LUMMUS CONSULTANTS
INTERNATIONAL

July 6, 2015

Chairman Jeffrey Johnson
Guam Public Utilities Commission
Suite 207, GCIC Building
Hagåtña, Guam 96932

Draft Whitepaper on Compressed Air Energy Storage Technologies

Dear Mr. Chairman,

Lummus Consultants International, Inc. ("Lummus Consultants") is pleased to submit this whitepaper to the Guam Public Utilities Commission ("GPUC") in response to a request by Mr. Fred Horecky to provide technology and market information relative to the status of compressed air energy storage applications.

We have previously provided the GPUC with some insight into other energy-related topics, such as: the prevalence of and implementation approaches for demand side management programs; time of use rate policies, including costs, benefits, and adoption of time-varying rates: and net energy metering policies and practices. This whitepaper focuses specifically on the status of compressed air energy storage technologies, worldwide, and more broadly on competing energy storage technologies and the market drivers impacting the adoption of energy storage solutions.

Lummus Consultants appreciates the opportunity to assist the Commission in this matter. If you have any questions or need further assistance, please do not hesitate to call or write.

Very truly yours,

Lummus Consultants International, Inc.

Kathleen A. Kelly

Kathleen A. Kelly
Director and Practice Lead

Introduction

Lummus Consultants International ("Lummus Consultants"), acting as an advisor to the Guam Public Utilities Commission ("GPUC"), was asked to prepare a whitepaper on the topic of compressed air energy storage ("CAES") technologies. This whitepaper discusses the status of CAES technologies, encompassing operating and developing projects, the history of this technology, and key players in this market. It goes on to describe the energy storage market more broadly, including competing energy storage applications and market drivers impacting the energy storage market - these include, for instance, recently enacted energy storage goals in the state of California and growing demand for distributed and utility-scale renewable energy projects, which could be sustained by energy storage technologies capable of mitigating renewable energy intermittency, providing additional grid support services, or enabling energy supply shifting and energy arbitrage.

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List of Acronyms

Acronym	Name
ACEEE	American Council for an Energy-Efficient Economy
CAES	compressed air energy storage
CPUC	California Public Utilities Commission
DECC	UK Department of Energy and Climate Change
DOE	US Department of Energy
EERS	Energy Efficiency Resource Standard
EIA	US Energy Information Administration
ESS	energy storage system
GPUC	Guam Public Utilities Commission
GW	gigawatts
LAES	liquid air energy storage
MTR	Minimum Technical Requirements
MW	megawatts
RFP	Request for Proposals
RPS	Renewable Portfolio Standard
TCE	TC Engineers, PC
UW-CAES	underwater compressed air energy storage

1 Compressed Air Energy Storage Technology

Compressed air energy storage ("CAES") is a technology that *consumes electricity* to compress air and then releases the air through a turbine to *generate electricity*. Like pumped storage hydroelectric plants, CAES uses off-peak electricity to store large quantities of energy that can then be used to generate electricity during peak demand periods. A CAES plant is designed to be able to produce electricity from compressed air over several hours, enabling energy management on the bulk electric power grid. Traditional CAES technology stores compressed air in underground geological formations, such as salt domes/caverns - emerging technologies, focused on smaller, localized applications of CAES, are seeking to store air above ground in tanks or pipes, or store air underwater in flexible balloons. These emerging technologies are working to address the increasing need for grid support brought on by a broader adoption of renewable energy technology - needs like energy shifting, capacity firming, frequency regulation, and spinning reserves.

There are currently three operational, commercial-scale CAES systems, worldwide, each of which is illustrated by a dark blue star in Figure 1 below. The first, located in Germany, came online in 1978 - it is a 321 MW facility that stores nuclear-sourced electricity at night, when demand is low, and provides on-peak electricity during the day, when demand is at its highest. The second commercial-scale facility, located in McIntosh Alabama, is a 110 MW facility that came online in 1991. This facility, again, uses nuclear-sourced energy to charge at night and discharges to the grid during peak periods in the day. The third facility, located in Gaines County, Texas, is a 2 MW facility commissioned in 2012 - this "General Compression Advanced Energy Storage" system stores wind-sourced electricity during periods of low demand.

Figure 1 Worldwide Compressed Air Energy Storage Systems

Developed by Lummus Consultants International.
Data Source: DOE Global Energy Storage Database, accessed March 9, 2015, available at http://www.energystorageexchange.org/.

In addition to the three commercial-scale facilities, Figure 1 identifies two facilities that are operating at demonstration-scale and pilot-scale in New Hampshire, USA, and Berkshire, UK, respectively – these are marked by blue circles. Figure 1 also identifies nine facilities that are under construction, contracted, or announced (see blue triangles) - all fourteen of these projects are described in more detail in Table 2.

Table 2 Worldwide Compressed Air Energy Storage Systems

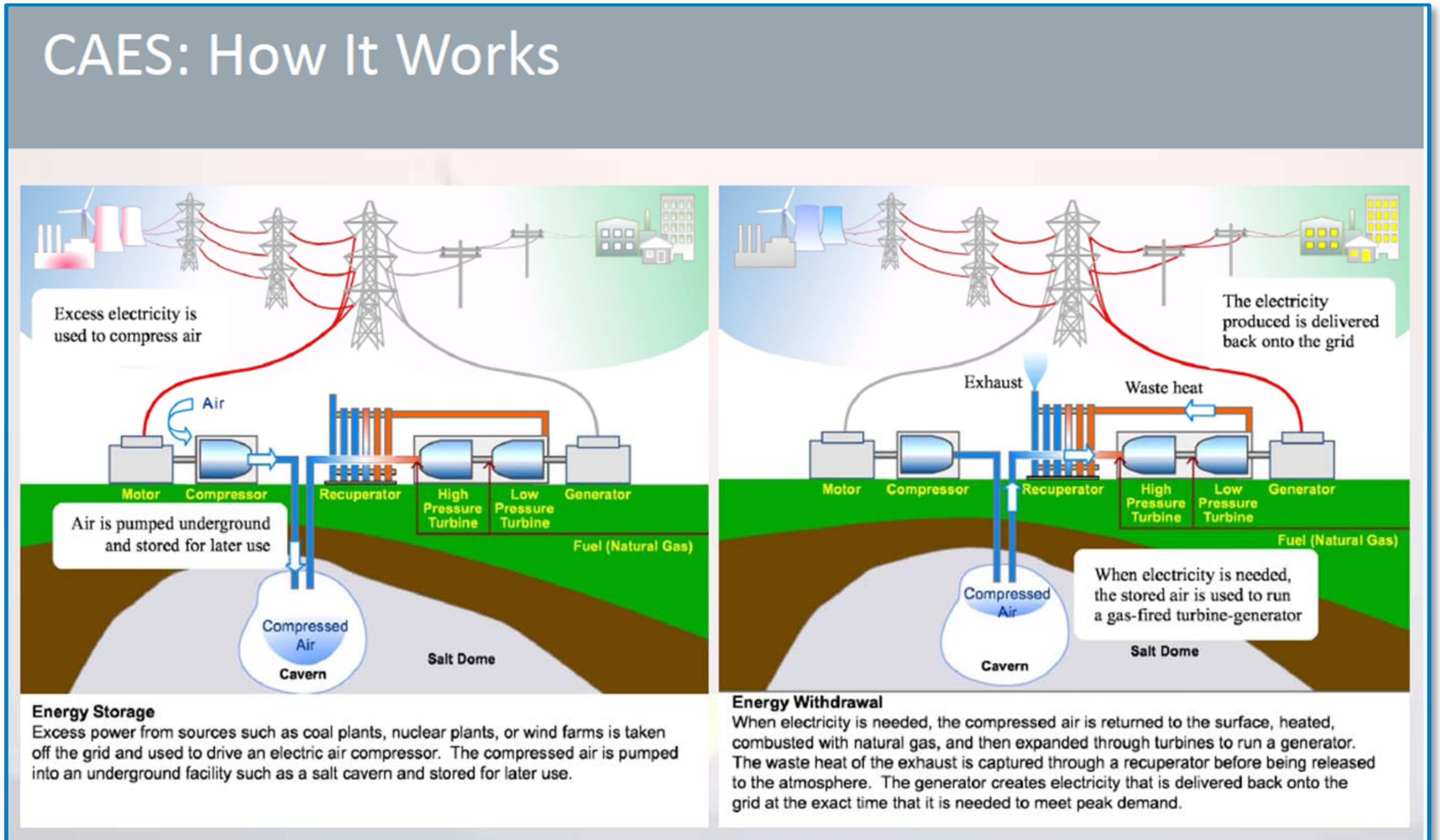
Project Name	Technology	Location	Rated Power (MW)	Duration at Rated Power (HH:MM)	Status
Operational Projects					
Kraftwerk Huntorf	In-ground Natural Gas Combustion Compressed Air	Germany	321	2:0	★ Operational *(online in 1978)*
McIntosh CAES Plant	In-ground Natural Gas Combustion Compressed Air	USA	110	26:0	✶ Operational *(online in 1991)*
Highview Pilot Plant	Modular Compressed Air Storage	UK	0.350	7:0	• Operational *(online 2011)*
Texas Dispatchable Wind	In-ground Iso-thermal Compressed Air	USA	2	250:0	★ Operational *(online in 2012)*
SustainX Inc Isothermal Compressed Air Energy Storage	Modular Iso-thermal Compressed Air	USA	1.5	1:0	• Operational *(online in 2013)*
Under Construction Projects					
ATK Launch Systems Microgrid CAES	Modular Compressed Air Storage	USA	0.080	0:45	Under Construction
Hydrostor UCAES Demonstration Facility	Modular Compressed Air Storage	Canada	1	4:0	Under Construction
Adele CAES Project	In-ground Iso-thermal Compressed Air	Germany	200	5:0	Under Construction
Pollegio-Loderio Tunnel ALACAES Demonstration Plant	Adiabatic Compressed Air Storage	Switzerland	0.5	4:0	Under Construction
Contracted Projects					
Hydrostor UCAES Aruba Project	Modular Compressed Air Storage	Aruba	1	8:0	Contracted
Announced Projects					
Pacific Gas and Electric Company Advanced Underground Compressed Air Energy Storage	In-ground Compressed Air Storage	USA	300	10:0	Announced
Next Gen CAES using Steel Piping	Modular Compressed Air Storage	USA	9	4:30	Announced
NYSEG Seneca/Watkins Glen CAES Project	In-ground Compressed Air Storage	USA	0	0:0	Announced
Apex Bethel Energy Center	In-ground Compressed Air Storage	USA	317	96:0	Announced

Source: DOE Global Energy Storage Database, accessed March 9, 2015, available at http://www.energystorageexchange.org/.
Records highlighted in red are currently being verified by the database.

1.1 How It Works

Commercially-available CAES projects operate by compressing air into an underground facility, such as a salt cavern, and then releasing air to generate electricity. Electricity is consumed in the compression process by the motor and the compressor (see left-hand side of Figure 3), and electricity is generated in the decompression process (see the right-hand side of Figure 3).

Figure 3 How Traditional Compressed Air Energy Storage Works



Source: City of Burbank Water and Power, "*The Problem with the Duck Curve*", prepared for the Electric Power Conference, April 22, 2015.

Compression of air generates heat, while the decompression of air requires an input of heat - there are three ways that CAES systems deal with this heat exchange process, each of which is discussed briefly below.

