship with the public sector,

utilities are able to achieve cost recovery from such public goods through the Cost Allocation Mechanism (CAM)¹. While a private investor would look skeptically at the cost-recovery prospects of installing storage for a generally more reliable grid, utility companies are in fact guaranteed cost recovery as well as a reasonable level of profit for investment in assets deemed beneficial to the grid by the public sector (Energy Division, 2010). This problem is one fundamental to public goods and cannot necessarily be fully addressed through changes to the market structure; this first issue will be addressed in the Section 5, where policy recommendations are made.

The second main obstacle to monetization of storage's benefits is a matter of market design – storage does not fit neatly into the classification and valuation mechanisms used by the market upon which grid assets are currently bid and sold. The three main mechanisms for cost recovery of grid assets are the energy, capacity and AS markets (Energy Division & Policy & Planning Division, 2013). While alternatives to energy storage systems such as traditional generation, natural gas peaking plants, and even energy efficiency resources can be broadly classified and valued by these markets as either generation or load reduction, storage does not fit into this paradigm. ESS are unique in their ability to switch temporally from acting as either generation or load as well as in their ability to simultaneously provide multiple benefits to the grid. Despite these attributes, under the current system storage must bid into the same AS, energy and capacity markets as the other assets that these markets have actually been constructed for; this means that the unique abilities of storage systems such as extreme flexibility are not properly valued or compensated. While storage can still be remunerated for certain value streams in this context, studies have found that ESS are not usually cost-effective in scenarios where compensation is provided for only one or several of its value streams. For storage systems to become economic, allowing society to obtain all of the real but currently intangible benefits it provides, more comprehensive mechanisms must be constructed for the full cost recovery of storage projects by all parties.

¹ The CAM is a means by which utilities can “socialize” the cost of new, CEC-approved grid

3.4.1 CA Energy Markets

A good deal of ESS value lies in their ability to make the grid operate more efficiently and reliably as a whole, but some of their services do fit into the traditional markets for electricity grid assets in California. Here the CA markets for three fundamental energy services – capacity, ancillary services, and energy – are analyzed by virtue of their current and future prospects as cost recovery mechanisms for ESS.

Capacity

In contrast to other load-balancing entities such as the NYISO and PJM, the CAISO does not have an explicit market for capacity procurement. Rather, the CAISO mandates the adequate level of procurement for each LSE (currently defined as 15-17% above the forecast system need at any time) and then leaves it to LSE's to procure adequate capacity through bilateral contracts (Energy Division & Policy & Planning Division, 2013). Although determining the capacity value of an ESS is a difficult task due to the need for detailed modeling of system operations, this is a promising value proposition for utilities investing in ESS as capacity prices may increase as dispatchable generation is replaced with variable resources (OEERE, 2011). Though ESS are not currently eligible to provide capacity to utilities through the RA program, the CPUC is in the process of considering a rulemaking to allow compensation of ESS services in this way. There is a target date of 2014 for the CPUC ruling, meaning that if ESS qualify, utilities will soon be able to fulfill resource adequacy requirements through bilateral contracts with ESS merchant owners and developers (Cho, 2013). There has been a discussion of implementing a formal market for capacity like the ones that exist for other systems (Energy and Planning Division, 2013), in hopes that this would address the issue that “backup capacity is needed but not adequately remunerated” (Beckman, 2013).

Ancillary Services

Ancillary Services markets exist to ensure that enough flexible resources are made available for the CAISO to bring online as is necessary to balance supply and load. In California, AS markets exist for Frequency Regulation, Spinning Reserve, Non-spinning Reserve, Voltage Support and Black Start (definitions from Lin et al., 2011).

Frequency Regulation: A resource that can rapidly alter electricity output in response to direct digital control (Automatic Generation Control, or AGC) signals in order to maintain the target system frequency. AGC is used to maintain the Area Control Error (ACE) in the face of rapid load fluctuations, which can cause deviation from the ideal frequency and output. Can be further divided into Regulation Up (increase in output) and Regulation Down (decrease in output).

Spinning Reserve: The portion of unloaded synchronized generating capacity that is immediately responsive to system frequency and that is capable of being loaded in ten minutes, and that is capable of running for at least two hours

Non-Spinning Reserve: The portion of generating capacity that is capable of being synchronized and ramping to a specified load in ten minutes (or load that is capable of being interrupted in ten minutes) and that is capable of running (or being interrupted)

Voltage Support: Services provided by generating units or other equipment such as shunt capacitors, static VAR compensators, or synchronous condensers that are required to maintain established grid voltage criteria. This service is required under normal or system emergency conditions

Black Start: The procedure by which a generating unit self - starts without an external source of electricity thereby restoring a source of power to the CAISO balancing authority area following system or local area blackouts.

In particular, the Frequency Regulation market provides a compelling opportunity for energy storage technologies, which can provide both Regulation Up and Regulation Down services, unlike traditional regulation resources. Frequency regulation is a particularly viable use case for LESRs, for whom “the economic opportunity....is not in shifting power from off-peak to on-peak, but from their rapid response rate” (NY ISO, March 2010). Black start also provides a promising value proposition for storage facilities, in particular battery systems, which need no external electricity to be brought online.

While the CAISO required only 419MW of regulation capacity in 2009 (PG&E, 2010) it is predicted that when the state reaches its goal of 33% RPS, 1,114 MW of regulation capacity will be needed (CAISO, 2010). Quick ramping, flexible resources like most ESS can prove to be 3 to 3 times as efficient per MW rated power capacity than traditional regulation resources for two reasons (Lin et al., 2011). Firstly, FR can achieve their target level of dispatch much more quickly meaning that they can then be ordered to increase or reduce dispatch more often. Second, traditional resources have longer ramping periods and cannot shift their dispatch from positive to neutral or negative quickly and thus sometimes in fact dispatch in the wrong direction to meet system needs. For these reasons, investment in flexible regulation resources, as opposed to traditional slow-ramping ones, could decrease regulation procurement needs by up to 40% for CAISO – an enormous cost savings (Makarov et al, 2008). A CPUC analysis of different ESS use cases found that Frequency Regulation revenue was one of the most important value streams for ESS, and that the implementation of a rule that explicitly values “flexibility” of a resource would improve the cost-effectiveness of many ESS (EPRI, 2013). The CAISO has taken steps towards compensating FR for this valuable efficiency improvement (see Table 3), and CESA continues to lobby for AS markets more receptive to ESS characteristics and that more properly value ESS capabilities.

Energy

In order to acquire the electricity used in AS markets, arbitrage or for end use, ESS that is not paired with generation will purchase electricity either from local LSEs or by bidding directly onto the CAISO energy market as traditional generation or load, depending upon their size. There currently exists a 500kW minimum for resources to bid onto the CAISO wholesale market (FERC, 2010), which is an improvement from the previous 1MW requirement, but still places an inefficient restriction on smaller resources. Those smaller, distributed storage resources purchasing retail energy on the LSE tariffs will not be participating in energy arbitrage per se as they will not resell the energy, but rather will purchase electricity when it is inexpensive for later use when prices are higher at times of peak demand. Larger resources may attempt to take advantage of electricity price disparities between on- and off-peak pricing periods, or even between different electricity markets, by purchasing large blocks of cheap energy

and selling it later at a higher price. There does not currently exist a very strong economic case for ESS as residential energy management or for large scale energy arbitrage in CA, but this could and likely will change as the structure of electricity prices and LSE tariffs in CA come to more appropriately reflect the true social costs of generation.

There have been efforts, both at the federal and the state level, to improve these three markets in such a way that they will be able to more properly value and incentivize the unique capabilities of ESS and other FR. Table 3 on the following page highlights several of the most important recent pieces of legislation that have been passed with this goal in mind. These pieces of legislation mark progress towards the creation of a market structure that more appropriately values ESS and FR for their system benefits. In particular, the changes propelled by FERC 890 include amendments to the CAISO tariff that make the AS markets much more accessible to non-generator resources by 1) reducing the minimum power rating for eligibility to 500kW from 1MW 2) specifying that resources will only be counted as providing energy under the continuous energy requirement once they have reached their target level of dispatch (not while ramping) 3) reducing the continuous energy requirement for AS to 30 minutes for spinning and non-spinning reserves, 60 minutes for day-ahead regulation, and 30 minutes for real-time regulation (from the current unilateral two hour requirement) (FERC, 2010).

At the moment the CA electricity markets present several disjointed but usable avenues for the realization of some of storages' value streams. Of the ESS value streams not applicable to these markets, some are inherently restricted to certain ownership categories – for example the deferral of new transmission and distribution lines by utilities. Four general ownership categories can be identified as utilities, merchants, generators and end users. Each of these parties will have different incentives for how to use their storage capacity and indeed different prospects for value recovery due to some market limitations.

Table 3: Legislative Market Reform for ESS in CA.

Legislation	Effect	Status
AB 2514	Mandates 1.325 GW of procurement goals for IOUs in California by 2020.	Active in CA.
SB 412	Self Generation Incentive Program provides \$2.00/W rated capacity to storage systems capable of discharging at capacity for at least 2 hours a day. Maximum size of 3 MW.	Active in CA.
Federal Investment Tax Credit	Allows for a federal tax rebate of 30% of ESS project value, if paired with photovoltaics.	Active in CA.
FERC 890	Requires ISO to “account for the special circumstances presented by intermittent generators” by developing appropriate market rules, tariffs, and control algorithms for new technologies such as ESS.	Tariff Amendments implemented by CAISO.
FERC 755	Establishes two-tier compensation method for ancillary service markets. Adds pay-for-performance standard, increasing the value of flexible assets like energy storage.	Implemented by CAISO (with mileage product).
FERC 764	Transmission providers to offer an option to schedule energy in 15 - minute increments, creates an opportunity to improve CAISO real - time market design (proposed full three settlement market: day ahead, 15 minute real time, 5 minute real time markets) (Casey, 2013).	Implementation planned (Spring 2014)
FERC 784	Permits third parties to sell AS to transmission providers at market-based rates. Requires transmission providers to consider speed and accuracy of resources in determining reserve requirements for self-supply of AS. Creates reporting mechanisms to track and record ESS costs for increased transparency.	Not yet implemented by CAISO.
FERC 792	Expands Small Generation Interconnection Agreements and Procedures to include energy storage devices. Clarifies capacity stating LSE’s should “generally assume the maximum capacity that the storage device is capable of injecting when deciding whether a device may be interconnected” (Sutherland Asbill & Brennan LLP, 2013)	Not yet implemented by CAISO.

3.4.2 Ownership Category

Utilities

Utilities are perhaps the best positioned entities to simultaneously capture multiple value streams from energy storage projects, and as such the most likely to find cost-effective applications for storage technology. ESS have greater value if deployed as a system level asset (OEERE, 2011), and utilities are the best positioned to employ them in such a way due to their control of T&D lines and their relationships with parties at all points on the grid. Utilities have been left to bear many of the costs of renewable integration in California. Energy storage projects will allow the deferral of expensive T&D system upgrades that would otherwise be necessitated by increasing levels of renewable energy penetration, as well as helping utilities avoid imbalance charges that are increasing annually with RES market penetration – total CAISO charges increased from around \$165 million in 2011 to nearly \$235 million in 2012 (Kurlinski, 2013.). At the same time, utility-owned ESS will be able to provide services to the CAISO's energy and ancillary services markets including the newly-adjusted, pay-for-performance Frequency Regulation market that explicitly values the quick response times of many ESS (See Table 3). Some regulatory uncertainty does come in to play here – if the storage resource is owned by a publicly regulated utility or other LSE, then presumably the project should be financed via the CAM – it is unclear whether ESS owned by such an entity should be able to access AS market revenues (DNV KEMA, n.d.).

Capacity

Utilities and other Load Serving Entities (LSE) in CA are required to procure and demonstrate Resource Adequacy (RA) on an annual basis. Utilities are generally expected to own little capacity themselves but rather to purchase their RA requirements through contracts with third parties, and then to distribute the costs of this among energy users through the CAM. There is no centralized market for capacity in CA at the moment, although there is discussion of introducing one in the face of increasing future capacity needs (Energy Division and Policy & Planning Division, 2013).

Merchant

It is unlikely that utilities will be allowed ownership over most of the ESS installed on the CA grid. The mandate allows for 50% ownership, but this will likely decrease as ESS become less of a novelty and come to be viewed as more of a standard grid asset, which utilities have been discouraged from owning in California since the deregulation of the electricity market at the turn of the century. Under the mandate 50% of the ESS must be procured from third parties, and if an independent industry for storage develops in CA it will likely take the form of merchant-owned storage facilities. These facilities will (dependent on the aforementioned CPUC ruling) be able to sell capacity to LSE's as well as to bid into the ancillary services and energy markets. Specifically in the energy markets, merchant owners could look to profit from energy arbitrage.

