EAST BAY community energy
The Power to Choose

Notes regarding submitting comments on this Draft Work Product:

Comments are Due November 30th, 2017.

Comments shall be no longer than 5 pages.

Comments should be submitted to LDBPcomments@ebce.org

LCOE Analysis

for

East Bay Community Energy

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BACKGROUND

The goal of this tool is to show currently trending market costs for the distributed generation technologies most readily available in Alameda County. These costs are expressed in levelized cost of energy or "LCOE" format, which represents the net present value of all energy procured from a resource over a fixed period of time. LCOE is a frequently used metric for cost comparisons between energy generation technologies.

The tool also shows potential capacities and energy output associated with these technologies. This allows the user to see an overall weighted cost of energy for the DG portfolio. The tool also allows the user to adjust the quantities of each DG technology to see how the overall weighted energy cost of the portfolio changes with varying resource mixes.

APPROACH

Cost

As solar is by far the most prevalent DG technology in the County and local system pricing is well established, solar cost estimates were built from the ground up for various system sizes using known pricing for individual components.

For the other resources, costs were primarily taken from empirical data, vendor quotes, and published industry reports.

Costing data is broken out into 3 categories: initial capital cost, annual fixed cost, and annual variable costs. As stated above, the cost estimates for most resources were not built from the ground up, so this is the highest level of granularity which can be reliably provided.

Energy Production and Capacity Factor

For both solar and wind, energy production is dependent on the system configuration and location. For this reason energy production estimates for solar and wind were derived using modeling tools with inputs specific to the County.

For the other technologies that are not constrained by resource availability, energy yields were based on typical runtimes for these resources.

Note that for the storage technologies in particular, usage rates can vary greatly depending on the needs of the grid. An LCOE for typical usage rates has been provided, though the "Calculator" tab allows the user to adjust the capacity factor and see the impacts on LCOE.

LCOE

Once cost and energy yield figures were established, LCOE is a simple summation. NREL's online LCOE calculator was used to run the numbers. A discount rate of 6% was chosen.

> Important Note: As energy procurement represents a large capital investment with a payback over multiple decades, LCOE is highly sensitive to both financing

costs and the selected discount rate. This is particularly true for DG technologies such as wind and solar in which the costs are front loaded.

Important Note 2: The concept of LCOE is less clear for storage technologies, as you are not paying for the creation of energy but rather the shifting of energy to different times. For flywheels, which are often used for grid regulation, both charging and discharging have been included in the energy side of the LCOE equation. For other storage resources, only discharging cycles have been included.

FINDINGS

As solar PV has by far the greatest potential among DG resources in Alameda County, the overall procurement costs for local DG will be largely driven by solar. Solar LCOEs range from $0.10/kWh for large ground mount systems in the sunnier eastern side of the County to $0.156/kWh for smaller rooftop systems along the Bay.

Large scale wind turbines in the northeastern corner of the County (where wind speeds are highest) have the lowest LCOE of any resources assessed at $0.084/kWh.

For the other DG technologies, the LCOE can vary greatly depending on the fuel source and plant capacity factor (for biofuel power plants) and runtime (for fuel cells and batteries). Median values for these variables were chosen for this analysis.

The LCOE results and assumptions can be found in the accompanying excel workbook.

Comparison to Lazard's LCOE Analysis

Lazard is a financial advisory and asset management firm that produces a commonly referenced LCOE report. Our LCOE ranges generally fall within the bounds of their price specifications, with some exceptions:

- Our wind LCOE is outside of (higher than) the range they give. The Lazard report assumes a capacity factor of 30-35% for the southwest, whereas the highest capacity factor we're finding in Alameda County is only 29%.
- Our solar rooftop LCOE is within the Lazard specified range for rooftop C&I prices, though our large scale solar ground mount LCOE is above Lazard's range for utility scale solar pricing. This is because the Lazard report assumes larger system sizing (10 MW) and more importantly assumes higher insolation than is available in Alameda County.

"Calculator" Tab

The LCOE tool contains a "Calculator" tab in which the user can select a resource and adjust parameters to see the impact on LCOE.

Note: Solar LCOEs were derived independently, so results provided for the base case will not align exactly with results from the "Calculator" tab.

Instructions: Filter resources using the drop down in **Cell C5** (or by manually hiding rows). The numbers in the **"Visible Rows Only"** total line will update to reflect the resource mix you've chosen.

