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SEIN: Breaking Barriers Resilient Energy System Analysis

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June 2022

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- This analysis relies on site information provided to NREL by the Solar Energy Innovation Network (SEIN)/Atlanta University Center (AUC) and Georgia Power that has not been independently validated by NREL.

- The analysis results are not intended to be the sole basis of investment, policy, or regulatory decisions.

- This analysis was conducted using the NREL REopt® Model (https://www.reopt.nrel.gov). REopt is a techno-economic decision support model that identifies the optimal set of energy technologies and dispatch strategy to meet site energy requirements at minimum lifecycle cost, based on physical characteristics of the site and assumptions about energy technology costs and electricity and fuel prices.

- The data, results, conclusions, and interpretations presented in this document have not been reviewed by technical experts outside of NREL or SEIN/AUC.

Solar Energy Innovation Network: Program Overview

The Solar Energy Innovation Network (SEIN) is a collaborative research program that supports multi-stakeholder teams in researching and sharing solutions to real-world challenges associated with solar energy adoption.

- **Approach**
  - Teams identify local and regional challenges, and receive technical and financial assistance to formulate and test innovations and validate new models.
  - Research and innovative solutions are shared through peer network and stakeholders nationally.

- **Objective**
  - Develop innovative solutions that make solar energy adoption easier, and enable adoption by stakeholders across the United States facing similar challenges.

SOLAR ENERGY INNOVATION NETWORK
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Breaking Barriers: Project Overview

- The Breaking Barriers project was selected to participate in SEIN Round 2, and was led by Groundswell, a D.C.-based clean energy project developer.

- The Breaking Barriers team included Partnership for Southern Equity, Atlanta University Center campus facility managers and professors, the City of Atlanta's Neighborhood Planning Unit T, and Georgia Power Company.
  - The project aimed to design and construct innovative urban energy resiliency hubs integrating microgrid technology, solar generation, and energy storage in Atlanta colleges and communities.
  - The hubs would help these historically Black colleges and universities (HBCUs) and the energy-burdened broader community in West Atlanta be more resilient, in addition to informing new course curricula at Atlanta University Center campuses.

Breaking Barriers: Report Overview

- Through the SEIN Program, the Breaking Barriers team determined that the resilience hub at the Atlanta University Center would be powered by a solar photovoltaic (PV) and battery energy storage system (BESS).

- **This report** details two of NREL's analytical support efforts for the Breaking Barriers project. Namely,
  1. *At a set PV size, what is the relationship between size of the BESS, economic performance, and resilience capability?*
  2. *What are the electrical and cost considerations of an island-able microgrid interconnection for the resilience hub?*

- This report is one in a series of publications produced from this project. See the Breaking Barriers team's final project report for more information.

Analysis Overview

Analysis Overview

As a part of SEIN, the Breaking Barriers team worked to evaluate and plan for a solar and battery system to power a resilience hub at the Atlanta University Center (AUC).

- There are four campuses at the AUC which together comprise the Atlanta University Center Consortium (AUCC): Clark Atlanta University, Morehouse College, Morehouse School of Medicine, and Spelman College.
- The PV system and BESS will be sited at the Morehouse College Parking Deck while the resilience hub will be sited at the Manley College Center at Spelman College (see maps on next slides). The hub and energy systems have multiple intended purposes:
  - **During electrical grid outages, the system would provide resilient backup power to the Manley College Center resilience hub.**
  - **During normal grid-connected operations, the system would serve loads on the Morehouse College 2400 Cluster circuit, providing energy cost savings.**
    - The 2400 Cluster circuit is the meter on Morehouse's campus nearest to the Morehouse Parking Deck, serving three campus buildings with sufficient combined electrical load for the 918-kW PV system to effectively offset.

Analysis Overview: AUC Map

Morehouse Parking Deck (Morehouse College)

Manley College Center (Spelman College)

Manley College Center is a centrally located student center with a cafeteria and independent water chilling equipment.

The four campuses that comprise the AUC are shown here.

The PV/BESS system is planned for the Morehouse Parking Deck, while the campus resilience hub will be at Spelman's Manley College Center.

The star indicates a potential site for a separate resilience hub in the community just to the east of the AUC.

Analysis Overview: AUC Map

Morehouse Parking Deck (Morehouse College)

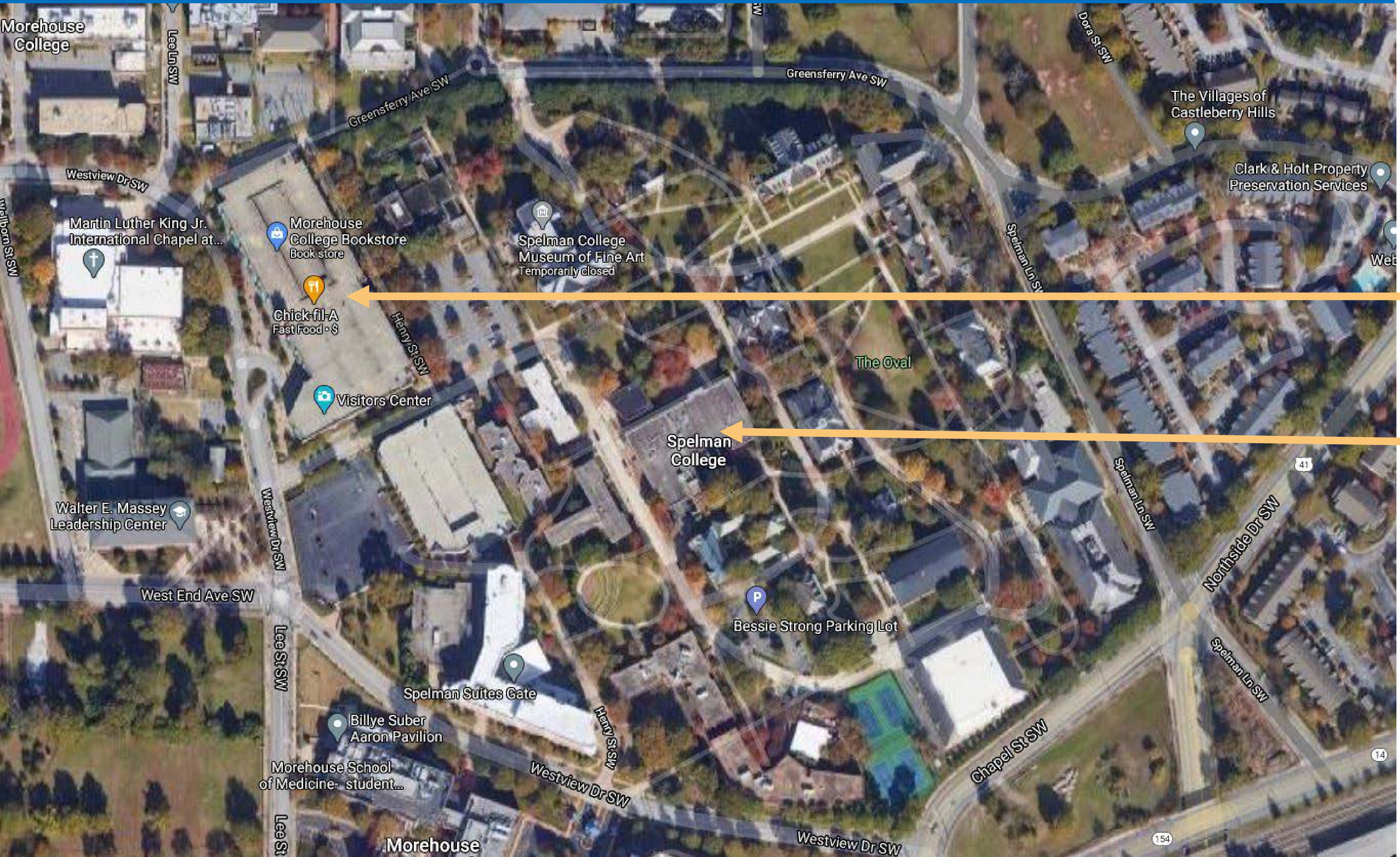
Manley College Center (Spelman College)

Detail area on next slide

The four campuses that comprise the AUC are shown here.

The PV/BESS system is planned for the Morehouse Parking Deck, while the campus resilience hub will be at Spelman's Manley College Center.

Analysis Overview: AUC Map



Morehouse Parking Deck (Morehouse College)

Manley College Center (Spelman College)

Analysis Overview: Goals

1. Economics & Resilience Analysis

With many possible options for the system's battery size, the Breaking Barriers team needed insight into the **relationships between BESS size, economic performance, and resilience** at the Manley College Center. These insights inform entering procurement negotiations with project developers, establishing resilience capabilities that the HBCU campuses can plan around, and guiding the team's fundraising targets.

Goals:

- Understand the costs and value of the proposed PV system.
  - Considering available space at the AUC, the maximum PV system size is 918-kW DC.
- Using NREL's Renewable Energy Optimization (REopt) platform, evaluate potential BESS sizes for:
  - <u>System costs</u> (including capital costs, operations and maintenance (O&M) costs, and battery replacement costs).
  - <u>Grid-connected value</u> (through electricity cost savings during non-outage conditions).
  - <u>Resilience</u> (as measured by the probability of Manley College Center being powered by the system throughout a given grid outage).

Economics & Resilience Analysis: Steps

The economics & resilience analyses presented in these slides answer the following questions:

1. **Grid-Connected Cost Savings:** How much grid-connected cost savings can the proposed PV system provide on its own and in conjunction with various BESS sizes?

2. **Initial Resilience (battery at 100% charge):** How much resilience do those BESS sizes provide, in conjunction with the proposed 918-kW PV system, assuming that the battery's only use is resilience? (i.e., assuming that the battery sits fully charged and is ready to be dispatched in case of grid outage).

3. **Advanced Resilience:** If the BESS is dispatched to maximize grid-connected economic value, as in Step 1, what are the impacts on the resilience value identified in Step 2, given that the BESS is less likely to be fully charged at the time of an unexpected grid outage?

4. **Comparison and Selection:** Using this analysis, allow the Breaking Barriers team to make an informed recommendation for the BESS size and operation resilient energy system.

Analysis Overview: Goals

2. Microgrid Interconnection Analysis

In order to provide power during a grid outage, the energy systems and resilience hub need to be connected in a safe and “island-able” manner (electrically isolated from the grid). Analysis of **potential electrical configurations and estimated setup costs** inform entering a required interconnection agreement with Georgia Power, as well as requests for engineering firms to construct the system.

Goals:

- Identify viable electrical connections from the PV + BESS system to the resilience hub at Spelman College’s Manley College Center.
- Estimate the equipment and installation costs for each option.
- Evaluate each option for its flexibility to accommodate future upgrades or additions to the microgrid and campus.

Microgrid Interconnection Analysis: Steps

The microgrid interconnection analysis presented in these slides identifies and evaluates various electrical interconnection schemes with the Spelman College electrical distribution system by addressing the following steps:

1. **Interconnection Options:** Identify conceptual, electrically viable potential PV/BESS interconnection configurations.

2. **Rough Order-of-Magnitude (ROM) Cost Estimates:** Identify conceptual ROM cost estimates for needed major components (beyond PV panels and battery banks) of the microgrid/ resilience-enhancing energy system.

3. **Potential Capacity for Future Growth:** Describe the potential for future resilient PV additions enabled by each of the conceptual PV/BESS interconnection configurations.

4. **Comparison and Selection:** Using this analysis, allow the Breaking Barriers team to make an informed recommendation for the interconnection of the campus resilience center.

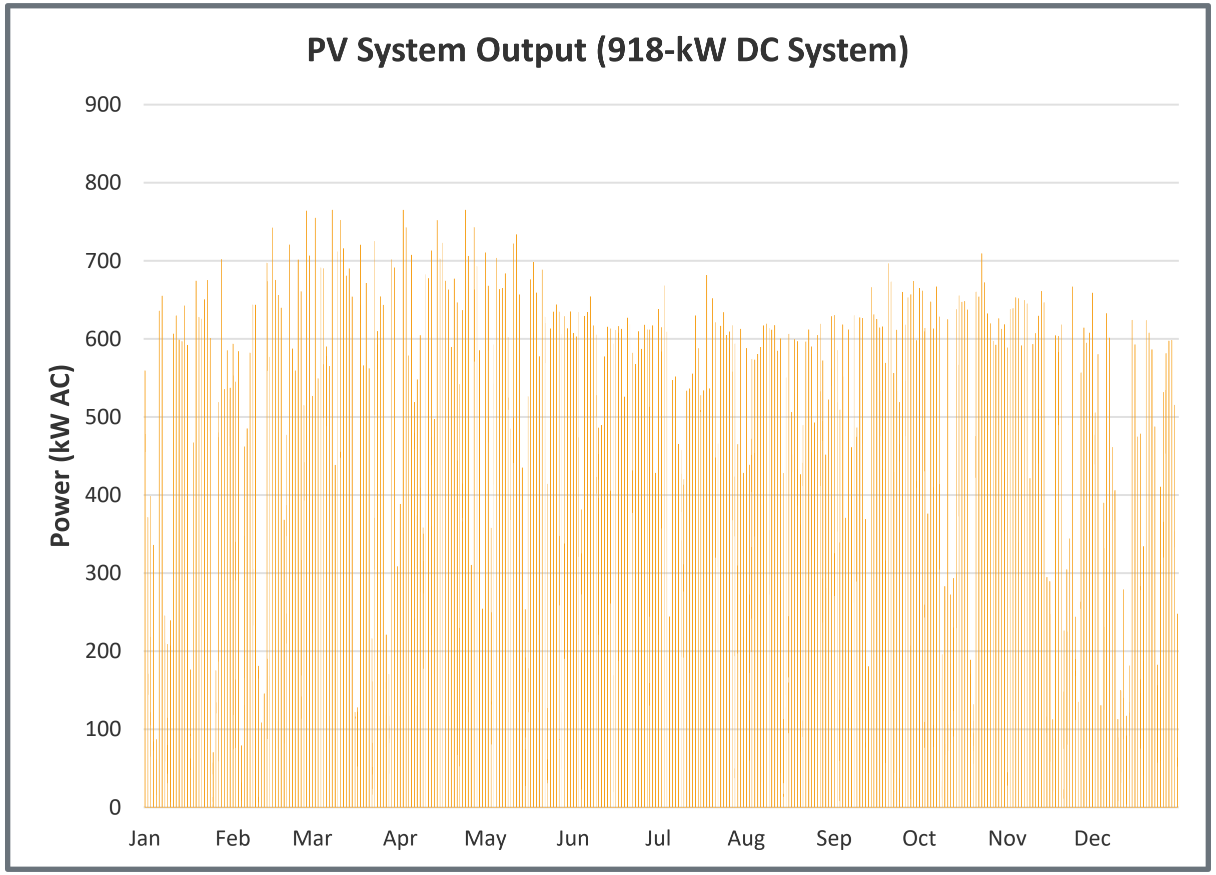
Summary of Results

Summary of Results: Economics & Resilience

1 of 5 – PV System

A 918-kW DC canopy PV system located on the Morehouse Parking Deck can provide electricity cost savings and resilience.

- Knowing the size, type, and location of the PV system informs several levels of subsequent analysis, produced using NREL's REopt and PVWatts platforms:
  - Capital and O&M costs
  - Projected annual electricity output (see graph)
  - Utility cost savings provided by the PV system through the electricity demand it offsets
  - Resilience of the PV + BESS system, based on the ability of the PV system to recharge the BESS during an outage.



Summary of Results: Economics & Resilience

2 of 5 – PV System

- **The canopy PV system is estimated to**:
  - Require $3.21M for capital costs and $0.27M for O&M.
  - Save $0.8M to $1.4M in utility costs over the useful life of the system.
  - Result in a net present value (NPV) of -$2.08M to -$2.78M.

- **The range of these results reflects modeling of the PV system within the price regimes of two different years: 2019 and 2020**
  - 2019 was an abnormally hot year in Atlanta, resulting in higher-than-average electricity prices in the analyzed Georgia Power rate (real time pricing, or RTP; Slide 31).
  - 2020 was characterized by suppressed electricity demand due to the COVID-19 pandemic, resulting in lower-than-average RTP rates.
  - Higher electricity prices lead to increased value for the PV system, as greater utility costs are avoided.

PV ECONOMIC RESULTS: CAPITAL COSTS, O&M COSTS, AND NPV RANGES

PV capital costs ($M)			$3.21M
PV lifecycle O&M costs ($M)			$0.27M
NPV (relative to base case) ($M)	Direct purchase	With 2019 RTP	-$2.08M
		With 2020 RTP	-$2.69M
	Third-party financing	With 2019 RTP	-$2.17M
		With 2020 RTP	-$2.78M

Direct purchase assumes the PV system is purchased by the campuses at a lower cost of capital (discount rate) than if the system were procured by a **third-party** developer. Slide 27 describes more scenario details.

Summary of Results: Economics & Resilience

3 of 5 – PV and BESS

- A **battery energy storage system (BESS) will be co-located with the solar PV system to provide backup power** to Manley College Center. A range of BESS sizes are modeled.

- **Varying BESS size in the analysis is crucial for understanding the costs and capabilities of different PV + BESS systems**, to arrive at an optimal system design choice for the AUC's resilience needs.

- **BESS size is expressed as the duration the BESS could supply the peak electrical load at Manley College Center**—assuming it starts from 100% state of charge (SOC) and isn't recharged.
  - For example, NREL and the Breaking Barriers team estimated Manley's peak load to be roughly 365 kW (Slide 41)
  - Using commercially available BESS size denominations, a 4-hour battery would therefore have 400 kW of power capacity (to supply the full building load) and 1600 kWh of energy capacity (to last for four hours at that power output level)
  - This definition leads to **conservative estimates of outage survivability** because Manley College Center is unlikely to always demand its peak load
  - In practical resilience contexts, battery systems can endure longer outages by being recharged from the PV system when solar power is available.