- *Diabatic*, where the heat generated during air compression is wasted to the atmosphere and then air is reheated upon removal from storage - usually via a natural gas fired burner; note this is the technology used with the first two commercial-scale systems in Germany and in McIntosh, Alabama.
- *Isothermal*, where operating temperatures are attempted to be maintained through constant heat exchange to the environment; this approach has been used in compressed air vehicles and was part of early designs for compressed air torpedoes, using seawater as the heat exchanging medium. The SustainX ICAES project at SustainX's headquarters in Seabrook, New Hampshire was completed in 2013, becoming the world's first megawatt-scale isothermal CAES system.[1]
- *Adiabatic*, which essentially stores the heat that is generated and returns it to the air upon decompression - the theoretical efficiency of this process approaches 100%, whereas in practice it is expected to be 70%. The Adele CAES Project in Sachsen-Anhalt, Germany, that was planned to begin construction in 2013 would be the first adiabatic CAES project. A second adiabatic demonstration project, Pollogio-Loderio Tunnell ALACAES Demonstration Plant, in Ticino, Switzerland is expected to be commissioned in 2015 - that project will use an abandoned tunnel in the Swiss Alps to store compressed air and will use a packed bed of rocks to store the heat from compression.

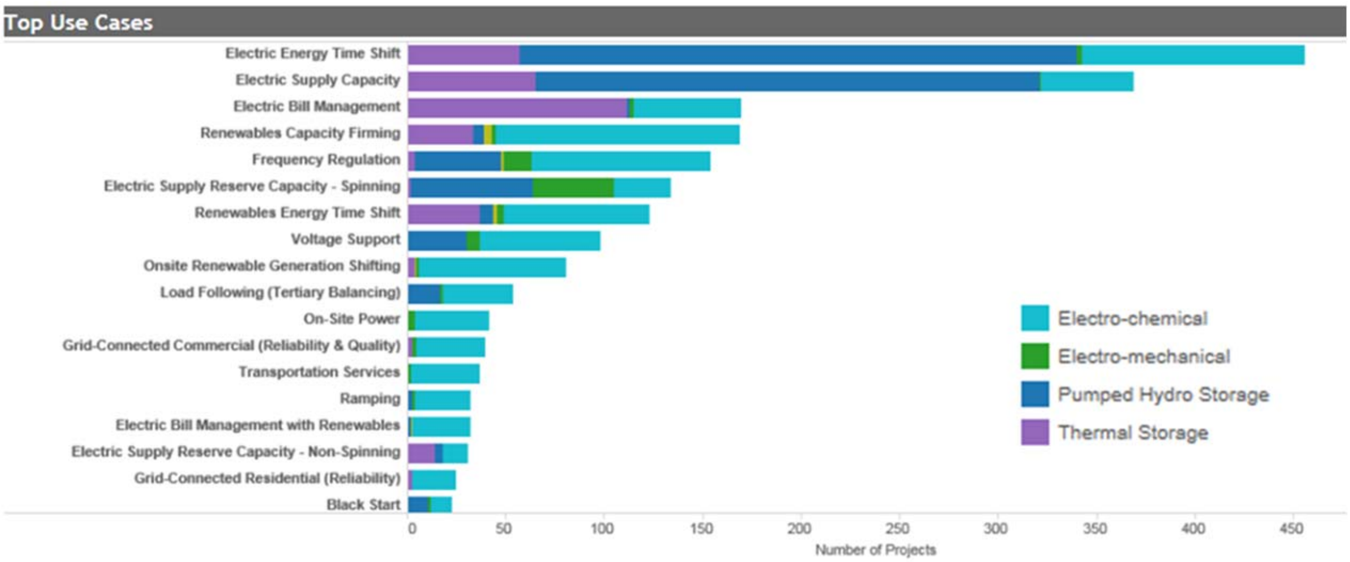
Technology for developing underground compressed air storage reservoirs is the same as that used for underground natural gas storage facilities and benefits from extensive natural gas industry experience in identifying suitable sites and for estimating development costs. Suitable underground storage reservoirs can be provided from a variety of subsurface conditions, but are most likely to consist of an underground cavern, salt deposit, which can leach out to form a reservoir, or aquifer. These storage installations are commonly used in the natural gas industry for natural gas storage. Identification, evaluation and preparation of the subsurface reservoir are provided by specialty contractors who do this for natural gas storage systems using similar techniques. These contractors will determine the available reservoir capacity, certify the viability of a reservoir, and design the wellhead. A high pressure wellhead is installed and sealed, with isolation valves and automatic control valves connected to the charging and discharging pipe connections. Redundant pressure measurement devices are installed to support monitoring and control.

[1] The Daily Fusion, "*World's First Isothermal Compressed Air Energy Storage System Connected to Grid*", September 19, 2013, http://dailyfusion.net/2013/09/worlds-first-isothermal-compressed-air-energy-storage-system-connected-to-grid-20611/.

1.2 Why It's Used

Energy storage can be used for a variety of applications, from energy time shift and bill management, to supply capacity, to renewable energy firming, frequency regulation and ramping. Figure 4 provides a visualization of the top use cases for energy storage by number of projects operating world-wide.[2] The largest segment of storage technology, by rated power, is pumped hydro storage, which can be seen in Figure 4 as dark blue bars.

Figure 4 Energy Storage Use Cases for Operating Projects



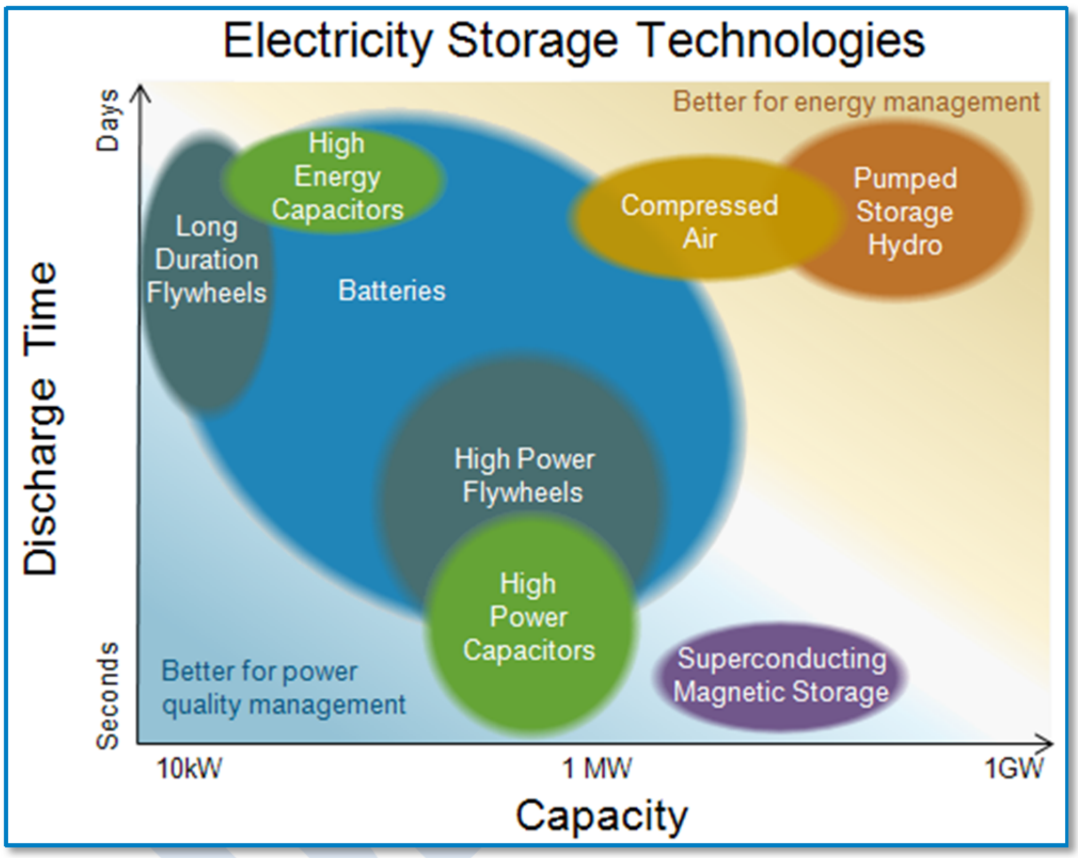
Source: DOE Global Energy Storage Database, accessed May 13, 2015, available at http://www.energystorageexchange.org/.

CAES technology (5 operating projects) and flywheel technology (28 operating projects) together make up the broad category of "electro-mechanical" energy storage technology, shown as green bars in Figure 4. The primary use for CAES is energy time shifting - whether that's nuclear energy, renewable energy, or others. Additional applications for these same CAES projects include spinning reserve, renewable capacity firming, and frequency regulation. According to the same data, flywheels are primarily used for frequency regulation, spinning reserve, voltage support, and resiliency – flywheels are capable of providing instantaneous responses to grid signals, making them best suited for these kinds of grid support and power quality services.

[2] Projects can have multiple use cases.

Figure 5 identifies some common storage types and generally positions each one based on their relative size, shown on the x-axis, and their discharge duration capability, shown on the y-axis. In general, larger-scale, longer-duration storage technologies are better for energy management, like energy time shifting, and smaller-scale, shorter duration storage technologies are better for power quality management, like voltage support and frequency regulation.

Figure 5 Variations in Energy Storage Technology Characteristics



Source: US EIA, "*Electricity storage technologies can be used for energy management and power quality*", December 14, 2011, available at http://www.eia.gov/todayinenergy/detail.cfm?id=4310

Energy management refers to the ability for technologies to "move" energy supply from one part of the time-based load curve to another. Doing this often has many benefits, from avoiding what can be expensive installation and operation of peak capacity facilities, to realizing energy arbitrage opportunities inherent in price differences between low-demand hours and high-demand hours.

Power quality management refers to the ability for technologies to support continued, reliable electrical conditions, like voltage and frequency levels, on the electric power grid. The US EIA article referenced above notes, "*Power quality is an important attribute of grid electricity, as poor quality electricity—momentary spikes, surges, sags, or outages—can harm electronic devices*".[3]

[3] US EIA, "*Electricity storage technologies can be used for energy management and power quality*", December 14, 2011, available at http://www.eia.gov/todayinenergy/detail.cfm?id=4310

1.3 What It Costs

The U.S. Department of Energy's Global Energy Storage Database provides reporting on funding sources and anticipated capital expenditures[4] for energy storage projects. Seven of the fourteen the projects listed previously in Table 2 are described, in terms of capital expenditures, funding sources, and/or funding levels, in Table 6, just below.

