Title
Quantifying the Cost-Effectiveness of Energy Storage Systems for the City of San Diego

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EXECUTIVE SUMMARY

With climate change becoming more of a reality in recent years, people are changing their habits. The City of San Diego notices the problem and addressed it in December 2015 with the Climate Action Plan, boasting ambitious goals of becoming 100% renewable by 2035 using a community choice aggregation (CCA) program or possibly another program[1]. Although a great cause, it misses an element in making that a reality: energy storage systems. Energy storage systems are key to integrating renewable intermittent energy sources into the current energy grid.[15]

In this paper, we look into and compare the cost-effectiveness of pumped hydro energy storage and two alternative battery energy storage systems using the Electricity Power Research Institute's Energy Storage Valuation Tool 4.0. We also look into the amount of greenhouse gas emission reduction each energy storage system provide to the grid.

By using different parameters of participation in a CCA, we come to the conclusion that it is most cost-effective to have a 50kW/4hr battery placed at either the customer end, at the final line transformer, or at the transmission. It gives $1.89 benefit to each customer per year. Deploying energy storage systems into the City of San Diego energy grid may not provide as much economic benefit, but it does provide many other benefits.

Energy storage systems also help reduce CO_2 and SF_6, both of which are greenhouse gases. Including energy storage systems means reducing the need for peaker plants that use natural gas or fossil fuels. Natural gas and coal plants emit approximately 469 tonnes CO_2 per GWh_e and 974 CO_2 tonnes per GWh_e respectively, whereas a battery energy storage system, or BESS, emits approximately 152 tonnes CO_2 per GWh_e. SDG&E currently uses natural gas, so each customer would be emitting around 0.0003 tonnes CO_2 (0.345 kg).[2] By simply switching to battery storage, it could reduce each customer's emissions to at least 0.0001 tonnes CO_2 per GWh_e (0.112 kg. This is a huge

[1] Community Choice Aggregation is an alternative supplier of electric energy that would use the existing SDG&E distribution and transmission system to supply the electricity. (City of San Diego Climate Action Plan) It basically allows local governments and some special districts to aggregate their electricity load in order to purchase and/or develop power on behalf of their residents, businesses, and municipal accounts. (Lean Energy US)

[2] The total population of the City of San Diego is 1,356,000 according to the U.S. Census. The emission reduction value through energy storage systems is calculated by dividing emissions by each storage system by the population utilizing it.

bonus for the City of San Diego to consider since its main goal in the Climate Action Plan is to reduce greenhouse gas emissions. As for SF_6, leaking transmission lines contributed around 12.5 Tg CO_2 Eq. in 2006 and costed around $6-$9/lb[7] worth of damages to the United States. If we could reduce the amount of transmission needed by incorporating energy storage systems, it would decrease the risk of leaking SF_6 into the atmosphere.

Energy storage systems not only provide a reduction in GHG emissions, but also contribute approximately 13 services to three stakeholder groups, which include independent system operators, utilities and customers.[16] It also helps regulate the amount of load in the energy grid.[16] In Figure 6, we can see the amount of regulation energy storage systems provide to the energy grid so that peaker plants are not needed to meet the demand of the customers during peak hours.

The overall integration of energy storage systems can contribute benefits to the consumer and three stakeholder groups, and can also reduce the overall greenhouse gas emissions. I strongly encourage the Environmental and Economic Sustainability Task Force to highly consider including energy storage systems in the Climate Action Plan to assure we will be doing our very best to meet greenhouse gas reductions goals while also benefiting economically.

SCIENCE

Energy storage systems are not only beneficial in increasing reliability to the energy grid, but also helps decrease the amount of greenhouse gas emissions, such as carbon dioxide (CO_2) and sulfur hexafluoride (SF_6).

By implementing energy storage systems, it decreases the use of peaker plants[3] and other fossil fuel powered storage plants. Figure 1 shows how much emissions each form of storage uses. Even if the City of San Diego decides to stack multiple forms of storage, it will produce significantly less GHG emissions than that of a natural gas storage plant, which is what SDG&E is currently using. With the 50kW/4hr battery system, it would only produce 152 tonnes CO_2 per GWh_e compared to the current SDG&E natural gas plant that produces 469 tonnes CO_2 per GWh_e. The City of San Diego can stack three battery energy storage systems to equate to one natural gas power plant.

[3] Peaker plants are power plants that generally run only when there is a high demand for electricity. In the US, peaker plants are generally gas turbines that burn natural gas, but can also burn diesel oil and jet fuel.

