California Energy Commission

CONSULTANT REPORT

Lancaster Advanced Energy Community

Avenue I Microgrid Cost Benefit Analysis

Prepared for: **California Energy Commission**
Prepared by: **Energy Solutions**

California Energy Commission

Edmund G. Brown Jr., Governor

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ABSTRACT

Based on the research, modeling and analysis outlined in this report, and coupled with the previous deliverable, *Lancaster Avenue I Technical Design*, the following report details the costs and benefits of installing a community microgrid in Lancaster, California. The resulting benefit cost ratios include capital expenditures, operations and maintenance, grid purchases, grid sales, and avoided emissions. Two ownership structures are presented for the analysis, customer-owned and Lancaster Choice Energy owned. This report identifies the most cost-effective option for the microgrid design presented in the previous deliverable.

Keywords: California Energy Commission, Microgrids, Cost Benefit Analysis

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EXECUTIVE SUMMARY

Avenue I (referred to as the "project") is a 5.84-acre lot located in Lancaster, California between Avenue I and West Avenue H and between Elm Avenue and Sierra Highway. The project is owned by the City of Lancaster and is planned for a single-family attached development of approximately 75 units. Each of the units will follow one of three (3) floor plans of three to four bedrooms, ranging from 1,400 to 1,900 square feet. The entire development will be outfitted with Distributed Energy Resources (DER) to meet the electrical power demand of the community. Two use cases are analyzed, the first being where customers own and operate the DER assets and participate in Net Energy Metering (NEM). The second being Lancaster Choice Energy (LCE) will own the community's DER assets, infrastructure, and control. The units will be operated by the Lancaster Housing Authority as low-income units. The following outlines the reports major results and analysis.

Summary of Selected Use Case

In the previous deliverable, the project team recommended a Hybrid Use Case. This model aimed to strike a balance in terms of cost, emissions, and resiliency, as well as the spatial considerations of the proposed Avenue I site. With shared flywheel energy storage, the analysis showed that Avenue I can achieve greater resiliency and less than half the emissions at roughly 40% lower net present cost than with Li-ion battery storage. Much of this is due flywheels having a design life that is 2-3 times greater than Li-ion batteries. Given that there are relatively few flywheel installations, especially in residential microgrid applications, there is a need for demonstration projects that can further validate the favorable analytical results.

Having consulted with LCE and realizing that flywheels are still a semi-unproven technology in residential microgrids, the project team decided to analyze the Hybrid Use Case by varying the storage technology (i.e. flywheel versus battery storage) and ownership models (i.e. LCE owned[1] assets versus Customer owned assets).

The four use cases analyzed and their associated objectives are listed in Table 1. Costs values were calculated using researched expenses and HomerPro© microgrid modeling software. Cost inputs to Homer were capital expenses, operation and maintenance, and utility grid rates. Benefits were modeled using the resulting Homer simulation export. Using the Homer microgrid data grid sales, avoided grid purchases, and avoided emissions could be calculated. A summary of the benefit to cost ratios of the analyzed use cases is shown in Table **2**.

A detailed summary of the methodology used to calculate the benefit to cost ratios is listed in Chapter 2. Further results are detailed in Chapter 3.

1 LCE owned assets were assumed in the previous deliverable – Avenue I Microgrid Technical Design.

Table 1 Summary of use cases analyzed

Use Case	Objectives
LCE-Owned Assets – Community Storage	• LCE pays capital expenses and operations costs to own the assets within Avenue I. The community shares centralized storage for peak demand reduction and backup power.
LCE-Owned Assets – Battery Storage	• LCE pays capital expenses and operations costs to own the assets within Avenue I. Each home is installed with battery packs for peak demand reduction and backup power.
Customer-Owned Assets – Community Storage	• The customers own the equipment on their homes and use as they see fit. Capital costs are wrapped into the home prices, operation and maintenance casts are shared by the customers. Energy storage is centralized and shared in the community.
Customer-Owned Assets – Battery Storage	• The customers own the equipment on their homes and use as they see fit. Capital costs are wrapped into the home prices, operation and maintenance casts are shared by the customers. Battery packs are installed within each home

Table 2 Summary of Benefit Cost Ratios

Use Case	Benefit to Cost Ratio
LCE-Owned Assets – Community Storage	1.01
LCE-Owned Assets – Battery Storage	.20
Customer-Owned Assets – Community Storage	1.20
Customer-Owned Assets – Battery Storage	.89

CHAPTER 1: Introduction

Avenue I Background

Avenue I (referred to as the "project") is a 5.84-acre lot located in Lancaster, California between Avenue I and West Avenue H and between Elm Avenue and Sierra Highway. The project is owned by the City of Lancaster and is planned for a single-family attached development of approximately 75 units. Each of the units will follow one of three (3) floor plans of three to four bedrooms, ranging from 1,400 to 1,900 square feet. The entire development will be outfitted with Distributed Energy Resources (DER) to meet the electrical power demand of the community. Two use cases are analyzed, the first being where customers own and operate the DER assets and participate in Net Energy Metering (NEM). The second being Lancaster Choice Energy (LCE) will own the community's DER assets, infrastructure, and control. The units will be operated by the Lancaster Housing Authority as low-income units.

Purpose of this Document

The project architect has developed three conceptual plans for the development and is in the process of obtaining tentative tract map approval. Once the Lancaster Planning Commission and City Council approve the tentative tract map, the architect will develop the project's architectural and construction documents and prepare to break ground on the project. The previous deliverable – Microgrid Technical Analysis – outlined the trade-offs and benefits of different technical aspects of a residential microgrid. Based on research, analysis, and modeling presented in that report, the Project Team recommended a technical design of the community microgrid to the City of Lancaster. This report will expand upon that document and outline the cost and benefit tradeoffs for the proposed residential microgrid, including equipment sizing, storage strategy, control strategy, and billing structure. Figure 1 details the modeling process the Project Team followed to 1) form a technical design for the Avenue I microgrid and 2) evaluate the costs and benefits of the selected use case.

