Mapping the System:
The Role of Energy Storage in Grid Decarbonization of California

APSC 498-T

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Abstract

The state of California is committed to reducing their carbon emissions, specifically targeting the way they generate electricity. Senate Bill 100, passed in 2018, targets 60% renewable energy on the grid in 2030. Increasing the amount of inherently variable, renewable, power generation sources, such as wind and solar, into the grid follows a need to add energy storage. Storage technology allows renewable energy to better compete and adapt to the infrastructure that is designed for large coal and gas power generators. The different services and benefits for energy storage, the various technologies, as well as a description of California's grid system are included within this paper. The grid is divided into the transmission grid, operated by the California Independent System Operator (CAISO) and distribution grid, operated by Investor Owned Utilities (IOUs). The California Public Utilities Commission and Federal Energy Regulatory Commission regulate CAISO and the IOUs respectively. The California Energy Commission develops new policy with the goal of meeting California's renewable energy target. They investigate and de-risk new technology by funding innovative pilot projects, such as battery storage systems. With the data collected from these projects, the California Energy Commission was able to release a software valuation tool in 2017 that allows anybody to weigh the costs and benefits of adding a different storage technology to a specific area. California is making tremendous headway with increasing the amount of renewable generation sources and associated energy storage, and are slowly becoming a world leader in the area. Regulation and policy should continue to evolve as the grid adapts. A gap identified is the current focus on batteries and short-term energy storage technology. Seasonal energy storage will probably become more important at 60% renewable generation, and technology beyond pumped hydro should be investigated.

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Introduction

California is at the leading edge of electric grid decarbonization. In September 2018, the California Legislature passed Senate Bill 100, mandating 33% of retail electricity sales to come from renewables by 2020, 60% from renewables by 2030, and 100% from zero-carbon energy by 2045 [1]. The distinction between the 2030 target of 60% renewables and the 2045 target of zero-carbon is important, because it is well assessed that decarbonizing the electric power sector is most inexpensively achieved with a diverse mix of resources, including low carbon baseload (e.g. nuclear or fossil with carbon capture) [2]. Nevertheless, 60% is a high penetration of renewable power.

Power generation must be met with instantaneous demand. The variable nature of renewable energy generation does not always align with demand, which means that the value of renewable energy declines as more of it enters the grid (the system not responding otherwise). Energy storage technology allows for matching variable generation with consumption, and for creating a more flexible and resilient grid overall. Implementing storage goes hand-in-hand with the growth of renewable energy.

Energy storage can provide additional benefits to the grid system such as increasing reliability, providing ancillary services for power quality, and preventing the need for more costly transmission and distribution system upgrades. However, energy storage for the grid is a relatively new technology and regulators, utilities, and developers are just catching up to the market it is creating [3]. Appropriately understanding, valuing, and implementing energy storage will significantly help California achieve their goals of grid decarbonization.

This report assesses the energy storage landscape for grid decarbonization in California. The first section describes the use cases that energy storage can provide to the grid, which can be stacked to increase its value. The next section describes the major storage technologies and maps them to their use cases. The final section analyzes the California grid system and how the market and regulation are evolving to adopt storage technologies. In general, the future is bright for energy storage, and California should continue its effort to maximize the value of these technologies.

This report is complemented by a systems map of the topic in Appendix A.

Storage Use Cases

Many studies have been conducted on the different values and services that energy storage can provide and, overall, there are thirteen main services that can be provided to stakeholders [4]. The three stakeholders include: independent service operators (ISOs) and regional transmission organizations (RTOs), utilities, and consumers. Benefits overlap between the different stakeholders, but dividing services by group allows for a better understanding and definition of the services themselves. These groups and the role energy storage plays can be better understood through Figure 1. Furthermore, the actual value that energy storage and its related services can deliver to the different stakeholders ranges drastically over variables, such as where the resources are deployed, making generic approximations difficult [5].