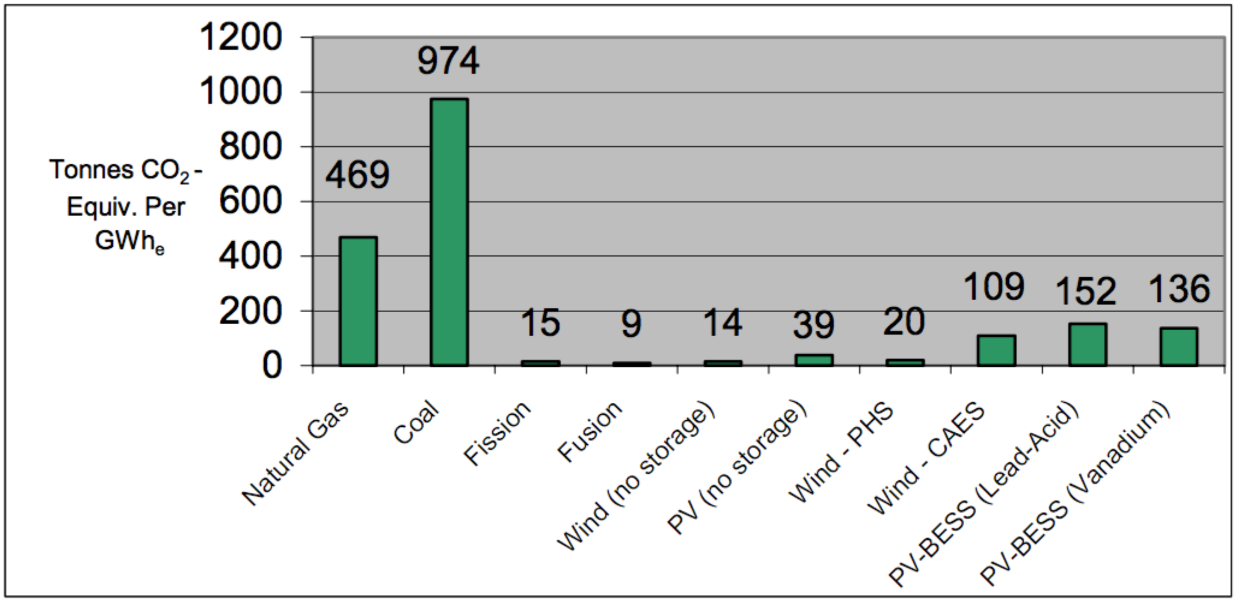

FIGURE 1. CO_2 EMISSION RATES FOR VARIOUS GENERATION TECHNOLOGIES[4]

Not only do energy storage systems reduce CO_2 emissions, but also SF_6. Energy storage systems reduce the amount of transmission lines, which also reduce the amount of SF_6 leakage.[5] SF6 is a gaseous dielectric used in high voltage electrical equipment as an insulator and/or arc quenching medium.[5] The largest use of SF6, both in the United States and internationally, is an electrical insulator and interrupter in equipment that transmits and distributes electricity.[5] Emission of SF_6 from an estimated 1,364 electric power system utilities were estimated to be 12.5 Tg CO_2 Eq. in 2006.[6] The cost per pound of SF_6 is around $6-$7, not accounting for inflation[7]. With the estimated amount of SF_6 emissions, this will cost around $179,125,588,025.21 to the United States. Although SF_6 emissions are not as significant as that of CO_2, it has a very high atmospheric lifetime compared to CO_2. CO_2 has an atmospheric lifespan of 5-200 years[8] whereas SF_6 has an atmospheric lifetime of 3,200 years[9]. The Environmental Protection Agency deems it to be the most potent and persistent

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[4] https://www.seventhwave.org/sites/default/files/223-1.pdf

[5] Trends in SF6 Sales and End-Use Applications: 1961-2003, Katie D. Smythe, RAND Environmental Science and Policy Center

[6] Technical Support Document for Process Emissions of Sulfur Hexafluoride (SF_6) and PFCs from Electric Power Systems: Proposed Rule for Mandatory Reporting of Greenhouse Gases, Nov 2010, U.S. Environmental Protection Agency, Office of Air and Radiation

[7] http://www.c2es.org/docUploads/mrv-workshop-rand.pdf

[8] IPCC states the CO_2 atmospheric lifetime is 5 – 200 years https://www.ipcc.ch/ipccreports/tar/wg1/016.htm

[9] https://www3.epa.gov/climatechange/ghgemissions/gases/fgases.html

greenhouse gas.[10] Due to regulations, SF_6 emissions is luckily decreasing, as we can see in Figure 2.