Energy Arbitrage

Energy arbitrage is perhaps the most intuitive and straightforward potential use for energy storage, and is hypothetically possible for any entity that submits energy bids into the CAISO energy markets. Most studies have found that investments in energy storage technologies for energy arbitrage purposes alone would not provide ample revenue to achieve what is normally considered an acceptable return on investment (Kintner-Meyer, 2010). This could certainly change within the California framework if legislation is introduced to address the increasing disparity between generation peak hours and peak load through a more responsive, real-time pricing mechanism that would help create more extractable value in this area; AB 327 suggests this may happen before the end of this decade. Dependent on location, enterprising merchant storage owners could also leverage differences between energy markets; a proposed CAES plant in Texas is looking to do just that by purchasing and providing energy on both the Electric Reliability Council of Texas (ERCOT) and the Southwest Power Pool (SPP) markets (Giberson, 2011). Although arbitrage is at its core a profit-maximizing behavior, it can produce some welfare effects by leveraging lower electricity prices in one area and selling them at competitive prices in another, presumably utilizing available energy more efficiently and cost-effectively; indeed, a study found that of all third-party owners, merchant-owned ESS would provide the most welfare benefits (Sioshansi, 2010).

Renewable Energy Generators

Although it is not the most valuable use of ESS to the system as a whole to have facilities co-located on-site with generation due to incentive issues that lead to the production of an inefficiently high amount of producer surplus (Sioshansi, 2010; EPRI, 2013), renewable energy suppliers could benefit in several ways from on-site storage.

Higher Value for Power Purchase Agreements

Storage capabilities would allow intermittent renewables to “smooth” their energy output and make their energy more predictable, and thus more attractive and valuable to utilities and other potential contract customers who wish to form Power Purchase Agreements (PPAs). With sufficient storage, certain types of intermittent renewables could become dispatchable, thus increasing their capacity value. As an expert contact in the Regulatory and Market Affairs Division at Brightsource Energy expressed to me during a conversation about storage, the storage capability that is inherently present in their concentrated solar power (CSP) technology is their main competitive advantage over other renewable energy generators, fetching their energy a higher price in Power Purchase Agreements (PPAs) made with utilities. Although the several PPA’s Brightsource held that explicitly valued their energy storage capabilities were either rejected by the CPUC or have been terminated, the ability to internally control their own energy output is of great value to them as a generation facility (David Schlosberg, Personal Communication, November 2013).

Sales on CALPX

Generation facilities not under contract, on the other hand, could hypothetically hold their energy from the market until peak hours when it fetched a higher price on the CALPX market, a form of arbitrage of sorts. As levels of intermittent generation increase, however, storage will most importantly allow generators to dramatically decrease losses from curtailment orders, simply storing the energy until it was permissible to release it to the market, rather than letting their facilities sit idle. Curtailment comes at a high cost to renewable energy providers – they would lose both the 12 cent/kWh production incentive that they currently earn in CA, as well as effectively increasing the levelized cost of their energy because they would be producing less energy while capital costs remained the same.

Customer/End User

Electricity consumers – residential or C&I customers - who wish for more control over when and at what price they purchase electricity from the grid may invest in an ESS. Much of the value of an ESS to an end user will be related to their own personal electricity bill –note that time-of-use (TOU) energy management is by far the most valuable potential market value in Figure 8 - by investing in an ESS, they will be able to avoid peak rates and reduce potentially expensive peak demand surcharges. Empowering consumers to take greater control of their energy use patterns is of no small value – this use has in fact been estimated to be the largest source of market potential for a national energy storage industry (see Figure 8), if the correct incentives are provided. For residential customers in CA, the recently passed AB 327 prohibits the implementation of mandatory time-of-use (TOU) pricing until 2018, at which point the CPUC is authorized to mandate TOU (CALSEIA, 2013). This should open up a large market for residential scale, distributed energy storage that can be aggregated and used as grid scale-assets – a similar trend is already happening with C&I customers who currently face TOU pricing in CA.

Since the passage of the California mandate, a company named Stem has targeted hotels, chain stores and restaurants as potential customers for its load shifting technologies, which they say could decrease a customers' energy bill by 10-40% (Wang, 2013). In addition to saving their customers a substantial amount of money, companies such as Stem may be able to sell the capacity provided by their units to utilities; Stem is currently in talks with some CA utilities about such an arrangement. The use of such technology also provides a valuable public good in generally cheaper and cleaner electricity, as a reduction of only 5-10% in peak demand has been shown to dramatically decrease electricity prices across a given area (Fox-Penner, 2010). Although incentives for such behavior exist for the commercial and industrial sectors since the implementation of time-of-use charges, until 2018 the majority of retail customers will receive only tiered rates that do not reflect the true production costs of the energy they use, and that therefore provide little incentive to manage energy use temporally.

Efforts are being made to create a more competitive marketplace for energy services in California, in which all parties can more easily realize the value provided by ESS. Indeed, bulk energy time management and ancillary service markets will provide the majority of the cost-effective value propositions for energy storage systems in the near term (EPRI, 2013). The problem with all of these niche value propositions, however, is that they only exist because of the fact that the grid is operating on the 20th century, load balancing paradigm due to the fundamental inability to store energy. Energy market products such as Frequency Regulation have value precisely because of the need to instantaneously match supply with demand, which would not be as much of an issue on a grid with significant storage capacity. This means that some of the benefits accrued to society from the installation of storage, including progress towards such a future grid, may be true public goods and as such must be addressed through policy and larger economic incentives rather than by simple restructuring of the market. The following section identifies some of the public goods provided by energy storage.

3.5 Systemic Effects of Storage on Grid

The role to be played on the electricity grid by ESS and its substitute load-balancing services will only increase as California moves closer to its 2050 emissions reduction goal. The recently legislated AB 327 has established California's 2020 goal of 33% renewables as a floor, and authorized the CPUC to further increase RPS procurement goals. Between this and the recent success of the state's carbon cap and trade program, which has completely sold out of permits during its first two years of operation (Spross, 2013), it can be stated with a fair amount of certainty that the state is headed in the direction of continually expanding levels of RES as well as towards the internalization of the costs of carbon emissions. These trends will combine to create more viable cost-effective applications for energy storage, as a complement to a growing RES sector. At the same time, the ability of the grid to store electricity from these resources through ESS will become a much more important public good as well.

Section 2.3 discussed the increasing probability of curtailment of RES as market penetration levels increase, if storage is not installed or other measures taken to prevent this. The alternative is a huge public investment in transmission lines at an equally huge cost to taxpayers, but this will not be necessary if storage is installed in

strategic locations, allowing loads to be shifted by a couple of hours or more. Both California's RPS and its cap and trade program will function to bolster the case for ESS as a means of reducing curtailments and avoiding overinvestment in transmission.

ESS technologies are valuable to the grid as a whole because they give grid operators the ability to maximize energy production from the lowest marginal cost (and cleanest, if pollution costs are internalized) generation resources on the grid, given the generation assets that exist. At the moment, when RES facilities are told to curtail production they reduce their output of zero marginal cost, zero emissions energy, which is later compensated for by ramping up production of peaking plants, usually in the form of Flexible Thermal Generation (FTG). RES producers operating under a PPA are fairly indifferent when it comes to curtailment because their contracts with IOUs include a provision that they will be compensated at a specified price for curtailed generation (Mulooly et al., 2011). This system is fundamentally inefficient from an economic, a GHG emissions, and a purely energetic point of view.

Economic

When the grid turns down a unit of renewable energy, it means two things. First, that unit of curtailed energy will need to be compensated for by the production of an equal unit of fossil-fuel derived energy at a later time, which in addition to costing more under the GHG cap and trade framework also creates the need for more FTG capacity. Second, due to the fact that the RPS mandates that a certain amount of energy *delivered for retail use* be derived from renewable sources, the decision not to produce this unit of renewable energy also means that another unit of renewable energy must be produced elsewhere as well, to fulfill RPS obligations. If all RES are not producing energy at 100% of their capability, it will require the construction of more RES plants on the grid than is truly necessary to reach this goal. It will also require overinvestment in the expensive FTG facilities that compensate for these RES during on-peak hours.

Even though electricity prices do not represent with complete accuracy the actual marginal system costs of producing a unit of energy, they can be a good proxy for the overall efficiency with which grid assets are being employed because they do reflect a general socialization of the costs of electricity production by the utility or other

load serving entity. A 2004 study modeling the effects of CAES, battery and PHS on electricity prices found that in a scenario involving 20 percent wind energy supply by 2030, storage could function to significantly decrease electricity prices (Sullivan et al., 2008). It is important to consider that many ESS value propositions are highly dependent on high energy prices (EPRI, 2013). If enough storage is deployed to drastically reduce energy prices it is possible that some value propositions of these storage devices could be threatened by their own effects on the system. Clearly, however, if energy prices drop further with the addition of more storage then value is still created with the addition of ESS. This is simply not value that can be easily monetized by any single party, and thus can be considered a public good that should be incentivized.

Carbon Dioxide Emissions

The major externality that is often not included in the prices seen by today's energy users is the social costs of the Carbon Dioxide (CO₂) emitted during its production. In the energy sector, there is already an implicit cost in fossil fuel use due to the RPS. As explained in the previous section, there is a very expensive opportunity cost involved in the substitution of carbon intensive energy production for carbon neutral sources. California has taken further steps towards internalizing the costs of these emissions through the establishment of a cap and trade (C&T) system for CO₂. In theory, this C&T system should lower the "cost-effectiveness bar" for ESS and other clean technologies by making it more expensive to use 20th century, heavily polluting ones to create electricity, thus incentivizing the CA electricity sector to institute a larger number of technologies with CO₂ mitigation potential. It is not so clear, however, that ESS will help reduce the energy sector's CO₂ emissions as a whole if storage facilities are dispatched in the most cost-effective manner. The earliest applications of ESS will be employed towards the most profitable opportunities, and potentially towards applications which may not be in line with using ESS to reduce CO₂ emissions as is laid out below.

If employed properly, ESS has the potential to reduce an electricity sector's CO₂ emissions by storing renewable, zero marginal cost and zero emissions electricity and using it to replace the energy that would otherwise be created by fossil-fuel powered

plants at peak hours. The clearest case of this would be with a storage facility owned and located with a renewable energy producer. This RES might be told to curtail their energy production at off-peak hours in order to avoid the curtailment of other resources with a higher cost to shut down, or to reduce the strain on transmission lines.

Traditionally, this energy would be replaced with electricity created from fossil-fuel powered peaking plants, but if the RES had storage on-site they would be able to hold this energy until it was needed and release it at peak hours, mitigating the need for operation of the peaking plant.

This is the most basic example, however, and the carbon mitigation potential of ESS becomes much less clear when storage is installed elsewhere in the grid. For one, an ESS that operated in the same way as the RES-owned and operated one discussed above, but that drew electricity from the grid, would in fact be drawing indiscriminately from the aggregate production of all resources on-line at that time. If fossil-fuel plants are running at this time, as they are in fact running 24 hours a day in CA, storage facilities will in fact be storing and dispatching dirty energy as well as clean. The inability of grid-connected storage to discriminate between clean and dirty energy makes the CO₂ mitigation potential of ESS technologies, and thus the potential for CO₂ reduction policies to financially propel an energy storage industry, much more ambiguous. An ESS integration study of the Dutch electricity system in fact found that the implementation of ESS *increased* the total amount of CO₂ emissions by employing cheap, off-peak coal-generated electricity to offset the lower-carbon, but more expensive to run, natural gas plants that are used at peak hours (Ummels et al., 2008).

The relationship between off-peak wind and coal may not be such a large issue in CA due to the relatively low amount of coal-powered baseload plants in operation in the state (Energy and Environmental Economics, Inc., 2010), but the lesson remains the same. Under real market conditions, the system with the least dispatch cost (short-run marginal cost) is dispatched first (Greenblatt, 2013), and even though RES have a marginal cost of dispatch near zero, some baseload coal plants will in fact pay to avoid curtailing output due to potentially expensive cycling costs that could reach as high as \$0.47–1.14/MWh of curtailed energy, under a high RES market penetration scenario (Lew, 2012). When cycling costs are taken into consideration, it becomes clear that

ESS could potentially mitigate some of the carbon cost implicit in the RPS. If an ESS absorbed off peak coal energy from a generator willing to pay them to do so and provided it to the grid later, the storage would in fact serve to substitute coal generation for what would normally be on-peak generation from natural gas, which is a cleaner, if more expensive, alternative. Until there is a carbon price high enough to offset cycling costs, this will be an issue. Only a price on carbon that would push baseload coal plants' marginal costs of operation during off peak hours higher than the cost of halting operations and suffering the costs of restarting the plant will address this issue. Until then, coal generators would rather sell this energy at a cost to ESS facilities and ESS that is employed from a lowest system-cost standpoint will in fact enable coal, the cheapest dirty generation.