Table 6 Capex and Funding for CAES Projects

Project Name	Rated Power (MW)	Capital Expenditure ($)	Funding (Source - Amount)	Effective Unit Cost ($/MW)
Operational Projects				
McIntosh CAES Plant	110	$65M	Not available	$590,909/MW
SustainX Inc. Isothermal Compressed Air Energy Storage	1.5	Not available	ARRA†, Smart Grid Demonstration Program - $5.4M	Not available
Highview Pilot Plant	0.350	Not available	UK Department of Energy and Climate Change, Smart Grid Demonstration Capital Grant Programme - $1.76M	Not available
Under Construction Projects				
ATK Launch Systems Microgrid CAES	0.08	$3.6M	Federal/National Office of Electricity and Reliability – RD&D - $1.6M	$45,000,000/MW
Pollegio-Loderio Tunnel ALACAES Demonstration Plant	0.50	$4M	ALACAES - $2.5M Swiss Federal Office of Energy - $1.5M	$8,000,000/MW
Announced Projects				
Pacific Gas and Electric Company Advanced Underground Compressed Air Energy Storage	300	$355M	ARRA†, DOE Grant Program - $25M State / Provincial / Regional Commercialization Incentive* - $25M	$1,183,333/MW
NYSEG Seneca/Watkins Glen CAES Project*	0	$125M	ARRA†, Smart Grid Demonstration Program - $29.5M	Not available

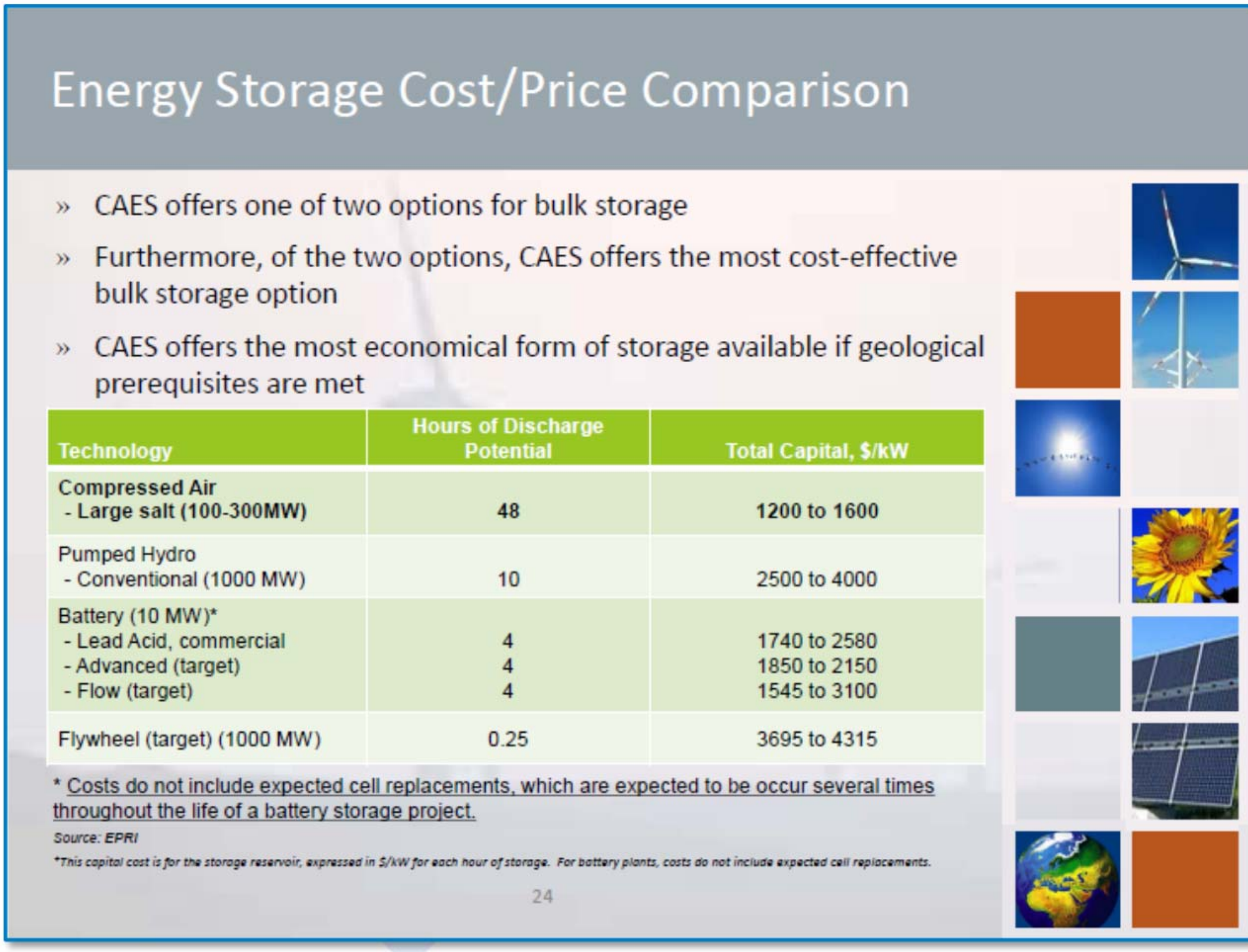
†"ARRA" indicates funding from the U.S. "Federal/National American Recovery and Reinvestment Act of 2009 - RD&D".
* NYSEG concluded that the economics of the NYSEG/Watkins Glen CAES Project were not favorable for development in the current and forecast wholesale electric market in New York State, and further project development work was not warranted.
Source: DOE Global Energy Storage Database, accessed March 9, 2015, available at http://www.energystorageexchange.org/.
Records highlighted in red are currently being verified by the database.

In general, the traditional CAES storage technology can be the most cost-effective "bulk energy storage option", when compared to the other primary technology for this application, pumped hydro storage. Figure 7, presented

4 "Capital Expenditures" is defined in the DOE Global Energy Storage Database as "*The total up-front capital expense of the system stated in dollars*."

by the City of Burbank at the Electric Power Conference - 2015 in Chicago, Illinois, captures general $/kW cost information for CAES technology, as well as comparative cost information to other types of energy storage technologies, including others used for bulk energy management (i.e., pumped storage hydro) and power quality management (i.e., batteries and flywheels).

Figure 7 Energy Storage Cost/Price Comparison, Electric Power Conference - 2015



Technology	Hours of Discharge Potential	Total Capital, $/kW
Compressed Air **- Large salt (100-300MW)**	**48**	**1200 to 1600**
Pumped Hydro - Conventional (1000 MW)	10	2500 to 4000
Battery (10 MW)* - Lead Acid, commercial - Advanced (target) - Flow (target)	 4 4 4	 1740 to 2580 1850 to 2150 1545 to 3100
Flywheel (target) (1000 MW)	0.25	3695 to 4315

Source: City of Burbank Water and Power, "*The Problem with the Duck Curve*", prepared for Electric Power Conference, April 22, 2015.

1.4 Key Players in the CAES Market

Established companies and companies to watch in the CAES market are each briefly discussed below. These include the following:

- Dresser-Rand, a provider of traditional CAES technology that was used it the McIntosh Alabama facility;
- General Compression and SustainX, who have announced a potential merger, providing above-ground and underground technologies; SustainX has a demonstration scale facility operating in New Hampshire and General Compression has a commercial-scale facility paired with wind generation operating in Texas;
- Hydrostor, a Toronto-based company pursuing underwater air storage technology with a demonstration scale facility under construction in Lake Ontario;
- Highview Power Storage, which is currently operating a demonstration-scale facility in the UK; and,
- LightSail, a California-based company that recently announced a new cost-reducing strategy for their water-spray technology.

Dresser Rand

Dresser-Rand provides custom-engineered rotating equipment to several industries, including oil, gas, petrochemical, power generation, and process. One of their many products and services is the "SmartCAES", Compressed Air Energy Storage system.

A recent article on the Power Mag website discussed the April 2015 "Electric Power Conference", including a quote from Dresser Rand's business development director:

> *"CAES is a mature technology that has nevertheless seen only limited application. In a sense, it's been a solution in search of a problem until recently. Bobby Bailie, business development director-CAES for Dresser Rand—which developed the only CAES plant in the U.S.—told attendees, 'We've been waiting 23 years for the market to catch up.'*
>
> *"Dresser-Rand's latest technology, which it calls SmartCAES, offers turndown capacity from 10% to 100% with a flat heat rate across that range. The system can manage less than 10 minute startup time in generation mode and can ramp 20% rated power per minute."*[5]

Dresser-Rand provided the energy storage technology, including the entire turbomachinery train and controls,[6] used in the McIntosh CAES facility and provides full support services to that facility's owner, the PowerSouth electric cooperative. Dresser-Rand is also a partner to a project looking to deploy CAES technology paired with wind turbine technology in Wyoming - a project called "Pathfinder Wind Energy". Figures 8 and 9 provide excerpts from that project's website, in particular the discussion of the CAES component of the project.

[5] Power Mag "CAES a Potential Solution to California's "Duck Curve," Say Experts", April 22, 2015, available at http://www.powermag.com/caes-a-potential-solution-to-californias-duck-curve-say-experts/.

[6] Dresser-Rand website, accessed May 13, 2015, available at http://www.dresser-rand.com/products-solutions/systems-solutions/compressed-air-energy-storage-solutions/.

Figure 8 Pathfinder Project Website: "Our CAES Project"

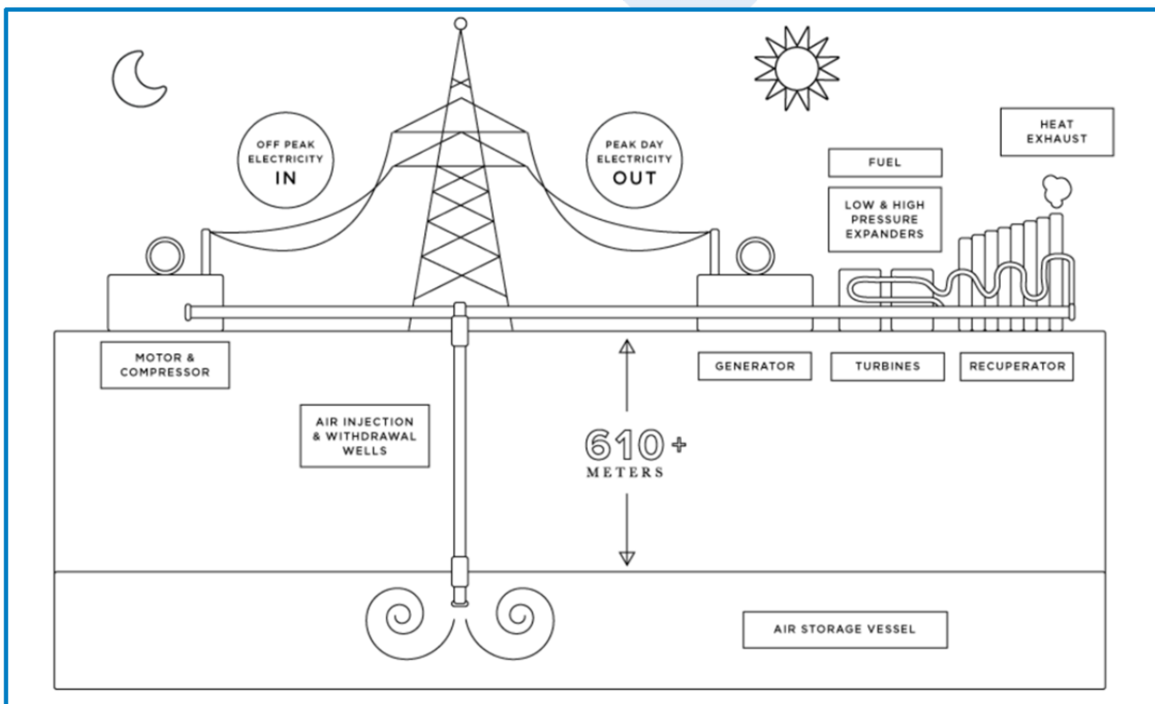
OUR CAES PROJECT

"It's really simple."

George Lucas, the lead CAES engineer at Dresser Rand, explains.

"Electricity generated by wind in Wyoming is first sent by power lines to Utah. During periods of low demand, surplus electricity generated by wind is stored in a unique salt formation found only in Utah. Electricity generated in Wyoming can power compressors in Utah that pump air into underground salt domes. Later, when the electricity is needed in California, the compressed air drives turbines that regenerate electricity very efficiently. Storage and regeneration in Utah means electricity generated by wind in Wyoming is available any time of the day to people in California."