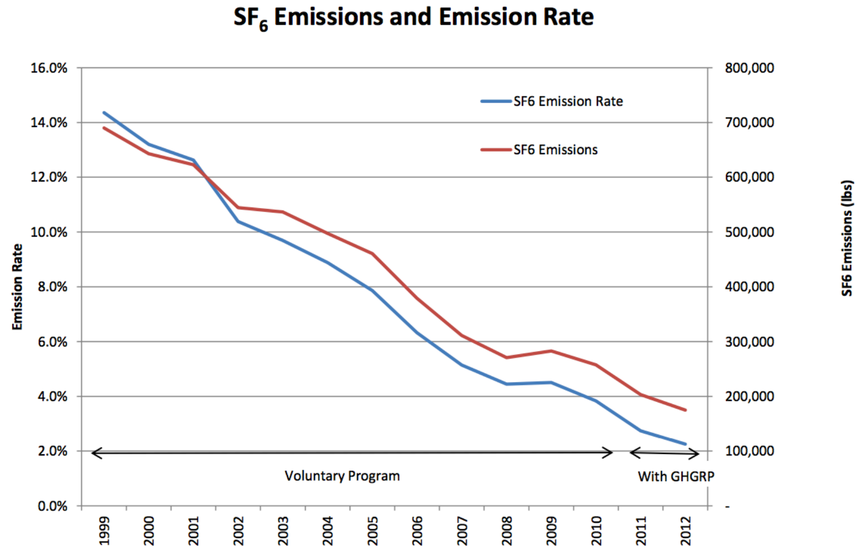

FIGURE 2. SF_6 EMISSIONS AND EMISSION RATE AFTER (EPA 2014)

POLICY

Community Choice Aggregation is "a state policy that enables local governments to aggregate electricity demand within their jurisdictions in order to procure alternative energy supplies while maintaining the existing electricity provider for transmission and distribution services."[11] This does not mean the City of San Diego will be replacing SDG&E. SDG&E will continue to run the transmission lines and distribution of the energy.[10] The City of San Diego Climate Action Plan looks to procure 91% of its electricity supply from renewable sources by 2035 while achieving the remaining 9% through greenhouse gas reduction targets.[12] The supply procurement will depend on the rate of participation in the CCA program. Say, if only 50% of the population participates, the City of San Diego will be purchasing less and this may result in a more expensive price. The more that participate, the cheaper the wholesale price of renewable energy will be. The City of San Diego will run on an "opt-out" system, where participants will be automatically opted in to the program and will be required to send an opt-out form to exit the program. An opt-out system is assumed because it assumes participants will be more likely to neglect opting out of a system.

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[10] https://www.epa.gov/sites/production/files/2016-02/documents/rand-partnership-update-presentation-2014-wkshp.pdf

[11] http://apps3.eere.energy.gov/greenpower/markets/community_choice.shtml

[12] The City of San Diego Climate Action Plan December 2015 – Appendices https://www.sandiego.gov/sites/default/files/final_december_2015_cap_all_appendices.pdf

For this project, the participation rate chosen for the modeling runs were from current community choice aggregation programs. The lowest participation rate is 170,430 people; the median participation rate is 307,448; and the highest participation rate is 587,881. Rather than using participation rate as a percentage of the programs' population, we chose to use the number of people to see what the lowest threshold was to make it worthwhile to conduct a CCA program.

AB2514 is another factor into why the City of San Diego should be looking into cost-effective energy storage systems. AB2514 would "require the California Public Utilities Commission to open a proceeding to determine appropriate targets, if any, for each load-serving entity to procure viable and cost-effective energy storage systems and…to adopt an energy storage system procurement target…"[13] Although AB2514 only dictates that each "load-serving entity" should procure viable and cost-effective energy storage systems, it does not specifically target a community choice aggregation program. However, in Section 1, it states that "expanding the use of energy storage systems can assist…community choice aggregators…in integrating increased amounts of renewable energy resources into the electrical transmission and distribution grid in a manner that minimizes the emissions of greenhouse gases. This relates to the project in the sense that we are trying to find the most "cost-effective energy storage system."

APPENDICES

ENERGY STORAGE VALUATION TOOL 4.0 DESCRIPTION AND RESULTS

The Energy Storage Valuation Tool 4.0 was created by Electric Power Research Institute in 2014. The ESVT 4.0 modeling tool as chosen for this particular project because it assesses the cost-effectiveness of energy storage systems through multiple inputs provided by the California Public Utility Commission[14] and is therefore directly related to quantifying the cost-effectiveness of certain energy storage systems for the City of San Diego. The results provided by the tool provide a comparison of direct, quantifiable benefits versus costs to all parties benefiting from storage operation on a net present value basis, and is unable to quantify indirect impacts.[14]

ESVT estimates the relative cost-effectiveness and expected operation of energy storage under a given set of assumptions shown in chart 1. Inputs are provided by the

[13] http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200920100AB2514

[14] Cost-Effectiveness of Energy Storage in California, Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007, EPRI 2013

CPUC technical staff. EPRI configured and performed analysis with the ESVT on a set of approximately 30 "runs" covering three use cases. Financial and economic assumptions were given values, whereas storage technology & costs and grid services & analyses varied between each form of energy storage system. With the grid services and analyses, we tried to stay consistent with the functions that each energy storage system would serve to the energy grid. For example, under "Power Reliability," we changed the storage location for the batteries investigated to see where it would provide the most benefits. There were many other options for grid services and analyses, but the ones chosen are shown in chart 1. These were chosen because they were compatible with the energy storage systems chosen for the area of the City of San Diego and they provided the highest benefits to the customers.

The numerical values of each parameter per energy storage system is listed in chart 3, excluding financial and economic assumptions because those are set rates and did not vary between each system.