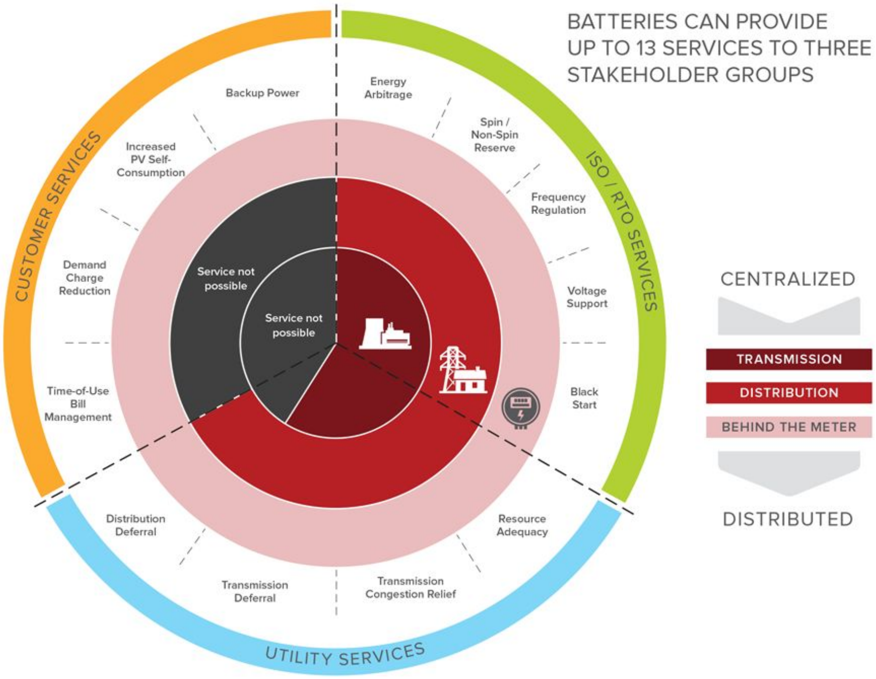


Figure 1: 13 Services that Energy Storage can Provide for 3 Stakeholder Groups [4]

1.0 ISO/RTO Services

Energy storage devices are capable of providing a variety of services and benefits at the grid-level scale to the ISOs/RTOs.

1.1 Energy Arbitrage

Storage can purchase electricity directly while the marginal price of energy is low, typically during nighttime hours or when variable renewable sources are generating at peak, and then sell the electricity back to consumers when the price of energy is high.

1.2 Frequency Regulation

Frequency regulation helps ensure that the frequency of all the generating power plants and associated loads stay within tight bounds to maintain stability [6]. Energy storage can tackle this instantaneously because of the advantage of fast ramp up and down times relative to a generating plant.

1.3 Spin/Non-Spin Reserve

The ISOs/RTOS must be able to handle the loss of the any of the generating plants in the system without disrupting the entire grid, which means that all generators have a small immediate reserve capacity that can come online and serve the associated loads [6]. Non-spinning reserve refers to the generation capacity that is not instantaneously available and will take time to come online.

1.4 Voltage Support

Similar to frequency regulation, storage can help provide voltage regulation across the transmission and distribution grid for reliable power by ensuring that both the real and reactive power production is matched with demand.

1.5 Black Start

Power generating plants often need a local power source to help restore operation in the event of a power outage, whereas some of the larger power plants are themselves black start capable.

2.0 Utility Services

Utility services generally fall into two categories: transmission and distribution system upgrade deferral, as well as resource adequacy and transmission congestion relief.

2.1 Resource Adequacy

Utilities must ensure generators meet their designated load requirements, specifically during peak-electricity consumption, and often energy storage can help relieve large investments in increasing the capacity of generators.

2.2 Distribution Deferral

Investments in energy storage can help delay, reduce or entirely avoid more costly investments in distribution system upgrades that would otherwise be necessary to meet anticipated load growth on the grid.

2.3 Transmission Congestion Relief

Utilities can avoid charges obtained from using congested transmission lines during peak-times by deploying localized energy storage to meet the necessary energy demand in that area.