Figure 9 Pathfinder Project Website, CAES Technology Schematic



Source (Figures 8 and 9): Pathfinder website; http://www.pathfinderwindenergy.com/caes/; accessed on June 16, 2015.

General Compression, SustainX

On March 30, 2015, General Compression and SustainX released a statement that they'd signed a letter of intent to merge their companies. The new company, "GCX Energy Storage" would continue the focus held by both startups independently - to provide "fuel-free" CAES technology.

Both companies have successfully commissioned CAES projects - General Compression's technology is in use at the utility-scale, 2 MW by 300 MWh facility in Gaines, Texas facility where it stores wind power, and SustainX's full-scale demonstration project, a 1.5 MW by 1 MWh facility, is operating at SustainX headquarters in Seabrook, New Hampshire[7]; it is the world's first "isothermal" CAES project and it stores air in industrial pressure vessels above-ground, as opposed to traditional air storage in underground salt caverns. An article that points to rumors of a recent layoff at SustainX anticipates that the merger with General Compression is an indication that the startup has abandoned the goal of developing an above-ground air storage solution.[8]

Hydrostor

The Canadian startup company Hydrostor is in the process of constructing their demonstration-scale "UW-CAES" project in Toronto. This project would be the world's first "underwater"("UW") CAES facility (see Figure 10). Hydrostor's website summarizes this technology as follows:

> *"The Hydrostor system efficiently converts electrical energy to compressed air via an advanced adiabatic compression system. This air is then sent to a series of flexible accumulators located 50-500 meters below the surface of a body of water. Once in the accumulators, the energy can be stored until required by the grid. When the energy is required, the weight of the water pushes the air back to the surface where our system directs it through an expander driving a generator thus supplying energy to the grid and completing the storage cycle."*

The company's value proposition is that this approach combines the "*low-cost and capacity of large-centralized systems*", with the "*flexibility to locate and scalability of the small-decentralized systems*". Hydrostor offers that its technology could be sited near major cities, many of which are located near large bodies of water. This represents added value over the traditional underground CAES technology, which relies more on availability of land area and specific geological characteristics to be successful.

The Hydrostor company is run by a six-member management team, a five-person Board of Directors that includes the CEO and the President, and four research advisors with doctorate degrees in their fields.

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[7] General Compression and SustainX Press Release, available at http://www.generalcompression.com/index.php/news.

[8] GreenTechMedia, "*SustainX to Merge with General Compression, Abandon Above-Ground CAES Ambitions*", by Jeff St. John, March 31, 2015; available at http://www.greentechmedia.com/articles/read/sustainx-to-merge-with-general-compression-abandon-above-ground-caes-ambiti,

Figure 10 Hydrostor Project Website

Source: Hydrostor website, available at http://www.hydrostor.ca/project/

The 750 kW UW-CAES facility will interconnect with the Ontario-based utility, Toronto Hydro. Hydrostor also has a power purchase agreement in place with WEB Aruba N. V., the island of Aruba's water and power utility, for a facility that would be cited near Aruba's Vader Piet Wind Park.[9] A September 2014 article in Renewable Energy World discussed the opportunities and challenges of this technology via an interview with Hydrostor's CEO, Curtis VanWallegham.

> *"The technology's advantages include off-the-shelf compressors, turbines, heat exchangers as well as "free" air and ocean pressure. UW-CAES advocates even note that the tech is environmentally friendly and the bags can act as "artificial reefs" for marine life."*[10]

Barriers that remain to be overcome are largely tied to the permitting and safety of such large-scale underwater structures – buoyant forces from the compressed air require an anchor of about 3-4 times the size of the air accumulator bag itself. Maxim de Jong, CEO and Chief Engineer of Thin Red Line Aerospace, manufacturer of the "energy bags" said in the Renewable Energy World article, "*…the bag alone would weigh 500 metric tons and if something like this were to cut loose, you could sink an oil tanker.*"[11]

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[9] Renewable Energy World, "*Underwater Compressed Air Energy Storage: Fantasy or Reality?*", September 16, 2014, available at http://www.renewableenergyworld.com/articles/2014/09/underwater-compressed-air-storage-fantasy-or-reality.html.

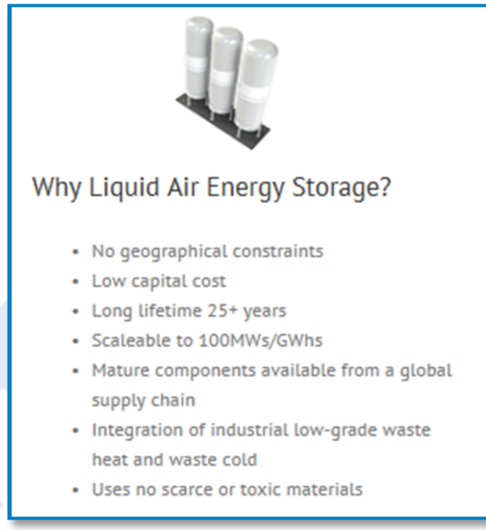
[10] Ibid.

[11] Ibid.

Highview Power Storage

Highview Power Storage is located in London's Trafalgar Square - the company was founded in 2005 and is a "*developer of large-scale energy storage solutions for utility and distributed power systems*". Highview Power Storage operates with a six-member management team, including CEO Gareth Brent and a five-person team of "Non-Executive Directors".

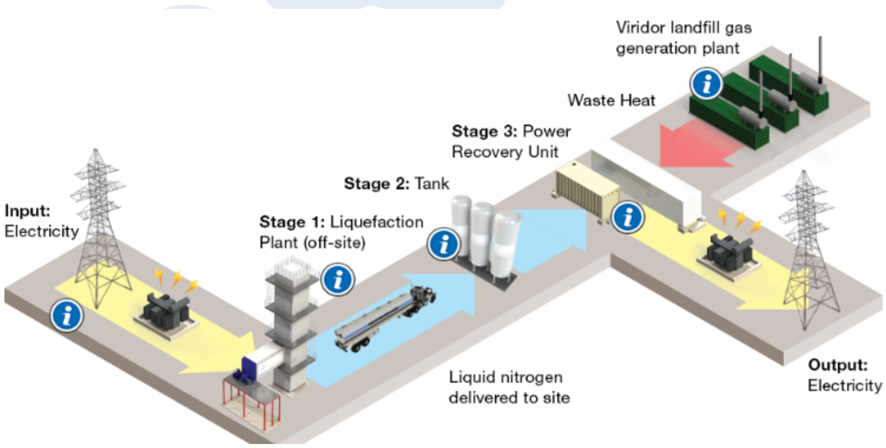
Highview's technology was successfully commissioned with a 350 kW by 2.5 MWh pilot project in 2011, located in Slough, UK. The technology relies on storing air in liquid form above ground and can also be designed to leverage waste heat from industrial processes to aid in the efficiency of the energy recovery process. According to the Highview website, this pilot facility was connected to the grid and "subjected to a full testing regime, including performance testing for the US PJM electricity market".[12] The plant is now in the process of being relocated to the University of Birmingham's campus and is expected to be re-commissioned in the spring of 2015.



A description of the benefits of this "liquid air energy storage" ("LAES") technology is included on the Highview Power Storage website (see image at right). Similar to other companies, Highview's technology seeks to break free from the geological requirements inherent in traditional CAES technology that relies on storing air in underground salt caverns.

With funding from the UK's Department of Energy and Climate Change ("DECC"), Highview Power Storage is working to develop a 5 MW by 15 MWh LAES system that will be paired with a Viridor landfill gas generation plant. This combined facility will not only store "wrong time" generation, but it will also convert low-grade waste heat to power. An image of this proposed process is shown below in Figure 11.

Figure 11 Highview Power Storage Pre-commercial Demonstrator, Online 0215



Source: Highview Power Storage website, available at http://www.highview-power.com/portfolio-items/pre-commercial-demonstrator-online-2015/.

[12] Highview Power Storage website, "*Liquid Air Energy Storage (LAES) pilot plant, July 2011 - November 2014*", available at http://www.highview-power.com/portfolio-items/liquid-air-energy-storage-system-pilot-plant-april-2011-present/?portfolioID=48

LightSail Energy

LightSail Energy, headquartered in Berkley, California, is a startup company that operates with six team members, including co-founders Danielle Fong, Steve Crane, and Edwin Berlin, Jr., plus various investors, seven of them publically stated on their website.

According to the company's website, LightSail Energy's compressed air process is differentiated by the use of a fine, dense water spray to absorb heat during air compression and provide that same heat energy during air expansion. Air is stored in "low-cost air storage tanks", or for larger installations, in underground caverns like traditional technologies.

The "Opportunity" tab of the company's website speaks to the different facts and figures about today's power industry, including the opportunity presented by the concept of energy storage. LightSail Energy is targeting the development of technologies that, paired with power generation like wind energy and other clean, intermittent, off-peak, sources, will be less expensive than the construction of additional peaking fossil facilities and the transmission and distribution infrastructure needed to support peak grid operation.

Figure 12, below, presents a few of these "value propositions" - the first is a demonstration of how today's power delivery infrastructure is utilized, proposing that energy storage can help increase that utilization without adding more infrastructure; the second is a depiction of how LightSail Energy technologies compare to more traditional peaking capacity generation, like diesel generators and natural-gas fired peaker plants on a cents per kilowatthour Levelized Cost of Energy basis.