The parameters in green are those that are given by ESVT 4.0. This means, once the user chooses the type of energy storage, the tool automatically fills in these numbers. These numbers are averages of current energy storage system technologies and what they are able to provide, such as its discharge capacity and minimum capacity duration. The green parameters are a big factor in what your result is since it is the first step to choosing which energy storage system you want evaluated.

The parameters in yellow are those that give the user options. For example, "price selection" allows the user to choose which ISO region they belong to or which they are analyzing. In this case, San Diego belongs to CalSO, so that is the option chosen. The most recent data collected for the price selection is from 2013, so inflation is not included in these runs to account for the present year. Storage location allowed the user to choose where they wanted the storage system to be located. ESVT 4.0 would pop a message saying "not compatible" when a location is chosen that does not work, such as inputting Olivenhain dam on the customer end. The use case assuming the storage location of "transmission" was specifically used because it would play a role in "peaker substitution."[14] This was a prioritized case by the CPUC[14] and we felt it was important to include the BESS in this use case. Another prioritized case by the CPUC was distribution level energy storage, so we included substations and final line transformers.[14] According to the Rocky Mountain Institute, deploying customer-sited energy storage systems would provide the most amount of benefits to the energy grid, so that motivated us to include customer-sited ones for the compatible energy storage systems.[16]

The red values are those that are calculated by ESVT 4.0 depending on what inputs are set for the green and yellow parameters. The load capacity value changes depending on the capital cost of the energy storage system, the region price selection, the storage location, and the customer class chosen for each run. As is visible in chart 3, the capacity value increases with each storage system. A capacity value uses statistical approaches to determine the ability of a generation resource to maintain a reliable system and meet demand.[15]

It was surprising to see that the batteries did not vary too much with the different location of the energy storage system. The locations were determined by what is compatible with the system. For example, another Olivenhain Dam cannot be built at the customer end of the energy grid as it is simply impossible and is not wise with the land use issues and feasibility. Therefore, it must be located near a larger area such as the generator end since the presumed generating area will be where the renewable energy facility is built. Each location needed a separate run, with a total of 11 runs for the energy storage systems chosen.

Outputs of the ESVT are given in benefit-to-cost ratio. If the ratio is larger than 1, then the energy storage system within those parameters is cost-effective. If it is less than 1, then the energy storage system within those parameters is not cost-effective. Chart 2 will show the cost-benefit ratio. The benefits vary depending on where the energy storage system is located (e.g. at the customer end, substation, or transmission). We can see that the 1mW/4hr energy storage system shows to have the largest cost-benefit ratio and building another Olivenhain Dam (pumped-hydro) is not cost-effective. This could be due to multiple factors such as land use and water scarcity. However, the 50kW/4hr battery has the highest benefit-to-customer price, yielding around $1.89 per customer benefit compared to the $0.10 benefit that the 1mW/4hr battery receives. We can see this in Figure 3, 4, and 5.

ESVT 4.0 is a very useful and beneficial tool to all utilities that are looking into the cost-effectiveness of energy storage systems to reach their energy storage goal under AB2514. However, like many other modeling systems, there are challenges and flaws to the model. Energy storage valuation continues to be a challenge due to unique technology attributes, technology uncertainties, and regulatory challenges.[12] The results of ESVT 4.0 also do not consider the indirect impacts of storage deployment levels on market prices or operation of other assets, and do not consider third-party business models or regulatory considerations that may limit real-world monetization.[14]

[15] http://www.nrel.gov/docs/fy13osti/57582.pdf

ESVT 4.0 Input Parameters	Storage Technology and Costs	Energy Storage System		
		Discharge Duration (Hr)		
		Capital Costs		
		Discharge Capacity (kW)		
	Financial and Economic Assumptions	Ownership		
		Inflation Rate		
		Fuel Escalation Rate		
		Federal Income Tax Rate		
		State Income Tax Rate		
		Property Tax Rate		
		Federal Investment Tax Credit		
		% Capitol Cost Eligible for ITC		
		$/kW State and or Local Rebate		
	Grid Services and Analysis	Transmission Services	Transmission Voltage Support	
		System Market Services	Local Electricity Supply Capacity	System Load Selection
				Load Capacity Value
				Minimum Capacity Duration
				Probability to Dispatch in Capacity Hours
			Frequency Regulation	Price Selection
				Market Type
				Allow Load

				State of Charge Regulation
				Max Market Award
			Synchronous Reserve Spin	Price Selection
				Allow Load
				Max Market Award
				Probability to Dispatch in Capacity Hours
		Customer Premise Services	Power Quality	Customer Class (Ind, Comm, Res)
				Voltage Level
			Power Reliability	Region
				Storage Location
				Power Reliability Reservation (hrs)
				Customer Class (Ind, Comm, Res)
				Regional Outage Statistics

Chart 1. ESVT 4.0 Input Parameters

	Cost	Cost-Benefit Customer	Cost-Benefit Final Line Transformer	Cost-Benefit Substation	Cost-Benefit Transmission	Cost-Benefit Generator
50MW/4hr	$266,917.00	1.163	1.187	1.171	1.167	N/A
1MW/4hr	$4,165,900.00	1.446	1.476	1.457	1.450	N/A
Olivenhain Dam	$4,860,400.00	N/A	0.838	0.822	N/A	0.816

Chart 2. Cost-Benefit ratio of the three investigated energy storage systems.