2.4 Transmission Deferral

Investments in energy storage can help delay, reduce or entirely avoid more costly investments in transmission system upgrades that would otherwise be necessary to meet anticipated load growth on the grid.

3.0 Customer Services

Customer services like bill management can help provide direct benefits to end users, where the value of these services is from storage being deployed behind-the-meter. These services also benefit ISOs/RTOs and utilities, but the monetary value directly impacts the behind-the-meter customers.

3.1 Time-of-Use Bill Management

Customers that have personal energy storage can minimize their electricity purchases during peak electricity-consumption hours by purchasing and storing electricity when it is at a lower rate and using the storage during periods of higher rates.

3.2 Increased PV Self Consumption

To maximize the financial benefit of behind-the-meter solar photovoltaic (PV), consumers can store their excess electricity production to be used at a later time when the sun has set.

3.3 Demand Charge Reduction

Demand charges are based on peak power, not energy, and consumers could reduce their costs with utilizing their personal energy storages.

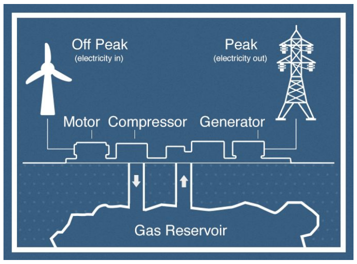
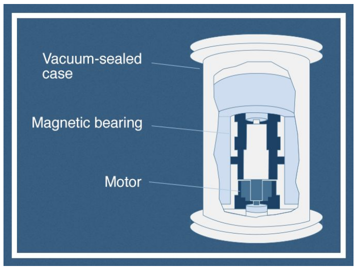
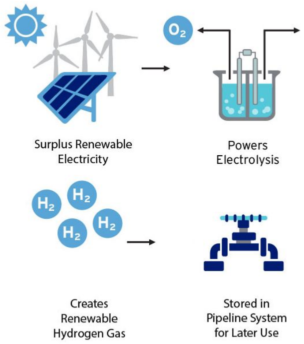
3.4 Backup Power

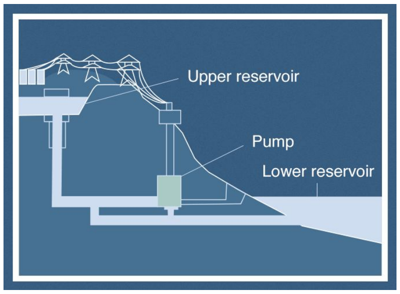
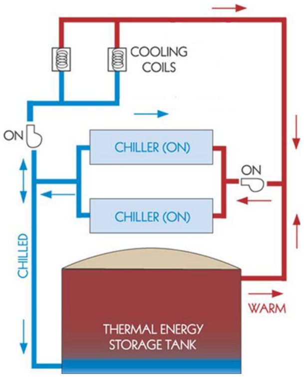
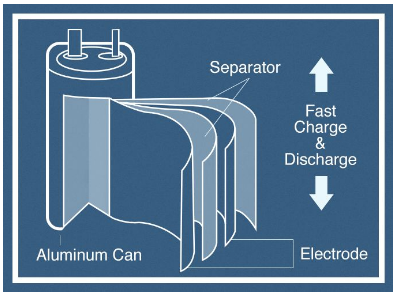
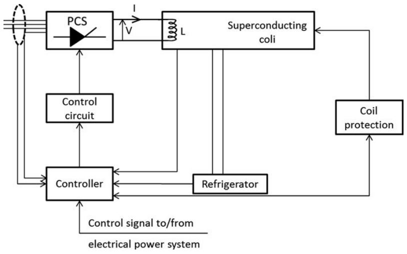
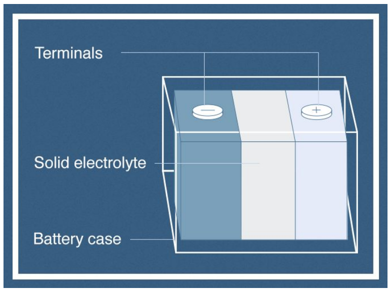
In the event of a grid failure, consumers would undoubtedly benefit from having personal energy storage that could supply them with backup power during an outage.

