

FINAL REPORT

Demonstrating the Benefits of Long-Duration, Low-Cost Flow
Battery Storage in a Renewable Microgrid

ESTCP Project EW19-5312

DECEMBER 2019

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ACRONYMS AND ABBREVIATIONS

\$/kW_c Cost of critical load coverage

AC Alternating current

AESOP Ameresco Energy Storage Optimization Platform

ARB Air Reserve Base

BESS Battery Energy Storage System

BMS Battery Management System

CAISO California Independent System Operator

CapEx Capital Expense

CLCP Critical Load Coverage Probability

CLCPC Critical Load Coverage Probability Curve

CSP Curtailment Service Provider

DC Direct Current

DCM Demand Charge Management

DE Designated Entity

DER Distributed Energy Resource

DR Demand Response

DG Diesel Generator

DoD Department of Defense

ERCOT Electric Reliability Council of Texas

ESPC Energy Savings Performance Contract

ESTCP Environmental Security Technology Certification Program

FERC Federal Energy Regulatory Commission

HIL Hardware In the Loop

HVAC Heating, Ventilation and Air Conditioning

ICF Issue for Construction

IEP Installation Energy Plan

ISO Independent System Operator

ISO-NE Independent System Operator of New England

kW Kilowatt

kWh Kilowatt-hour

LCOE Levelized Cost of Energy

LCOS Levelized Cost of Storage

Li-Ion Lithium - Ion

MISO Midwest Independent System Operator
MP Market Participant
MTBF Mean Time Between Failure
MTTR Mean Time To Repair
MW Megawatt

NAS Naval Air Station
NASA National Aeronautics and Space Administration
NDS National Defense Strategy
NPV Net present value
NREL National Renewable Energy Laboratory
NYISO New York Independent System Operator

O&M Operations and Maintenance
OpEx Operating Expense

P_{fr} Probability of Failure to Run
P_{fs} Probability of Failure to Start
PCS Power Conversion System
PM Preventative Maintenance
PS Peak Shaving
PV Photovoltaic

RTE Round Trip Efficiency
RTO Regional Transmission Organization
RTU Remote Terminal Unit

SCE Southern California Edison
SGIP Self-Generation Incentive Program
SMECO Southern Maryland Electric Cooperative
SOC State of Charge
SOE State of Energy
SPP Southwest Power Pool

TMY Typical Meteorological Year
TOU Time of Use
TRL Technology Readiness Level

UESC Utility Energy Services Contract
UPS Uninterruptible Power Supply

VRF Vanadium Redox Flow
VRFB Vanadium Redox Flow Battery

WAPA Western Area Power Administration
Wh Watt-hour

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ABSTRACT

The purpose of this project was to investigate the techno-economic benefits that large scale, stationary energy storage technology could provide to military microgrid installations. Maintaining continuity of electric power supply to serve mission critical loads within military installations is a top priority throughout the Department of Defense. Recent increases in the frequency of utility power outages due to weather related events and the potential for cybersecurity threats have created new challenges to ensuring resilient installation operation. Microgrids, often containing diesel generators (DGs) and advanced battery systems, can allow installations to maintain continuity of service and continue to serve critical loads for long duration outages. To date, lead acid and more recently lithium ion batteries have been included as assets that complement DG operation as opposed to DG replacement assets, primarily because of the high cost and limited energy duration of those commercially available battery technologies. However, recently developed flow battery storage technology is a promising potential alternative to reduce dependence on DGs while still ensuring system reliability. Vanadium Redox Flow (VRF) batteries offer unique differentiators to lead acid and Li-Ion battery technologies such as increased safety, longer rated duration, and longer life. However, the nascency of VRF technology and limited understanding of reliability and operational performance, coupled with high equipment cost, typically limit the opportunities for field deployment. It is the objective of this work to study the VRF technology and characterize its reliability related performance to support a microgrid and the economic value the technology can generate for a site, while identifying limitations or challenges related to the technology that need improvement to foster growth of the technology sector.

The core technical work of this project entailed statistical reliability analysis using Monte Carlo based simulation methods, operational modeling of “value stacking” of energy storage using Ameresco’s Python-based AESOP optimization tool, and assessment of 20-year economic feasibility of flow battery, lithium ion battery, and DG enabled microgrids. Time series and Monte Carlo modeling methods were used to simulate system operation. The results suggest that there is the potential to replace a redundant DG with a VRF battery while ensuring adequate reliability of the microgrid and lowering the cost of critical load support as compared to a DG microgrid. However, results show that certain economic and market conditions are needed to yield such benefits, and that significant capital and operational cost reductions of VRF battery equipment are needed to offer a better alternative to lithium ion battery technology. Finally, because of key initial assumptions within the scope of this work, it is recommended that further investigation be performed to assess the feasibility of the VRF battery solution while incorporating electric distribution system details and further studying the response time, operating characteristics, and system life considerations of the VRF technology.

Technical analysis and results allowed for determination of appropriate system sizing, estimated implementation cost, expected annual operating and maintenance costs, and annual savings and value of the proposed VRF BESS systems at each site that satisfied the baseline reliability Critical Load Coverage Probability Curve (CLCPC). The metric for acceptable reliability performance was a CLCPC that met or exceeded the ESTCP provided fixed load baseline coverage curve as modeled against the 100% of critical load profile. A 20-year net present value (NPV) approach was used to assess project economics, to determine battery configurations that provided an equal or lower cost of critical load support as compared with the DG only baseline.

EXECUTIVE SUMMARY



INTRODUCTION

Ameresco Inc., with its partner 2ndPath Energy, completed this ESTCP funded project to investigate and advance the state of the art of flow battery energy storage – a promising new storage technology. The purpose of this project is to study the reliability and operational effectiveness of flow battery storage and quantify the extent to which this new storage technology could reduce reliance on diesel generators (DGs) in a military microgrid.

Our team is completing this work as part of what we intend to be a three-phase effort. This first phase provides an in-depth study into the technology with a scope of work focused on technology research, analytical modeling, and analysis. We believe the conclusions of this first phase support future investigation to conduct Hardware in the Loop (HIL) testing of the technology to validate the findings of this Phase 1 work. Finally, if justified, we look forward to completing a third phase whereby we would complete a field installation and demonstration of the flow technology, demonstrate its capabilities and effectiveness in a microgrid, and validate the revenue generating opportunities this technology can offer during grid tied conditions as compared to how our team projected them in phase one through analytical modeling.

Our team has specific interest in investigating Vanadium Redox Flow (VRF) Battery Energy Storage Systems (BESSs). We cross compare its techno-economic performance with DG technology, a proven and widely deployed backup generation technology, and with lithium ion (Li-Ion) BESS technology, the predominant advanced storage technology at this time. There is interest in investigating how battery storage could perform as a replacement for a DG within a microgrid and determining what technical and economic barriers exist that need to be mitigated to foster adoption. DG technology is a reliable, low cost tried and true generation technology that is deployed at scale throughout virtually every Department of Defense (DoD) installation. However, fundamentally, DGs are uni-directional in that they only discharge power and cannot store energy. Also, they are often limited in the value they can provide during normal, utility grid connected situations, as they typically cannot operate continuously because of emissions limitations. Finally, there is widespread interest throughout the energy industry to develop methods to reduce emissions and reliance on fossil fuel powered equipment. Long duration, reliable energy storage offers promise as one technology that can work towards this goal, especially when paired with low or no emission generation technology such as solar photovoltaics and combined heat and power. As such, investigating the opportunity to reduce reliance on DGs offers value to the DoD and energy industry at large.

As discussed in detail in this technical report, VRF storage offers attractive differentiators that could provide an alternative to Li-ion storage technology – which is the most common technology being deployed today. These include the ability to store 10 to 12 hours of rated energy capacity, little to no degradation in retained energy capacity over time, and inherently safer chemistry characteristics as compared with Li-Ion storage that reduce the need for costly auxiliary systems.

Despite some commercial VRF product offerings in the market, the technology is still a nascent technology with very few large-scale deployments throughout the world. Thus, the technology is still at a high cost relative to what it could be at scaled production levels. Further, this investigation quantified the impacts of some of the less desirable technical characteristics of VRF storage, namely lower round trip efficiency and higher auxiliary system loads attributable to the mechanical pumping systems of the system architecture.

OBJECTIVES

The work herein studied five DoD installations across the continental United States. At each site, the technical objectives aimed to quantify how large-scale battery energy storage can add technical and economic value to a baseline microgrid. The baseline microgrid at each site contains a series of DGs sized to meet critical load with N+1 redundancy and uninterruptible power systems (UPSs) to provide ride through power supply to a subset of critical loads. There is no large-scale battery energy storage in the baseline microgrid. This report describes the methodology, simulations, results and conclusions of how a VRF BESS should be sized to replace a single DG asset and how that replacement impacts statistical reliability of operation, grid tied operation, and economic cost of serving critical load. Table 1 summarizes the discrete objectives of the project that were investigated for each site.

Table 1. Project Objectives

Objective	Category of Interest	Description of Objective
<i>Objective 1</i>	<i>Reliability</i>	Calculate hourly probability of serving 100% of the critical load requirement during a utility outage of up to 168 hours in duration that could start at any hour of the year
<i>Objective 2</i>	<i>Reliability</i>	Calculate hourly probability of serving 130% of the critical load requirement during a utility outage of up to 168 hours in duration that could start at any hour of the year
<i>Objective 3</i>	<i>Reliability</i>	With no diesel fuel supply, calculate hourly probability of serving 30% of critical load during a utility outage of up to 24 hours that could start at any hour of the year
<i>Objective 4</i>	<i>Reliability</i>	With no diesel fuel supply, calculate hourly probability of serving 10% of critical load during a utility outage of up to 24 hours that could start at any hour of the year
<i>Objective 5</i>	<i>Reliability</i>	Determine the minimum amount of power and energy the BESS needs to provide the microgrid such that the Objective 1 outcome meets or exceeds the fixed load baseline performance
<i>Objective 6</i>	<i>System Design</i>	Identify the full system rated power and energy capacity sizing of the optimally sized BESS
<i>Objective 7</i>	<i>Economic Feasibility</i>	Quantify annual value proposition of BESS through retail and wholesale use cases, based on current and future volatile market conditions
<i>Objective 8</i>	<i>Economic Feasibility</i>	Calculate the cost of securing critical load for the BESS enabled microgrid as a function of 20-year Net Present Value and how this compares to the baseline, DG only microgrid
<i>Objective 9</i>	<i>Reliability & Economic Feasibility</i>	Identify if VRF or Li-Ion is the preferred technology for the proposed BESS.

A detailed explanation of assumptions that were made are provided throughout this report. There are certain key assumptions notable for this summary that are important to recognize when assessing the context and conclusions of this study. First, each installation was analyzed assuming the site's electric distribution system was a perfectly functioning, single-feeder electrical system. This means that all generation assets and critical and non-critical loads are modeled to be on a single circuit. This guidance was prescribed by the ESTCP program. It is recognized that this is an unrealistic condition, however, and would be an important area of differentiation for future investigation.

Next, a key assumption was the allowance of a BESS to be charged from surplus DG generation capacity within the storage enabled microgrid. In reality, an installation may not want to do this if they preferred to run only the necessary DG capacity and conserve diesel fuel supplies. Also, this operation would use more fuel for the same amount of served electric energy because of the BESS round trip efficiency, which is notably lower for VRF technology than Li-Ion technology. However, allowing the BESS to charge from DG capacity only within an outage period helps prolong the usability of the BESS as a dispatchable asset to serve more critical load during high demand times.

Third, determination of reliability probability statistics for the VRF Storage technology heavily influenced reliability results. Our team worked to collect as much relevant and useful information and feedback as we could gather about the technology to inform this decision. However, there is limited field experience and vendor testing that provides the ability to publish these parameters. This highlighted an area where vendor testing is lacking and further ESTCP investigation would significantly benefit the industry. Thus, it is possible that the probability of failure to start (P_{fs}) and mean time between failure (MTBF) metrics used in this Phase 1 work are not reflective of true long-term field performance. Validation of the metrics used for this study will be an important aspect of Phase 2 HIL and Phase 3 field demonstration scopes of work. For this study, our team concluded that P_{fs} and MTBF metrics of 1.0% and 1095 hours, respectively, were reasonable assumptions based on the data and information in hand and reasonable engineering judgement. This compares to the ESTCP provided DG metrics of 0.2% and 1700 hours, respectively.

Since calculation of hourly probability curves are a critical technical objective of this work, it is important to briefly introduce that concept and clearly establish the baseline for performance. A large portion of the analysis of this project worked toward defining a Critical Load Coverage Probability Curve (CLCPC) under various scenarios and conditions. The CLCPC provides expected probability of serving 100% of the hourly critical load for each site as a function of outage duration, from 1 to 168 hours. Our team developed a Monte Carlo based simulation method to calculate CLCPC curves. This utilized 100 discrete iterations of simulation analysis across 8760 outage blocks, each 168 hours in duration. Hourly calculations from each of the 100 iterations were averaged to compile a single hourly CLCPC curve.

CLCPC data for the DG only baseline microgrid was provided by ESTCP. This was provided for the case where the amount of critical load was fixed and equal to the site's annual peak critical load (referred to elsewhere in this report as the fixed load baseline). This was also provided for the scenario where the amount of critical load varied hourly and equaled a fixed percentage of the site's hourly electric load, as determined by ESTCP and the installation (referred to elsewhere in this report as the variable load DG-only scenario). It is worth noting that the fixed hourly peak critical load scenario is the worst-case scenario to analyze, as much of the time the amount of critical load to serve is overstated and requires more generation capacity from the DG assets.

Ameresco validated its reliability model by re-creating the fixed load baseline and variable load DG-only scenarios to ensure results aligned with ESTCP provided figures. Figure 1 shows this comparison for one example site (Westover ARB).

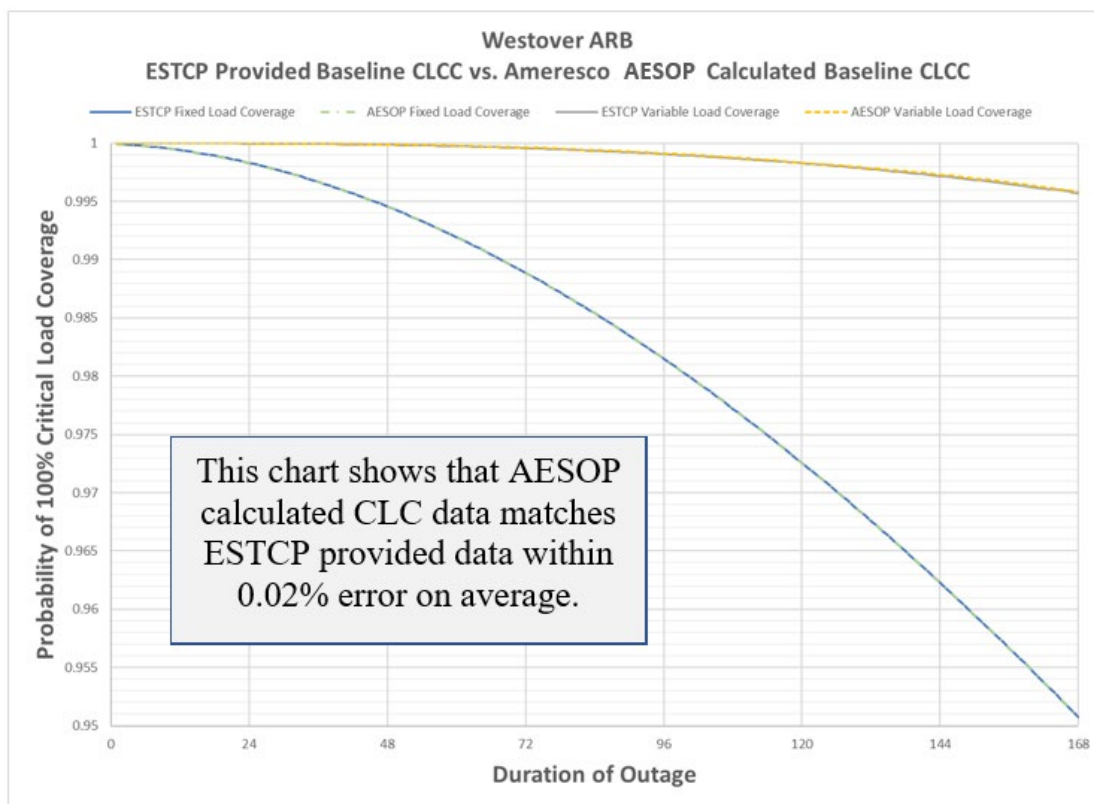


Figure 1. Example Critical Load Coverage Probability Curve

Finally, it is important to clearly state that the basis for “successful” reliability performance of the BESS enabled microgrid is the fixed, peak critical load curve and not the variable load DG-only curve. This was directed by ESTCP. However, it is important to note that this yields an indirect comparison since the BESS enabled load coverage curves analyze the variable critical load data profile.

TECHNOLOGY DESCRIPTION

There are three generation and storage equipment types and two simulation programs that comprise the core technologies being analyzed and utilized within the scope of this project. The three equipment types being compared include DGs, VRF batteries, and Li-Ion batteries. The baseline technology for assessment is the DG. The new technology which is the primary focus for investigation through this work is the VRF battery. Since VRF storage technology is a nascent technology with very little field deployment experience, the project team felt it was prudent to compare analysis results of the VRF technology to that of Li-Ion storage technology. Li-Ion storage is the primary technology being deployed for MW scale energy storage systems, comprising greater than 90% of all distributed storage deployments over the last several years^{ix}.

A major technical objective was to determine if the equipment reliability of VRF technology is sufficient to serve as a replacement technology for a DG asset within a microgrid. However, even if that proves to be true, a critical secondary objective of the project team was to determine if there is a viable business case for VRF technology over Li-Ion technology, and what project screening metrics and equipment price points are required to enable VRF technology to be a better business choice for deployment. To investigate these objectives, Python based statistical simulation and time-series software programs were developed and used.

A detailed description of the VRF battery technology is provided in the body of this technical report. Fundamentally, VRF batteries produce or absorb electrical current by pumping a vanadium-based electrolyte solution through a power stack across a membrane. Flow batteries differentiate themselves from Li-Ion in that the power (kW) and energy (kWh) components can be adjusted independently of one another without impacting performance. By increasing the volume of electrolyte, flow batteries can provide a 12 hour or longer solution. Further, the claimed lack of energy capacity degradation over time ensures a consistent level of performance over the life of the project while reducing maintenance and replacement costs associated with today's Li-Ion batteries. Flow battery manufacturers report negligible energy capacity degradation after 10,000 full cycles, whereas Li-Ion energy capacity degradation can range from 2-4% or more annually, depending on use cases. Also, flow storage typically has a broader ambient operating temperature range, requiring less active thermal management and could more easily serve a wider array of geographic regions without additional heating, ventilation and air-conditioning (HVAC) cost. These benefits create opportunity to solve the problems noted above and could serve as a key building block to achieving a renewable based microgrid that can sustain load for days or weeks with reduced reliance on DGs.

Table 2 to the right provides a summary of the key technology assumptions used for the VRF and Li-Ion battery equipment.

	Units	VRF	Li-Ion
Round Trip Charge/Discharge Efficiency	%	76%	85%
Auxiliary Power Draw	kW/MW Rated	11 - 72	0.75 - 5
Controls Auxiliary Load	kWh/day	0.3	0.3
AC Equipment Cost	\$/kW	\$ 250	\$ 250
DC Equipment Cost	\$/kWh	\$ 480	\$ 350
Balance of Plant Installation Cost	\$/kWh	\$ 275	\$ 275
Annual Energy Capacity Degradation	%/Year	0 - 0.5%	2-4%

Table 2. Assumed Battery Specifications

The overarching objective of this project is to determine what configuration of battery system(s) provide adequate reliability performance at equal or lower cost of critical load support as compared to a DG only baseline microgrid. This configuration is defined by the quantity of unique BESS units (1 or more) and the amount of total power and energy required from a BESS within a microgrid to maintain the stated reliability performance over an outage of up to 168 hours duration.

To determine the target configuration, our team completed a sequenced series of modeling efforts for each site which included baseline DG characterization, Monte Carlo based statistical reliability modeling, modeling of expected BESS hourly operation in grid tied settings to quantify value creation opportunities, and economic analysis. All three of these modeling tools leveraged Python programming language and were integrated into Ameresco's internally developed energy storage modeling tool, referred to as the Ameresco Energy Storage Optimization Platform (AESOP). This tool existed prior to the completion of this phase of ESTCP work, however, a significant achievement of this ESTCP work is the expansion of the tool to include all of the required modeling capabilities described above. This allowed for a centralized tool to be used to complete all required analysis. This ESTCP effort has also allowed advancement of the grid tied modeling capabilities of the tool, allowing for more value stacking use cases to be analyzed. This effort not only enhanced our analysis of the five installations under investigation but also support improved energy storage analysis for other Ameresco developed Federal Government energy projects that include battery measures

PERFORMANCE ASSESSMENT

Ameresco conducted statistical reliability and time series grid tied modeling across the five installations to assess microgrid and BESS performance. This included reliability modeling of multiple scenarios of critical load to serve, ranging from 10% to 130% of nominal critical load, scenarios with and without diesel fuel availability, and multiple market condition scenarios. Across all scenarios, Ameresco calculated probability curves for no photovoltaic (PV) production and expected PV production conditions. We felt this was justified since it is likely PV would not be operational in a severe weather induced outage for potentially multiple days. We recognize PV may be available to an intermediate extent, but our approach characterizes the full range of reliability performance into which any of these scenarios would fall. Prior to running the Monte Carlo based reliability models, Ameresco characterized ideal operation of the DG assets across all five sites to inform power and energy microgrid requirements of the storage system aimed at replacing the least running DG. This provided an initial input of the storage power and energy available for microgrid reliability modeling as shown in Table 3. For clarity, this is not the total BESS system size, but the amount of power and energy a BESS needs to provide to the microgrid for acceptable reliability performance. This analysis showed that the least running DG for Westover only had one hour of projected operation under ideal conditions, whereas the remaining sites had between 12 and 56 hours within a single outage block.

Table 3. BESS Power and Energy Requirements for Passing Critical Load Coverage

	Units	Westover	Patuxent River	NAS CC	Fort Bliss	March ARB
Microgrid Minimum Power Requirement	kW	207	514	659	507	250
Microgrid Minimum Energy Requirement	kWh	207	6958	7264	3574	3509
Number of BESS Units Required	#	1	1	1	1	2

Once the microgrid requirements of the BESS were established, Monte Carlo based reliability simulations were completed to quantify the probability of critical load coverage when replacing a single DG with a BESS with the above stated power and energy capacity. As previously mentioned, the model was configured to allow the BESS to charge from surplus DG capacity.

Table 4 summarizes the results, providing the calculated probability of critical load coverage under all requested conditions. Details of all reliability performance charts are provided in the Technical Report and supplementary Appendices.

Table 4. Summary of Critical Load Coverage Modeling Results

Critical Load %	Reliability Modeling Results Summary	Westover ARB	NAS Patuxent River	NAS Corpus Christi	Fort Bliss	March ARB
100%	Critical Load CLC Baseline Req. at 168 Hrs	0.95076	0.67376	0.85815	0.82253	0.95076
100%	BESS Enabled Variable Load CLC at 168 Hours	0.97170	0.90028	0.92551	0.95656	0.98326
130%	BESS Enabled CLC Probability at 168 Hours	0.81173	0.29558	0.45154	0.66019	0.81098
30%	No DG BESS Only CLC Probability at 1 Hour	0.03167	0.00000	0.00000	0.00000	0.99481
30%	No DG BESS Only CLC Probability at 24 Hour	0.00000	0.00000	0.00000	0.00000	0.00000
10%	No DG BESS Only CLC Probability at 1 Hour	0.99003	0.00000	0.00000	0.06930	0.99990
10%	No DG BESS Only CLC Probability at 24 Hour	0.00000	0.00000	0.00000	0.00000	0.00000
30%	No DG PV+BESS CLC Probability at 1 Hour	0.41085	0.06815	0.09932	0.35519	0.99932
30%	No DG PV+BESS CLC Probability at 24 Hour	0.00000	0.00000	0.00000	0.00000	0.00000
10%	No DG PV+BESS CLC Probability at 1 Hour	0.99431	0.27192	0.30639	0.47862	0.99995
10%	No DG PV+BESS CLC Probability at 24 Hour	0.00000	0.00000	0.00321	0.00000	0.90949

Once reliability modeling was complete, the next step was to quantify how much value a BESS could generate through utility billing savings and wholesale energy market opportunities. Ameresco studied each site's utility rate conditions as well as the rules and regulations of available wholesale market products where relevant. This allowed us to determine a use case stack for each site. This stack is summarized in Table 5. The available value creation use cases that were identified included Retail Demand Charge Management (DCM), Retail Time of Use (TOU) Energy Savings, Wholesale Energy market participation co-optimized with Wholesale Synchronous Reserves, and Wholesale Regulation. We then worked to enhance the modeling capabilities of the AESOP tool to be capable of simulating those use cases. This primarily involved expanding our existing DCM and Regulation modeling functionality and adding the new use cases of Retail TOU, and Wholesale Energy coupled with Reserves.

Table 5. Grid Tied Use Case Stacks for Each Site

Site	ISO	Retail DCM	Retail TOU	Wholesale Energy	Wholesale Reserves	Wholesale Regulation
Westover ARB	ISO-NE	•	• (1)	•	•	•
NAS Patuxent River	PJM	•		•	•	•
NAS Corpus Christi	ERCOT	•				
Fort Bliss	N/A	•	•			
March ARB	CAISO	•	•	•	•	

1 Requires 80% RTE to be economically justified. Applicable to Li-Ion, not Flow.

Next, we determined the appropriate battery system sizes to model under grid-tied conditions to quantify the value each system could generate for each site, considering both VRF and Li-Ion equipment solutions. We approach sizing of possible configurations by making sure the full BESS rated power and energy capacity met the microgrid requirements, had a power capacity appropriate to replace one DG for each site, and assessed rated durations from 1 to 10 hours. It should be noted that systems with durations of 1 to 4 hours are Li-Ion technology and those with 6 to 10 hours of duration are VRF technology. Though there are not rigid limits on durations for each technology, these bounds are aligned with the strengths of each technology and the commercially available products on the market today.

We then completed grid tied modeling simulations for a total of 30 unique BESS systems sizes across the five installations. This allowed for determination of expected annual value (savings and revenue) for each BESS option. For each system size, we estimated implementation cost and annual operation expenses based on Ameresco’s experience developing and operating these battery systems. This allowed for assessment of economic viability of each option to determine the BESS size that provided the best opportunity for economic viability at each installation. Our team selected the optimal system size for a VRF and Li-Ion BESS at each site to allow comparison of each storage technology.

COST ASSESSMENT

As further described in the Technical Report, multiple levels of economic assessment were completed to determine the optimal VRF and Li-Ion BESS sizing for each microgrid. Of the 6 BESS sizes considered for each site, a single VRF and Li-Ion BESS was selected for each site based on estimated simple payback. Then, a detailed 20-year economic pro-forma was created for each system, in both current and future market and cost scenarios. The 20-year net present value (NPV) of each microgrid was then calculated and normalized by the amount of each site’s critical load. This identified the cost of critical load coverage for each site’s DG only baseline and battery enabled microgrid systems. A summary of these results is provided in Table 6. These results show that there are scenarios where the BESS enabled microgrid can reduce the site’s cost of critical load support now or in the future. However, the VRF BESS technology in all cases provides a higher cost of critical load support – primarily due to higher capital costs, lower round trip efficiency, and significantly higher auxiliary loads which reduce the operating value of the VRF storage systems.

Table 6. Cost of Critical Load Support Results Summary

Installation	# of DG Assets	DG Capacity Per Asset (kW)	# of BESS Assets	BESS Total Power Capacity	BESS Total Energy Capacity	BESS Lower SOE	Grid Tied Use Case Stack	Cost of Critical Load Support (\$/kW-c)
				kW	kWh	kWh		
March ARB	4	250	0	N/A	N/A	N/A	None	\$416
	3	250	2 VRF	875	7,000	3509	DCM+WH E&R	\$317 (f) to \$519 (c)
	3	250	2 Li-Ion	3,500	7,000	3509	DCM+WH E&R	\$229 (f) to \$525 (c)
NAS Corpus Christi	7	750	0	N/A	N/A	N/A	DR + PS	\$89
	6	750	1 VRF	1,217	7,300	0	DCM	\$109 (f) to \$132 (c)
	6	750	1 Li-Ion	3,650	7,300	0	DCM	\$90 (f) to \$115 (c)
Fort Bliss	8	2000	0	N/A	N/A	N/A	None	\$83
	7	2000	1 VRF	2,000	12,000	0	DCM	\$104 (f) to \$117 (c)
	7	2000	1 Li-Ion	2,000	4,000	0	DCM	\$88 (f) to \$93 (c)
Westover ARB	4	750	0	N/A	N/A	N/A	DR	\$166
	3	750	1 VRF	750	4,500	0	FR	\$196 (f) to \$251 (c)
	3	750	1 Li-Ion	750	750	0	FR	\$129 (f) to \$156 (c)
NAS Patuxent River	12	750	0	N/A	N/A	N/A	DR	\$98
	11	750	1 VRF	1,167	7,300	0	DCM+WH E&R	\$111 (f) to \$128 (c)
	11	750	1 Li-Ion	3,500	7,000	0	DCM+WH E&R	\$96 (f) to \$121 (c)

CONCLUSIONS

This work offered significant insight into the viability of replacing a DG with a BESS in a microgrid. First, based on assessment of the reliability modeling results and critical load coverage curves produced, we can conclude that a VRF battery enabled microgrid can provide satisfactory reliability performance at all five sites by meeting the baseline performance requirement over a 168-hour outage that could occur at any time. However, we can also conclude for all five sites that critical load coverage at 168 hours was below the variable load DG-only coverage by between

1.6% to 3.0%. This is to be expected since the newer VRF technology is assumed to have lower reliability factors than the DG technology. This result indicates that there is significant justification for the further investigation of the VRF technology as to be explored in follow on Phase 2 testing, with a focus on testing and validating the true reliability metrics of the technology.

From an economic standpoint, results show that there is also opportunity for large scale storage to provide a lower \$/kW_e under certain conditions. However, due to today's VRF BESS equipment pricing higher operating costs, there is not a clearly established case for a VRF BESS providing a preferable technology solution to Li-Ion BESS technology. It is important to recognize that VRF BESS technology is early on in its development and deployment lifecycle and has not yet appreciated the vast cost reductions due to economy of scale that Li-Ion has enjoyed. Should costs of the VRF technology decrease in the future, there may very likely be conditions where a VRF BESS would provide a more attractive solution than Li-Ion. This may be the case, for example, in markets where wholesale products, which are more lucrative for higher power systems, are not viable and where there are high retail demand rates with sites that have relatively flat load profiles and a need for longer duration energy storage.

In conclusion, the work herein has made a significant contribution to the body of knowledge of VRF storage technology. We feel the conclusion that the reliability of VRF BESS technology is sufficient against the baseline for performance is a major observation of this project and one that warrants further investigation through a Phase 2 HIL simulation and potentially a follow-on Phase 2 field demonstration. There is also the potential for VRF battery technology to provide important benefits to a project as compared with Li-Ion technology while improving safety and reducing long term replacement requirements. Continuing to investigate the technology through follow on phases will further the state of the art of this new storage technology and provide critical feedback to the industry of technical and economic aspects of the technology that need to be improved. Ameresco and its team looks forward to furthering our work to investigate advanced energy storage and its impacts to resiliency and reliability of military installations.

TECHNICAL REPORT

The following sections of this report introduce the project, provide background information on the proposed Vanadium Redox Flow (VRF) battery technology, describe project performance objectives, summarize key information of the DoD sites that were analyzed, and describe in detail the analysis methodology, performance and cost assessments, and conclusions.

1.0 INTRODUCTION

Ameresco Inc., with its partner 2ndPath Energy, completed this ESTCP funded project to investigate and advance the state of the art of flow battery energy storage – a promising new storage technology.

The objective of this project was to assess, demonstrate, and validate the operational effectiveness of flow battery storage and quantify the extent to which this technology could replace or significantly reduce the need for diesel generators (DGs), while advancing the state of the art of flow battery storage technology. The project fulfilled this work through analytical modeling and an assessment of the opportunity for widespread deployment throughout the Department of Defense (DoD). Efforts for Phase 1 (design and modeling) are detailed in this report.

Our team is completing this work as part of what we intend to be a three-phase effort. This current first phase provides an in-depth study into the technology with a scope of work focused on technology research, analytical modeling, and analysis. If the conclusions and results support future investigation, we intend to conduct a second phase focused on in depth hardware testing and verification of the reliability of the technology in a Hardware in the Loop (HIL) environment. Finally, if justified, we look forward to completing a third phase whereby we would complete a field installation and demonstration of the flow technology, demonstrate its capabilities and effectiveness in a microgrid, and validate the revenue generating opportunities this technology can offer during grid tied conditions as compared to how our team projected them in Phase 1 through analytical modeling.

1.1 BACKGROUND

For many decades, DGs have played an integral role in providing emergency backup power to DoD installations. These assets are vital to installations serving critical electrical load during times of utility outage, ensuring that the installation can sustain mission critical operations. DGs are proven, reliable, and cost-effective assets that are widely deployed and operable today. However, these benefits do not come without a few drawbacks or limitations. First, DGs typically take tens of seconds or sometimes multiple minutes to come online and be ready to serve load. Uninterruptible Power Supply (UPS) systems, which can respond extremely quickly to maintain critical load operation with a transfer time as fast as 2 – 10 ms, can provide ride-through capabilities that may overcome this shortfall of DGs. However, UPS systems are very limited in their duration and may not be able to compensate for a longer-term delay or outage for the DG unit. Additionally, each site's UPS sizing and setup may not be synchronous with the full energy and power capabilities of the DGs. Second, there are various initiatives through the DoD and private sector to reduce dependence on diesel fuel. These efforts are primarily motivated by a desire to reduce dependence on fuel sourced from foreign locations, reduce operations cost, and reduce emissions. Finally, while DG assets are very reliable assets, emissions limitations typically prevent them from operating on a continuous basis while the site is connected to the utility grid. This limits the value the asset creates during the majority of the hours of the year. Further, since these assets are remaining idle and unused for much of their life, the risk of failure or maintenance related issues could increase.