While ESS, in particular ESS with long storage capacities, have the potential to mitigate some level of CO₂ emissions, the direct emissions effects of storage implementation in all but the most basic applications is far from clear. Regulatory uncertainty abounds – for example, if an ESS provides sufficient load to allow a RES to continue providing energy to the grid, but the ESS draws this energy from the grid as a whole, should that energy be credited as free of emissions? Due to such uncertainties, ESS probably should not and will not be significantly affected by CO₂ pricing schemes until a better means of establishing its system-wide CO₂ effects is developed.

Energetic

Though boundary lines do need to be drawn at some point in the analysis of a system, it is important to at least consider the energetic effects of constructing and using energy storage devices themselves. Indeed, a recent study found that from a net energetic perspective, it would be inefficient to store the energy from a wind facility using any extant battery technology, largely because some of these technologies could only store over their lifetime the equivalent of four or five times the amount of energy that was expended in producing them (Barnhart et al., 2013). They further asserted that “electricity generated using solar PV technologies can be stored efficiently using all plotted technologies, while wind power should be stored with more energetically favorable storage options such as PHS and CAES” (Barnhart et al., 2013). These net

energy implications are important from an environmental standpoint, but likely will not be considered in the actual deployment of storage technologies.

Significant curtailment of renewable resources in California is still a future issue, but a not too distant one. Figure 5 demonstrated that significant curtailment can begin as early as 40% market penetration of intermittent RES. At this point the decision will have to be made whether it would be wiser for the state to invest in energy storage to ensure that all of these clean energy facilities are optimized, or to construct additional FTG as well as more renewable energy generation facilities than is truly necessary to meet the RPS. This would be an incredibly expensive social investment in unnecessary grid infrastructure, and at this point the use case for long-duration storage should become much more attractive. Even before this point, however, energy storage can provide a valuable public good in reduced electricity prices for the system as a whole. Chapter 4 constructs some scenarios to see how these systemic effects of energy storage might play out at various levels of storage deployment on the California electricity grid.

Chapter 4: Scenarios

Energy storage as a grid asset is only in the early stages of commercialization, and as such no “standard model” has been established for how it should be deployed. It is unclear at the moment whether the 1.325 GW of mandated storage, or the storage installed after that, will take the form of large, centralized bulk storage units or a larger number of smaller, distributed energy storage (DES) units. Further, it is not evident that Energy Storage Systems (ESS) will become an established, cost-effective grid asset independent of the CPUC procurement mandate, which equates to a significant but certainly not a transformative presence of storage on the grid. As I was told by the former Chairman of the California Energy Commission (CEC), the true metric used by utilities when it comes to installation of grid assets is “what does it cost to keep the lights on” (Joe Desmond, personal communication, November 2013). If load serving entities (LSE) can “keep the lights on” more cost-effectively in the face of a changing grid through the use of alternative schemes and technologies, storage will not find many cost-effective implementations.

In this chapter, we construct several possible scenarios based on plausible projections of the current regulatory and economic state of the energy market in California. The potentially transformative nature of distributed energy storage to the current, environmentally damaging energy use paradigm makes it tempting to speculate as to what effects large scale deployment of such technology might have, but the difficulties involved in quantitative modeling of such systemic effects remind us that it is important to remember that these are only possibilities and not forecasts. The Office of Energy Efficiency and Renewable Energy has estimated that it would take approximately 10,000 person-hours to develop a tool capable of measuring and contrasting the respective values of distributed and bulk energy storage systems over the next ten years (OEERE, 2011). Though that was not an endeavor that fell within the scope of this thesis, what this paper truly aims to assess is not the normative question of how the grid should develop its storage capacity but rather the positivistic one of how grid scale storage likely *will* develop in the state of California. For this purpose it is important to first assess the primary “competition” for grid-scale ESS.

4. 1 Substitute Goods

Energy storage is not the only answer to the issues faced by California’s evolving electricity grid in coming decades. Energy storage techniques are only one way to address the difficulties associated with renewables integration, and are unique from competitors only in their ability to address many of these issues simultaneously. This capability comes with a price tag, however, and if alternatives exist that will allow the grid to deal with these problems more cheaply, these will be implemented first. The three main grid assets that can provide some of the same services as an ESS, or “substitute goods”, are Flexible Thermal Generation (FTG), demand response (DR), and the sharing of supplies and reserves over large areas through increased connectivity.

Long Distance Electricity Trading

One option for integrating renewable resources is the establishment of larger “balancing areas” (BA) – interconnected grids that can trade energy services in order to establish economies of scale and more competitive ancillary services markets. The main value of larger BAs to renewables integration can be found in the concept of “statistical independence” (EERE, 2011). This term refers to the idea that while the real time variability in output of any given RES may be high, a larger BA can aggregate the outputs of a much larger amount of RES, spread across a larger geographic area, thus lowering the statistical probability that aggregate output will vary significantly in real time. There has in fact been a trend towards larger balancing areas in the US over the past few decades, with the CAISO recently approving the market design for a Western Interconnection Imbalance Market that will allow CAISO to trade energy and energy-related services with the Oregon-based PacifiCorp, expected to go online in October 2014 (Renew Grid, 2013).

There are limits to the ability of this option to serve as a useful RES integration resource. First, the CAISO already constitutes a large balancing area in and of itself, responsible for managing 80% of California’s electricity flow and roughly 35% of the electricity used in the entire Western Interconnection (CAISO, 2013). While enlarging a BA would certainly prove beneficial to small, isolated grids, the CAISO already has

access to a large variety of technologically and geographically diverse resources; it is not clear that further expansion would provide substantial benefits to such a large BA, especially when the substantial transmission and congestion costs of long distance transmission are accounted for. Second, while increased cooperation between or even consolidation of BAs is desirable from the standpoint of statistical independence and competitive energy markets, the ability of ISOs to do so is limited by the physical reality of existing transmission lines. Growth in peak demand from AC units, computers and other modern necessities has exceeded transmission capacity annually by 25% (Brown & Koomey, 2003). California already faces a shortage of transmission lines which has caused the appearance of “transmission-constrained” areas that suffer from a lack of “local capacity” even while “system capacity” is in oversupply (Energy Division & Policy & Planning Division, 2013). Even within the context of CAISO, the CPUC has identified this issue as a reason to pursue investment in flexible resources (FR) like ESS, which can address local capacity needs without the construction of transmission lines, rather than to build new T&D lines, which can take five to ten years to install and carry very high fixed costs. All of this means that while contracts between the CAISO and other BAs could yield some desirable results, they would likely come with very high transaction costs in the form of new transmission lines.

Flexible Thermal Generation

Another potential substitute for ESS is the installation of more Flexible Thermal Generation (FTG) capacity, primarily in the form of natural gas peaking plants. Compared to other forms of conventional generation, these plants have the lowest upfront investment costs and comparatively high fuel costs (Eurelectric, 2011), making them an attractive option for LSEs looking to add capacity that will be operational only during times of peak load. ESS employed for the purpose of meeting peak load have nearly the opposite investment profile – extremely high upfront costs and negligible operational and maintenance costs once installed. In procuring either resource, potential investors will ultimately choose one based on the levelized cost of energy (LCOE) of each resource. LCOE computation can be a highly detailed procedure when discounting and other necessary subtleties come into play, but in concept is fairly simple: divide the lifetime costs of procuring, running and maintaining an energy resource by the amount of electricity it can provide over its lifetime. While this metric is

very complicated to compute for an ESS due to the multiplicity of potential operational strategies for such a system, the lifetime costs to the system, once procured, would be very certain as fixed, upfront costs account for a much greater portion of ESS costs than variable ones (Rastler et al., 2012). For FTG, on the other hand, LCOE is extremely dependent upon fuel prices - installing FTG is making a bet on low natural gas prices for ten or fifteen years, a risky move for the CA electricity grid.

Traditionally FTG been used to provide peaking power as well as ancillary services (AS) to the electricity grid due to their relative operational flexibility as compared to other traditional generation plants, which often incur high costs when cycling – changing output to produce significantly more or less power than their rated capacity (Lefton & Besuner, 2006). An “average” FTG could be considered one with the ability to ramp at 5.1% per minute, reaching full power output in about 20 minutes, although newer, state-of-the-art plants will have superior operational features (Lin et al, 2011). Though this flexibility is competitive with that of bulk storage techniques such as compressed air energy storage (CAES), it is significantly slower than that of most LESRs. This has implications for the AS applications and effectiveness of each technology; one study found that the CA electricity grid would require 2.5 times the amount of rated power capacity in FTG to provide the regulation services that could be provided by flywheel technology (Makarov et al., 2008). Lin et al., 2008, provides an illustrative example of how a LESR might help avoid excess capacity on the grid:

“Imagine that a system operator experiences a sudden generation loss. To meet NERC requirements², the operator must bring on 25 MW in additional generation within the next ten minutes. In other words, over the next ten minutes, the system operator needs a 2.5 MW per minute ramp rate total from all generators providing regulation. If the only regulation generators are gas turbines with a 5.1% ramp rate, there needs to be 49.1 MW of these gas turbines online to meet the operator’s ramp requirement. In contrast, 25 MW of energy storage could provide the full 25 MW of additional power within 20 milliseconds.”

Despite the superiority of certain ESS technologies in terms of flexibility, FTG also holds one very important advantage: unlimited generation capacity. While an ESS can

² NERC CPS2 requirements

deploy electricity to the grid at its rated power capacity only until the energy it is capable of storing runs out, once a FTG has ramped fully it can provide its rated power to the grid for an indefinite amount of time, using the energy stored in a virtually unlimited supply of fossil fuels. LESRs such as the flywheels modeled in Makarov et al., 2008, can dispatch their power instantaneously, they can do so for only a limited amount of time, making them more suitable for addressing unpredictable net load swings caused by contingencies such as weather patterns or generation loss, as in the example cited above. It is for this reason that although ESS and FTG will compete for some value streams on the future grid, at the moment the two are better viewed as complementary goods (Casten, 2013).

The types of bulk storage ESS that could compete with FTG for applications with longer energy needs, such as CAES and pumped hydroelectric storage (PHS), faced higher upfront costs as well as the same transmission constraints as FTG, while LESRs are not truly viable replacements for FTG in terms of provision of peak power. Until a commercially viable ESS with high power *and* energy capacity comes to the market, both flexible thermal generation and energy storage resources will be necessary on the CA electricity grid. A study conducted by Eurelectric concluded that in Europe “gas-fired power stations will be one of the most important contributors to the integration of RES” (Eurelectric, 2011), the same will likely be true for California in the absence of disruptive technological change in the ESS sector.

Demand Response

Demand response (DR) can be defined basically as programs that influence the behavior of end-use electricity consumers through incentives or other pricing schemes in order to reduce their demand at peak hours. Although DR requires the use of financial incentives to influence behavior, it can often be one of the cheapest options available in addressing load balancing issues due to the capital-intensive nature of electricity grid infrastructure. Indeed, pilot programs in the US have reported a benefit: cost ratio of 7:1 for certain programs (Albadi & El-Saadany, 2008). DR resources are already in use by investor-owned utilities (IOU) statewide that currently use them to meet Resource Adequacy requirements (Perlstein et al., 2012); one of the most widely

used DR techniques is time-of-use (TOU) pricing, which has been found to be especially effective when combined with critical peak pricing.

DR has the potential to provide cost-effective mitigation of grid reliability concerns at low RES penetration levels, but it has limitations. First, DR depends on shifting consumer behavior and studies have shown that when it comes to electricity use, consumers have a very low elasticity in the short run (Borenstein et al, 2009). Elasticity of demand for electricity increases in the long run and in response to very aggressive pricing policies, which have achieved in reducing peak demand by up to 42% (Charles River Associates, 2005). The fact remains, however, that while some consumer electricity use can be shifted from peak periods with appropriate price signals, the electricity usage of most consumers is determined more by their daily schedule than by their electricity bill. While some electricity end-uses, i.e. agricultural pumping, can occur at any time of the day, there are some uses of electricity that are time dependent and simply cannot be shifted (for example, lighting or use of appliances) without the use of technologies with temporal load shifting capabilities. Second, while DR can cost-effectively shift general usage patterns, it lacks in the areas of response time and precision, characteristics that are essential to the proper function of AS markets. A recent report found that although DR could be a good candidate for the new flexible resources AS markets in CA, nearly all DR programs would require at least some modifications in order to become eligible for the AS market (Perlstein et al., 2012). Lastly, while DR can effectively provide regulation up services to the grid, they are limited in their ability to provide regulation down services, which would consist of programs to increase consumer demand, a goal seemingly perverse to the conceptual motivations of DR in the first place.