Microgrid Use Cases

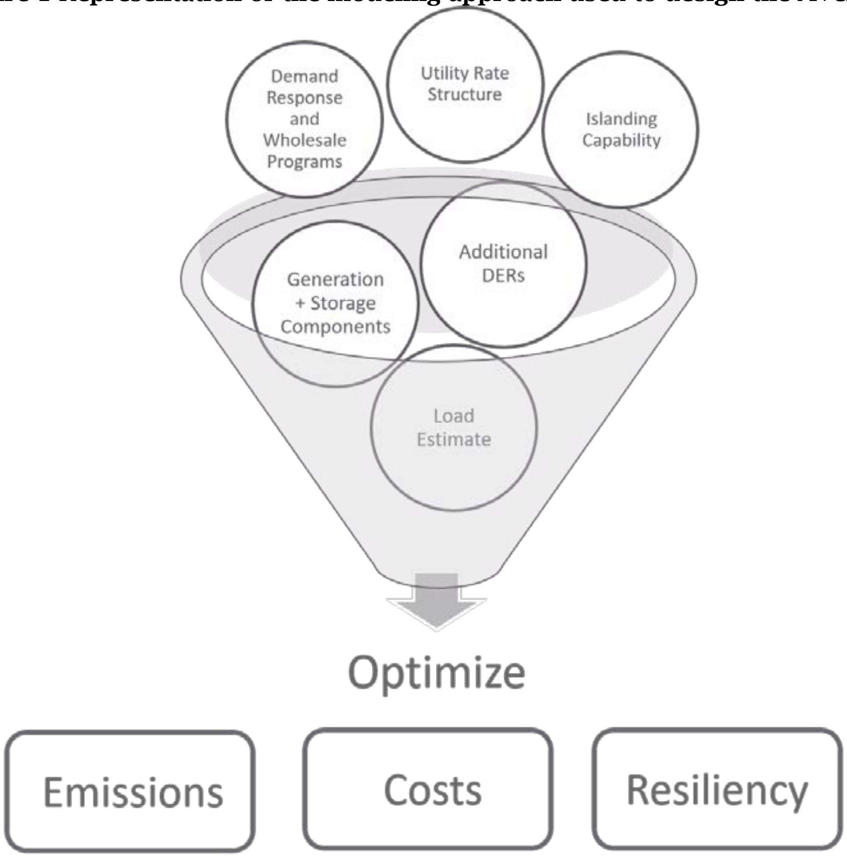
After considering input from a variety of stakeholders including LCE and the Lancaster Housing Authority, the Project Team identified three potential use cases (Table 1) for the Avenue I microgrid: Resiliency & Excess Generation (R&EG), Energy Bill Savings (EBS), and Emissions Reductions (ER). These use cases form the foundation of the technical design analysis as they impact the load estimate, DER components, sizing configurations, and control strategy needed for the microgrid. In the Technical Design, the Project team recommended an all-electric hybrid use-case that blended the three aforementioned scenarios into a design recommendation. After consulting with stakeholders again, the

Project team has identified four ownership and control structures (Table 2) for which to conduct the cost-benefit analyses.

Table 3 Summary of the previously defined use cases.

Use Case	Objectives	Design Considerations	Value Streams
Resiliency & Excess Generation (R&EG)	• Highly reliable • Maximize islanding capability • Support loads with DERs • Support future EV penetration	• Initially oversized PV/storage capacity to support future EV loads	• Participate in demand response or wholesale programs using excess generation • Near complete functionality in the event of grid outages or natural disasters
Energy Bill Savings (EBS)	• Minimize the cost of energy • Maintain some islanding capability	• Reduced islanding capability allows for smaller PV/storage	• TOU price arbitrage • Some functionality in a grid outage or natural disaster
Emissions Reductions (ER)	• Minimize energy related emissions	• All-electric homes • Consider life-cycle emissions	• Climate action plan goals
Hybrid Microgrid	• Maximize benefits of the above use cases for practical community microgrid design	• Maintain a level of autonomy in case of blackouts while reducing emissions. • Minimize the customer's energy bill	• Hybridizes the above use case value streams

Figure 1 Representation of the modeling approach used to design the Avenue I microgrid.



Assumptions

The Hybrid Microgrid (HMG) developed in the Technical Design will be considered in the following cost-benefit analysis. The project team made the following high-level assumptions in the process of developing the project's technical design:

- **Grid embedded microgrid –** The Project Team did not consider scenarios in which Avenue I is an independent, off-grid community.
- **100% renewables design –** Given the City of Lancaster's commitment to climate change mitigation and renewable energy laid out in its draft Climate Action Plan, only designs with renewable energy generation[2] were considered. No on-site diesel or gas electricity generation was considered.
- **Islanding capability –** While various definitions of 'microgrid' exist, the Project Team assumed the defining characteristic of a microgrid to be its ability to disconnect and 'island' from the larger macro-grid. Thus, cases in which the project operates strictly as a net-metered, community solar development, without energy storage infrastructure, were not considered. While the targeted islanding

2 Lancaster's ZNE Ordinance requires that each home has at least 2 W/ft^2 of installed solar. Therefore, only solar generation was considered as a renewable energy source for the Avenue I microgrid.

capability varies by use case, only designs with some combination of generation and energy storage were considered. Also, implicit in this assumption is the requirement that the microgrid is capable of re-synchronizing with the macro-grid after any islanding event (planned or unplanned).

- **25-year period of analysis.** The Project Team chose 25 years (2020-2045) as the period for which to analyze various design configurations and performance. Due to the stage of project development, the Project Team assumed that Avenue I will not likely be operational until approximately 2020. Projecting out 25 years from that point allows for consideration of storage replacement costs, changes in utility rates, and EV penetration without introducing amplified levels of uncertainty into the analysis.
- **Lancaster ZNE Ordinance.** The Project Team assumed Avenue I's compliance with the recent Lancaster ZNE Ordinance. Since behind-the-master-meter generation is essential to the microgrid operation, the Project Team constrained the design options to ensure that each home in Avenue I has at least 2W/ft^2 of installed solar.

In addition, the following assumptions were made to analyze the cost-benefit trade-offs of the HMG.

- **Cost of Solar PV.** The assumed cost of solar installations was taken from California Solar Statistics (CSS) and California Distributed Generation Statistics (DG Stat) databases, as well as the NREL PV Cost Benchmarking reports[3][4]. The assumed effective useful life was 30 years and replacement panels were given a reduced capital price for the analysis.
- **Cost of Energy Storage.** Two storage strategies were analyzed: Battery Packs and Flywheels. Capital expenses and effective useful life for batteries were referenced from Lazard[5]. Associated flywheel costs were available through an NDA with market representatives.
- **Net Present Costs.** HomerPro© modeling was utilized for cost calculations. The modeling software can optimize for lowest net present cost using Equation 1.

$$\sum_{n=1}^{N}\sum_{m=1}^{M} i_{mn}(CapEx_{mn} + Replace_{mn} + Salvage_{mn} + O\&M_{mn} + Fuel\ Costs_{mn}) \quad (1)$$

Where: n = the lifetime of the project in years

m = Component within the total system

i = Real discount rate

3 *California Solar* Statistics. California Solar Initiative. https://www.californiasolarstatistics.ca.gov/.

4 *California Distributed Generation* Statistics. Energy Solutions. http://californiadgstats.ca.gov/.

5 *Lazard's Levelized Cost of Storage – Version 2.0*. Lazard. December 2016.

CapEx, Replace, Salvage, O&M, Fuel Costs = The projects associated costs and revenues.

- **Net Present Value.** The net present value of the systems presented were calculated to analyze the benefit to cost ratios of the individual use cases. The equation used is shown in Equation 2 below.

$$\sum_{n=0}^{N} C * \{1 - \frac{(1+i)^{-n}}{i}\} - Cap_{ex} \quad (2)$$

Where: *n* = the lifetime of the project in years

C = The expected cash flow over the life of the project

i = Real discount rate

CHAPTER 2: Methodology

Introduction

HomerPro© modeling was utilized for generating cost information in the cost benefit analysis. Properly identifying the use cases to be analyzed was the first step in developing the analysis. The Project team used four differentiations of the Hybrid Use Case from the previous Technical Design. These differentiations were decided upon based on ownership structures and storage capabilities of Avenue I. Ownership of assets within Avenue I affects the capital expenditures and operating costs of the system. Energy storage was found to be the most cost-intensive component of the Avenue I microgrid and thus two strategies for storage were decided upon: battery packs installed in the individual homes or community storage supplied by underground flywheels. A summary of use cases included in the cost-benefit analysis is summarized in Table 4.