For the past several years, large scale, commercially available battery energy storage systems (BESSs) have grown in maturity and have begun being adopted on a large scale through utility, commercial, and federal government sectors. The core storage technology of the vast majority of these distributed storage systems is Lithium Ion (Li-Ion) battery cell technology. Li-Ion technology has matured significantly and reduced in cost dramatically, primarily due to increase in production to serve the personal electronics, computer, and electric vehicle markets. In parallel, a variety of system integrators and equipment providers now provide megawatt (MW) scale Li-Ion BESS systems. These systems are re-chargeable and can generate or absorb significant amounts of power while responding nearly instantaneously to dispatch commands. Figure 2 shows a representative diagram of a typical Li-Ion cell.

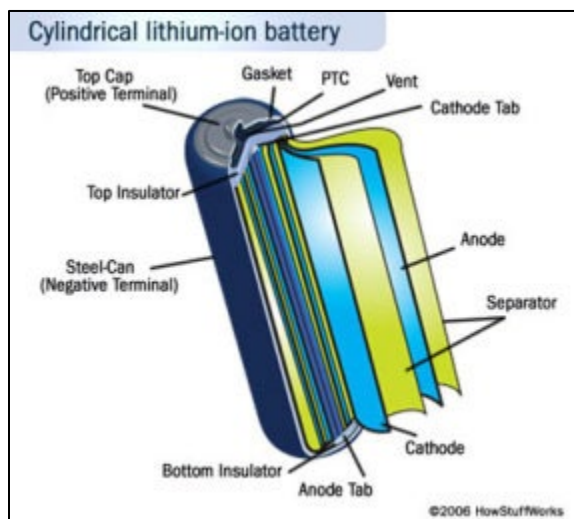


Figure 2. Expanded View of Li-Ion BESS i

However, these battery systems to date have been limited in the duration of energy storage they can provide. The relationship between power and energy capacity of a cell is limited by the design of the battery cell being used, and is also limited by the options of standard product offerings available from equipment vendors. In a lithium-ion cell, power capability is a function of the number of electrodes in the cell which correlate to current capability. The more electrodes there are in a cell, the more current a cell can provide or absorb. Conversely, the energy capacity of the cell is a function of the volume of active material in which lithium ions can be stored. Thicker layers of active material coated on electrodes allow for greater energy capacity in a given volume. Since more layers of electrode reduces the useable volume for storing energy, there is a trade-off between power and energy ratio that is made when designing a Li-Ion cell for a given application and the physical dimensions create an eventual limitation of how much energy can be stored in a given cell. These cells are then assembled in a system architecture that ultimately provides a rated power capacity (kW) and rated energy capacity (kWh). The duration of the system is the amount of time the system could charge or discharge at its full rated power capacity.

Although it is not impossible to have slightly longer duration, the majority of commercially available Li-Ion stationary battery products on the market have durations between 0.5 hours to 4 hours. This means that if the system was fully charged and discharged at its maximum power rating, it could only provide power for about four hours before being fully depleted and in need of re-charge.

The systems could run for longer durations at lower power; however, designing a system in such a way degrades the economic justifications that have been essential to Li-Ion's deployment to date. Though four hours could be sufficient for a number of grid-tied operational use cases, this is a limiting factor to considering these BESS systems as a potential replacement for a DG asset within a microgrid. Since military installations are preparing for outages that could last for multiple days or even as long as one week, four hours is not sufficient to serve load for that period of time without having to drastically upsize the size of the battery with respect to the amount of critical load to be served. Also, Li-Ion systems have other shortcomings that the industry would like to improve upon. One example is the fact that the retained energy capacity of the system degrades over time. The amount of degradation depends on use of the system but could be as high as 2-4% annually. This reduction in retained capacity is primarily due to degradation of materials inside each battery cell – limiting the amount of useable energy capacity over time. This negatively impacts the amount of value the system could provide later in life, or creates a need to augment or maintain capacity throughout life, which carries a cost. Further, since Li-Ion cells operate under an exothermic reaction that creates heat, these BESS systems require additional sub-systems of complex monitoring and controls, thermal management systems, and fire suppression systems to ensure continued safe operation. Though these systems have become fully developed and are standard in today's Li-Ion BESS systems, this does increase cost and complexity of the product and adds technology risk to the solution.

Finally, there is interest in exploring alternatives to Li-Ion due to their use of significant amounts of rare earth metals such as cobalt. The use of these materials that are limited in their abundance can create supply chain shortages which can lead to occasional price spikes in equipment cost.ⁱⁱ Further, in some cases the supply chain methods related to sourcing materials like cobalt have involved sourcing from controversial regions.ⁱⁱⁱ Leading Li-Ion cell producers are said to have begun shifting their supply chain practices to avoid these concerns, however that may impact product availability or cost.^{iv} Flow battery equipment providers claim that their avoidance of these rare earth minerals is a differentiator that could lead to more consistent and less controversial supply of materials in the long term.

A variety of new storage technologies are in development that offer alternatives to Li-Ion. Our team has specific interest in investigating VRF BESSs. We cross compare its techno-economic performance with DG technology, a proven and widely deployed backup generation technology, and with Li-Ion BESS technology, the predominant advanced storage technology of our day. There is interest in investigating how battery storage could perform as a replacement for a DG within a microgrid and determining what technical and economic barriers exist that need to be mitigated to foster adoption. DG technology is a reliable, low cost tried and true generation technology that is deployed at scale throughout virtually every DoD installation. However, fundamentally, DGs are unidirectional in that they only discharge power and cannot absorb power. Also, they are limited in the value they can provide during normal, utility grid connected situations, as they typically cannot operate continuously because of emissions limitations. Finally, they cannot typically provide a seamless transition from grid connected to independent, islanded, operation of a microgrid because of the relatively long time required to startup and synchronize, often creating a temporary lapse in the continuity of power supply for an installation. The advancement of distributed battery technology creates interest in conducting this investigation. Battery systems are bi-directional, meaning they can charge and discharge to serve as a load or a generator.

They also offer millisecond level response time and thus can provide power nearly instantaneously upon dispatch, potentially allowing the site to island without experiencing a temporary loss of power supply. Finally, battery systems can operate continuously during utility grid connected states to provide savings and revenue streams from various retail and wholesale use cases.

As discussed in detail in this technical report, VRF storage offers attractive differentiators that could provide an enhanced storage solution. These include the ability to store 10 to 12 hours of rated energy capacity, vendor stated little to no degradation in retained energy capacity over time, and inherently safer chemistry characteristics as compared with Li-Ion storage that reduce the need for costly auxiliary systems. Despite these strengths, the technology is still a nascent technology with very few large-scale deployments throughout the world and the technology is still at a high cost relative to what it could be at scaled production levels. With such little field experience, there is a need to better characterize the reliability and performance of the VRF technology. This investigation looks to study the impacts of some of the less desirable technical characteristics of VRF storage, namely lower round trip efficiency and higher auxiliary system loads attributable to the mechanical pumping systems of the system architecture.

Since the VRF BESS technology is so new, there is limited data available from testing or field environments and a detailed understanding of the technology and its capabilities in various situations is needed. As the industry works hard to focus on product development, growth to large-scale commercial manufacturing, and installing and operating initial demonstration projects, this study offers a detailed, holistic, and objective investigation of the technology and which aspects need to improve to continue to advance the state of the art of flow battery storage. It is intended that the outcomes and conclusions of this work will inform developers, equipment providers, and DoD agencies on how VRF energy storage technology can be improved to support implementation.

1.2 OBJECTIVE OF THE DEMONSTRATION

The overall objective of this project is to investigate to what extent a BESS can replace a single DG asset within a microgrid and characterize the related impact on the ability to reliably serve critical load during an outage and the cost of such critical load support. Our approach focused on replacing the least running DG within a microgrid with a VRF BESS. We are not proposing to replace or reduce the use of UPSs as compared to the baseline microgrid. The primary reason for this is that we do not believe the response time of a VRF or Li-Ion BESS is fast enough to adequately replace the UPS. As previously mentioned, the UPS is an extremely fast responding asset with a transfer time of 2-10 ms. Advanced VRF and Li-Ion batteries are very fast, but typically offer a response time on the order of 100 ms or longer depending on the capabilities of controllers, switching equipment and the inverter.

This emphasized replacing only one diesel generator at each site. As shown later in this report, analysis was completed to project diesel generator run time and energy consumption to support the baseline microgrid. In these scenarios, it is assumed the n_{th+1} generator at all sites is reserved for redundancy, and all other generators run at increasing levels of degree to support critical load. Results of our analysis show that run time requirements for the n_{th} generator and n_{th-1} generator increase dramatically at all sites. The run time requirements of the n_{th-1} requirements significantly exceed the amount of energy a storage system could potentially be sized for. As such, it was deduced that it would not be feasible to replace more than one diesel generator with a battery at any site.

Specifically, the technical objectives of the project are to demonstrate:

1. how replacement of a single DG with a VRF battery affects the probability of serving critical load over a seven-day period within an islanded military microgrid
2. quantify the impact that solar PV generation can have to this probability of serving critical load as stated in objective 1
3. the value that flow batteries can generate during grid-tied (non-islanded) hours via electric utility bill savings and participation in local utility programs and regional wholesale electric markets as compared with DGs and Li-Ion storage
4. the technical advantages and disadvantages (e.g. round-trip efficiency, energy density, energy capacity degradation, auxiliary system load, ramp-rate, etc.) of flow batteries compared with Li-Ion storage.
5. Quantify how replacement of a single DG with a BESS affects 20-year net present value project economics and the related cost of critical load support (\$/kW_e)

1.3 REGULATORY DRIVERS

Energy storage delivers economic and resiliency value to the bulk electricity grid and distribution system from the Federal to the State and local level. The National Defense Strategy (NDS), released in 2018 by the DoD helps to guide initiatives for energy resilience. Two of the primary focus areas of the NDS are Energy Resilience and Energy Performance. Energy Resilience is the ability to “prepare for and recover from energy disruptions that impact mission assurance on military installations. Further, energy resilience encourages the necessary planning and capabilities to ensure available, reliable, and quality power to continuously accomplish DoD missions.”^v The Energy Performance Program includes Readiness Outcomes where knowledge of assets that improve energy resilience is required. Understanding what technology is available and how it performs in the field is critical. One of the unique features of the flow energy storage technology we are investigating in our project is the ability to decouple power and energy storage capacity of a system. This may provide DoD installations the flexibility to increase the duration of an energy storage system cost effectively should mission requirements change, when compared to existing energy storage technology solutions. The Lethality Outcomes goals outlined in the NDS include prioritizing critical loads, and energy storage is ideally suited to seamlessly support critical loads during a loss of utility. Long duration energy storage, and other new storage technology solutions, may provide more flexibility in determining and prioritizing critical loads. Installation Energy Plans (IEP) are another DoD policy designed to create dynamic plans to improve resilience and contribute to mission assurance. The IEPs require annual reviews of the energy resiliency and cybersecurity objectives. Deploying new, but validated scalable energy storage technology, as done through hardware-in-the-loop testing will give the DoD another asset to mitigate newly identified changes to energy risks of critical missions.

Electricity markets managed by Independent System Operators (ISOs) or Regional Transmission Organizations (RTO) and operate under the jurisdiction of the Federal Energy Regulatory Commission (FERC) are currently implementing significant rule changes as a result of Order 841.

FERC issued Order 841 in 2018, and the ISO and RTOs submitted their compliance filings in December of 2018. New market rules that recognize the unique characteristics of battery storage and remove barriers to participation will be implemented as soon as December of 2019. Some ISOs, such as ISO-New England, have already implemented favorable participation models in advance of the FERC implementation date. Order 841 requires market rules that recognize the unique physical and operational characteristics of energy storage systems through the creation of a new electric storage resource market participation model. The Order was designed to level the playing field with existing demand and supply-side resources (e.g. natural gas generators) by allowing energy storage to compete in all wholesale markets it is technically capable of providing. By allowing energy storage to access additional value streams, the financial justification for energy storage becomes more robust, while also expanding the reliability and resiliency benefits energy storage can provide to the bulk electric system. Improved economics through diversified market services may allow energy storage to be deployed in situations where it previously could not be justified. For example, the status quo pairing of energy storage with a solar PV system at a DoD installation may only be able to capture surplus PV and offset utility import. With Order 841, the energy storage can generate additional value by participating in wholesale markets, providing low-cost energy services to the bulk electric system. Leveraging customer-sited distributed energy resources allows both the DoD and civilian operations to benefit from the deployment of new energy storage technology solutions that are well suited to participate in wholesale electricity markets.

Several states have implemented explicit mandates for energy storage. Some of the most substantial are in California (1,325 MW by 2020 per AB 2514)^{vi}, Massachusetts (1,000 MWh by 2025 per H.4857)^{vii}, and New York (1,500 MW by 2025 per A6571)^{viii}. These mandates may channel deployment through the utilities in the states. Many DoD installations are large utility customers, and therefore provide a valuable pilot location for new energy storage technology. Validation of new energy storage technologies that can then be deployed in civilian applications immediately improves the resiliency of specific DoD installations, while advancing the future reliability of the US bulk electricity grid.

In states where utilities are vertically integrated (e.g. Indiana, Minnesota, Colorado), there has been an increase in legislation mandating energy storage to be included in long-term resource plans or as part of pilot projects. The mandates include traditional configurations where energy storage is paired with solar PV generation, but they also explore innovative third-party ownership options and micro-grid deployments. Legislation has also been introduced to allow regulated utilities to own energy storage. Both methods may lend themselves to the development of projects at DoD installations with new energy storage technology solutions through utility energy service contract contracting (UESC) mechanism. Ameresco has also engaged in energy savings performance contracts (ESPC) projects with DoD installations where energy storage can help alleviate high demand charges in utility costs as well as where energy resiliency is a foundational piece of the design. Energy storage often plays a critical role in the successful implementation, and new storage technology may serve to enhance future designs.

For ISOs that are primarily located in a single state (e.g. CAISO, ERCOT and NYISO), there can be a direct link between the state's energy and resiliency goals, and the structure of the electricity market. Aligning the goals of multiple states, (i.e. ISO-NE, PJM, MISO, SPP), is more complex, but nevertheless feasible. ISOs are mandated to operate markets that are technology neutral and must meet strict reliability criteria in the least-cost manner. However, market rules inevitably reflect the technology present when rules are created, and it is challenging to completely divorce the two.

Some ISOs have taken steps to accommodate differing initiatives from member states that are pushing for more renewable generation, while also internally recognizing the potential of energy storage technologies to harden the bulk electricity grid. In ISO-NE, which operates across six states, for example, fuel security in the winter where natural gas is widely used for electricity and heat can cause scarcity conditions that threaten the reliability of the entire ISO-NE territory. Long duration, multi-day conventional generating technology will continue to supply the vast majority of the system's demand. However, fast responding re-chargeable resources, like energy storage, provides ISOs a new type of flexible resource that helps make better use of variable winter generators like solar and wind and aids the ISO in its mitigation of these seasonal challenges. Recognizing the value of storage, ISO-NE is creating a market framework where energy storage is properly compensated for the services it delivers.^{ix} Storage also provides value for resource adequacy when paired with variable energy resources improving economics of projects that are competing with non-variable energy resources. The range of energy storage systems will vary greatly across the territory but given the uncertainty and potential duration of many weather-related reliability concerns, it is prudent to characterize the value of long-duration energy storage technologies at DoD installations.

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2.0 TECHNOLOGY DESCRIPTION

The specific energy storage technology being investigated through this project is the VRFB battery (VRFB). Through this effort, we also compared how grid tied VRFB technology creates value through retail and wholesale markets with Li-Ion BESS technology, which is the predominant storage technology today. The following sections describe the unique characteristics of the technology and why it is worthy of investigation, its current state of technology readiness and deployment, and to what extent it is being utilized in microgrid projects.

2.1 TECHNOLOGY OVERVIEW

Energy storage is serving a more important role in resiliency efforts across public and private installations throughout the world. The adoption of distributed energy resources (DERs) paired with advanced storage and microgrid controls is enabling consumers to operate independently during times of utility outage while maintaining seamless continuity of power supply to larger percentages of their site electric load. Battery energy storage as a redundancy and resiliency asset can trace its roots to UPS systems, providing, at most, a few minutes of backup power to small loads. Battery energy storage systems have since scaled to the mega-watt level and can deliver a few hours of capacity. These systems have considerably enhanced resiliency efforts and transformed microgrid designs into robust systems that can support a much wider range of critical loads and integrate with available traditional fossil fuel fired spinning generation as well as renewable generation. The next leap in energy storage technology, as both a microgrid and bulk electric grid asset, is to leverage its fast response time and ability to recharge with renewable generation to completely replace spinning generation (e.g. backup DGs). Numerous utilities are already making efforts to replace end of life peaking plants that infrequently run with very large BESS systems that can provide power for 2 to 4 hours.^x This likely requires energy duration levels beyond what is commercially mature today. One technology that has the potential to deliver this service is the VRFB. The VRFB technology is investigated in this project to assess its ability to be deployed as part of an integrated microgrid solution, which may include energy efficiency measures, microgrid controls, economic dispatch controls, and existing and/or new on-site generation.

Today's Li-Ion storage technology, which comprised over 90% of new storage deployments in 2017^{xi}, generates or absorbs current through the movement of charged lithium particles from one solid electrode to another within a cell. The amount of power (kW) and energy capacity (kWh) is a function of the electrode quantity and surface area, respectively. Multiple cells are assembled in a series-parallel configuration to form a battery. As a Li-Ion battery is charged and discharged over its life, the retained energy storage capacity depletes due to material degradation and impedance growth. The limitation on discharge duration of a Li-Ion battery is a result of a finite amount of volume that can be realistically packed and assembled in a cell, and because of the need to balance rated power and energy capacities to maximize life under a proposed duty cycle.

Flow battery storage is a fundamentally different electrochemical storage technology. Current is generated when a charge carrying liquid electrolyte solution is pumped from tanks through an electrode cell and into another tank. Charging and discharging occurs through the exchange of ions across and/or through a membrane within the stack of cells. As with Li-Ion, an inverter then converts the direct current (DC) to alternating current (AC) power. The DC power is a function of the surface area and number of membrane cells where the exchange of ions occurs, while the energy capacity is a function of the volume of electrolyte solution stored in the tanks.

This allows for more expansion of electrolyte and a longer duration capability than Li-Ion. Figure 3 below depicts a simplified diagram of VRFB operation (components not to scale).

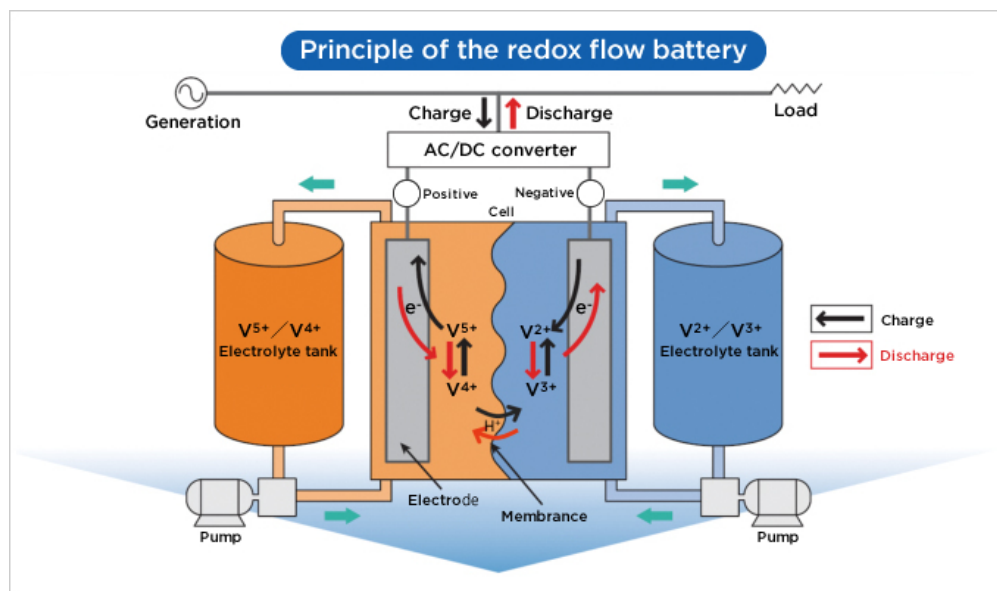


Figure 3. Principle Operation of a Redox Flow Battery^{xii}

In the last decade, flow battery systems have never been more than a few percentage points of the total new energy storage systems deployed, instead seeing flat to declining growth on an annual basis.^{xiii} This is in stark contrast to the growth of Li-Ion energy storage, which saw 232% year-over-year increase in the first quarter of 2019 and typically makes up over 99% of all recently installed systems.^{xiv} The benefits of this ESTCP funded work will provide the DoD and the industry at large a more detailed understanding of flow technology, supporting potential future growth in deployments. The technology is typically evaluated at Technology Readiness Level (TRL) 7 – System Prototype Demonstration in an Operational Environment.^{xv} Despite limited project deployment, the technology itself has undergone significant development and testing in private industry and at U.S. Federal government laboratories and agencies. Continuous development efforts have been on-going since the 1950s, with significant effort invested by NASA in the 1970s who produced the first iron-and-chromium redox flow battery. The first VRFB was initially developed in 1984.^{xvi} There are a handful of flow battery manufacturers in the marketplace today working to commercialize flow battery products. These companies range from startups with novel cell stack and electrolyte designs, to established companies looking to extend their product offerings in a new market. As with the Li-Ion battery industry when it was in its early growth phase, the regular announcement of company partnerships, acquisitions and failures are one indication of a number of aspects of a dynamic and evolving commercial market.

During this project, Ameresco conducted extensive research into flow battery technology, had discussions with numerous equipment providers, and gathered information for assessment of the technology and utilization of inputs and assumptions into our modeling. Similar to Li-Ion technology, there are multiple sub-categories of flow storage technology. As part of this effort, our team assessed three distinct types of flow battery chemistries: Vanadium; Zinc-Iron; and Zinc-Bromine as shown in Table 7.

Table 7. Types of Flow Batteries

Types of Flow Batteries	Liquid-Liquid	Liquid-Metal
Alkaline-Based	-	Zinc-Iron
Acid-Based	Vanadium	Zinc-Bromine

Through our technology assessment, we evaluated a total of 19 different technology providers who are developing and commercializing flow battery products. We assessed these companies and products based on characteristics including the type of chemistry they offer, company maturity, product maturity, system form factor, manufacturing location, rated power and energy configurations of their standard offerings, efficiency, operating temperature range, physical dimensions, cost, and more.

Based on assessment of numerous products, Table 8 provides a brief summary of basic characteristics of flow batteries. It should be noted that these are not representative of every product nor a single product but are intended to provide a “nominal” glance at flow battery technology in general.

Table 8. Assumed VRF Operating Parameters

Parameter	Typical Flow Characteristic
Rated Power (kW)	Up to 500 kW in a 40' container
Rated Energy (kWh)	400 kWh to 1,000 kWh for a 40' container
Round Trip Efficiency (%)	70% +/- 6%
Auxiliary Load Requirements (kW/MW)	10 - 80 kW/MW of power capacity
Energy Capacity Degradation	< 0.5% per year
Response Time	1 sec-1 min depending on mode of operation

The mechanical nature of the flow battery technology creates significantly different operating conditions as compared with “solid-state” storage technologies like Li-Ion which can significantly impact operational performance. Two specific differences are the auxiliary loads required to power pumping and cooling systems for the flow technology, and the round-trip efficiency of the system. As further described later in this report, our findings show that these operational differences create significantly less net value for behind the meter retail billing savings or wholesale market participation use cases, creating a greater challenge for VRF technology to provide lower cost of critical load support than Li-Ion storage.

In order to accurately model the VRF technology, our team established the following equations for auxiliary load which were derived based on technology research and conversations with vendors.

When discharging,

$$\text{If State of Charge (SOC)} > 10\%, P_{aux} = P_{pump-active} * (\text{No. of 1MW Units}) + P_{ec} + P_{edc}$$

If $SoC < 10\%$, $P_{aux} = (P_{pump-active} + P_{pump-ramp}) * (No. \text{ of IMW Units}) + P_{ec} + P_{edc}$

When charging,

At all SOC states, $P_{aux} = (P_{pump-active} + P_{cooling}) * (No. \text{ of IMW Units}) + P_{ec} + P_{edc}$

When idle,

At all SOC states, $P_{aux} = P_{pump-idle} * (No. \text{ of IMW Units}) + P_{ec} + P_{edc}$

Where:

$P_{pump-active} = 16 \text{ kW}$ (Active pumping load)

$P_{ec} = 1 \text{ kW}$ (Electronics and controls load)

$P_{edc} = 0.125 \text{ kW}$ (Economic dispatch controller load)

$P_{pump-ramp} = a \text{ linearly scaled value between } 8 \text{ kW at } 10\% \text{ SOC to } 0 \text{ kW at } 0\% \text{ SOC}$

$P_{cooling} = 55 \text{ kW}$ (Cooling system load during charging)

For a 1MW VRF resource, the above calculations yield a continuous auxiliary load of 11.125 kW when idle, up to 25.125 kW when discharging, and 72.125 kW when charging.

By comparison, based on our experience with multiple leading Li-Ion BESS equipment providers, the range of auxiliary loads for a similarly sized 1 MW system is between 1 kW to 5 kW. This shows that VRF aux loads are up to fifteen times higher than Li-Ion systems. These very high aux loads for VRF technology have been identified as a significant issue with the VRF technology inhibiting its potential for success, the impacts of which are quantified later in this report.

Through our research, including conversations with several flow battery equipment providers, it is clear that significantly more testing is required to characterize performance and reliability of the technology. To date, an in-depth understanding of the behavior and response time of the VRFB technology does not seem to have been developed, as companies focus (rightfully so) on product development and manufacturing. Two specific examples of this are verifying the speed of response during conditions where the VRFB would be needed for seamless islanding support, and the ability to accurately follow a high throughput, bipolar dispatch profile such as that of a frequency regulation ancillary service use case. Further, the long-term effects on system durability under these types of situations that require constant activity from the VRFB are not well understood.

Further testing and deployment experience is needed to more clearly define the reliability of the technology both in the lab and in the field. Most vendors appear to not yet have data on the Mean Time Between Failure (MTBF) of their product as part of a complete system (i.e. DC and AC components of a turnkey solution), either from laboratory testing or field deployments. Testing of individual components (e.g. cell stacks) is more robust, but data of the interaction of all the components are lacking. In part, this may be due to the rapid iterative development stage of VRFB technology, where new generations of the products are introduced frequently. This is especially true if changes are aimed at improving reliability (e.g. introducing magnetic bearing pumps for hermetic sealing and increased operational reliability). This makes it challenging to collect enough data on any given version to properly quantify MTBF and Probability of Failure to Start (P_{fs}) which are key metrics for this work. As a result, it proved difficult to accurately identify P_{fs} and MTBF metrics from vendors for the VRFB technology. Despite these challenges, we selected VRFB over other flow sub-chemistries because it has the longest development history and the largest number of active vendors, and more importantly, vendors that have existed for the longest period of time.

With that history comes more industry data and product descriptions. Moreover, since there are more vendors, it gives confidence that there will be commercial options when translating this research project to the field deployment phase. Similarly, vendors have not yet well characterized long term performance of the technology when subjected to specific use cases – especially high throughput and quickly responding applications such as frequency regulation or smoothing of PV generation.

Advancing the state of the art of the technology by conducting robust, controlled, and focused reliability testing in a HIL environment and in the field clearly seems to be an important need for the industry and an area where the ESTCP program can significantly impact. No matter how cost effective a VRFB can become, industry wide adoption of the technology will not materialize without a detailed and quantitatively supported characterization of the reliability and operational effectiveness of the technology. Of the vendors we evaluated, very few have deployed a system designed as part of a microgrid. The limited exposure to the technical requirements of microgrids highlights the importance of including additional vendors in robust real-world scenarios, starting with HIL testing. Validating additional vendors of different flow sub-chemistries will enhance the equipment options available to the DoD as long-duration energy storage technology becomes a more important component for delivering energy security in a microgrid.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Flow batteries differentiate themselves from Li-Ion in that the power (kW) and energy (kWh) components can be adjusted independently of one another without impacting performance. The decoupling of power and energy has several advantages. By increasing the volume of electrolyte, flow batteries can provide a 12 hour or longer duration of rated power capacity. This is a significant distinction from today's stationary Li-Ion products, which typically have a duration of rated capacity between 0.5 to 4 hours. While there are some Li-Ion systems with duration longer than 4 hours, this is often not economically viable and most commercially available Li-Ion storage product offerings are not sold with duration longer than 4 hours. Adding additional electrolyte volume later in a flow battery project's lifetime to reflect changing needs can be done without overbuilding other parts of the system. End of life recycling is also easier with VRFB systems. The vanadium can be extracted from the electrolyte and sold back to the commodity market, and the rest of the solution can be disposed of safely. End of life recycling for Li-Ion systems has yet to be properly addressed by industry players and has become more and more a hot topic looking to be addressed by industry regulators.

Safety is a paramount concern with any energy storage technology and has become highly publicized after the fire of a few Li-Ion systems. The electrolyte of VRFB, consists primarily of water. The vanadium is dissolved in water (along with other chemicals that make-up the proprietary electrolyte solution), and the electrochemical reaction is only mildly exothermic, effectively eliminating the concern of fire that is present with Li-Ion systems. Removing fire safety from the design considerations may facilitate a VRFB to be placed inside or underneath a building, or closer to other pieces of critical energy infrastructure. It is acknowledged that the electrolytes used in VRF systems are highly acidic, but the related health risks are manageable and equipment vendors have assumed standard practice to design secondary containment systems into their container design to manage worst case scenario electrolyte leaks.

Since the voltage and current generation is a function of ions exchanged between vanadium in two different oxidation states for the positive and negative side of the system, there is no energy capacity degradation of the electrolyte over time. Further, the lack of energy capacity degradation of the electrolyte solution over time ensures a consistent level of performance over the life of the project while reducing replacement costs associated with today's Li-Ion batteries. Flow battery manufacturers report negligible energy capacity degradation after 10,000 full cycles, whereas Li-Ion energy capacity degradation can be significant after only 1,000 full cycles¹. Also, flow storage typically has a broader ambient operating temperature range, requiring less active thermal management and could more easily serve a wider array of geographic regions without additional HVAC cost. These benefits indicate that flow batteries could serve as a key building block to achieving a renewable based microgrid that can sustain load for days or weeks without reliance on DGs.

The focus to date on short-duration (up to 4 hours) storage coupled with significant price drops of Li-Ion cells driven by widespread adoption of Li-Ion in consumer electronics and electrified vehicles have accelerated the Li-Ion based stationary storage sector far ahead of flow batteries. The electrolyte solution and the cell stack are the two primary pieces of intellectual property and thus proprietary to each flow vendor, and the electrolyte solution is the single biggest cost in a system. The remainder of systems are typically built using commercially available off-the-shelf components and helps to keep the remaining initial system costs low. Moreover, this helps contain costs during the entirety of the project lifecycle. Prior to operation, standard parts will help to drive down initial equipment costs by leveraging existing economies of scale and existing supply chains, the latter will also help scale deployments should VRFB adoption become widespread. During the operating phase of a project, readily available parts will ensure system operation and maintenance is feasible and cost-effective. Vanadium is also extensively used in the steel industry, with robust existing supply chains and an active secondary market once a project is decommissioned.

2.3 RISKS ASSOCIATED WITH THE TECHNOLOGY

There are several inherent limitations of flow storage relative to Li-Ion energy storage systems that likely will not be eliminated through engineering and product development. One of the drawbacks of VRFB relative to Li-Ion is a lower Round Trip Efficiency (RTE). This metric is often described as the ratio of useable output energy to the input energy. Once the operation of pumps and efficiency of the cell stack is factored in, the RTE of VRFB is about 15% lower than commercially available Li-Ion systems. Despite a lower average HVAC parasitic load due to the large thermal mass of the electrolyte solution, VRFB have higher auxiliary system load (measured as kWh/day). This is mostly attributed to the pumps required to move the electrolyte solutions and is a required load for the system to operate. Near constant operation of the pumps, even if at a reduced duty cycle, will likely be required to keep a VRFB ready to support transition to island operation when included in a microgrid design. There are also physical limitations to the size of the cell stacks to maintain a constant pressure of the liquid through the stacks, and this will act as a fixed space constraint for present and future systems. The energy density of the electrolyte (kWh/ft³) can be improved, and is an area of active research, however, it is unlikely it will reach the same density as Li-Ion cells.

¹ This degradation is highly dependent on the discharge rate, depth of discharge, and environmental conditions in addition to the number of cycles, and can thus vary by product and use case

The tanks holding the electrolyte can be stacked vertically, but the required installation area will likely be larger than for a similarly sized Li-Ion system.

Specific focus has been made during Phase I on quantifying the impact of these shortcomings. For example, RTE significantly impacts net revenue from providing frequency regulation as an ancillary service in wholesale electricity markets since the battery experiences high amounts of charge and discharge energy throughput while following the ISO's dispatch signal. A lower RTE causes the battery's state of energy (SOE) to more rapidly decline to 0%, given an otherwise energy neutral dispatch signal, forcing it out of the market for recharging. Although this would occur to some extent with any BESS, the lower RTE causes quicker SOE decay, reducing potential market revenue and increasing operating cost related to recharging. However, a flow battery with significantly longer duration will be able to perform in the market for longer periods of time before being depleted, which could be advantageous in wholesale energy or capacity markets. As summarized in Section 6, the grid tied modeling of this work provided quantitative information used to assess the impact that these efficiency and auxiliary load issues have on system operation and project economics.

As noted earlier, flow energy storage systems have seen limited deployment with effectively no increase in annual growth rates over the last decade. Predicting the trend of new technology at the early stages of development can be particularly challenging (e.g. the innovation "S-curve"). However, with five more years of development, many vendors will likely achieve sufficient accelerated laboratory runtime testing to validate performance and reliability under several use cases required for microgrid operations.

Material and environmental safety risks of VRFB are limited. The electrolyte solution is highly acidic (pH around 1), but tanks are enclosed with secondary containment tanks. Sensors monitor pH and liquid levels. In discussions with several vendors, leaks in the tanks do not manifest as catastrophic failures, but instead as slow faults that offer enough time to safely stop the system, isolate the leak, and repair or replace components. Since the tanks, pumps and other components are off-the-shelf, there would not be a need to wait for the manufacturing of custom parts.

However, as this ESTCP solicitation recognizes, there is a need for storage solutions of significantly longer duration that provide a lower levelized cost of stored energy over a 20-year project term, and flow storage technologies offer significant promise for achieving those goals.