Resource		Energy				Cost			LCOE	Notes
Resource Type	Capacity (MW)	Capacity Factor (%)	Annual Production (MWh/yr)	T&D Losses (%)	Delivered Energy (MWh/yr)	Capital Cost ($/W)	Annual Fixed Cost ($/kW-yr)	Annual Variable Cost ($/kWh)	LCOE, 20 Year Fixed ($/kWh)	Notes
Solar Photovoltaic										
PV - 100 kW Roof - Oakland	50	17%	74,500	0.0%	74,500	$ 2.30	$ 15.00	$ -	$ 0.160	Clean Coalition estimates potential in 100-500 kW category is roughly equal to combined potential of larger categories (over 1 GW county-wide). Grid capability limits total built environment solar to around 300 MW before triggering significant upgrades, thus the smaller number being used here for capacity.
PV - 500 kW Roof - Oakland	50	17%	74,500	0.0%	74,500	$ 2.06	$ 15.00	$ -	$ 0.146	Clean Coalition estimates potential in 500-1000 kW category is roughly equal to potential in >1 MW category (over 600 MW county-wide). Grid capability limits total built environment solar to around 300 MW before triggering significant upgrades, thus the smaller number being used here for capacity.
PV - 1 MW Roof - Oakland	100	17%	149,000	0.0%	149,000	$ 1.90	$ 15.00	$ -	$ 0.138	Clean Coalition identified 660 MW of potential at sites >1MW county-wide. Grid capability limits total built environment solar to around 300 MW before triggering significant upgrades, thus the smaller number being used here for capacity.
PV - 100 kW Roof - Livermore	50	18%	78,600	0.0%	78,600	$ 2.30	$ 15.00	$ -	$ 0.152	see above
PV - 500 kW Roof - Livermore	50	18%	78,600	0.0%	78,600	$ 2.06	$ 15.00	$ -	$ 0.139	see above
PV - 1 MW Roof - Livermore	100	18%	157,200	0.0%	157,200	$ 1.90	$ 15.00	$ -	$ 0.131	see above
PV - 1 MW+ Tracking - Livermore	100	25%	222,600	0.0%	222,600	$ 1.86	*$ 15.00*	$ -	$ 0.103	No siting survey performed. Clean Coalition estimates 500 MW potential. Grid capacity limits to around 100 MW without triggering significant upgrades.
Wind										
Wind - Coastal	24	18%	37,844	0.5%	37,655	$ 2.45	$ 35.00	$ -	$ 0.150	
Wind - Inland - High Yield	28	29%	71,660	1.0%	70,943	$ 2.45	$ 35.00	$ -	$ 0.089	
Wind - Inland - Med Yield	30	23%	61,756	1.0%	61,138	$ 2.45	$ 35.00	$ -	$ 0.113	
Wind - Inland - Low Yield	28	11%	27,246	1.0%	26,974	$ 2.45	$ 35.00	$ -	$ 0.249	
Biofuels										
Biofuels - Landfill Gas	5	80%	35,040	1.0%	34,690	$ 2.10	$ 315.00	$ 0.020	$ 0.092	
Biofuels - Biomass Combustion, Steam Turbine	20	80%	140,160	1.0%	138,758	$ 2.75	$ 110.00	$ 0.055	$ 0.106	Fuel source local agricultural waste
Biofuels - Biomass Gasification, Gas Turbine	5	80%	35,040	1.0%	34,690	$ 3.25	$ 162.50	$ 0.054	$ 0.119	Fuel source local woodchips
Fuel Cell										
Fuel Cell	2	95%	16,644	0.5%	16,561	$ 5.50	$ -	$ 0.065	$ 0.123	For base load power. Assumes no CHP.
Storage										
Storage - Battery - Lithium Nickel Cobalt Manganese Oxide	5	17%	7,300	7.0%	6,789	$ 1.15	$ 50.00	$ -	$ 0.111	Capacity factor includes discharge time only (not charging time). T&D losses is used as a proxy for energy conversion losses.
Storage - Battery - Lithium Iron Phosphate	5	17%	7,300	7.0%	6,789	$ 1.20	$ 50.00	$ -	$ 0.114	Capacity factor includes discharge time only (not charging time). T&D losses is used as a proxy for energy conversion losses.
Storage - Battery - Lithium Titanate	5	17%	7,300	7.0%	6,789	$ 1.44	$ 50.00	$ -	$ 0.129	Capacity factor includes discharge time only (not charging time). T&D losses is used as a proxy for energy conversion losses.
Storage - Battery - Vanadium Redox Flow	1	17%	1,460	30.0%	1,022	$ 1.63	$ 62.00	$ -	$ 0.200	Capacity factor includes discharge time only (not charging time). T&D losses is used as a proxy for energy conversion losses.
Storage - Flywheel	20	50%	87,600	6.0%	82,344	$ 7.66	$ 42.00	$ -	$ 0.172	Capacity factor includes both charging and discharging time. T&D losses is used as a proxy for energy conversion losses.
Storage - Compressed Air	5	17%	7,300	40.0%	4,380	$ 0.73	$ 21.00	$ -	$ 0.097	Capacity factor includes discharge time only (not charging time). T&D losses is used as a proxy for energy conversion losses.
Storage - Thermal (Ice-based technologies)	2	12%	2,160	5.0%	2,052	$ 0.59	$ 23.00	$ -	$ 0.073	Capacity factor includes discharge time only (not charging time). T&D losses is used as a proxy for energy conversion losses.
TOTALS & WEIGHTED AVERAGES (Visible Rows Only)	**685**	**1,840**	**1,260,390**	**0.3%**	**1,256,409**	**$ 2.25**	**$ 25.90**	**$ 0.00**	**$ 0.129**	
GRAND TOTALS & WEIGHTED AVERAGES	**685**	**1,840**	**1,260,390**	**0.3%**	**1,256,409**	**$ 2.25**	**$ 25.90**	**$ 0.00**	**$ 0.129**	