Figure 12 LightSail Energy Website

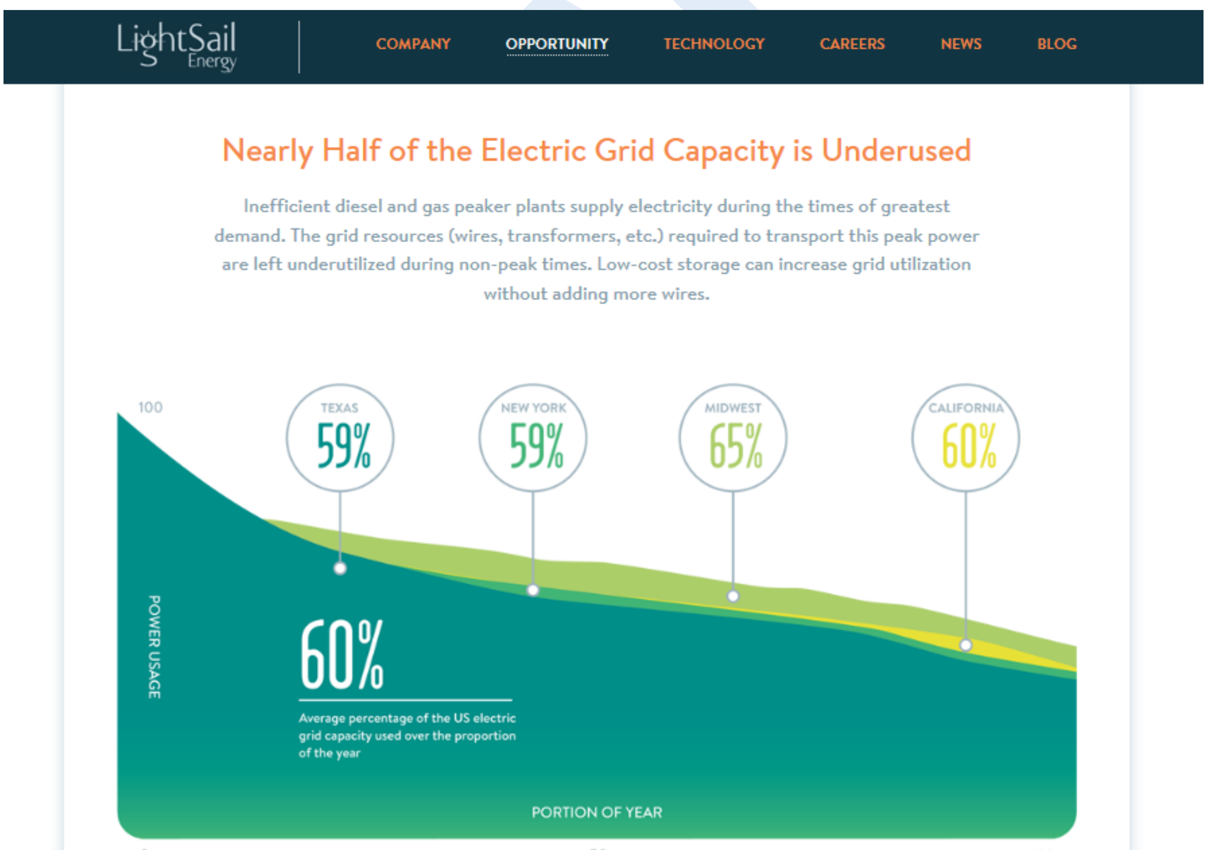
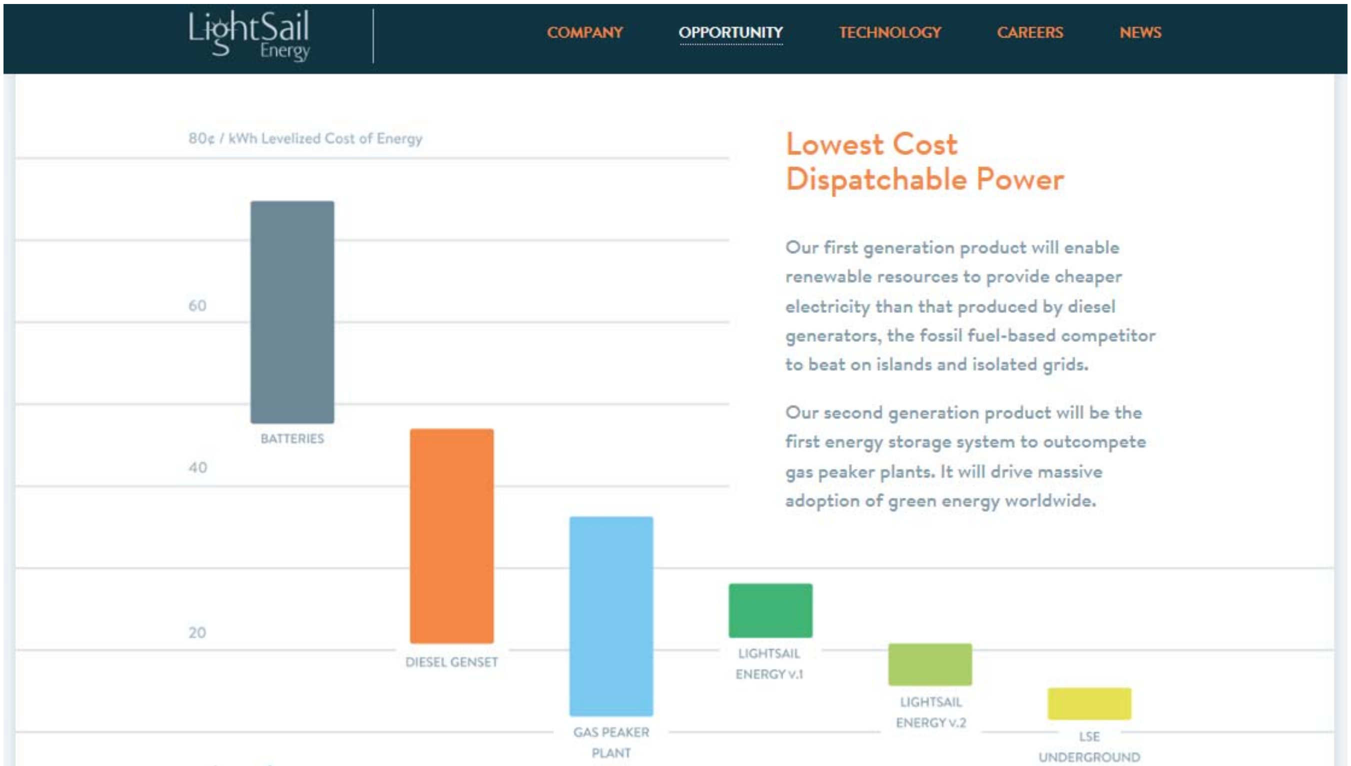


Figure 12 (continued) LightSail Energy Website



Source: LightSail Energy Website, accessed on June 16, 2015, available at http://www.lightsail.com/opportunity/

One of LightSail Energy's co-founders, and its chief scientist, Danielle Fong, spoke at an event in San Francisco in April 2015, revealing for the first time the "V2" version of LightSail's technology, shown in Figure 12, above, as a light green bar. This next generation technology achieves a lower levelized cost of energy as a result of a large reduction in capital costs, though the details of that achievement are not yet public.

A GTM Greentech Grid article wrote that LightSail is "*backed by some of the country's most prominent venture capitalist tech billionaires*"[13] and that the company has announced two field projects to date – one will store energy from a wind turbine project in Nova Scotia,[14] and the other will store energy from a solar photovoltaic project on Naval Base Ventura County in California.[15]

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[13] GTM Greentech Grid, "*LightSail's Secret Plan to Slash the Costs of Compressed Air Energy Storage*", April 28, 2015, available at https://www.greentechmedia.com/articles/read/LightSails-Secret-Plan-to-Slash-the-Costs-of-Compressed-Air-Energy-Storage?utm_source=Storage&utm_medium=Headline&utm_campaign=GTMDaily.

[14] The Queens County Advance, "*Innovative Wind Energy Project coming to Queens*, "July 29, 2014, available at http://www.theadvance.ca/News/Local/2014-07-29/article-3816244/Innovative-wind-energy-project-coming-to-Queens/1.

[15] California Energy Commission, "*Energy Commission Awards Nearly $4 Million for Research Projects*", April 30, 2013, available at http://www.energy.ca.gov/releases/2013_releases/2013-04-30_4_million_for_research_projects.html

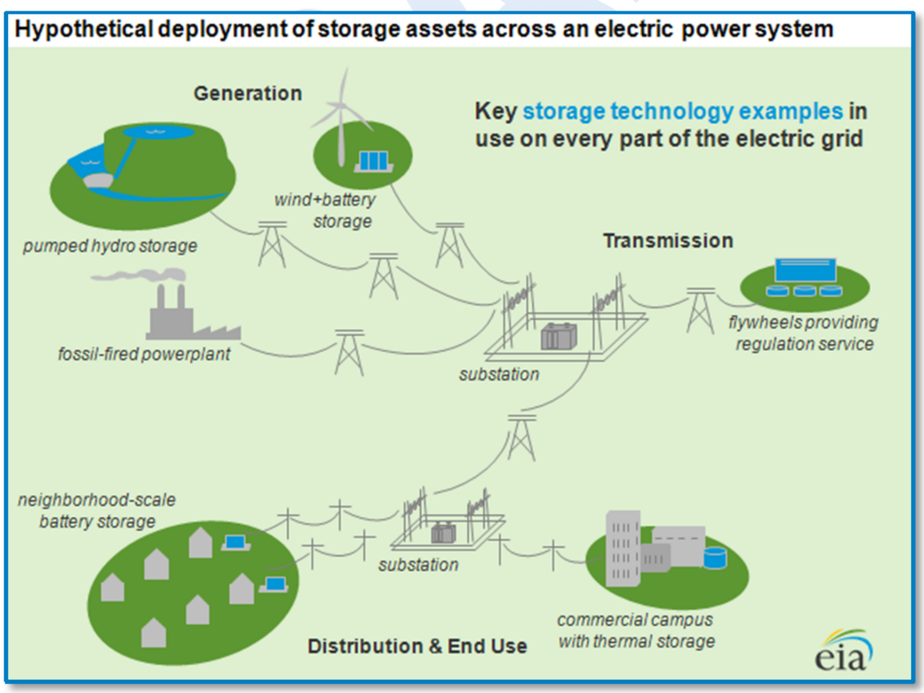
2 Competing Energy Storage Alternatives

The Energy Storage Association summarizes energy storage technologies in the following categories:

- *Solid State Batteries* - a range of electrochemical storage solutions, including advanced chemistry batteries and capacitors;
- *Flow Batteries* - batteries where the energy is stored directly in the electrolyte solution for longer cycle life, and quick response times;
- *Flywheels* - mechanical devices that harness rotational energy to deliver instantaneous electricity;
- *Compressed Air Energy Storage* - utilizing compressed air to create a potent energy reserve;
- *Thermal* - capturing heat and cold to create energy on demand; and,
- *Pumped Hydro-Power* - creating large-scale reservoirs of energy with water.

Each of the technologies contained within these categories provides a different range of capabilities - some can provide short, instantaneous bursts of energy, which can be utilized to support power quality and regulation services at the transmission service level of the grid, whereas other types, like pumped storage hydro and CAES, can provide a longer-duration discharge of energy, which can be used to smooth out a given area's daily load shape, storing energy at night, and releasing it during peak hours of the day. Figure 13 provides an illustration from the U.S. EIA showing where the different types of energy storage technologies can provide value to today's electric power system – CAES would typically be sited similarly to pumped storage hydro.

Figure 13 Applications of Energy Storage on the Electric Power System



Source: U.S. Energy Information Administration, "Electricity storage: Location, location, location … and cost", June 29, 2012; available at http://www.eia.gov/todayinenergy/detail.cfm?id=6910#tabs_ElecStorage-5

2.1 GPA's Energy Storage Feasibility Study

To determine the feasibility, performance, and cost of adding an energy storage system ("ESS") to the Guam grid, GPA contracted with TC Engineers, PC ("TCE") to provide an energy storage feasibility study, which was finalized on August 29, 2014. This study did not analyze pumped storage hydro or compressed air energy storage for the reason that "*…these technologies are highly location specific and may not provide the type of response necessary for spinning reserve applications*".[16] The technologies that were analyzed included commercially-available battery and flywheel technologies and the three locations evaluated were the Agaña, Harmon, and Marbo Substations. The following expert identifies the cost per kW findings for these technologies and locations:

> *"An evaluation of the cost estimates for the three (3) locations indicate that on average, it would cost $1.26 Million/MW for a building-based battery ESS, $1.34 Million/MW for a containerized battery ESS, and $1.42 Million/MW for a 5-minute flywheel system."*[17]

The feasibility study ultimately concluded and recommended that a 40 MW, 10 MWh, battery-based ESS located at Agaña at a cost of $49.6 Million would be feasible, and that GPA should use a request for proposals ("RFP") process with broad specificity to acquire an ESS. The RFP broadness was meant to ensure that GPA could "*…evaluate more alternatives and chose the best storage technology and system that best meets GPA's requirements*."[18]

2.2 Tesla and Solar City Battery Alternatives

On April 30th of 2015, Tesla unveiled their home-scale and utility-scale battery products. The "Powerwall", meant for residential home use has two sizing options – the first, a 7 kWh unit, costs $3,000 and is meant for daily use, and the second, a 10-kWh size meant for weekly cycle power back-up, costs $3,500.[19]

- Tesla has teamed with Vermont-based utility Green Mountain Power as a "channel partner" for the distribution of Powerwalls.
- SolarCity, a major solar panel installer that holds a large share of the residential rooftop solar market and whose board of directors is chaired by Tesla's Elon Musk, announced on April 30th that they would be providing "*a turnkey battery backup service that includes permitting, installation and ongoing monitoring*."[20]

SolarCity's press release goes on to say that, "*Incorporating Tesla's new battery technology, SolarCity is now able to configure a solar system (along with other energy management technologies) as a stand-alone, off-grid power supply. SolarCity plans to first offer these off-grid systems to eligible Hawaii customers that might otherwise be prevented from using solar power*."