The load profile of the Avenue I neighborhood remained consistent from previous technical analyses and assumes the community will be developed electric vehicle (EV) ready. The penetration of EV's is assumed to be a significant portion of the community's load by the year 2045.

Table 4 Summary of use cases analyzed

Use Case	Objectives
LCE-Owned Assets – Community Storage	• LCE pays capital expenses and operations costs to own the assets within Avenue I. The community shares centralized storage for peak demand reduction and backup power.
LCE-Owned Assets – Battery Storage	• LCE pays capital expenses and operations costs to own the assets within Avenue I. Each home is installed with battery packs for peak demand reduction and backup power.
Customer-Owned Assets – Community Storage	• The customers own the equipment on their homes and use as they see fit. Capital costs are wrapped into the home prices, operation and maintenance casts are shared by the customers. Energy storage is centralized and shared in the community.
Customer-Owned Assets – Battery Storage	• The customers own the equipment on their homes and use as they see fit. Capital costs are wrapped into the home prices, operation and maintenance casts are shared by the customers. Battery packs are installed within each home

Cost Inputs for Models

Solar PV Generation

Installed PV solar panel costs were obtained from the California Solar Statistics (CSS)[6] and California Distributed Generation Statistics (DG Stat)[7] databases. Current data within CSS lists residential solar installed between 2015-2017 as costing between $1 and $9 per Watt installed. DG Stat averages the total cost per watt to equal $3.80 in 2017 and trending lower. Accounting for the continued fall in solar prices, the Project Team estimated $3.30/Watt AC PV installed for the analysis.

Energy Storage Systems

The initial cost of battery storage systems was obtained from research conducted by Lazard[8] on the cost of replacing batteries. Figure 2 shows the results of this research, with microgrid Li-Ion batteries ranging from $754 - $1,005 per kWh, commercial batteries having a larger cost range of $871 - $1,557 per kWh. To account for trends in declining costs, the total cost including installation was calculated to be $750/kWh of battery storage installed. This cost sufficiently reduces the total costs of the initial battery installation while being consistent with microgrid-scale and commercial-scale batteries analyzed by Lazard.

Flywheel Energy Storage

Early in the project, the client expressed interest in examining community energy storage solutions. Outreach to a local flywheel manufacturer allowed the project team to sign a non-disclosure agreement (NDA) based on the selected Technical Design microgrid model. Costs of the flywheels are kept proprietary per the signed NDA. Modeled flywheel costs are in line with capital Li-Ion expenditures and able to provide higher renewable penetration to the Avenue I microgrid.

Cost of Carbon Dioxide

Cost of carbon dioxide (CO_2) was obtained from the California Carbon Dashboard. As of January 16, 2018, the cost was approximately $15.28 per metric ton[9] of CO_2.

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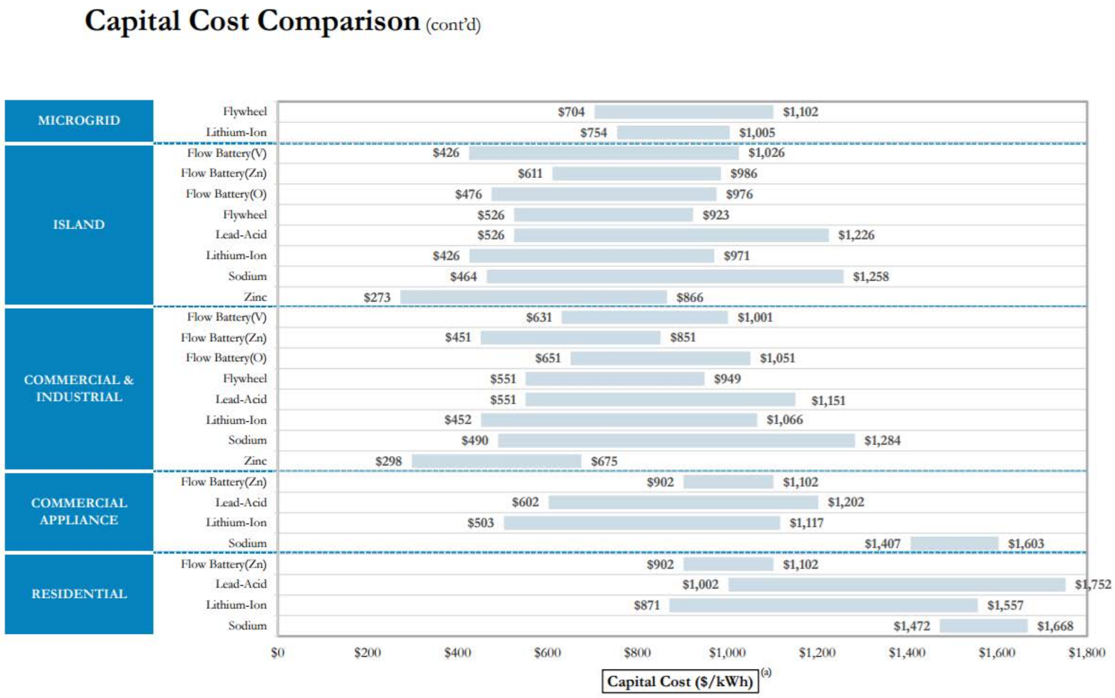
6 *California Solar* Statistics. California Solar Initiative. https://www.californiasolarstatistics.ca.gov/.

7 *California Distributed Generation* Statistics. Energy Solutions. http://californiadgstats.ca.gov/.

8 *Lazard's Levelized Cost of Storage – Version 2.0*. Lazard. December 2016.

9 *California Carbon Dashboard* - http://calcarbondash.org/

Figure 2 Lazard Analysis of Battery Storage



The project's storage qualifies for incentives through California's Self Generation Incentive Program (SGIP), which reduces the cost of battery installations to approximately $570/kWh (without installation costs). With additional incentives via the Income Tax Credit (ITC), the total costs drop to approximately $360/kWh.

System Inverters

Residential PV systems installed on the Avenue I homes will likely be installed with single-phase string inverters to convert the current from DC to AC. The National Renewable Energy Lab (NREL) benchmarks costs of single-phase string inverters at an average of $0.19/Watt of AC installed (W_{AC}).10 For this analysis, battery and flywheel inverter costs are rolled into total installation costs of the systems. The inverters in this analysis are "smart" inverters, meaning they maintain a level of control over their associated assets and have communication ability with the microgrid controller.