APPENDIX

General Assumptions
Discount Rate: 6%
Resource Specific Assumptions
Solar
LCOEs derived using the PPA rate an asset owner would need to sell at to achieve an 8% IRR over a 20 year project lifetime.
Site lease cost 20% of revenue, non-prevailing wage, installation in 2018
LCOE includes an $0.003-$0.004/kWh adder for prevailing wage
Installation in 2018
Interconnection cost $0.07/watt urban, $0.20/watt rural
Inverter replacement reserve of $20/kW/yr
Insurance costs 0.5%
Wind
Grid integration cost $0.20/watt
*Commencing construction by Dec 31, 2018 which qualifies for ($0.023/kWh * 0.6) = $0.0138/kWh production tax credit for first 10 years of operation*
Landfill Gas
Internal combustion engine power technology
Cost data from IRENA report "Biomass for Power Generation", June 2012 (Section 5)
Biomass Steam Turbine
Stoker boiler power technology, no CHP
Cost data from IRENA report "Biomass for Power Generation", June 2012 (Section 5)
Annual variable costs include $0.05/kWh feedstock cost (appropriate for local agricultural residue) and $0.005/kWh for other variable costs (disposal, unplanned maintenance, equipment replacement, etc).

Biomass Gas Turbine
Fixed bed gasifier power technology
Cost data from IRENA report "Biomass for Power Generation", June 2012 (Section 5)
Annual variable costs include $0.05/kWh feedstock cost (appropriate for local woodchips) and $0.004/kWh for other variable costs (disposal, unplanned maintenance, equipment replacement, etc).
Fuel Cell
Annual variable costs include $0.025/kWh fuel cost (natural gas) and $0.04/kWh O&M costs
Cost data from Lazard study version 10
Lithium Batteries
Capital cost of $1.15-$1.44/watt includes $0.39-$0.68/watt for the batteries, $0.42/watt for power conversion equipment, $0.19/watt for control systems and BOS, and $0.15/watt for installation.
Annual cost of $50/kW-yr includes $9/kW-yr for regular O&M and $275/kW for major maintenance in years 5, 10, and 15 (annualized to $41/kW-yr).
5 MW should not be considered the county-wide potential; it was chosen as the size for a battery program for the purposes of this LCOE calculation.
The capacity factor is highly variable and depends on the needs of the grid. For this LCOE calcuation, 4 hours per day of discharge was chosen (representative of peak time shaving each day).
T&D loss factor is actually a placeholder for the conversion efficiency of the batteries, since losses in conversion have a similar effect as line losses. The round trip conversion efficiency is around 93% for a typical Li-ion battery.
Flow Batteries
Capital cost of $1.63/watt includes $0.60/watt for the batteries, $0.63/watt for power conversion equipment, $0.23/watt for control systems and BOS, and $0.17/watt for installation.
Annual cost of $62/kW-yr includes $10/kW-yr for regular O&M and $700/kW for major maintenance in years 8 and 16 (annualized to $52/kW-yr).
1 MW should not be considered the county-wide potential; it was chosen as the size for a battery program for the purposes of this LCOE calculation.