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3.0 PERFORMANCE OBJECTIVES

The primary objective of this work is to demonstrate how flow battery energy storage can add reliability and economic value to a DG baseline microgrid. This was investigated through a series of sub-objectives, summarized in Table 9, each of which were assessed through analytical modeling of defined microgrid configurations and scenarios. The baseline microgrid referred to throughout this report contains a series of DGs sized to meet critical load with N+1 redundancy and UPSs to provide ride through power supply to a subset of critical loads. There is no BESS in the baseline microgrid. The BESS enabled microgrid replaced the least running DG at each site with an appropriately sized VRF battery for comparison to the baseline.

Table 9. Performance Objectives

Objective	Category of Interest	Description of Objective
<i>Objective 1</i>	<i>Reliability</i>	Calculate hourly probability of serving 100% of critical load requirement during a utility outage of up to 168 hours in duration that could start at any hour of the year
<i>Objective 2</i>	<i>Reliability</i>	Calculate hourly probability of serving 130% of critical load requirement during a utility outage of up to 168 hours in duration that could start at any hour of the year
<i>Objective 3</i>	<i>Reliability</i>	With no diesel fuel supply, calculate hourly probability of serving 30% of critical load during a utility outage of up to 24 hours that could start at any hour of the year
<i>Objective 4</i>	<i>Reliability</i>	With no diesel fuel supply, calculate hourly probability of serving 10% of critical load during a utility outage of up to 24 hours that could start at any hour of the year
<i>Objective 5</i>	<i>Reliability</i>	Determine minimum amount of power and energy BESS requirements such that the Objective 1 outcome meets or exceeds the fixed load baseline performance
<i>Objective 6</i>	<i>System Design</i>	Identify the rated power and energy capacity sizing of the optimally sized BESS
<i>Objective 7</i>	<i>Economic Feasibility</i>	Quantify annual value proposition of BESS through retail and wholesale use cases, based on current and future volatile market conditions
<i>Objective 8</i>	<i>Economic Feasibility</i>	Calculate the cost of securing critical load for the BESS enabled microgrid as a function of 20-year Net Present Value and how this compares to the baseline, DG only microgrid
<i>Objective 9</i>	<i>Reliability & Economic Feasibility</i>	Identify if VRF or Li-Ion is the preferred technology for the proposed BESS.
<i>Objective 10</i>	<i>Economic Feasibility</i>	If required, identify the price point at which VRF BESS technology provides a preferred solution as compared with Li-Ion

The investigation strived to create a BESS enabled microgrid that meets or exceeds the performance of the existing resiliency assets (i.e. the DGs), at five military installations. Details of these installations are provided in Section 4. Our specific performance objectives are based on the initial Broad Agency Announcement soliciting proposals, clarified in the Project guidance from November 2018, and reiterated through the guidance given by the ESTCP team. The primary and alternative objectives are described in more detail below. Following this description of objectives, an example table of performance objectives and results is provided for Westover ARB. Similar tables for all investigated sites are provided in Appendix A.3.

3.1 PRIMARY OBJECTIVE

1. Objective: *Reliability to Meet 100% of Installation Critical and Ride-through Load*

- **Description:** *This objective is the primary scenario for which the microgrid is being designed. With this objective we can answer whether the energy security performance of the microgrid with the proposed BESS solution will meet or exceed the required reliability for 100% of the defined critical load for a 24-hour and a seven-day outage for each of the evaluated installations.*
- **Metric:** *This metric is defined by an hourly probability curve of the likelihood of the microgrid to be able to successfully operate and fulfill 100% of the site's critical electric load required from hours 1 to 168 after an outage at the installation ("Critical Load Coverage Probability Curve" or "CLCPC"). The baseline for success assumes a constant hourly load profile equal to each site's annual peak hourly critical load (kW).*
- **Requirements for Success:** *If the CLCPC meets or exceeds the fixed load baseline microgrid's CLCPC for each installation at 24 and 168 hours of the outage, the microgrid meets the required performance. Additionally, if the CLCPC curve exceeds the fixed load baseline CLCPC curve for all hours in the outage, the set of assets simulated (DGs plus battery storage) in the microgrid configuration are deemed favorable and included for further grid-tied modeling.*

3.2 ALTERNATIVE TECHNICAL SCENARIOS

2. Objective: *Reliability to Meet 130% of Installation Critical and Ride-through Load*

- **Description:** *This objective allows us to understand the performance of the microgrid when critical loads are above historical projections due to load growth or rare circumstances. It also allows visibility into the capacity of the microgrid to serve load beyond the critical load.*
- **Metric:** *The metric for this objective is the same as for Objective #1.*
- **Requirements for Success:** *No minimum performance was required*

3. Objective: *Reliability to Meet 10% and 30% of Installation Critical and Ride-through Load when no Diesel Fuel is Available*

- **Description:** *This objective allows us to understand the performance of the microgrid when there is a fuel shortage in an extended duration outage and extreme circumstances. Given that most microgrid configurations will always include some DGs, this scenario is critical for the military installations' emergency preparedness planners to understand.*
- **Metric:** *The metric for this objective is the same as for Objective #1.*
- **Requirements for Success:** *No minimum performance was required.*

3.3 FINANCIAL OBJECTIVE

4. Objective: *Net Life-cycle Costs of Deployment and Operation (corresponding to technical objective 1 above) & Associated Cost of Critical Load Coverage*

- **Description:** *This objective aims to determine if a storage-enabled microgrid that meets or exceeds reliability performance of the baseline microgrid can reduce the cost of critical load coverage (\$/kW_c) as compared to the baseline microgrid. This was completed for current cost and market conditions and future cost and market conditions.*

- **Metric:** Costs are calculated using the 20-year net present value methodology applied to the baseline microgrid and distributed by the ESTCP team.
- **Requirements for Success:** In order to succeed, the cost of critical load support of the battery enabled microgrid should be equal to or less than the cost of critical load support of the DG only baseline microgrid.

Table 10 summarizes these performance objectives and results for Westover ARB. Similar tables for all sites are provided in Appendix A.3

Table 10. Westover ARB Performance Objectives & Results

WESTOVER ARB				
Performance Objective	Metric	Requirements	Success Criteria	Results
1. Reliability to Meet 100% of Installation Critical and Ride-through Load	Critical and ride-through load served during outage (that can begin at any time)	Performance measured for outages of any duration between 1 hour and 168 hours	Meets or exceeds reliability probability curve from fixed load baseline microgrid specifically for 24- and 168-hour outages. Compares favorably with fixed load baseline microgrid at other outage durations under 168 hours.	<u>Baseline</u> 24-h: 0.99831 168-h: 0.95076 <u>Proposed BESS</u> 24-h: 0.99923 168-h: 0.97170
2. Reliability to Meet 130% of Installation Critical and Ride-through Load			Proportion of critical and ride-through load served (probabilistically) for 24- and 168-hour outages. No minimum standard.	<u>No PV</u> 24-h: 0.98210 168-h: 0.81173 <u>Expected PV</u> 24-h: 0.98671 168-h: 0.84147
3. Reliability to Meet 10% and 30% of Installation Critical and Ride-through Load when no Diesel Fuel is Available		Performance measured for outages of any duration between 1 hour and 24 hours	Proportion of critical and ride-through load served (probabilistically). No minimum standard.	<u>10% No PV</u> 1-h: 0.99003 4-h: 0.00056 24-h: 0.00000 <u>10% Exp. PV</u> 1-h: 0.99431 15-h: 0.00638 24-h: 0.00000 <u>30% No PV</u> 1-h: 0.03197 4-h: 0.00011 24-h: 0.00000 <u>30% Exp. PV</u> 1-h: 0.41085 13-h: 0.00316 24-h: 0.00000
4. Net Life-cycle Costs of Deployment and Operation (corresponding to technical objective 1 above)		Calculate per methodology distributed with baseline microgrid data and results	Net cost (per kW of critical load) is at or below level of baseline microgrid in current and future volatile scenarios	<u>Baseline</u> \$166/kW <u>VRF Current</u> \$251/kW <u>Li-Ion Current</u> \$156/kW <u>VRF Future</u> \$196/kW <u>Li-Ion Future</u> \$129/kW

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4.0 FACILITY/SITE DESCRIPTION

There are five military installations chosen for investigation through this Phase 1 scope of work. They include two Navy installations – Naval Air Station (NAS) Patuxent River and NAS Corpus Christi, two Air Force installations – Westover Air Reserve Base (ARB) and March ARB, and one Army installation – Fort Bliss. These sites provide a diverse mix of site operations, load profiles, critical load levels, geographic location, utility rate parameters, and wholesale market opportunities. The peak annual electric load ranges from 3.4 MW to 33.9MW across the five installations. The critical load ratio specified across the sites ranges from 7.5% to 50%.

Table 11 summarizes the major characteristics of each site based on ESTCP provided installation data (e.g., physical, energy assets, electricity rates, and markets).

Table 11. Installation Energy Data

	Units	Westover ARB	NAS Patuxent River	NAS Corpus Christi	Fort Bliss	March ARB
State	--	Massachusetts	Maryland	Texas	Texas	California
ISO	--	ISO-NE	PJM	ERCOT	N/A	CAISO
Annual Peak Demand (kW)	kW	3,414	33,958	23,965	67,605	7,998
Annual Electric Energy Consumption (kWh)	kWh	16,604,852	187,845,654	121,527,298	331,184,255	43,528,894
Critical Load %	%	50.0%	23.6%	18.4%	18.5%	7.5%
PV Capacity (kW-AC)	kW-AC	1,931	1,931	1,159	5,986	386
PV Annual Generation	kWh	2,929,437	3,580,856	2,164,223	14,459,881	903,505
Annual Utility Import (kWh)	kWh	13,675,415	184,264,798	119,363,075	316,724,374	42,625,389
# DGs	#	4	12	7	8	4
DG Capacity Per Unit (kW)	kW	750	750	750	2,000	250
Capital Cost of DG	\$/kW	\$ 750	\$ 750	\$ 750	\$ 600	\$ 1,100
Heat Rate of DG	Btu/kWh	12,040	12,040	12,040	10,618	14,404
Annual O&M and Testing Cost of DG	\$/DG	\$ 7,000	\$ 7,000	\$ 7,000	\$ 20,000	\$ 6,500
Diesel Fuel Price	\$/gal	\$ 2.65	\$ 2.74	\$ 2.42	\$ 2.59	\$ 2.97

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The five sites were selected to create a portfolio of geographic and market diversity, allowing for a wide range of options for potential Phase 2 demonstration environments. Consideration was also given to the available value-generating applications, which vary based on the regional market and regulatory environments. This selection of locations will help assess if any particular regions pose greater market opportunities or barriers than others.

Figure 4 below shows a map of ISO regions in the United States overlaid by locations of each of the installations this investigation studied. A summary of each installation's operations and activity follows the figure.

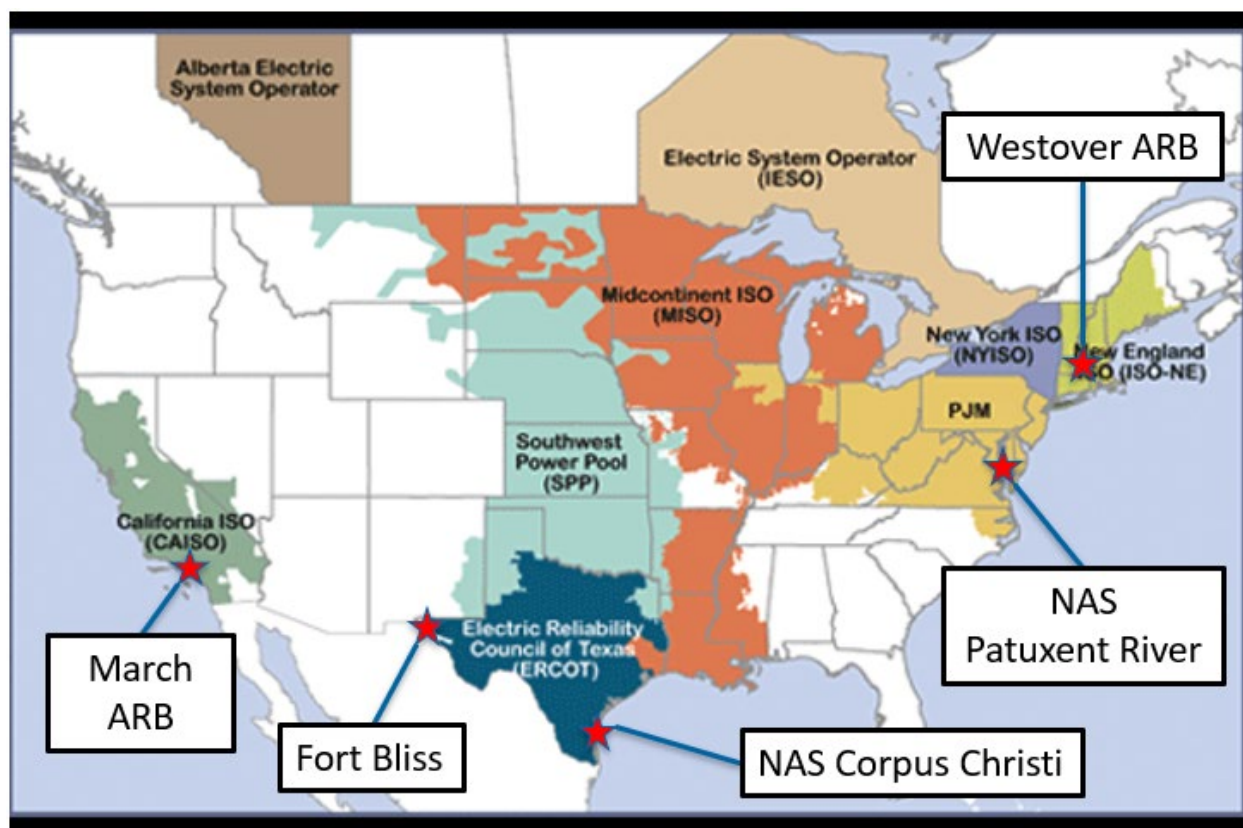


Figure 4. Map of Site Locations^{xvii}

Westover Air Reserve Base

Westover ARB is located in Chicopee and Ludlow, Massachusetts. The site receives delivery of electric service from the Chicopee Electric Light municipal utility and is located within the ISO-New England regional electric system. The installation is the nation's largest Air Force Reserve base and is home to more than 5,500 military and civilian workers.^{xviii} The site has been in operation since 1940 and currently provides rapid air lift services in support of military and humanitarian operations. The baseline conditions of the site include an annual peak demand of 3.4 MW, (4) DGs each rated at 750 kW, a 2.0 MW-AC Solar PV system, and a critical load percentage of 50%.

Naval Air Station Patuxent River

NAS Patuxent River is located in Solomons Island, Maryland approximately 90 miles north of Norfolk, Virginia and 65 miles south of Washington, D.C. The site receives electric service from the Southern Maryland Electric Cooperative (SMECO) and is located within the PJM regional electric system. The site serves as the Naval Air Systems Command Headquarters, hosts the U.S. Naval Test Pilot School, the Atlantic Test Range, and has evolved into the Center of Excellence for Naval Aviation.^{xix} The site is the second largest of the five investigated with an annual peak demand of 33 MW. The site includes (12) DGs each rated at 750 kW, a 2.0 MW-AC Solar PV system, and a critical load percentage of 23.6%.

Naval Air Station (NAS) Corpus Christi

NAS Corpus Christi is located in Corpus Christi, Texas on the shore of the Gulf of Mexico. The site receives electric service from AEP Texas Central and is located within the ERCOT electric system. The site has hosted Naval pilot training since 1941 and currently serves to conduct pilot training for the Navy, Marine Corps, and Coast Guard. The site is also home to the Corpus Christi Army Depot, the primary aviation maintenance depot for Department of Defense rotary wing aircraft.^{xx} The baseline conditions of the site include an annual peak demand of 23.9 MW, (7) DGs each rated at 750 kW, a 1.1 MW-AC Solar PV system, and a critical load percentage of 18.4%.

Fort Bliss

Fort Bliss is a 1,700 square mile United States Army installation headquartered in El Paso, Texas. It is the largest installation in the US Army Forces Command and second largest Army installation. Fort Bliss executes deployment operations and provides facilities and services that assists units in sustaining their combat readiness.^{xxi} The site receives electric service from El Paso Electric. It is the only site of the five investigated that is not located in an ISO territory and is therefore not regulated by ERCOT or FERC. From an electric consumption standpoint, Fort Bliss is the largest of the five sites an annual peak demand of 67.6 MW, (8) DGs each rated at 2000 kW, a 5.9 MW-AC Solar PV system, and a critical load percentage of 18.5%.

March Air Reserve Base

March ARB is located in Riverside County, California approximately 60 miles from Los Angeles. March ARB is home to the Air Force Reserve Command's Fourth Air Force Headquarters and the 452nd Air Mobility Wing.^{xxii} The site receives electric service from Southern California Edison (SCE), energy supply from the Western Area Power Administration (WAPA) and is located within CAISO territory. The baseline conditions for March ARB include a peak demand of 7.9 MW, (4) DGs each rated at 250 kW, a 386 kW-AC Solar PV system, and a critical load percentage of 7.5%.

Analysis of hourly load data provided for each site shows that each installation has a unique load profile. An installation's load profile shape will vary based on a number of factors include weather, occupancy trends, operations, equipment, on-site generation, etc. This load profile also has a relationship with the opportunity for DERs to provide value to the site. For example, since energy storage systems are limited energy resources, the amount of retail demand savings that could be realized is a function of the shape of the daily load profile. For a given amount of energy storage capacity (kWh), a site with a spikier load profile will realize more demand reduction (kW) than a site with a flatter load profile. Figure 5 and Figure 6 plot each site's annual peak day hourly load profile, before any existing PV is accounted for. For Bliss, NAS Corpus Christi, and NAS Patuxent River each have annual peak demands greater than 20 MW and are collectively shown on Figure 5. March ARB and Westover ARB, each with annual peaks below 10 MW, are shown on Figure 6.

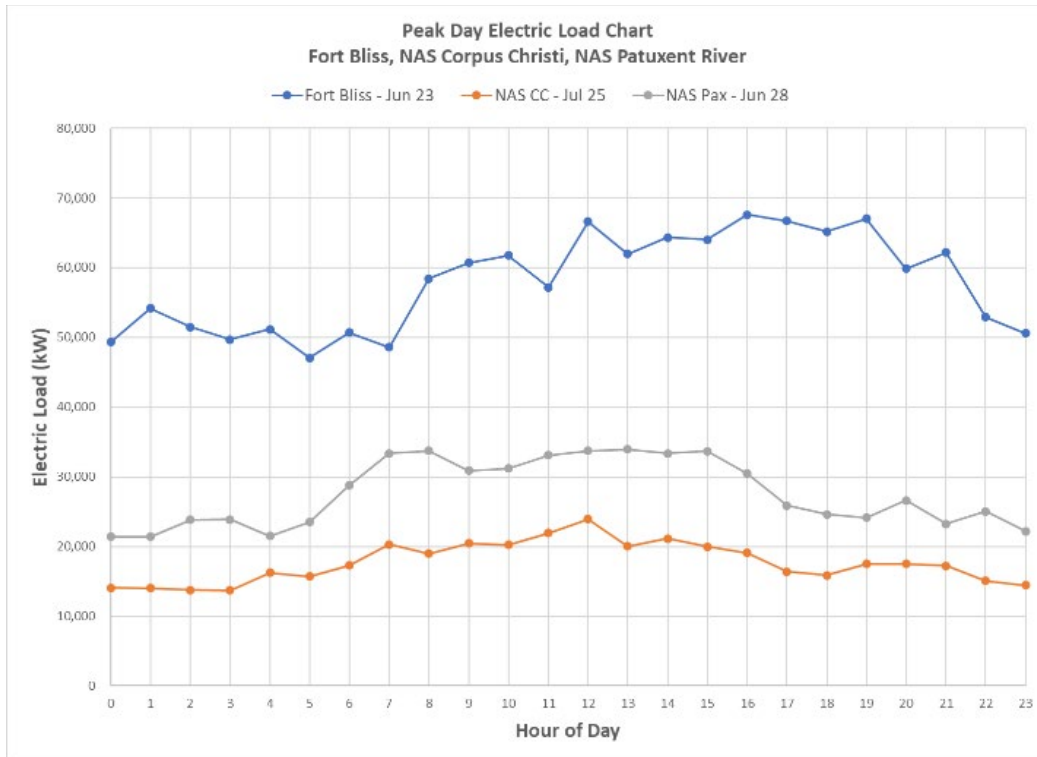


Figure 5. Comparison of Existing Electric Load Profile - Fort Bliss, NAS CC, NAS Patuxent River

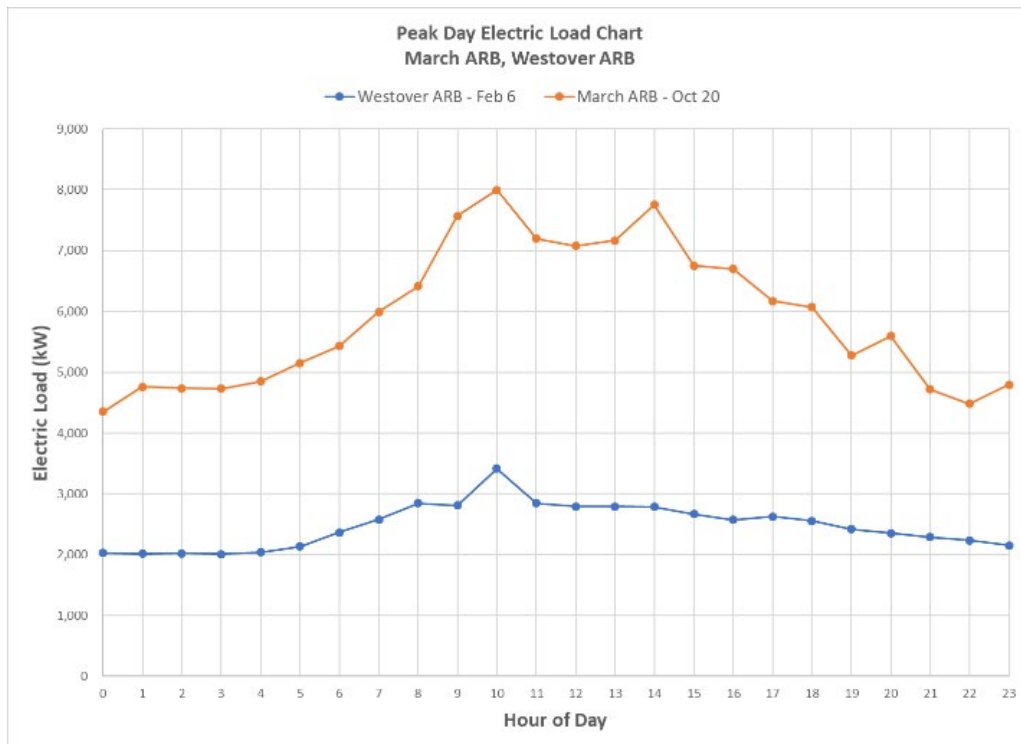


Figure 6. Comparison of Existing Electric Load Profile - March ARB & Westover ARB

4.2 FACILITY/SITE CONDITIONS

For each of the five installations, we modeled grid tied operating simulations of VRF and Li-Ion BESS systems of a range of system sizes. Once the minimum BESS power and energy requirements of the microgrid were established (as described in Section 5), a series of rated power and energy system sizes that met or exceeded those minimum requirements were identified. This spanned a range of BESS systems of 1 to 10 hours of duration, which was a reasonable limitation of range based on standard product offerings of Li-Ion and VRF BESS equipment providers. The use cases investigated through this work included:

- Retail Demand Charge Management (DCM)
- Retail Time of Use (TOU) Energy Savings
- Wholesale Energy & Reserves (co-optimized)
- Wholesale Regulation

Our team recognizes that there could be significant value in providing wholesale capacity obligations with a standalone energy storage resource or one paired with on-site generation. We also recognize that the requirements for providing capacity vary from ISO to ISO. For example, a resource providing capacity in PJM is required to be available for at least 10 hours which will be significantly more difficult for a BESS than in ISO-NE, where the capacity requirement is 4 hours. Since it was not a government objective to assess the capacity market, we did not quantify the value this use case could provide and instead focused on the aforementioned retail and wholesale use cases. Further, it should be noted that Fort Bliss is located in Texas but is not located in ERCOT territory and therefore does not have access to any wholesale market participation. Finally, through our assessment of market participation opportunities for storage, the opportunities for storage located behind the meter are relatively absent in ERCOT and were therefore treated as not available for NAS Corpus Christi.

If it is determined a BESS can reliably replace a DG asset at a site, the value of the capital expenditure and operating expense savings for each site is also listed. It is our position that there are no diesel fuel savings to be accounted for either in microgrid operation (since the BESS can recharge from the DGs, using the fuel) or grid tied operation. During microgrid operation, it was assumed that there was an infinite supply of diesel fuel per guidance from the ESTCP program. During grid-tied operation, a small number of DGs operate to provide demand response or peak shaving at some sites, or do not operate at all at other sites where those use cases are prohibited. At the sites where DGs do participate in demand response or peak shaving, the operation of the BESS would not reduce or eliminate that operation from other DGs in the fleet. A summary of the identified use cases for each site is shown in Table 12.

Table 12. Grid Tied Use Case Stacks for Each Site

Site	ISO	Retail DCM	Retail TOU	Wholesale Energy	Wholesale Reserves	Wholesale Regulation	One Time DG CapEx Savings	Annual DG OpEx Savings (not incl. fuel)
Westover ARB	ISO-NE	•	• (1)	•	•	•	\$562,500	\$7,000
NAS Patuxent River	PJM	•		•	•	•	\$562,500	\$7,000
NAS Corpus Christi	ERCOT	•					\$562,500	\$7,000
Fort Bliss	N/A	•	•				\$1,200,000	\$20,000
March ARB	CAISO	•	•	•	•		\$275,000	\$6,500

1

Requires 80% RTE to be economically justified. Applicable to Li-Ion, not Flow.

Representative Battery Energy Storage System Description

The following provides a high-level summary of the basic components and maintenance requirements of Li-Ion and VRF battery systems. Figures 8 and 9 depict a general configuration of a Li-Ion and VRF BESS, respectively. Generic scopes of annual maintenance for each technology are provided in Tables 13 and 14, showing that a similar scope of annual maintenance is expected for VRF systems than Li-Ion systems. The scope of work and schedules for each technology are based on documentation from various well-established Li-Ion vendors Ameresco has worked with in the past, or from discussions with VRF vendors looking to establish a presence in the energy storage market. This is intended only to give a basic understanding of the technology and not necessarily fully reflective of systems installed in the field. All energy storage systems analyzed for this work were assumed to be AC coupled.

High level components of Lithium-ion battery energy storage system

Lithium-ion battery energy storage systems transform chemical energy into electricity using electrochemical cells. Energy as electric charge is stored in the lithium ions that move from the negative electrode (anode) through a non-aqueous electrolyte to the positive electrode (cathode). The voltage developed by a battery cell depends on the lithium compound used for the cathode and electrolyte and the resultant electrochemical potential change in the reaction.

The capacity of a battery cell is the amount of electric charge delivered at a voltage and is dependent on the chemical characteristics of the cells. As a result, cells have inherent electric charge and voltage potential. In order to increase terminal voltage of a battery beyond that of a single cell, cells are stacked in series; while stacking cells in parallel increases the capacity at the terminal voltage of a single cell. Stacking in a series-parallel combination increases both and is how larger battery systems are assembled. In commercially available cells, the electrolyte is a flammable material and needs to be kept within a specified temperature range during operation. The electric charge generated by a battery is direct current, meaning it is a constant, unidirectional flow.

A battery management system (BMS) controls the charge and discharge of cells, ensuring they are cycled evenly, and operates the thermal management system to ensure the cells stay within appropriate temperature ranges. A power conversion system (PCS) then transforms the direct current into alternating current that is more widely used by both equipment and the electric grid and then connected to any project specific power conversion equipment (e.g. medium voltage transformers). Figure 7 shows a simplified one-line diagram of a Li-Ion BESS.

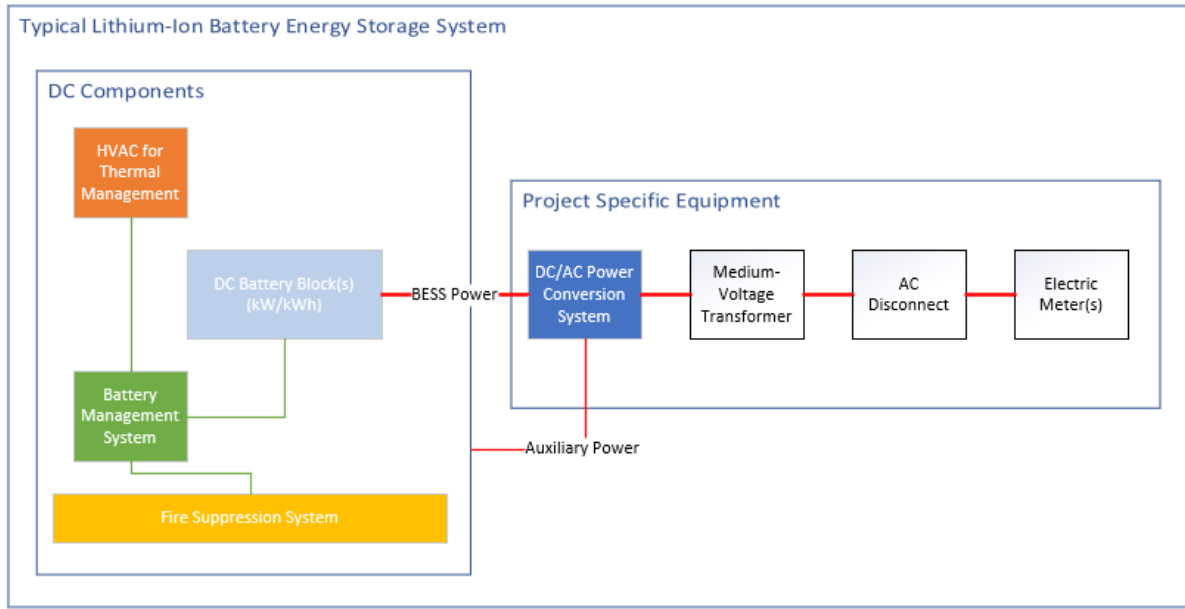


Figure 7. Simplified One-Line of a Li-Ion BESS

Table 13. Sample Preventative Maintenance Checklist for Li-Ion BESS

Lithium-Ion	Preventative Maintenance (PM) Task	Frequency
Electrical	Visual inspection of wires and breakers	6 months
	Test backup batteries and replace if necessary	6 months
	Cable harness inspection or replacement	1 year
Mechanical	Repair any deteriorated weather-stripping	6 months
	Check for external debris and leaks	6 months
	Torque and calibration checks	1 year
Fire Suppression System	Verify tank pressure gauges, resolve any faults	6 months
HVAC	Verify module temperature in allowed range	6 months
	Remove airborne contaminants from condenser finned coils	6 months
	Inspect and replace air filter if necessary	6 months
	Ventilation system inspection, cleaning	1 year
	Battery pack refrigerant refill and coolant pump replacement	5 years
	Battery pack coolant system refill, fan and valve replacement	10 years
PCS (Inverter)	Inspect and replace air filter if necessary	6 months
	Inspect and clean heat exchange coil and fans air paths	6 months
	Coolant refill, fan and pump replacement	10 years

High level components of Vanadium redox flow battery energy storage system

Vanadium redox flow battery (VRFB) energy storage system transform chemical energy into electricity by leveraging the potential energy difference of different oxidation states of vanadium (element symbol V). Vanadium salts are dissolved into a solution of sulfuric acid and water, creating a vanadium-based electrolyte with a specific ratio of V^{3+} and V^{4+} vanadium ions, and these make up the anolyte and catholyte, respectively, and are stored in separate tanks. The tanks are then enclosed in a secondary container in case of leakage. The electrolyte is pumped from each tank across and through a membrane to operate the battery. The charging process oxidizes the catholyte and converts the V^{4+} to V^{5+} and the anolyte is reduced from V^{3+} to V^{2+} , and external power is used during the charging phase to enable the reduction-oxidation reactions. The opposite occurs during the discharge phase, where the vanadium ions in the catholyte convert back to V^{4+} and the vanadium ions in the anolyte convert back to V^{3+} while generating a current. Pumping is required during all charge and discharge operation. Since there is no physical or chemical dependency between the electrolyte and the cell stack, VRFB can scale the power and energy components of a system independently. The same cell stack can be used with 10 gallons of electrolyte, or 600 gallons of electrolyte. Conversely, one cell stack or several cell stacks could all be connected to the same volume of electrolyte solution. Due to the thermal mass of a liquid electrolyte, the thermal management of a VRFB is different from lithium-ion systems since the electrolyte is non-flammable and less affected by changes in ambient temperature. As a result, no fire suppression system is required with VRFB. Operation of cooling fans is typically only required during the charging cycle. Magnetically coupled pumps are used to increase reliability, decrease operating costs, and isolate mechanical systems from any potential leaks in the electrolyte tanks. Similar to a lithium-ion system, a battery management controller orchestrates the operation of the pumps and thermal management system based on the operation of the VRFB system. The cell stack is connected to a DC-DC converter to boost the DC voltage to reduce the parasitic losses that occur when the stacks operate at high voltages. The DC voltage is boosted to match the requirements of the PCS and is connected to any additional project specific power conversion equipment (e.g. medium voltage transformers). Figure 8 shows a simplified one-line diagram of a VRF BESS.