Utility Grid Rates

Grid rates were inputted into HomerPro© to reflect residential rates available to SoCal Edison (SCE) and Lancaster Choice Energy (LCE) customers. SCE confirmed that the Time-of-Use General Service 3 (TOU-GS-3) rate for commercial customers is the correct rate

10 Ardani, K. et al. *Installed Cost Benchmarks and Deployment Barriers for Residential Solar Photovoltaics with Energy Storage: Q1 2016.* National Renewable Energy Laboratory. Golden, CO. February 2017.

schedule for the project from LCE's perspective. The Project Team assumed residential rates will be used for the customer-owned models. Energy charges were obtained from LCE's TOU-DB rate schedule and combined with SCE's T&D and CCA surcharges. Examples of the associated rate schedules are shown in Figure 3 below.

Figure 3 LCE TOU-DB Rate Schedule[11]

RESIDENTIAL CUSTOMERS				
SCE EQUIVALENT SCHEDULE	LCE RATE SCHEDULE	UNIT/PERIOD	DESCRIPTION	LCE ADOPTED 2018 RATE
TOU-D-A	**TOU-D-A (continued)**	WINTER		
		PEAK	2 pm to 8 pm summer and winter weekdays except holidays	$ 0.18046
		OFF-PEAK	All hours –all year, every day	$ 0.09696
		SUPER OFF-PEAK	10 pm to 8 am-all year, every day	$ 0.02146
	BASELINE CREDIT ($/KWH.METER/DAY)	All Usage		($ 0.07926)
TOU-D-B	**TOU-D-B**			
	ENERGY CHARGE ($/KWH)	SUMMER	June 1 to Sept 30	
		PEAK	2 pm to 8 pm summer and winter weekdays except holidays	$ 0.23876
		OFF-PEAK	All hours –all year, every day	$ 0.04184
		SUPER OFF-PEAK	10 pm to 8 am-all year, every day	$ 0.01731
		WINTER	October 1 – May 31	
		PEAK	2 pm to 8 pm summer and winter weekdays except holidays	$ 0.11976
		OFF-PEAK	All hours –all year, every day	$ 0.03626
		SUPER OFF-PEAK	10 pm to 8 am-all year, every day	$ 0.02146

Grid sales are assumed to be available to Avenue I through participation through net energy metering (NEM) in the customer owned models. In the LCE owned models, it is assumed LCE would use Avenue I as a demand response resource (DR) and export excess generation only if an SCE demand response event was called.

11 *Lancaster Choice Energy Rate Schedules* - http://www.lancasterchoiceenergy.com/billing-rates/commercial-rates/

Figure 4: SCE TOU-GS-3-B Rate Schedule[12]**.**

RATES (Continued)

	Delivery Service								Generation[9]	
	Trans[1]	Distrbtn[2]	NSGC[3]	NDC[4]	PPPC[5]	DWRBC[6]	PUCRF[7]	Total[8]	UG**	DWREC[10]
Option B										
Energy Charge - $/kWh/Meter/Month										
Summer Season - On-Peak	(0.00239) (R)	0.00245 (I)	0.00487 (R)	0.00005 (I)	0.01021 (R)	0.00549	0.00046 (I)	0.02114 (R)	0.10130 (I)	0.00000
Mid-Peak	(0.00239) (R)	0.00245 (I)	0.00487 (R)	0.00005 (I)	0.01021 (R)	0.00549	0.00046 (I)	0.02114 (R)	0.05852 (I)	0.00000
Off-Peak	(0.00239) (R)	0.00245 (I)	0.00487 (R)	0.00005 (I)	0.01021 (R)	0.00549	0.00046 (I)	0.02114 (R)	0.03706 (I)	0.00000
Winter Season - On-Peak	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mid-Peak	(0.00239) (R)	0.00245 (I)	0.00487 (R)	0.00005 (I)	0.01021 (R)	0.00549	0.00046 (I)	0.02114 (R)	0.05355 (I)	0.00000
Off-Peak	(0.00239) (R)	0.00245 (I)	0.00487 (R)	0.00005 (I)	0.01021 (R)	0.00549	0.00046 (I)	0.02114 (R)	0.04264 (I)	0.00000
Customer Charge - $/Meter/Month		462.59 (I)						462.59 (I)		
Demand Charge - $/kW of Billing Demand/Meter/Month										
Facilities Related	4.63 (R)	13.66 (I)						18.29 (I)		
Time Related										
Summer Season - On-Peak		0.00						0.00	20.01 (I)	
Mid-Peak		0.00						0.00	3.94 (I)	
Winter Season - Mid-Peak		0.00						0.00	0.00	
Off-Peak		0.00						0.00	0.00	
Voltage Discount, Demand - $/kW										
Facilities Related										
From 2 kV to 50 kV	0.00	(0.22) (R)						(0.22) (R)		
Above 50 kV but below 220 kV	0.00	(7.31) (R)						(7.31) (R)		
At 220 kV	0.00	(13.66) (R)						(13.66) (R)		
Time Related										
From 2 kV to 50 kV	0.00	0.00						0.00	(0.39) (R)	
Above 50 kV but below 220 kV	0.00	0.00						0.00	(1.07) (R)	
At 220 kV	0.00	0.00						0.00	(1.08) (R)	
Voltage Discount, Energy - $/kWh										
From 2 kV to 50 kV	0.00000	0.00000						0.00000	(0.00140) (R)	
Above 50 kV but below 220 kV	0.00000	0.00000						0.00000	(0.00309) (R)	
At 220 kV	0.00000	0.00000						0.00000	(0.00312) (R)	
Power Factor Adjustment - $/kVAR										
Greater than 50 kV		0.47						0.47		
50 kV or less		0.55						0.55		
California Alternate Rates for Energy Discount - %		100.00*						100.00*		

Comparisons between SCE and Lancaster Choice Energy rates are available through LCE's website. A direct comparison to SCE's TOU-GS-3 exists in LCE's rate structure, defined as TOU-GS-3-B. Like Figure 4, Figure 5 describes associated costs for LCE commercial customers, including a $16/kW summer peak demand charge and $3/kW summer mid-peak demand charge.

12 *SoCal Edison Rate Schedules* - https://www.sce.com/tariffbooks

Figure 5 LCE TOU-GS-3-B Rate Schedule.

TOU-GS-3-B	**TOU-GS-3-B**					
	ENERGY CHARGE ($/KWH)	SUMMER	June 1 through September 30			
		PEAK	12 noon to 6 pm summer weekdays, except holidays	$ 0.08849	10.00%	$ 0.07964
		MID-PEAK	8 am to 12 noon and 6 pm to 11 pm summer weekdays, except holidays	$ 0.04832	10.00%	$ 0.04349
		OFF-PEAK	All hours other than Peak and Mid-Peak	$ 0.02816	10.00%	$ 0.02534
		WINTER	October 1 through May 31			
		MID-PEAK	8 am to 12 noon and 6 pm to 11 pm winter weekdays, except holidays	$ 0.04365	10.00%	$ 0.03928
		OFF-PEAK	All hours other than Mid-Peak	$ 0.03340	10.00%	$ 0.03006
					CREDIT (MDC)	
TOU-GS-3-B	**TOU-GS-3-B (continued)**					
	DEMAND CHARGE ($/KW)	SUMMER TR PEAK	12 noon to 6 pm summer weekdays, except holidays	$ 18.79241	10.00%	$ 16.91317
		SUMMER TR MID-PEAK	8 am to 12 noon and 6 pm to 11 pm summer weekdays, except holidays	$ 3.70023	10.00%	$ 3.33020

Final analysis of the Avenue I microgrid will use SCE's TOU-GS-3 schedule after confirmation with Lancaster Choice Energy. SCE will treat the project as a commercial load and charge LCE the associated costs listed above.