Summary of Results: Economics & Resilience

4 of 5 – BESS

- These results show the resilience performance of the energy system under different BESS size and usage conditions.
- **Battery storage can provide cost savings (Slide 33) by using stored electricity to offset campus consumption on an on-call basis when grid electricity prices peak.**
  - By contrast, the PV system by itself will provide cost savings only when the sun is shining, whether or not those times coincide with peak utility prices.
- **However, using the BESS for cost savings decreases the stored energy available for backup power in case of grid outage.**
  - The rate the BESS is recharged by the PV system during an outage is outstripped by the rate the BESS discharges electricity to power the resilience hub. Therefore, how full the BESS is (state of charge, or SOC) when the outage occurs significantly affects its resilience capability.
  - For example, a 12-hr BESS is estimated to provide power throughout 91% of all 24-hr outages if it starts at 100% full.
  - ...But the 12-hr BESS will only survive 54% of 24-hr outages if it is regularly discharged to provide cost savings during non-outage conditions.

BESS RESILIENCE		4-hr battery	8-hr battery	12-hr battery	16-hr battery	24-hr battery
Probability of outage survival if battery is at 100% SOC at outage start						
Outage Duration	4 hours	100%	100%	100%	100%	100%
	12 hours	43%	94%	100%	100%	100%
	24 hours	3%	54%	91%	100%	100%
	48 hours	0%	14%	46%	71%	96%
Probability of outage survival with regular battery cycling (based on 2019 RTP)						
Outage Duration	4 hours	62%	82%	96%	100%	100%
	12 hours	30%	57%	73%	85%	96%
	24 hours	1%	27%	54%	71%	88%
	48 hours	0%	8%	23%	39%	66%

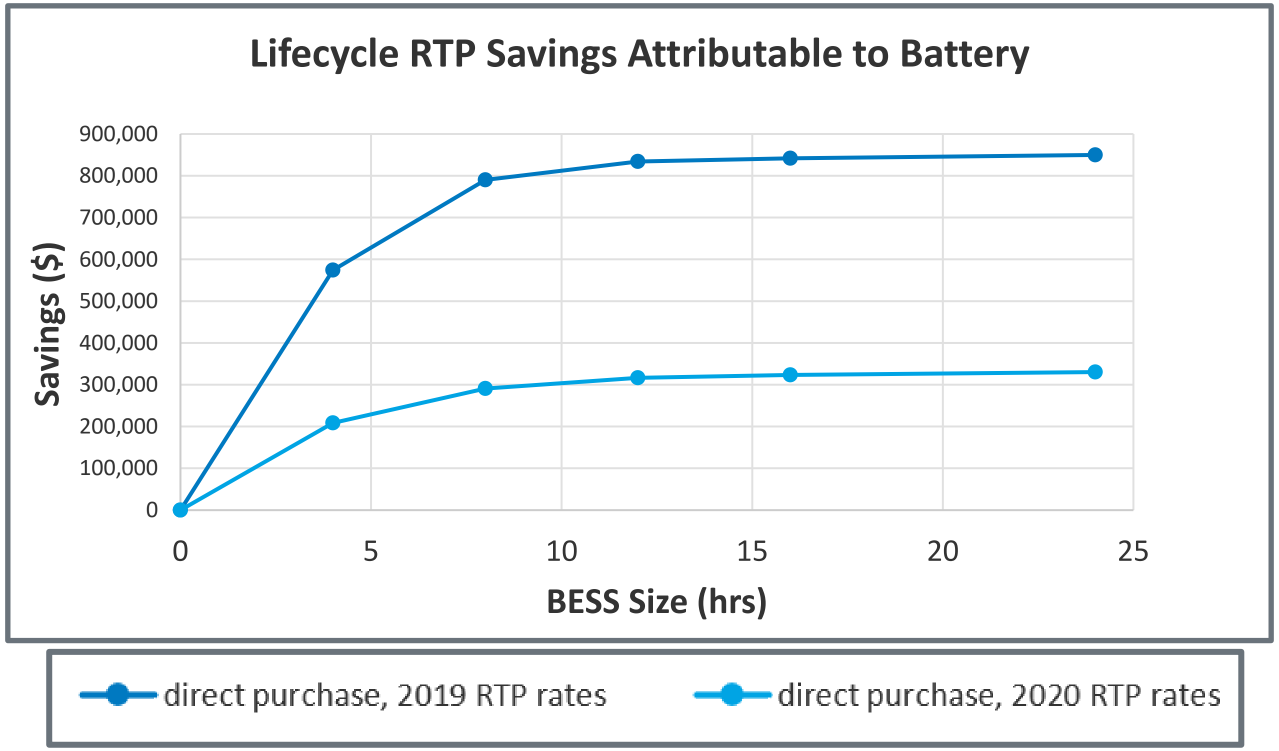
Summary of Results: Economics & Resilience

5 of 5 – PV and BESS

- All modeled BESS sizes result in negative estimated NPVs for the combined PV + BESS system; selected results are shown in the table. **The magnitude of a negative NPV may be considered the "cost of resilience" provided by the system.**

- The plot displays selected modeling results for a BESS used for regular grid-connected cost savings.
  - Electricity cost savings increase with larger battery capacity, but the marginal value plateaus between the 8- and 12-hour BESS sizes.
  - This plateau reflects the majority of electricity price (RTP, Slide 31) spikes already being offset.
  - The year of electricity rates impacts BESS cost savings: 2019 had more RTP spikes than 2020.
    - The spikes are where the BESS can maximize RTP savings.

BESS ECONOMICS		PV + 4-hr battery	PV + 8-hr battery	PV + 12-hr battery	PV + 16-hr battery	PV + 24-hr battery
BESS CAPITAL & REPLACEMENT COSTS (before incentives)						
Battery capital costs ($M)		$1.01M	$1.68M	$2.35M	$3.02M	$4.37M
Battery replacement costs ($M)		$0.48M	$0.80M	$1.12M	$1.44M	$2.08M
PV + BESS NPV with regular grid-connected battery cycling						
NPV (relative to base case) ($M)	With 2019 RTP	-$2.82M	-$3.47M	-$4.29M	-$5.15M	-$6.88M
	With 2020 RTP	-$3.79M	-$4.58M	-$5.42M	-$6.28M	-$8.01M



Summary of Results: Microgrid Interconnection

To increase resilience at Spelman College's Manley College Center, **secure electrical interconnections must be established to allow the PV + BESS systems to provide power during an outage.**

- Without proper electrical isolation, equipment, and monitoring, the resilient energy system could energize unintended power lines during an outage, leading to safety hazards for utility repair staff.
- NREL's experience with microgrid design assistance was leveraged to identify potential interconnection approaches that could **both** deliver resilient power at Manley College Center and comply with Georgia Power's requirements for electrical isolation ("islanding") during a grid outage.
- Interconnection approaches were evaluated based on:
  - Estimated cost of equipment
  - Interconnection voltage
  - Future growth potential (ability of the microgrid to incorporate more solar generation or building loads).

Summary of Results: Microgrid Interconnection

NREL developed estimates for four potential courses of action (COAs) to electrically interconnect the resilient energy system to Manley College Center (see table to the right).

- The range of these estimates is an additional $1.3M–$2.5M, depending on site conditions and interconnection approach (Slide 51).
- **Each interconnection approach has implications for the system's potential future growth.**
  - The campuses may desire the flexibility to add PV capacity or have the resilient energy system power additional buildings; the ease of these future additions varies between COAs.

NOTE: These results are based on rule-of-thumb cost estimates. Reviews of the site conditions, detailed engineering plans, and detailed discussion with Georgia Power are needed before investment decisions and specific COAs are determined.

ELECTRICAL INTERCONNECTION COST ESTIMATES (Rough Order of Magnitude – ROM)

Course of Action (COA)	Interconnection Voltage	ROM Cost Estimate and Range	Future Growth Potential
COA 1A (2.4kV at switchgear)	**2.4kV**	**$1.7M ($1.2M–$2.8M)**	**Limited due to 2.4kV circuit energy capacity**
COA 1B (19.8kV at switchgear)	**19.8kV**	**$2.5M ($1.8M–$4.2M)**	**Most potential for additional PV (19.8kV circuit); most stable microgrid voltage operation**
COA 2 (2.4kV at manhole)	**2.4kV**	**$1.3M ($0.9M–$2.2M)**	**Limited due to 2.4kV circuit energy capacity**
COA 3 (2.4kV express line)	**2.4kV**	**$1.8M ($1.3M–$3.0M)**	**Unknown right-of-way (ROW) costs, limited to 2.4kV line**

1. Economics & Resilience Analysis

Key Considerations & Steps

Economics & Resilience Analysis: Steps

The economics & resilience analyses presented in these slides answer the following questions:

1. **Grid-Connected Cost Savings:** How much grid-connected cost savings can the proposed PV system provide on its own and in conjunction with various BESS sizes?

2. **Initial Resilience (battery at 100% charge):** How much resilience do those BESS sizes provide, in conjunction with the proposed 918-kW PV system, assuming that the battery's only use is resilience? (i.e. assuming that the battery sits fully charged and is ready to be dispatched in case of grid outage).

3. **Advanced Resilience:** If the BESS is dispatched to maximize grid-connected economic value, as in Step 1, what are the impacts on the resilience value identified in Step 2, given that the BESS is less likely to be fully charged at the time of an unexpected grid outage?

4. **Comparison and Selection:** Using this analysis, allow the Breaking Barriers team to make an informed recommendation for the BESS size and operation resilient energy system.

Economics & Resilience Analysis: Key Considerations

PV System and Solar Resource

- The 918-kW DC PV system size was determined by Groundswell in a separate analysis and is used as an input to this analysis.
- With the PV size and Atlanta location, NREL's REopt tool modeled the PV system's projected electricity output across an entire year.
- This modeled electricity output helps determine the amount of utility cost savings provided by the PV system (through the electricity demand it offsets).
- The modeled electricity output also informs the resilience of a PV + BESS system, based on the ability of the PV system to recharge the battery during an outage.
- The solar resource estimate is based on a typical meteorological year (TMY). Outage duration survivability results are only approximations, based on TMY resource, estimated Manley College Center loads, and assumptions about the stored energy in the battery when loss of grid power may occur. The uncertainty in all of these parameters will impact actual durations of backup power.

Economics & Resilience Analysis: Key Considerations

Costs and Interconnection

- The capital costs of the PV and BESS in this section are based on national average estimates, cited here, as well as premium costs for canopy PV installations obtained by Groundswell. These estimates **include the costs to interconnect to Morehouse**'s electrical system.

- The capital costs in this section **do not include the costs to also interconnect the system to Spelman**'s Manley College Center. The interconnection options and cost estimates for connecting the PV and BESS system for resilient backup power to the Manley College Center are described later in this presentation (Slide 51).

Economics & Resilience Analysis: Key Considerations

Ownership Models Evaluated

- **Direct purchase assumptions**: Campuses own and operate the system; there is a 5% discount rate for campuses; there are no tax incentives; and the battery can charge from PV and/or grid.

- **Third-party ownership assumptions**: A developer owns and operates the system; campuses pay for electricity purchases from the system; there is an 8.3% discount rate for the developer; there is a 26% federal investment tax credit (ITC) and a 5-year modified accelerated cost recovery system (MACRS) for beneficial depreciation, with a 100% bonus MACRS for both PV and battery; and the battery can only charge from PV.

Economics & Resilience Analysis

1. Grid-Connected Cost Savings
2. Initial Resilience: Outage Survivability With Battery at 100% Charge
3. Advanced Resilience: Outage Survivability With Battery Dispatched to Maximize Economic Value
4. Comparison and Selection

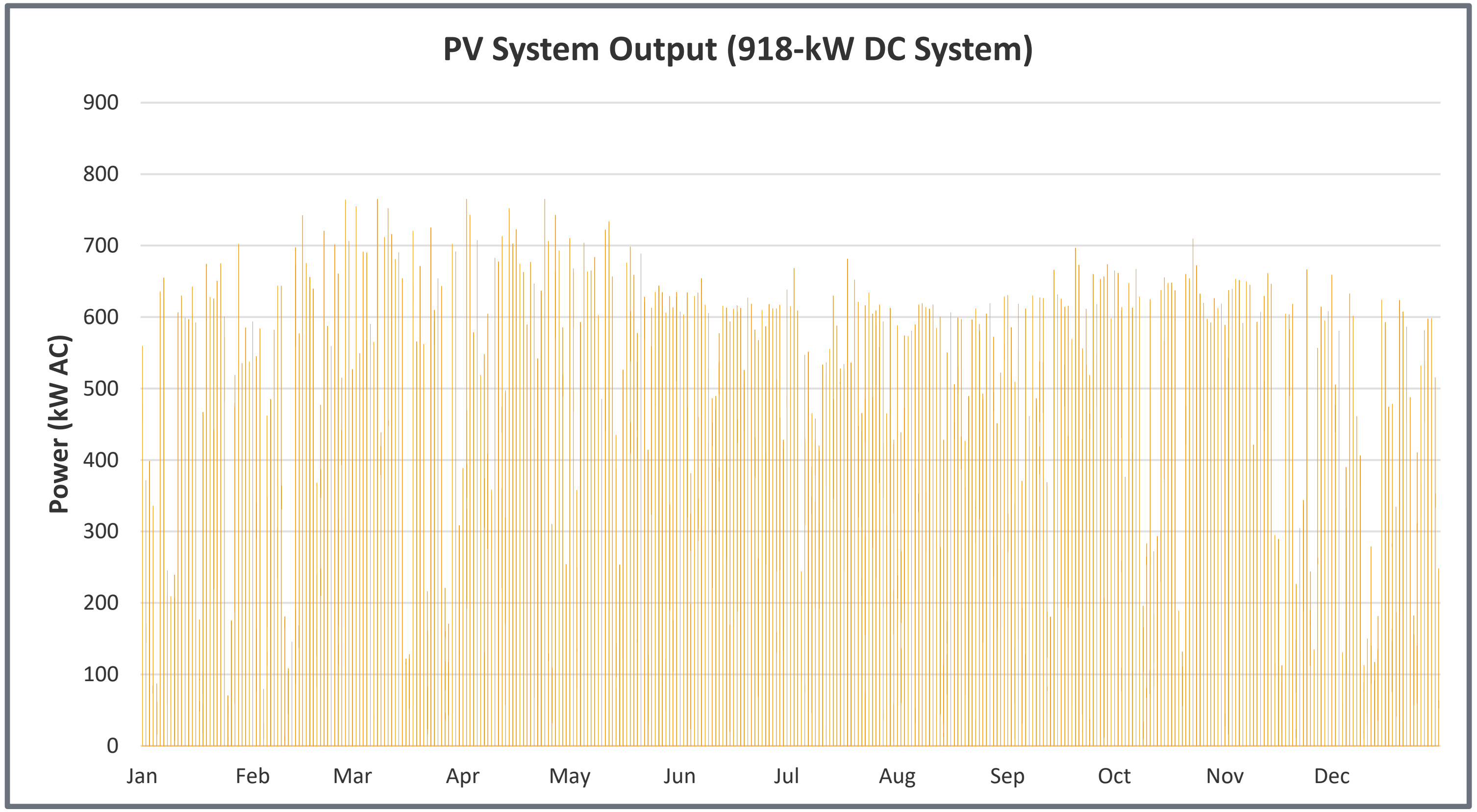
Economics & Resilience Analysis

1. Grid-Connected Cost Savings

Grid-Connected Cost Savings: Solar PV

Solar PV Assumptions

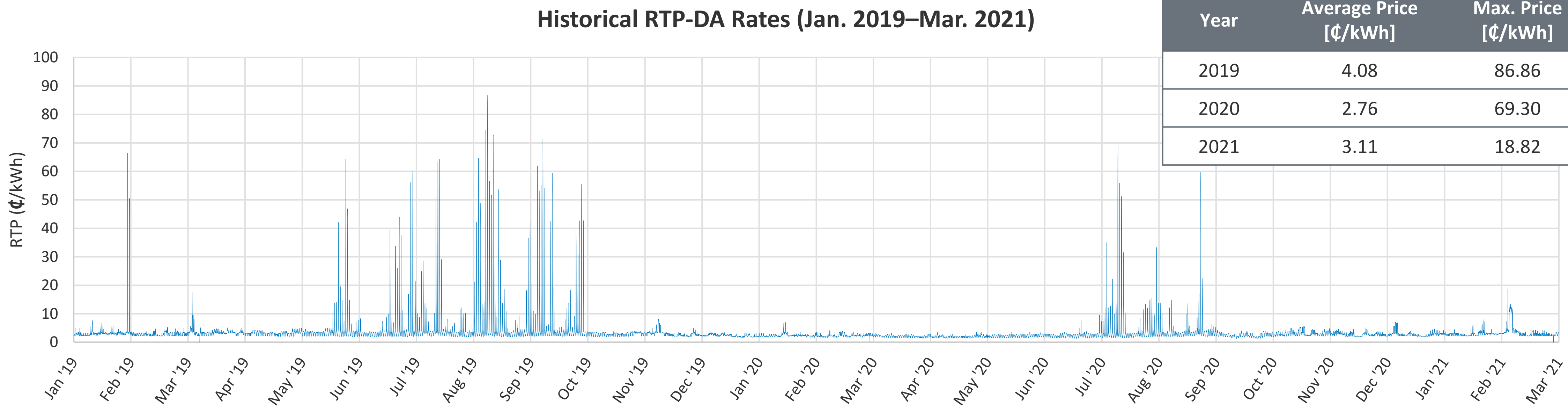
- Capacity: 918-kW DC
- System losses: 14.08%
- Tilt angle: 20°
- DC-to-AC ratio: 1.2
- Inverter efficiency: 96%
- Capacity factor: 16.3%
- Annual generation: 1,312.5 MWh
- Capital cost: $3,500/kW DC
- O&M cost: $16/kW DC/year



Grid-Connected Cost Savings: Rates

- Understanding electricity prices is prerequisite for modeling PV/BESS cost savings. AUC sites purchase electricity from Georgia Power (GPC), and the Morehouse “2400 Cluster” meter is billed on a combined “RTPDSLM” rate:
  - The Customer Base Load (CBL), a pre-calculated hourly load profile, is billed at the School Load Management (SLM) rate
  - Load consumed in excess of the CBL is charged at GPC’s Real Time Pricing (RTP) - Day Ahead (DA) rate
  - If the site consumes less than the CBL in a time period, the site is credited at the RTP-DA rate.