Storage Technologies

Various storage technologies exist today ranging from simple batteries to pumped hydro storage that are in different stages of their grid deployment feasibility, as well as the services they can provide to the different stakeholders. Selecting the appropriate technology for different levels of grid development is crucial to the success of energy storage. At the highest level, technologies are classified according to the medium in which energy is stored. Table 1 outlines the different energy storage technologies below:

Table 1. Energy Storage Technology

Technology / Storage Medium	Diagram	Method
Compressed Air (CAES)		Energy is stored as a high pressure and temperature gas. Requires a large underground reservoir and is 40-70% efficient
Flywheel		Energy is stored as kinetic energy in a large spinning mass, often steel. Vacuum sealing minimizes frictional losses in the process.
Power-to-Gas		Energy stored in chemical potential of a combustible gas. This method requires an existing gas distribution infrastructure.

Pumped Hydro		Energy stored in gravitational potential difference between two large bodies of water.
Thermal Storage		Energy stored as a thermal gradient between a hot or cold object and environment.
Super-Capacitors		Energy stored as an electric field potential with near instantaneous response to loads
Superconducting Magnetic Energy		Energy stored as magnetic field potential.
Batteries		Energy stored as electrochemical potential. Chemistry can be adapted to suit the application.“Flow batteries” make use of an electrolyte tank and pump to increase capacity.

To meet grid demand, the storage system must have a high instantaneous power (W) and total capacity (Wh). Typical values of each method are shown in Figure 2. The blue dotted iso-lines show that the discharge time is inversely proportional to capacity. This shows that technologies with large capacities such as pumped hydro are ideal for storing large amounts of power from renewables and discharging during times where generation is lower whereas supercapacitors and flywheels are more suitable for power factor and frequency correction.