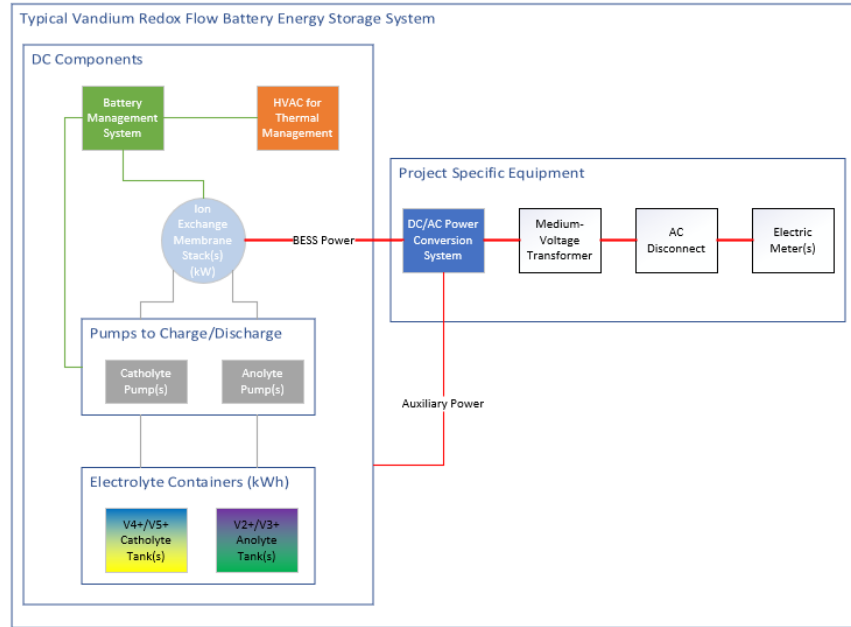


Figure 8. Simplified One-Line of VRF BESS

Table 14. Sample Preventative Maintenance Checklist for VRF BESS

VRFB	Preventative Maintenance (PM) Task	Frequency
Electrical	Visual inspection of wires and breakers	6 months
	Clean power connection	2 years
	Inspect sensor harness and wiring	2 years
	Replace DC/DC converter	12 years
Power Stack	Replace cell stack(s), including reference	11 years
Mechanical/Electrolyte	Perform pump motor vibration analysis	6 months
	Sensor calibration	6 months
	Inspect and clean electrolyte pumps and tanks	2 years
	Adjust electrolyte Vanadium balance	4 years
	Replace electrolyte pumps	8 years
	Repair/refurbish electrolyte hose and fittings	8 years
HVAC	Inspect and replace air filter if necessary	6 months
	Ventilation system inspection, cleaning	1 year
	Remove airborne contaminants from condenser finned coils	6 months
PCS (Inverter)	Inspect and replace air filter if necessary	6 months
	Inspect and clean heat exchange coil and fans air paths	6 months
	Coolant refill, fan and pump replacement	10 years

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5.0 METHODOLOGY

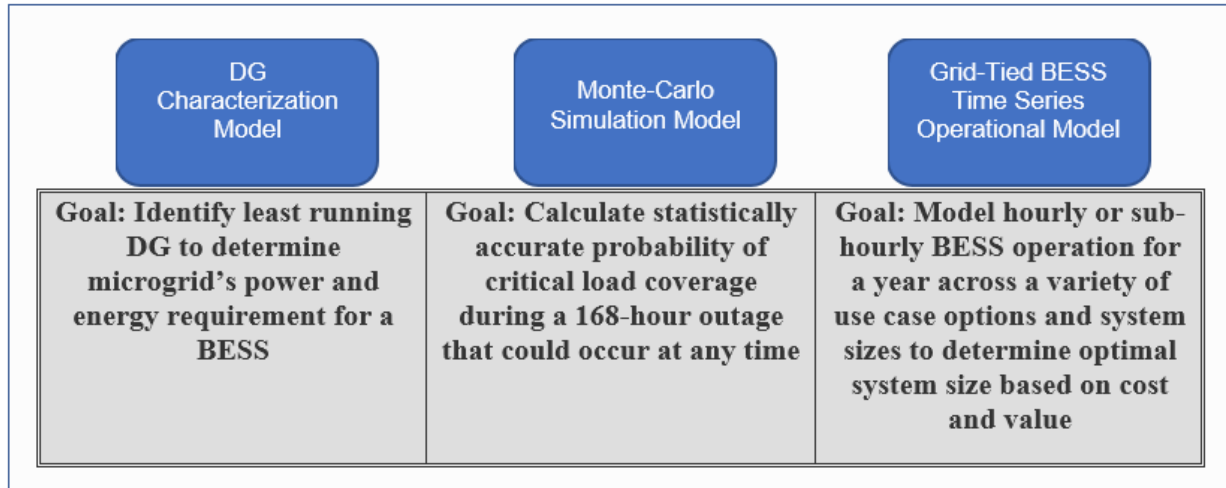
5.1 SUMMARY OF TECHNICAL METHODOLOGY

The objective of this project is to determine what configuration of battery system(s) provides adequate reliability performance in a way that also provides equal or lower cost of critical load support. Conceptually, although BESS equipment has a higher cost than DG, the ability for a stationary BESS to yield higher annual value than a DG during normal grid tied operation could enable a more economically viable choice that also provides new flexibility to microgrid operation. Each site investigated in this project has multiple DG assets as part of its baseline microgrid. Our team's objective was to identify the least running DG, determine how much power and energy was required by that DG during a seven-day islanding period, and size a BESS to replace that single asset. From a microgrid support standpoint, this BESS configuration is defined by the quantity of BESS units (1 or more) and the amount of total power and energy capacity needed by the microgrid to maintain or exceed the existing reliability performance over an outage of up to 168 hours. The potential need for more than one BESS unit depends on the failure mode of Monte Carlo reliability modeling. The required amount of critical load may fail to be served if a BESS does not have enough power, does not have enough energy, or fails to start or to continue to run. This failure to start or failure to run are modeled based on a statistical rate of occurrence utilizing assumed reliability metrics. In the case where equipment reliability is the failure mode, splitting the system into multiple independent systems reduces the likelihood of total failure and increases the probability of the BESS enabled microgrid to serve the desired critical load.

Once this was identified, we then modeled grid tied operation of up to six BESS sizes that each satisfied the microgrid power and energy requirements. Once the estimated annual value, implementation cost, and annual operating expenses were identified for each BESS, we down selected to the most economically viable VRF and Li-Ion BESS for each site. Finally, we calculated the cost of critical load support of the BESS enabled microgrids and compared to that of the baseline DG only microgrid. This series of modeling phases is depicted in Figure 9 below.

Our investigation chose not to propose replacement of the existing UPS assets at the studied installations. UPSs are already established and well equipped to provide seamless ride-through capability to top priority critical loads. If a BESS had available energy capacity at the time of the outage, it could supplement the amount of critical load that could be seamlessly islanded during an outage. However, for the scope of this work it was preferred to focus on quantifying the extent to which a BESS can reduce DG reliance – a desirable objective working towards a longer-term vision of less dependence on fossil fuels.

It is envisioned that the proposed BESS would be dispatched during normal grid tied operation to maximize value through retail utility billing savings and participation in wholesale market opportunities where available. Control of the asset would be managed by on-board BMS, an Economic Dispatch Controller, and/or controls and communication equipment required to participate in wholesale markets such as Frequency Regulation where relevant. During grid tied operation, the BESS would be allowed to charge and discharge across its full range of energy capacity since the UPS assets carry ride through responsibility. At the time of an outage, the BESS would be immediately fully charged from surplus DG capacity as further described below, enabling it to serve critical load during times when all other DG assets are at capacity, and re-charge during times of low critical load and surplus PV and/or DG generation capacity.



AESOP: Ameresco Energy Storage Optimization Platform

Figure 9. BESS Enabled Microgrid Modeling Phases using AESOP

This methodology involved a series of steps of modeling and analysis to ultimately identify a

The following information describes in detail the analysis process that was completed for each site, accompanied by a flow diagram located in Appendix A.2.3.

DG Characterization (further detailed in section 5.2)

1. Characterize the run time of each DG to meet variable critical load for each site, across 8760 unique 168-hour outage scenarios (Note this is the variable load DG-only case, as opposed to the fixed load baseline used as the performance requirement).
 - a. Assumes all DGs run as expected and when needed. Does not yet include P_{fs} or MTBF).
 - b. DGs modeled to run in cascaded sequence, in which the previous DG reaches maximum power output before the next DG operates
2. For the Nth DG (i.e. the last unit needed to cover the maximum critical load over the year), determine the maximum power and maximum energy output required out of the 8760 outage scenarios
3. VRF BESS with that amount of kW and kWh used for microgrid reliability modeling

Microgrid Reliability Modeling (further detailed in section 5.3)

4. Run Monte Carlo based reliability modeling for all 8760 unique 168-hour outage scenarios to create a CLCPC for the BESS enabled microgrid configuration
 - a. Incorporates P_{fs} and MTBF for the DGs and BESS
 - b. Includes 100 iterations in the Monte Carlo simulation to balance computational speed with sufficient iterations

- c. BESS state of energy is tracked for each iteration of each scenario to capture the energy limited nature of battery systems
 - d. BESS is allowed to recharge from excess solar PV or DG capacity, with priority given to charging from PV first when available
 - e. Failure to cover the critical load in any hour renders all subsequent hours as also failing
5. Compare the CLCPC of the BESS enabled microgrid to the fixed load baseline CLCPC provided by ESTCP to determine whether the reliability performance is maintained or exceeded for a 168-hour outage
 6. If the BESS enabled CLCPC does not meet or exceed the fixed load baseline CLCPC, increase the quantity of BESS units within the microgrid reliability model by one and repeat steps 4 and 5 (the total power and energy capacity remains unchanged, but is now split between multiple BESS units), otherwise proceed to step 7
 7. The current BESS enabled microgrid configuration is selected and taken as the minimum size and number of BESS units required for maintaining or exceeding the CLCPC during a 168-hour outage

Grid Tied Modeling

8. Determine a range of BESS sizes to model in grid tied operation, scaling up from the size determined in step 7
 - a. Include BESS durations (ratio of energy capacity to power capacity) of 1 to 10 hours
 - b. Durations of 1 to 4 hours are designated as lithium-Li-Ion BESS units, and durations more than 4 hours are designated as flow BESS units
9. Identify the use cases available to the BESS as a behind the meter asset based on the wholesale market region and utility rate structure
10. Model operation of the BESS in grid tied operation using
 - a. Simulations performed in AESOP, Ameresco's energy storage simulation tool
 - b. Unique simulation performed for each BESS size and each stack (combination) of use cases
11. Quantify the simple payback of each BESS size and use case stack simulated to identify the most promising combination
12. Create a 20-year financial proforma with detailed budgetary estimates of implementation cost, operating expenses, and annual value for the selected BESS size and use case stack
13. Compare the 20-year NPV of the BESS enabled microgrid to the baseline microgrid to conclude if the BESS enabled microgrid provides a reduction in the cost of critical load coverage

Hourly load and PV generation data was provided by the ESTCP program for each site. For all microgrid (islanded) modeling, this hourly data was used and not adjusted. For grid tied modeling efforts, sites that did not include frequency regulation use cases were also only modeled on an hourly interval basis. However, for sites that included Frequency Regulation as a desired use case, a more granular data interval was needed. This applied to NAS Patuxent River in PJM territory and Westover ARB in ISO-NE territory. Our team adjusted the hourly load, generation, and market data to a 15-minute interval basis. This was necessary from our standpoint for two primary reasons. First, a more granular dataset is needed to accurately model the behavior of the battery during regulation participation. When providing frequency regulation, the BESS responds on a 2 or 4 second basis and can actively switch between charge or discharge across its full power range at any of these intervals. If this use case were to be modeled on an hourly basis, it would not capture the changing power dispatch of the BESS nor the energy throughput that the battery experiences over the course of an hour – which has significant impact on sizing the battery and its expected degradation over life. Second, modeling on a fifteen-minute basis was appropriate as compared to an even finer granularity to align the dataset with typical utility metering intervals. Most utilities meter and bill their customers on a fifteen-minute basis. Since participation in the FR market follows a charge/discharge signal provided by the ISO and not the utility, it is important to quantify the demand and energy impact regulation participation has. If the system were to charge at a high power during certain time of use periods, there is the possibility it could impact the site's monthly demand charges. Similarly, for sites with time of use energy rate structures, it is important to understand how much energy is being imported from the utility during each TOU window. For these reasons, adjusting the dataset from an hourly to fifteen-minute basis allows for better characterization of BESS operation and accurate re-calculation of site utility costs after BESS operation.

5.2 DG CHARACTERIZATION METHODOLOGY

Our approach was to target replacing a single DG asset with a VRFB and quantify the impact on reliability and economic feasibility. To do this, we needed to first characterize how the DGs in the baseline microgrid would be expected to operate during an outage to serve varying critical load.

The AESOP tool was configured to model “ideal” operation of the DGs, assuming perfectly reliable response of the DG assets and not yet factoring in the reliability metrics of P_{fs} and MTBF. The model assessed the amount of hourly critical load to be served, assuming the 100% critical load case, and determined how many DGs were needed and how much power was required from each to serve the load. It was assumed that there was no PV generation in this calculation to be able to characterize the worst-case scenario and because it was specified that there was no PV present in the fixed load baseline microgrid performance. Assuming steady state power output over the course of each hour, the model then tracked cumulative energy generation of each DG for the duration of a 168-hour long outage scenario. This was repeated for 8760 unique outage scenarios, with each outage scenario starting on a different hour of the year and lasting for 168 hours (for outage scenarios starting within the last 168 hours of the year, hours from the start of the year were duplicated and added as needed to create a complete 168 hour scenario). Upon analyzing the simulation results, it was noted that at each site the last generator was never needed, confirming that the sites indeed had N+1 redundancy in DGs.

Analysis of the “ideal” operation results allowed us to determine maximum power and total cumulative energy of each DG required to operate during the most demanding outage scenario. As an example, Table 15 summarizes the results for Westover ARB. Results tables of DG characterization for all sites are provided in Appendix A.3.1.

Table 15. DG Characterization Results for Westover ARB

	Maximum Power (kW)	Cumulative Energy (kWh)	Maximum Runtime (Hours)
Generator 1	750	126,000	168
Generator 2	750	79,934	168
Generator 3	207	207	1
Generator 4	-	-	0

Table 16 below summarizes key statistics for each site. Though it was recognized that these were ideal characterizations of the DG assets, the Generator Max Power (kW) and Generator Energy (kWh) results for each site provided an important starting point for identifying the amount of power and energy needed in a BESS to support the microgrid by replacing a DG. The BESS sizes determined through this approach were used in the Monte Carlo based reliability modeling, further described in the next section, to determine if the BESS size provided satisfactory reliability or if additional units were needed.

Table 16. Summary of DG Characterization Results for All Sites

	Westover	NAS Patuxent	NAS Corpus Christi	March ARB	Fort Bliss
Min Site Load (kW)	106	15,267	4,844	1,967	17,771
Avg Site Load (kW)	1,896	21,444	13,873	4,969	37,806
Max Site Load (kW)	3,414	33,958	23,965	7,998	67,605
Min Critical Load (kW)	53	3,603	891	148	3,288
Avg Critical Load (kW)	948	5,061	2,553	373	6,994
Max Critical Load (kW)	1,707	8,014	4,409	600	12,507
Min PV Generation (kW)	-	-	-	-	-
Avg PV Generation (kW)	334	409	247	103	1,651
Max PV Generation (kW)	1,931	1,931	1,159	386	5,986
DG ONLY-Maximum Values of Generator Parameters During 168 hour Outage					
Last Generator Needed-DG only (#)	3	11	6	3	7
Generator Max Power (kW)	207	514	659	100	507
Generator Energy (kWh)	207	6,958	7,264	3,509	3,574
Generator Fuel (gallons)	17.93	602.71	629.17	363.65	273.01
Generator Fuel Cost (\$)	\$47	\$1,651	\$1,523	\$1,080	\$707
Generator Run Time (hours)	1	23	27	56	12

5.3 MICROGRID RELIABILITY MODELING METHODOLOGY

The reliability results for the technical Performance Objectives #1-#4, described in Section 3.0 above, were modeled using a Monte Carlo simulation incorporated into AESOP to determine the CLCPC for an outage lasting 168 hours. For outage scenarios that could occur at any time, the statistical probability of serving a specified amount of critical load for a given duration was calculated. This was accomplished using three dimensional matrices with the following dimensions (shown graphically in Figure 10).

Number of Monte Carlo Iterations x Number of Outage Scenarios x Outage Duration

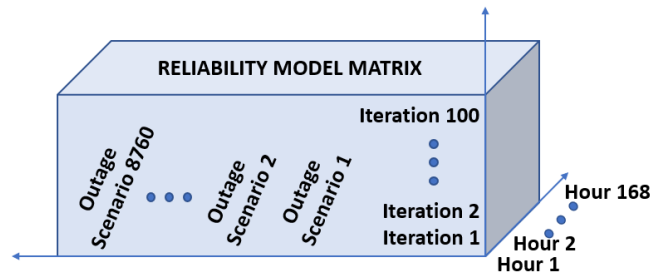


Figure 10. Conceptual Representation of Monte Carlo Simulation Method

Each location in the three-dimensional matrix contains a value that indicates whether the critical load for the given iteration and hour of an outage scenario was successfully covered by the available solar PV, DGs, and BESS units. In order to balance computational speed with having a sufficient number of iterations, 100 iterations were performed for each simulation (resulting in matrix dimensions of 100 x 8760 x 168). The number of DGs and BESS units available is dependent on the respective P_{fs} and MTBF values that govern whether an asset failed during a given hour (using equations from the *Calculating the Reliability of a Backup System with Parallel Generators* report provided by ESTCP and located in Appendix A.2). We assumed the critical loads were covered first by the available solar PV and DG units, and subsequently covered by the BESS. During times in which there was excess solar PV or DG capacity, it was made available to charge the BESS. Failures of any component in the system rendered the energy from that component unavailable for the remainder of the outage. Furthermore, failure of the combined available assets to cover the critical load in a given hour rendered all subsequent hours of the outage as also having failed.

The above analysis resulted in a populated matrix containing a value of 0 if the assets failed to cover the critical load, and a value of 1 if the assets successfully covered the critical load. The average was taken across all 100 iterations to obtain a CLCPC for each of the 8760 outage scenarios. These CLCPCs were then averaged together to obtain the overall CLCPC for the microgrid configuration simulated.

The fixed load baseline reliability curves provided by ESTCP were used as the benchmark for this analysis. The variable load DG-only reliability curves provided by ESTCP were replicated to test the validity of the model. The Monte Carlo simulation model within AESOP was able to provide outputs within an average of 0.02% of the ESTCP variable load DG-only values.

Thus, we felt confident comparing the storage enabled microgrid modeling to ESTCP's output for the fixed load baseline and variable load DG-only microgrid model.

The output of each simulation of the microgrid configurations was a CLCPC which allowed us to compare performance against the fixed load baseline microgrid and determine success or failure of the system based on Performance Objective #1. If the initial BESS sizing did not pass Performance Objective #1, we increased the number of BESS units to improve reliability through redundancy (the original power and energy capacity was split between multiple units). The final passing configuration was then tested against Performance Objectives #2-#4 for documentation.

Initial simulations replaced one DG with one BESS. During each simulation, the BESS was allowed to charge from the PV asset and surplus capacity from the group of DG assets if available. If capacity from the PV and DGs was available, priority was placed on charging from the PV asset first. If the microgrid successfully achieved Performance Objective #1, the system moved forward to be tested on the remaining Performance Objectives. In the case of March ARB, the resulting CLCPC did not meet fixed load baseline CLCPC, so the number of BESS units was increased to two, after which the CLCPC did exceed the fixed load baseline (the remaining sites exceeded the fixed load baseline CLCPC with just one BESS unit). Other variables tested to complete Performance Objectives #1-#4 are shown in Table 17 below.

Table 17. Supplemental Reliability Simulation Scenarios

Variable	Changes to Baseline
# of DG units available	N, 0 (for no fuel cases)
PV available	100%, 0%
% of Critical Load	100%, 130%, 30%, 10%
BESS available	1 unit, 2 units (March ARB only) <i>(sizing configurations based on external analysis)</i>

The availability of on-site PV generation impacts the probability of serving critical load during any potential outage block. It is well characterized in the PV industry that solar PV production varies seasonally and annually based on weather. To account for this, the PV data utilized was generated using a standard method of averaging Typical Meteorological Year (TMY) based weather data to project an average PV generation profile over a 30-year basis. However, since the availability of PV at the start of an outage is highly dependent on the cause of that outage, it is more difficult to determine how to incorporate PV in the microgrid reliability modeling. If the outage is induced by severe weather, it is likely that the PV will produce no energy for potentially multiple days, before potentially returning to production once a storm has passed. This specific available profile, however, would be very dependent on-site location, strength of the storm, duration of the storm, any potential damage to PV equipment, and a number of other variables. On the other end of the spectrum, an outage that may be caused by a non-weather-related event such as a cybersecurity threat or utility side of the meter fault may have no impact to PV production at all.

Given the wide range of possible outcomes that could occur given these variables, our team decided it would be most useful to assess situations with the expected amount of PV and no PV at all. This then provides a range of probability of load coverage within which any scenario would fall. Although this approach doesn't address specific variability of PV within a given possible scenario, it quantifies the PV related risk and its impact to probability of load coverage that installations should understand and plan for.

Since the primary purpose for the BESS is to provide support in the event of a utility outage, and because an outage can theoretically occur at any time, the amount of energy reserved for microgrid support (thus, not made available for grid tied use) is an important determination. The assumption that the BESS is able to charge from excess solar PV and DG capacity in the reliability model, therefore, has implications on the amount of energy available for grid tied operation. A reliability model was run for each of the sites with the BESS units starting the outage with zero energy to quantify the impact on the CLCPC. For all of the sites except for March ARB, the BESS units were recharged during the outage from the excess capacity and there was minimal impact to the CLCPC. The impact at March ARB was more significant, however, and the CLCPC dropped below the fixed load baseline. Subsequent analysis referred back to the DG characterization and found that this was likely due to the fact that the Nth DG at this site was needed for nearly three times as many hours as any of the other sites, indicating that if a BESS were to replace the DG, it would not be able to recharge enough to provide adequate critical load coverage. This finding suggests that the minimum state of energy allowed for the grid tied model at March ARB should not be reduced, while the other sites were able to use their full energy capacity for grid tied operation.

Constraints of our reliability modeling include the lack of data available for key failure statistics for flow batteries. We had conversations with vendors to better understand how the systems operate and what the failure characteristics are, however, reliability metrics are not yet readily available for these systems. This is partially because not enough systems have been commercially deployed and operated for the length of time required to collect the data to quantify such metrics. We therefore used the availability metric, which is provided by vendors, to derive the reliability metrics needed to simulate the microgrid reliability scenarios.

5.4 GRID TIED MODELING METHODOLOGY

The BESS size and number of units determined through the reliability modeling was taken as the minimum configuration to be modeled in grid tied operation. However, in order to take further advantage of the monetizable use cases available to behind the meter energy storage, several other sizes of BESS were considered. This included BESS durations from 1 to 10 hours. Durations of 1 to 4 hours were designated as Li-Ion BESS units, and durations more than 4 hours were designated as VRF BESS units.

The available use cases available to each site were also identified based on the utility rate structure and wholesale market region (note: while NAS Corpus Christi is geographically within the ERCOT wholesale market region, our research indicated that wholesale use cases in ERCOT are not currently available to energy storage assets located behind the meter). The use cases evaluated in this study include retail billing savings from demand charge management and time of use energy arbitrage, as well as wholesale market revenues from operation in the energy markets (day-ahead and real-time), spinning reserves, and frequency regulation. Section 6.4 contains a table showing the available use cases for each site modeled.

Of these two categories, retail billing savings are the more predictable source of value since the rates are typically stable and known well in advance. Thus, BESS operation through the course of the day can be more readily planned for to ensure there is enough energy capacity. Wholesale markets, on the other hand, are variable by nature and have significantly more uncertainty in their pricing and operational dispatch, causing the amount of revenue that can be achieved from BESS operation to also vary. Given this fundamental difference between retail and wholesale use cases, retail billing savings were prioritized for grid tied modeling. During times in which these use cases were not available, wholesale market use cases were added (as appropriate and available) to stack additional value. It is recognized that participation in certain wholesale market products requires must offer obligations for the times the asset bids into the market. To ensure we did not model retail operation that conflicted with wholesale market participation, our approach focused on only planning to bid into wholesale markets during hours when no retail billing savings operation was to be performed.

To determine what, if any, minimum state of energy was required for grid tied operation, our team assessed the impact of entering an islanding period with a fully discharged BESS at 0% SOC. Since the BESS is not intended to be used for islanding support, which is the UPS's responsibility, the main objective was to verify if letting the BESS SOC deplete to zero compromised the ability to meet the required reliability performance metric. For each site, the microgrid reliability models were run with the BESS assumed to have 0% SOC at the beginning of each outage block. The BESS would then immediately be allowed to charge from any available PV generation capacity or surplus DG generation capacity from DG units that were not required to immediately generate to serve the requisite amount of critical load. This work showed that for all sites except March ARB, it was acceptable to allow the BESS to discharge to 0% SOC during grid tied operation without compromising microgrid performance. For March ARB, a 50% minimum SOC limit during grid tied operation was needed to ensure no impact to reliability performance.

During grid tied operation, the specific charging and discharging profile of the BESS is dependent on use case operation. These use cases are described below. Generally speaking, for all use cases except regulation, the BESS was programmed to charge during low price or low demand times and discharge during high price or high demand times. For regulation dispatch, charging and discharging of the BESS was modeled to follow a historical understanding of the ISO's frequency regulation signal. During all grid tied modeling the provided hourly TMY PV generation data was assumed to be available. The grid tied operational model first reduced the site demand by the hourly PV availability, and then modeled BESS operation against the post-PV expected demand profile.

Ameresco studied each site's utility rate conditions as well as the rules and operating requirements of available wholesale market products where relevant. This allowed us to determine a use case stack for each site as shown in Table 18. This stack is summarized by the following table. The available value creation use cases that were identified included Retail DCM, Retail TOU Energy Savings, Wholesale Energy market participation co-optimized with Wholesale Synchronous Reserves, and Wholesale Regulation. We then worked to enhance the modeling capabilities of the AESOP tool to be capable of simulating those use cases. This primarily involved expanding our existing DCM and Regulation modeling functionality, and adding the new use cases of Retail TOU, Wholesale Energy, and Wholesale Reserves.

Table 18. Grid Tied Use Case Stacks for Each Site

Site	ISO	Retail DCM	Retail TOU	Wholesale Energy	Wholesale Reserves	Wholesale Regulation
Westover ARB	ISO-NE	•	• (1)	•	•	•
NAS Patuxent River	PJM	•		•	•	•
NAS Corpus Christi	ERCOT	•				
Fort Bliss	N/A	•	•			
March ARB	CAISO	•	•	•	•	

1 Requires 80% RTE to be economically justified. Applicable to Li-Ion, not Flow.

Next, we determined the appropriate battery system sizes to model under grid-tied conditions to quantify the value each system could generate for each site, considering both VRF and Li-Ion equipment solutions. We approach sizing of possible configurations by making sure the full BESS rated power and energy capacity met the microgrid requirements, had a power capacity appropriate to replace one DG for each site, and assessed rated durations from 1 to 10 hours. It should be noted that systems with durations of 1 to 4 hours are Li-Ion technology and those with 6 to 10 hours of duration are VRF technology. Finally, we confirmed that since we are allowed to charge the BESS from DG, we can allow the grid tied operation of the BESS to use the full range of rated energy capacity for all sites except March ARB without impacting reliability performance. For March ARB, it was determined we needed to always reserve 3,509 kWh for the microgrid, thus the system's energy capacity was oversized by 50% for grid tied operation. This verification step was completed by running Monte Carlo reliability simulations with initial BESS state of Energy of 0 kWh and comparing to the simulations with a 100% initial BESS SOE.

5.4.1 Retail Use Cases

The retail utility rate structure for each location modeled was programmed into AESOP to enable utility costs to be calculated for the baseline and post-BESS operation cases, the difference between which is the savings. Many utility rate structures have certain hours of the day specified as higher priced demand and energy hours and are the time periods targeted for demand charge management and energy arbitrage. This was true for some of the sites' energy charges, however, it is notable that all of the sites modeled had a non-coincident demand charge, meaning that the maximum utility demand at any hour over a given month is billed at the demand rate. For sites that have particularly peaky loads where the peak demand in a month is much greater than the average demand, BESS operation can be quite effective for managing those costs

Demand charge management was modeled by dispatching the BESS during times of high demand to maintain a reduced level of maximum utility import at the given site. This was done on a monthly basis to generate meaningful savings over the year. Energy arbitrage was modeled by dispatching the BESS when there was a large enough difference in the higher and lower priced energy time periods to create savings (discharging during the higher priced time period and recharging during the lower priced time period) despite the energy losses due to the round trip efficiency.

5.4.2 Wholesale Use Cases

While wholesale market rules in different control areas are often nuanced and participation models for storage are still in the development process, we modeled these use cases from the standpoint of a behind the meter distributed energy resource, which has different nomenclature used from market to market. A threshold offer price was determined using the calculated cost to recharge the BESS, and it was assumed that the BESS “cleared” the market when the day-ahead price rose above the offer price. For hours in which the BESS did not clear in the day-ahead market, the same offer price was used to determine if the BESS cleared in the real-time market. If the BESS cleared in either of these markets, a comparison was made between the cost to perform in the market and the expected hourly wholesale value. A decision of whether or not to operate was then made based on this relative cost comparison. If the BESS did not clear either market, it was assumed to be placed in the Spinning Reserves market and collect revenue accordingly.

For the frequency regulation use case, the offer price was set to zero to make the BESS a price taker and improve its chances of clearing the market. The reason for this is that the regulation signal in ISO-NE and PJM, the two markets in which frequency regulation was simulated, is conditionally neutral and allows the BESS to maintain at a higher state of energy for longer periods of time, thus allowing it to stay in the market. This is not the case in the energy market, in which the BESS depletes its energy within a handful of operational hours.

Regulation pricing is cleared hourly by the market is in inherently variable based on energy market conditions. There are a number of factors that could influence the direction of regulation market pricing over short- and long-term outlooks. These include electricity and gas pricing, weather, market competition, and the saturation levels of variable generation resources on the grid. Future pricing could increase or decrease based on these conditions and how they may differ from region to region. Therefore, it is not accurate to simply assume a marginal escalation rate in the annual value of this revenue stream, as may be assumed for inflation or other economic factors. As such, our team made the decision to not include any escalation or degradation in regulation value in our 20-year economic modeling.

Simulations were performed in AESOP for the various BESS sizes and use cases. Where possible, multiple use cases were combined, or stacked, together to create multiple value streams from operation of the BESS. The characteristics of the BESS, such as round-trip efficiency and auxiliary load requirements, were also tailored to the technology being simulated (i.e. Li-Ion or VRF BESS). At all sites, the BESS was assumed to not be allowed to export electricity back to the utility grid, and thus all operation is at most able to reduce the utility import to zero across all use cases.

It is noted that the economic value modeled through the grid tied modeling assumed perfect knowledge of the site load, solar PV generation, and wholesale market pricing provided by ESTCP (we supplemented this data for the frequency regulation use case with dispatch signal data available from the ISO-NE and PJM websites). In a real-world situation, these data would not be perfectly known in advance and BESS operation would need to rely on a combination of forecasting and real-time response from the BESS. This is particularly true when trying to stack value streams from multiple use cases and creates a need to account for the uncertainty in use case economic value. Nevertheless, the modeling results discussed here do provide a meaningful indication of the value potential that the BESS can have. See Appendix A.2 for a list of all input assumptions used in the modeling.

5.4.3 System Size Selection

The microgrid power and energy requirements define how much power and energy a BESS needs to be capable of providing support to the microgrid but does not define the optimal full BESS system size. This full system size is defined by the nameplate Rated Power Capacity (kW) and Rated Energy Capacity (kWh). To determine this for each site, a set of six system sizes was established for each installation with rated durations ranging from 1 hour to 10 hours.

Our team's intention was to determine the smallest set of BESS systems that was sized to replace a single DG and also met the microgrid power and energy requirements. This required scaling the amount of power or energy capacity, depending on which parameter was the limiting factor in relation to the DG capacity. For example, at Westover ARB the DG capacity is 750 kW, the microgrid power requirement was calculated as 207 kW, and the microgrid energy requirement was calculated as 207 kWh. With the DG size being the limiting design parameter, we established the Rated Power Capacity of each BESS to be 750 kW, and then scaled energy capacities from 1-hour duration (750kWh) to 10 hour duration (7500 kWh). This is shown in Table 19 below. For NAS Patuxent River, however, the rated energy capacity was the limiting design metric. The DG size was again 750 kW, but the microgrid power and energy requirements needed to replace the least running DG were calculated as 514 kW and 6,958 kWh, respectively. We therefore set the rated energy capacity of each BESS to 7,000 kWh, and scaled power from 7,000 kW (1 hour duration) down to 700 kW (10 hours). It should be noted that, had the 10-hour system with 700 kW been the preferred VRF size, we would have only taken capital expense credit for 700 kW of DG capacity. We felt this would be prudent since it would not be a fair replacement and unjustified to claim the value of the full DG capacity. However, this situation did not materialize as it was not the preferred system size. A unique exception to this process was at Fort Bliss, where it was observed that the one-hour solution did not have sufficient energy capacity to meet the microgrid minimum energy requirement. As such, that size was not selected for grid tied value characterization.

Table 19. Summary of All Modeled BESS Sizes

	DG Capacity (kW)	uGrid Power Req. (kW)	uGrid Energy Req. (kWh)	uGrid Start SOE Req.	Power Capacity (kW)	Energy Capacity (kWh)	Duration (Hours)
Westover ARB	750	207	207	0	750	750	1
					750	1500	2
					750	3000	4
					750	4500	6
					750	6000	8
					750	7500	10
NAS Patuxent River	750	514	6958	0	7000	7000	1
					3500	7000	2
					1750	7000	4
					1167	7000	6
					875	7000	8
					700	7000	10
NAS Corpus Christi	750	659	7294	0	7300	7300	1
					3650	7300	2
					1825	7300	4
					1217	7300	6
					913	7300	8
					730	7300	10
Fort Bliss	2000	507	3574	0	2000	2000	1
					2000	4000	2
					2000	8000	4
					2000	12000	6
					2000	16000	8
					2000	20000	10
March ARB (2 BESS Units)	250	250	3509	3509	7000	7000	1
					3500	7000	2
					1750	7000	4
					1167	7000	6
					875	7000	8
					700	7000	10

Since the unit cost of VRF battery equipment is understood to be significantly higher than Li-Ion, and the round trip efficiency and auxiliary system loads of VRF are higher than Li-Ion, it would not be possible for a VRF battery with one to four hours of duration to provide better project economics than Li-Ion systems with one to four hours of duration. Such a VRF system would have a higher implementation cost and lower annual value in all cases. Therefore, there was no justification in modeling the VRF technology's grid tied operation for those system sizes.

Similarly, Li-Ion systems with rated durations beyond 4 hours are not available to the best of our knowledge. As such, only VRF systems were modeled for durations of greater than 4 hours.

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6.0 PERFORMANCE ASSESSMENT

This section documents the methodology of how we analyzed results and the microgrid and grid tied analysis results for the five installations under investigation. All aspects of microgrid reliability modeling and grid tied modeling discussed in Section 5.0 were completed.