Demand response measures can achieve some of the same goals as energy storage by taking advantage of elasticity of electricity demand, where it exists, and promoting load-shifting behavior through the use of incentives. In this sense DR and ESS can be considered competitive, substitute goods for some applications. At the same time, however, the very changes in consumer behavior that DR aims to induce – reduction of electricity usage during peak load, shifting of load and investment in on-site generation capacity – further necessitate technologies with load-shifting capability

such as ESS for situations where electricity demand is truly inelastic, and energy must be used during certain time of day. One notable example of this is can be seen in Ice Energy's thermal energy storage systems, which are used to shift customers' electricity consumption for daytime air-conditioning uses to the nighttime. Through the aptly named "Project Cool Move", Ice Energy aggregates a network of distributed storage units to provide clean, cheap capacity for purchase by utilities (Ice Energy website) while simultaneously allowing customers to take advantage of the incentives provided by TOU pricing. Thus while DR may at first disadvantage ESS by providing a lower-cost option for shifting energy use in some situations, in the long run the incentive structures created by DR measures will create more value propositions for certain ESS technologies, especially those with long duration load-shifting capabilities.

As the CA electricity grid currently exists, there are some RES integration opportunities for which any of these three options is capable of providing the grid capabilities needed at a lower cost than ESS. At the same time, ESS prices are dropping and will continue to do so with the implementation of the CA mandate, while ESS remains the most flexible and versatile integration resource available. Furthermore, the substitute goods listed above "are ultimately limited in scale and scope" (Denholm, 2012), while many of the ESS technologies coming to market are modular and thus scalable to grid needs. The bottom line is that as the CA electricity grid evolves, ESS will eventually become a cost effective option as the opportunities to use cheaper substitute goods expire. Whether or not ESS will become cost-effective *before* some of these substitutes depends largely upon the other factors that follow.

4.2 Scenario Components

Energy Storage System Technology

The single most significant factor to consider in the construction of grid-deployment scenarios is technology. Technology shifts have the potential to profoundly influence any market, and the market for energy storage in CA is no different. A recent survey of energy storage CEOs uncovered a general consensus; the probability is very high that one or more disruptive technologies will be introduced to the energy storage industry within the next five years (Munsell, 2013). Should ESS technology advance as rapidly as these industry experts predict, the CA energy storage industry will be one that is quite sensitive to technological change in its development. Although it is clearly difficult to predict a “disruptive” technology, some characteristics that such a storage technology may hold are identified.

Though all storage techniques aim to improve certain metrics – efficiency, levelized cost of energy and power, etc. - certain types of storage technology are more subject to technological change than others. While bulk storage and other technologically simple load shifting techniques such as CAES and thermal energy storage are unlikely to see notable technological advances due their maturity as well as their physical limitations, emerging storage technologies – in particular, new types of batteries – are poised for major improvements in coming years.

Bulk storage is currently much cheaper than battery storage for most applications, but batteries have an advantage over many bulk storage systems in both their operational flexibility and the fact that they are constrained by their current technological state rather than geographic or physical factors (Kintner-Meyer, 2010) – that is to say, there is a lot of room for improvement. In particular, battery storage is well poised to control the market for small scale DES due to their high energy densities and locational flexibilities (Rastler, 2010). Important areas for battery improvement include:

Safety

For any ESS that would be located with or near residential DG units, safety is the primary concern. Battery technologies that have not shown that they can perform safely without risk of fires or other hazardous events will not be installed at the residential or community level. In particular, Lithium-Ion batteries are prone to oxidization reactions and fires, and must undergo extensive and expensive safety precautions before being ready for such an application (Hadjipaschalis et al., 2009).

Durability

One of the main limiting factors in achieving cost-effective battery storage is the short life cycle of many of these technologies. A study found that increasing the life span of batteries to be the most feasible way to increase the “energy stored on electrical energy invested” (ESOI) ratios – the life-cycle energetic efficiency – of using these devices (Barnhart et al., 2013), which is an important consideration in terms of sustainability. Increased durability of these devices will similarly increase the return on investment (ROI) of these devices, decreasing their LCOE over their lifespan and improving cost-effectiveness (EPRI, 2013).

Materials

An important aspect of a successful battery technology will be the resources it uses to store chemical charge. The choice of abundant resources to serve as the electrodes and other components of batteries will contribute to the creation of technologies that are both less expensive and more sustainable (Armand & Tarascon, 2008). This is one advantage that metal-air batteries, such as Eos Energy’s zinc-air battery system, have over batteries with high-efficiencies but that consume scarce and valuable resources such as lithium.

Energy Capacity

Lastly, and perhaps most importantly, a disruptive battery storage technology will be one that is capable of providing a high energy capacity as well as the high power capacity that they are currently valued for. Only when battery technologies that are currently deployed primarily as limited energy storage resources (LESR) become capable of providing energy to the grid for long durations with an LCOE comparable to that of traditional generation will energy storage systems become a truly viable replacement for FTG.

These operational characteristics are those of a technology that could prove disruptive to the energy storage industry as a whole. Perhaps most importantly, an ESS technology that is truly “disruptive” in terms of changing not only the applications for which storage is cost-effective but also expanding the ones that it is technologically capable of providing will need to be able to cheaply store electricity for long periods of time. In addition, a technology that could achieve significant enough market penetration to replace FTG and corner the market for DES in the state of CA must be safe, durable, and sourced from cheap, sustainable materials in order to gain acceptance from a social and a fiscal standpoint. If such a technology is modular or highly scalable in some other way, then opportunities could open up not just for DES but for larger grid-scale applications as well.

CA Electricity Market Factors

The CA electricity market is not an isolated system but rather is intricately connected to and influenced by developments in the economic, political and social sphere at both the state and the federal level. In addition to the potential for disruptive technological change, developments in the US energy sector as a whole that could influence the economic viability of ESS on the CA electricity grid. Table 4 on the following page outlines some of the major factors considered in the scenarios to follow.

Table 4: Major Factors considered in Scenario Construction.

Energy Storage Policy	At both the state and the federal level, the regulatory environment remains ambiguous for emerging storage technologies. The FERC, CAISO and other relevant institutions are in the midst of developing the “rules” that will govern and shape energy storage market prospects as well as the nature of its deployment in CA.
Renewables Mix	As ESS are primarily a complementary good to whatever generation exists on an electricity grid, the nature of the facilities that are creating the energy to be stored will have a profound effect on the value propositions of an ESS on the grid. In particular, the balance between wind and solar penetration under the RPS will affect the energy storage industry.
Electricity Pricing Schemes	Figure 8 identified the market potential for an energy storage industry in California. By far, the most significant potential value stream (at over \$4 billion for 2004-2014) was time-of-use energy cost management. This value stream will not be unlocked without the implementation of pricing schemes that more appropriately reflect the costs of energy production.
Utility Influence	The traditional utility business model has its roots in the 20 th century energy sector paradigm of a small number of large power plants, connected by large transmission lines, providing most of the electricity to the grid. Utilities are politically powerful entities, and as many of the profit opportunities of utilities are stranded with this paradigm, they may resist the evolution of distributed generation and the distributed storage to come with it.
Commercial Adoption	The ability of third parties to develop a “standard model” for procurement of ESS towards specified applications and thereby bypass regulatory concerns and other uncertainties will greatly influence overall adoption of ESS. Residential solar systems and Ice Energy’s thermal energy storage systems are good examples of this.

4.3 Energy Storage Deployment Scenarios

4.3.1 Baseline Scenario

The first scenario that is important to consider is what could be called the “baseline” scenario. In this model, little technological change occurs for either energy storage or renewable technologies. The amount of renewables on the grid increases past the 33% RPS target, but the composition of these RES remains roughly the same with wind providing the majority of the energy to meet RPS compliance standards. Wind facilities face an increasing threat of curtailment due to both inadequate transmission and the threat of over-generation during certain periods of the year (Hawkins et al., 2007). The 1.325 GW of storage is installed by 2024, but as no disruptive, highly scalable ESS technology with high energy capacity comes into play, this storage is deployed mainly to fill in niche applications. Significantly, because the mandate requires procurement of only 1.325 MW of storage but places no duration requirement on these resources, we can feasibly envision such a world where “utilities that don’t want to spend a lot of money on this obtain a lot of low [energy] capacity resources” (Schlosberg, personal communication, November 2013). On this electricity grid, storage has three main economical value propositions:

- 1) Provision of Ancillary Services, in particular Frequency Regulation, to markets that have come to accept quick and responsive LESRs as the most appropriate technology for this purpose, due to their flexibility.
- 2) Thermal Energy Storage will continue to provide a cheap load-shifting technique to account for excess off-peak energy from wind and other resources.
- 3) Bulk storage for an increasing amount of wind energy that continues to have high output during off-peak hours.

Energy storage fills some important grid needs in this scenario, but these will really only constitute niche applications. Wind power in CA is characterized by high production levels during the night and is almost completely non coincident with peak or

even medium levels of demand due to the fact that “wind speeds are greatest when system demand is lowest” (Hennessy et al., 2005). A proliferation of wind powered RES would necessitate, and thereby create value streams for, ESS with large energy capacities and the ability to store energy for long periods of time. Without technological advances in energy capacity, however, these value streams go unfulfilled because at the moment “only two technologies—pumped hydroelectric storage and compressed air energy storage (CAES)—are cost-effective at the large temporal scales (several hours to days) needed to complement wind energy” (Greenblatt et al., 2007). Without considerable storage on the system, transmission constraints become increasingly problematic in terms of both curtailment of Renewable Energy Sources (RES) and meeting local capacity needs of certain areas.

Certain RES whose nature or location lend themselves to cost-effective storage, especially Concentrated Solar Power (CSP) facilities, will procure on-site storage capabilities in order to increase their capacity payments or to reduce curtailment. In particular, RES facilities large enough to create the economies of scale necessary to justify on-site bulk storage, such as Tehachapi wind farm, will install ESS in the form of large scale batteries or CAES, where feasible geologically feasible. Significant market potential will be created for demand response (DR) and other load-shifting alternatives such as thermal energy storage (TES). TES for the offset of peak electricity demand from air conditioning is already one of the most economically viable applications on the grid and will continue to be used, but only to the extent that a market exists for this single use application.

A recent CPUC report stated that there is a great need on the CA electricity grid for local, transmission-constrained capacity while there is in fact excess capacity for the system as a whole (Energy Division & Policy and Planning Division, 2013). This would suggest a higher value of storage facilities located closer to load, but no technology comes into play that will allow such deployment in this scenario. The lack of a technology that allows retail customers to cost-effectively manage their electricity time-of-use means that a huge potential value stream goes unfulfilled in this scenario, even if dynamic TOU pricing is introduced. The flexibility of the high power capacity resources added to the grid and used for certain Ancillary Services means that some of

the most marginal peaking plants will be made unnecessary, but Flexible Thermal Generation (FTG) will largely still be needed to address the fact that much of the energy produced under RPS does not match peak demand levels. More transmission will need to be constructed in order to connect the large peaking plants that will be needed to meet load, as well as for the large wind generation plants that produce energy at night. Overall, storage is not located or operated in a way that optimizes its potential to enhance grid efficiency in this scenario.

4.3.2 “Big Shifters”

This scenario envisions the development of a battery storage technology that could store large amounts of energy for a long time, but needed to appeal to economies of scale at the MW level to do so. This technology would likely be a large, grid-scale type battery of the type envisioned by Eos Energy Storage, which produces containerized, MW scale metal-air batteries. It is assumed that technological advances in PV allow RES to shift slightly towards solar up until 2016, at which point growth slows due to the retirement of the investment tax credit (ITC) that currently funds up to 30% of PV systems costs. This is consistent with the findings of a recent study that the costs of distributed solar will decline through 2016, but then rise significantly in 2017 and not return to pre-2016 levels until after 2020 (Energy and Environmental Economics, Inc., 2012). This has the potential to put a dent in the growth of solar PV as an industry, and could mean that growth slows considerably after 2016, allowing wind to fill in the “compliance gaps” left as per compliance with the RPS. The result is a grid that obtains a slightly higher proportion of its energy from solar generation than at the moment, but that still leans heavily on wind generation.

On the regulatory side of things, the CPUC develops an asset class for energy storage technology and allows it to become eligible as capacity for procurement by utilities under their Resource Adequacy requirements. This is a likely development considering the recent order by the CPUC that SCE procure at least 50 MW of energy storage resources in the Los Angeles basin, a development that “provides a much needed market signal that energy storage will be considered as a key asset class to help California address its long term local reliability needs” (“California Requiring”, 2013).