- From conversations between GPC and the Breaking Barriers team, we assume that PV/BESS generation would offset the electricity consumption billed under the RTP-DA rate.
  - Analyses include sensitivity studies of 2019 and 2020 RTP prices.

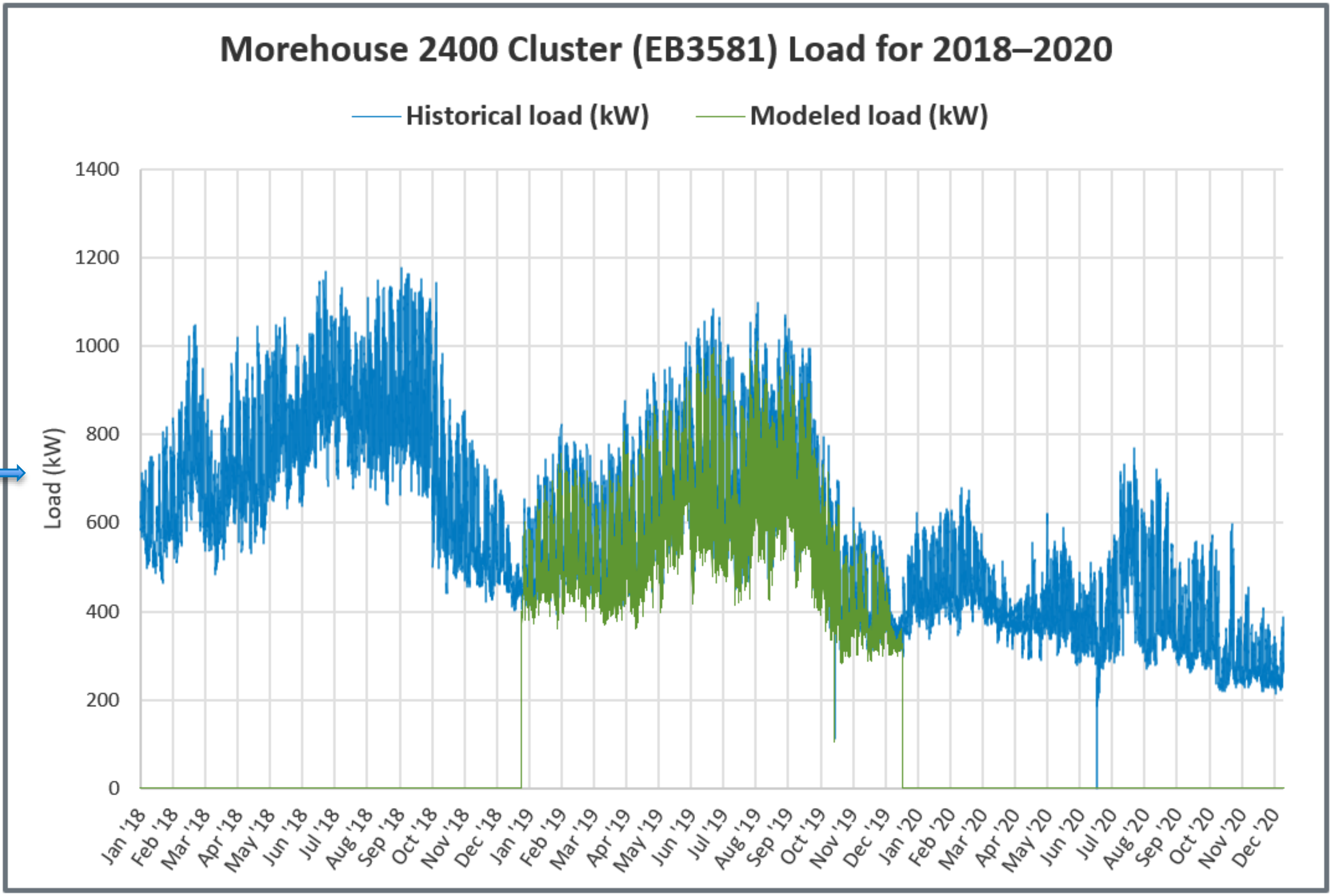


Year	Average Price [¢/kWh]	Max. Price [¢/kWh]
2019	4.08	86.86
2020	2.76	69.30
2021	3.11	18.82

Grid-Connected Cost Savings: Load

During grid-connected (non-outage) operations, the team decided that the PV/BESS systems will tie into the Morehouse "2400 Cluster" at Meter EB3581 and offset electricity demand at three campus buildings.

- NREL's REopt tool overlays this demand with electricity prices and PV/BESS generation to model and optimize a given system's economic benefits.
- Morehouse provided 30-minute interval data for the meter from 01/01/2018–12/31/2020; these data are shown on the plot to the right.
  - The load decrease from 2018 to 2019 is due to energy conservation measures
  - The load decrease from 2019 to 2020 is due to energy conservation measures and COVID-19 effects.
- This analysis uses the 2019 load reduced by 8% across all timesteps of the year (**in green**), as recommended by Morehouse College Energy Manager Courtney Mayes, to reflect the projected post-COVID load.



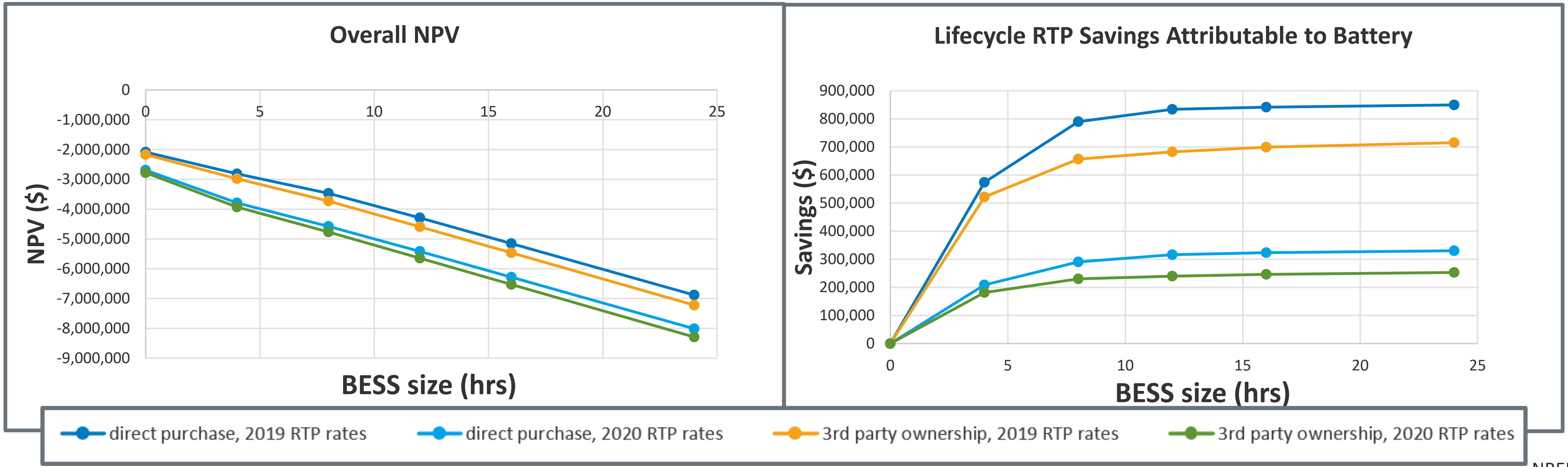
Grid-Connected Cost Savings: Economics

The plot on the <u>left</u> shows the lifetime PV + BESS system profitability, or net present value (NPV), of each system evaluated.

- Because each system's NPV is less than zero, these values can be considered the "cost of resilience" for each scenario.
- The economics of the direct purchase option are slightly more favorable than third-party ownership (Slides 34-35).

The plot on the <u>right</u> shows how the incremental electricity cost savings increase with larger battery capacity, but the marginal value plateaus between the 8- and 12-hour BESS sizes.

- This plateau reflects that the majority of RTP rate spikes are already being offset by the PV system and BESS.
- RTP rate year impacts BESS cost savings: 2019 had more RTP spikes than 2020. These spikes are where batteries can maximize RTP savings.



Grid-Connected Cost Savings: Direct Purchase Economics

This table describes the detailed economic modeling results of purchasing the PV system directly (i.e., not through a third-party developer), with a range of BESS sizes, and discharging the battery to maximize electricity cost savings. Direct purchase assumes a lower discount rate (cost of capital) but no access to incentives such as tax credits or accelerated depreciation. The data here, alongside the graphs on the prior slide, show that **direct purchasing provides a slight financial advantage over third-party development**.

		Base Case		PV Only		PV + Battery									
DER Sizes	**PV capacity (kW-DC)**	---		918 kW		918 kW		918 kW		918 kW		918 kW		918 kW	
	Battery capacity (kW/kWh)	---		---		400 kW/1600 kWh		400 kW/3200 kWh		400 kW/4800 kWh		400 kW/6400 kWh		400 kW/9600 kWh	
	Battery duration (hrs)	---		---		4 hrs		8 hrs		12 hrs		16 hrs		24 hrs	
DER Costs	**PV capital costs ($M)**	---		$3.21M		$3.21M		$3.21M		$3.21M		$3.21M		$3.21M	
	PV lifecycle O&M costs ($M)	---		$0.27M		$0.27M		$0.27M		$0.27M		$0.27M		$0.27M	
	Battery capital costs ($M)	---		---		$1.01M		$1.68M		$2.35M		$3.02M		$4.37M	
	Battery replacement costs ($M)	---		---		$0.48M		$0.80M		$1.12M		$1.44M		$2.08M	
RTP data used in analysis:		2019	*2020*	2019	*2020*	2019	*2020*	2019	*2020*	2019	*2020*	2019	*2020*	2019	*2020*
RTP Savings	**Year 1 RTP savings ($k/yr)**	---	---	$77.2k	*$43.6k*	$109.0k	*$55.1k*	$120.8k	*$59.6k*	$123.2k	*$61.1k*	$123.7k	*$61.4k*	$124.1k	*$61.8k*
	Year 1 savings from battery ($k/yr)	---	---	---	---	**$31.7k**	***$11.5k***	**$43.6k**	***$16.0k***	**$46.0k**	***$17.5k***	**$46.4k**	***$17.8k***	**$46.8k**	***$18.2k***
	Lifecycle RTP savings ($M)	---	---	$1.40M	*$0.79M*	$1.97M	*$1.0M*	$2.19M	*$1.08M*	$2.23M	*$1.11M*	$2.24M	*$1.11M*	$2.25M	*$1.12M*
	Lifecycle savings from battery ($M)	---	---	---	---	**$0.57M**	***$0.21M***	**$0.79M**	***$0.29M***	**$0.83M**	***$0.32M***	**$0.84M**	***$0.32M***	**$0.85M**	***$0.33M***
Overall Economics	**% of DER costs recouped by RTP savings — PV**	---	---	40%	*23%*	← assume these values apply to all scenarios; assess marginal value-add of battery below.									
	% of DER costs recouped by RTP savings — Battery	---	---	---	---	44%	*16%*	36%	*13%*	27%	*10%*	22%	*8%*	15%	*6%*
	NPV (relative to base case) ($M)	---	---	-$2.08M	*-$2.69M*	-$2.82M	*-$3.79M*	-$3.47M	*-$4.58M*	-$4.29M	*-$5.42M*	-$5.15M	*-$6.28M*	-$6.88M	*-$8.01M*
	NPV (relative to PV only) ($M)	---	---	---	---	-$0.73M	*-$1.10M*	-$1.38M	*-$1.88M*	-$2.21M	*-$2.73M*	-$3.07M	*-$3.59M*	-$4.80M	*-$5.32M*

Grid-Connected Cost Savings: Third Party Economics

This table describes the detailed economic results of purchasing the PV system through a third-party developer, with a range of BESS sizes, and discharging the battery to maximize electricity cost savings. Third-party acquisition assumes a higher discount rate than direct purchase by the campuses, but also allows access to financial incentives such as tax credits. The data here, and the graphs on Slide 33, show that **direct purchasing provides a slight financial advantage over third-party development**.

		Base Case		PV Only		PV + Battery									
DER Sizes	PV capacity (kW-DC)	---		918 kW		918 kW		918 kW		918 kW		918 kW		918 kW	
DER Sizes	Battery capacity (kW/kWh)	---		---		400 kW/1600 kWh		400 kW/3200 kWh		400 kW/4800 kWh		400 kW/6400 kWh		400 kW/9600 kWh	
DER Sizes	Battery duration (hrs)	---		---		4 hrs		8 hrs		12 hrs		16 hrs		24 hrs	
DER Costs	PV capital costs (before incentives) ($M)	---		$3.21M		$3.21M		$3.21M		$3.21M		$3.21M		$3.21M	
DER Costs	PV lifecycle O&M costs ($M)	---		$0.27M		$0.27M		$0.27M		$0.27M		$0.27M		$0.27M	
DER Costs	Battery capital costs (before incentives) ($M)	---		---		$1.01M		$1.68M		$2.35M		$3.02M		$4.37M	
DER Costs	Battery replacement costs ($M)	---		---		$0.48M		$0.80M		$1.12M		$1.44M		$2.08M	
DER Costs	Capital cost savings from incentives ($M)	---		$0.77M		$1.01M		$1.17M		$1.34M		$1.50M		$1.82M	
RTP data used in analysis:		2019	*2020*	2019	*2020*	2019	*2020*	2019	*2020*	2019	*2020*	2019	*2020*	2019	*2020*
RTP Savings	Year 1 RTP savings ($k/yr)	---	---	$77.2k	$43.6k	$106.0k	$53.6k	$113.5k	$56.3k	$114.9k	$56.9k	$115.8k	$57.2k	$116.7k	$57.6k
RTP Savings	Year 1 savings from battery ($k/yr)	---	---	---	---	**$28.8k**	***$10.0k***	**$36.2k**	***$12.7k***	**$37.6k**	***$13.2k***	**$38.5k**	***$13.6k***	**$39.4k**	***$14.0k***
RTP Savings	Lifecycle RTP savings ($M)	---	---	$1.40M	*$0.79M*	$1.92M	*$0.97M*	$2.06M	*$1.02M*	$2.08M	*$1.03M*	$2.10M	*$1.04M*	$2.12M	*$1.04M*
RTP Savings	Lifecycle savings from battery ($M)	---	---	---	---	**$0.52M**	***$0.18M***	**$0.66M**	***$0.23M***	**$0.68M**	***$0.24M***	**$0.70M**	***$0.25M***	**$0.72M**	***$0.25M***
Overall Economics	% of DER costs recouped by RTP savings — PV	---	---	39%	*22%*	← assume these values apply to all scenarios; assess marginal value-add of battery below.									
Overall Economics	% of DER costs recouped by RTP savings — Battery	---	---	---	---	**39%**	***14%***	**30%**	***10%***	**22%**	***8%***	**18%**	***6%***	**12%**	***4%***
Overall Economics	NPV (relative to base case) ($M)	---	---	-$2.17M	*-$2.78M*	-$2.98M	*-$3.93M*	-$3.73M	*-$4.77M*	-$4.59M	*-$5.64M*	-$5.46M	*-$6.53M*	-$7.22M	*-$8.29M*
Overall Economics	NPV (relative to PV only) ($M)	---	---	---	---	-$0.81M	*-$1.15M*	-$1.56M	*-$1.99M*	-$2.42M	*-$2.87M*	-$3.29M	*-$3.75M*	-$5.05M	*-$5.51M*

Grid-Connected Cost Savings: Results Summary

Key Takeaways:

- The 918-kW DC PV system could provide $77.2k of year 1 RTP cost savings (based on 2019 RTP)
- Lifetime savings only cover 40% of modeled PV capital and O&M costs, yielding an NPV of -$2.08M.

- All BESS sizes result in negative NPVs for the overall system, and the grid-connected economics of the BESS can vary significantly based on RTP electricity rates (i.e., 2019 prices vs. 2020 prices).
  - The grid-connected value of the battery system is primarily related to reducing grid electricity purchases during spikes in RTP, and **most of this available value is captured by an 8-to-12-hour BESS**, **leading to diminishing returns on larger BESS investments.**
  - The BESS value is so dependent on these occasional rate spikes in part because the low average price of electricity in Georgia Power's Atlanta territory leads to few other opportunities for significant cost savings.

- Direct purchase economics are slightly more favorable than third-party financing on a life cycle cost basis.
- Third-party financing could become marginally more unfavorable if the developer does not have the tax appetite to take advantage of the 100% bonus MACRS depreciation.