Tax Incentives

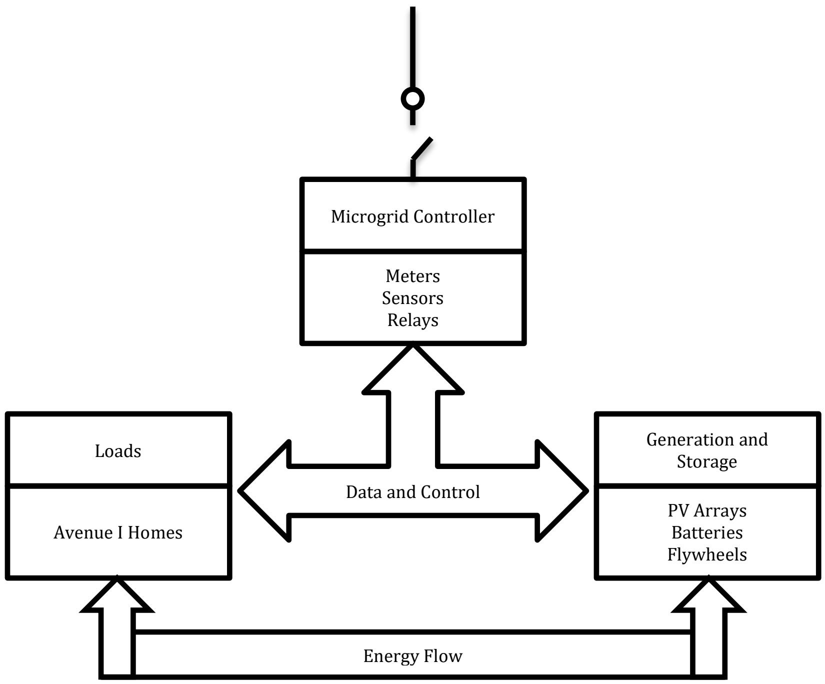
The Federal Investment Tax Credit (ITC) helps bring down the cost of the solar PV system. As the benefit-cost analysis is conducted through LCE and the customer's perspective, the ITC is assumed to be a benefit rather than a transfer payment between the federal government and LCE/customers. In 2015, the federal government passed an omnibus spending bill that extended the ITC through 2021, though at a declining rate (30% through December 31, 2019, 26% in 2020, 22% in 2021), and then 10% after 2022). To take advantage of the ITC at its highest, the Project Team recommends completing the project development before 2020. Further, to qualify for the full ITC, the system must be configured such that only the solar PV is charging the onsite batteries. This was considered in the design of the system.

Control Systems and Strategies

The final control strategy was decided upon in the previous deliverable – *Avenue I Microgrid Technical Design*. A sample of the data and control flow is outlined in Figure 6. This control strategy takes advantage of a decentralized, bi-directional flow of control logic and data. Information is exchanged from the SCE distribution grid to the microgrid controller – out to the smart home meters and smart inverters, and back to the microgrid controller.

Capital and installation costs of grid-tied inverters and grid-form inverters are assumed to be rolled into the costs of the equipment for this analysis. Avenue I is also assumed to be a grid-connected microgrid, thus a significant portion of the control signals will come from the SCE grid. The assumed control strategy for this situation is a simple load-follow strategy, where increased load within the Avenue I homes is accounted for by smart inverters and then microgrid controllers dispatch energy storage to meet load demand.

Figure 6 Use Case Control and Data Flow



Model Development

Homer Pro and Excel-based models were built to calculate the benefit-cost ratios for Avenue I. Using researched capital and replacement costs and inputting the described utility rates into the Homer Pro simulation software allowed the project team to determine the Levelized Cost of Electricity (LCOE), and Net Present Costs (NPC). Net Present Value (NPV), and discounted annual benefits were modeled using the Microsoft Excel.

Granular exports from Homer described the nominal capital, operating, fuel, and replacement costs as well as a calculated salvage value present after the project's lifetime. To offset the simulated costs, the project team determined the benefits after consulting various stakeholders. In each case, the avoided grid purchases customers or LCE would see with the installation of a microgrid was considered one of, if not the most valuable benefit.

To calculate the avoided purchases, the total energy purchases the model procured was subtracted from the load and multiplied by the time-of-use rate as described in Equation 3.

$$Avoided\ Grid\ Purchases = (kW_{Load} - kW_{Grid}) * \$_{Grid} \quad (3)$$

In conjunction with the avoided grid purchases, avoided line losses and emissions were accounted, shown in Equations 4 and 5.

$$Avoided\ Line\ Losses = Avoided\ Grid\ Purchases * \gamma \tag{4}$$

Where γ is the line loss factor[13]

$$Avoided\ Emissions = Grid\ Emissions_{Grid} - Grid\ Emissions_{Model} \tag{5}$$

Consultation with stakeholders revealed that were LCE to elect to own the energy assets within the Avenue I microgrid, the CCA could count the aggregated exports towards their Resource Adequacy (RA) requirements. Using RA data for Southern California, the avoided costs of procuring additional resources was factored into the LCE-owned models. Calculation of the avoided RA is described in Equation 6.

$$\mathrm{RA}_{\mathrm{value}} = \$_{RA} * kW_{Peak_{Month}} \tag{6}$$

13 Wong, Lana. 2011. *A Review of Transmission Losses in Planning Studies*. California Energy Commission. CEC - 200 - 2011 - 009

CHAPTER 3: Use Case Analysis

Summary of Selected Use Case

In the previous deliverable, the project team recommended a Hybrid Use Case. This model aimed to strike a balance in terms of cost, emissions, and resiliency, as well as the spatial considerations of the proposed Avenue I site. With shared flywheel energy storage, the analysis showed that Avenue I can achieve greater resiliency and less than half the emissions at roughly 40% lower net present cost than with Li-ion battery storage. Much of this is due flywheels having a design life that is 2-3 times greater than Li-ion batteries. Given that there are relatively few flywheel installations, especially in residential microgrid applications, there is a need for demonstration projects that can further validate the favorable analytical results.

Having consulted with LCE and realizing that flywheels are still a semi-unproven technology in residential microgrids, the project team decided to analyze the Hybrid Use Case by varying the storage technology (i.e. flywheel versus battery storage) and ownership models (i.e. LCE owned[14] assets versus Customer owned assets).

Customer-Owned Assets

The first set of analyses assume the assets in Avenue I are sold to the customers purchasing the ZNE homes. The customers are assumed to have the ability to participate in the Net Energy Metering (NEM) program offered through LCE and control the assets as they see fit. While battery storage will be local to each individual home, offering the customer local control of the batteries, community storage is assumed to be financed by the whole community and used to shave peak demand and provide backup generation. A rate schedule was assumed for the residents after consultation from the utility and CCA stakeholders. This analysis places the Avenue I residents on the equivalent TOU-DB rate schedule from SoCal Edison (SCE).