	50mW/4hr Battery	1mW/4hr Battery	Olivenhain Dam
Capital Costs	$240,000	$3,600,000	$2,850,000
Discharge Duration (hr)	4 hrs	4 hrs	8 hrs
Discharge Capacity	50kW	1000kW	1000kW
Transmission Voltage Support	$0/kVar-yr	$0/kVar-yr	$0/kVar-yr
System Load Selection	CAISO: 2013	CAISO: 2013	CAISO: 2013
Load Capacity Value	$200/kW-yr	$250/kW-yr	$400/kW-yr
Minimum Capacity Duration	4 hrs	4 hrs	8 hrs
Probability to Dispatch in hrs	100%	100%	100%
Price Selection	CAISO: 2013	CAISO: 2013	CAISO: 2013
Market Type	Reg Up/Down Separate	Reg Up/Down Separate	Reg Up/Down Separate
Allow Load	Yes	Yes	Yes
Max Market Award	50kW	1,000kW	1,000kW
Customer Class	Residential	Residential	Residential
Voltage Level	Primary	Primary	Primary
Region	CA	CA	CA
Storage Location	Customer, Final Line Transformer, Substation, Transmission	Customer, Final Line Transformer, Substation, Transmission	Final Line Transformer, Substation, Generator
Power Reliability Reservation	4 hrs	4 hrs	8 hrs
Customer Class	Residential	Residential	Residential
Region Outage Statistics	0.21	0.21	0.18

Chart 3. Grid Services and Analysis Parameters for 50mW/4hr Battery, 1mW/4hr Battery, and Olivenhain Dam