This scenario has several important implications for the CA electricity grid. It will enable the development of “microgrids” that can temporally manage energy use within a certain timeframe. These pockets of local reliability will be much less reliant on the grid as a whole and will have greatly enhanced local capacity and reliability, which the CPUC has stated as an urgent need of the CA electricity grid (Energy Policy and Planning Division, 2013). This ability to stagger demand between these “microgrids” also greatly reduces the need for transmission and distribution upgrades, because the need for instantaneous delivery of energy to the grid as a whole will be buffered to some extent. It is unclear who might own these facilities, but they will be highly attractive to both merchant vendors and utilities. When utilities consider procurement of grid assets, “the first rule of project development is site control” (Desmond, personal communication, November 2013), so it is clear that they would prefer for a storage unit to be under their ownership and control. Analysis would suggest, however, that creation of centralized, utility-owned storage facilities is not the socially optimal way to structure energy storage capacity on the grid; one study found that merchant owned and operated storage facilities would provide the greatest welfare benefits in terms of price reduction (Sioshansi, 2010).

Though dynamic TOU residential pricing has not been implemented in the “Big Shifters” scenario, these devices would still be able to achieve some load-shifting value. Under a merchant scenario, this would be achieved by merchants obtaining large amounts of energy from the grid at cheap wholesale off-peak prices and then offering it for sale to nearby end-users at a price lower than the utilities’, but still at a profit. If the storage was utility owned, the utility could simply “charge” these storage facilities during off-peak hours and use them to provide power to localized areas during what would normally be on-peak hours, allowing them to defer expensive investments in FTG and transmission. Storage will help greatly reduce overall system costs in the “Big Shifter” scenario, but a large value proposition is lost due to faulty policy that continues to improperly incentivize residential electricity consumers and fails to encourage optimal storage use.

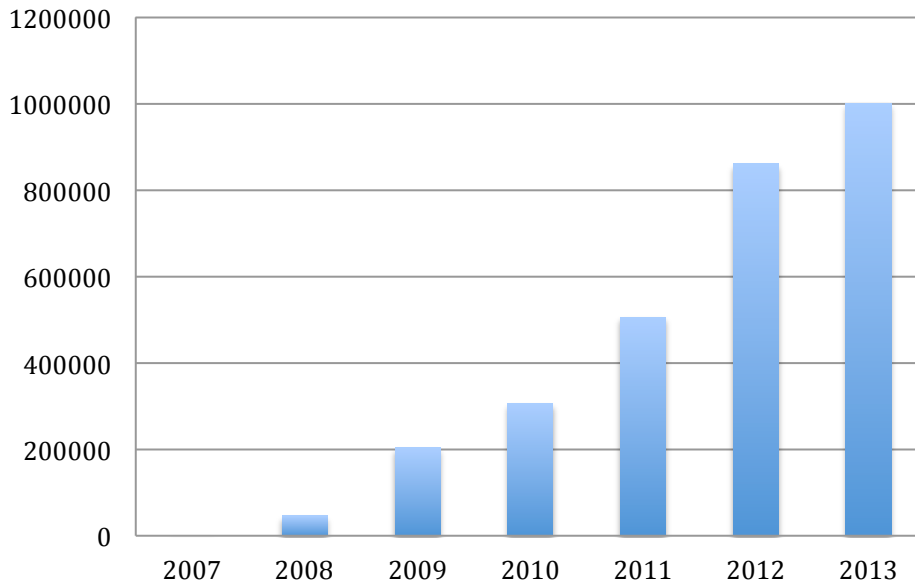
4.3.3 Solar Solution

The third scenario envisions an explosion of solar RES on the CA electricity grid, with storage technologies evolving as a “Solar Solution” to the challenges produced by this a trend. Solar powered RES have been found to be fairly coincident with peak demand at low penetration rates (Denholm et al., 2007), while even at higher penetration rates solar PV production misses areas of peak demand by only a few hours. ESS to be paired specifically with solar technologies will require less energy capacity, needing to store the electricity for only a matter of a couple of hours or less. This seems to be a feasible direction for storage technologies to evolve, given the current concentration of energy storage companies on power capacity, as opposed to energy capacity (Munsell, 2013), as well as the findings of one cost-effectiveness study that concluded “storage system duration of 2 hours exceeded cost - effectiveness of 4 hours” (EPRI, 2013). In this scenario, these devices would not need to appeal significantly to economies of scale to operate cost-effectively, but there may be few reasons to deploy them at a scale lower than the MW level as they would still look to more well-developed ancillary services (AS) markets for a significant portion of their profits. These markets would include the option for utilities to procure ESS ancillary service “capabilities” on a multi-year ahead market similar to the way that utilities fulfill “Resource Adequacy” requirements.

“Solar Solution” is a probable scenario in that solar power certainly seems to have a promising future in California. FERC Chairman John Wellinghoff recently stated his belief that solar “is growing so fast that it is going to overtake everything” (Trabish, 2013). The “Golden State” has witnessed an explosion in the growth of its solar industry due to a combination of technological advances and incentive schemes. Figure 9 on the following page displays the impressive growth in distributed generation (DG) solar energy as a result of the California Solar Initiative (CSI).

Figure 9: Growth in CA Solar Energy under California Solar Initiative

Annual Solar Energy Production Under CSI, in MWh



* 2007 Production figures begin at 5/31/2007.

** 2013 production figures do not include production for the months of November or December.

Source: California Solar Statistics Website.

Grid-connected PV is undergoing exponential growth across the country, and particularly in CA where the amount of capacity (in MW) installed in 2011 increased by fully 110% from that installed in 2010 (Sherwood, 2012). As Figure 9 shows, residential PV systems are very much following this trend in California. Policy seems to be on solar's side as well in California, with the recently passed AB327 removing the proposed cap on net metering programs in CA (Hales, 2013a). The decision will lend more confidence to third party solar companies and further strength an industry that seems poised to continue its impressive growth in the state of CA. The very passage and nature of AB327 indicate the growing economic and political power of the solar community in CA. As Carrie Cullen Hitt, senior vice president of state affairs for the Solar Energy Industry Association, was quoted, AB 327 is a sign that solar energy is

“now a significant part of the economy and that's why you see all this [legislative] activity.” (Carus, 2013).

The actual deployment of storage on the “Solar Solution” grid would not be significantly different from that of the Baseline scenario, but that is due more to the lack of disruptive change in ESS technology than any other factors. Due to the fact that most ESS on this grid would be incapable of shifting load past a couple of hours, one of its primary value propositions would remain the Ancillary services markets. For this reason, it would make little sense to deploy ESS scaled lower than the MW level, as resources smaller than 500kW would not be able to bid into these markets (FERC, 2010). The results of a recent CPUC use-case study found that the Frequency Regulation and the Spinning Reserve markets provide significant financial remuneration to such Limited Energy Storage Resources (LESR) (EPRI, 2013). The slight increases in energy capacity under this scenario would allow this storage technology to dominate these AS markets, replacing the need for any FTG that would have served this need.

Ancillary services are a niche market, however, and once sufficient storage capacity was installed to fill them there would likely be few value propositions left for low-energy storage systems. The large-scale deployment of PV would help the use-cases for this type of storage as a technology able to increase the capacity value of solar generation, thanks to its limited load shifting capability. As a scalable resource, these ESS would be able to be applied to the transmission and distribution system roughly in a way that roughly mimicked the composition of renewable energy sources, and could thus help shift load by the several hours that would likely be necessary for a grid with so many PV generation facilities. Bulk storage would still be applied for most load-shifting purposes for wind and resources other than solar, however, due to the inability of this technology to shift energy by a significant temporal factor.

4.3.4 “Sponge Grid”

The fourth scenario, “Sponge Grid”, entails the most technological change. Under this scenario, solar PV costs continue to drop significantly enough to offset the expiration of subsidies, while the energy storage industry sees a major breakthrough in a highly modular technology that can store energy for long periods of time without appealing to economics of scale to do so. This makes for a grid that can “absorb” energy at numerous points spread evenly through the system, like a sponge. The prohibition of mandatory time-of-use (TOU) rates for residential customers expires in 2018, at which point the CPUC takes advantage of the authority it was recently granted by AB327 to establish statewide, dynamic TOU rates (Carus, 2013). The CPUC further addresses its noted need for local capacity (Energy Policy & Planning Division, 2012) by incentivizing the deployment of the 12,000 MW of distributed generation that Governor Brown has stated as policy goal by 2020 (Trabish, 2012). Third-party ownership models are created that expedite the installation of both DG solar PV and this new, modular storage technology, and many home owners install this technology in order to take advantage of the pricing disparities created by TOU pricing. “Smart grid” technology allows electricity consumers to become much more responsive to electricity prices, partially mitigating the inelasticity of demand noted of 20th century electricity consumers (Borenstein, 2009).

As a good that is complementary to whatever RES exists on the market, more distributed generation (DG) means more potential for distributed energy storage (DES). Eric Carlson, lead architect of energy systems at SolarCity (a residential PV installer, which recently installed its first 100 energy storage systems) was recently quoted asserting “storage will be absolutely necessary to enable the deployment of solar across the grid at extremely high penetrations” (Lacey, 2013a). A study of PV penetration levels in modern electricity grids reinforces this belief, finding that large-scale deployment of DG PV technologies – on the order of provision of 50% of a system’s energy needs – would require a “radical transformation of the electricity system—from a centrally controlled to a highly distributed and interactive system” involving DES as well as other smart grid features (Denholm & Margolis, 2007b). While 50% is a large number, recall that solar PV capacity value can drop by as much as two thirds when solar PV reaches market penetration of 10% on an energy basis, due to

non coincidence with peak demand (Mills, 2013). This scale of PV deployment, especially distributed PV, would create a need for ESS and other capacity increasing technologies.

Although solar PV currently accounts for only .9% of California's annual electricity consumption (Nyberg, 2013), much more significant deployment may not be so far off if the exponential growth rates currently observed in that California residential PV market continue. The installations of solar PV under the CSI have accounted for a percentage of total CA electricity usage that has grown at approximately 75.2% a year. Should this type of growth continue in California, distributed PV alone could account for 4.1% of California's total energy consumption, as early as 2016 (Appendix 3). Though the CSI program has nearly run out of funding in CA (Trabish, 2012), federal incentives for residential solar are set to extend through the year 2016 (Sherwood, 2012), which provides a level of certainty that this type of growth will continue at least through that year.

This scenario assumes that the commercial, third party solar installation companies become strong enough to survive and flourish through 2016 and beyond. Even three years before the scheduled termination of these subsidies, the distributed solar PV industry is showing signs of robust growth independent of government incentives, due largely to "falling component and transaction costs." (Grueneich et al., 2013). In the first quarter of 2013 alone, 71.3 MW of capacity were installed in the form of residential systems, and 18.5% of that capacity was installed without the support of any state-level incentives whatsoever (Kann, 2013). This is an enormous advance for an industry that has traditionally relied heavily on state incentives and other types of subsidies to sustain itself, and is a good sign that DG is on the cusp of a major explosion in California.

An important trend to note is the increasing amount of distributed residential PV systems that have been procured under a third party ownership model. This model accounts for the falling transaction costs of installation for residential customers. The percentage of residential systems installed under such an ownership model has increased more than fivefold in only 3 years, skyrocketing from 14% in 2009 to 72% in

2012 (Loewen et al., 2012). Dropping component costs paired with such innovative third-party ownership models mean that an increasing number of residential PV installations are being completed without any funding from the CSI, as the few hundred dollars available to installers of residential PV systems have become “insignificant” (Sherwood, 2012). “Sponge grid” sees a similar third party ownership model develop for the new, scalable storage technology that enables electricity customers to take a high level of control over their energy use. The commercial sector has already begun uptake of energy storage, with SolarCity recently pairing with Tesla Motors in a contract that will see the two companies working to develop a “service [that] will use a combination of solar panels, big batteries and advanced software to cut utility bills for clients” (Baker, 2013).

The benefits of this storage deployment scenario to the electricity grid as a whole are enormous. Local capacity concerns are addressed, increasing local reliability and mitigating the need to address these concerns through the construction of new transmission lines. Locating storage near both DG and load means that load can be balanced within “microgrids”, largely mitigating the need for ancillary services. Placing storage close to load would reduce losses of energy during transmission as well, which typically run from 3-5% but can exceed 20% during peak periods of congestion (Casten, 2013). Peak load would essentially become nonexistent, as customers would take advantage of dynamic TOU rates by programming their residential storage to simply absorb energy when prices were lowest, and perhaps even to sell energy back to the grid when prices were high. Overall, the pricing disparity between periods would decrease, because only the lowest marginal cost resources would ever be brought online to provide electricity, as dictated by consumer demand. Low electricity prices could threaten some of the value propositions for these devices, as noted in section 3.5, but once ESS becomes an established grid asset and no longer a novelty, it will likely be there to stay.