As previously mentioned, our analysis focused on replacing the least running DG at each site with a BESS. “Least running” refers to the DG with the lowest expected energy generation during outage scenarios, not including the N+1 DG which would be maintained for redundancy. We sized this BESS by first characterizing the expected run time of each DG in the variable load DG-only microgrid. This then gave an indication of the minimum power and energy requirements a BESS would need to be capable of offering to the storage enabled microgrid. These are considered “design requirements” but do not directly infer the final proposed BESS system size. Finally, various BESS sizes, defined by rated power capacity (kW) and rated energy capacity (kWh) configurations that are suitable for each technology were modeled for grid tied operation. These are summarized in Table 19 above. Results of this grid tied operation informed selection of the final BESS system size for each site, which are tabulated in Table 21.

6.1 RELIABILITY METHODOLOGY

In order to conduct the performance assessments and calculate the CLCPC for each storage-enabled microgrid, we needed to simulate operation of the microgrid as an integrated system over a course of time, the 168-hour outage window, in which each time step affected the next. After studying modeling of microgrid performance in previous publicly available research, we determined that Monte Carlo simulation was the favored approach in this type of context.

Additionally, the Monte Carlo simulation allowed us to manage the complexity of tracking across each hour the state of charge of the battery – its increases due to excess supply by the DG units or decreases due to the need of the Critical Load. This calculation was tracked for every hour in a 168-hour outage that could start in any given hour in a year, resulting in 8760 scenarios.

In order to ensure model accuracy, we ran 100 iterations of the simulation for each scenario. Given the density of these calculations, the Python programming allowed us to make the calculations extremely efficient.

The Monte Carlo simulation was set up to be able to derive the CLCPC curve for:

- the baseline microgrid, using both the fixed load baseline and variable load DG-only scenarios
- the baseline microgrid with PV available, including in various reliability scenarios
- the storage-enabled microgrid

The storage-enabled microgrid simulation was run as described in Section 5.3.

See Appendix A.2.1 for a detailed explanation of the reliability model.

6.2 RELIABILITY ASSUMPTIONS

Assumptions used in the modeling are listed in Appendix A.2. Of note are the reliability assumptions for the BESS units – failure to start (P_{fs}) and failure to run (P_{fr}). These assumptions were derived after conducting due diligence with the VRF equipment vendors. Since Li-Ion technology was not part of the scope of microgrid modeling, reliability metrics for Li-Ion were not calculated.

Operational information was obtained for a 500 kW/ 6,000 kWh VRF BESS that had 1.5 years of field operation and an availability of 93% over the 18-month period. Though very limited information was available, and details on the specific failures modes that led to the 7% downtime could not be provided, enough information was provided to estimate a MTBF for a grid scale VRF system similar to the technology under investigation. Table 20 summarizes the calculation steps used to determine the assumed MTBF used in reliability modeling of this project.

Table 20. VRFB MTBF Calculation Summary

Metric	Value	Unit
Operational Field Time	1.5	Years
Hours of Field Deployment	13,140	Hours
System Operator Stated Availability	93%	%
Hours Available	12,220	Hours
Hours Unavailable	919.8	Hours
Hours of Planned Maintenance (based on vendor stated 80 hours of annual PM)	120	Hours
Hours of Unplanned Downtime	799.8	Hours
Assumed Average Time to Repair Per Failure	12	Hours
Calculated Estimate of Quantity of Failures During Performance Period	12	Failures in 1.5 Years
Calculated Mean Time Between Failure	1095	Hours

The data seemed reasonable, as compared to both the vendor’s marketed claim of 95% as well as understanding the likelihood of failure for battery technology. Using this availability data, we were able to derive a value for P_{fs} and MTBF, which dictates P_{fr}^2 , by incorporating an assumed mean time to repair (MTTR) and planned maintenance outages. We assumed 72 hours (3 days) to repair a failure, based on 1 day to diagnose the issue, 1 day to ship parts and people to the site, and 1 day to resolve the issue. We then assumed 80 hours of annual preventative maintenance, as suggested by the technology vendor. Utilizing these assumptions yields an MTBF of 1095 hours. This seems reasonable given it is less favorable than DG performance, which is to be expected of a less mature technology.

² Per ESTCP calculations for DG reliability, $P_{fr} = 1 - \exp(-t/MTBF)$

It is important to note that the root causes of a failure to start or operate for a battery system are significantly different than those of a diesel generator. Moreover, failure mechanisms of a VRF could be different from failure of a Li-Ion battery asset given their differences in design and operation. Battery systems are inverter-based assets coupled with DC storage units, with integrated controls and communication systems to manage safe operation aligned with the desired use case. For a VRF battery, failures could stem from an issue with the controller or BMS that may bring the system to an unavailable state until rectified. Failures could also arise from an equipment issue with one or more bi-directional inverters associated with the system, or from an issue related to the various DC sub-systems and components. For a VRF battery, this could be related to a pump fault or issue with a power stack within the DC storage system. However, failures related to these inverter or DC system issues may not result in a complete failure of the system given the modularity of most advanced battery system designs. A fault of one component related to the DC storage system may just reduce the available energy or power capacity of the system. If a system has multiple inverters, an inverter fault should only make that inverter power capacity and its related DC storage capacity unavailable, but the rest of the system should still be operable. Thus, complete failure of a battery system would likely only materialize because of a controls and communications issue or if all inverters associated with the system failed to operate.

We can further extrapolate likely P_{fs} using the calculated MTBF, assumed MTTR and planned maintenance hours by simulating outages, planned and unplanned, into a 5-year simulated operation model. Doing so indicates a P_{fs} of somewhere between 1.0% and 1.1%. We proceeded with an assumption of 1.0% for P_{fs} , which would imply about five times as many start failures as the DG units, which seemed reasonable given the immaturity of the technology.

The data from our calculation of P_{fs} is shown in Appendix A.2.2. This method assumed that over a time period of 43,800 hours (five years), the VRF BESS should be available 40,734 hours based on an expected 93% equipment availability. Our objective was to create an hourly time series model to back calculate this availability using reasonable operating assumptions of the system. We assumed 72 hours for mean time to repair after a failure, and 400 hours of total planned maintenance time over five years. We also assumed that each time the asset starts, it runs for 12 hours continuously and then is on standby for 6 hours at a time. This was intended to mimic typical operation of a battery in peak shaving or frequency regulation – two common use cases. The hourly calculations use these assumptions to project for each hour if the system is running, is in standby, or has failed to start or failed to run based on a P_{fs} input and an assumed MTBF of 1,095 hours as calculated above. Using this Microsoft Excel based calculation tool, we iterated the P_{fs} metric until the calculated availability matched the expected 40,734 hours available with as much accuracy as the tool would allow. This yielded a calculated P_{fs} between 1.0% and 1.1% to match a VRF BESS system with 93% availability.

6.3 MICROGRID RELIABILITY PERFORMANCE

At all five installations, VRF BESS enabled microgrid configurations were established that met the minimum reliability requirement as summarized in Table 21. Scenarios that did not successfully pass were not included in the final cost assessment modeling (examples of scenarios that were not able to pass included microgrid configurations where redundancy of the BESS was not sufficient). This means that the BESS enabled microgrid's probability of covering 100% of the hourly specified critical load with no PV available met or exceeded the baseline (DG only) microgrid's coverage under the fixed peak load conditions (the fixed load baseline) at every hourly point along the CLCPC. The CLCPCs for all installations are included in Appendix A.3.2.

Table 21. Microgrid DG+BESS Configurations

Westover ARB:	(3) 750 kW DG + (1) BESS of at least 207 kW/207 kWh
<i>NAS Patuxent River:</i>	<i>(11) 750 kW DG + (1) BESS of at least 514 kW/6958 kWh</i>
<i>NAS Corpus Christi:</i>	<i>(6) 750 kW DG + (1) BESS of at least 659 kW/7264 kWh</i>
<i>Fort Bliss:</i>	<i>(7) 2000 kW DG + (1) BESS of at least 507 kW/3574 kWh</i>
<i>March ARB:</i>	<i>(3) 250 kW DG + (2) BESS of at least a combined 250 kW/3509 kWh</i>

Table 22 below shows the performance results for the BESS enabled microgrids with and without PV included. It also shows, the percentage increases of the BESS enabled microgrid's coverage at 168 hours. The sites exceeded the reliability requirement by between 2 to 22%. However, it is important to note that comparing the BESS enabled microgrid performance under the hourly variable load profile against the DG only microgrid under the fixed peak load profile (the fixed load baseline used as the performance requirement) is not a fair or direct comparison. The fixed peak hourly load profile is an extreme scenario where the site's annual peak load occurs every hour of the year – which would likely never happen – and thus requires maximum operation of the generating assets yielding higher probabilities of failure. Table 22 also shows that when the BESS enabled microgrid is directly compared to the DG only microgrid under the same variable load profile, its performance is worse in all cases by between 1.5% to 3.0% without PV. If PV is included, the performance exceeds the variable load DG-only case at NAS Patuxent, NAS Corpus Christi, and March ARB but still is worse at Westover and Fort Bliss. Figure 11 plots the critical load curves illustrating this comparison for Westover ARB. Full page CLCPCs for all sites are provided in Appendix A.3.2.

Table 22. Table of 100% CL Reliability Results

100% CL NO PV 168 Hr Probabilities					
Site	Requirement	DG Only Baseline	DG+BESS	Delta to Req.	Delta to DG Only
Westover	0.95076	0.99584	0.9717	2.09%	-2.41%
NAS Patuxent	0.67368	0.92723	0.90028	22.66%	-2.70%
NAS CC	0.85815	0.94125	0.92551	6.74%	-1.57%
Fort Bliss	0.82253	0.98647	0.95656	13.40%	-2.99%
March ARB	0.95076	0.97867	0.95125	0.05%	-2.74%
100% CL Expected PV 168 Hr Probabilities					
Site	Requirement	DG Only Baseline	DG+BESS	Delta to Req.	Delta to DG Only
Westover	0.95076	0.99584	0.97474	2.40%	-2.11%
NAS Patuxent	0.67368	0.92723	0.96962	29.59%	4.24%
NAS CC	0.85815	0.94125	0.97726	11.91%	3.60%
Fort Bliss	0.82253	0.98647	0.96648	14.40%	-2.00%
March ARB	0.95076	0.97867	0.98326	3.25%	0.46%

Table 22 reports results of scenarios that include differing amounts of critical load and generation assets. The “Requirement” scenarios refer to the minimum performance requirement for adequate system reliability. This was calculated under a scenario where the hourly critical load was always equal to the site’s annual peak critical load (the fixed load baseline), and all load was served by only DG assets. The “DG Only Baseline” scenario assumed a variable hourly critical load profile (the variable load DG-only scenario) and all such load was served only by DG assets. Finally, the “DG+BESS” scenarios also assumed a variable hourly critical load profile, but one DG asset was replaced by a VRF BESS.

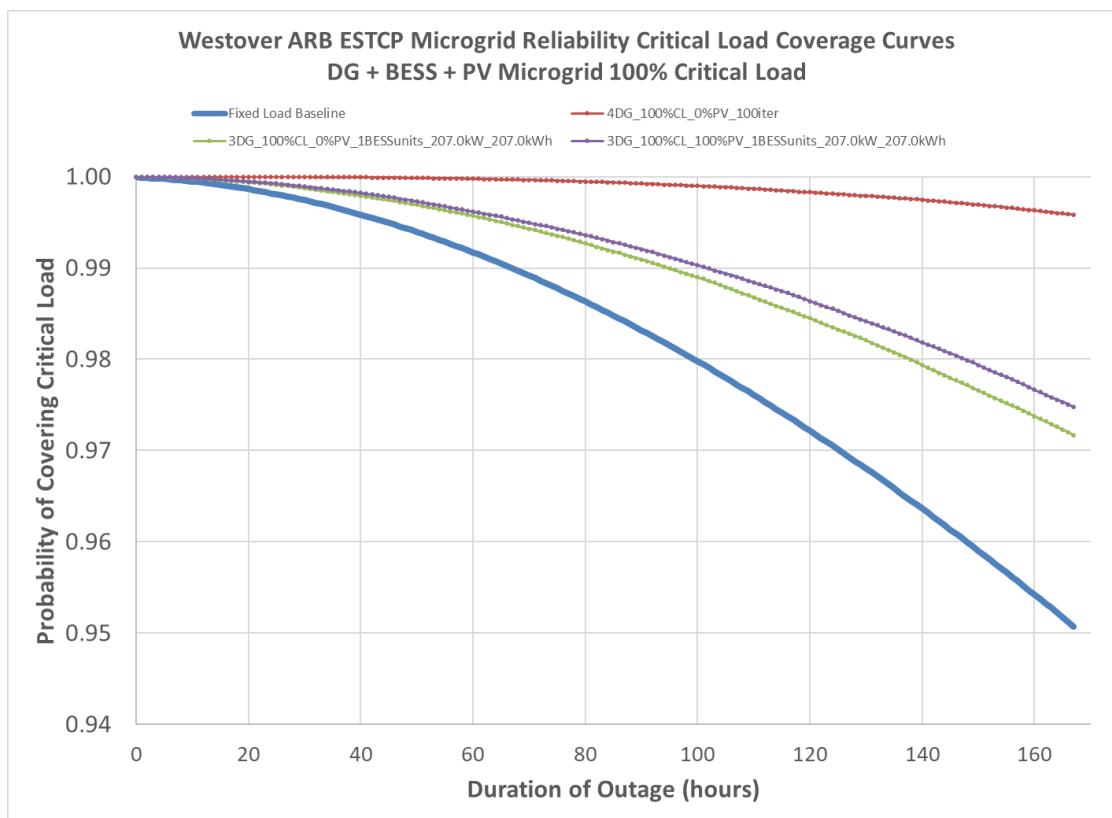


Figure 11. Westover ARB CLCPC for 100% Critical Load Scenarios

To assess the impact to reliability of higher than expected load, the same process was used to model critical load coverage of each installation against a 130% critical load profile. This means the hourly critical load profile was 30% higher for each hour of the year than the 100% critical load profile previously discussed.

Table 23 summarizes these 130% critical load coverage results. In all cases the coverage at 168 hours is significantly reduced as compared to the 100% critical load profile and does not meet the fixed load baseline requirements. This ranges from 14% worse at March ARB to over 60% worse at NAS Patuxent River, implying that each site has a different sensitivity to maintaining reliability under higher than expected load conditions. This is a result of the shape of the load profile and the percentage of critical load, which determines how many assets need to operate to serve all critical loads. Sites with more stringent critical load requirements will naturally have more assets running to serve that load. If load then grows to a level higher than expected, the probability of failure increases.

Table 23. Table of 130% CL Reliability Results

130% CL 168 Hr Probabilities				
Site	No PV	Delta from 100%	Expected PV	Delta from 100%
Westover	0.81173	-16.0%	0.84147	-13.3%
NAS Patuxent	0.29558	-60.5%	0.47233	-49.7%
NAS CC	0.45154	-47.4%	0.74379	-23.3%
Fort Bliss	0.66019	-29.6%	0.72321	-24.3%
March ARB	0.81098	-14.0%	0.92999	-5.3%

An example CLCPC for Westover ARB is provided in Figure 11, with the remainder provided in Appendix A.3.2.

The final set of reliability cases that were explored were under the condition of no diesel fuel supply and subsequently no DG availability. In all other cases, the diesel fuel supply was assumed to be infinite per guidance from the ESTCP program. The no diesel fuel supply scenarios assessed conditions with 10% and 30% of the expected critical load for each site. The probability of covering the requisite amount of critical load was calculated through 168 hours. Performance was assessed at 1 hour and 24 hours.

As expected, absence of the diesel generators significantly hampers, or eliminates, the ability to serve critical load during microgrid operation. The magnitude of critical load that can be served is dependent upon the availability of PV generation and the state of charge of the BESS at the time the islanding event begins. Situations in which the outage is not weather induced and begins during the day increases the probability that critical load can be served for a longer duration, as PV can directly serve load or charge the BESS if surplus capacity is available. The ability to serve load when outages begin at night is more difficult and strictly dependent on the state of energy of the BESS.

Reliability models for all previously described scenarios assumed the BESS had 0% SOE at the beginning of the outage and could then immediately be charged by surplus DG capacity. For the no diesel fuel and PV scenario with a BESS starting the outage at 0% SOE, it is an obvious conclusion that no critical load could ever be served during the outage. As such, this situation was not modeled. For situations where no DG nor PV is available, it was therefore determined to assume the BESS was fully charged at the start of the outage to characterize the longest amount of time critical load could be served. As expected, the microgrid at Westover ARB installation required a smaller BESS configuration due to the relatively infrequent operation of the last-running (or the Nth) DG unit. All other sites required BESS durations (kWh/kW ratios) in excess of 7 hours, with over 14 hours needed in the case of March ARB. The calculated BESS power and energy requirements for each site are shown in Table 24.

In the alternative technical scenario for 130% critical load, most microgrid systems performed fairly well, in excess of 70% probability of covering load in the 168th hour of an outage event.

These probabilities are further improved with 100% production of the PV available during such expected scenarios. In the alternative technical scenario of no fuel for the DG, the BESS-only systems have a reasonable probability of performing in most cases up to 10 hours, especially for the 10% critical load scenarios. These probabilities are further improved with 100% production of the PV available during such expected scenarios.

Table 24. Calculated Microgrid BESS Requirements for Each Site

	Units	Westover	Patuxent River	NAS CC	Fort Bliss	March ARB
Microgrid Minimum Power Requirement	kW	207	514	659	507	250
Microgrid Minimum Energy Requirement	kWh	207	6958	7264	3574	3509
Number of BESS Units Required	#	1	1	1	1	2

6.4 VRF AND LI-ION GRID TIED BESS PERFORMANCE

Once reliability modeling was complete, the next step was to model grid tied operation of multiple battery system sizes for each site, following the methodology described in Section 5. The goals of this step were to determine what the optimal BESS system size is for each site to quantify how much value a BESS could generate through utility billing savings and wholesale energy market opportunities.

The array of 30 unique system sizes described in Section 5 were modeled to simulate expected grid tied operation. This allowed for determination of expected annual value (savings and revenue) for each BESS option. For each system size, we estimated implementation cost and annual operation expenses based on Ameresco's experience developing and operating these battery systems. This allowed for assessment of economic viability of each option to determine the BESS size that provided the best opportunity for economic viability at each installation. Our team selected the optimal system size for a VRF and Li-Ion BESS at each site to allow comparison of each storage technology.

For example, at Westover ARB simulation data from our AESOP model runs were analyzed to assess simple payback based on assumed costs and calculated value for three Li-Ion system sizes and three VRF system sizes. The use case stacks included all feasible combinations of demand charge management, retail time of use arbitrage, wholesale energy coupled with reserves, and wholesale frequency regulation. For the VRF systems, retail time of use energy arbitrage was not modeled since the round-trip efficiency of the technology is too low compared to the on peak and off-peak delta in utility energy rates to make that use case value positive. Figure 12 below provides an example chart that is generated from the output data of our AESOP grid tied modeling tool.

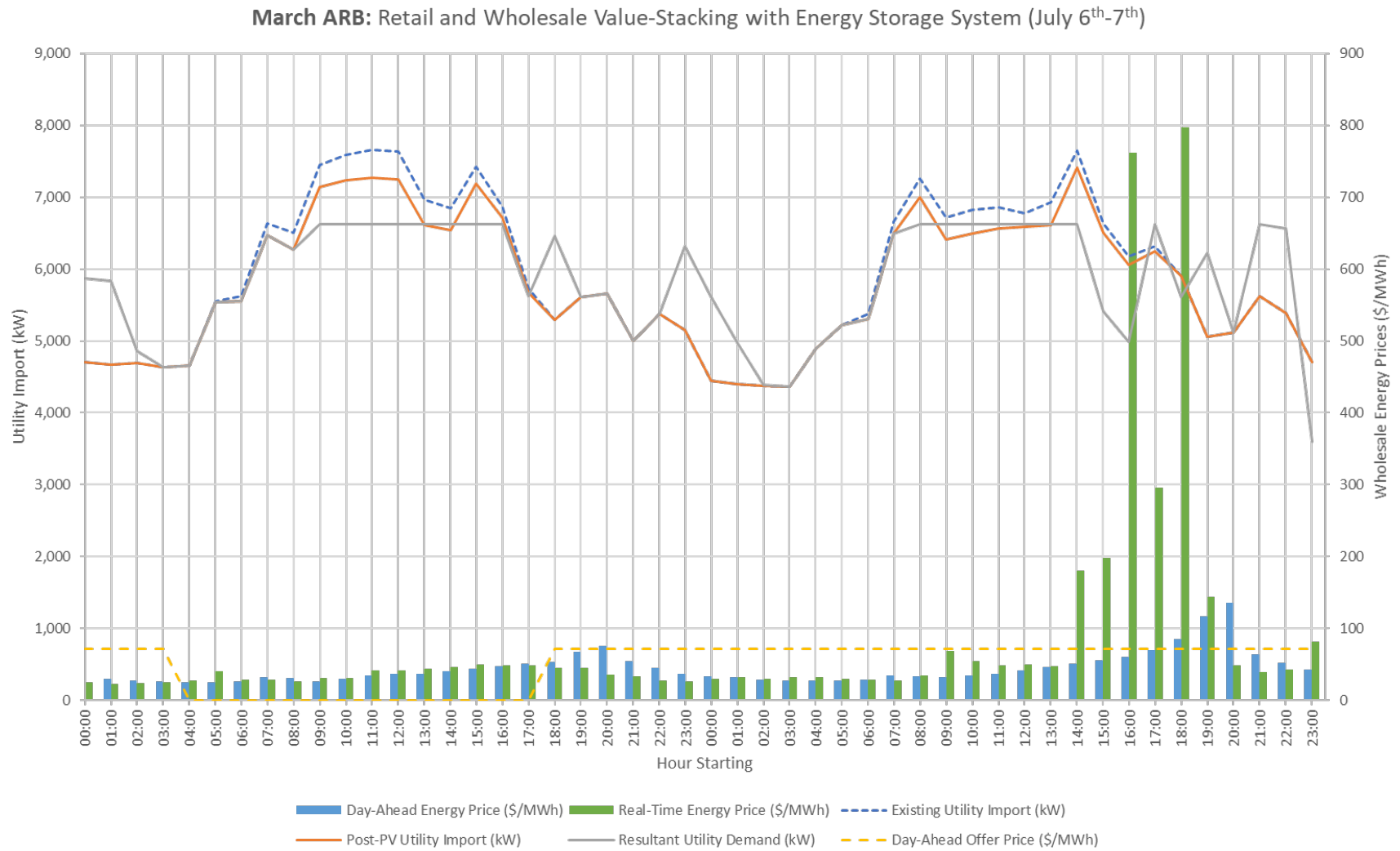


Figure 12. Example Plot of AESOP Modeled BESS Operation

Analysis of grid tied modeling results informed down-selection to a single Li-Ion and single VRF BESS for each of the five installations, as well as the preferred use case stack for each system. Table 25 summarizes these down-selections and notes the lower SOE limit required during grid tied operation to maintain the microgrid reliability performance previously described.

Table 25. Down-selected BESS System Sizes for Each Installation

Installation	Rated Power	Rated Energy	Lower SOE	Grid Tied Use Case Stack
	kW	kWh	kWh	
March ARB	875	7,000	3509	DCM+WH E&R
	3,500	7,000	3509	DCM+WH E&R
NAS Corpus Christi	1,217	7,300	0	DCM
	3,650	7,300	0	DCM
Fort Bliss	2,000	12,000	0	DCM
	2,000	4,000	0	DCM
Westover ARB	750	4,500	0	FR
	750	750	0	FR
NAS Patuxent River	1,167	7,300	0	DCM+WH E&R
	3,500	7,000	0	DCM+WH E&R

To make this down-selection, we estimated simple payback of each configuration using estimated system implementation cost, AESOP calculated annual value, and estimated annual operating expenses. Cost assumptions used for these calculations are described in Section 7. By way of example, Table 26 shows these results for the array of system sizes and use case stacks for Westover ARB. For Westover ARB, Li-Ion estimated implementation costs ranged from \$0.76 to \$2.1 M and were modeled to have the potential for between -\$5,000 to \$88,000 in annual value. Annual operating costs were estimated to range from \$9,000 to \$30,00 for Li-Ion systems. For the VRF systems at this site, estimated implementation costs ranged from \$3.6M to \$5.9M, but annual value ranged from -\$11,000 to \$44,000. Annual operating costs for the VRF technology were estimated to range from \$22,000 to \$44,000. From this array of system size options, we down-selected to the 750 kW – 750 kWh Li-Ion system and the 750kW – 4,500 kWh VRF system, with Frequency Regulation as the preferred use case for each technology.

The following tables summarize modeled annual value potential for a BESS participating in a variety of use cases. These include: demand charge management (DCM); retail energy time of use management (ENTOU); wholesale market frequency regulation (FR); and wholesale energy and reserves (Wholesale E&R).

Table 26. Westover ARB Grid Tied Modeling Results Summary

Power Capacity (kW)	Energy Capacity (kWh)	Assumed Imp. Cost	Use Case Stack	Modeled Annual Value	Est. Annual O&M Costs	Simple Payback
Li-Ion BESS Sizes						
750	750	\$756,250	DCM + ENTOU + FR	\$24,514	\$13,352	68
750	1500	\$1,225,000	DCM + ENTOU + FR	\$23,890	\$14,838	136
750	3000	\$2,162,500	DCM + ENTOU + FR	\$26,758	\$18,958	278
750	750	\$756,250	DCM + ENTOU	\$19,429	\$9,750	79
750	1500	\$1,225,000	DCM + ENTOU	\$25,860	\$12,000	89
750	3000	\$2,162,500	DCM + ENTOU	\$30,536	\$16,500	155
750	750	\$756,250	DCM + FR	\$43,585	\$18,533	31
750	1500	\$1,225,000	DCM + FR	\$40,395	\$19,143	58
750	3000	\$2,162,500	DCM + FR	\$39,624	\$22,295	125
750	750	\$756,250	DCM	\$17,508	\$9,750	98
750	1500	\$1,225,000	DCM	\$30,943	\$12,000	65
750	3000	\$2,162,500	DCM	\$36,447	\$16,500	109
750	750	\$756,250	ENTOU	\$3,638	\$9,750	NEG
750	1500	\$1,225,000	ENTOU	\$3,493	\$12,000	NEG
750	3000	\$2,162,500	ENTOU	(\$4,888)	\$16,500	NEG
750	750	\$756,250	FR	\$85,420	\$23,736	13
750	1500	\$1,225,000	FR	\$87,227	\$26,265	21
750	3000	\$2,162,500	FR	\$88,215	\$30,887	38
750	750	\$756,250	DCM + ENTOU + Wholesale E&R	\$25,832	\$11,330	53
750	1500	\$1,225,000	DCM + ENTOU + Wholesale E&R	\$31,048	\$13,554	70
750	3000	\$2,162,500	DCM + ENTOU + Wholesale E&R	\$35,158	\$18,077	127
750	750	\$756,250	DCM + Wholesale E&R	\$28,887	\$12,312	46
750	1500	\$1,225,000	DCM + Wholesale E&R	\$33,295	\$14,350	65
750	3000	\$2,162,500	DCM + Wholesale E&R	\$38,510	\$18,748	110
750	750	\$756,250	Wholesale E&R	(\$2,667)	\$15,008	NEG
750	1500	\$1,225,000	Wholesale E&R	(\$5,419)	\$17,531	NEG
750	3000	\$2,162,500	Wholesale E&R	(\$1,411)	\$22,268	NEG
Vanadium Redox Flow BESS Sizes						
750	4500	\$3,685,000	DCM + FR	(\$7,410)	\$24,128	NEG
750	6000	\$4,817,500	DCM + FR	(\$6,231)	\$28,223	NEG
750	7500	\$5,950,000	DCM + FR	(\$8,808)	\$32,053	NEG
750	4500	\$3,685,000	DCM	\$5,266	\$21,000	NEG
750	6000	\$4,817,500	DCM	\$4,884	\$25,500	NEG
750	7500	\$5,950,000	DCM	\$3,350	\$30,000	NEG
750	4500	\$3,685,000	FR	\$44,125	\$35,141	411
750	6000	\$4,817,500	FR	\$44,575	\$39,693	987
750	7500	\$5,950,000	FR	\$44,482	\$44,137	17,255
750	4500	\$3,685,000	DCM + Wholesale E&R	\$11,016	\$22,444	NEG
750	6000	\$4,817,500	DCM + Wholesale E&R	\$10,033	\$26,777	NEG
750	7500	\$5,950,000	DCM + Wholesale E&R	\$6,049	\$30,979	NEG
750	4500	\$3,685,000	Wholesale E&R	(\$11,874)	\$26,503	NEG
750	6000	\$4,817,500	Wholesale E&R	(\$11,260)	\$31,112	NEG
750	7500	\$5,950,000	Wholesale E&R	(\$11,194)	\$35,671	NEG

The economics of the selected BESS enabled microgrids with these two systems were then further investigated as described in Section 7. The results shown in Table 26 shows that the simple paybacks of most configurations are very poor. Generally speaking, relatively low demand rates at this site created limited opportunity for retail billing savings. Simple paybacks listed as “NEG” means that the annual operating expenses exceeded the annual potential value. Typically, utility billing demand savings are a primary driver of battery project economics but require demand rates on the order of \$20/kW to \$30/kW to create viable economics for a standalone system. Energy time of use savings can provide incremental additional value that can help project economics but are rarely sufficient to pay for a system on their own in an acceptable amount of time. The configurations with wholesale use cases have notably improved paybacks, especially those operating in the ISO-NE frequency regulation market.

Table 26 also highlights the stark differences in economic performance between the Li-Ion and VRF technologies. All of the VRF systems have more rated energy capacity than the Li-Ion systems, which may lead one to think more value could be generated. However, the lower round trip efficiency and significantly higher auxiliary system loads severely reduce the net value the systems generated once the operational and cost related impacts of those specifications were included in the modeling. Six of the fifteen configurations had a net annual loss – meaning that the recharge costs and auxiliary energy draw costs were greater than the electric bill savings or revenue the system earned. The VRF FR cases showed annual value in excess of \$40,000, however this is almost half of the value the FR Li-Ion systems generated. This is again a result of increased recharge and auxiliary load costs, as well as the fact that FR revenue is a function of system power and less a function of energy capacity. Having significantly more rated energy capacity does not necessarily increase the amount of FR value a BESS can generate.

Once the optimal BESS systems were determined for each site, the next objective was to determine how replacement of the least running DG in each baseline microgrid with these BESS systems affected the 20-year net present value of the microgrid. This calculation and results are described in Section 7.

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7.0 COST ASSESSMENT

Multiple levels of economic assessment were completed to determine the optimal VRF and Li-Ion BESS sizing for each microgrid and its impact on cost of critical load support. Of the 6 BESS sizes considered for each site, a single VRF and Li-Ion BESS was selected for each site based on estimated simple payback. Then, a detailed 20-year economic pro-forma was created for each system, in both current and future market and cost scenarios. This pro-forma accounted for initial capital cost, annual operating and preventive maintenance costs including assumed escalation rates, and annual value as calculated from the grid-tied modeling efforts.

The 20-year net present value of each microgrid was then calculated and normalized by the amount of each site's critical load. This identified the cost of critical load coverage for each site's DG only baseline and battery enabled microgrid systems. A summary of these results is provided in Table 27. These results show that there are scenarios in which the BESS enabled microgrid can reduce the site's cost of critical load support now or in the future. However, the VRF BESS technology in all cases provides a higher cost of critical load support – primarily due to higher capital costs and significantly higher auxiliary loads which reduce the operating value of the VRF storage systems.

Table 27. Cost of Critical Load Support Results Summary

Installation	# of DG Assets	DG Capacity Per Asset (kW)	# of BESS Assets	BESS Total Power Capacity	BESS Total Energy Capacity	BESS Lower SOE	Grid Tied Use Case Stack	Cost of Critical Load Support (\$/kW-c)
				kW	kWh	kWh		
March ARB	4	250	0	N/A	N/A	N/A	None	\$416
	3	250	2 VRF	875	7,000	3509	DCM+WH E&R	\$317 (f) to \$519 (c)
	3	250	2 Li-Ion	3,500	7,000	3509	DCM+WH E&R	\$229 (f) to \$525 (c)
NAS Corpus Christi	7	750	0	N/A	N/A	N/A	DR + PS	\$89
	6	750	1 VRF	1,217	7,300	0	DCM	\$109 (f) to \$132 (c)
	6	750	1 Li-Ion	3,650	7,300	0	DCM	\$90 (f) to \$115 (c)
Fort Bliss	8	2000	0	N/A	N/A	N/A	None	\$83
	7	2000	1 VRF	2,000	12,000	0	DCM	\$104 (f) to \$117 (c)
	7	2000	1 Li-Ion	2,000	4,000	0	DCM	\$88 (f) to \$93 (c)
Westover ARB	4	750	0	N/A	N/A	N/A	DR	\$166
	3	750	1 VRF	750	4,500	0	FR	\$196 (f) to \$251 (c)
	3	750	1 Li-Ion	750	750	0	FR	\$129 (f) to \$156 (c)
NAS Patuxent River	12	750	0	N/A	N/A	N/A	DR	\$98
	11	750	1 VRF	1,167	7,300	0	DCM+WH E&R	\$111 (f) to \$128 (c)
	11	750	1 Li-Ion	3,500	7,000	0	DCM+WH E&R	\$96 (f) to \$121 (c)

7.1 COST CATEGORIES & ASSUMPTIONS

To estimate implementation costs of the BESS systems within the microgrid, Ameresco leveraged its project development and implementation experience, including significant historical Li-Ion BESS pricing data, which includes quoted pricing for over 100 systems from more than 20 unique equipment providers, for system sizes ranging from 250 kW to 10,000 kW and 1 to 4 hours in duration. We also utilized order of magnitude cost information for VRF equipment obtained from multiple VRF equipment providers. From this data, estimated average equipment costs for each technology were determined. An implementation cost estimate was compiled for each VRF and Li-Ion BESS system that was analyzed.

The cost categories and assumed costs for each technology that were utilized in project economic analysis are described in Tables 28 and 29. Throughout these cost assumptions, kW and kWh refer to the system's rated power and energy capacities, respectively.