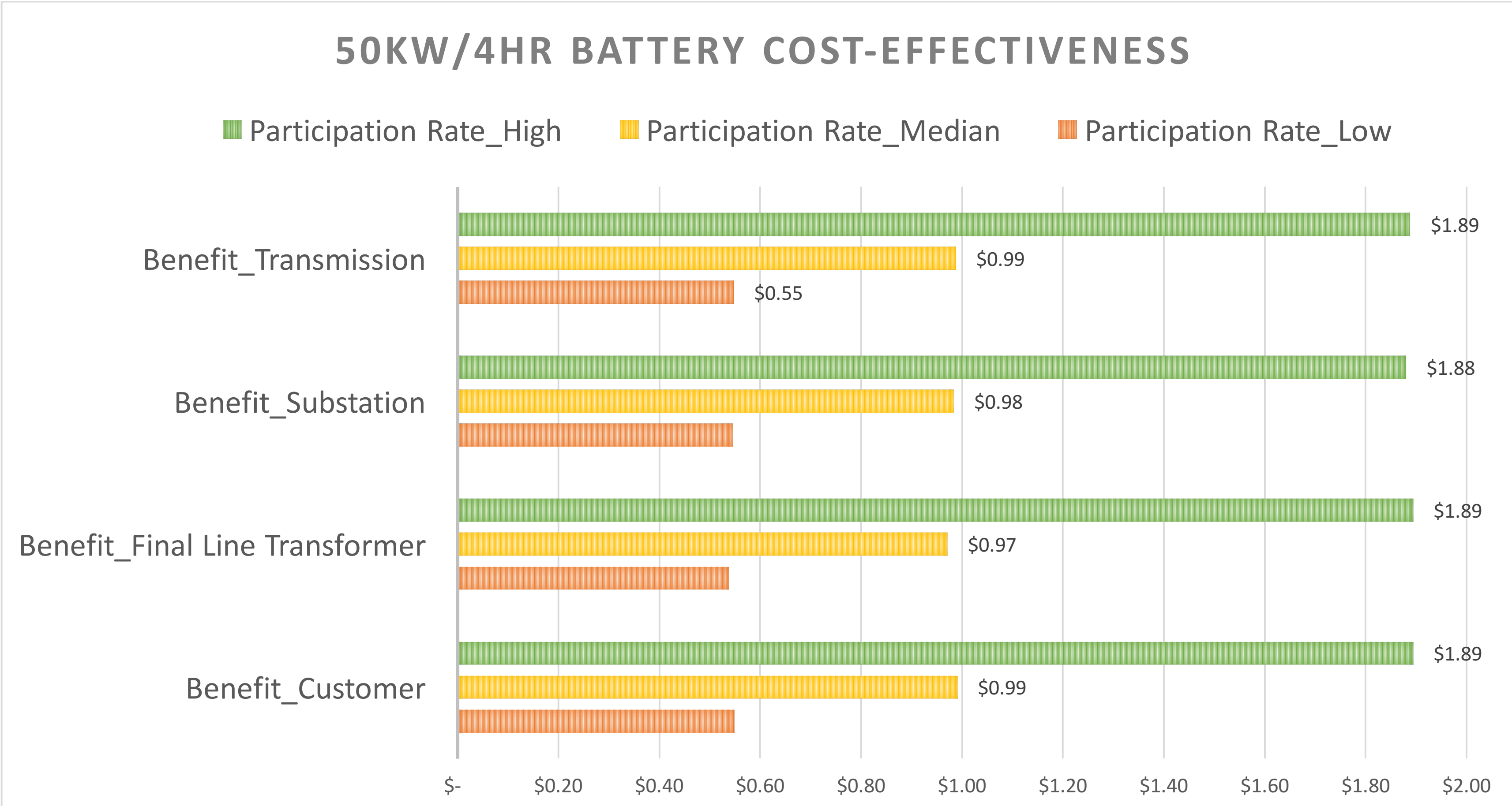

FIGURE 3. 50KW/4HR BATTERY COST-EFFECTIVENESS

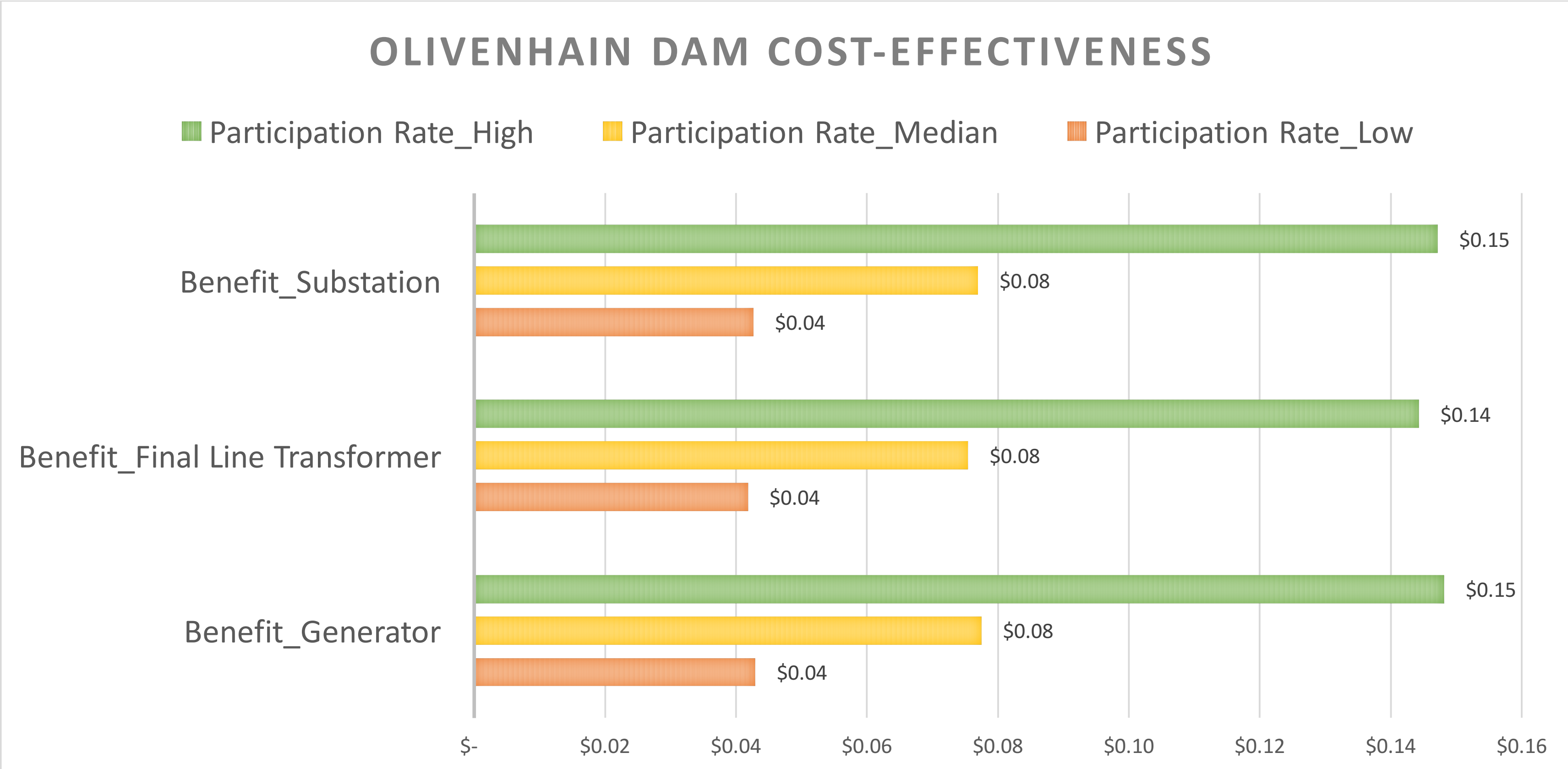

FIGURE 4. OLIVENHAIN DAM COST-EFFECTIVENESS

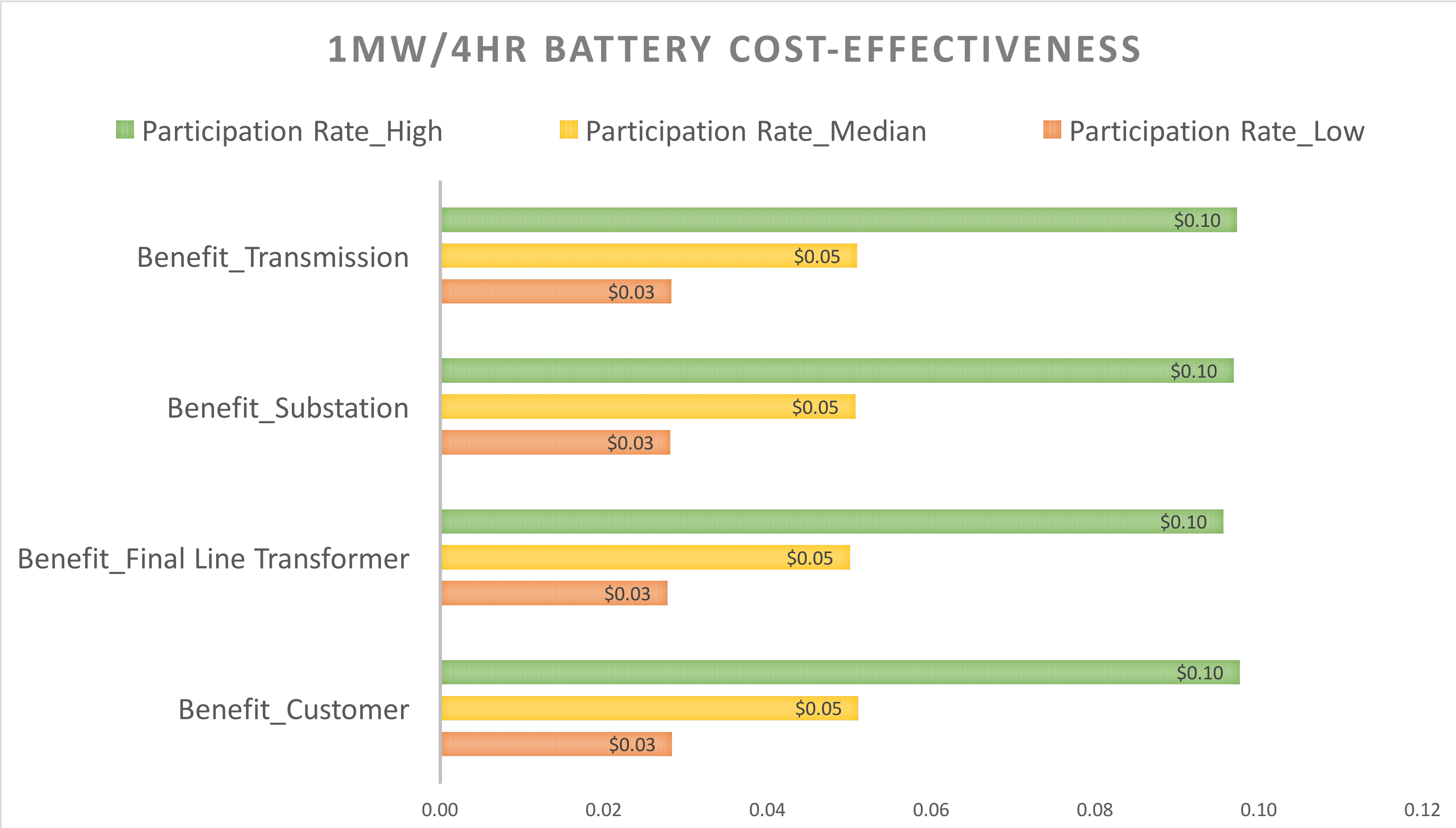

FIGURE 5. 1MW/HR BATTERY COST-EFFECTIVENESS

Benefits of Energy Storage Systems

Energy storage can contribute approximately thirteen services to the energy grid for three stakeholder groups defined as the independent system operators (ISOs) and regional transmission organizations (RTOs), utilities, and customers.[16] Chart 4 defines the benefits provided by energy storage systems to the aforementioned stakeholder groups. Energy storage systems are hard to pinpoint one particular function as it serves as a generator, transmission, and storage device. Because it serves various functions, it can provide more benefits than simply transmitting renewable energy into the energy grid.