DES seems to hold much promise in the state of California, especially in light of the state’s ambitious environmental goals, the proliferation of DG resources, and the stated need for local, rather than system capacity by the CPUC. If enough decentralized energy storage is implemented it will challenge the operational balance

paradigm upon which the current electricity grid is based, creating a scenario where homes or communities could simply charge their storage facilities when energy is inexpensively available, rather than having utilities and public entities racing to constantly match generation with demand. Table 5 below outlines the four scenarios, contrasting them against the attributes of the storage technology that becomes dominant, for side-by-side comparison.

Table 5: Energy Storage Deployment Scenarios, by Technology Attributes

Economies of Scale

Low Energy Capacity	<p>Baseline Scenario</p> <p>Primarily wind on the grid, more transmission, big losses from curtailment. LESRs dominate Ancillary Services, some bulk storage employed for wind load shifting.</p>	<p>“Big Shifters”</p> <p>Eos style, high energy capacity MW scale storage. Offsets peakers and new transmission lines, shifts load and reduces curtailment. Increased local capacity and opens door for deployment of DG.</p>	High Energy Capacity
	<p>“Solar Solution”</p> <p>Cheap, scalable storage, but not load shifting. DES would only be necessary at extremely high penetration levels of PV or DG. Storage still primarily valued for AS.</p>	<p>“Sponge Grid”</p> <p>Cheap, low economy of scale, storage that can shift load. Commercially deployed at residential scale, huge TOU value created, large system efficiency gains.</p>	

Modular, Distributed

Chapter 5: Recommendations for California

The CA electricity sector will face a period of unprecedented change in coming decades as the grid undergoes a transformation that is a physical manifestation of the changing paradigm of energy use in our Golden State. The successful evolution of the current grid to one that is capable of absorbing clean electricity and shifting it temporally will require well-informed and stringent policy to guide its progress – the California deregulation crisis was an example of what can happen when significant change in the structure of the electricity market is not accompanied by appropriate policy. A new market design will be necessary to govern this transformed electricity system, and it is “likely that it will contain a significantly higher level of regulation and administrative intervention” (Beckman, 2013). Though government agencies will necessarily play a role in restructuring such an essential sector of our state’s economy, they will need to enlist the help of both the utilities and a robust clean energy private sector to implement the goals and visions of their policies. It is essential that policy surrounding the deployment of ESS and other aspects of the “smart grid” be well informed in order to appropriately guide the private sector’s actions. In this chapter, some recommendations are provided for the state as it moves forward with this exciting transformation.

5.1 Barriers to Address

5.1.1 Technical

Some of the issues confronting ESS are a simple matter of the disparity between the technological capabilities of modern grid assets and those of the grid itself: ESS represent an advanced, 21st century technology that is being applied to a 20th century grid. There is a consequent lack of certainty about the interconnection process of ESS onto the grid and into the electricity markets. Some of these issues include:

- A grid that was constructed for one-way flows of electricity rather than the two-way flows of energy that ESS will create, and the difficulties in maintaining a balanced system without the necessary metering (Ferber, 2013).

- Market dispatch software that is unable to account for ESS operational features such as the speed of dispatch, their ability to specify a negative minimum operating point, and the possibility to be dispatched as both regulation up and regulation down (Tretheway, 2010).
- Lack of a technology capable of coordinating and netting the capacity value of distributed LESRs together for sale as Resource Adequacy or on future Capacity markets (Tretheway, 2010).
- Inability of ISO metering systems to measure the performance of LESR with quick responsiveness (NY ISO, 2010).

The installation of more advanced information technology at various locations within the grid will assist with the deployment of technologies such as ESS that require advanced and intricate operational strategies and signals to operate in a maximally efficient manner. Smart meters will be an absolutely essential aspect of any successful deployment of distributed energy storage (DES) for the purposes of grid efficiency. California has already recognized the value of such “smart grid” technology, and the CPUC has accordingly required that the CA IOUs install smart meters at the location of all end-users of electricity by 2020, with nearly 10 million already installed (“Smart Grid Report” – 2012, 2013). This will make for a grid that is significantly more receptive to ESS and other 21st century technologies.

5.1.2 Stakeholder Resistance

The energy industry has not traditionally been the most dynamic or receptive to change. A “game-changer” technology will be met with some resistance from stakeholders throughout the energy industry, resulting in inertial forces that could work against the deployment of energy storage on the grid despite the force of the mandate and the potentially high value of ESS to the grid as a whole.

Risk Averse Utilities

The regulatory and economic space in which utilities currently reside “penalizes innovation and risk-taking activities by utilities” because in order to be ensured their reasonable rate of return on investment, they must invest in assets that will be “used

and useful” (Grueneich et al., 2013). This, in addition to the fact that the “reasonableness” of a utility investment is assessed after-the-fact, means that utilities have little reason to pursue emerging technologies when they are ensured a profit margin by sticking with the energy sector status quo.

Skeptical Third Party Investors

Lack of commercial operating experience can often prove a catch-22 for emerging technologies projects such as energy storage when trying to gain capital investment. Potential financiers often require demonstrated commercial success before investing money with a project, but no commercial projects will be deployed until a sufficient amount of venture capital can be raised. The procurement mandate has addressed this uncertainty by essentially guaranteeing a market for the earliest grid scale ESS deployments, ones that would likely otherwise be viewed as financially risky projects. The mandate will already largely address this issue by ensuring the development of at least some commercial storage projects, as well as promoting a “learn-by-doing” approach to the development of viable market opportunities. These investors will likely also be put off by the complex bidding strategies that may be required to optimize the value of energy storage devices in a market context (Gyuk, 2011).

Uninformed Electricity Consumers

Electricity prices are a very politically charged and sensitive issue in California. Because most consumers have little idea where their electricity comes from but rather only see a bill at the end of each month, it is sometimes difficult to accept changes in electricity pricing. Due to their distant relationship with customers and their links with the public sector, utilities can come to be viewed as government entities trying to take undue control over electricity use. Electricity use is something that many customers have come to view as a right rather than a good that they consume, so when they see a larger bill without any explanation they will resist this change.

Although part of this amounts to true resistance against utility attempts to take more control over electricity use, a recent Sacramento Municipal Utility District pilot program for dynamic pricing hypothesized that consumer resistance is more “inertia” than anything, noting that while 20% of people who were given the option decided not

to enroll in the program from the start, nearly 90% of those who were automatically enrolled in the program stayed in it (Herter, 2013). This inertia will likely be easier to address than straight out resistance to changes in pricing schemes, and educating customers about the environmental effects of their energy use may help them to become more receptive.

5.1.3 Market Structure

ESS are currently at a major disadvantage to other grid assets when it comes to achieving project remuneration through the energy markets in CA. Storage technologies must compete in prejudiced markets against alternate technologies that these markets have been explicitly constructed for. This makes it difficult for ESS to gain adequate compensation over a project lifetime to provide a leveled cost of energy (LCOE) or power (LCOP) that is competitive with that of potential substitutes. Some of the major issues with the current wholesale electricity market structure include:

- Poor understanding of ESS capabilities: No firm numbers have been established as a basis for understanding ESS capabilities to provide grid services such as capacity. Better accounting will allow ESS to become eligible for the provision and compensation of more grid services. In particular, California is developing a process to understand ESS Resource Adequacy capabilities.
- Poorly constructed price signals (wholesale): Basic market structure that does not explicitly value ESS capabilities.
- Lack of cohesive regulatory framework: Uncertainty on the regulatory level makes it difficult to formulate optimization strategies for ESS.
- No Long Term Contracts: At the moment, prospective ESS depend entirely upon spot markets such as the energy and ancillary services markets to fund their projects – there is no upfront funding for such services as there are for long-term power purchase agreements (PPA) with generators. (Lin, 2011). The uncertainty inherent in such an arrangement makes it difficult to promote ESS as a sound investment, especially in a highly risk-averse energy market environment. A long-term contract for regulation services, similar to the ones used by utilities to ensure resource adequacy with conventional generation, would help overcome this significant market barrier (Lin, 2011).

Price Signals (retail)

The wholesale electricity markets need improvement, but the state of the retail electricity market is perhaps even more prohibitive to potential energy storage value streams. The paradigm of cheap electricity as a right, combined with the political risks involved with opposing this status quo, have made for a regulatory and policy environment in the CA energy sector that favors cheap electricity. The prices that end-users on the CA electricity grid see today are not an accurate representation of the true social cost of producing it, nor do they truly reflect even the purely economic costs of production. The two main flaws with the current pricing schemes are that 1) they fail to internalize the social costs of electricity production, and 2) they do not reflect the marginal cost of the energy consumed by any given end-user.

Recall from Figure 8 that TOU energy management was found to be the single greatest potential value stream of energy storage applications in California. At the moment however, there is very little incentive for any residential purchasers of energy on the retail markets to manage their energy use temporally because the current structure of electricity contracts are not time-variant. These contracts effectively subsidize electricity for peak users by overcharging consumers who purchase electricity only when the costs of balancing supply with load are relatively low. On the other hand, dynamic rates reduce overall system costs by inducing customers to reduce electricity use during peak hours reducing the need for expensive peaking plants.

A lot can be said about the inefficiencies inherent in a flat rate, and even in basic tiered electricity pricing systems, but in the 20th century the reality was that the information necessary to implement more accurate pricing systems simply could not be obtained. With the advent of the “smart grid” and advanced metering, however, there no longer remains any justification for these rates. As Lee Friedman puts it:

“Time - invariant rates are a historical anachronism, a system of grossly inefficient subsidies and penalties that no longer has a legitimate basis for continuation. It seems unconscionable for us to continue to subsidize peak - load consumption when

its social costs are so great, and to penalize off - peak consumption when it holds so much promise as a method of environmental improvement.” (Friedman, 2009).

5.2 Recommendations

5.2.1 Send Appropriate Price Signals

The implementation of appropriate pricing systems will unlock massive potential for value creation in reduced electricity prices, as well as in the mitigation of unnecessary social costs in terms of both environmental degradation and an inefficiently costly electricity grid. Cost-effective energy storage would be one very promising means of realizing that potential by empowering energy users to take much greater control over the prices they paid for their electricity, with their desired time of consumption having much less bearing on this decision.

When electricity prices are crafted in such a way that end-users face strong incentives to use energy at times when the marginal system costs of electricity production are low, it can benefit both the utility and its customers. For example, the thermal energy storage systems employed by Ice Energy to shift air conditioning electricity use to the night time profit from the time-differential prices seen by large electricity users in the state, while the local utility is able to reduce their peak capacity needs thanks to this shift. Though TOU measures have been implemented for Commercial and Industrial (C&I) customers in CA, however, even the tiered pricing system employed by the state is merely a rough approximation of temporal change in marginal cost of energy production. Generally speaking, the more closely a pricing system can induce customers to shape their electricity usage patterns based on real-time marginal system costs, the more benefits will be created for the electricity grid as a whole. A comprehensive case study of dozens of utilities across the country found that pricing systems which “dynamically track system capacity and cost conditions” were most effective in achieving goals like reduction of peak demand and local capacity constraint (Energy and Environmental Economics, Inc., 2005). This study further found that when pricing programs produced net benefits to the system as a whole, contracts could be constructed in such a way that both a utility and its customers saw a share of the benefits.

Friedman suggests a “two-part tariff” as a basis for a new, more socially efficient electricity pricing mechanism. Under such a tariff, a consumer’s electricity bill would consist of two parts. The first part would be a “fixed charge” that was calculated to reflect the services that the customer received simply by virtue of being connected to the grid – transmission lines, the capacity of the grid to provide electricity when they want it, etc. This fixed charge could be applied on a tiered system to allay equity concerns. The second part of the bill would be a “usage charge” that was calculated considering both the amount of electricity consumed and the true marginal cost to the system of actually producing that energy (Friedman, 2009). AB 327 authorizes IOUs to employ a “fixed rate” charge of up to \$10 per month, in order to enable cost recovery of fixed costs (Cares, 2013). Though this may reduce incentives for energy efficiency and net energy use reduction in the immediate future, it could also be an important step towards such a “two part tariff” electricity pricing scheme that more accurately represents the costs of grid services provided to end-users.