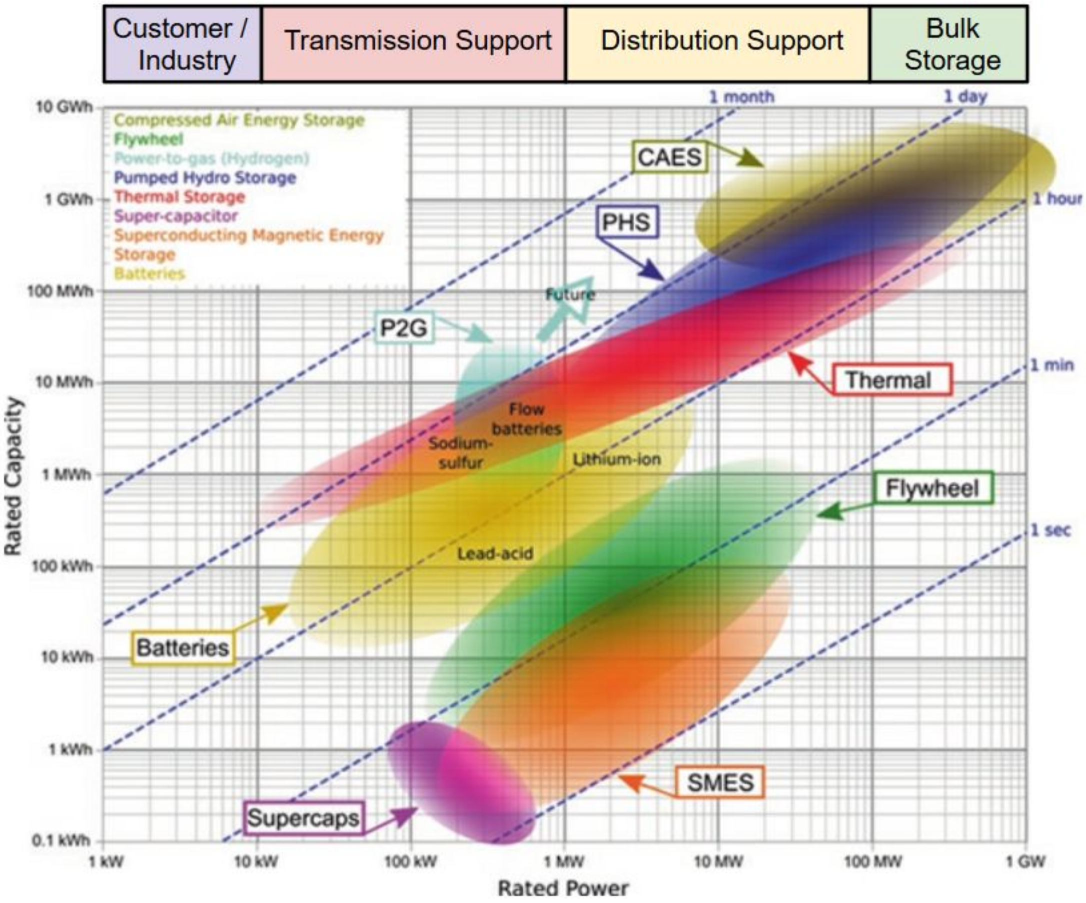


Figure 2: The Capacity and Power of Different Energy Storage Systems [7]

In addition to the capacity and instantaneous power of the storage system, system efficiency and depth of discharge are also important metrics. Efficiency refers to the percentage given by the energy delivered from storage medium over the amount of energy stored. Higher efficiency is always desirable. The depth of discharge is a percentage which expresses how much energy in the storage system can be discharged of its theoretical maximum capacity. This metric exists due to technical limitations. A pumped hydro turbine, for example, should not be run until dry or a battery should not be charged or discharged fully to extend the life of the system. A high depth of discharge is also desirable. Each technology is at varying levels of deployment in California. Currently only three types are in active use as seen in Table 2.

Table 2. Current California Energy Storage Mix [8]

Installed Technology	Installed Power (MW)	Technical Challenges and Limitations
Pumped Hydro	4517	● Site selection limited ● Large land requirements ● Fluctuations due to rainfall
Thermal	36	● Passive losses ● Limited to installations for heating or cooling
Battery	177	● Decreasing discharge depth over time ● Chemical supply chain issues

Pumped hydro is the preferred storage method for large scale grid storage. The different technologies are at various phases in their deployment stage in California, ranging from pre-feasibility to grid deployment. The 6.25kWh Amber Kinetics flywheel system, for example, has been qualified under a CPUC Self-Generation Incentive for small scale energy storage. A PG&E report has stated that compressed air storage is technically feasible, but falls short on being economical [9]. PG&E has also recently signed a power purchase agreement for the world's largest battery storage system in order to replace natural gas peaking plants [10]. While technological development is mostly handled by private companies and generators, grid deployment and use cases will be driven by market forces, regulators and their policies [11].

The California Grid System

The electrical grid in California, as in much of North America, is divided into the high voltage transmission system, and the lower voltage distribution system. CAISO operates the transmission system and the IOUs own the assets and operate the distribution system. Different parts of the grid are controlled by different regulators, and there are other participants such as generators, storage providers, and the public. The California grid system is depicted in a system map in Appendix A.

1.0 Major Players and Responsibilities

1.1 Regulators

California Legislature: Pass major legislation for California's clean energy transition, including SB 100 that mandates 60% renewable power by 2030.

California Energy Commission (CEC): Develop energy policy for California. Fund innovative projects to decarbonize the grid.

California Public Utilities Commission (CPUC): Regulate public utility providers to ensure consumers have access to safe, reliable, low-cost utilities. Describe grid operational needs and resource characteristics through the Long Term Procurement Planning (LTPP) process.

Federal Energy Regulatory Commission (FERC): Regulate the ISO/RTO, including how to classify and compensate grid assets.

1.2 Grid Operators

California Independent System Operator (CAISO): Maintain reliability on the high voltage transmission grid by matching demand and supply. Operate the wholesale electricity market. Identify expected transmission capacity needs through an annual Transmission Planning Process (TPP).