Grid-Connected Cost Savings: Notes

Notes:

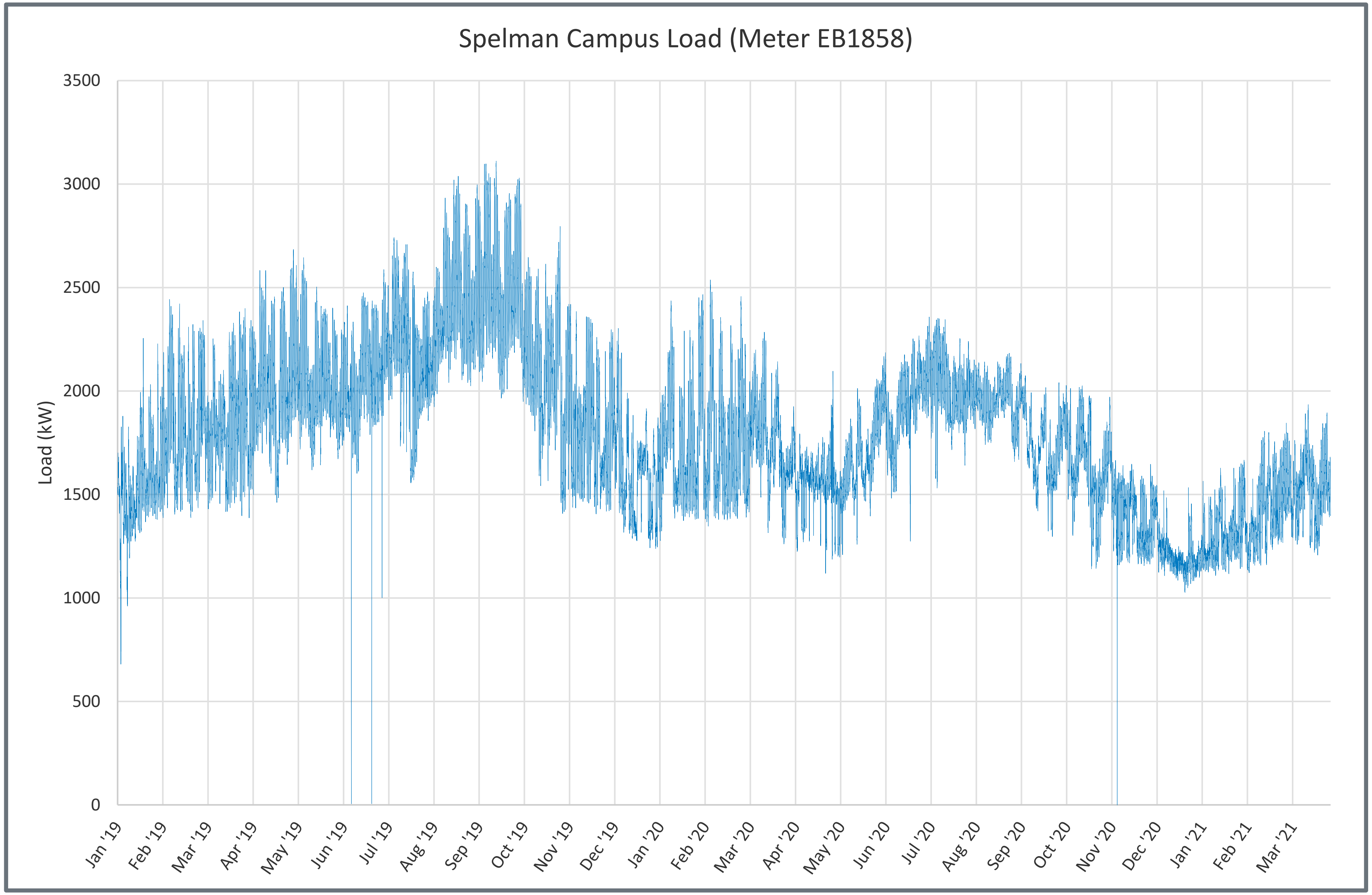
- Georgia Power allows compensation for grid exports of excess onsite renewable generation (for systems totaling ≤80 MW) if a site is designated as a Qualifying Facility (QF).
  - QF status may require additional setup and interconnection costs.
  - The analyzed PV + BESS system is not expected to generate significantly more power than the Morehouse 2400 Cluster's load (only 1.0% of annual gross load; see Appendix), meaning that opportunities for the modeled system to export energy to the grid would be rare.
  - For these reasons, the Breaking Barriers team did not pursue QF status for this project, and the results assume that the site is not a designated QF and thus does not receive compensation for exported energy to the grid.
- RTP savings identified by REopt modeling show maximum economic potential for modeled load, solar resource, and real time pricing.
  - Achieving these savings requires cost-optimal economic dispatch of assets, which may not be perfectly achieved in real-world conditions.

Economics & Resilience Analysis

2. Initial Resilience: Outage Survivability With Battery at 100% Charge

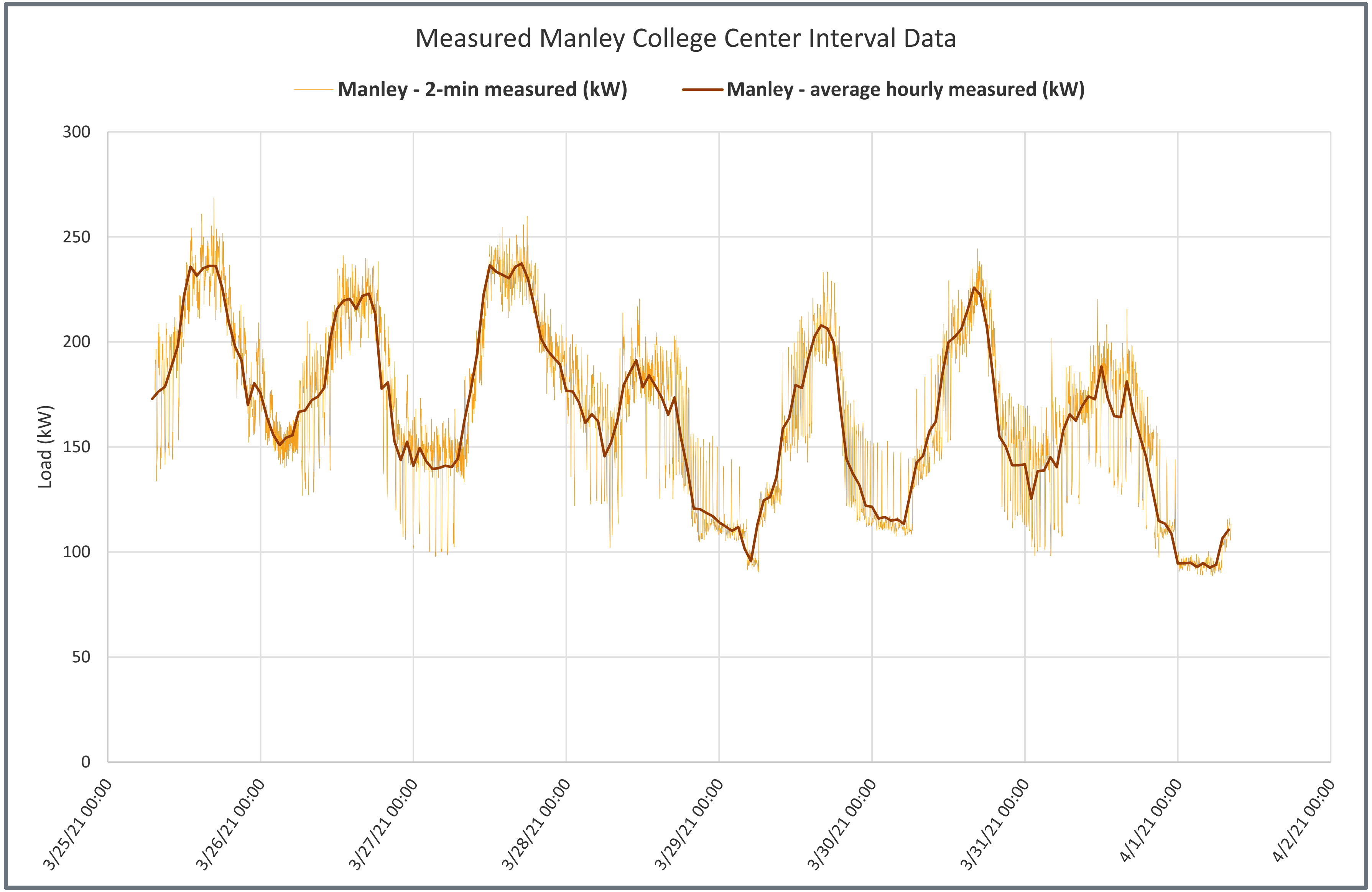
Initial Resilience: Load

- The PV and storage system is intended to provide resilience to the Manley College Center at Spelman College.
- **Characterizing Manley's electrical load** is crucial for estimating its outage survivability when powered by various PV + BESS systems.
- Spelman College campus is metered at a single point (Meter EB1858), for which 30-minute interval data was provided from 1/1/19–4/11/21 (see graph).



Initial Resilience: Load

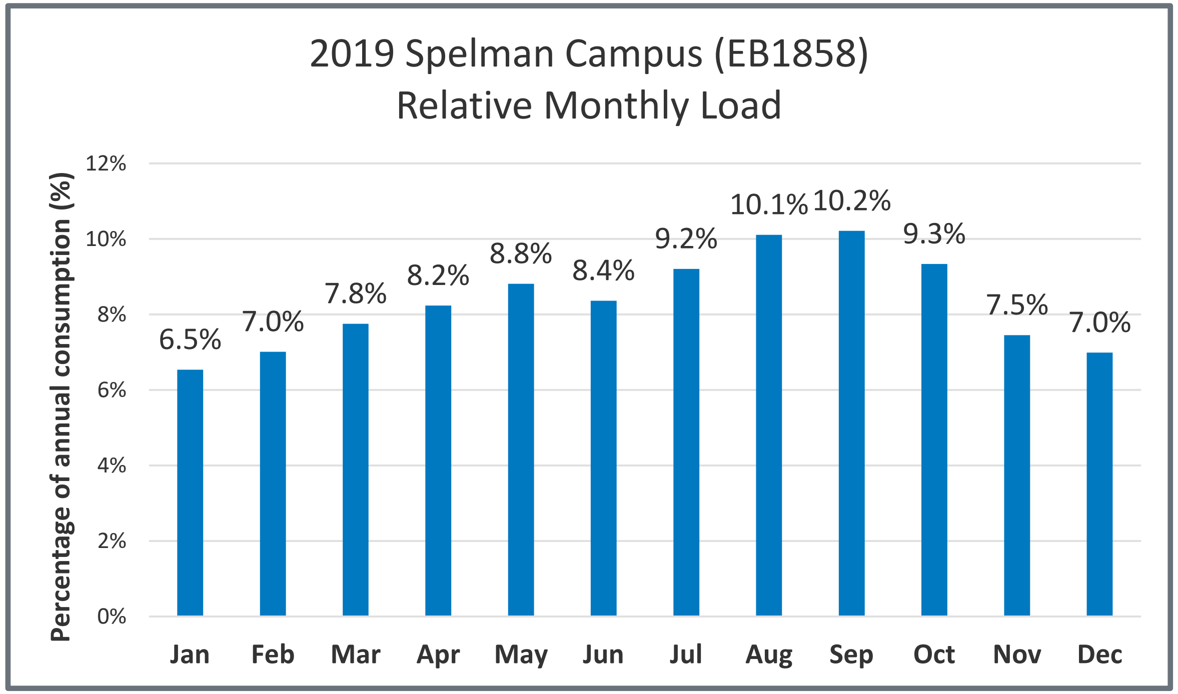
- The Manley College Center sits behind the main campus meter (previous slide) but is not sub-metered, so **the load of the building itself was unknown.**
- The Breaking Barriers team hired a contractor to measure 2-minute interval data at the Manley College Center for one week 3/25/21–4/1/21 (see graph).
- During this week, the Manley College Center comprised 10.4% of the overall campus load.

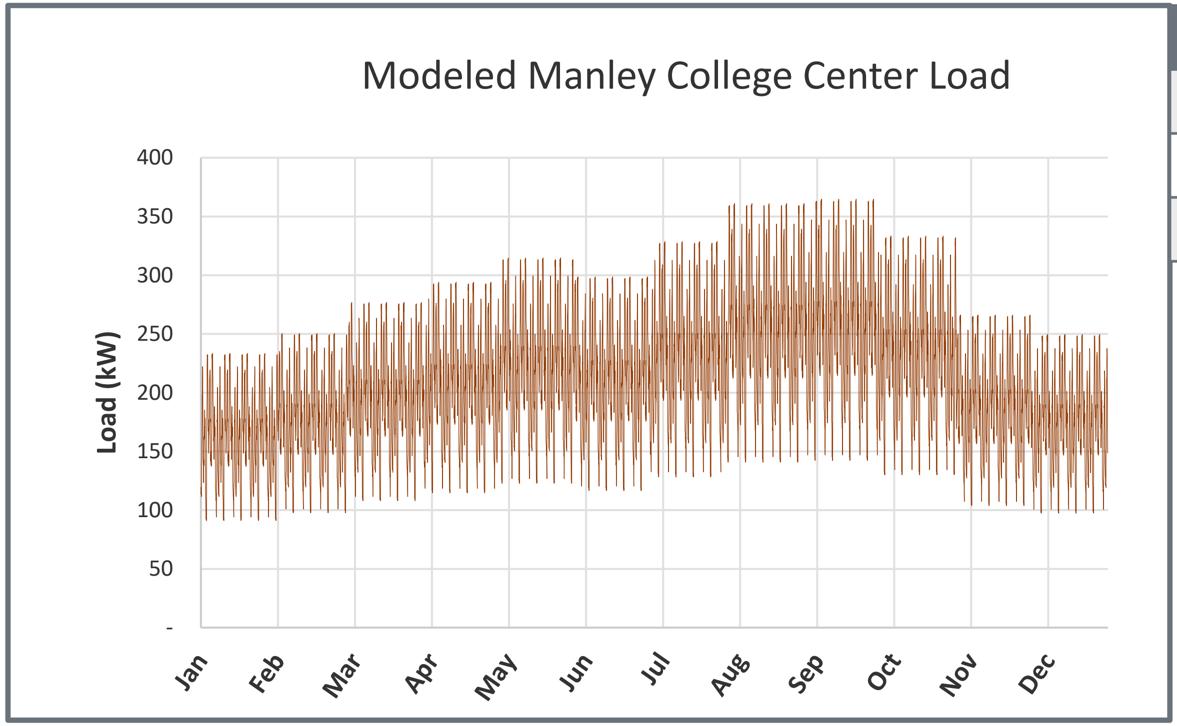


Initial Resilience: Load

NREL took the week of measured load at Manley College Center and estimated an annual load profile of the facility by:

- Understanding the monthly distribution of the entire Spelman campus's energy consumption throughout the year (top graph).
- Comparing the 2019 Spelman campus load to the 2020 (COVID) Spelman campus load (a 14.3% decrease in load was observed from 2019 to 2020)
  - Then scaling up the measured load to compensate for these COVID effects.
- Extrapolating the measured load across the year and scaling each month up/down to match the campus's annual profile.
- **This estimated load for Manley College Center (bottom graph)** was then used for outage survivability analysis (results on next slide).

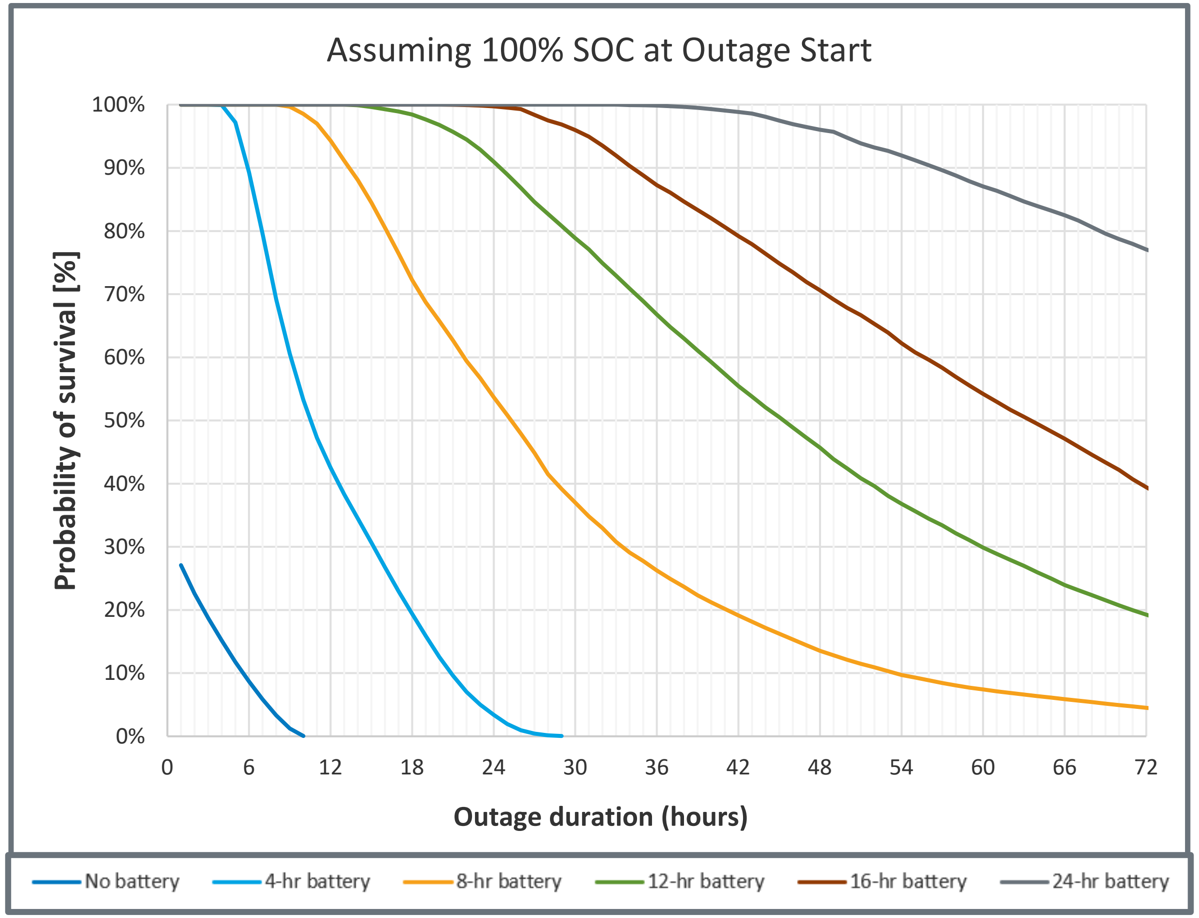




Load (kW)	
Avg.	208.7
Max.	364.8
Min.	91.1

Initial Resilience: Outage Survivability

- Results are shown for the resilience of the 918-kW PV system paired with various BESS sizes **at full charge**; the chart on the right displays selected data points from the plot on the left, showing how resilience increases with storage capacity.
- Again, outage survivability **estimates are conservative** because the analysis assumes that the Manley College Center draws its peak load at all times, whereas the building's real-world power demand is likely to fluctuate.