Household Storage

Resembling a typical solar plus storage installation, this use-case assumes battery packs are installed within the Avenue I homes. Like the Technical Design, system sizing is determined by assuming the community must be able to operate 100% islanded using only PV and batteries. Table 3 summarizes the PV and battery capacities based on the Technical Design's Hybrid Model.

14 LCE owned assets were assumed in the previous deliverable – Avenue I Microgrid Technical Design.

Table 5 Customer Use Case – Installed Capacity and Energy Production- Battery Storage

Component	Total Installed Capacity	Energy Production
Solar PV Panels	450 kW (6 kW per home)	772 MWh
Li-Ion Battery Pack	1,005 kWh (equivalent of 1 Tesla Powerwall per home)	142 MWh (Throughput)
DC/AC Converter	250 kW	N/A

If LCE decides to move forward with battery installations in the Avenue I home the cost-effective option is to maximize the PV installations to increase the value of NEM exports. A single PowerWall per home is suggested to aggregate enough load to provide peak shavings and backup generation to the Avenue I microgrid. The battery size was also selected for the predicted increase in EV penetration throughout the community by the year 2045.

Total renewable penetration of the use case is an average 55.7% over a 25-year analysis period. The battery capacity offers Avenue I up to 8 hours of autonomy in a blackout situation. A summary of the associated costs of the system is listed in Table 4.

Table 6 Customer Use Case – System Costs – Battery Storage

System Cost	Value ($)
Initial Capital	$1,310,000.00
Annual Operating Costs	$56,900.00
LCOE	$0.11/kWh
Net Present Cost	$2,310,000.00 M

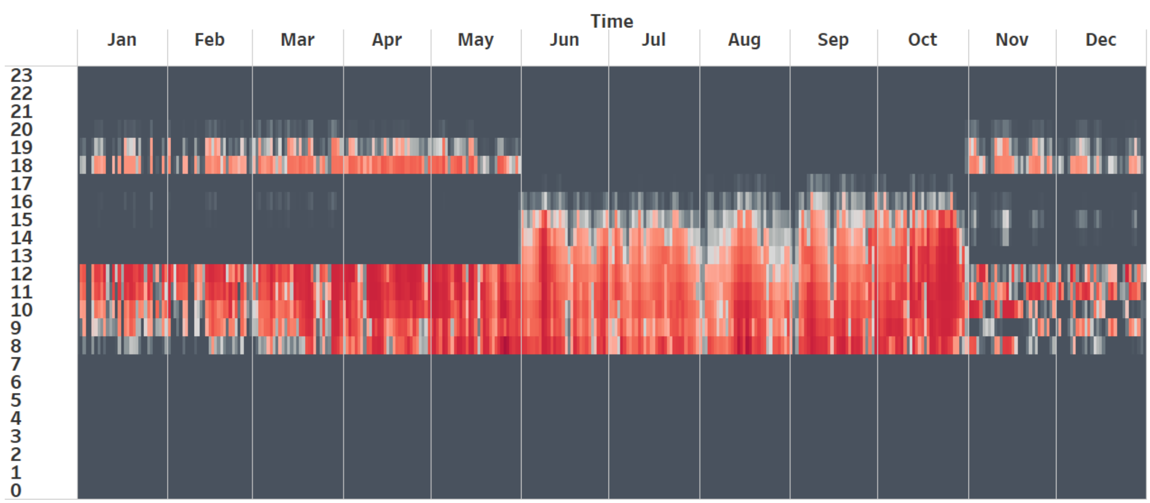
Lancaster's City Ordinance requires new homes built to be installed with at least 2W/ft^2 of solar PV. Assuming this would be the use case had a microgrid not been installed, a comparison between use case economics can be made. Comparing the Customer Owned – Household Storage use case with the Lancaster City Ordinance is outlined in Table 5.

Table 7 Customer Use Case - Economic metrics – Battery Storage

Economic Metric	Value
Internal Rate of Return	5.3%
Simple Payback	10.46 Years

Energy exports for the community are shown visually in Figure 7. All homeowners in the community are assumed to be enrolled in NEM and export energy back to the grid at the retail rate of energy.

Figure 7 NEM Grid Sales - Customer Owned Battery Packs



Calculating the benefit to cost ratio requires quantifying benefits of installing the microgrid at Avenue I. Discounted benefits over a 25-year period at a discount rate of 5% are shown in Table 6. Assuming Avenue I is comprised of 75 ZNE homes an average dollar amount per customer can also be calculated.

Table 8 Customer Use Case - Benefit Summary - Battery Storage

Benefit	Value ($)	Value/Customer/Year ($)
Avoided Energy Charges	$558,462.72	$297.85
Grid Exports	$440,645.78	$235.01
Avoided Line Losses	$29,598.79	$15.79
Avoided Emissions	$14,420.54	$7.69
Net Present Value	($142,435.24)	N/A
Benefit to Cost Ratio	.89	N/A

Community Storage

To align with the Hybrid Use Case suggested in the Technical Analysis, flywheel community storage was also analyzed. Contrary to the use case suggested by the project team, the installed flywheel storage was assumed to be financed and owned by the community. To combat the associated costs of 1,005 kWh of batteries in the previous use case the project team decided upon a community storage strategy. Intricacies of cost sharing between residents for financing the flywheel capital, installation and maintenance are not examined in this analysis. Rather, the total costs are aggregated on the community-scale and distributed evenly to the customers. Avenue I customers are assumed to be on the LCE equivalent TOU-DB rate schedule. Table 9 summarizes the PV and Flywheel capacities used in the community storage use cases.

Table 9 Customer Use Case - Installed Capacity and Energy Production – Flywheel Storage

Component	Total Installed Capacity	Energy Production
Solar PV Panels	450 kW (6 kW per home)	772 MWh
Flywheel	1,200 kWh (equivalent to 14 flywheels installed)	302 MWh (Throughput)
DC/AC Converter	250 kW	N/A

The flywheels are deemed more economically viable in participating in peak demand reduction for the community and providing backup power. Even more so than the battery storage case, flywheels enable most of the PV load to be exported for NEM sales rather than providing power to the homes. Total renewable penetration in the community drops slightly to 48.9% resulting in increased grid purchases and associated grid emissions. The flywheels do, however, offer Avenue I over 15 hours of autonomy in the event of a blackout, surpassing the autonomy power of the battery installations. With favorable installation costs over batteries, flywheels also reduce the capital expenditures that would need to be paid to finance the storage systems. The associated costs of the community storage use case are summarized in Table 10.