Tesla also announced a utility-scale battery product on April 30th – the "Powerpack" is a 100 kWh battery block that can scale "*infinitely*", according to Musk.

[16] TG Engineers, PC, prepared for GPA, "*Engineering & Technical Services for Energy Storage Feasibiliy Study, Final Report, GPA-RPF-13-007*", dated August 29, 2014, page 28.
[17] Ibid, page 63.
[18] Ibid, page 5.
[19] SNL, "*Tesla unveils $3,000 home energy storage battery, also utility-scale battery*", May 1, 2015, available at https://www.snl.com/InteractiveX/Article.aspx?cdid=A-32415711-12853&mkt_tok=3RkMMJWWfF9wsRoju6XAcO%2FhmjTEU5z16eUuXaG%2FlMI%2F0ER3fOvrPUfGjI4CT8BlMa%2BTFAwTG5toziV8R7DNLM1wy8YQWhPh.
[20] Solar City Press Release, April 30, 2015, available at http://www.solarcity.com/newsroom/press/solarcity-introduces-affordable-new-energy-storage-services-across-us.

Tesla battery customers include the following list:[21]

- Texas-based utility Oncor and California-based utility Southern California Edison,
- Demand response provider EnerNOC,
- Amazon Web Services,
- AES Energy Storage, the biggest utility-scale storage developer in the US[22], and
- Advanced Microgrid Solutions, a company that designs, finances, installs and manages advanced energy storage solutions for commercial, industrial and government building owners.[23]

[21] GTM Greentech Grid, "*What Advanced Microgrid Solutions Plans to Do With 5,000 Tesla Powerpack Batteries*", June 8, 2015, available at http://www.greentechmedia.com/articles/read/what-advanced-microgrid-solutions-plans-to-do-with-5000-tesla-powerpack-bat.

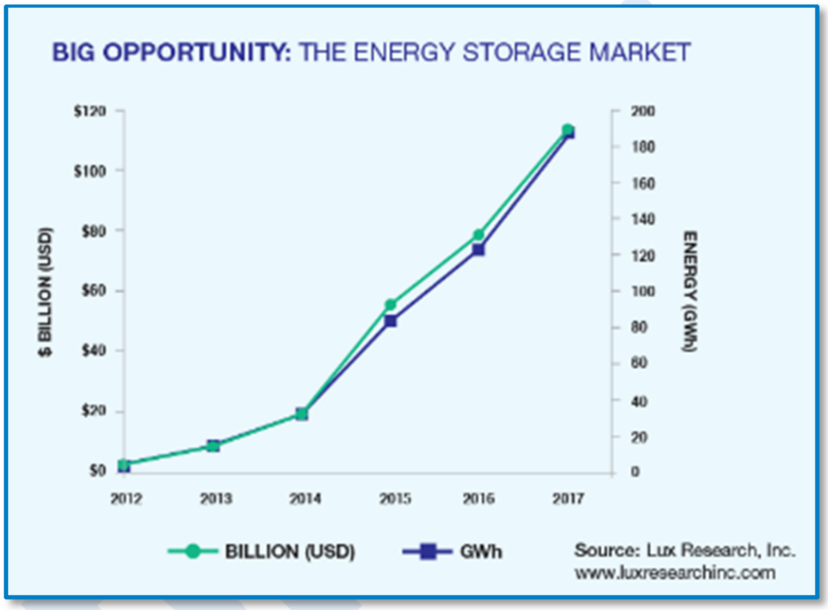
[22] GTM Greentech Grid "*AES Growing its Energy Storage Fleet, Project Pipeline in the Americas and EU*", April 27, 2015, available at http://www.greentechmedia.com/articles/read/AES-Growing-its-Energy-Storage-Fleet-Project-Pipeline-in-the-Americas-and.

[23] PR Newswire, "*Advanced Microgrid Solutions Signs 500 MWh Energy Storage Deal with Tesla*", June 4, 2015, available at http://www.prnewswire.com/news-releases/advanced-microgrid-solutions-signs-500-mwh-energy-storage-deal-with-tesla-300094291.html

3 Market Drivers for Energy Storage

The value of the energy storage market has been quantified by multiple website and research organizations - a few examples of these are included below.

- *"According to market research firm IHS, the energy storage market is set to "explode" to an annual installation size of 6 gigawatts (GW) in 2017 and over 40 GW by 2022 — from an initial base of only 0.34 GW installed in 2012 and 2013."* [24]
- *"An IMS Research report expects the market for storing power from solar panels – which was less than $200 million in 2012 – will catapult to $19 billion by 2017."*[25]
- *According to Lux Research, an independent research and advisory firm, the global potential for grid energy storage by 2017 is $113.5 billion, accounting for 185 GWh (52 GW) of capacity.*[26]



What is driving this rapid growth projection? The concept of energy storage has long-been pursued by the electric industry as a way to increase the efficiency of the electric grid - shifting generation requirements from peak periods to off-peak periods and regulating the frequency of energy distribution. With the rapid growth in other power industry technologies, and the intermittent nature of these technologies, however, this market is gaining new attention from governments, businesses, and customers. Technologies like renewable energy generation, plus transmission and distribution system automation and control technologies like the Smart Grid, and other advanced metering technologies, have reinvigorated the business case for energy storage. The value proposition of these technologies, combined with new policies to incentivize energy storage development stand to drive further energy storage market growth in future years.

[24] Energy Storage Association, "*Facts and Figures*", available at http://energystorage.org/energy-storage/facts-figures.

[25] Ibid.

[26] Highview Power Storage website, "Market", available at http://www.highview-power.com/market/

Key market drivers relevant to the CAES market include value-added applications for storage technology and the introduction of energy storage standards and solicitations for storage projects. Each of these, in addition to market barriers for CAES, is discussed below.

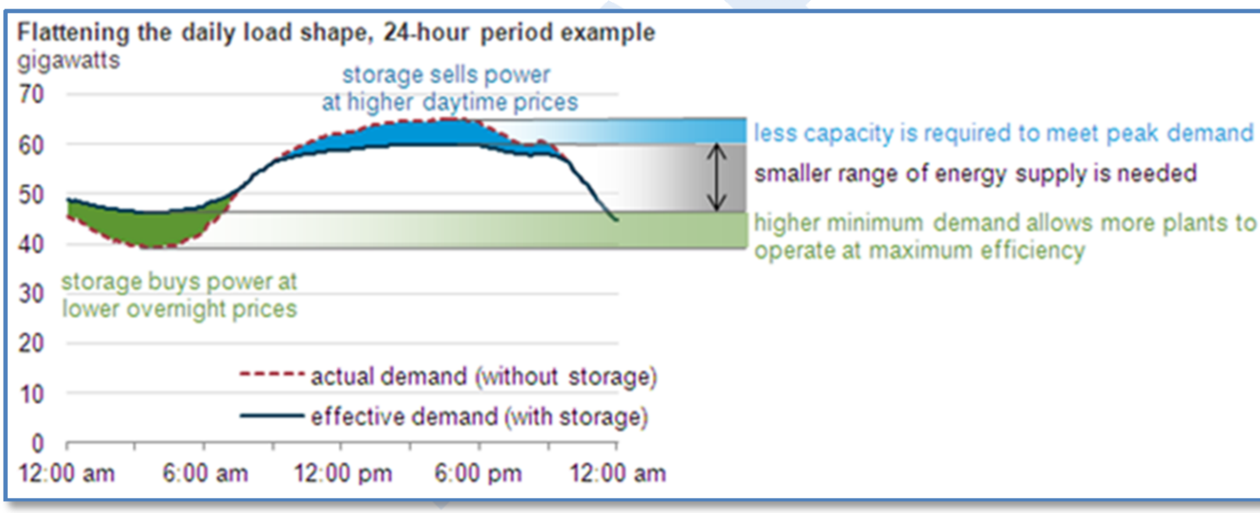
3.1 Value-Added Applications of Storage

The most prevalent applications of CAES technologies include daily energy management and renewable energy integration.

3.1.1 Daily Energy Management

Energy storage technologies that operate over daily or hourly time durations, such as CAES and pumped storage hydro for instance, present opportunities to decrease both the capacity-related and energy-related costs of operating the bulk electric system. Figure 14 below, developed by the U.S. Energy Information Administration presents a standard daily load shape (see red dashed line). The green area shows the impacts of energy storage technologies as they're consuming energy from the grid (i.e., "charging"). This has the effect of raising the system load to the level of the solid blue line. The difference between the dashed red line and the solid blue line, as noted with a green area and green text, "*allows more plants to operate at maximum efficiency*". Conversely, closer to the peak period of the day (see blue area and blue text), energy storage technologies can generate electricity (i.e., discharge), which has the effect of lowering the system demand, thereby lowering the capacity requirements needed to meet peak.

Figure 14 Energy Storage used for Daily Energy Management



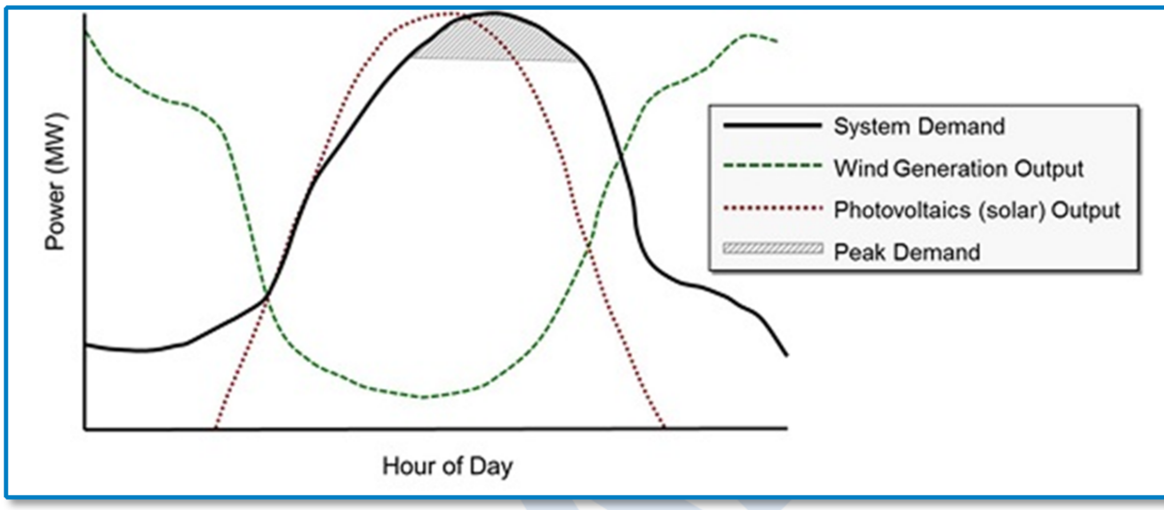
Taken together, the effects of storage, as shown above, increase the operating efficiency of existing capacity, thereby potentially decreasing the unit cost of energy by more efficiently utilizing fuel inputs, and decreasing the need for new capacity by lessening the peak demand of the system.