Investor Owned Utilities (IOUs): Operate the distribution grid to provide electricity services to the public. Procure assets to maintain reliability on the grid. Under the jurisdiction and guidance of the CPUC. Includes: Pacific Gas and Electric (PG&E), Southern California Edison (SCE), San Diego Gas and Electric (SDG&E).

1.3 Other Players

Generators: Own and operate energy generation projects for profit (e.g. wind/solar farms). Operate in the wholesale markets, affecting the price of energy throughout the day and year.

Storage Developers: Own and operate energy storage projects for profit. Interact with CAISO in the wholesale markets, or with IOUs to perform grid services on the transmission side.

Storage Producers: Produce and supply different storage technologies. May or may not be a project developer. Tesla is an example of a battery producer and project developer.

Supply Chain: Particularly important because of the restricted supply of certain metals for battery technology.

Public: Users of energy that want to pay the cheapest price. May or may not own storage or generation assets.

2.0 Energy Storage in the Market

Broadly speaking, energy storage can provide demand management on the distribution grid, or operate in the wholesale electricity market on the transmission grid. Connecting distributed storage to the transmission grid allows for participation in the wholesale market. Storage also increases the flexibility and reliability of the grid, allows consumers to make better use of home solar systems, and opens up possibilities for microgrids [3].

Large storage projects find it easier to reap value from if the grid, but require the expertise and funding of a developer. Smaller-scale consumer storage systems can participate more in the grid particularly if they are connected to the IoT (i.e. “smart-grid”). An interesting idea is to aggregate distributed storage resources so that these devices can *act* as a large-scale system.

As described earlier in the report, there are many benefits energy storage can provide to a renewable-based grid. Regulating storage so that these benefits can be stacked is key to maximizing its economic value. If regulations can find better ways of rewarding energy storage it will take more traction in the market, aiding the implementation of renewables. This is the major positive feedback loop in the system, the magenta “renewables + storage” loop in Appendix A.

Another feedback loop in the system, teal in Appendix A, is the classic technology learning curve. One example: the price of lithium ion batteries fell 50% globally from 2013 to 2018 [12]. Energy storage producers and the associated supply chain are to thank for this. However, the supply of metals has had social and environmental issues that should not be brushed aside. The responsibility of regulating and providing a market for storage falls on the CEC, CPUC, FERC, IOUs, and CAISO. This is highlighted in the light-blue "Regulation and Operation" loop in Appendix A.

3.0 California's Evolving Regulation

California has taken significant steps to try to understand and value energy storage technologies for market regulation. In late 2014, CAISO, CPUC, and CEC released a roadmap for maximizing the value of energy storage technology in California. The roadmap identified the importance of expanding revenue opportunities for storage projects, reducing costs and clarifying the application process for grid connection, and overall creating a transparent market for storage development [3]. Prior to 2014 the CPUC already provided funding programs to incentivize customer-side energy storage adoption.

Since then, the CPUC has evolved their regulations to help storage stack its value, called a Multiple Use Application (MUA) [12]. Just last year, FERC introduced new "market rules that properly recognize the physical and operational characteristics of electric storage resources" [13].

Furthermore, in 2017 the CEC released a publicly accessible software for energy storage project valuation and optimization, called StorageVET. The software provides cost-benefit analysis for many different types of storage technologies for use by developers, utilities, and consumers. The software can assess wholesale market revenues and additional revenues from grid services for transmission connected storage projects, as well as avoided retail energy and demand charges for consumer side projects. Up to date regulations and price data are built-in. Overall this should significantly facilitate storage adoption by developers, consumers, and utilities [14].

The evolving regulatory framework has led to the procurement of 1,620 MWs from 2010-2018, which surpasses the CPUC mandate of 1,325 for 2020 [12]. California is paving the way for regulating energy storage technologies.

4.0 Future Outlook

The future looks bright for storage as new technologies continue to come down in cost and the grid system figures out better ways of balancing renewable energy and storage. The regulation should continue to develop alongside the technologies and markets. As more projects are developed, costs should decline, and storage and renewable energy can grow together. There is tremendous opportunity for technology and project developers to capitalize on this market.