OUTAGE SURVIVABILITY (%) – 918-kW DC PV With Various BESS Sizes

		PV only	PV + 4-hr battery	PV + 8-hr battery	PV + 12-hr battery	PV + 16-hr battery	PV + 24-hr battery
Assuming 100% SOC at outage start:							
Outage Duration	4 hours	15%	100%	100%	100%	100%	100%
	12 hours	0%	43%	94%	100%	100%	100%
	24 hours	0%	3%	54%	91%	100%	100%
	48 hours	0%	0%	14%	46%	71%	96%

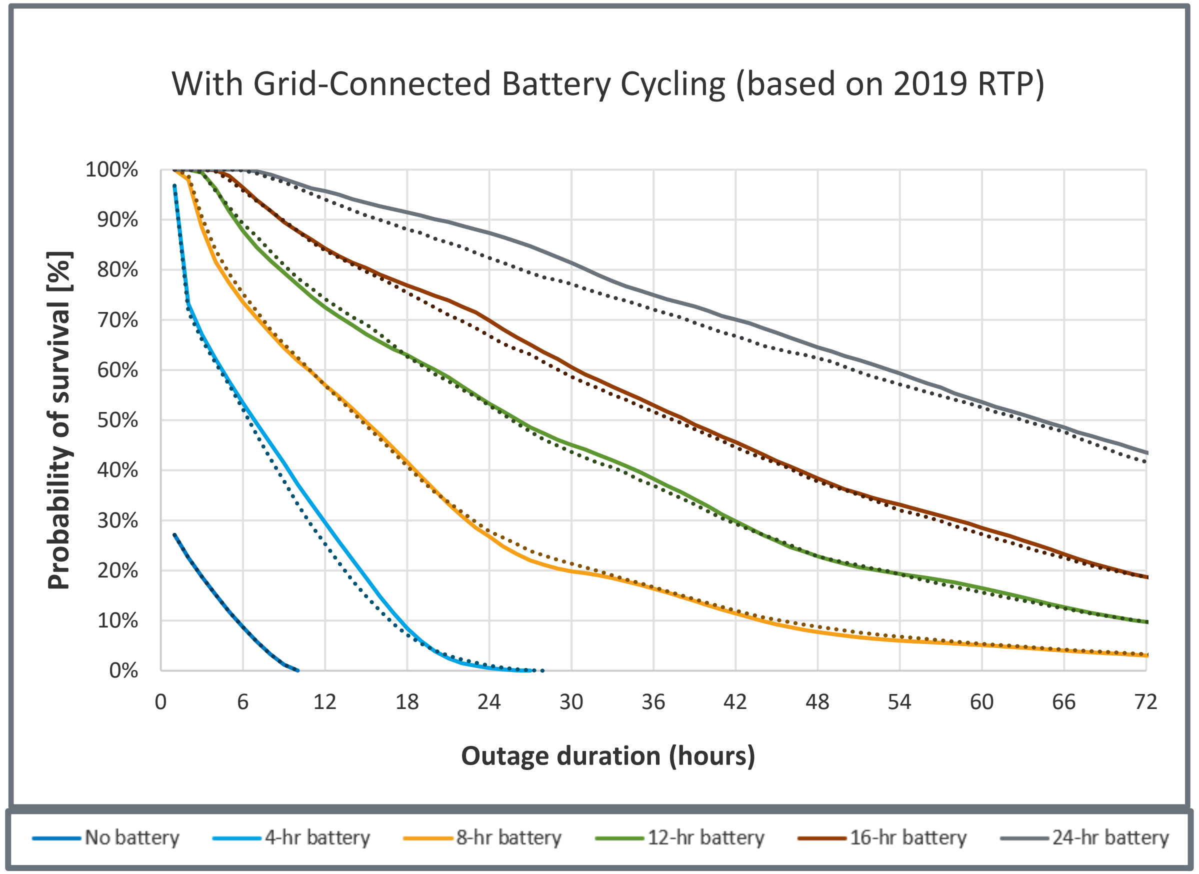
Legend:	0%–39%	40%–89%	90%–100%

Economics & Resilience Analysis

3. Advanced Resilience: Outage Survivability With Battery Dispatched to Maximize Economic Value

Advanced Resilience: Outage Survivability

- Results are shown for the resilience of the 918-kW PV system paired with various BESS sizes **when used to maximize electricity cost savings through grid-connected dispatch**; the chart and plot show the lowered resilience for a given BESS size due to this usage. Again, outage survivability **estimates are conservative** because the analysis assumes that the Manley College Center draws its peak load at all times, whereas the building's real-world power demand is likely to fluctuate.



Note: dashed lines in lower plot indicate third-party financing dispatch, which slightly differs from direct purchase due to PV-only charging of battery in the third-party scenario.

OUTAGE SURVIVABILITY (%) – 918-kW DC PV With Various BESS Sizes

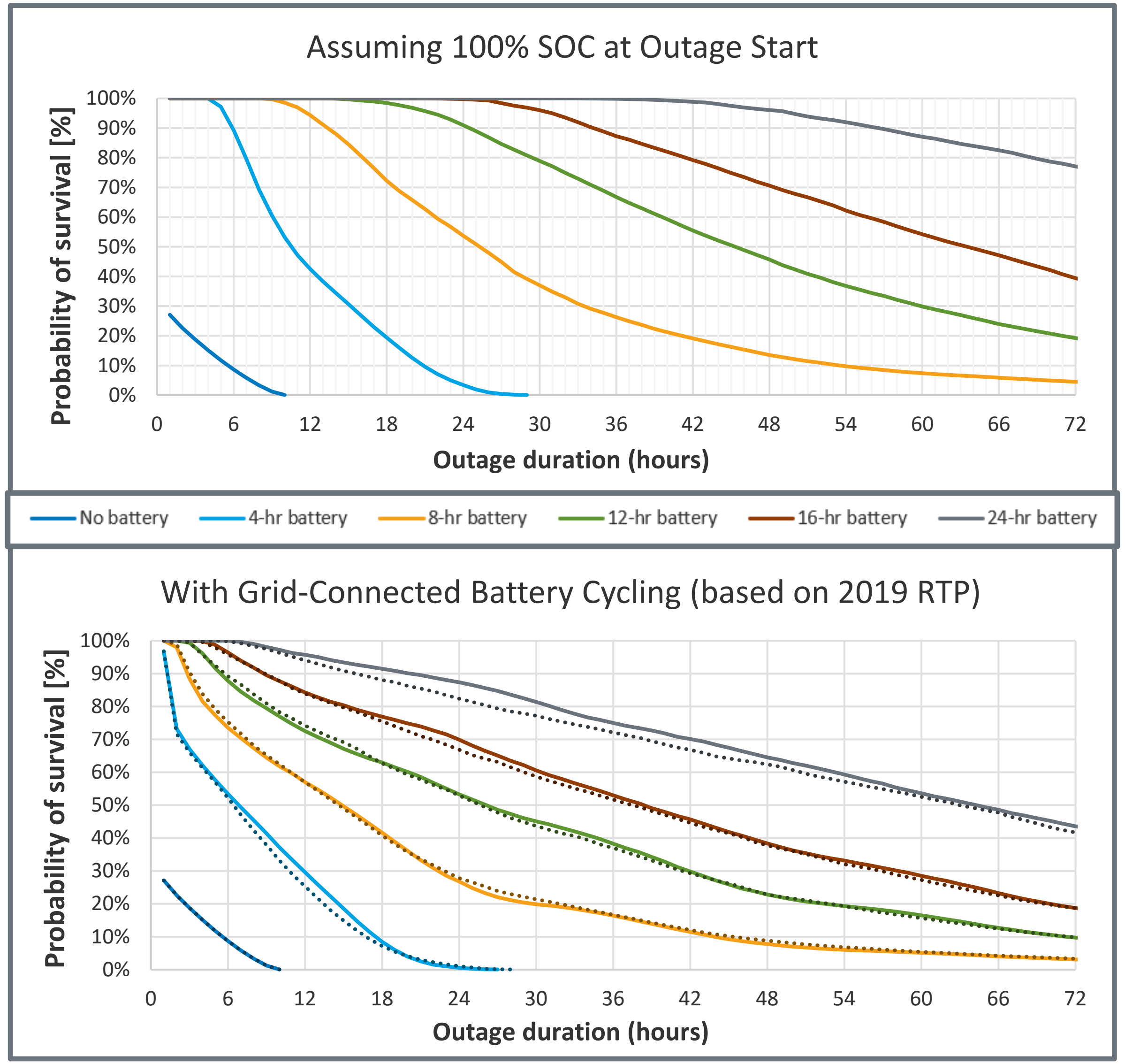
		PV only	PV + 4-hr battery	PV + 8-hr battery	PV + 12-hr battery	PV + 16-hr battery	PV + 24-hr battery
With grid-connected battery cycling (based on 2019 RTP, direct purchase dispatch):							
Outage Duration	4 hours	15%	62%	82%	96%	100%	100%
	12 hours	0%	30%	57%	73%	85%	96%
	24 hours	0%	1%	27%	54%	71%	88%
	48 hours	0%	0%	8%	23%	39%	66%

Legend:	0%–39%	40%–89%	90%–100%

Economics & Resilience Analysis

4. Comparison and Selection

Comparison and Selection: Outage Survivability



Note: dashed lines in lower plot indicate third-party financing dispatch, which slightly differs from direct purchase due to PV-only charging of battery in the third-party scenario.

OUTAGE SURVIVABILITY (%) – 918-kW DC PV With Various BESS Sizes

		PV only	PV + 4-hr battery	PV + 8-hr battery	PV + 12-hr battery	PV + 16-hr battery	PV + 24-hr battery
Assuming 100% SOC at outage start:							
Outage Duration	4 hours	15%	100%	100%	100%	100%	100%
	12 hours	0%	43%	94%	100%	100%	100%
	24 hours	0%	3%	54%	91%	100%	100%
	48 hours	0%	0%	14%	46%	71%	96%
With grid-connected battery cycling (based on 2019 RTP, direct purchase dispatch):							
Outage Duration	4 hours	15%	62%	82%	96%	100%	100%
	12 hours	0%	30%	57%	73%	85%	96%
	24 hours	0%	1%	27%	54%	71%	88%
	48 hours	0%	0%	8%	23%	39%	66%

Legend: 0%–39% | 40%–89% | 90%–100%

Comparison and Selection : Results Summary

Key Takeaways:

- The NPV can be considered the “cost of resilience” for each scenario.
- The “RTP savings from battery” can be considered the “value of battery operations during non-outage conditions.”

- All evaluated BESS sizes lead to less favorable NPVs of the overall system, with larger batteries achieving progressively smaller marginal cost savings.
  - RTP savings recoup a maximum of ~44% of modeled BESS capital and replacement costs (based on 2019 RTP).
  - Much lower cost recovery applies to larger BESS sizes and 2020 RTP rates.

- Allowing the BESS to provide grid-connected RTP savings reduces the life cycle cost of the system and thus increases the NPV, but this cycling also reduces the system’s resilience to grid outages, as indicated by the associated decrease in outage survivability .
  - Depending on the Breaking Barriers team’s resilience goals, a *smaller* BESS that is <u>*not*</u> used for grid-connected RTP savings may be more cost-effective than a *larger* BESS that <u>*is*</u> used for grid-connected RTP savings.
  - Choosing not to use the BESS for grid-connected RTP savings may also extend battery life (not modeled).

Comparison and Selection: Results Summary

Based on these results provided by NREL,
the Breaking Barriers team selected
direct purchase ownership of a 12-hr BESS,
to be used only in the case of grid outage

(see highlighted area of next slide)

Comparison and Selection: Results Summary

This table compares the economics and outage survivability of battery systems maintained at 100% SOC to those of battery systems regularly discharged to maximize electricity cost savings, displaying tradeoffs between NPV and outage survivability for a given BESS size.

System chosen by Breaking Barriers team

COMBINED ECONOMIC & RESILIENCE RESULTS			PV only	PV + 4-hr battery	PV + 8-hr battery	PV + 12-hr battery	PV + 16-hr battery	PV + 24-hr battery
If battery is not used for RTP savings and is at 100% SOC at outage start:								
Outage duration		**4 hours**	15%	100%	100%	100%	100%	100%
		12 hours	0%	43%	94%	100%	100%	100%
		24 hours	0%	3%	54%	91%	100%	100%
		48 hours	0%	0%	14%	46%	71%	96%
NPV (relative to base case) ($M)	**Direct purchase**	**With 2019 RTP**	-$2.08M	-$3.39M	-$4.26M	-$5.13M	-$6.00M	-$7.73M
		With 2020 RTP	-$2.69M	-$4.00M	-$4.87M	-$5.74M	-$6.61M	-$8.34M
	Third-party financing	**With 2019 RTP**	-$2.17M	-$3.50M	-$4.39M	-$5.28M	-$6.16M	-$7.94M
		With 2020 RTP	-$2.78M	-$4.11M	-$5.00M	-$5.89M	-$6.77M	-$8.55M
With grid-connected battery cycling (based on 2019 RTP, direct purchase dispatch):								
Outage duration		**4 hours**	15%	62%	82%	96%	100%	100%
		12 hours	0%	30%	57%	73%	85%	96%
		24 hours	0%	1%	27%	54%	71%	88%
		48 hours	0%	0%	8%	23%	39%	66%
NPV (relative to base case) ($M)	**Direct purchase**	**With 2019 RTP**	-$2.08M	-$2.82M	-$3.47M	-$4.29M	-$5.15M	-$6.88M
		With 2020 RTP	-$2.69M	-$3.79M	-$4.58M	-$5.42M	-$6.28M	-$8.01M
	Third-party financing	**With 2019 RTP**	-$2.17M	-$2.98M	-$3.73M	-$4.59M	-$5.46M	-$7.22M
		With 2020 RTP	-$2.78M	-$3.93M	-$4.77M	-$5.64M	-$6.53M	-$8.29M

Comparison and Selection: Results Summary

Notes:

- The Manley College Center load may be able to be reduced from the modeled load to extend the resilience benefits of the overall system.
  - **This load reduction may be accomplished:**
    - **Through normal operational variation**
      (e.g., chilling equipment running periodically instead of continuously)
    - **Or through energy conservation efforts during an outage**
      (e.g., disconnecting nonessential equipment).
  - For any given BESS size and outage duration, this load reduction would result in a higher probability of the system surviving the outage.

Additional costs of microgrid integration and electrical interconnection to Spelman's campus are described in the next section.

2. Microgrid Interconnection Analysis

Microgrid Interconnection Analysis: Key Considerations

- To increase resilience at Spelman College's Manley College Center, secure electrical interconnections must be established to allow the PV + BESS systems to provide power during an outage.

- Without proper electrical isolation, equipment, and monitoring, the resilient energy system could energize unintended power lines during an outage, leading to safety hazards for utility repair staff.

- NREL's experience with microgrid design assistance at military installations and in other settings was instrumental to articulating potential interconnection approaches that could deliver resilient power at Manley College Center while conforming with Georgia Power's requirements for electrical isolation ("islanding") during a grid outage.

- NREL developed estimates for four potential courses of action to electrically interconnect the resilient energy system to Manley College Center.

- These results are based on rule-of-thumb cost estimates. Reviews of the site conditions, detailed engineering plans, and detailed discussion with Georgia Power are needed before investment decisions and specific courses of action are determined.

Microgrid Interconnection Analysis: Steps

The microgrid interconnection analysis presented in these slides identifies and evaluates various electrical interconnection schemes with the Spelman College electrical distribution system by addressing the following steps:

1. **Interconnection Options:** Identify conceptual, electrically viable potential PV/BESS interconnection configurations

2. **Rough Order-of-Magnitude (ROM) Cost Estimates:** Identify conceptual ROM cost estimates for needed major components (beyond PV panels and battery banks) of the microgrid/ resilience-enhancing energy system

3. **Potential Capacity for Future Growth:** Describe the potential for future resilient PV additions enabled by each of the conceptual PV/BESS interconnection configurations

4. **Comparison and Selection:** Using this analysis, allow the Breaking Barriers team to make an informed recommendation for the interconnection of the campus resilience center.

Microgrid Interconnection Analysis

1. Interconnection Options
2. Rough Order of Magnitude (ROM) Cost Estimates
3. Potential Capacity for Future Growth
4. Comparison and Selection

Microgrid Interconnection Analysis

1. Interconnection Options

Interconnection Options: Key Considerations

- Spelman has 2.4kV (*older*) and 19.8kV (*newer*) electrical distribution systems
  - Manley College Center is currently connected at 2.4kV
  - 2.4kV connections have greater risk of the system's solar power exceeding safe capacity limits
  - Manley College Center's service may be upgraded to 19.8kV in the course of normal campus maintenance.

- To island the system and provide resilience, electrical/microgrid controls are needed to, in order:
  1. Disconnect from Morehouse nominal PV/BESS interconnection (2.4kV)
  2. Disconnect from Spelman's Georgia Power (GPC) service (both North and South) (19.8kV)
  3. Configure Spelman electrical distribution for island-mode operation
     a. Open/close desired switches for microgrid sectionalization
     b. Switch controls may be automated (adds cost) or manual (adds time to open/close)
  4. Verify GPC disconnect and Spelman sectionalization configuration
  5. Form Spelman microgrid or direct service connection to Manley College Center.