Table 28. VRF BESS Cost Categories

VANADIUM REDOX FLOW BESS COST CATEGORIES		
Initial BESS Equipment Purchase	• DC Storage Block – Electrolyte Tanks – Power Stacks – Mechanical Pumping Systems – Thermal Management Systems – Enclosure/Container • Bi-Directional Power Conversion System • Battery Management System • Shipping • Installation & Commissioning Support • Customer Training	\$250/kW + \$480/kWh
Electrolyte Leasing Plan	• Upfront purchase • Lease over 20 years at 5% per year	Upfront purchase of electrolyte assumed to be 50% of \$/kWh BESS equipment cost
Engineering Design	• Issue for Construction (IFC) Design Package • Permitting • Interconnection Application	\$100,000
Installation	• Site Preparation • Civil Foundations • Running of electrical and communications conduit and wiring • Mechanical rigging, landing, mounting • DC and AC Electrical Interconnection	\$275/kWh
Balance of Project Costs	• (3) Revenue grade meters • Zero Tax assumed • Development, Project Management and Over Head Costs	Varies by use case and system size

For the Li-Ion BESS systems, the current market cost categories considered included:

Table 29. Li-Ion BESS Current Market Cost Categories

Li-Ion BESS COST CATEGORIES		
Initial BESS Equipment Purchase	• DC Storage Block – Battery Racks – Enclosure/Container – Thermal Management System – Fire Suppression System • Bi-Directional Power Conversion System • Battery Management System • Shipping • Installation & Commissioning Support • Customer Training	\$250/kW + \$350/kWh
Capacity Maintenance Plan	• Assumed upfront payment of 20-year Capacity Maintenance Agreement, ensuring rated energy capacity for 20-year term. • This was included to provide a fair comparison to the VRFB which does not experience energy capacity degradation	\$187/kWh
Engineering Design	• Issue for Construction (IFC) Design Package • Permitting • Interconnect Application	\$100,000
Installation	• Site Preparation • Civil Foundations • Running of electrical and communications conduit and wiring • Mechanical rigging, landing, mounting • DC and AC Electrical Interconnection	\$275/kWh
Other	• (3) Revenue grade meters • Zero Tax assumed • Development, Project Management and Over Head Costs	Varies by use case and system size

For both technologies, cost of controls was accounted for based on the planned use cases for the site as shown in Table 30.

Table 30. Controls Cost Categories

CONTROLS COST CATEGORIES		
Peak Shaving Controls (For projects participating in Demand Charge Management)	• Peak Shaving Controls Equipment • Controls Initial Setup	\$15,000
Market Participation Controls (For projects participating in Wholesale Market Use Cases)	• Router/RTU Equipment • Market Participation Telemetry Setup • Market Participation State of Charge Management Setup	\$17,000

Annual Operations & Maintenance (O&M) cost categories for each technology are summarized in Table 31. Since auxiliary power costs and re-charge costs are associated with the net change in a site's annual electric utility costs, the savings reported are net savings and inclusive of these operating costs.

Table 31. Operations & Maintenance Cost Categories

Annual O&M Cost Categories	O&M Cost Category	VRF Year 1 Cost	Li-Ion Year 1 Cost
	Annual Equipment Preventive Maintenance	\$10,000	\$10,000
	Vanadium Leasing Cost (VRF Only, and if leasing selected over initial purchase)	6% of Electrolyte Value For 20 Years	Not Applicable
	Controls Software Licensing & Support (for peak shaving only)	\$5,000	\$5,000
	Cellular Data Plan (for peak shaving only)	\$1,800	\$1,800
	Wholesale Market CSP Services	20% of Annual Wholesale Revenue	20% of Annual Wholesale Revenue

All operating expenses were assumed to escalate at 2.2% annually in line with inflation. A 6.0% investment rate was used for financial NPV calculations. For revenue generated from wholesale market products (e.g. regulation or energy), it was assumed that a 20% service charge would be paid to a Curtailment Service Provider (CSPs). The CSP holds the responsibilities of Designated Entity (DE) and Market Participant (MP). By assuming these roles, the CSP has responsibility for registering, bidding, scheduling, and settling the asset into the market. The CSP is responsible for maintaining registration and operating requirements, including a network operation center operable twenty-four hours per day, seven days a week. In addition, the CSP takes on market risk relative to performance, subject to reasonable adherence to operating agreements. This 20% service charge is in line with our experience with CSPs, and was also recommended by ESTCP in the provided site information.

Since our reliability modeling showed that we had determined BESS configurations that allowed for replacement of the least running DG while maintaining the reliability performance target, we also claimed capital and annual operating expense savings associated with the DG being replaced. These values were specified by the ESTCP program as shown in Table 32.

Table 32. Assumed DG capital and operating costs

	Units	Westover ARB	NAS Patuxent River	NAS Corpus Christi	Fort Bliss	March ARB
# DGs	#	4	12	7	8	4
DG Capacity Per Unit (kW)	kW	750	750	750	2,000	250
Capital Cost of DG	\$/kW	\$ 750	\$ 750	\$ 750	\$ 600	\$ 1,100
Annual O&M and Testing Cost of DG	\$/DG	\$ 7,000	\$ 7,000	\$ 7,000	\$ 20,000	\$ 6,500

The BESS enabled microgrids were also assessed using future technology pricing to observe the viability of the BESS assuming projected costs five years from now. For VRF systems, we assumed five-year future costs 38% lower than today's estimated costs. For Li-Ion systems, we assumed five-year future costs 28% lower than today's assumed costs for both upfront equipment and capacity maintenance costs.

These assumptions were based on Lazard's Levelized Cost of Storage (LCOS) Analysis v4.0 published in 2018, as shown below in Figure 13. Our team also found these projected cost declines to be reasonable based on our insight into battery equipment costs from our direct project development experience in the industry. Our team determine current market cost estimates primarily using our own project data and awareness of technology costs from direct experience in the industry. We then referenced the cost reduction projects over a five-year period from the Lazard report to project 2025 costs. Although the Lazard data is from 2018 to 2022, we assumed that the rate of cost reduction would remain the same, and therefore used the five-year average reductions to project our 2020 costs to estimated 2025 costs.

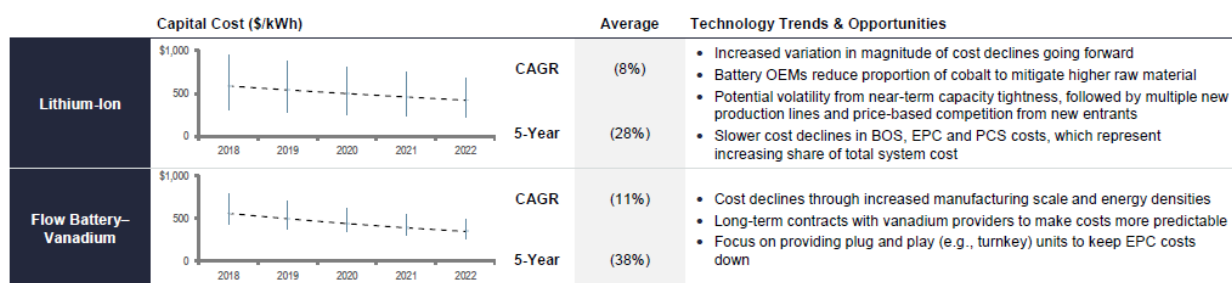


Figure 13. Project 5-year cost declines for Li-Ion and VRF BESS technology^{xxiii}

7.2 SITE COST AND SAVINGS DETAILS

Using the aforementioned cost assumptions, full implementation cost estimates were calculated for each down-selected system configuration. These costs, as well as annual value and year 1 operating expenses, are shown in the following tables for each installation.

March ARB

The previously described cost assumptions were used to calculate implementation cost estimates for the two BESS systems down selected at March ARB. Since March ARB is in California, it is eligible for the state's Self-Generation Incentive Program (SGIP). This is a tiered incentive program that energy storage system owners are eligible to apply for. Ameresco has direct experience with obtaining funding from this program through the projects we have developed in California. The incentive is primarily based on the BESS's rated energy capacity and is offered in decreasing \$/Wh steps. We assumed the March ARB systems would both be eligible for SGIP incentives valued at \$0.30/Wh. If fully awarded, 50% of this incentive funding is awarded upfront and the remaining 50% on a performance-based basis pro-rated over the first five years of operation. For the March ARB VRF system, the option to lease the electrolyte and pay an annual leasing fee was more cost effective than upfront total purchase.

These results, summarized in Table 33, show how the VRF system had significantly less retail savings than the Li-Ion systems because of the previously discussed auxiliary power and round-trip efficiency issues. For this site, the impact of these issues was modeled to be over \$30,000 per year. Both system configurations have the same energy capacity, but the higher power capacity of the Li-Ion system enables over \$150,000 more in wholesale market value – which are power focused markets.

Table 33. March ARB BESS Cost & Savings Summary

Installation		March ARB	
Storage Technology		VRF	Li-Ion
Rated Power	kW	875	3,500
Rated Energy	kWh	7,000	7,000
Lower SOE Limit	kWh	3,509	3,509
Current Market Implementation Cost	\$	\$3,516,363	\$6,661,900
Current Market Retail Savings	\$/Year	\$146,984	\$ 180,205
Current Market Wholesale Value	\$/Year	\$57,635	\$ 172,306
Current Market Total Annual Value	\$/Year	\$204,619	\$ 352,511
Future Market Implementation Cost	\$	\$3,069,918	\$4,549,902
Future Market Retail Savings	\$/Year	\$140,135	\$ 168,620
Future Market Wholesale Value	\$/Year	\$123,603	\$ 300,858
Future Market Total Annual Value	\$/Year	\$263,738	\$ 469,478

Fort Bliss (Table 34)

At Fort Bliss, only retail billing savings use cases were determined to be accessible. There are also no incentive programs known to be available for energy storage in Texas. These results again show the impacts of auxiliary load and round-trip efficiency issues pertaining to VRF systems. The VRF system, which has three times the rated energy capacity of the Li-Ion system and conceptually should produce significantly more savings, was modeled to produce over \$15,000 less in retail savings than the Li-Ion system. This shows how selection of a VRF system over a Li-Ion system for behind the meter retail use cases is very difficult until these operational issues can be improved. Since there are no wholesale use cases, the future market scenario values do not change compared to the current market scenario.

Table 34. Fort Bliss BESS Cost & Savings Summary

Installation		Fort Bliss	
Storage Technology		VRF	Li-Ion
Rated Power	kW	2,000	2,000
Rated Energy	kWh	12,000	4,000
Lower SOE Limit	kWh	0	0
Current Market Implementation Cost	\$	\$7,831,500	\$4,459,700
Current Market Retail Savings	\$/Year	\$95,152	\$ 112,853
Current Market Wholesale Value	\$/Year	\$0	\$ 0
Current Market Total Annual Value	\$/Year	\$95,152	\$ 112,853
Future Market Implementation Cost	\$	\$6,965,780	\$3,252,844
Future Market Retail Savings	\$/Year	\$95,152	\$ 112,853
Future Market Wholesale Value	\$/Year	\$0	\$ 0
Future Market Total Annual Value	\$/Year	\$95,152	\$ 112,853

Westover ARB (Table 35)

Westover ARB's presence in New England enabled the most use cases to be considered of any installation investigated. The Massachusetts SMART incentive program was also considered for both technologies. It was determined to be not available for the Li-Ion system since a 2 hour or longer duration system is required. It was determined that the VRF would be eligible for the incentive if paired with PV, and receive an incentive value of \$0.0565/kWh of PV production. With the specified PV system generating 2,929,437 kWh annually, a total incentive value of \$165,513 was included in the VRF economics. It should be noted that the rules of this program are likely to change in the near future and the value of this incentive may likely change.

With relatively low retail savings opportunity based on this site's utility tariff, the optimal configuration was a frequency regulation only use case. As with other sites, the auxiliary load and round-trip efficiency issues of the VRF technology significantly impacted net revenue by increases the retail electricity costs as a result of market participation. The VRF requires more energy to operate, and the lower round trip efficiency has an even more notable impact on a high throughput use case like frequency regulation that requires frequent re-charging of the BESS. The impact of these issues in this case was over \$40,000 annually.

Analysis of revenue also shows that having significantly more duration of storage does not create opportunity for more market revenue. The frequency regulation signal is conditionally neutral, meaning that in general the amount of energy asked to be absorbed will be close to equal to the amount of energy asked to be generated over a 30-minute period. Thus, a BESS with 1 hour of storage is appropriately sized to follow the signal well and generate maximum revenue. For the case of the VRF battery, adding four more hours of duration and subsequently increasing implementation cost by almost \$2M yielded only \$1,000 in additional annual revenue.

Table 35. Westover ARB BESS Cost & Savings Summary

Installation		Westover ARB	
Storage Technology		VRF	Li-Ion
Rated Power	kW	750	750
Rated Energy	kWh	4,500	750
Lower SOE Limit	kWh	0	0
Current Market Implementation Cost	\$	\$2,867,037	\$1,067,775
Current Market Retail Savings	\$/Year	\$(51,580)	\$(9,509)
Current Market Wholesale Value	\$/Year	\$95,704	\$94,930
Current Market Total Annual Value	\$/Year	\$44,124	\$85,421
Future Market Implementation Cost	\$	\$2,542,392	\$811,302
Future Market Retail Savings	\$/Year	\$(51,580)	\$(9,509)
Future Market Wholesale Value	\$/Year	\$112,867	\$111,996
Future Market Total Annual Value	\$/Year	\$61,287	\$102,487

NAS Corpus Christi (Table 36)

The conditions at NAS Corpus Christi are very similar to Fort Bliss, with no wholesale market or energy storage incentive opportunities known to be available. However, with the BESS energy capacity being the primary factor of design and system selection, both VRF and Li-Ion systems have the same amount of energy capacity but differing rated power capacities. This enables the VRF system to be more competitive than at Fort Bliss. The opportunity to lease electrolyte creates a significantly lower upfront implementation expense for the VRF system. However, the AESOP modeled retail billing savings value is lower than the Li-Ion system by over \$200,000 per year, once again because of lower round trip efficiency and significantly higher auxiliary system load requirements.

Table 36. NAS Corpus Christi BESS Cost & Savings Summary

Installation		NAS Corpus Christi	
Storage Technology		VRF	Li-Ion
Rated Power	kW	1,217	3,650
Rated Energy	kWh	7,300	7,300
Lower SOE Limit	kWh	0	0
Current Market Implementation Cost	\$	\$4,822,813	\$8,015,615
Current Market Retail Savings	\$/Year	\$153,752	\$ 387,245
Current Market Wholesale Value	\$/Year	\$0	\$ 0
Current Market Total Annual Value	\$/Year	\$153,752	\$ 387,245
Future Market Implementation Cost	\$	\$4,296,130	\$5,813,103
Future Market Retail Savings	\$/Year	\$153,752	\$ 387,245
Future Market Wholesale Value	\$/Year	\$0	\$ 0
Future Market Total Annual Value	\$/Year	\$153,752	\$ 387,245

NAS Patuxent River (Table 37)

NAS Patuxent River was also eligible for retail billing savings coupled with wholesale market participation being located in PJM territory. A modest \$75,000 incentive value was also included in implementation cost economics, which is the maximum per project funding available from the Maryland Energy Storage Tax Credit program.

Once again the two systems had identical energy capacities and varying power capacities. As observed in ISO-NE, the additional power capacity of the Li-Ion BESS yielded more than twice the wholesale market value as compared to the VRF system. In congruence with other sites, the higher auxiliary loads and lower round trip efficiency negatively impacted retail billing savings. This use case stack included demand charge reduction coupled with PJM wholesale energy and reserves. With lower power capacity to reduce demand and higher operational energy costs, the retail billing savings of the VRF system were modeled to be less than half of the Li-Ion system.

Table 37. NAS Patuxent River BESS Cost & Savings Summary

Installation		NAS Patuxent River	
Storage Technology		VRF	Li-Ion
Rated Power	kW	1,167	3,500
Rated Energy	kWh	7,000	7,000
Lower SOE Limit	kWh	0	0
Current Market Implementation Cost	\$	\$4,575,313	\$7,636,900
Current Market Retail Savings	\$/Year	\$91,020	\$ 233,449
Current Market Wholesale Value	\$/Year	\$35,821	\$ 93,308
Current Market Total Annual Value	\$/Year	\$126,841	\$ 326,757
Future Market Implementation Cost	\$	\$4,070,273	\$5,524,902
Future Market Retail Savings	\$/Year	\$72,300	\$ 214,077
Future Market Wholesale Value	\$/Year	\$113,759	\$ 275,596
Future Market Total Annual Value	\$/Year	\$186,059	\$ 493,673

7.3 VERIFICATION OF BASELINE COST OF CRITICAL LOAD SUPPORT

Once project costs and savings were calculated, the next step was to assess how the BESS enabled microgrids impacted cost of critical load support (\$/kW_c) as compared to the DG only baseline microgrid. This was evaluated by identifying the 20-year Net Present Value (NPV) of each microgrid configuration and dividing that by the peak critical load to serve for the site within the microgrid. The \$/kW_c metric for each microgrid configuration was calculated as:

- *20-Year NPV of installation electricity costs in microgrid*
 - *For the DG only baseline microgrid, this included emergency demand response revenues and effects of peak shaving*
 - *For the BESS enabled microgrid, this included BESS enabled retail savings and wholesale market revenues*
 - *Minus,*
- *20-Year NPV of installation electricity costs without microgrid*
- *20-Year NPV of capital and O&M costs for assets and microgrid infrastructure*
 - *For the DG only baseline microgrid, this included all DGs, including related fuel costs*
 - *For the BESS enabled microgrid, this included one less DG, DG related fuel costs for demand response and peak shaving, the proposed BESS including related capital and operating expenses*

To ensure we could calculate the BESS enabled microgrid NPV correctly, we first calculated the NPV and cost of critical load support of the DG only microgrids. Our calculations perfectly matched the ESTCP provided results – confirming that our method was correct. To do this, we built a 20-year pro-forma of implementation expense, annual operation and maintenance expenses, and annual value of the microgrid assets. All pro-formas are provided in Appendix A.4. Calculated values for the baseline microgrid are as follows, with an excerpt from the March ARB baseline pro-forma below (see Table 38 and Figure 14).

Table 38. March ARB Cost of Critical Load and NPV Summary

Baseline DG Only Microgrid	20 YR NPV of Installation Electricity Costs in Baseline Microgrid (Post DR and PS)	20 YR NPV of Installation Electricity Costs Without Microgrid	20 YR NPV of Capital and O&M Costs of Baseline Microgrid	Installation Annual Peak Critical Load (kW)	20-Year Cost of Critical Load Support (\$/kW _c)
March ARB	\$59,997,761	\$59,997,761	\$4,993,095	600	\$416
Fort Bliss	\$282,262,196	\$282,262,196	\$20,685,695	12,507	\$83
Westover ARB	\$19,521,417	\$20,453,782	\$6,615,177	1,707	\$166
NAS Corpus Christi	\$93,611,863	\$96,814,750	\$11,079,935	4,410	\$89
NAS Patuxent River	\$282,262,196	\$282,262,196	\$20,685,695	12,507	\$83

		March ARB Microgrid Economics									
		Inflation Rate	2.2%								
		Investment Rate	6.0%								
		DG Quantity	4								
		Capacity of Each DG (kW)	250								
		Capital Cost of Each DG (\$/kW)	\$ 1,100								
		Year 1 DG O&M Cost Per Unit	\$ 6,500								
		UPS Quantity	3								
		Capacity of Each UPS (kVA)	250								
		Energy Capacity of Each UPS (kWh)	63								
		Capital Cost of Each UPS (\$/kVA)	\$ 647								
		Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66								
		Variable O&M Cost of UPS (\$/MWh)	\$ 4.39								
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BASELINE MICROGRID (POST DR AND PS)	\$59,997,761										
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$59,997,761	Operating Yr.	1	2	3	4	5	6	7		
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 4,993,095	Line Item	2019	2020	2021	2022	2023	2024	2025	2026	2027
Years	20	Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,000
Installation Peak Annual Load (kW)	7998	DG Capital & Annual O&M Cost	\$ 1,100,000	\$ 26,000	\$ 26,572	\$ 27,157	\$ 27,754	\$ 28,365	\$ 28,989	\$ 29,626	\$ 30,280
Critical Load %	7.5%	DG Demand Response Operating Fuel Cost	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Annual Critical Load	599.85	UPS Capital & Annual O&M Cost	\$ 485,250	\$ 10,246	\$ 10,471	\$ 10,702	\$ 10,937	\$ 11,178	\$ 11,424	\$ 11,675	\$ 11,926
		Total Annual Baseline Capital+O&M Costs	\$ 3,585,250	\$ 103,246	\$ 105,517	\$ 107,839	\$ 110,211	\$ 112,636	\$ 115,114	\$ 117,646	\$ 120,226
		Annual Electricity Costs	\$ 4,400,000	\$ 4,496,800	\$ 4,595,730	\$ 4,696,836	\$ 4,800,166	\$ 4,905,770	\$ 5,013,697	\$ 5,123,926	\$ 5,232,000
Energy Security Cost Metric	\$416	Emergency Demand Response Rev	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
ESTCP Provided Security Cost Metric	\$416	Peak Shaving Rev from DG Assets	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Match?	YES	Net Annual Electricity Costs	\$ 4,400,000	\$ 4,496,800	\$ 4,595,730	\$ 4,696,836	\$ 4,800,166	\$ 4,905,770	\$ 5,013,697	\$ 5,123,926	\$ 5,232,000

Figure 14. March ARB Baseline Microgrid Pro-Forma

7.4 CALCULATION OF BESS ENABLED MICROGRID COST OF CRITICAL LOAD SUPPORT

The same process was used to calculate the cost of critical load support for the VRF and Li-Ion BESS enabled microgrids. This was done for both the current and future market scenarios, resulting in 20 total calculations across the five sites under investigation. All pro-formas for the BESS enabled microgrids are also provided in Appendix A.4. Table 39 below summarizes the results and compares to the previously discussed baseline microgrid results. For the BESS enabled microgrids, (f) refers to the future volatile case and (c) refers to the current market scenario case.

There are multiple BESS enabled microgrid scenarios that provide a lower cost of critical load support than the DG only microgrid. At Westover ARB, the Li-Ion BESS enabled microgrid is modeled to provide a lower cost of critical load support in the current market scenario. This is the only installation where this occurred and shows it may be a top candidate for further investigation through Phase 2 and Phase 3 of this work. March ARB, Westover ARB, and NAS Patuxent River all had future market scenarios with a lower cost of critical load support. It should be noted that the capital and operating costs savings related to the replaced DG that were accounted for in economics played a significant role in this. Conceptually, we expect the opportunities for the BESS enabled microgrids to outperform the DG enabled microgrids to expand as the battery industry continues to mature. As equipment becomes more reliable, costs come down, and cost of electricity goes up, the value and economic viability of a battery system will only improve. For the VRF system, if the significant impacts of the high auxiliary power loads and low round trip efficiency can be mitigated over time, that technology will provide significantly greater potential to a microgrid project.

Table 39. Cost of Critical Load Summary for All Sites

Installation	# of DG Assets	DG Capacity Per Asset (kW)	# of BESS Assets	BESS Total Power Capacity	BESS Total Energy Capacity	BESS Lower SOE	Grid Tied Use Case Stack	Cost of Critical Load Support (\$/kW-c)
				kW	kWh	kWh		
March ARB	4	250	0	N/A	N/A	N/A	None	\$416
	3	250	2 VRF	875	7,000	3509	DCM+WH E&R	\$317 (f) to \$519 (c)
	3	250	2 Li-Ion	3,500	7,000	3509	DCM+WH E&R	\$229 (f) to \$525 (c)
NAS Corpus Christi	7	750	0	N/A	N/A	N/A	DR + PS	\$89
	6	750	1 VRF	1,217	7,300	0	DCM	\$109 (f) to \$132 (c)
	6	750	1 Li-Ion	3,650	7,300	0	DCM	\$90 (f) to \$115 (c)
Fort Bliss	8	2000	0	N/A	N/A	N/A	None	\$83
	7	2000	1 VRF	2,000	12,000	0	DCM	\$104 (f) to \$117 (c)
	7	2000	1 Li-Ion	2,000	4,000	0	DCM	\$88 (f) to \$93 (c)
Westover ARB	4	750	0	N/A	N/A	N/A	DR	\$166
	3	750	1 VRF	750	4,500	0	FR	\$196 (f) to \$251 (c)
	3	750	1 Li-Ion	750	750	0	FR	\$129 (f) to \$156 (c)
NAS Patuxent River	12	750	0	N/A	N/A	N/A	DR	\$98
	11	750	1 VRF	1,167	7,300	0	DCM+WH E&R	\$111 (f) to \$128 (c)
	11	750	1 Li-Ion	3,500	7,000	0	DCM+WH E&R	\$96 (f) to \$121 (c)

7.5 FURTHER POTENTIAL FOR COST DECLINE – PARALLELS TO SOLAR PV INDUSTRY

Over the last 10 years, the Solar PV industry has grown tremendously, in large part due to significant equipment and implementation cost reductions. It is commonly discussed that the energy storage industry may be at the beginning of a similar growth trajectory and period of cost decline. While these technologies are complementary in many ways, the fundamental components of technology are very different – so it may not be fair to claim battery systems will follow a parallel cost curve to what solar PV experienced between 2010 and today. On the other hand, battery systems are used for far more applications than solar PV. Li-Ion batteries are used in mobile devices, laptops, personal electronics – and more recently electric vehicles. The global exponential adoption of these products provides the Li-Ion battery industry massive momentum to continue to grow and could give credibility to the argument that costs will decline as quickly, or potentially more quickly, than solar PV. The industry has not yet seen as widespread adoption for VRF technology, so it remains to be seen how the maturity of that technology may evolve over the next five to ten years.

By way of comparison, the National Renewable Energy Laboratory has completed extensive work to monitor cost declines of the PV industry. As shown in Figure 15, the Commercial PV industry has experienced a reduction in implementation cost from \$5.43/W in 2010 to \$1.83/W in 2018. This is a reduction of over 66% in eight years – or over 8% per year on average. If the battery industry met or slightly exceeded this, that could indicate cost reductions on the order of 50% over the next five years. That would be almost twice what our team assumed for our future market scenario analyses for Li-Ion technology and would undoubtedly enable significantly more viable project opportunities for deployment of this storage technology.

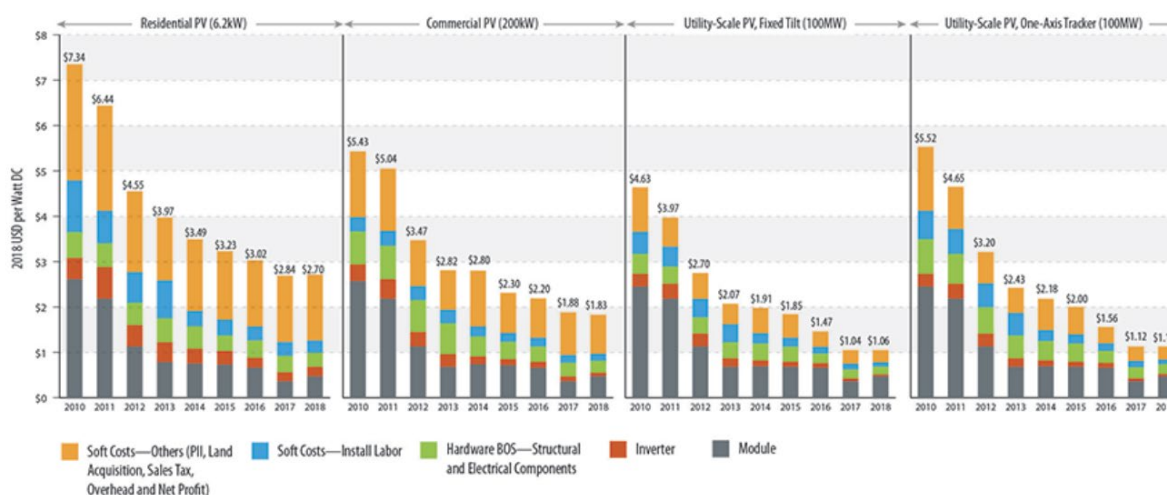


Figure 15. NREL Solar PV Cost Benchmark ^{xxiv}

8.0 STUDY CONCLUSIONS AND OUTCOMES

This work has provided significant insight into the potential for large scale battery energy storage to enhance resiliency of military microgrids. The work herein also offers a unique comparison between DGs, VRF storage, and Li-Ion storage and helps to characterize the opportunities and limitations of each technology. The robust data and information created from this Phase 1 study shows that there is the potential for energy storage to reduce reliance on DGs within a microgrid while simultaneously reducing an installation's cost of critical load support over a twenty-year period. This is primarily attributable to the opportunity for a large scale energy storage system to operate continuously in a grid paralleled state to generate savings and revenue through retail and wholesale use cases. However, analysis of results shows that this occurs only under certain conditions and is more likely to occur in regions with high costs of electricity and clearly defined market opportunities for storage participation. Key observations about VRF equipment were made which will inform the industry on how the technology can continue to improve and further benefit DoD installations. This work significantly contributes to the body of knowledge of VRF battery technology – helping to advance the state of the art of this promising new technology.

Through assessment of the reliability modeling results and critical load coverage curves produced, we can conclude that a VRFB enabled microgrid provides satisfactory reliability performance at all five sites by meeting the fixed load baseline performance requirement over a 168-hour outage that could occur at any time. However, we can also conclude for all five sites that critical load coverage at 168 hours was below the variable load DG-only coverage by between 1.6% to 3.0%. This is to be expected since the newer VRF technology is expected to have lower reliability factors than the DG technology. Reliability modeling also shows that the presence of on-site solar PV generating assets positively impact microgrid performance and in some cases create better reliability performance than the variable load DG-only case. As this objective of determining the reliability of a VRF BESS enabled microgrid is a major performance objective of this Phase 1 scope of work, this is a very important and informative conclusion. This result indicates that there is significant justification for the further investigation of the VRF technology in follow on Phase 2 testing, which will help validate Phase 1 conclusions and confirm or adjust the reliability assumptions made herein.

From an economic standpoint, our results allow us to conclude that there is opportunity for a BESS enabled microgrid to reduce the cost of critical load support at Westover ARB under today's market conditions. If projected market conditions of this work materialize, this opportunity could also expand to NAS Patuxent River and March ARB. However, this work shows that there appear to be significant challenges with VRF technology that need to be improved to provide an economically better alternative to Li-Ion battery technology. Based on today's expected VRF BESS equipment pricing and significant impacts of system auxiliary loads and round-trip efficiency, there is not a clearly established case for a VRF BESS providing a preferable technology solution to Li-Ion BESS technology for behind the meter customer sited deployments. Our modeling results show that these efficiency and auxiliary load issues significantly reduce the net annual savings the systems can generate and hamper the viability of the VRF technology. Even if the equipment cost of the technology were to decrease significantly, these high operating costs due to continuous operation of pumping systems and lower inherent electrochemical efficiency severely decreases the total annual value of the project. As noted above, Ameresco is working to verify this observation. However, if it holds true, that would be a major technical flaw with the technology that would need to be resolved to support viability of widespread adoption.

It is important to note that a critical aspect of Phase 2 work is to verify the accuracy of the assumed efficiency and auxiliary load metrics. Considering that VRF BESS technology is early on in its development and deployment lifecycle

and has not yet achieved the economies of scale that Li-Ion has enjoyed, this conclusion is logical based on current market conditions. However, should costs of the VRF technology decrease in the future, there may very likely be conditions where a VRF BESS would provide a more attractive solution than Li-Ion.

In summary, Table 40 below provides succinct results for each of the objectives that were defined at the beginning of this project.

Table 40. Project Results Summary

Objective 1	Calculate the hourly probability of serving 100% of the critical load requirement of each site during a utility outage of up to 168 hours in duration that could start at any hour of the year
	Result 1: Complete. VRF BESS configuration was established at each site that satisfied this objective
Objective 2	Calculate the hourly probability of serving 130% of the critical load requirement of each site during a utility outage of up to 168 hours in duration that could start at any hour of the year
	Result 2: Complete. Results vary widely across sites, but 168-hour probability of coverage ranges from 30 – 86%.
Objective 3	For the case of no diesel fuel supply, calculate the hourly probability of serving critical 30% of the load for each site during a utility outage of up to 168 hours in duration that could start at any hour of the year
	Result 3: Complete. Generally poor performance, with coverage probably dropping toward 0% quickly and generally far less than a day of any probability of coverage at all. Presence of PV has notable positive impact to performance. March ARB has significantly better performance than the other 4 sites in this scenario.
Objective 4	For the case of no diesel fuel supply, calculate the hourly probability of serving critical 10% of the load for each site during a utility outage of up to 168 hours in duration that could start at any hour of the year
	Result 4: Complete. Generally poor performance, with coverage probably dropping toward 0% quickly and generally far less than a day of any probability of coverage at all. Presence of PV has notable positive impact to performance. March ARB has significantly better performance than the other 4 sites in this scenario.
Objective 5	Determine the minimum amount of power and energy a BESS needs to provide to the microgrid such that the Objective 1 outcome meets or exceeds the fixed load baseline performance
	Result 5: Complete. Results as described above in this report. Microgrid power requirements range from 207 kW to 659 kW. Microgrid energy requirements range from 207 kWh to 7264 kWh.
Objective 6	Identify the rated power and energy capacity sizing of the optimally sized BESS for each site
	Result 6: Complete. Results as described above in this report. VRF BESS rated power and energy capacities range from 875 – 2,000 kW and 7,000 – 12,000 kWh, respectively. Li-Ion BESS rated power and energy capacities range from 2,000 – 7,000 kW and 4,000 – 7,300 kWh, respectively.
Objective 7A	Quantify the annual value each BESS can generate for the site through retail utility billing savings and participation in the relevant wholesale market products for that site, based on current market conditions
	Result 7A: Complete. Current market condition value opportunities have been calculated for all sites. These ranged from \$85,000 to \$387,000, annually.
Objective 7B	Quantify the annual value each BESS can generate for the site through retail utility billing savings and participation in the relevant wholesale market products for that site, based on future volatile market conditions
	Result 7B: Complete. Future market condition value opportunities have been calculated for all sites. These ranged from \$102,000 to \$493,000, annually.
Objective 8	Calculate the cost of securing critical load for the BESS enabled microgrid as a function of 20-year Net Present Value and how this compares to the baseline, DG only microgrid
	Result 8: Complete. 5 of 20 unique scenarios analyzed showed potential for lower cost of critical load support with BESS enabled microgrid, contained to March ARB, Westover ARB and NAS Patuxent River.
Objective 9	Identify if VRF or Li-Ion is the preferred technology for the proposed BESS at each site.
	Result 8: In all cases, Li-Ion offered a lower cost of critical load support.