3.1.2 Renewable Energy Integration

With a worldwide focus on reducing carbon emissions and a continuing commitment of many states and countries to reduce the cost of energy, many policies and practices have been adopted to incentivize and support renewable energy technologies, including things like Production Tax Credits, Renewable Energy Credits, Net Metering, and Renewable Portfolio Standards. In the first quarter of 2015, 53% of all new generating capacity in the U.S. came from wind projects and 17% came from solar projects[27] - both of these technologies present a variety of opportunities and challenges.

Figure 15, below, shows the relative timing of wind and solar generation supply versus system demand; the gray shading on the system demand curve indicates the period of the day when peak demand typically occurs. As can be seen in this figure, the shape and timing of the generation output from wind and solar don't quite match up with the timing and shape of the system demand. Storage can aide in capturing this renewable generation when it's available, and discharging it at a time that better supports meeting power demand.

Figure 15 Comparison of Daily Profiles of Wind and Solar Generation versus System Demand



Source: Energy Storage Association, "*Renewable Integration Benefits*", available at http://energystorage.org/energy-storage/energy-storage-benefits/benefit-categories/renewable-integration-benefits

3.2 Energy Storage Standards and Procurements

Newer technologies used for energy storage are now moving from the test stage to commercialization, prompted by legislation as well as RFPs. The state of California passed the first energy storage law in 2010. The law, AB 2514, which took effect on January 1, 2011, requires utilities to procure energy storage systems beginning in 2015. While the law as written did not include specific targets, the California Public Utilities Commission ("CPUC") subsequently set a mandate of 1.3 GW of storage by 2020 for the state's three investor-owned utilities. The CPUC's energy storage website[28] provides valuable references to events, activities, studies, whitepapers, and workshop documents that chronicle the development of this California standard. Southern California Edison, Pacific Gas & Electric, and San Diego Gas & Electric have already begun the procurement process in order to meet the 2020 energy storage target, with RFPs for energy storage issued in late 2014.

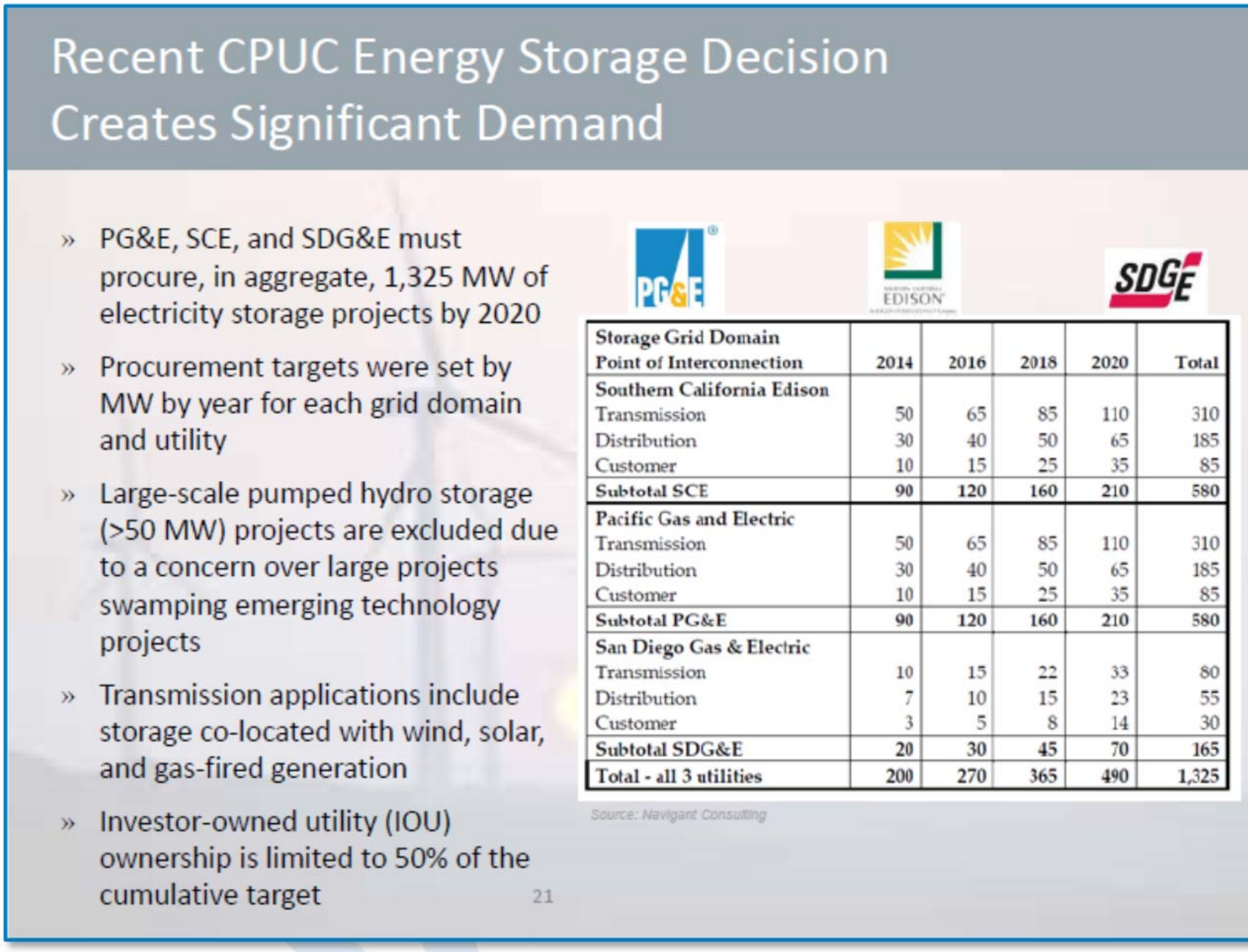
Energy storage development and investment is also being driven in California by the state's current and proposed Renewable Portfolio Standards (RPS) and greenhouse gas reduction targets - RPS targets that resulted in California being the top producer of non-hydroelectric renewable electricity among the fifty states in 2014.

[27] Renewable Energy World, "*Renewables Account for 75 Percent of New US Generating Capacity in First Quarter of 2015*", April 23, 2015, available at http://www.renewableenergyworld.com/articles/2015/04/renewables-account-for-75-percent-of-new-us-generating-capacity-in-first-quarter-of-2015.html.

[28] Available at http://www.cpuc.ca.gov/PUC/energy/electric/storage.htm.

Figure 16 provides a summary of the California energy storage performance standards.

Figure 16 California Energy Storage Performance Standards



Storage Grid Domain Point of Interconnection	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**

Source: City of Burbank Water and Power, “The Problem with the Duck Curve”, prepared for the Electric Power Conference, April 22, 2015.

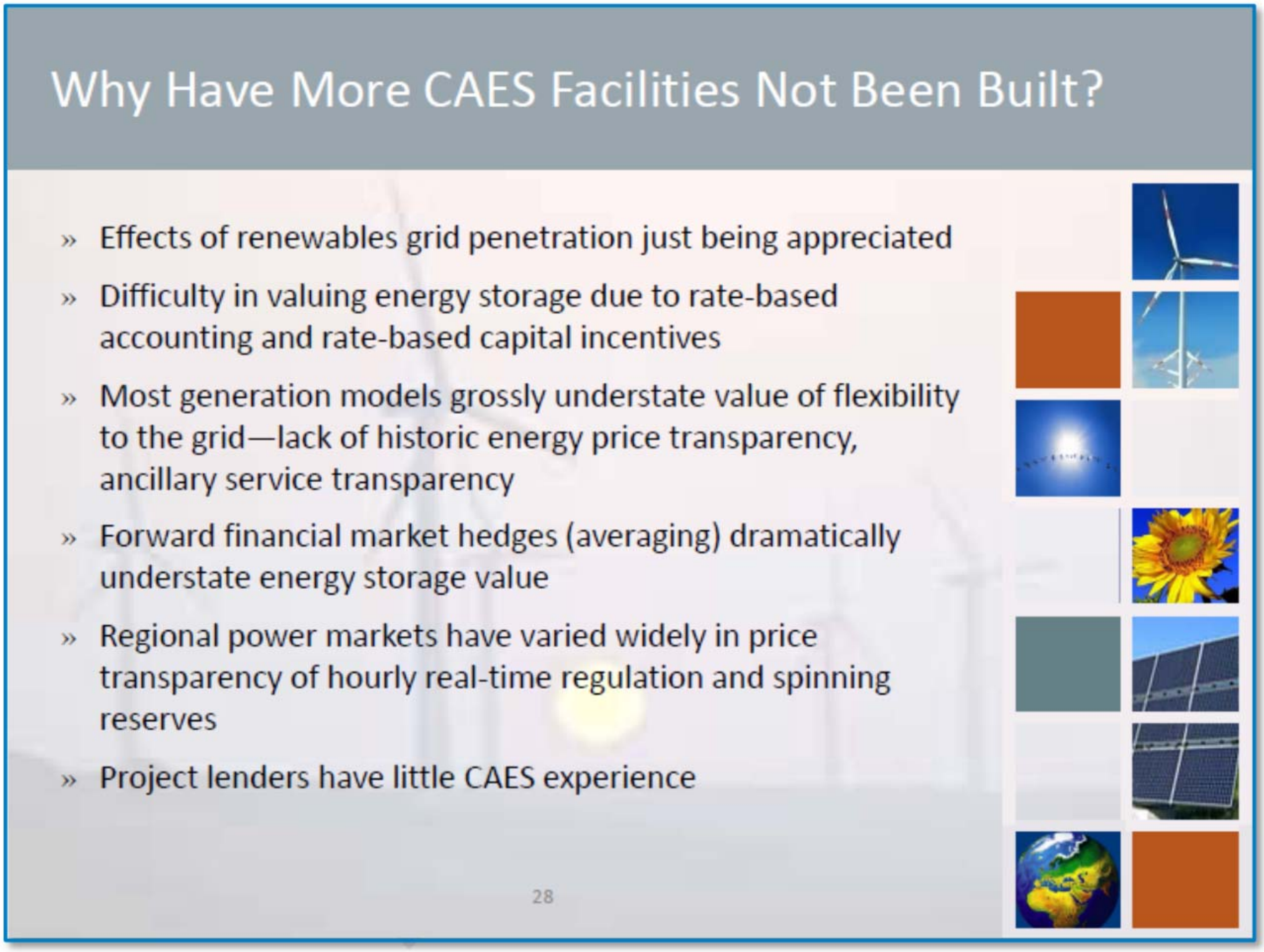
Other states are issuing RFPs for energy storage projects as well. In 2014, Hawaiian Electric Company issued RFPs for 60 to 200 MW of storage to help with the increasing levels of renewables on O‘ahu by 2017, and is open to all technologies including batteries, flywheels, and compressed gas, among others. New Jersey is investigating energy storage projects and in New York, incentives have been put in place to provide demand reduction, including energy storage. In Canada, Ontario is requesting 50 MW of energy storage.

Puerto Rico has put in place a set of minimum technical requirements (“MTRs”) related to all new renewable generation. In order to handle the intermittent nature of wind and solar power, all new renewable energy projects must include enough energy storage to provide 45% of a unit’s maximum capacity for one minute. Each unit must also have enough storage to provide 30% of capacity for frequency regulation.