A gap identified in the literature for California’s energy storage system is the focus is on short term energy storage and batteries. Batteries have known social and environmental life cycle issue, such as with mining and inadequate waste recycling. Long term, seasonal energy storage, aside from pumped hydro, has not yet been implemented. This type of technology may not be needed yet, but will probably become necessary with upwards of 60% renewables penetration. Possibilities for power-to-gas and hydrogen infrastructure should be investigated in California, which can can interact with energy systems beyond the grid. Groups like the CEC can fund pilot projects to begin to evaluate the technological feasibility and market regulatory needs for long-term energy storage.

References

[1] California Legislature. (2018). *Senate Bill No. 100: California Renewables Portfolio Standard Program: Emissions of Greenhouse Gases*. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100

[2] Sepulveda, N., Jenkins, J., de Sisternes, F., & Lester, R. (2018). The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation. *Joule*, *2*(11), 2403-2420. doi: 10.1016/j.joule.2018.08.006

[3] California Independent System Operator; California Public Utilities Commission; California Energy Commission. (2014). *Advancing and Maximizing the Value of Energy Storage Technology*. https://www.caiso.com/documents/advancing-maximizingvalueof energystoragetechnology_californiaroadmap.pdf

[4] Fitzgerald, G., Mandel, J., Morris, J., & Touati, H. (2015). *The Economics of Battery Energy Storage: How multi-use, customer-sited batteries deliver the most services and value to customers and the grid*. Rocky Mountain Institute. Retrieved from https://rmi.org/insight/economics-battery-energy-storage/

[5] Energy Storage Association. (2016). *Grid Operation Benefits*. Retrieved from http://energystorage.org/energy-storage/energy-storage-benefits/benefit-categories/grid-perations-benefits

[6] Mclaren, J. (2016). *Batteries 101 Series: Use Cases and Value Streams for Energy Storage*. National Renewable Energy Laboratory. https://www.nrel.gov/state-local-tribal/blog/posts/batteries-101-series-use-cases-and-val E-streams-for-energy-storage.html

[7] Komarnicki, P., Lombardi, Pio., and Styczynski, Z. (2017). *Electric Energy Storage Systems - Flexibility Options for Smart Grids.* Springer. Retrieved from https://www.springer.com/us/book/9783662532744

[8] California Energy Commission. (2019). *Tracking Progress - California Energy.* Retrieved from https://www.energy.ca.gov/renewables/tracking_progress/

[9] Brown, E. G. (2018). *Technical Feasibility of Compressed Air Energy Storage Using a Porous Rock Reservoir*. California Energy Commission. Retrieved from http://www.energy.ca.gov/2018publications/CEC-

500-2018-029/CEC-500-2018-029.pdf

[10] Public Utilities Commission of the State of California. (2018). *DRAFT REDACTED RESOLUTION Resolution Energy Division* Retrieved from http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M229/K550/229550723.PDF

[11] "CPUs - The Tech Report." Accessed April 1, 2019. https://techreport.com/cpu/.

[12] California Public Utilities Commission. (2018). *Energy Storage Market Survey and Recommendations*. http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Test_Calendar/CPUC%20Energy%20Storage%20Market%20Survey%20and%20Recommendations%2010.22.18(1).pdf

[13] FERC Issues Final Rule on Electric Storage Participation in Regional Markets. (2018). Retrieved from https://www.ferc.gov/media/news-releases/2018/2018-1/02-15-18-E-1.asp#.XKKGLi0-KRs

[14] California Energy Commission. (2017). *Final Project Report: Validated and Transparent Energy Storage Valuation and Optimization Tool*. https://www.energy.ca.gov/2017publications/CEC-500-2017-016/CEC-500-2017-016.pdf