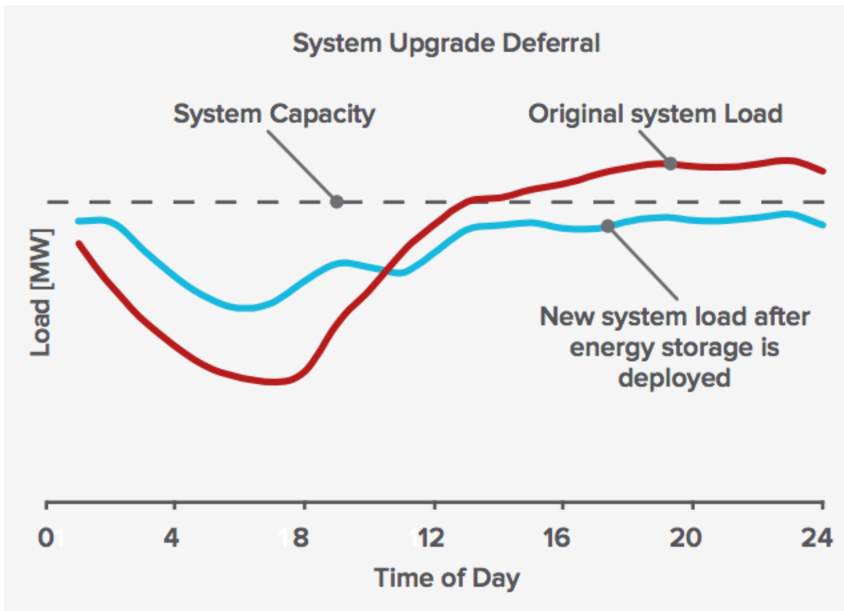

Figure 6 System Load Capacity Comparison Between Original System Load vs Net System Load After Deplying Energy Storage Systems[16]

Future of Energy Storage Systems

Energy storage systems are currently very expensive and cities looking into renewable energy may not have the capital for it. Some of the future research needed to overcome these barriers of making energy storage systems a mainstream integration to renewable energy are: cost-competitive energy storage systems, validated performance and safety, equitable regulatory environment, and industry acceptance.[17]

[16] 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 2015

[17] http://energy.gov/sites/prod/files/2014/09/f18/Grid%20Energy%20Storage%20December%202013.pdf

	Service Name	Definition
ISO/RTO Services	Energy Arbitrage	The purchase of wholesale electricity while the locational marginal price (LMP) of energy is low and sale of electricity back to the wholesale market when LMPs are highest.
	Frequency Regulation	The immediate and automatic response of power to a change in locally sensed system frequency, either from a system or from elements of the system.
	Spin/Non-Spin Reserves	Spinning reserve is the generation capacity that is online and able to serve load immediately in response to an unexpected contingency event, such as an unplanned generation outage. Non-Spinning reserve is generation capacity that can respond to contingency events within a short period, typically less than 10 minutes, but is not instantaneously available.
	Voltage Support	Voltage regulation ensures reliable and continuous electricity flow across the power grid. Voltage on the transmission and distribution system must be maintained within an acceptable range to ensure that both real and reactive power production are matched with demand.
	Black Start	In the event of a grid outage, black start generation assets are needed to restore operation to larger power stations in order to bring the regional grid back online. In some cases, large power stations are themselves black start capable.
Utility Services	Resource Adequacy	Instead of investing in new natural gas combustion turbines to meet generation requirements during peak electricity-consumption hours, grid operators and utilities can pay for other assets, including energy storage, to incrementally defer or reduce the need for new generation capacity and minimize the risk of overinvestment in that area.
	Distribution Deferral	Delaying, reducing the size of, or entirely avoiding utility investments in distribution system upgrades necessary to meet projected load growth on specific regions of the grid.

	Transmission Congestion Relief	ISOs charge utilities to use congested transmission corridors during certain times of the day. Assets including energy storage can be deployed downstream of congested transmission corridors to discharge during congested periods and minimize congestion in the transmission system.
	Transmission Deferral	Delaying, reducing the size of, or entirely avoiding utility investments in transmission system upgrades necessary to meet projected load growth on specific regions of the grid.
Customer Services	Time-of-Use Bill Management	By minimizing electricity purchases during peak electricity-consumption hours when time-of-use (TOU) rates are highest and shifting these purchase to periods of lower rates, behind-the-meter customers can use energy storage systems to reduce their bill
	Increased PV Self-Consumption	Minimizing export of electricity generated by behind-the-meter photovoltaic systems to maximize the financial benefit of solar PV in areas with utility rate structures that are unfavorable to distributed PV
	Demand Charge Reduction	In the event of grid failure, energy storage paired with a local generator can provide backup power at multiple scales, ranging from second-to-second power quality maintenance for industrial operations to daily backup for residential customers.
	Backup Power	In the event of grid failure, energy storage paired with a local generator can provide backup power at multiple scales, ranging from second-to-second power quality maintenance for industrial operations to daily backup for residential customers.

CHART 4. BENEFITS TOWARDS INDEPENDENT SYSTEM OPERATORS, REGIONAL TRANSMISSION ORGANIZATIONS, UTILITIES, AND CUSTOMERS