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A.1 INSTALLATION DATA APPENDIX

Information specific to each of the five sites was provided by the ESTCP program and is shown below. This was accompanied by hour

Fort Bliss

Load Information

Data Field	Value in BAA Instructions	Value in Current Spreadsheet
PV Project Capacity (kW-AC)	6,200	6,200
Total Peak Demand (kW-AC)	69,000	67,605
(Peak) Critical Load (kW-AC)	12,500	12,507
Portion of Critical Load Requiring Ride-Through (kW-AC)	6,000	6,000
Total Annual Electricity Cost (not including PV costs)	\$20.7 million	\$20.7 million

Critical Loads as a % of Gross Total Electricity Consumption; apply same % to each hourly interval	Portion of Critical Load Requiring Ride-Through (kW-AC)	Ownership of On-Installation Distribution System
18.5%	6,000	Privatized via a 50-year contract with Rio Grande Electric Cooperative

Baseline Microgrid Asset Information

Diesel Fuel Price (\$/gallon)	On-Installation Diesel Fuel Supply (gallons)	Capacity of Each Diesel Genset (kW)	# of Diesel Gensets
\$2.59	150,000	2,000	8
Capital Cost of Diesel Genset (\$/kW)	Annual O&M and Testing Cost of Each Diesel Genset	Heat Rate of Diesel Gensets (Btu/kWh)	
\$600	\$20,000	10,618	
Capacity & Duration of Each UPS	# of UPS	Capital Cost of UPS (\$/kVA)	
2,000 kVA 500 kWh	4	\$486	
Fixed O&M Costs of UPS (\$/kVA-year)	Variable O&M Cost of UPS (\$/MWh)	Asset Lives of Diesel Gensets and UPS (years)	
\$5.98	\$1.21	20	

Utility Rate Information

Monthly Fixed Charges	On-Peak Firm Energy Charges (\$/kWh)	Off-Peak Firm Energy Charges (\$/kWh)	Interruptible Energy Charges (\$/kWh)	Fuel Charges (\$/kWh)
\$820.00	\$0.121810	\$0.007750	\$0.004340	\$0.025243
Summer Firm Monthly Peak Demand Charges (\$/kW)	Winter Firm Monthly Peak Demand Charges (\$/kW)	Interruptible Monthly Peak Demand Charges (\$/kW)	Military Base Discount	Aggregate Taxes and Other Fees
\$20.21	\$16.02	\$2.22	20.0%	6.5%

Financial Information

Annual Inflation Rate; apply to all prices, including diesel fuel and electricity, and all O&M costs	Nominal Investment Discount Rate	Investment Horizon (years), beginning in 2020
2.2%	6.0%	20

March ARB

Load Information

Data Field	Value in BAA Instructions	Value in Current Spreadsheet
PV Project Capacity (kW-AC)	400	400
Total Peak Demand (kW-AC)	7,700	7,998
(Peak) Critical Load (kW-AC)	600	600
Portion of Critical Load Requiring Ride-Through (kW-AC)	350	350
Total Annual Electricity Cost (not including PV costs)	\$4.4 million	\$4.4 million

Critical Loads as a % of Gross Total Electricity Consumption; apply same % to each hourly interval	Portion of Critical Load Requiring Ride-Through (kW-AC)	Ownership of On-Installation Distribution System
7.5%	350	City Light and Power

Baseline Microgrid Asset Information

Diesel Fuel Price (\$/gallon)	On-Installation Diesel Fuel Supply (gallons)	Capacity of Each Diesel Genset (kW)	# of Diesel Gensets
\$2.97	10,000	250	4
Capital Cost of Diesel Genset (\$/kW)	Annual O&M and Testing Cost of Each Diesel Genset	Heat Rate of Diesel Gensets (Btu/kWh)	
\$1,100	\$6,500	14,404	
Capacity & Duration of Each UPS	# of UPS	Capital Cost of UPS (\$/kVA)	
250 kVA 63 kWh	3	\$647	
Fixed O&M Costs of UPS (\$/kVA-year)	Variable O&M Cost of UPS (\$/MWh)	Asset Lives of Diesel Gensets and UPS (years)	
\$13.66	\$4.39	20	

Utility Rate Information

Monthly Fixed Charges	Distribution Energy Charges (\$/kWh)	SCE Summer On-Peak Generation Charges (\$/kWh)	SCE Summer Mid-Peak Generation Charges (\$/kWh)	SCE Summer Off-Peak Generation Charges (\$/kWh)
\$2,110.04	\$0.02651	\$0.30144	\$0.08113	\$0.03562
SCE Winter Mid-Peak Generation Charges (\$/kWh)	SCE Winter Off-Peak Generation Charges (\$/kWh)	WAPA Generation Charges (\$/kWh)	Monthly Peak Demand Charges (\$/kW)	Aggregate Taxes and Other Fees
\$0.05148	\$0.04116	\$0.04181	\$8.77	0.0%

Financial Information

Annual Inflation Rate; apply to all prices, including diesel fuel and electricity, and all O&M costs	Nominal Investment Discount Rate	Investment Horizon (years), beginning in 2020
2.2%	6.0%	20

NAS Corpus Christi

Load Information

Data Field	Value in BAA Instructions	Value in Current Spreadsheet
PV Project Capacity (kW-AC)	1,200	1,200
Total Peak Demand (kW-AC)	24,000	23,965
(Peak) Critical Load (kW-AC)	4,400	4,410
Portion of Critical Load Requiring Ride-Through (kW-AC)	2,000	2,000
Total Annual Electricity Cost (not including PV costs)	\$7.1million	\$7.1million

Critical Loads as a % of Gross Total Electricity Consumption; apply same % to each hourly interval	Portion of Critical Load Requiring Ride-Through (kW-AC)	Ownership of On-Installation Distribution System
18.4%	2,000	Not provided; assume installation ownership of distribution system

Baseline Microgrid Asset Information

Diesel Fuel Price (\$/gallon)	On-Installation Diesel Fuel Supply (gallons)	Capacity of Each Diesel Genset (kW)	# of Diesel Gensets
\$2.42	50,000	750	7
Capital Cost of Diesel Genset (\$/kW)	Annual O&M and Testing Cost of Each Diesel Genset	Heat Rate of Diesel Gensets (Btu/kWh)	
\$750	\$7,000	12,040	
Capacity & Duration of Each UPS	# of UPS	Capital Cost of UPS (\$/kVA)	
250 kVA 63 kWh	9	\$647	
Fixed O&M Costs of UPS (\$/kVA-year)	Variable O&M Cost of UPS (\$/MWh)	Asset Lives of Diesel Gensets and UPS (years)	
\$13.66	\$4.39	20	

Utility Rate Information

Monthly Fixed Charges	Competitive Market Generation Charges (\$/kWh)	Distribution-Related Energy Charges (\$/kWh)
\$2,965.57	\$0.035660	\$0.000512
Transmission Monthly Peak Demand Charges (\$/kW)	Distribution Monthly Peak Demand Charges (\$/kW)	Aggregate Discount
\$5.476816	\$6.580761	3.0%

Financial Information

Annual Inflation Rate; apply to all prices, including diesel fuel and electricity, and all O&M costs	Nominal Investment Discount Rate	Investment Horizon (years), beginning in 2020
2.2%	6.0%	20

NAS Patuxent River

Load Information

Data Field	Value in BAA Instructions	Value in Current Spreadsheet
PV Project Capacity (kW-AC)	2,000	2,000
Total Peak Demand (kW-AC)	34,000	33,958
(Peak) Critical Load (kW-AC)	8,000	8,014
Portion of Critical Load Requiring Ride-Through (kW-AC)	4,000	4,000
Total Annual Electricity Cost (not including PV costs)	\$17.8 million	\$17.8 million

Critical Loads as a % of Gross Total Electricity Consumption; apply same % to each hourly interval	Portion of Critical Load Requiring Ride-Through (kW-AC)	Ownership of On-Installation Distribution System
23.6%	4,000	Not provided; assume installation ownership of distribution system

Baseline Microgrid Asset Information

Diesel Fuel Price (\$/gallon)	On-Installation Diesel Fuel Supply (gallons)	Capacity of Each Diesel Genset (kW)	# of Diesel Gensets
\$2.74	100,000	750	12
Capital Cost of Diesel Genset (\$/kW)	Annual O&M and Testing Cost of Each Diesel Genset	Heat Rate of Diesel Gensets (Btu/kWh)	
\$750	\$7,000	12,040	
Capacity & Duration of Each UPS	# of UPS	Capital Cost of UPS (\$/kVA)	
250 kVA 63 kWh	17	\$647	
Fixed O&M Costs of UPS (\$/kVA-year)	Variable O&M Cost of UPS (\$/MWh)	Asset Lives of Diesel Gensets and UPS (years)	
\$13.66	\$4.39	20	

Utility Rate Information

Monthly Fixed Charges	Summer Generation Charges (\$/kWh)	Winter Generation Charges (\$/kWh)
\$4,035.07	\$0.08011	\$0.05941
Miscellaneous Distribution Energy Charges (\$/kWh)	Monthly Peak Demand Charges (\$/kW)	Aggregate Taxes and Other Fees
\$0.00501	\$8.92	4.0%

Financial Information

Annual Inflation Rate; apply to all prices, including diesel fuel and electricity, and all O&M costs	Nominal Investment Discount Rate	Investment Horizon (years), beginning in 2020
2.2%	6.0%	20

Westover ARB

Load Information

Data Field	Value in BAA Instructions	Value in Current Spreadsheet
PV Project Capacity (kW-AC)	2,000	2,000
Total Peak Demand (kW-AC)	3,400	3,414
(Peak) Critical Load (kW-AC)	1,700	1,707
Portion of Critical Load Requiring Ride-Through (kW-AC)	900	900
Total Annual Electricity Cost (not including PV costs)	\$1.5 million	\$1.5 million

Critical Loads as a % of Gross Total Electricity Consumption; apply same % to each hourly	Portion of Critical Load Requiring Ride-Through (kW-AC)	Ownership of On-Installation Distribution System
50.0%	900	Utility owns distribution system from 13.8 kV line down to, and including, transformers

Baseline Microgrid Asset Information

Diesel Fuel Price (\$/gallon)	On-Installation Diesel Fuel Supply (gallons)	Capacity of Each Diesel Genset (kW)	# of Diesel Gensets
\$2.65	25,000	750	4
Capital Cost of Diesel Genset (\$/kW)	Annual O&M and Testing Cost of Each Diesel Genset	Heat Rate of Diesel Gensets (Btu/kWh)	
\$750	\$7,000	12,040	
Capacity & Duration of Each UPS	# of UPS	Capital Cost of UPS	
250 kVA 63 kWh	5	\$647	
Fixed O&M Costs of UPS (\$/kVA-year)	Variable O&M Cost of UPS (\$/MWh)	Asset Lives of Diesel Gensets and UPS (years)	
\$13.66	\$4.39	20	

Utility Rate Information

Monthly Fixed Charges	On-Peak Energy Charges (\$/kWh)	Off-Peak Energy Charges (\$/kWh)
\$135.00	\$0.0934	\$0.0751
Monthly Peak Demand Charges	Aggregate Discount	
\$6.52	9.0%	

Financial Information

Annual Inflation Rate; apply to all prices, including diesel fuel and electricity, and all O&M costs	Nominal Investment Discount Rate	Investment Horizon (years), beginning in 2020
2.2%	6.0%	20

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A.2 METHODOLOGY APPENDIX

MODELING INPUT ASSUMPTIONS

Input Variable	Assumption	Rationale
RELIABILITY MODELING		
DG Capacity	Varies by Installation	Provided by ESTCP
DG # of units	Varies by Installation	Provided by ESTCP
DG Failure to Start	0.2%	Provided by ESTCP
DG Mean Time Between Failure	1700 hours	Provided by ESTCP
DG Failure to Run	$1 - \exp(-t/MTBF_{DG})$	Provided by ESTCP
DG Performance after Failure to Run	Remains out of operation through duration of outage	Conservative assumption to account for unlikely scenario in which resources would not be available to put DG back into operation
PV Reliability	100%	Provided by ESTCP
PV Output	0%, 50%, 100%	Provides for microgrid that is able to operate independent of PV output
BESS Power	Varies by Installation, Sized to Replace least utilized DG	Ensures base level of cost reduction
BESS Energy	Varies by Installation, Sized to Replace least utilized DG	Ensures base level of cost reduction
BESS # of units	Varies by Installation in order to Meet Performance Objective #1	Ensure Objectives achieved
BESS Failure to Start	1.0%	Derived from vendor research
BESS Mean Time Between Failure	1095	Derived from vendor research
BESS Failure to Run	$1 - \exp(-t/MTBF_{BESS})$	Derived from vendor research
BESS AC Roundtrip Efficiency (without auxiliary load)	76%	Derived from vendor research
GRID-TIED MODELING		
BESS Power	Same as above	Same as above, plus larger sizes
BESS Energy	Same as above	Same as above, plus larger sizes
BESS AC Roundtrip Efficiency (without auxiliary load)	Same as above for flow BESS, 85% for Li-Ion BESS	Derived from vendor research, product spec sheets, past experience
Utility Rate Structure	Varies by Installation	Provided by ESTCP
Use Cases and Associated Inputs	Varies by Installation	Determined from research of site-specific retail and wholesale use cases available
BESS Cost	Varies by Installation	Derived from vendor research, product spec sheets, past experience

A.2.1 OVERVIEW OF THE RELIABILITY MODEL

Our reliability model, similar to ESTCP's calculated reliability in *Calculating the Reliability of a Backup system*, was designed such that we could measure the reliability across microgrid systems for each of the five installations modeled, while taking into account varying critical loads across different annual usage profiles. Additionally, the model is able to accommodate differing starting assumptions for baseline DG quantity and size, potential fuel outages, varying photovoltaic solar system PV production output scenarios, as well as a varying number of battery energy storage system (BESS) units and sizes. Our metrics for measuring success of the microgrid across all installations are:

- **Critical Load Coverage Probability (CLCP)** – the percentage probability that the critical load of a facility will be covered by the energy output of the microgrid system at any hourly timestep of a simulated outage event
- **Critical Load Coverage Probability Curve (CLCPC) curve** – the CLCPC outputs for a given outage event plotted for each hour along an axis of 168-hour event duration

The reliability of a microgrid system is dependent on the both the performance of each of the subsystems in the microgrid and the amount of critical load. The model is designed to be dynamic and account for the randomness of these two inherently variable factors for any given hour of the year. During any hour throughout the course of an outage event, the two variables may be affected by the performance of the microgrid system in the hours prior to the event hour being modeled. Given this complex nature of the system and variables, a Monte Carlo simulation approach was used to model the performance and reliability of the complete microgrid system in order to apply a statistical probabilistic approach for estimating failure rates over time. Our simulation sets out to answer the question:

Given a facility's critical load profile and without relying on the output of a PV system, what is the reliability of a microgrid system, made up of long-duration BESS units and DG units, to perform in providing energy required for a facility's critical load during an outage?

Each microgrid simulated was made of varying configurations with the following components:

- N_{DG} – # of DG units at the site
- N_{BESS} – # of BESS units at the site
- K_{DG} – power capacity of each DG unit
- K_{BESS} – total power capacity of all BESS units
- R_{BESS} – total energy capacity of all BESS units

The critical load varies for each hour of the year for each installation. In order to model outages that may start on any given hour, we differentiate between different hours during the modeling period, such that:

- t_0 – 1st hour of the outage event, where t_0 may equal 0 to 8759th hour of a year
- t – subsequent hour of the outage event, where t may equal 0 to 167
- $C_{(t)}$ – critical load during a given hour

For each of the 8760 outage scenarios, the model performs the following calculations for hours t_0 to $t=168$ and 100 iterations:

1. Apply random probability of failure to start, P_{fsDG} , for the available generators from the previous hour, $g_{DG(t-1)}$ (for the first hour of an outage, $g_{DG(t-1)} = g_{DG(t_0)} = N_{DG}$)
2. Sum the generators remaining available for the given hour, $g_{DG(t)}$, after accounting for failure to start
3. Apply random probability of failure to run, P_{frDG} , for the available generators and update the number available for the given hour, $g_{DG(t)}$
4. Calculate unserved critical load for the given hour, $USL_{(t)}$, based on the available DGs
 - $USL_{(t)} = C_{(t)} - (K_{DG} * g_{DG(t)})$
5. Apply random probability of failure to start, P_{fsBESS} , for the available BESS units from the previous hour, $g_{BESS(t-1)}$ (for the first hour of an outage, $g_{BESS(t-1)} = g_{BESS(t_0)} = N_{BESS}$)
6. Sum the number of BESS units available for the given hour, $g_{BESS(t)}$, after accounting for failure to start
7. Determine the available BESS power for the given hour, $P_{BESSavail(t)}$
 - $P_{BESSavail(t)} = (K_{BESS} * g_{BESS(t)}) / N_{BESS}$
8. If $USL_{(t)} > 0$ and $P_{BESSavail(t)} \geq USL_{(t)}$, calculate BESS discharge power, $P_{BESSdisch(t)}$, energy loss due to round trip efficiency, $r_{loss(t)}$, and auxiliary loads, $r_{aux(t)}$, and remaining BESS state of energy, $U_{BESS(t)}$, for the given hour
 - $P_{BESSdisch(t)} = USL_{(t)}$
 - $r_{loss(t)} = P_{BESSdisch(t)} * u_{loss}$, (u_{loss} is loss factor calculated in AESOP from round trip efficiency)
 - $r_{aux(t)}$ is a value calculated separately for auxiliary energy needed from the BESS
 - $U_{BESS(t)} = U_{BESS(t-1)} - P_{BESSdisch(t)} - r_{loss(t)} - r_{aux(t)}$ (for the first hour of an outage, $U_{BESS(t-1)} = U_{BESS(t_0)} = R_{BESS}$)
 - a. If $U_{BESS(t)} < 0$, the BESS units ran out of energy and the microgrid fails to cover the critical load
 - b. Else, apply random probability of failure to start, P_{frBESS} , for the available BESS units to determine the number of BESS units available at the end of the given hour, $g_{BESS(t)}$
9. Else, if $USL_{(t)} > 0$ and $P_{BESSavail(t)} < USL_{(t)}$, the BESS does not have enough power capacity and the microgrid fails to cover the critical load

10. Else, if $USL(t) < 0$ and $U_{BESS(t-1)} < R_{BESS}$, calculate BESS charge power, P_{BESSch} , energy loss due to round trip efficiency, $r_{loss(t)}$, and auxiliary loads, $r_{aux(t)}$, and remaining BESS state of energy, $U_{BESS(t)}$, for the given hour
 - $P_{BESSch(t)} = \min(-USL(t), P_{BESSavail(t)})$
 - $r_{loss(t)} = P_{BESSch(t)} * u_{loss}$, (u_{loss} is loss factor calculated in AESOP from round trip efficiency)
 - $r_{aux(t)}$ is a value calculated separately for auxiliary energy needed from the BESS
 - $U_{BESS(t)} = U_{BESS(t-1)} + P_{BESSch(t)} - r_{loss(t)} - r_{aux(t)}$ (for the first hour of an outage, $U_{BESS(t-1)} = U_{BESS(t0)} = R_{BESS}$)
 - Apply random probability of failure to start, P_{frBESS} , for the available BESS units to determine the number of BESS units available at the end of the given hour, $g_{BESS(t)}$

Based on the above logic, a three-dimensional matrix is populated representing the given hour of a given iteration of an outage scenario. A value of 1 indicates that the microgrid successfully covered the critical load, while a value of 0 indicates that the microgrid failed to meet the critical load (when failure occurs, the remaining hours in the given iteration are also marked as having failed). After all of the iterations and outage scenarios have been simulated, the CLCPC for each of the 8760 outage scenarios is calculated by finding the average across all 100 iterations. These CLCPCs were then averaged together to obtain the overall CLCPC for the microgrid configuration simulated.

The following assumptions and constraints were included in the reliability modeling:

- P_{fsDG} and P_{frDG} are as provided by ESTCP
- P_{fsBESS} and P_{frBESS} are derived using information provided by technology vendors and further explained in Section 6.2
- We assume that PV does not provide available energy to contribute to covering the critical load when determining whether a BESS size provides reliability to meet or exceed the CLCPC. We also simulate a scenario in which PV is available, however this was not used to determine whether the BESS size passed the reliability metric
- We assume that P_{fs} and P_{fr} for all DG and BESS are uncorrelated and independent.
- As the calculations described in A3.3 support, we assume that once an asset, either DG or BESS, fails to start or run, that the asset is unable to operate for the remaining duration of the outage.
- As the calculations described in A3.3 support, we assume that once the microgrid fails to cover the load, the microgrid is unable to cover load for the remaining duration of the outage.

A.2.2 FLOW BATTERY P_{fs} AND MTBF DERIVATION

Inputs (blue) and calculated values for the time series model of reliability parameters. Note that target availability of 93% occurs when P_{fs} is between 1.0% and 1.1%.

Time Period Considered (hr)	43,800
Assumed Availability (%)	93%
Available Hours from Assumed Availability (hr)	40,734.00
Assumed mean time between failure, MTBF (hr)	1,095
Assumed mean time to repair, MTTR (hr)	72
Assumed Maintenance Time (hr)	400
Assumed Probability to Fail to Start, P_{fs} (%)	1.0%
Run Hours Per Start (hr)	12
Standby Hours After Run (hr)	6
Number of Starts Before Failure	100
Calculated Available Hours from Assumed MTBF, P_{fs} , and MTTR (hr)	41,600
Calculated Unavailable Hours from Assumed MTBF, P_{fs} , and MTTR (hr)	2,200
Calculated Run Hours from Assumed MTBF, P_{fs} , and MTTR (hr)	27,602
Calculated Availability from Assumed MTBF, P_{fs} , and MTTR (%)	94.98%

Count run hours and start events

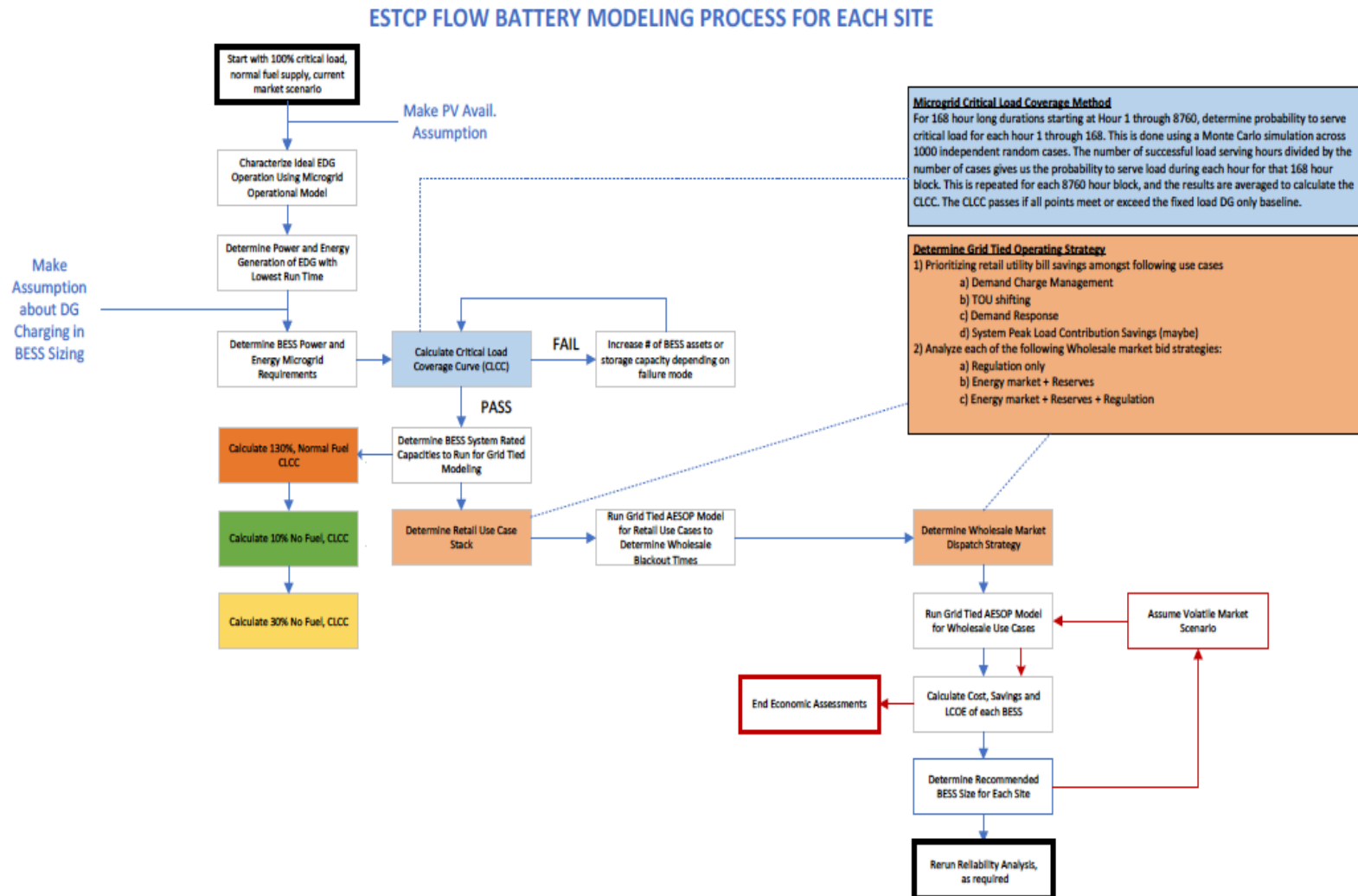


Hour	Run Time for Cycle (hr)	Standby Time (hr)	Total Run Time (hr)	Start Run Events	Fail to Run, 1 or 0	Fail to Start, 1 or 0	Outage Time (hr)	Available, 1 or 0	Running, 1 or 0
1	1 NA		1	1	0	0	0	0	1
2	2 NA		2	1	0	0	0	0	1
3	3 NA		3	1	0	0	0	0	1
4	4 NA		4	1	0	0	0	0	1
5	5 NA		5	1	0	0	0	0	1
6	6 NA		6	1	0	0	0	0	1
7	7 NA		7	1	0	0	0	0	1
8	8 NA		8	1	0	0	0	0	1
9	9 NA		9	1	0	0	0	0	1
10	10 NA		10	1	0	0	0	0	1
11	11 NA		11	1	0	0	0	0	1
12	12 NA		12	1	0	0	0	0	1
13	0	1	12	1	0	0	0	0	1
14	0	2	12	1	0	0	0	0	1
15	0	3	12	1	0	0	0	0	1
16	0	4	12	1	0	0	0	0	1
17	0	5	12	1	0	0	0	0	1
18	0	6	12	1	0	0	0	0	1
19	1 NA		13	2	0	0	0	0	1
20	2 NA		14	2	0	0	0	0	1

Outage occurs when run time hits MTBF or start events hits # of starts before failure

Hour	Run Time for Cycle (hr)	Standby Time (hr)	Total Run Time (hr)	Start Run Events	Fail to Run, 1 or 0	Fail to Start, 1 or 0	Outage Time (hr)	Available, 1 or 0	Running, 1 or 0
23922	0	6	1089	90	0	0	0	0	1
23923	1 NA		1090	91	0	0	0	0	1
23924	2 NA		1091	91	0	0	0	0	1
23925	3 NA		1092	91	0	0	0	0	1
23926	4 NA		1093	91	0	0	0	0	1
23927	5 NA		1094	91	0	0	0	0	1
23928	6 NA		1095	91	0	0	0	0	1
23929	7 NA		0	91	1	0	0	1	0
23930	8 NA		0	91	0	0	0	2	0
23931	9 NA		0	91	0	0	0	3	0
23932	10 NA		0	91	0	0	0	4	0
23933	11 NA		0	91	0	0	0	5	0
23934	12 NA		0	91	0	0	0	6	0
23935	0	1	0	91	0	0	0	7	0
23936	0	2	0	91	0	0	0	8	0
23937	0	3	0	91	0	0	0	9	0
23938	0	4	0	91	0	0	0	10	0
23939	0	5	0	91	0	0	0	11	0
23940	0	6	0	91	0	0	0	12	0
23941	1 NA		0	0	0	0	0	13	0

A.2.3 MODELING PROCESS FLOW DIAGRAM



A.3 PERFORMANCE APPENDIX

SUMMARY OF PERFORMANCE RESULTS

NAS Patuxent River				
Performance Objective	Metric	Requirements	Success Criteria	Results
1. Reliability to Meet 100% of Installation Critical and Ride-through Load	Critical and ride-through load served during outage (that can begin at any time)	Performance measured for outages of any duration between 1 hour and 168 hours	Meets or exceeds reliability probability curve from fixed load baseline microgrid specifically for 24- and 168-hour outages. Compares favorably with fixed load baseline microgrid at other outage durations under 168 hours.	<u>Baseline</u> 24-h: 0.98301 168-h: 0.67368 <u>Proposed BESS</u> 24-h: 0.99821 168-h: 0.90028
2. Reliability to Meet 130% of Installation Critical and Ride-through Load			Proportion of critical and ride-through load served (probabilistically) for 24- and 168-hour outages. No minimum standard.	<u>No PV</u> 24-h: 0.74008 168-h: 0.29558 <u>Expected PV</u> 24-h: 0.88588 168-h: 0.47233
3. Reliability to Meet 10% and 30% of Installation Critical and Ride-through Load when no Diesel Fuel is Available		Performance measured for outages of any duration between 1 hour and 24 hours	Proportion of critical and ride-through load served (probabilistically). No minimum standard.	<u>10% No PV</u> 1-h: 0.00000 24-h: 0.00000 <u>10% Exp. PV</u> 1-h: 0.27192 17-h: 0.00044 24-h: 0.00000 <u>30% No PV</u> 1-h: 0.00000 24-h: 0.00000 <u>30% Exp. PV</u> 1-h: 0.06815 9-h: 0.00034 24-h: 0.00000
4. Net Life-cycle Costs of Deployment and Operation (corresponding to technical objective 1 above)		Calculate per methodology distributed with baseline microgrid data and results	Net cost (per kW of critical load) is at or below level of baseline microgrid in current and future volatile scenarios	<u>Baseline</u> \$98/kW <u>VRF Current</u> \$128/kW <u>Li-Ion Current</u> \$121/kW <u>VRF Future</u> \$111/kW <u>Li-Ion Future</u> \$96/kW

NAS Corpus Christi				
Performance Objective	Metric	Requirements	Success Criteria	Results
1. Reliability to Meet 100% of Installation Critical and Ride-through Load	Critical and ride-through load served during outage (that can begin at any time)	Performance measured for outages of any duration between 1 hour and 168 hours	Meets or exceeds reliability probability curve from fixed load baseline microgrid specifically for 24- and 168-hour outages. Compares favorably with fixed load baseline microgrid at other outage durations under 168 hours.	<u>Baseline</u> 24-h: 0.99428 168-h: 0.85815 <u>Proposed BESS</u> 24-h: 0.99857 168-h: 0.92551
2. Reliability to Meet 130% of Installation Critical and Ride-through Load			Proportion of critical and ride-through load served (probabilistically) for 24- and 168-hour outages. No minimum standard.	<u>No PV</u> 24-h: 0.79367 168-h: 0.45154 <u>Expected PV</u> 24-h: 0.97407 168-h: 0.74379
3. Reliability to Meet 10% and 30% of Installation Critical and Ride-through Load when no Diesel Fuel is Available		Performance measured for outages of any duration between 1 hour and 24 hours	Proportion of critical and ride-through load served (probabilistically). No minimum standard.	<u>10% No PV</u> 1-h: 0.00000 24-h: 0.00000 <u>10% Exp. PV</u> 1-h: 0.30639 24-h: 0.00321 142-h: 0.00009 168-h: 0.00000 <u>30% No PV</u> 1-h: 0.00000 24-h: 0.00000 <u>30% Exp. PV</u> 1-h: 0.09932 14-h: 0.00011 24-h: 0.00000
4. Net Life-cycle Costs of Deployment and Operation (corresponding to technical objective 1 above)		Calculate per methodology distributed with baseline microgrid data and results	Net cost (per kW of critical load) is at or below level of baseline microgrid in current and future volatile scenarios	<u>Baseline</u> \$89/kW <u>VRF Current</u> \$132/kW <u>Li-Ion Current</u> \$115/kW <u>VRF Future</u> \$109/kW <u>Li-Ion Future</u> \$90/kW

FORT BLISS				
Performance Objective	Metric	Requirements	Success Criteria	Results
1. Reliability to Meet 100% of Installation Critical and Ride-through Load	Critical and ride-through load served during outage (that can begin at any time)	Performance measured for outages of any duration between 1 hour and 168 hours	Meets or exceeds reliability probability curve from fixed load baseline microgrid specifically for 24- and 168-hour outages. Compares favorably with fixed load baseline microgrid at other outage durations under 168 hours.	<u>Baseline</u> 24-h: 0.99246 168-h: 0.82253 <u>Proposed BESS</u> 24-h: 0.99921 168-h: 0.95656
2. Reliability to Meet 130% of Installation Critical and Ride-through Load			Proportion of critical and ride-through load served (probabilistically) for 24- and 168-hour outages. No minimum standard.	<u>No PV</u> 24-h: 0.89289 168-h: 0.66019 <u>Expected PV</u> 24-h: 0.95193 168-h: 0.72321
3. Reliability to Meet 10% and 30% of Installation Critical and Ride-through Load when no Diesel Fuel is Available		Performance measured for outages of any duration between 1 hour and 24 hours	Proportion of critical and ride-through load served (probabilistically). No minimum standard.	<u>10% No PV</u> 1-h: 0.06930 2-h: 0.00394 24-h: 0.00000 <u>10% Exp. PV</u> 1-h: 0.47862 14-h: 0.00011 24-h: 0.00000 <u>30% No PV</u> 1-h: 0.00000 24-h: 0.00000 <u>30% Exp. PV</u> 1-h: 0.35519 11-h: 0.00023 24-h: 0.00000
4. Net Life-cycle Costs of Deployment and Operation (corresponding to technical objective 1 above)		Calculate per methodology distributed with baseline microgrid data and results	Net cost (per kW of critical load) is at or below level of baseline microgrid in current and future volatile scenarios	<u>Baseline</u> \$83/kW <u>VRF Current</u> \$117/kW <u>Li-Ion Current</u> \$93/kW <u>VRF Future</u> \$104/kW <u>Li-Ion Future</u> \$88/kW