The capacity factor is highly variable and depends on the needs of the grid. For this LCOE calcuation, 4 hours per day of discharge was chosen (representative of peak time shaving each day).
T&D loss factor is actually a placeholder for the conversion efficiency of the batteries, since losses in conversion have a similar effect as line losses. The round trip conversion efficiency is around 70% for a typical vanadium flow battery.
Flywheel Energy Storage
Capital cost of $7.66/watt includes $4.50/watt for flywheel, $0.66/watt for control systems and BOS, and $2.50/watt installation.
Annual fixed cost of $42/kW-yr includes $5/kW-yr for regular O&M and $250/kW for major maintenance in years 5, 10, and 15 (annualized to $37/kW-yr)
20 MW is a common plant size for flywheel technology. This should not be considered the county-wide potential but rather representative of a single pilot project. 20 MW system mirrors recent Amber Kinetics install for PG&E and typical Beacon installs.
The capacity factor is highly variable and depends on the needs of the grid. Runtime may be nearly 24 hrs/day but at less than full capacity.
Capacity factor assumes both charging and discharging count as delivered energy for the LCOE calculation.
T&D loss factor is actually a placeholder for the conversion efficiency of the flywheel, since losses in conversion have a similar effect as line losses. The round trip conversion efficiency is around 88% for the Amber Kinetics system (6% is used for the T&D factor since we're counting energy as being utilized both ways).
Compressed Air Energy Storage
Capital cost of $0.73/watt includes $0.45/watt for the gas turbine used to generate electricty from the compressed air and $0.28/watt for balance of system components and installation.
Annual fixed cost of $21/kW-yr includes $4/kW-yr for regular O&M and $85/kW for major maintenance in years 4, 8, 12, and 16 (annualized to $17/kW-yr).
5 MW should not be considered the county-wide potential. It is unknown whether any underground storage locations (such as salt caverns) exist, though pilot programs have been done using steel pipes and other manufactured above ground storage techniques. While below ground CAES projects often have capacities of >100MW, the above ground pilots have typically been <10MW.
The capacity factor is highly variable and depends on the needs of the grid. For this LCOE calcuation, 4 hours per day of discharge was chosen (representative of peak time shaving each

day).
T&D loss factor is actually a placeholder for the conversion efficiency of CAES, since losses in conversion have a similar effect as line losses. The round trip conversion efficiency is around 60% for typical CAES projects (assuming waste heat utilization).
Thermal Storage (ice-based technologies)
Capital cost of $0.59/watt includes $0.25/watt for storage equipment, $0.19/watt for control systems and BOS, and $0.15/watt installation.
Annual fixed cost of $23/kW-yr includes $6/kW-yr for regular O&M and $112/kW for major maintenance in years 5, 10, and 15 (annualized to $17/kW-yr).
2 MW should not be considered the county-wide potential. This is a typical project size for the popular Ice Bear system from IceEnergy.
The capacity factor is highly variable and depends on cooling needs. For this LCOE calcuation, the system was assumed to run for 6 hrs/day for 180 days per year (when the cooling load is highest).
T&D loss factor is actually a placeholder for the conversion efficiency of ice based thermal storage, since losses in conversion have a similar effect as line losses. The round trip conversion efficiency is around 95% for typical Ice Bear system (according to product spec sheet).

References

1. Solar production estimates and LCOE calculations using National Renewable Energy Laboratory's System Advisor Model
2. LCOE calculations for other resources using National Renewable Energy Laboratory's LCOE Calculator
3. Wind speed data from AWS Truepower
4. Wind energy yield estimates using WindCad Turbine Performance Model by BWC
5. Biomass pricing from the International Renewable Energy Agency's Biomass for Power Generation Cost Analysis
6. Comparisons made to Lazard's LCOE Analysis

About Optony

Optony Inc. is a global research and consulting services firm focused on enabling government and commercial organizations to bridge the gap between clean energy goals and real-world results. Optony's core services offer a systematic approach to planning, implementing, and managing commercial and utility-grade renewable power systems, while simultaneously navigating the dramatic and rapid changes in the solar industry; from emerging technologies and system designs to government incentives and private/public financing options. Leveraging our independence, domain expertise and unique market position, our clients are empowered to make informed decisions that reduce risk, optimize operations, and deliver the greatest long-term return on their solar investments. Based in Silicon Valley, Optony has offices in Santa Clara, Chicago, and Beijing.

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