In implementing these systems, it is important that electricity customers are on board. A very promising recent study conducted by SMUD emphasized the positive aspects of the new pricing plan such as savings during off-peak hours to customers, while dense terms like “critical peak” and “load shifting” were left for the utility experts (Herter, 2013). Names like Optimum Off-Peak and Summer Weekday Value Plan were given to the new programs. These strategies are effective but not disingenuous; creating better rate structures truly present an opportunity for multiple parties to benefit, and this study simply demonstrates that utilities will be more successful in doing so if they make the transition as simple as possible for customers. Volunteer programs like this one are a good start, but they only attract energy users who save without altering their electricity usage patterns. To truly have an effect on system costs, it will be necessary to implement mandatory, dynamic time-of-use pricing that will more accurately incentivize socially advantageous energy use and penalize those who choose not to adjust to the needs of our society, thus “reducing overall costs and fairly allocating those higher costs” (Bender et al., 2005). California has taken notable steps towards doing so in allowing the CPUC to begin implementing mandatory TOU rates beginning in 2018, as per AB 327 (Carus, 2013).

5.2.2 Equitable Wholesale Energy Market Design

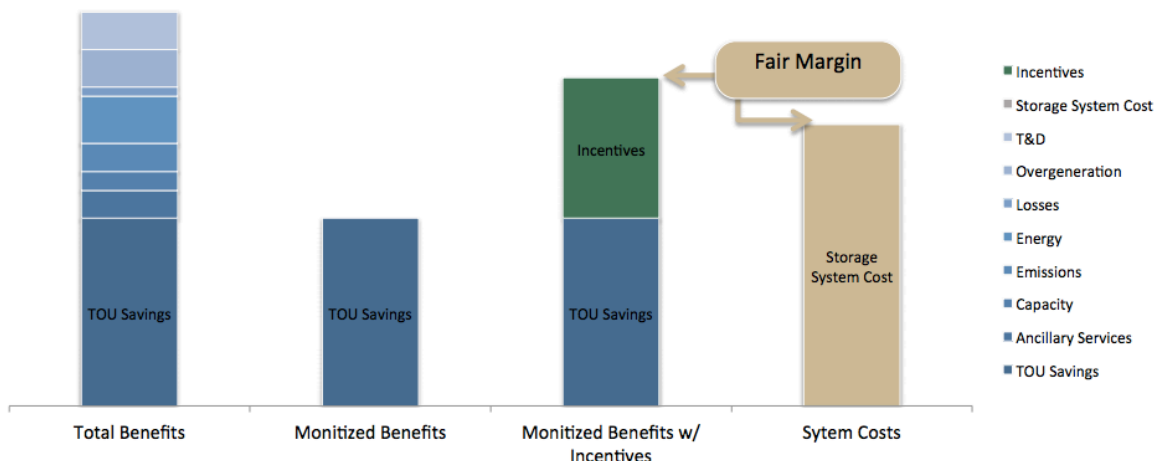
The California energy markets need to be restructured in such a way that they more appropriately reflect the physical realities of, and the consequent problems faced by, the grid. More explicit value must be assigned to factors such as location and dispatchability in addition to the \$/MWh metric currently used for most wholesale prices. In creating this new market design, it is important that a democratic process involving all stakeholders is used to ensure that all viewpoints and values are taken into account.

Public Good Subsidization

Not all of the benefits provided to society by the deployment of energy storage are easily quantifiable, but research is being conducted towards this goal. The quantification of benefits is essential to the establishment of policies that will create the socially efficient amount of storage on the California electricity grid. Though the positive externalities produced by storage systems justify subsidies or the “design of market mechanisms or contracts that compensate storage owners for the external effects of their storage use” (Sioshansi, 2010), in order to set those incentives to the right level, policymakers must know the amount of value that the policy will create. Once all value streams of a storage system are known and quantified, policymakers can proceed in establishing appropriate policies.

Section 3.5 outlines some of the system benefits that would justify such a subsidy. Under the mandate, the CPUC did not agree to assign “a public value to an agreed upon list of benefits ... [because] there is no standard value that is appropriate for all storage technologies” (CPUC, 2013). This is not important because the technologies deployed under the mandate will not need subsidization, given the backing from the mandate itself. As an energy storage industry develops, however it will be important to apply such a public good value to storage technologies to allow them to become competitive with substitute goods. Figure 10 on the following page provides an illustrative example of how the socially optimal level of energy storage will be reached only through application of incentives.

Figure 10: The Need for Energy Storage Incentives



Source: Strategen Consulting, 2011.

More appropriate incentives for generation.

Production tax credits and renewable energy credits are granted regardless of time or location, meaning that “current incentives for renewable energy are leading to sub-optimal capital allocation” (Casten, 2013). Renewable energy producers are paid on a \$/MWh basis so that even if the energy is produced at a time when the market would usually tell a facility not to produce, a renewable energy producer will continue to so because they are blindly subsidized by these incentive structures. These figures should be altered so that they incentivize renewable production that serves grid needs, as well as services, such as energy storage, that enable local capacity needs to be met through the use of renewable energy.

Invest in local energy systems first

California should create a market that concentrates on meeting load with local resources. This will help address the local capacity needs identified by the CPUC, which could be met quite effectively through the creation of “microgrids” as in the “Big Shifters” scenario. Though transporting electricity long distances makes sense when generators are bidding expensive energy with differing marginal costs, this makes less economic sense as an increasing amount of energy comes from zero marginal cost RES. Currently Distributed Generation is compensated through Net Metering and other

incentive programs, but in the long run these should be replaced with markets that are more receptive to smaller resources and “that pay DG...customers for all the value they provide, whether it is capacity, energy, transmission and distribution congestion relief, ancillary services, greenhouse gas reductions, or emission reductions” (Bender et al., 2005).

Develop a multi-year ahead “capabilities” market

Much in the same way that Resource Adequacy markets value the potential ability of a project to provide capacity to a utility, when needed, a market should be developed in which utilities can pay potential ESS project developers for the services they will be able to provide like ramping, load following, and regulation (Casey, 2013).

Develop Standard Contracts for ESS projects

The development and authorization of standard contracts for ESS project developers (accounting for the differences between technologies, of course) would greatly streamline the procurement process for all parties involved and would likely result in much greater uptake of ESS, where applicable. California energy markets are presided over by many different regulatory agencies at both the state and federal level. Project procurement should be streamlined to account for “gaps and overlaps” between these agencies that can be difficult to navigate for potential project developers (Grueneich et al., 2013). The California feed-in tariff allows eligible customer-generators to enter into 10-, 15- or 20-year standard contracts with utilities electricity. A similar system could be implemented to allow storage project owners to provide “energy services” such as load shifting and ancillary services to grid for the entirety of their useful life.

This strategy worked incredibly well for the residential solar market, where an explosion in the number of residential PV in the past five years is largely “due to the increased popularity of third party ownership models in the residential solar market” (Loewen et al., 2012). Unfortunately, as far as the scope of the mandate, the CPUC did “not require the IOUs to develop standard contracts” (CPUC, 2013). By the time the mandate has expired, however, the ESS industry will have developed significantly from its current state, and it would be wise to encourage the development of standard

contracts in a way so as to allow the market to take over easily. This is particularly true if one or several types of technologies come to dominate the market.

Clear Rules for ESS

Developing an asset class for different types of storage, in the relevant markets, would make it much easier for potential projects to identify potential value streams. See the NY ISO Case Study below for a good example of how this can be achieved.

Case Study: New York Regulation Market

The NY ISO has undertaken an initiative to make their Ancillary Services markets more receptive to new energy non-generator grid assets such as ESS. The ISO addressed this issue within its Regulation Service market by creating a new category of Regulation Service providers, LESR's, which is "characterized by its ability to provide continuous six-second changes in output coupled with its inability to sustain continuous operation at maximum energy withdrawal or maximum energy injection for an hour." (NY ISO, 2010). These providers are limited to providing regulation services, but are paid in the same manner – at the market-clearing price – as other resources. This is a good example of how avenues for cost recovery of storage technologies can be implemented into current market structures. Other adjustments made by the NY ISO to incorporate storage included market software adjustments, real time dispatch (RTD) adjustments to allow the evaluation of various LESR devices to receive or provide electricity, and Automated Generation Control (AGC) software to allow LESR's to be the first resource dispatched so as to take advantage of their extremely responsive nature (Lin et al., 2010). By removing the requirement of providing energy and allowing LESR's to provide pure regulation services, the NY ISO has "been able to create a market for a new class of resources" (NY ISO 2010) in a way that will enable LESRs to be used cost-effectively in one of their most relevant grid applications.

5.2.3 Enlist Utilities

As was examined in section 2.2, the role traditionally played by utilities is shrinking as the energy use paradigm shifts away from cheap energy as a right, and towards electricity as a product with a cost that reflects its true social costs of its production.

This shift has also created an equally important, if fundamentally different, role for an entity that can monitor and regulate energy use, ensure efficiency and reliability on the grid and help societies achieve their long-term energy policy goals. It will be necessary to fundamentally alter "utility institutional structures" to achieve a successful transition to the new energy grid envisioned by California (Grueneich et al, 2013). Fortunately, utility representatives themselves seem to recognize and in fact welcome this trend – over two-thirds of utilities representatives surveyed indicated a belief that the

deployment of smart grids – including ESS -and smart meters will create value that far surpasses industry forecasts (Accenture, 2013).

Although many load serving entities have been disaggregated, they remain the best positioned entities that currently exist to plan and operate grid assets with benefits at the level of the entire system in mind. Given the right incentives to do so, utilities will prove the most valuable ally of energy storage and other smart grid technologies that are valuable precisely for their ability to allow the grid operate at its most efficient. Allowing well-regulated utilities to own and operate storage facilities will result in “socially optimal storage use since these entities would be concerned with both producer and consumer surplus changes” (Sioshansi, 2010). Such a utility will use storage assets to reduce the costs of load balancing to the entire system, because it will be in their interest to do so. As an expert contact from SoCal Edison argued, limiting utility ownership of storage capacity under the mandate to 50% of procurement was not well-informed because when the utility owns an asset it allows for “much more flexibility...and it drives innovation” (SoCal Edison, Personal Communication, October 2012). Lastly, utilities are large and politically influential entities, and their help may in fact be needed to achieve many of the policy and market development goals outlined in the sections above. This point is proven by European utilities like RWE who have stated that they will “fight for the most reasonable market design” (Beckman, 2013) in the face of a changing grid.

Though utility representatives seem to be ready for the evolution of their organizations to occur, this will not occur unless the proper policy and regulatory environment is created in which utilities can undergo this transformation. This will involve sacrificing many of their traditional profit streams while creating new incentive structures for utilities, allowing them to profit from things like distributed generation, investment in local capacity and distribution lines, and using storage facilities to minimize the marginal cost of energy produced on the system at any given time. An alternate route would be to convert California utilities back to public entities, “smart grid operators” that would be by nature required to do these things, although that would entail the navigation of difficult political territory and is not likely in the near future.

Chapter 6: Conclusion

In the context of the California electricity grid, energy storage should be viewed primarily as one potential means to an end – the end being an electricity grid that is prepared to cope with the challenges that will come with the state’s ambitious environmental policies. As a complementary good to generation with low dispatchability, the value of energy storage systems will only grow with increasing levels of RES penetration. In general, any development that drives the CA electricity grid toward higher levels of renewables or more effective internalization of the true time-variant costs of electricity production in the state will make for a higher value of energy storage. The shifting of the energy use paradigm towards one that establishes electricity as a marginally-priced good as opposed to a right will also make energy storage capacity a more valuable product, and consequently create more potential cost-effective deployments. This is because at the most basic level, the behavior of the electricity grid as a whole is dictated by electricity demand, or the aggregate behavior of electricity consumers. The more that end-use electricity prices in the state come to reflect the true cost of producing and deploying one more unit of energy at the time it is consumed, the more electricity consumers will come to behave in ways that facilitate the deployment of load-shifting assets like storage.

On the other hand, contingencies that lead the California electricity grid to tend towards installation of further 20th century infrastructure and dependency on fossil fuels, without internalization of the social costs of such stagnation, will devalue storage systems and their potential applications. This is entirely possible in an energy sector still dominated by utilities with roots in the 20th century, cheap energy use paradigm, despite ambitious environmental policy from the state. Garnering the support of electric utilities is of the utmost importance in transforming the California energy sector into the electrified, decarbonized one that is needed to achieve the state’s 2050 emissions goals. To do so, California should look to the strategies adopted by utilities in Germany and other European states that face the same “existential crisis” as those in California.

Energy storage eventually will become cost effective for applications on the California electricity grid. This could occur through disruptive technological change, supportive policy, or even by process of elimination as all other means of addressing the reliability concerns that come with an increased level of renewable energy are expired. With such a potentially transformative technology, it is tempting to advocate the installation of energy storage as an end in itself, but ultimately this is not how business is conducted in the energy sector. Technologies must be commercially proven before even being considered for installation, and even then it is important to recall that as storage technologies are applied in an application specific approach, “some of them will be cost-effective a year from now, some 20 years from now” (SoCal Edison, Personal Communication, October 2013).