Interconnection Options

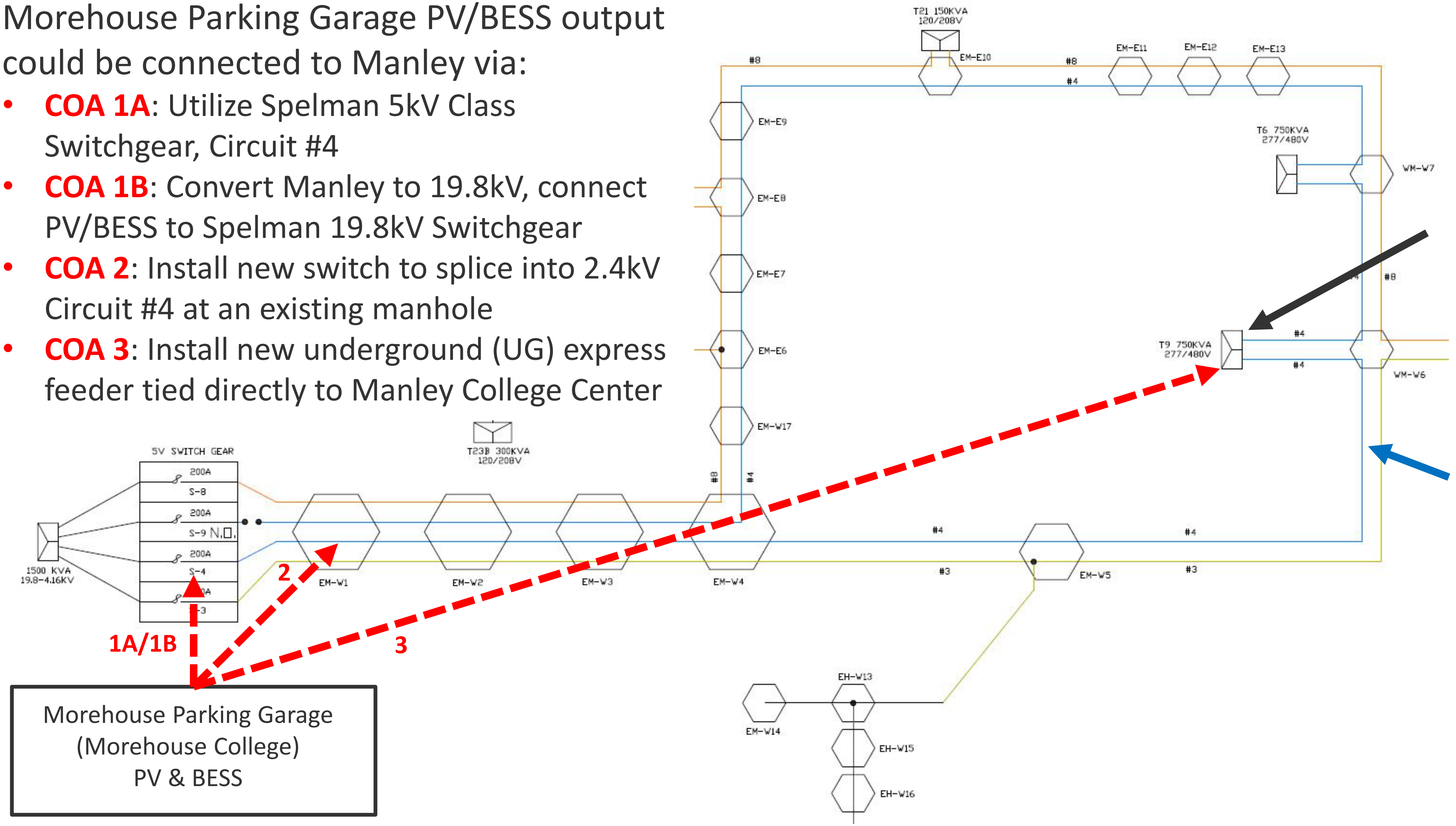
NREL identified the following **Interconnection Potential Courses of Action (COAs):**

- COA 1A: Connect PV/BESS output to existing 2.4kV circuit at switchgear (forms microgrid).
- COA 1B: Interconnect PV/BESS output to 19.8kV circuit and move Manley College Center to 19.8kV circuit (forms microgrid).
- COA 2: Connect PV/BESS output to existing 2.4kV circuit at manhole (forms microgrid).
- COA 3: Directly connect PV/BESS output to Manley College Center via an "express" circuit (forms direct service connection).

Interconnection Options

Morehouse Parking Garage PV/BESS output could be connected to Manley via:

- **COA 1A**: Utilize Spelman 5kV Class Switchgear, Circuit #4
- **COA 1B**: Convert Manley to 19.8kV, connect PV/BESS to Spelman 19.8kV Switchgear
- **COA 2**: Install new switch to splice into 2.4kV Circuit #4 at an existing manhole
- **COA 3**: Install new underground (UG) express feeder tied directly to Manley College Center



Microgrid Interconnection Analysis

2. Rough Order of Magnitude (ROM) Cost Estimates
3. Potential Capacity for Future Growth

ROM Cost Estimates: Range

- These Rough Order of Magnitude (ROM) cost estimates correspond to the Association for the Advancement of Cost Engineering International's (AACEI's) Estimate Class 5

- Class 5 estimates are used for concept screening and can include capacity factor, parametric model, engineering judgment, and/or analogy methodologies

- Once costs are estimated, Class 5 protocols prescribe that the associated range of costs be between -30% and +65% of the estimate

- Beyond hardware/installation costs, the following cost factors were included:
    - Area cost factor (ACF) for Atlanta: 92% (of subtotal)
    - Contingency cost: 20.0%
    - Overhead cost: 5.7%
    - Design cost: 6.0%.

ROM Cost Estimates: COA 1A

- COA 1A: **PV/BESS Interconnection at Spelman 2.4kV Switchgear**
  - This course of action interconnects at the relatively low 2.4kV, and so provides limited future growth potential in the case that the campuses add more PV capacity to the microgrid in the future.
  - If Spelman were to, through the normal course of campus maintenance, upgrade Manley College Center's electrical service to 19.8kV, this course of action would require additional upgrade costs for the PV + BESS system to be compatible with this upgrade.
  - This COA has the second-lowest cost requirement of the four COAs.

- Estimated COA 1A Resilience ROM Cost: **$1.2M–$2.8M** ($1.7M) in FY22$
  - Assumes:
    - Modification of existing Spelman 2.4kV switchgear, new supervisory control and data acquisition (SCADA), microgrid control system
    - Cybersecurity testing/commissioning
    - Underground line from Morehouse Parking Garage to Spelman 5kV Switchgear
    - Comm lines, meter, relays, circuit breakers.

ROM Cost Estimates: COA 1A

This table describes the itemized costs for interconnection COA 1A, leading to the total cost estimate and estimated range in accordance with AACEI Class 5 cost estimates. COA 1A has the second-lowest estimated cost of the four options.

COA 1A	Item	Unit Cost	Unit of Measure	Units	Est Cost	Notes/Details	Reference
Modify Spelman 5kV Switchgear	Modify existing Spelman 5kV Switchgear for integration of PV/BESS	$120,272	per unit	1	$120,272	Assumes modification of existing 5kV switchgear to include SCADA/Gen controller comm (probably high)	MCAS Pen/Engineering Judgment
SCADA	Supervisory control and data acquisition (SCADA)	$382.10	per kW	900	$343,887	Assume new or modify existing Morehouse and Spelman SCADA	OEI FY19 Cost Guide
Microgrid Controller	Low complexity microgrid controller	$265,225	EA	1	$265,225	Engineering judgment (might be low given two distribution system connections)	Engineering Judgment
Cybersecurity	Cybersecurity	$212,180	EA	1	$212,180	Engineering judgement, assuming cybersecurity commissioning/testing	Engineering Judgment
Underground (UG) Express Line	PV/BESS UG feeder to Spelman 5kV switch	$403.14	LF	200	$80,628	Assuming 1000MCM wire UG per ft w/trench per SDG&E Unit Cost minus 25% for ACF	SDG&E 2020 Unit Cost
Other Percentages	Communication line/fiber optic cable, meter, relays (3), circuit breakers (3)	$320,962	LS	1	$320,962	Assumes no trenching cost for fiber optic/cable runs; encrypted OTA possible?	Engineering Judgment

Subtotal		$1,343,154	
Area Cost Factor	92%	-$107,452	
Contingency	20.0%	$268,631	
Total Contract Cost		$1,504,333	
SIOH	5.7%	$85,747	
Design Build/Design Cost	6.0%	$90,260	
Total Cost Estimate		**$1,680,340**	

AACEI Class 5	Cost Estimate (escalated to FY22$)	
Low	**Estimate**	**High**
$1,180,000	**$1,680,340**	$2,770,000

ROM Cost Estimates: COA 1B

- **COA 1B: PV/BESS Interconnection at Spelman 19.8kV Switchgear**
  – This course of action allows for much greater energy capacity per circuit, and so provides the greatest future growth potential in case the campuses want to add more PV capacity to the microgrid in the future.
  – If Spelman were to, through the normal course of campus maintenance, upgrade Manley College Center's electrical service to 19.8kV, this course of action would also be immediately compatible with that change.
  – This COA has the highest cost requirement of the four COAs.
- Estimated COA 1B Resilience ROM Cost: **$1.8M–$4.2M** ($2.5M) in FY22$
  – Assumes:
    - Moving Manley College Center electric service from 2.4kV to 19.8kV
    - Modification of existing Spelman 19.8kV switchgear, new SCADA, microgrid control system
    - Cybersecurity testing/commissioning
    - Underground (UG) line from Morehouse Parking Garage to 19.8kV Switchgear
    - 1500kVA 2.4kV/19.8kV transformer, new 19.8kV padmount switch, new UG line from EM-W5 to Manley College Center
    - Comm lines, meter, relays, circuit breakers.

ROM Cost Estimates: COA 1B

This table describes the itemized costs for interconnection COA 1B, leading to the total cost estimate and estimated range in accordance with AACEI Class 5 cost estimates. COA 1B has the highest estimated cost of the four options.

COA 1B	Item	Unit Cost	Unit of Measure	Units	Est Cost	Notes / Details	Reference
Modify Spelman 25kV Switchgear	Modify existing Spelman 25kV Switchgear for integration of PV/BESS	$120,272	per unit	1	$120,272	Assumes modification of existing 20kV switchgear to include SCADA/Gen controller comm (probably high)	MCAS Pen/Engineering Judgment
Step-up Transformer	1500kVA 2.4kV/19.8kV step-up transformer	$73.13	per kVA	1,500	$109,695	Assuming custom manufactured xsfrmr, very conservative (high)	OEI FY19 Cost Guide
New UG Ductbank	New UG ductbank from EM-W5 to new 19.8kV T9 transformer	$403.14	LF	400	$161,257	Assuming 1000MCM UG per ft w/trench per SDG&E unit cost minus 25% for ACF	SDG&E 2020 Unit Cost
SCADA	Supervisory control and data acquisition (SCADA)	$382.10	per kW	900	$343,887	Assume new or modify existing Morehouse and Spelman SCADA	OEI FY19 Cost Guide
20kV Class Isolation Switch	New 20kV padmount SCADA switch at EM-W5 to island remaining 19.8kV from Manley/T9 transformer	$203,693	EA	1	$203,693	Assuming new padmount 20kV class SCADA switch at EM-W5	SDG&E 2020 Unit Cost
Microgrid Controller	Low complexity microgrid controller	$265,225	EA	1	$265,225	Engineering judgment (might be low given two distribution system connections)	Engineering Judgment
Cybersecurity	Cybersecurity	$212,180	EA	1	$212,180	Engineering judgment, assuming cybersecurity commissioning/testing	Engineering Judgment
UG Express Line	PV/BESS UG feeder to Spelman 19.8kV switch	$403.14	LF	200	$80,628	Assuming 1000MCM wire UG per ft w/trench per SDG&E unit cost minus 25% for ACF	SDG&E 2020 Unit Cost
New Manley Center 19.8kV/480V Transformer	New 19.8kV Transformer with re-connection	$113,300.00	EA	1	$113,300	New 19.8kV/480V 750kVA transformer with installation	SDG&E 2020 Unit Cost
New 19.8kV Connection	Assuming new trench/conductor to tap nearby 19.8kV ductbank	$403.14	LF	200	$80,628	SDG&E Rule 21 CY19 cost; unknown how much road cuts add	SDG&E 2020 Unit Cost
Other Percentages	Communication line/fiber optic cable, meter, relays (3), circuit breakers (3)	$320,962	LS	1	$320,962	Assumes no trenching cost for fiber optic/cable runs; encrypted OTA possible?	Engineering Judgment

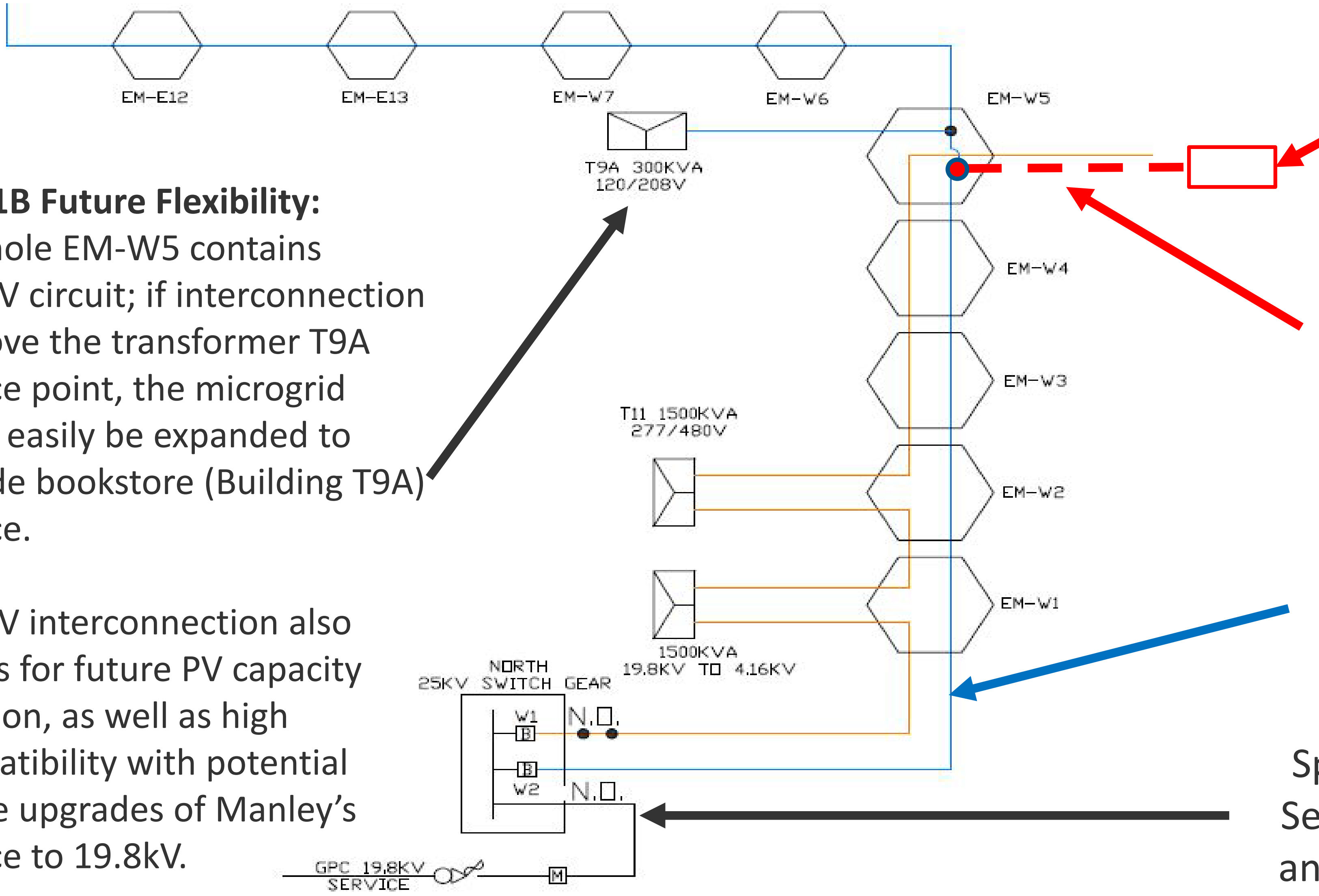
Subtotal		$2,011,727	
Area Cost Factor	92%	-$160,938	
Contingency	20.0%	$402,345	
Total Contract Cost		$2,253,135	
SIOH	5.7%	$128,429	
Design Build/Design Cost	6.0%	$135,188	
Total Cost Estimate		**$2,516,752**	

AACEI Class 5 Cost Estimate (escalated to FY22$)		
Low	**Estimate**	**High**
$1,760,000	**$2,516,752**	$4,150,000

Potential Capacity for Future Growth: COA 1B

COA 1B Future Flexibility: Manhole EM-W5 contains 19.8kV circuit; if interconnection is above the transformer T9A service point, the microgrid could easily be expanded to include bookstore (Building T9A) service.

19.8kV interconnection also allows for future PV capacity addition, as well as high compatibility with potential future upgrades of Manley's service to 19.8kV.



New Manley College Center Transformer T-9, 750kVA, 19.8kV–480V/277V

New 19.8kV underground line from EM-W5 to new 19.8kV T-9 transformer, approx. 550'

Spelman 19.8kV W2 Circuit (in blue)

Spelman GPC North Service Point: 19.8kV and 2.4kV switchgear

ROM Cost Estimates: COA 2

- **COA 2: PV/BESS Interconnection at Spelman 2.4kV Circuit at Manhole EM-W1**
  - Similar to COA 1A, this course of action interconnects at the relatively low 2.4kV, and so provides limited future growth potential in the case that the campuses want to add more PV capacity to the microgrid in the future.
  - If Spelman were to, through the normal course of campus maintenance, upgrade Manley College Center's electrical service to 19.8kV, this course of action would require additional upgrade costs for the PV + BESS system to be compatible with this upgrade.
  - This COA has the lowest cost requirement of the four COAs.

- Estimated COA 2 Resilience ROM Cost: **$0.9M–$2.2M** ($1.3M) in FY22$
  - Assumes:
    - **2.4kV circuit #4 at EM-W1 can be spliced**
    - New 5kV class padmount SCADA switch at EM-W1
    - Microgrid control system
    - Cybersecurity testing/commissioning
    - UG line from Morehouse Parking Garage to EM-W1
    - Comm lines, meter, relays, circuit breakers.

ROM Cost Estimates: COA 2

This table describes the itemized costs for interconnection COA 2, leading to the total cost estimate and estimated range in accordance with AACEI Class 5 cost estimates. COA 2 has the lowest estimated cost of the four options.