Table 10 LCE Use Case – System Costs – Flywheel Storage

System Cost	Value
Initial Capital	$1,160,000.00
Annual Operating Costs	$40,952.00
LCOE	$0.11/kWh
Net Present Cost	$ 1,870,000.00

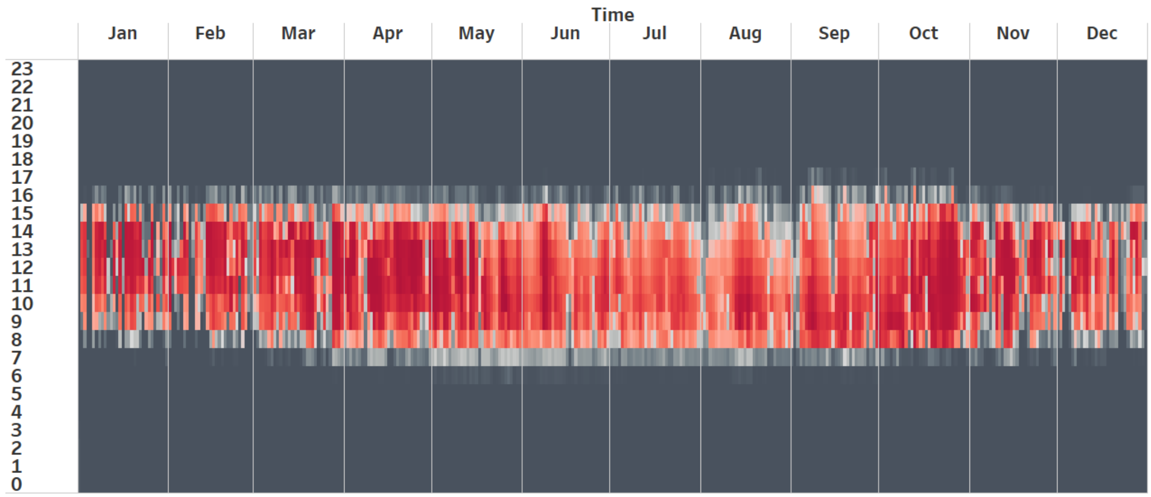
Economic metrics compared to the Lancaster City Ordinance use case are summarized in Table 11. Flywheel storage greatly improves the present and annual worth of the installed microgrid over the battery. The reduced capital of installing and maintaining the flywheels increases the present worth, but maintains a negative value due to decreased value in the TOU-GS-3-B NEM sell back rates.

Table 11 Customer Use Case - Economic metrics – Flywheel Storage

Economic Metric	Value
Internal Rate of Return	16.2%
Simple Payback	6.78 Years

Figure 8 shows the energy exports available to Avenue I customers in the flywheel use case. With the flywheels providing a large portion of the energy, the solar PV is freed to export energy during the day when load is low.

Figure 8 NEM Grid Sales - Customer Owned Flywheels



The benefits of the Community Storage can be quantified by analyzing the avoided energy purchases and the grid sales the residents of Avenue I receive. If LCE choose to proceed with this use case it should be noted that maintenance of the community storage is idealized in the modes i.e. it is assumed the nominal degradation of the flywheels occur and the equipment is properly maintained by the customers. Exports are visualized in Figure 8.

Table 12 Customer Use Case - Benefit Summary - Flywheel Storage

Benefit	Value	Value/Customer/Year ($)
Avoided Energy Charges	$477,038.00	$254.42
Grid Exports	$511,675.54	$272.89
Avoided Line Losses	$25,283.23	$13.48
Avoided Emissions	$11,933.59	$6.36
Net Present Value	$272 K	N/A
Benefit to Cost Ratio	1.20	N/A

Lancaster Choice Energy-Owned Assets

The following analyses assume Lancaster Choice Energy has purchased the Avenue I assets and will control, maintain, and replace as necessary. Through the CCA ownership structure, it is assumed residents of the homes can no longer participate in NEM to reduce their monthly energy bill. Additional value streams are available to LCE by using Avenue I as an aggregation asset[15]. This allows LCE to use the aggregated energy to sell wholesale to California Independent Systems Operator (CAISO).

HomerPro© requires a rate schedule input to properly calculate the levelized cost of electricity. The following use cases assume LCE is billed the TOU-GS-3-B rate schedule from SCE. The rate schedule is adjusted however, due to LCE's ability to use Avenue I as a procurement source. Thus, the costs of procuring energy are reduced.

Household Storage

Like the Customer-Owned use case, household storage will consist of battery packs installed in the residents' homes., though this analysis does not consider where the batteries are installed in the homes. LCE's ownership of the storage assets allows them to use the batteries to provide energy to Avenue I during peak hours and discharge during demand response events. Table 13 shows a summary of the modeled capacities.

Table 13 LCE Use Case – Installed Capacity and Energy Production- Battery Storage

Component	Total Installed Capacity	Energy Production
Solar PV Panels	255 kW	437 MWh
Li-Ion Battery Pack	1,005 kWh	134 MWh (Throughput)
DC/AC Converter	108 kW	N/A

The household storage use case minimizes PV installation compared to the sizing within the customer-owned model because LCE can no longer claim the ITC. By minimizing the solar installation, the upfront capital costs of the system are minimized. A summary of the use case's associated costs is listed in Table 14.

15 It is assumed that should the assets be used as primary generation

Table 14 LCE Use Case – System Costs – Battery Storage

System Cost	Value
Initial Capital	$892,320.00
Annual Operating Costs	$88,712
LCOE	$0.175/kWh
Net Present Cost	$2,450,000

Economic metrics are summarized in Table 15. The capital expenditures outweigh the discounted benefits over the 25-year lifecycle. Thus, a return rate less than one is achieved and the use case does not present itself economically viable for the Avenue I microgrid.

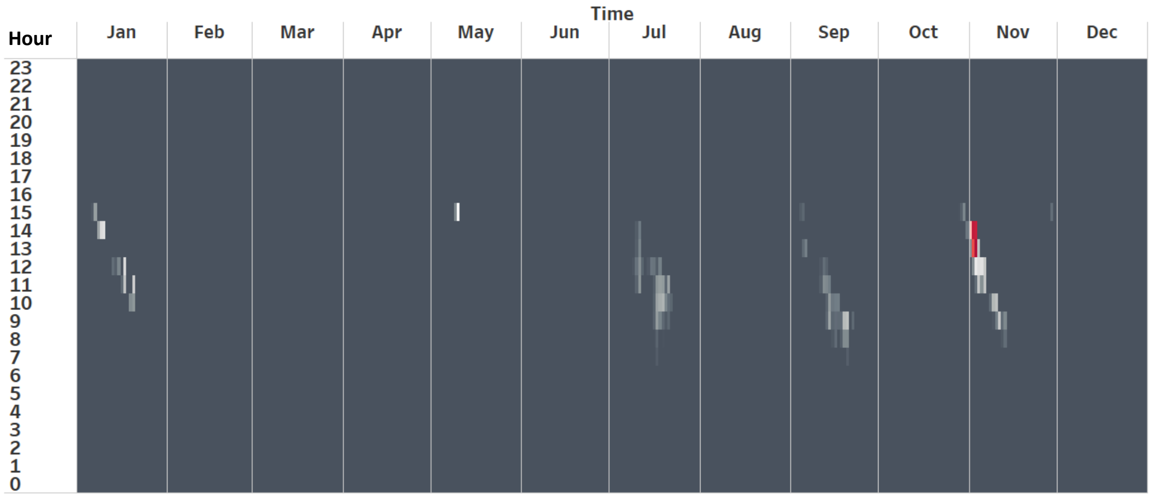
Table 15 LCE Use Case - Economic metrics – Battery Storage

Economic Metric	Value ($)
Internal Rate of Return	0.29%
Simple Payback	10.35 Years

When LCE owns the assets, the option for NEM to be quantified as a benefit is eliminated. As such, the benefits LCE could realize by owning the assets include: wholesale grid exports, avoided procurement, avoided resource adequacy (RA) costs, and avoided line losses from transmission and distribution, as well as avoided grid emissions.