3.3 Market Barriers for CAES

Though there are two commercial-scale CAES facilities that have both been operating for more than two decades, there still remain some market barriers to further CAES technology adoption. Each of these are summarized in Figure 17 below.

Figure 17 Market Barriers for CAES



Source: City of Burbank Water and Power, "*The Problem with the Duck Curve*", prepared for the Electric Power Conference, April 22, 2015.

In addition to these, a chief barrier in the past has been the availability of the right geological structure to house compressed air. This barrier ultimately halted a developing project in Iowa, which now has a lessons learned report and website available as a way of sharing information learned throughout the eight-year development process. Figure 18, below, provides a glimpse of this "Lessons from Iowa" website.

Figure 18 Iowa Stored Energy Park Project: Lessons from Iowa

Source: "Lessons From Iowa", http://www.lessonsfromiowa.org/about/; accessed on February 5, 2015.

4 Implications for Guam

As Guam considers its future resource mix, including whether there exists a possibility to leverage energy storage opportunities, particularly CAES, the following considerations might prove to be useful steps on the path forward.

- ***Consider Establishing Portfolio Standards for Desired Energy Investments*** - In order to further encourage desired energy investments and bolster desired energy markets on the island of Guam, the GPUC and/or the Guam legislature might consider establishing portfolio standards, such as renewable portfolio standards ("RPS"), energy efficiency resource standards ("EERS") or energy storage standards. Twenty-nine states, plus Washington, DC, and three U.S. territories have established RPS policies as a way of supporting the renewable energy industry and incentivizing the adoption of renewable energy technologies; eight states and Guam have adopted "renewable portfolio goals", which are similar to, but less formal than, RPS policies. EERS policies or goals have been adopted by just over half of the 50 U.S. states (18 states with standards; 8 states with goals) to provide a focus and priority on energy efficiency. Likewise, California became the first state to establish an energy storage standard. See Attachment A for summary maps regarding the RPS and EERS policies that are currently in place.

  A recent study by the American Council for an Energy Efficient Economy ("ACEEE") identifies EERS policies as being key drivers in states' achieving higher levels of energy efficiency.[29] EERS and RPS policies in the mainland U.S. have provided clear messages to the market place and to utilities that a given type of technology or investment, like renewable energy or energy efficiency, is preferred. As described earlier, the California legislature adopted such a standard in 2010, which was further defined in terms of specific targets, goals, and deadlines by the California Public Utilities Commission in 2013. California IOUs are now in the process of issuing RFPs for storage opportunities in order to meet these targets and will be responsible for procuring viable, cost-effective solutions.

- ***Consider Issuing a Broad Energy Storage RFP*** - Similar to the recommendation in GPA's energy storage feasibility study and similar to the activities of utilities in California, GPA could consider issuing a broad RFP for energy storage or incorporating energy storage opportunities in its future RFPs for renewable energy. An RFP process provides insight into the potential price points for multiple energy storage technologies – a broad solicitation provides an opportunity for vendors to offer creative storage options, potentially paired with renewable energy technologies, or sited in strategic locations to improve the reliability of GPA's grid or the power quality delivered to GPA's customers.

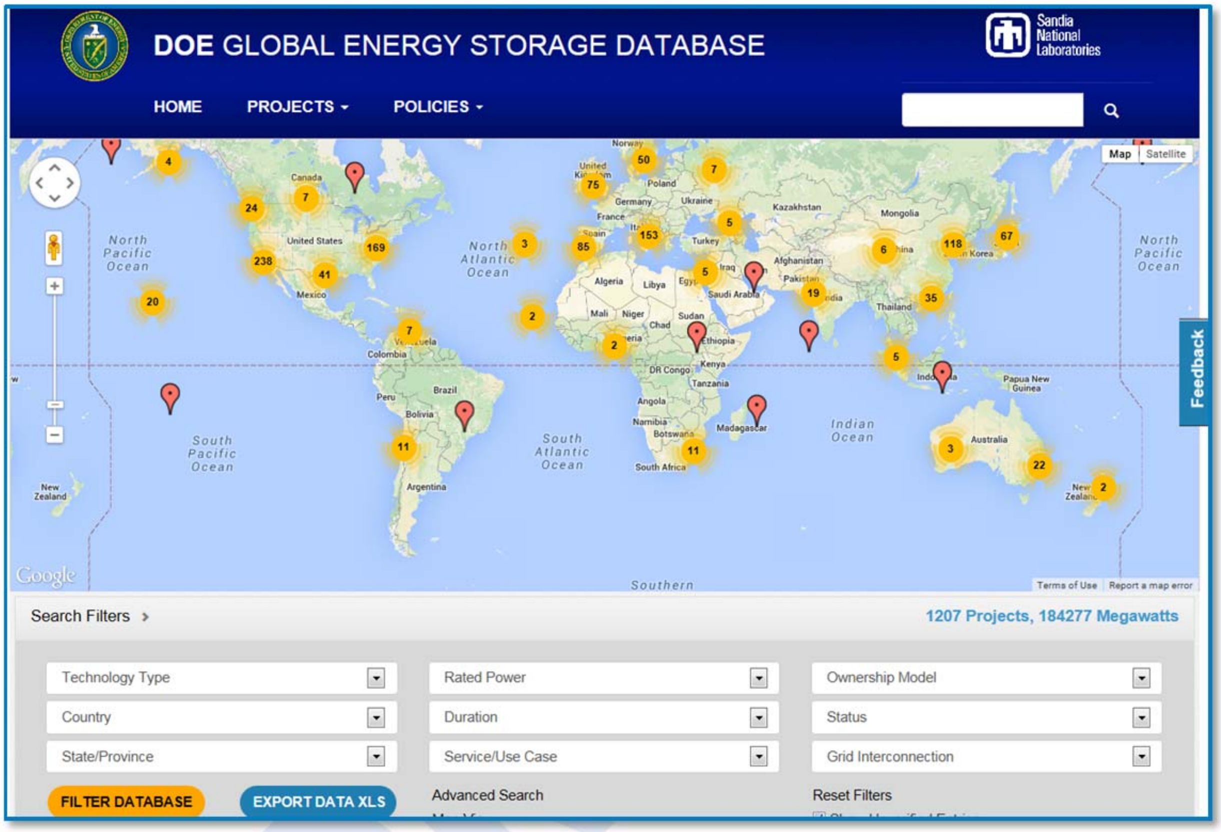
- ***Understanding Guam's Geology*** - Understanding the geology of Guam is one of the necessary first steps to determining whether conventional CAES technology could be implemented on the island. As discussed earlier, the only commercial-scale facilities currently in operation today rely on underground geological formations to house the compressed air. The island of Guam should consider evaluating the suitability of its geology for traditional CAES technologies and should continue to consider and evaluate whether evolving CAES technologies, such as UWCAES, for instance, might be suitable for the island.

- ***Tracking Energy Storage Developments*** - Multiple companies are working to develop CAES technologies that would be alternatives to conventional CAES implementation. The growth in renewable capacity and the technical requirements necessary to support that growth are the primary market drivers for bulk energy management storage solutions like CAES.

[29] American Council for an Energy-Efficient Economy, "*Policies Matter: Creating a Foundation for an Energy-Efficient Utility of the Future*", June 2015, available at http://aceee.org/policies-matter-creating-foundation-energy.

One source for tracking developing projects is the Department of Energy's "*Global Energy Storage Database*" - this database houses reference links and project information on an array of energy storage projects, including CAES and others, and also provides a basis for developing more macro-level trends and changes in the market.

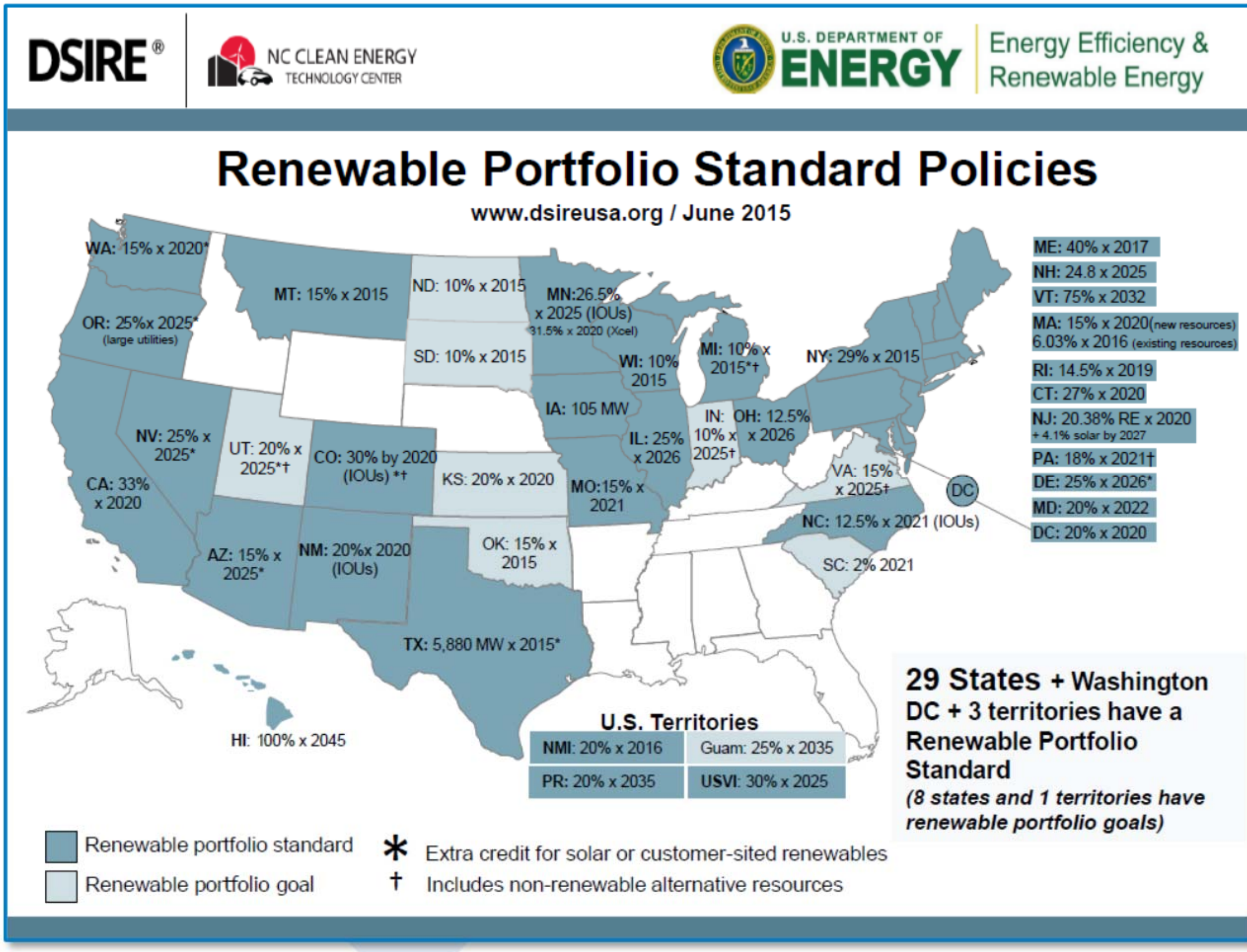
Figure 19 Department of Energy, Global Energy Storage Database



Source: DOE Global Energy Storage Database, available at http://www.energystorageexchange.org/projects

Attachment A - RPS and EERS Policies, by State and U.S. Territory

Attachment A Figure – RPS Policies Map



Attachment A Figure – EERS Policies Map