The world will be watching as California tests the waters of grid-scale energy storage in the coming decade, and murky waters they are. The energy storage industry remains a nascent one and as such will be exposed to the tides of change in technology, regulation and economics. A multitude of variables will affect whether these tides shift in favor of or against the deployment of energy storage capacity on a scale that is sufficient to truly challenge the 20th century electricity grid paradigm of operational balance. The scenarios constructed in Chapter 4 offer some insight into potential technical and regulatory changes and the effects they might have on an energy storage industry, but in the end the development of California’s energy storage industry will largely be a process of learning-by-doing. The lessons learned by California’s energy sector will be invaluable to electricity grids around the world, but it is important to remember that knowledge of this type is largely a public good. While there is value in being first, energy storage and other “smart grid” technologies should be deployed only as they become cost-effective, so as not to subsidize this knowledge by way of an undue burden on electricity consumers in the state of California.

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Appendix 1: 10 Year Market Potential of Energy Storage Industry in California.

1 Electric Energy Time-shift	400	700	Low: 80% efficiency, 2¢/kWh VOC, 4 hours. High: 80% efficiency, 1¢/kWh VOC, 5.5 hours.
2 Electric Supply Capacity	359	710	Low: mid/peak duty cycle combustion turbine, cost \$50/kW-year. High: combined cycle combustion turbine, cost \$99/kW-year.
3 Load Following	600	1,000	Low: simple cycle combustion turbine, price \$20/MW per service hour. High: combined cycle combustion turbine, price \$50/MW per service hour.
4 Area Regulation	785	2,010	Low: \$25/MW per hour, 50% capacity factor. High \$40/MW per hour, 80% capacity factor. For up regulation and down regulation.
5 Electric Supply Reserve Capacity	57	225	Low: \$3/MW per hour, 30% capacity factor. High \$6/MW per hour, 60% capacity factor.
6 Voltage Support	400	800	Low: prevent 1 outage lasting 1 hour over 10 years. High: prevent 2 outages lasting 1 hour over 10 years. Storage = 5% of load.
7 Transmission Support	192	192	Based on DOE/EPRI storage report[14].
8 Transmission Congestion Relief	31	141	Based on CAISO congestion prices in 2007.
9.1 T&D Upgrade Deferral 50th percentile	481	687	Low: upgrade factor = 0.25. High: upgrade factor = 0.33.
9.2 T&D Upgrade Deferral 90th percentile	759	1,079	Same as above.
10 Substation On-site Power	1,800	3,000	Based on cost for standard storage solution.
11 Time-of-use Energy Cost Management	1226	1226	Based on PG&E's A6 time-of-use tariff. Six hours of storage discharge duration.
12 Demand Charge Management	582	582	Based on PG&E's A6 time-of-use tariff. Six hours of storage discharge duration.
13 Electric Service Reliability	359	978	Low: \$20/kWh * 2.5 hours/year of avoided outages for 10 years. High: 10 Years of UPS Cost-of-ownership (present value).
14 Electric Service Power Quality	359	978	Low: avoided power quality related cost, 10 years. High: UPS cost-of-ownership, 10 years (present value).
15 Renewables Energy Time-shift	233	389	Low: bulk wind generation. High: baseload RE generation.
16 Renewables Capacity Firming	709	915	Low: fixed orientation distributed PV. High: bulk wind generation.
17.1 Wind Generation Grid Integration, Short Duration	500	1,000	Though the estimated benefit is relatively high, a modest amount of storage (<0.1 kW) is needed per kW of wind generation.
17.2 Wind Generation Grid Integration, Long Duration	100	782	Low: avoid 1 outage in 10 years from wind generation shortfall. High: high estimate of benefit for reduced transmission congestion.

Reproduced with data from Eyer and Corey, 2010.

Appendix 2: Overview of Extant MW Scale Storage Systems and Basic Metrics

Technology Option	Maturity	Capacity (MWh)	Power (MW)	Duration(hrs)	% Efficiency (total cycles)	Total Cost (\$/kW)	Cost (\$/kW-h)
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Application: Bulk Energy Storage to Support System and Renewables Integration

Pumped Hydro	Mature	1680-5300	280-530	6-10	80-82 (>13,000)	2500-4300	420-430
Pumped Hydro	Mature	5400-14,000	900-1400	6-10	80-82 (>13,000)	1500-2700	250-270
CT-CAES (underground)	Demo	1440-3600	180	8	See note 1 (>13,000)	960	120
CT-CAES (underground)	Demo	1440-3600	180	20	See note 1 (>13,000)	1150	60
CAES (underground)	Commercial	1080	135	8	See note 1 (>13000)	1000	125
CAES (underground)	Commercial	2700	135	20	See note 1 (>13000)	1250	60
Sodium-Sulfur	Commercial	300	50	6	75 (4500)	3100-3300	520-550
Advanced Lead-Acid	Commercial	200	50	4	85-90 (2200)	1700-1900	425-475
Advanced Lead-Acid	Commercial	250	20-50	5	85-90 (4500)	4600-4900	920-980
Advanced Lead-Acid	Demo	400	100	4	85-90 (4500)	2700	675
Vanadium Redox	Demo	250	50	5	65-75 (>10000)	3100-3700	620-740
Zn/Br Redox	Demo	250	50	5	60 (>10000)	1450-1750	290-350
Fe/Cr Redox	R&D	250	50	5	75 (>10000)	1800-1900	360-380
Zn/air Redox	R&D	250	50	5	75 (>10000)	1440-1700	290-340

Application: Energy Storage for ISO Fast Frequency Regulation and Renewables Integration

Flywheel	Demo	5	20	0.25	85-87 (>100,000)	1950-2200	7800-8800
Li-ion	Demo	0.25-25	1-100	0.25-1	87-92 (>100,000)	1085-1550	4340-6200
Advanced Lead-Acid	Demo	0.25-50	1-100	0.25-1	75-90 (>100,000)	950-1590	2770

Application: Energy Storage for Utility Transmission & Distribution Grid Support Applications

AES (aboveground)	Demo	250	50	5	See note 1 (>10,000)	1950-2150	390-430
Advanced Lead-Acid	Demo	3.2-48	1-12	3.2-4	75-90 (4500)	2000-4600	625-1150
Sodium-Sulfur	Commercial	7.2	1	7.2	75 (4500)	3200-4000	445-555
Zn/Br Flow	Demo	5-50	1-10	5	60-65 (>10,000)	1670-2015	340-1350
Vanadium	Demo	4-40	1-10	4	65-70	3000-3310	750-830

Redox					(>10,000)		
Fe/Cr Flow	R&D	4	1	4	75 (>10000)	1200-1600	300-400
Zn/air	R&D	5.4	1	5.4	75 (4500)	1750-1900	325-350
Li-ion	Demo	4-24	1-10	2-4	90-94 (4500)	1800-4100	900-1700

Recreated with data from Rastler, 2010.

Appendix 3: California Solar Initiative Metrics

Year	2008	2009	2010	2011
Total CA Electricity Consumption (MWh) *	268,155,000	259,584,000	258,525,414	272,645,317.1
Total Electricity Production under CSI (MWh)	46560	203352	306228	506127
CSI Proportion of Total	0.000173631	0.000783376	0.001184518	0.001856357

Data gathered from Energy Information Administration website at:
<http://www.eia.gov/electricity/state/california/pdf/california.pdf>

Regression analysis of CSI program, starting in 2008, yields that CSI production's proportion of total CA electricity consumption can be predicted by

$$y = 0.0001e^{0.7522x}$$

In 2016, with $x = 8$, $y = 0.04099355695$, or 4.1% of total consumption.

Appendix 4: Energy Storage Valuation Technology Run Reference and Results Summary.

Run #	Detail	B/C Ratio	Breakeven Capital Cost (\$/kWh)(2013\$)	Breakeven Capital Cost(\$/kW)(2013\$)
run1	Use Case 1 (Bulk Energy Storage): Base Case	1.17	842	1684
run1 2010	Use Case 1 Sensitivity: 2010 Ref Year	1.05	565	1130
run1 2010P4P	Use Case 1 Sensitivity: 2010 Ref Year with P4P regulation prices	1.23	1079	2159
run1 LMS100	Use Case 1: CONE derived with LMS100	1.17	824	1649
run1 lowCONE	Use Case 1 Sensitivity: low CONE	1.08	632	1264
run1a	Use Case 1 Sensitivity: 2 Replacements	1.07	619	1238
run1b	Use Case 1 Sensitivity: No regulation services	0.98	433	865
run1c	Use Case 1: higher CapEX assumption	0.91	842	1684
run1d	Use Case 1: higher variable O&M assumption	1.14	740	1480
run1e	Use Case 1 Sensitivity: 3 Replacements	0.97	377	754
run2	Use Case 1 Sensitivity: 2X Regulation Price	1.38	1593	3186
run3	Use Case 1 Sensitivity: 3 Hour Duration	1.10	594	1781
run4	Use Case 1 Sensitivity: 4 Hour Duration	1.05	465	1860
run10	Use Case 1 Sensitivity: Market Scenario 1	1.24	1010	2020
run11	Use Case 1 Sensitivity: Market Scenario 2	1.18	851	1701
run12	Use Case 1 Sensitivity: Market Scenario 3	1.47	1941	3883
run13	Use Case 1 Sensitivity: Market Scenario 4	1.40	1619	3238
run16	Use Case 1 Sensitivity: Flow Battery	1.23	675	2699
run16a	Use Case 1 Sensitivity: Flow Battery (high variable O&M)	1.20	628	2511
run17	Use Case 1 Sensitivity: Pumped Hydro	1.32	223	1783
run18	Use Case 1 Sensitivity: CAES	1.27	232	1853
run19	Use Case 2 (Ancillary Service Only): Base Case	1.40	6712	1678
run20	Use Case 1 Sensitivity: Project Start Year 2015	1.08	755	1509
run21	Use Case 1 Sensitivity: Project Start Year 2015 with P4P regulation prices	1.30	1471	2941
run22	Use Case 3 (Distributed Storage): Base Case	1.19	866	3464
run22no reg	Use Case 3 Sensitivity: No regulation	1.12	686	2745
run22b	Use Case 3 Sensitivity: 2 Hour	1.35	1509	3018

	Duration			
run23	Use Case 3 Sensitivity: 2X P4P regulation prices	1.35	1326	5306
run24	Use Case 3 Sensitivity: High Load Growth Rate	1.09	634	2537
run26	Use Case 3 Sensitivity: Flow Battery	1.32	1009	4037
run35	Use Case 3 Sensitivity: Project Start Year 2020	1.30	940	3761

Recreated with data from EPRI, 2013.

Appendix 5: Levelised Costs of Electricity From Various Technologies.

Technology	Life (year)	Typical Plant Size (MW)	Operation hours (h)(based)	2011	2030	2050	Efficiency (%)	CAPEX (EUR/kW)	Efficiency (%)	CAPEX (EUR/kW)	OPEX per year % of invest
				CAPEX (EUR/kW)	Efficiency (%)	CAPEX (EUR/kW)					
Gas open cycle	25	250	6000	650	45	650	45	650	45	650	3.0%
Gas CCGT	25	400	6000	800	60	800	62	800	62	800	2.5%
Hard coal 600	35	800	7500	1300	45	1300	47	1300	49	1300	2.0%
Lignite 600	35	800	7500	1400	43	1400	47	1400	49	1400	2.0%
Hard coal / Lignite 700	35	800	7500			2100	50	1800	52	1800	2.0%
Hard coal 700 + CCS	35	800	7500			3000	40	2700	41	2700	2.0%
HC 600 + Biomass-co-firing	30	800	7500	1390	45	1300	47	1300	49	1300	2.0%
Nuclear (EPR1600)	40	1600	7900	3000	36	2600	37	2600	37	2600	2.0%
Pumped storage	50-60	250	2500	1100-2400	80	1100-2400	80	1100-2400	80	1100-2400	1.0%
Run-of-river	50-60	20-250	6000	1800-2200	90	800-2200	90	800-2200	90	800-2200	1.0%
Wind onshore	25	2-3	1800	1100-1300	N/A	1100	N/A	1100	N/A	1100	3.3%
Wind off-shore (near)	25	5	3200	2000-2200	N/A	1800	N/A	1800	N/A	1800	4.3%
Wind off-shore far	25	5	3800	2600-3000	N/A	2200	N/A	2200	N/A	2200	5.0%
Solar PV	25	0.005-0.5	2000	1800-2800	N/A	1700	N/A	1700	N/A	1700	1.0%
Solar thermal CSP	30	2-50	2800	3000-3500	N/A	2000	N/A	2000	N/A	2000	2.0%
Biomass	30	25	7500	2500	~ 40	2500	~ 40	2500	~ 40	2500	2.5%

Recreated with data from VGB, 2012.