Responding to demand response events limits the revenue stream Avenue I would receive from wholesale exports. The model only exported excess energy during demand response events, shown in Figure 9. Energy sales are limited, and battery power is better suited for backup generation than a reliable source of revenue.

Figure 9 Grid Exports – LCE Owned Batteries.



A summary of the discounted benefits available to LCE is summarized in Table 16. High battery costs and limited grid exports lower the benefit to cost ratio to a level where investment in the use case is near infeasible for LCE. High avoided grid purchases maintain a level of attractiveness for Avenue I, however, as the batteries provide sufficient backup power to the Avenue I residents.

Table 16 LCE Use Case - Benefit Summary - Battery Storage

Benefit	Value	Value/Customer/Year ($)
Avoided Energy Charges	$523,981.40	$279.46
Grid Exports	$252.19	$0.13
Resource Adequacy Value	$6,649.33	$3.55
Avoided Line Losses	$27,771.45	$14.81
Avoided Emissions	$15,830.98	$8.44
Net Present Value	($1,072,346)	N/A
Benefit to Cost Ratio	0.20	N/A

Community Storage

Installation of underground flywheel storage limits the barriers of owning individual battery storage installed in customer's homes. LCE would have complete control of charging, dispatch, and be able to respond to DR events from a more centralized location. A summary of the system component sizing is summarized in Table 17.

Table 17 LCE Use Case – Installed Capacity and Energy Production- Flywheel Storage

Component	Total Installed Capacity	Energy Production
Solar PV Panels	450 kW	772 MWh
Flywheel	1,400 kWh	366 MWh (Throughput)
DC/AC Converter	132 kW	N/A

To take full advantage of the wholesale value stream and autonomy of flywheel energy storage a larger PV plus flywheel is needed. Higher PV installations equates to more charging of the flywheels and allows the model to export more energy during demand response events. A summary of the associated cost with the flywheel use case are summarized in Table 18

Table 18 LCE Use Case – System Costs – Flywheel Storage

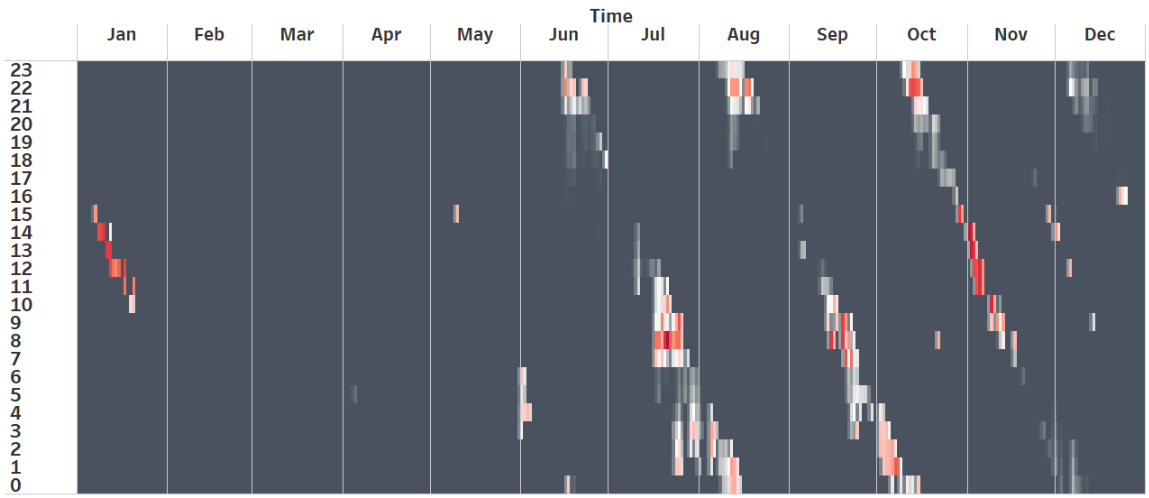
System Cost	Value
Initial Capital	$1,160,000
Annual Operating Costs	$36,685
LCOE	$0.127/kWh
Net Present Cost	$1,270,000

Table 19 LCE Use Case - Economic metrics – Flywheel Storage

Economic Metric	Value ($)
Internal Rate of Return	8.1%
Simple Payback	11.8 Years

Economic metrics compared to the Lancaster City Ordinance use case are summarized in Table 19. Lower operation and maintenance offsets higher upfront capital for flywheels. The results showed an attractive simple payback of less than 12 years. Flywheels provide a renewable penetration of 76.5% and are sized such that fewer grid purchases are needed. Excess energy exports are only available during demand response events and shown in Figure 10.

Figure 10 Demand Response Exports - LCE Owned Flywheels



The sizing of the flywheels limits the need for Avenue to purchase additional energy from the grid, increasing both the avoided energy charges and avoided emissions. A summary of the benefits available to LCE is summarized in Table 20.

Table 20 LCE Use Case - Benefit Summary - Flywheel Storage

Benefit	Value	Value/Customer/Year ($)
Avoided Energy Charges	$845,860.83	$451.13
Grid Exports	$4,883.72	$2.60
Resource Adequacy Value	$6,649.33	$3.55
Avoided Line Losses	$44,830.21	$23.91
Avoided Emissions	$26,368.32	$14.06
Net Present Value	$16,270	N/A
Benefit to Cost Ratio	1.01	N/A

CHAPTER 4: Conclusions

The above report is the final deliverable in the Lancaster Avenue I microgrid project. The analysis summarized the benefits and costs of four use cases based on the microgrid model selected in the previous deliverable - *Avenue I Microgrid Technical Design.*

The cost-benefit analysis assumed two types of energy storage were available to the microgrid, and two types of ownership models presented. Of the models analyzed, the LCE owned flywheel model provides the highest renewable penetration (76.5%) and most autonomy for the microgrid, but a neutral benefit to cost ratio of 1.01. Based on the analysis, the most cost-effective option for Avenue I is the installation of flywheels within the community and passing the ownership of the systems to the customers. The use case maintains a high renewable penetration of 64.6% and an attractive 1.2 benefit to cost ratio.

A summary of the benefit to cost ratios for the four use cases analyzed is presented in Table 21. The project team suggested that Lancaster Choice Energy consider installing flywheels into the Avenue I development for the most cost effective microgrid installation.

Table 21 Summary of Benefit Cost Ratios

Use Case	Benefit to Cost Ratio
LCE-Owned Assets – Community Storage	1.01
LCE-Owned Assets – Battery Storage	.20
Customer-Owned Assets – Community Storage	1.20
Customer-Owned Assets – Battery Storage	.89