COA 2	Item	Unit Cost	Unit of Measure	Units	Est Cost	Notes / Details	Reference
5kV Class Isolation Switch	New 5kV padmount SCADA switch at EM-W1 to operate in island mode	$152,770	EA	1	$152,770	Assuming new padmount 5kV class SCADA switch at EM-W1	SDG&E 2020 Unit Cost
SCADA	Supervisory control and data acquisition (SCADA)	$382.10	per kW	900	$343,887	Assume new SCADA required	OEI FY19 Cost Guide
Cybersecurity	Cybersecurity	$212,180	EA	1	$212,180	Engineering judgment, assuming cybersecurity commissioning/testing	Engineering Judgment
Splice Into Existing 2.4kV Circuit #4	Splice into UG 2.4kV circuit #4 at EM-W1	$9,834.54	EA	1	$9,835	PG&E Rule 21 CY19 cost; unknown how much road cuts add	PG&E 2020 Unit Cost
Other Percentages	Communication line/fiber optic cable, meter, relays (3), circuit breakers (3)	$320,962	LS	1	$320,962	Assumes no trenching cost for fiber optic/cable runs; encrypted OTA possible?	Engineering Judgment

Subtotal		$1,039,633	
Area Cost Factor	92%	-$83,171	
Contingency	20.0%	$207,927	
Total Contract Cost		$1,164,389	
SIOH	5.7%	$66,370	
Design Build/Design Cost	6.0%	$69,863	
Total Cost Estimate		**$1,300,623**	

AACEI Class 5 Cost Estimate (escalated to FY22$)		
Low	**Estimate**	**High**
$910,000	**$1,300,623**	$2,150,000

ROM Cost Estimates: COA 3

- **COA 3: Express Underground (UG) Feeder from PV/BESS to Manley College Center**
  - This course of action bypasses existing circuits and directly connects the PV + BESS system to Manley at the relatively low 2.4kV, and so provides no future growth potential in the case that the campuses want to add more PV capacity to the microgrid in the future.
  - If Spelman were to, through the normal course of campus maintenance, upgrade Manley College Center's electrical service to 19.8kV, this course of action would require additional upgrade costs for the PV + BESS system to be compatible with this upgrade.
  - This COA has the second-highest cost requirement of the four COAs due to conservative estimates of right-of-way costs.
- Estimated COA 3 Resilience ROM Cost: **$1.3M–$3.0M** ($1.8M) in FY22$
  - Assumes:
    - **UG right-of-way is available and does not include inordinate road cut costs**
    - Microgrid control system
    - Cybersecurity testing/commissioning,
    - New UG ductbank and line from Morehouse Parking Garage to Manley College Center (1350')
    - Service panel connection at Manley College Center
    - Comm lines, meter, relays, circuit breakers.

ROM Cost Estimates: COA 3

This table describes the itemized costs for interconnection COA 3, leading to the total cost estimate and estimated range in accordance with AACEI Class 5 cost estimates. COA 3 has the second-highest estimated cost of the four options.

COA 3	Item	Unit Cost	Unit of Measure	Units	Est Cost	Notes / Details	Reference
SCADA	Supervisory control and data acquisition (SCADA)	$382.10	per kW	900	$343,887	Assume new SCADA required	OEI FY19 Cost Guide
Cybersecurity	Cybersecurity	$212,180	EA	1	$212,180	Engineering judgement, assuming cybersecurity commissioning/testing	Engineering Judgment
New Ductbank & Conductor	New UG line - trench & install	$403.14	LF	1,350	$544,242	SDG&E Rule 21 CY19 cost; unknown how much road cuts add	SDG&E 2020 Unit Cost
Other Percentages	Communication line/fiber optic cable, meter, relays (3), circuit breakers (3), service panel connection	$370,962	LS	1	$370,962	Assumes no trenching cost for fiber optic/cable runs; encrypted OTA possible?	Engineering Judgment

Subtotal		$1,471,271	
Area Cost Factor	92%	-$117,702	
Contingency	20.0%	$294,254	
Total Contract Cost		$1,647,823	
SIOH	5.7%	$93,926	
Design Build/Design Cost	6.0%	$98,869	
Total Cost Estimate		**$1,840,619**	

AACEI Class 5 Cost Estimate (escalated to FY22$)

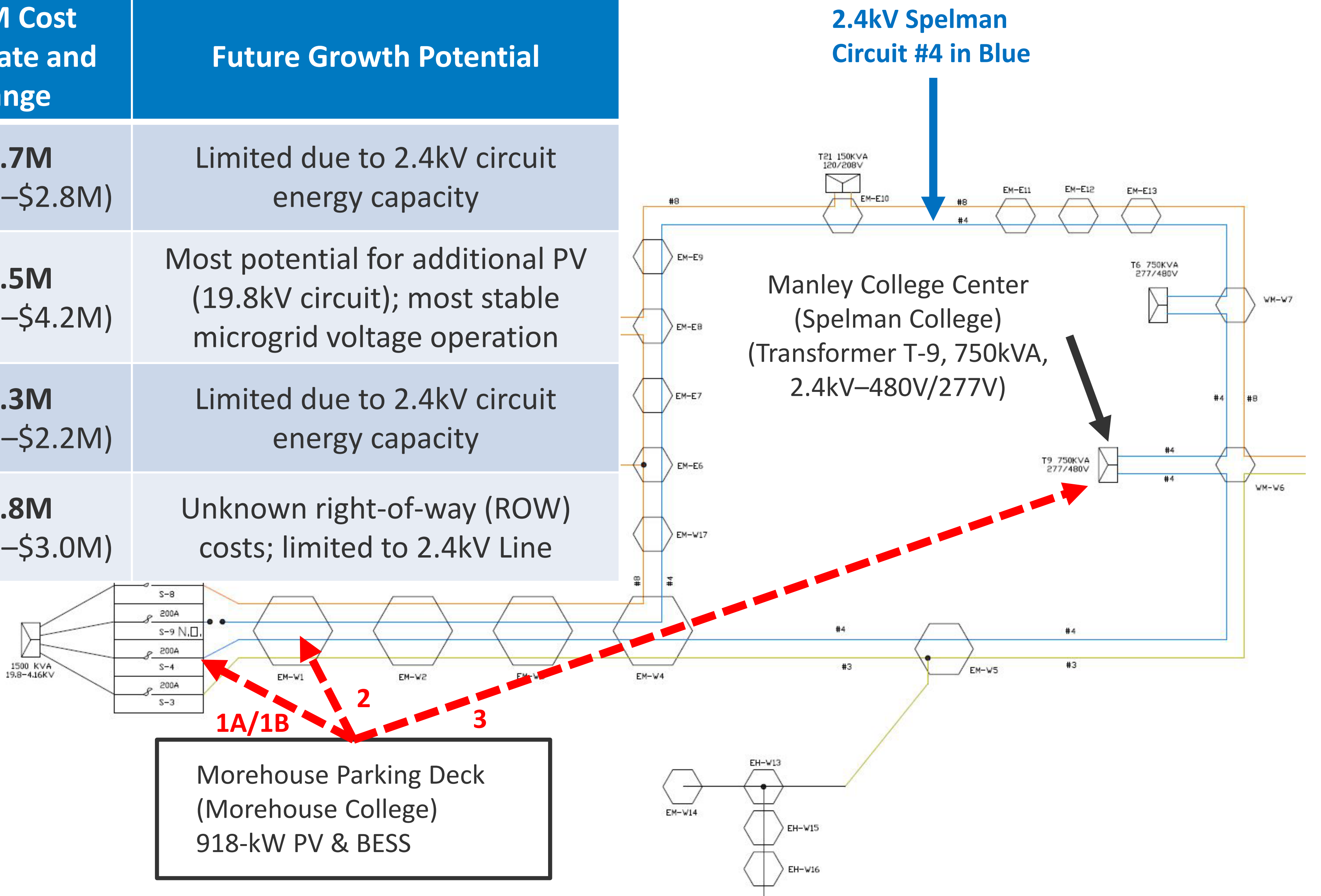
Low	**Estimate**	**High**
$1,290,000	**$1,840,619**	$3,040,000

Microgrid Interconnection Analysis

4. Comparison and Selection

Comparison and Selection: Results Summary

Spelman Interconnection Courses of Action	Interconnection Voltage	ROM Cost Estimate and Range	Future Growth Potential
COA 1A	2.4kV	**$1.7M** ($1.2M–$2.8M)	Limited due to 2.4kV circuit energy capacity
COA 1B	19.8kV	**$2.5M** ($1.8M–$4.2M)	Most potential for additional PV (19.8kV circuit); most stable microgrid voltage operation
COA 2	2.4kV	**$1.3M** ($0.9M–$2.2M)	Limited due to 2.4kV circuit energy capacity
COA 3	2.4kV	**$1.8M** ($1.3M–$3.0M)	Unknown right-of-way (ROW) costs; limited to 2.4kV Line



Comparison and Selection: Results Summary

Key Takeaways

- The four evaluated interconnection options range between \$1.3M and \$2.5M in estimated cost (\$0.9M–\$4.2M including the full uncertainty range).
    - COA 1B has the highest estimated cost, while COA 2 has the lowest.
    - COA 1B provides the most future system flexibility, while COA 3 provides the least.

Comparison and Selection: Results Summary

Key Takeaways

- Areas of uncertainty that could result in cost adjustments include:
  - Automated vs. manual controls: this analysis assumes automated controls, but costs could be lowered by installing manual controls instead. Manual controls will cause it to take longer to electrically isolate the system during an electrical outage, especially if the cause of the outage (e.g., natural disaster) also obstructs staff from accessing the controls.
  - Future Manley College Center electrical upgrades: though currently unplanned, Manley may be upgraded from 2.4kV to 19.8kV service. **This upgrade would require additional adaptation costs for every COA except COA 1B** to maintain resilience capabilities.
  - Splicing of circuit for COA 2: this analysis assumes that the 2.4kV circuit at manhole EM-W1 can be spliced. If not, COA 2 would be subject to increased costs and/or lowered electrical feasibility.
  - Underground connection for COA 3: discussions with the Breaking Barriers team did not suggest that an already-constructed path was available for the underground feeder, and this analysis assumes new ductwork is needed for the entire underground path. If existing ductwork could be leveraged, the cost of COA 3 would be reduced.

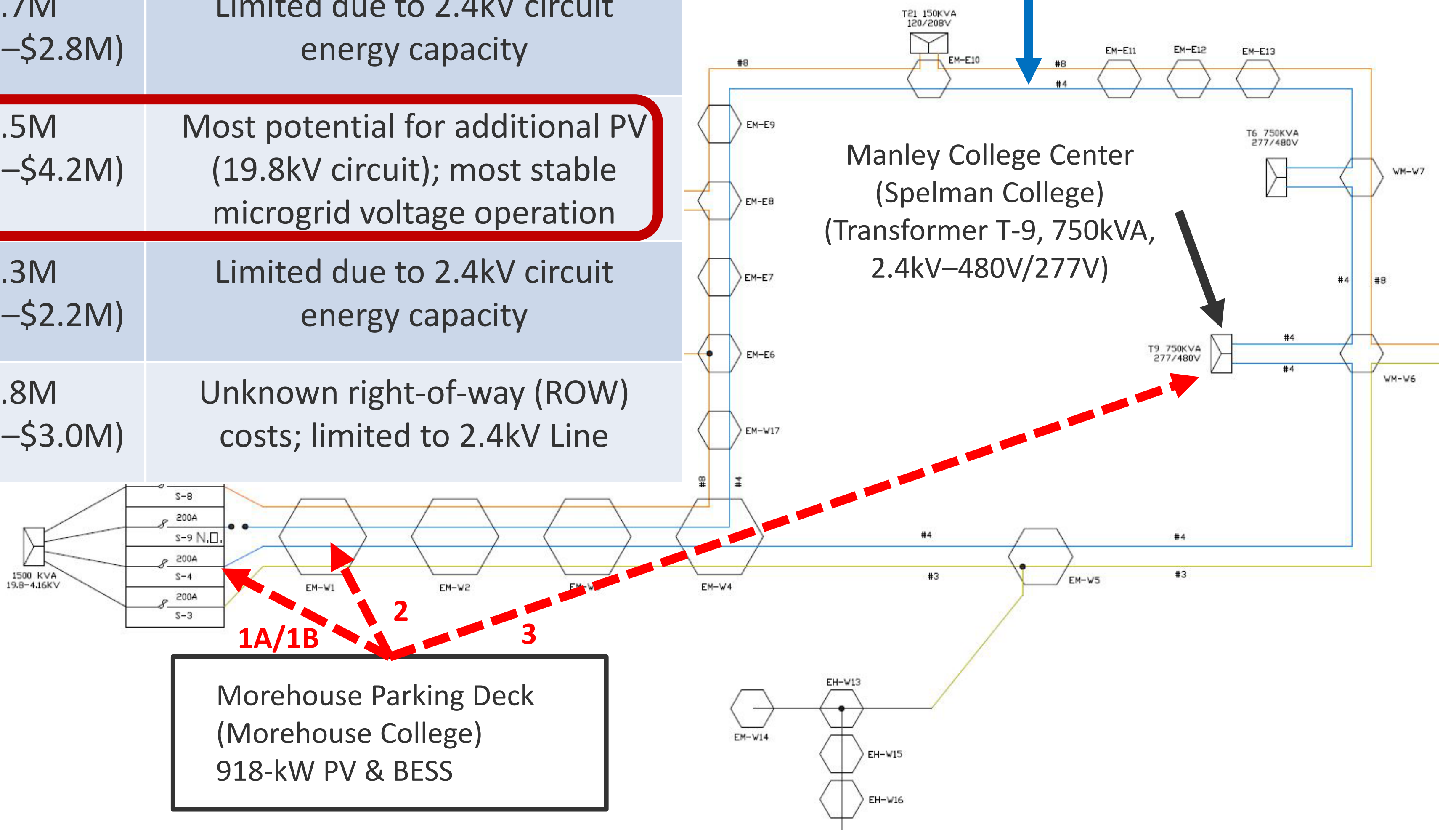
Comparison and Selection: Results Summary

Based on this analysis from NREL, the Breaking Barriers team selected COA 1B (with COA 3 as backup).

Microgrid Interconnection Analysis: Results Summary

Spelman Interconnection Courses of Action	Interconnection Voltage	ROM Cost Estimate and Range	Future Growth Potential
COA 1A	2.4kV	$1.7M ($1.2M–$2.8M)	Limited due to 2.4kV circuit energy capacity
COA 1B	19.8kV	$2.5M ($1.8M–$4.2M)	Most potential for additional PV (19.8kV circuit); most stable microgrid voltage operation
COA 2	2.4kV	$1.3M ($0.9M–$2.2M)	Limited due to 2.4kV circuit energy capacity
COA 3	2.4kV	$1.8M ($1.3M–$3.0M)	Unknown right-of-way (ROW) costs; limited to 2.4kV Line

Chosen by Breaking Barriers team



Conclusions and Outcomes

Conclusions and Outcomes

Through collaborative discussions with Breaking Barriers team members and in-house modeling expertise, **NREL estimated economic performance, grid outage survivability, and microgrid setup costs for a PV + BESS system serving Spelman's Manley College Center and Morehouse College under a variety of battery size, microgrid interconnection, ownership model, and utility price scenarios.**

The Breaking Barriers team, led by Groundswell, took the insights of these catered analyses to form recommendations and a business plan for proceeding with project development. The selected battery size and the operational and microgrid interconnection approach are shown to the right.

In parallel with the business plan, the Breaking Barriers partners proposed to seek funding for the HBCU campus resilience center/microgrid. Further, Groundswell and its organizational partners in Breaking Barriers plan to collaborate through a process of seeking bids for engineering/design services for the microgrid, with component plans for phased solar PV installation, dedicated lines and switchgear to charge the battery, and sizing and installation of the battery serving the Manley College Center.

Options Chosen by Breaking Barriers Team

COMBINED ECONOMIC & RESILIENCE RESULTS			PV + 12-hr battery
Battery is not used for RTP savings and is at 100% SOC at outage start:			
Outage duration		4 hours	100%
		12 hours	100%
		24 hours	91%
		48 hours	46%
NPV (relative to base case) ($M)	Direct purchase	With 2019 RTP	-$5.13M
		With 2020 RTP	-$5.74M

Spelman Interconnection Course of Action	Interconnection Voltage	ROM Cost Estimate and Range	Future Growth Potential
COA 1B	19.8kV	$2.5M ($1.8M–$4.2M)	Most potential for additional PV (19.8kV circuit); most stable microgrid voltage operation

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Thank you

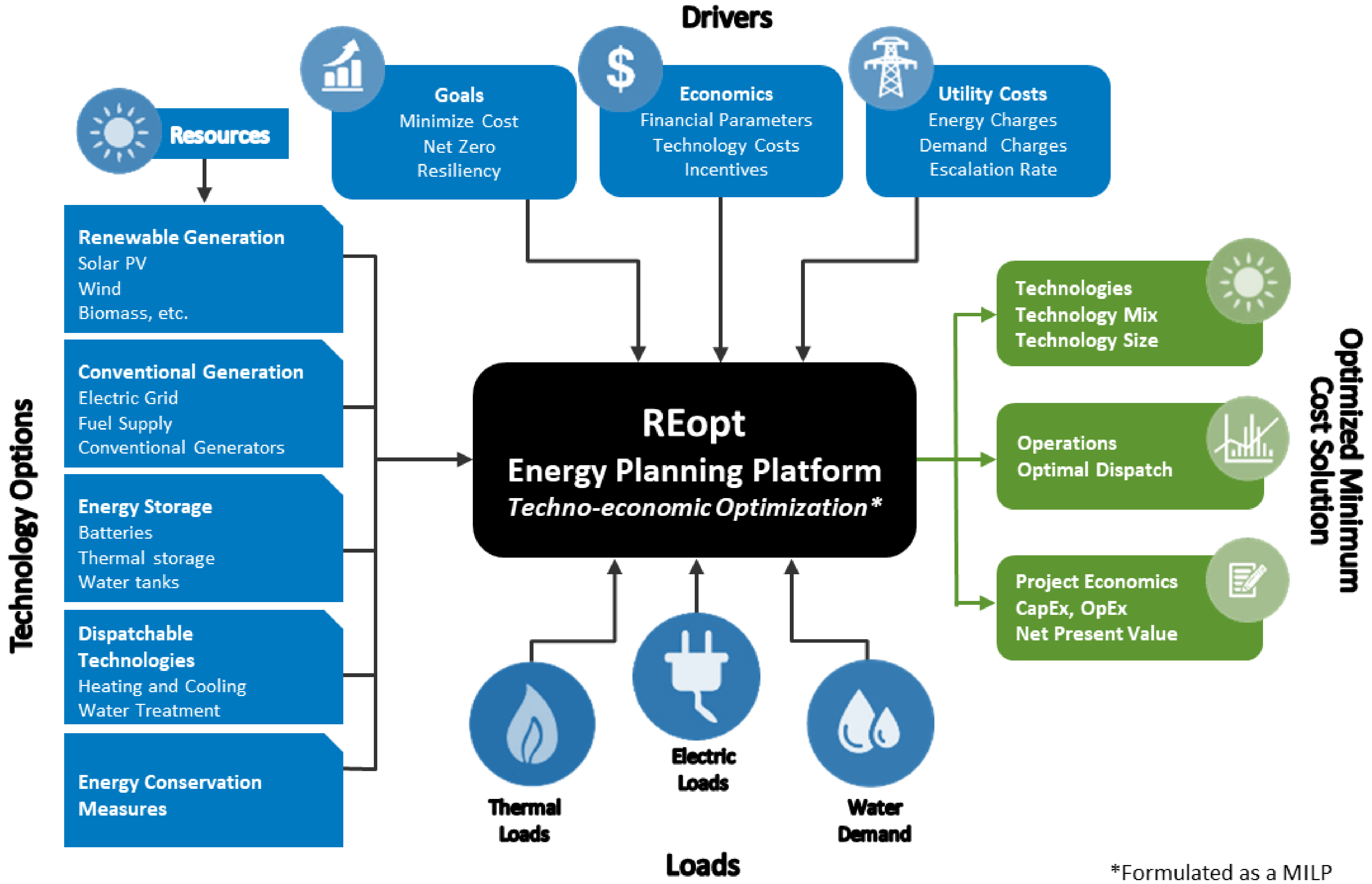
NREL/TP-7A40-81623

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Appendix:

Techno-Economic and Resiliency Analysis Data & Assumptions

REopt Inputs and Outputs



*Formulated as a MILP

Economic Modeling & Assumptions

The following assumptions were used in the REopt modeling and optimization:

- Analysis period: 25 years (battery replacement in year 10)
- Inflation rate: 2.5%/year
- Electricity cost escalation rate: 2.3%/year
- Net metering: No net metering or other compensation for grid exports (site may be able to receive some compensation if it qualifies as a QF)
- Ownership models:
  - Direct purchase by site:
    - Campus' discount rate: 5%
    - Incentives: none
    - Battery is allowed to charge from PV and/or the grid.
  - Third-party ownership:
    - Campus' discount rate: 5%
    - Developer discount rate: 8.3%
    - Incentives: 5-year MACRS with 100% bonus MACRS and 26% ITC applied to both PV and battery
    - Battery charging limited to PV only (no grid charging) to maximize tax incentives available

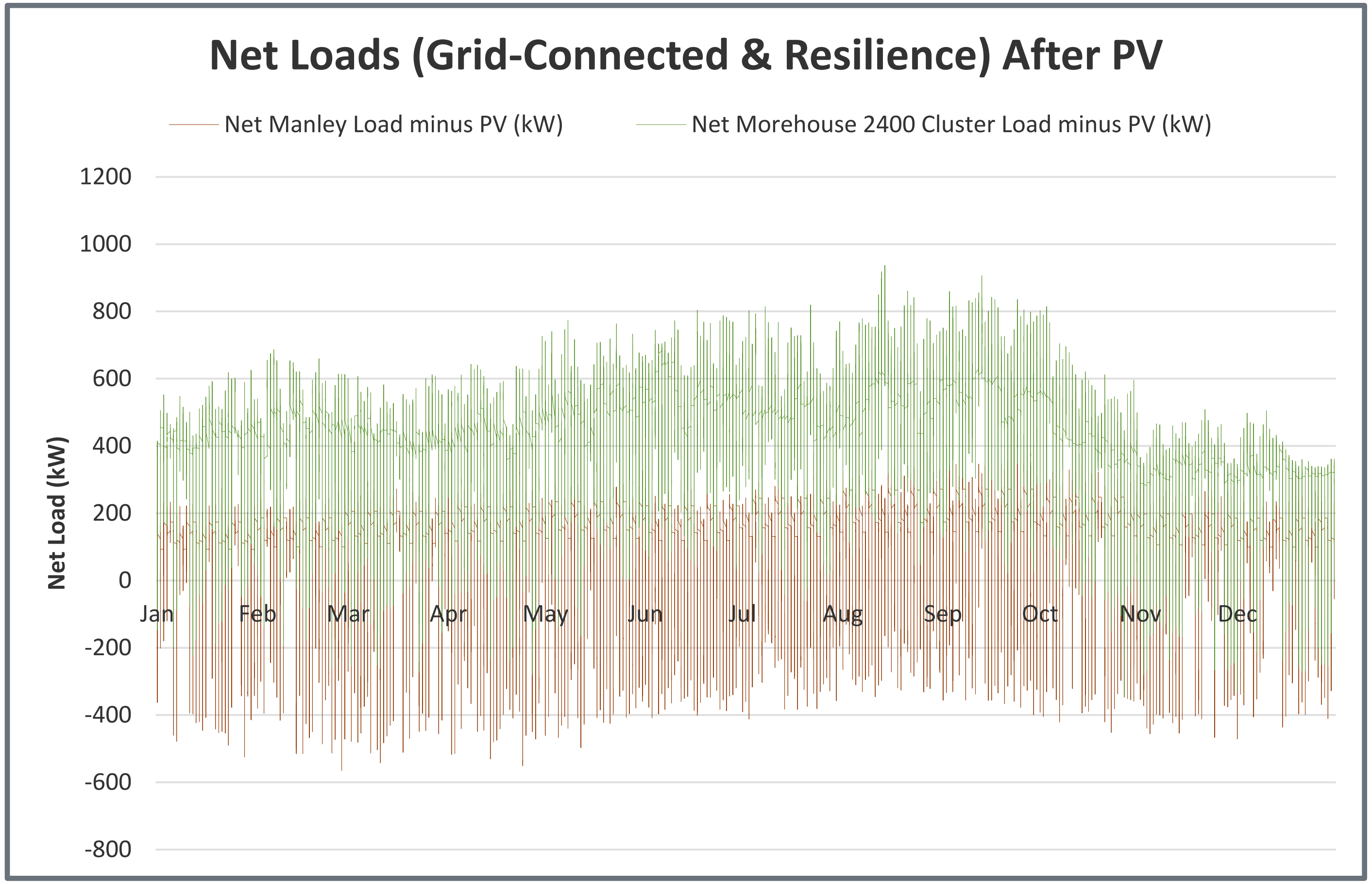
For each system evaluated, REopt calculates the minimum lifecycle costs (LCC) and net present value (NPV) of the system:

- LCC = capital costs + O&M costs + battery replacement costs + RTP costs across the 25-year analysis period
- NPV = $LCC_{BAU} - LCC_{investment}$, where BAU is the "business as usual" base case of no PV and no battery, and the "investment" case is the PV and/or battery system being evaluated in that scenario.

Net Loads Minus PV

- **Morehouse 2400 Cluster (Grid-Connected) Net Load:**
  - 47.7 MWh of excess PV generation
    - = 3.6% of annual PV generation
    - = 1.0% of annual gross load
  - *Without a battery*, excess PV generation could be exported to the grid (possibly compensated if the site qualifies as a QF) or curtailed
  - *With a battery*, excess PV generation could be stored, to be used onsite or to be exported to the grid at a later time; additionally, PV generation could be stored for use onsite at a time with higher RTP.

- **Manley College Center (Resilience) Net Load:**
  - 546.0 MWh of excess PV generation
    - = 41.6% of annual PV generation
    - = 29.9% of annual gross load
  - *Without a battery*, excess PV generation would be curtailed (and the site would require some alternative grid-forming technology, such as a generator, to supplement the PV system in case of a grid outage)
  - *With a battery*, excess PV generation could be stored to support resilience loads not covered by PV generation at a later time.

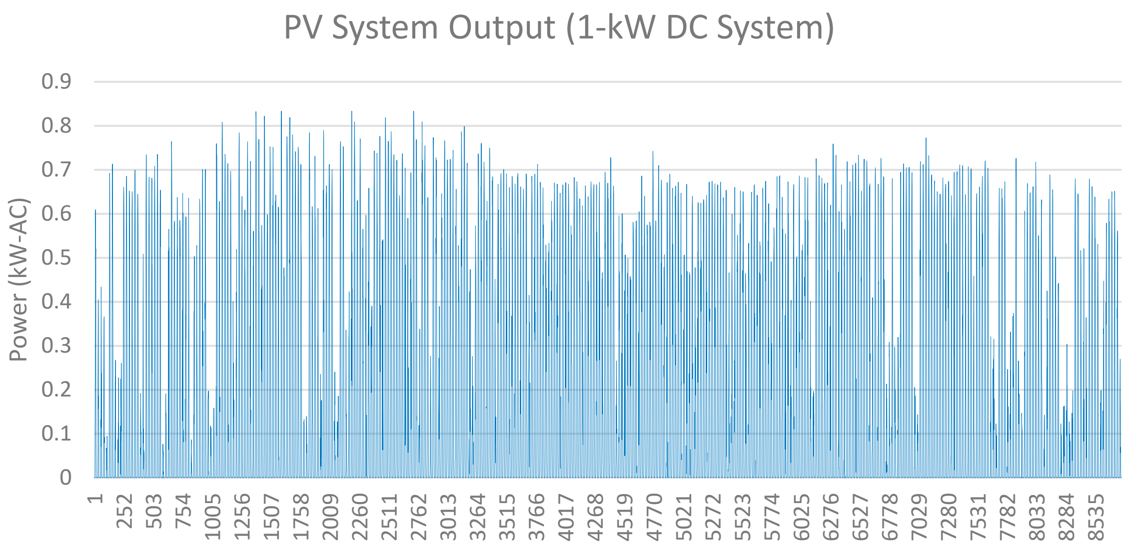


Note: net loads less than zero indicate excess PV generation.

Battery Storage Assumptions

- Battery chemistry: lithium-ion
- Battery is allowed to charge from the grid and/or PV
- Round trip (AC-AC) efficiency: 88.9%
- State of charge (SOC):
  - Minimum SOC: 20%
    - This assumption was applied to both grid-connected and resilience analyses; in reality, the site may be tempted to discharge the battery below this threshold in case of emergency, but this could result in damage to the battery
  - Initial SOC at outage start:
    - In the initial resilience analysis, the battery is only used for resilience, to be 100% charged when a grid outage occurs.
    - In the updated resilience analysis, the battery is assumed to be dispatched to maximize grid-connected cost savings. Thus, its availability for resilience may be reduced.
- Costs:
  - Capital costs: \$420/kWh + \$840/kW
  - Replacement costs (year 10): \$210/kWh + \$420/kW
- Capacities evaluated:
  - Inverter capacity (kW): sized to cover peak resilience load (rounded from actual peak resilience load of ~361 kW to 400 kW)
  - Duration (hrs) and energy capacity (kWh): given a goal of sustaining outages in the range of 4–24 hours, several battery durations were evaluated: 4, 8, 12, 16, and 24 hrs.
    - Note these energy capacities correspond to *total* capacity, including the 20% that is not available due to the minimum SOC constraint.

Generation from Solar PV

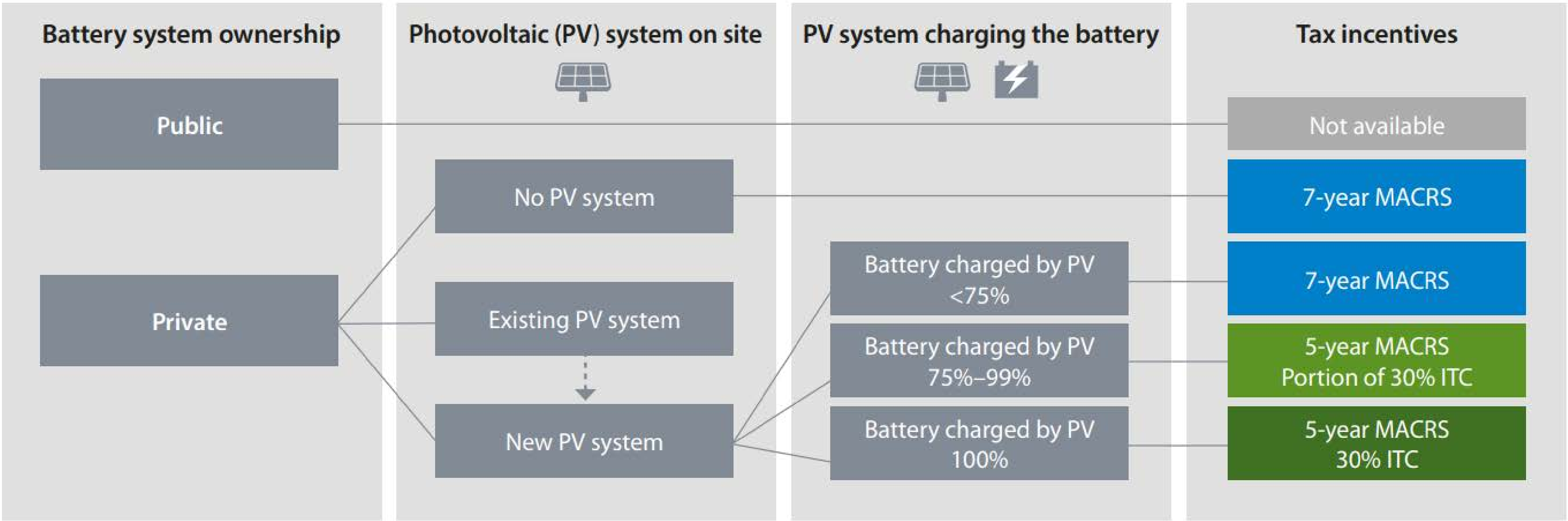


PVWatts: Hourly PV Performance Data	
Requested Location:	Atlanta, GA
Location:	Lat, Lon: 33.73, -84.38
DC System Size (kW):	1
Module Type:	Standard
Array Type:	Fixed (open rack)
Array Tilt (deg):	20
Array Azimuth (deg):	180
System Losses:	14.08
Invert Efficiency:	96
DC-to-AC Size Ratio:	1.2
Capacity Factor (%):	16.3
Annual kWh Generation per kW Capacity:	1,429

- NREL used PVWatts® to estimate the annual generation of a 1-kW DC PV system located in Atlanta, GA. This generation profile can be scaled for different system sizes.
- A 1-MW DC fixed-axis (roof-mounted) system generates approximately 1,429,000 kWh in year 1
  - 1,429,000 kWh is estimated to cover ~1.6% of AUC's total annual site load

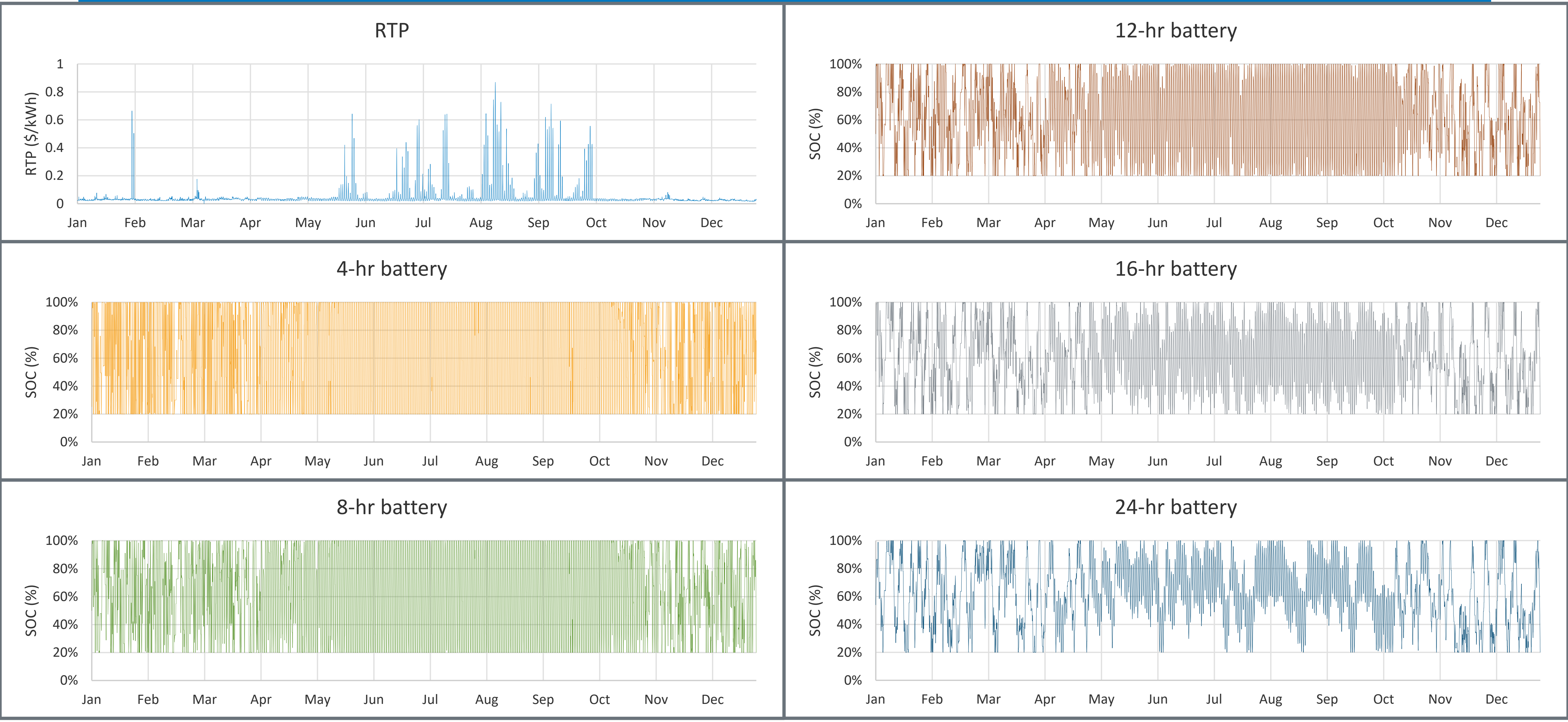
Federal Incentives for Batteries, Based on PV System

Federal Tax Incentives for Energy Storage Systems



https://www.nrel.gov/docs/fy18osti/70384.pdf

Battery SOC Timeseries (for 2019 RTP data)



Battery SOC Timeseries (for 2020 RTP data)