Appendix

APSC 498T - DECARBONIZING CALIFORNIA'S GRID WITH ENERGY STORAGE

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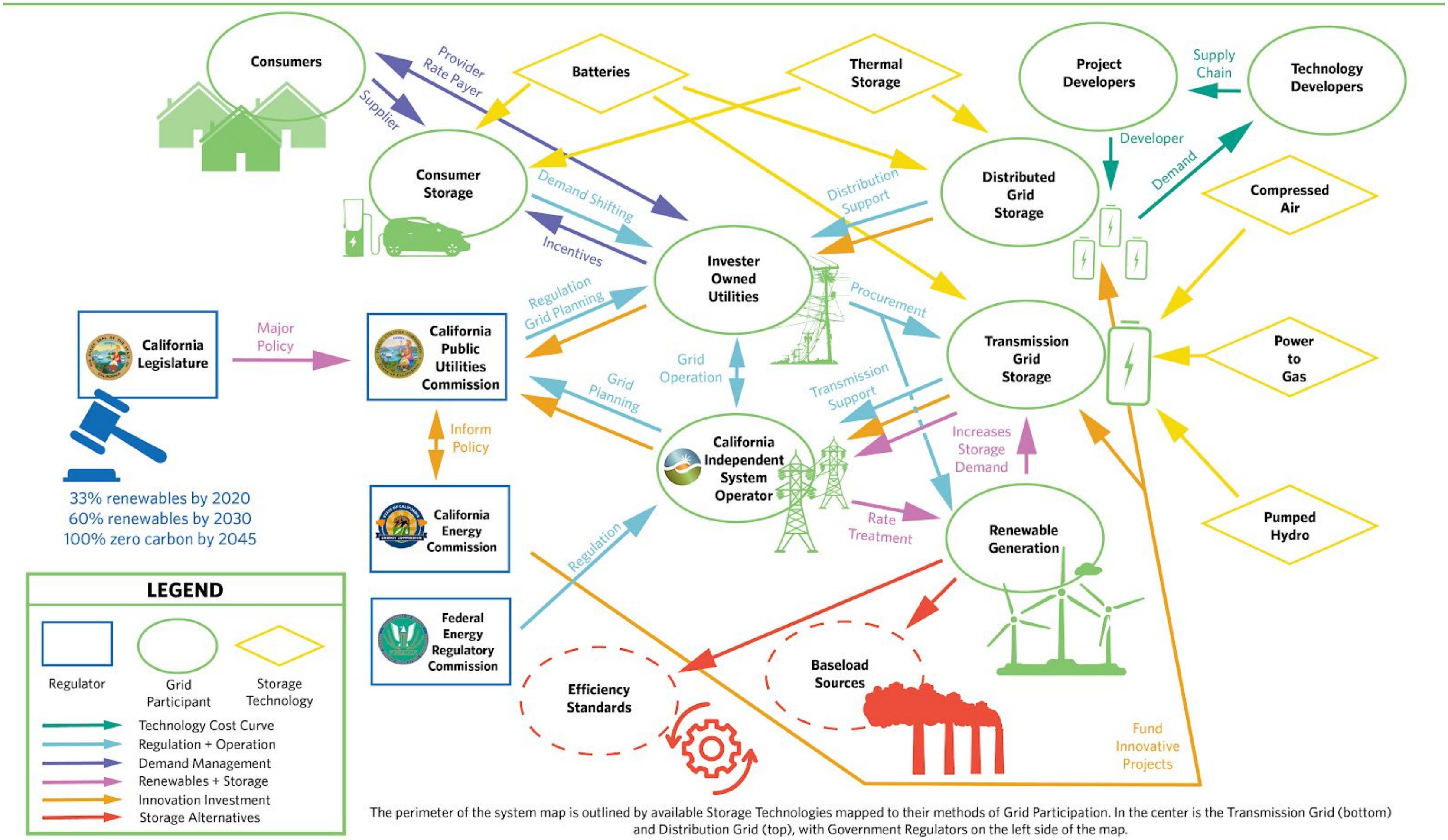

The perimeter of the system map is outlined by available Storage Technologies mapped to their methods of Grid Participation. In the center is the Transmission Grid (bottom) and Distribution Grid (top), with Government Regulators on the left side of the map.