March ARB				
Performance Objective	Metric	Requirements	Success Criteria	Results
1. Reliability to Meet 100% of Installation Critical and Ride-through Load	Critical and ride-through load served during outage (that can begin at any time)	Performance measured for outages of any duration between 1 hour and 168 hours	Meets or exceeds reliability probability curve from fixed load baseline microgrid specifically for 24- and 168-hour outages. Compares favorably with fixed load baseline microgrid at other outage durations under 168 hours.	<u>Baseline</u> 24-h: 0.99831 168-h: 0.95076 <u>Proposed BESS</u> 24-h: 0.99907 168-h: 0.95125
2. Reliability to Meet 130% of Installation Critical and Ride-through Load			Proportion of critical and ride-through load served (probabilistically) for 24- and 168-hour outages. No minimum standard.	<u>No PV</u> 24-h: 0.98707 168-h: 0.81098 <u>Expected PV</u> 24-h: 0.99779 168-h: 0.92999
3. Reliability to Meet 10% and 30% of Installation Critical and Ride-through Load when no Diesel Fuel is Available		Performance measured for outages of any duration between 1 hour and 24 hours	Proportion of critical and ride-through load served (probabilistically). No minimum standard.	<u>10% No PV</u> 1-h: 0.99990 19-h: 0.00068 24-h: 0.00000 <u>10% Exp. PV</u> 1-h: 0.99995 24-h: 0.90949 168-h: 0.01935 <u>30% No PV</u> 1-h: 0.99481 9-h: 0.00171 24-h: 0.00000 <u>30% Exp. PV</u> 1-h: 0.99932 24-h: 0.00078 38-h: 0.00021
4. Net Life-cycle Costs of Deployment and Operation (corresponding to technical objective 1 above)		Calculate per methodology distributed with baseline microgrid data and results	Net cost (per kW of critical load) is at or below level of baseline microgrid in current and future volatile scenarios	<u>Baseline</u> \$416/kW <u>VRF Current</u> \$519/kW <u>Li-Ion Current</u> \$525/kW <u>VRF Future</u> \$317/kW <u>Li-Ion Future</u> \$229/kW

A.3.1 DG CHARACTERIZATION RESULTS

Westover ARB

	Maximum Power (kW)	Cumulative Energy (kWh)	Maximum Runtime (Hours)
Generator 1	750	126,000	168
Generator 2	750	79,934	168
Generator 3	207	207	1
Generator 4	-	-	0

NAS Patuxent River

	Maximum Power (kW)	Cumulative Energy (kWh)	Maximum Runtime (Hours)
Generator 1	750	126,000	168
Generator 2	750	126,000	168
Generator 3	750	126,000	168
Generator 4	750	126,000	168
Generator 5	750	126,000	168
Generator 6	750	126,000	168
Generator 7	750	119,747	168
Generator 8	750	84,728	142
Generator 9	750	47,729	82
Generator 10	750	24,504	47
Generator 11	514	6,958	23
Generator 12	-	-	0

NAS Corpus Christi

	Maximum Power (kW)	Cumulative Energy (kWh)	Maximum Runtime (Hours)
Generator 1	750	126,000	168
Generator 2	750	126,000	168
Generator 3	750	126,000	168
Generator 4	750	111,292	168
Generator 5	750	43,537	103
Generator 6	659	7,264	27
Generator 7	-	-	0

March ARB

	Maximum Power (kW)	Cumulative Energy (kWh)	Maximum Runtime (Hours)
Generator 1	250	42,000	168
Generator 2	250	33,871	168
Generator 3	100	3,509	56
Generator 4	-	-	0

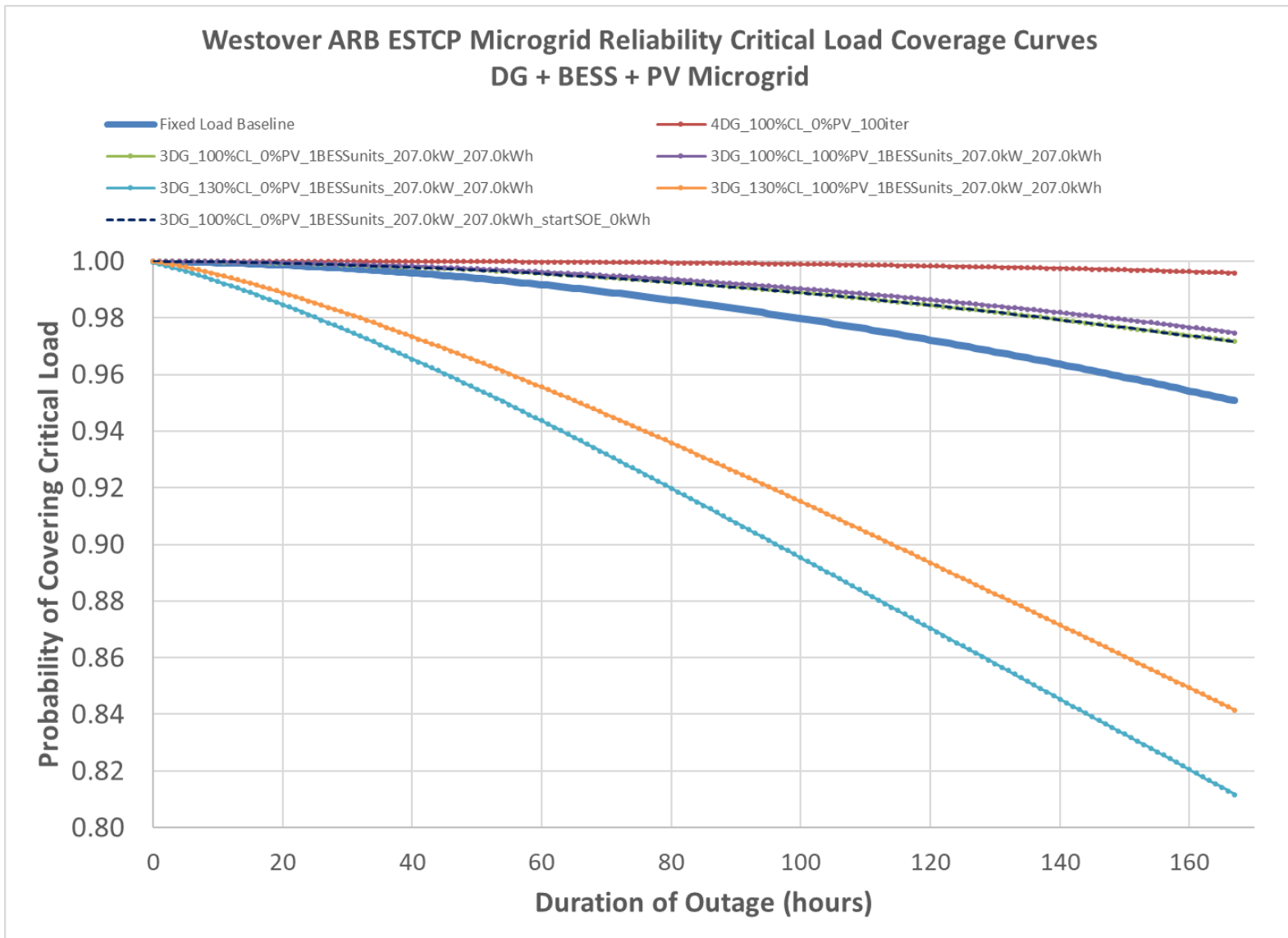
Fort Bliss

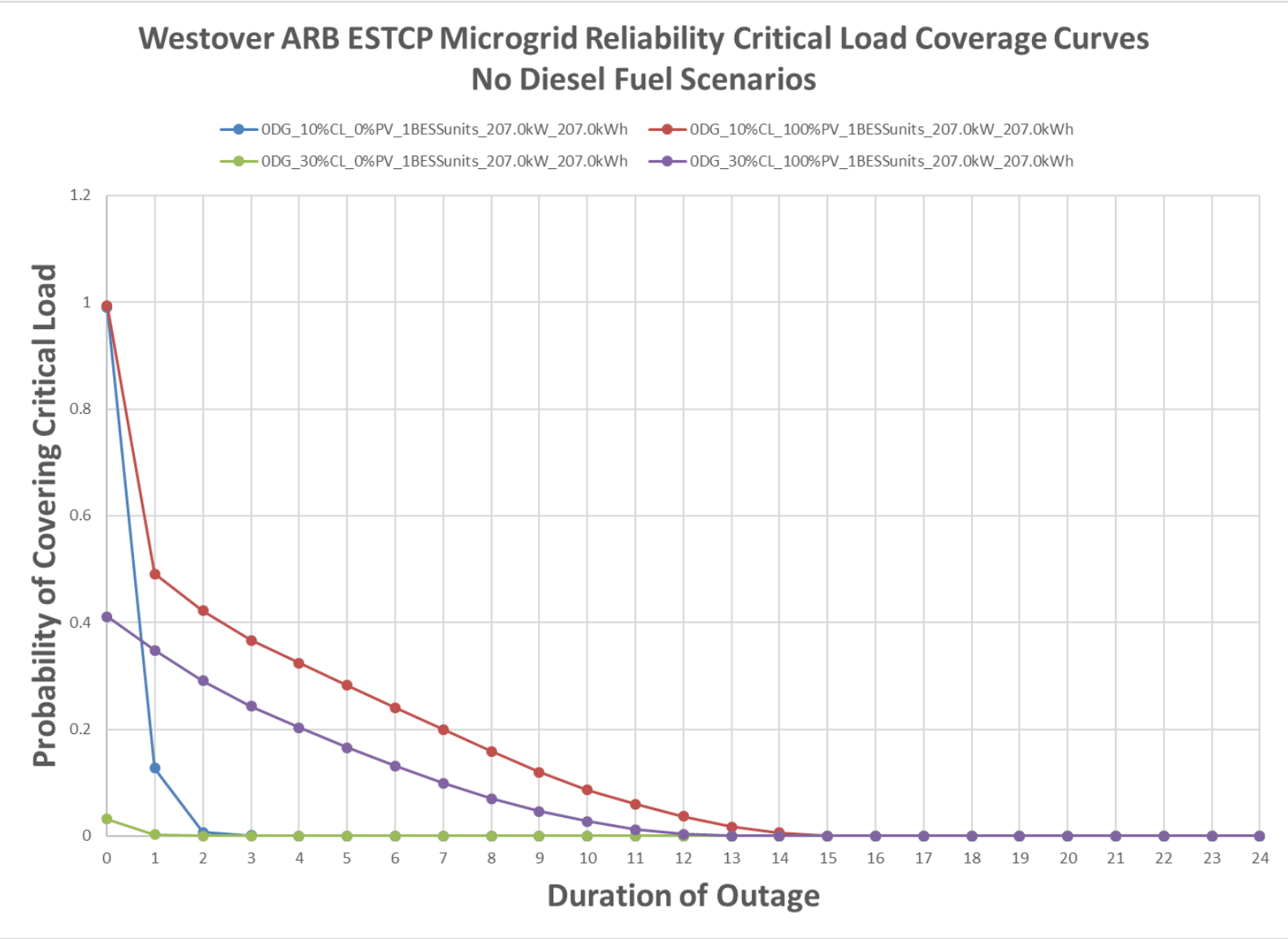
	Maximum Power (kW)	Cumulative Energy (kWh)	Maximum Runtime (Hours)
Generator 1	2,000	336,000	168
Generator 2	2,000	336,000	168
Generator 3	2,000	336,000	168
Generator 4	2,000	324,661	168
Generator 5	2,000	219,129	145
Generator 6	2,000	78,039	75
Generator 7	507	3,574	12
Generator 8	-	-	0

A.3.2 RELIABILITY PERFORMANCE RESULTS

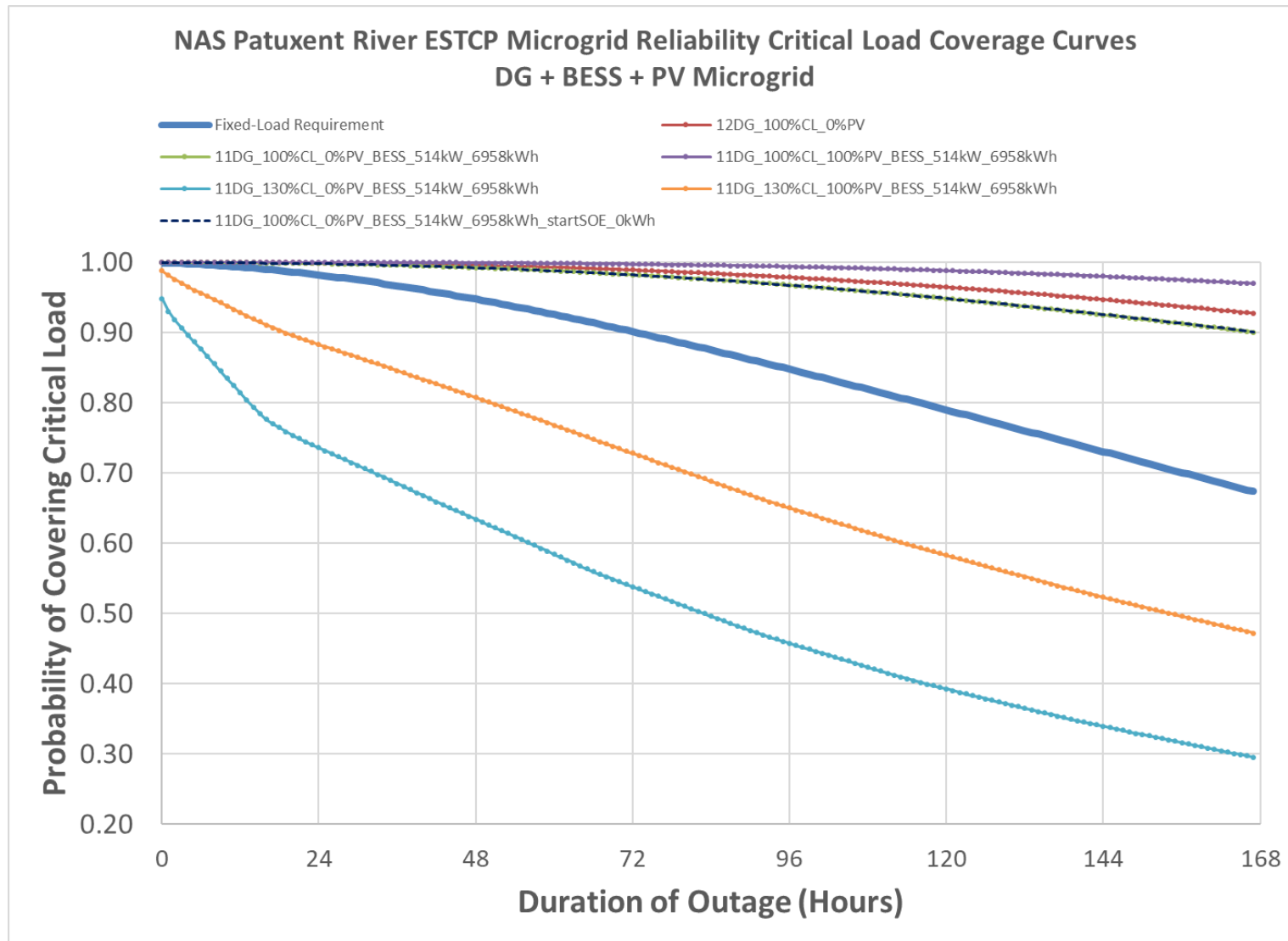
The following graphs show the CLCPC curves for each of the five installations.

Westover ARB Critical Load Coverage Charts (1 VRF BESS, 207kW-207 kWh Microgrid Availability)

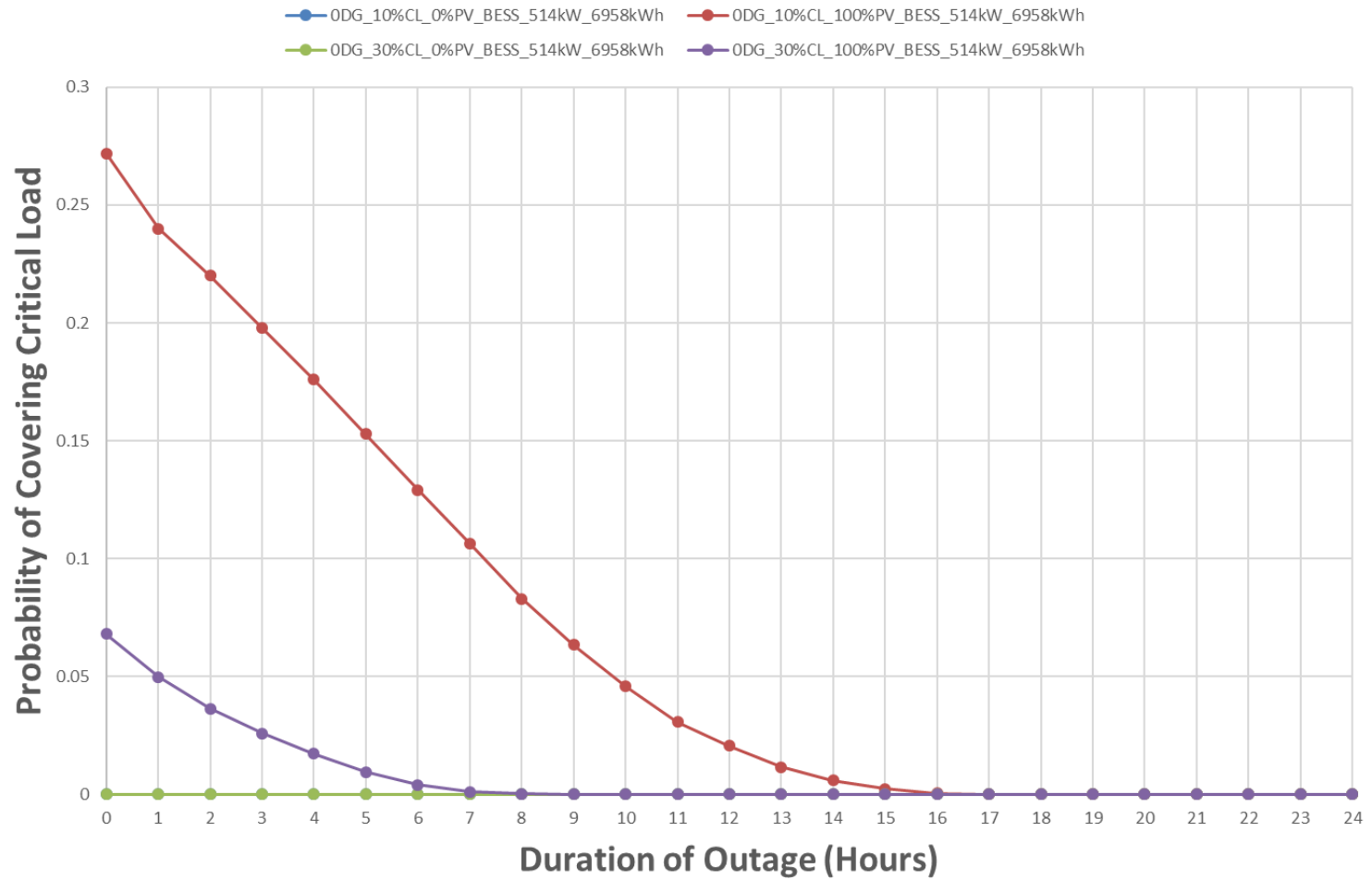




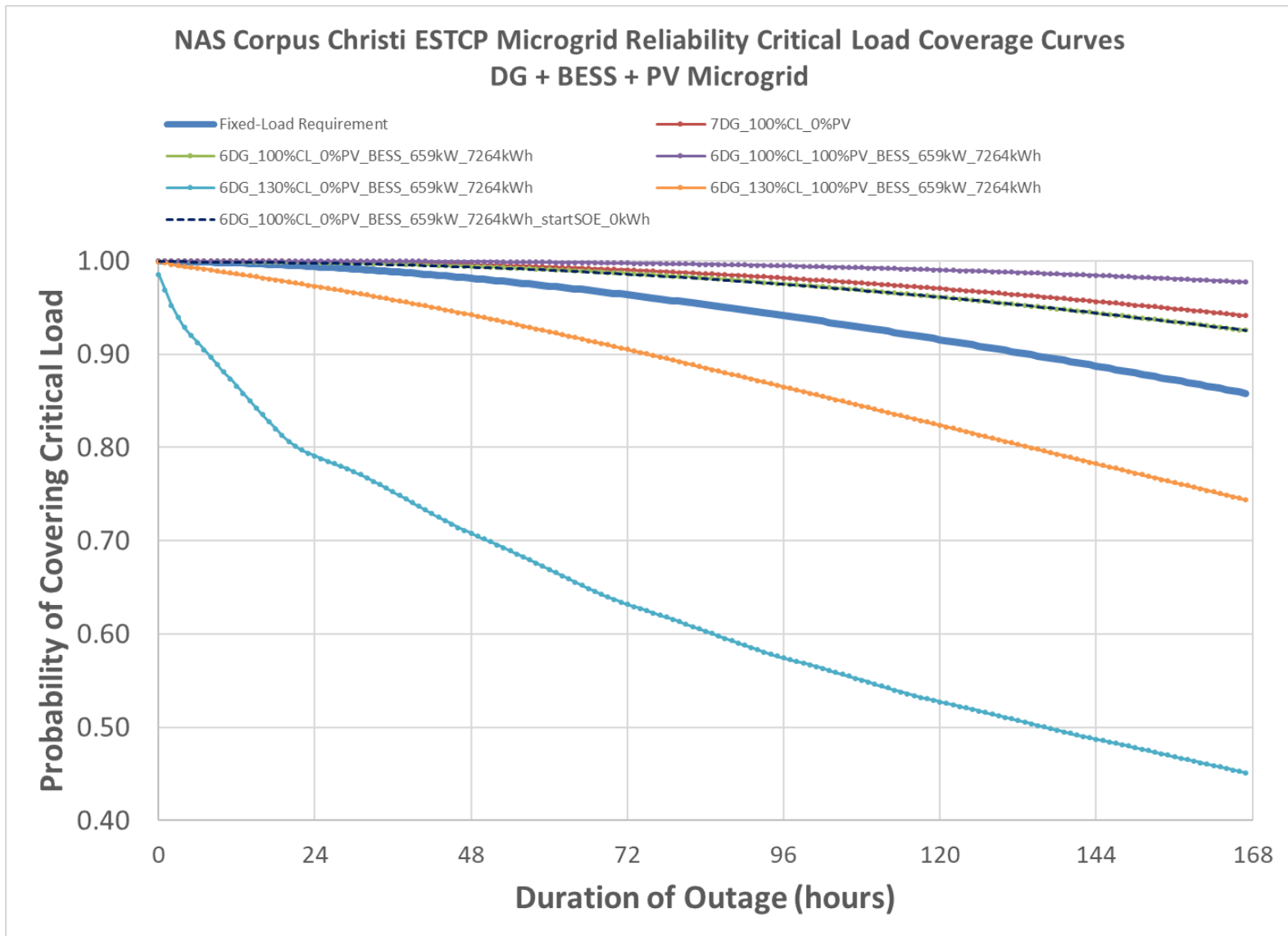
NAS Patuxent River Critical Load Coverage Charts (1 VRF BESS, 514kW-6958 kWh Microgrid Availability)



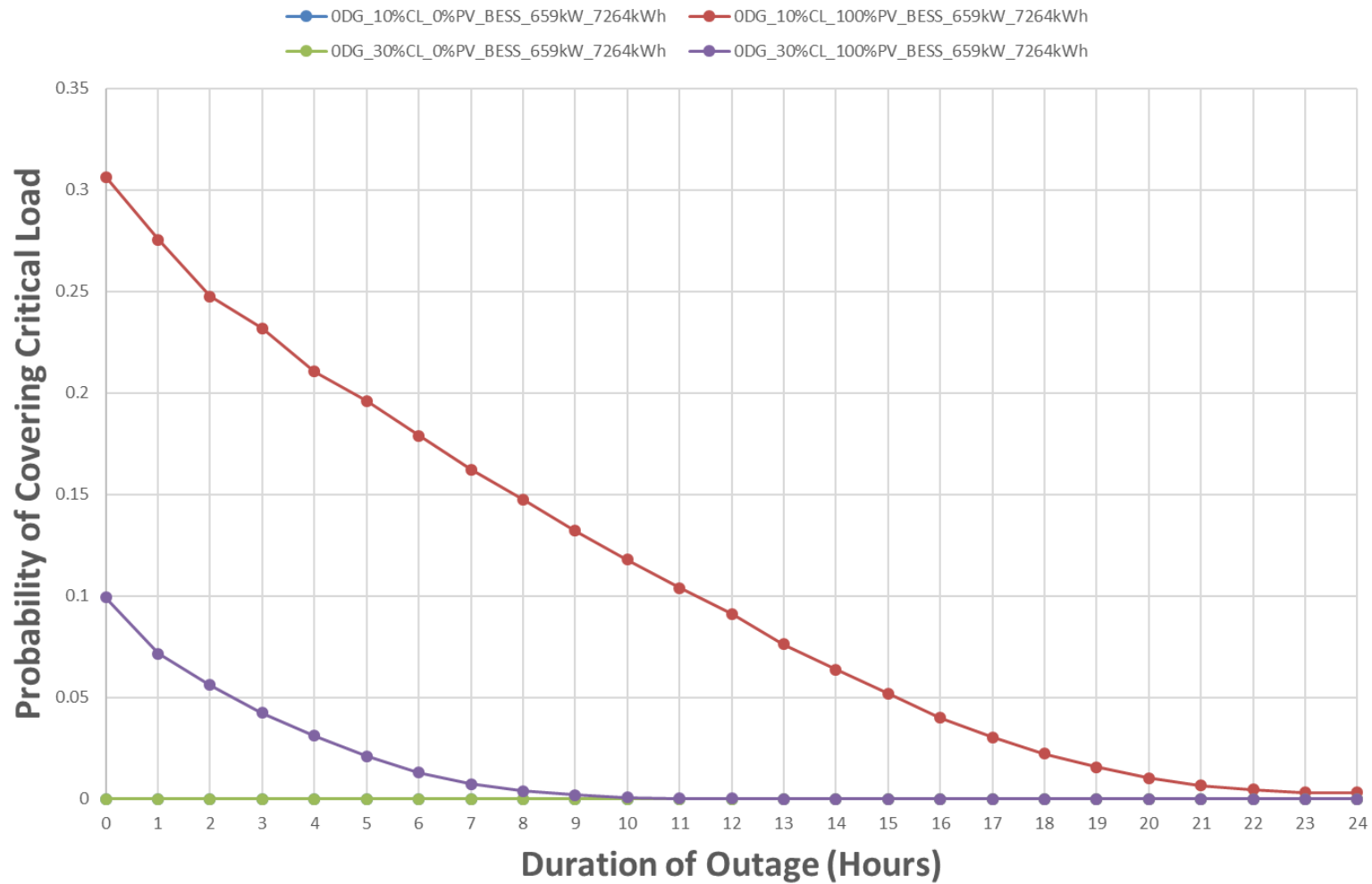
NAS Patuxent River ESTCP Microgrid Reliability Critical Load Coverage Curves No Diesel Fuel Scenarios



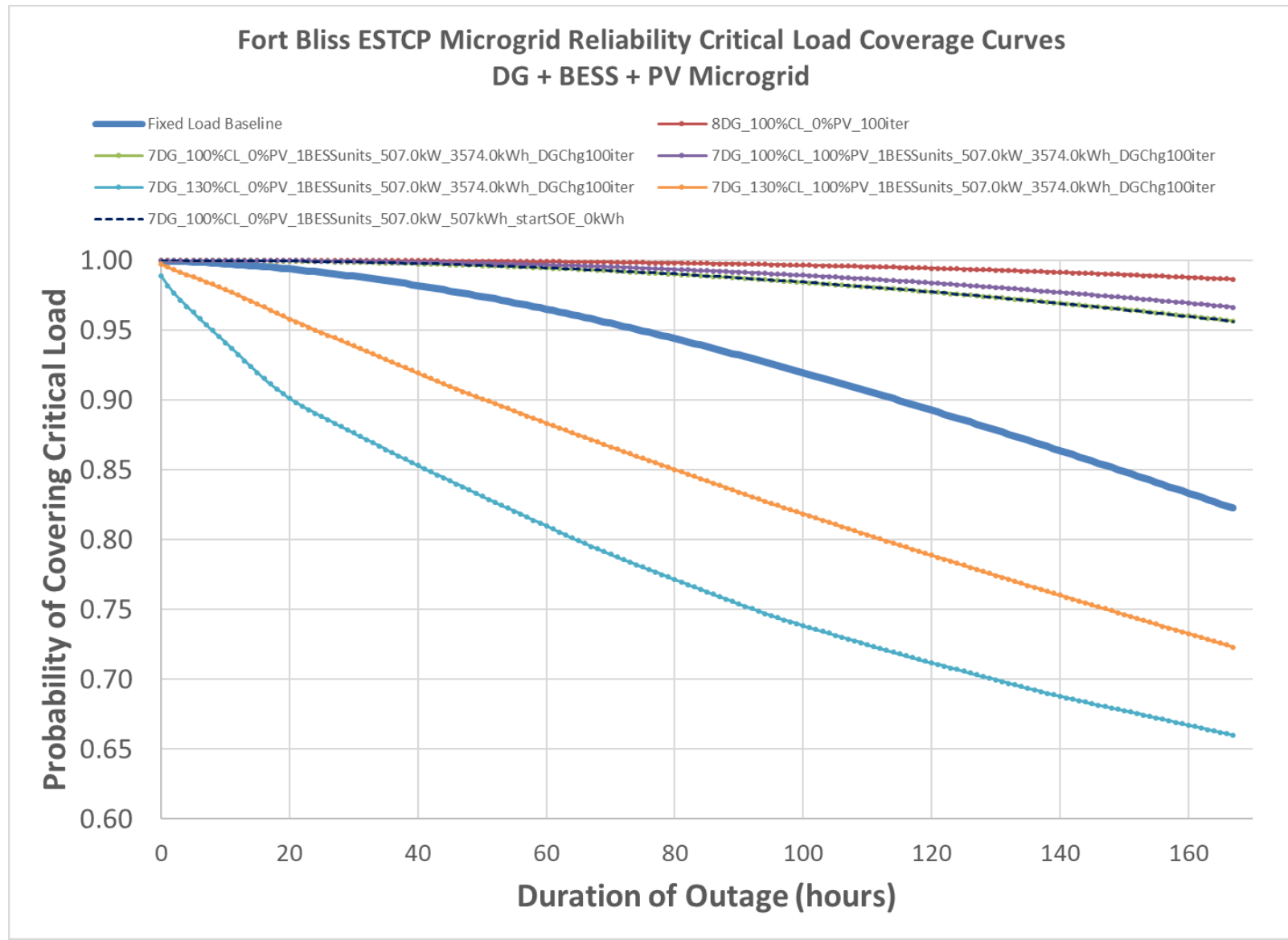
NAS Corpus Christi Critical Load Coverage Charts (1 VRF BESS, 659kW-7264 kWh Microgrid Availability)



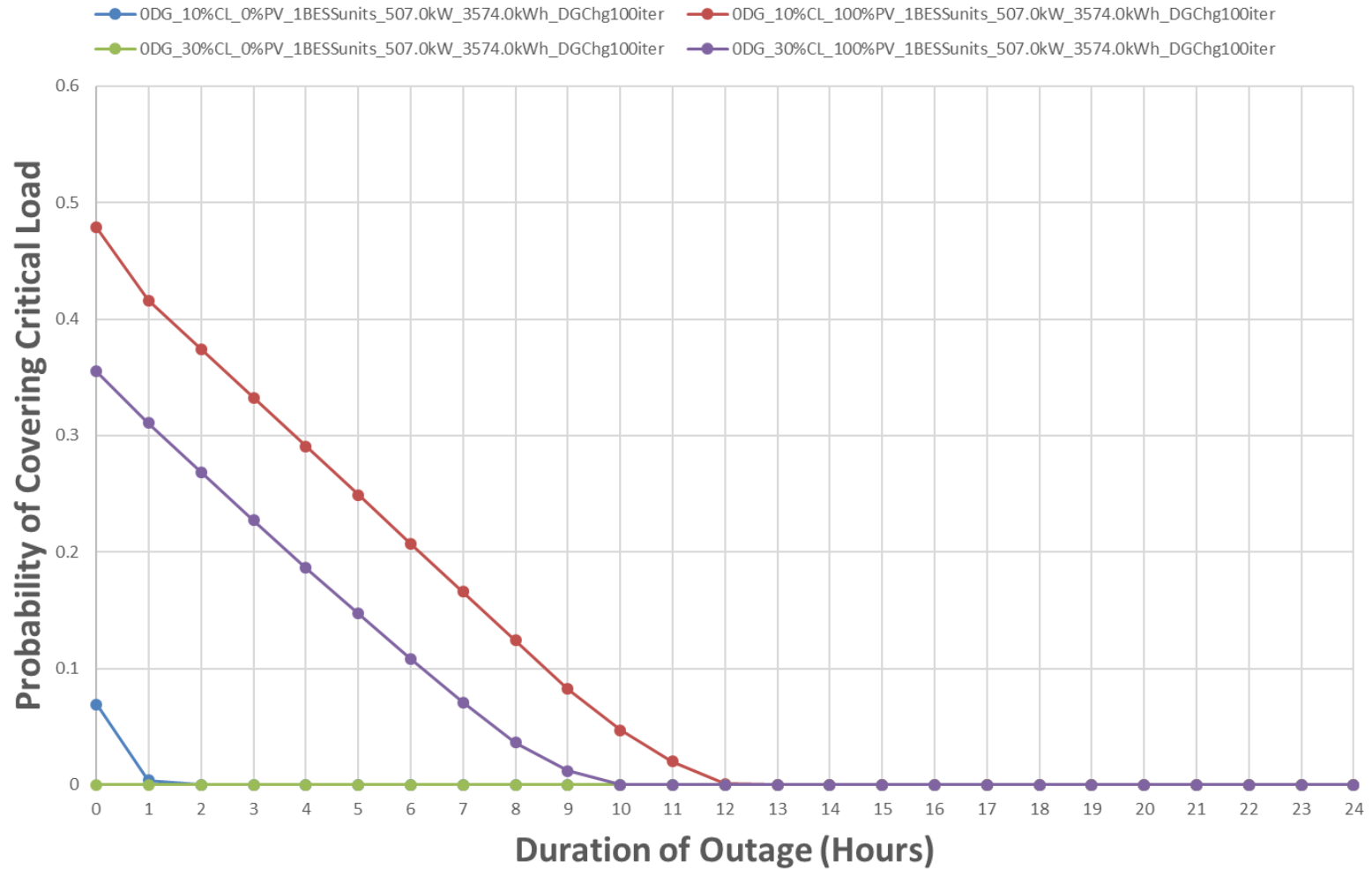
NAS Corpus Christi ESTCP Microgrid Reliability Critical Load Coverage Curves No Diesel Fuel Scenarios



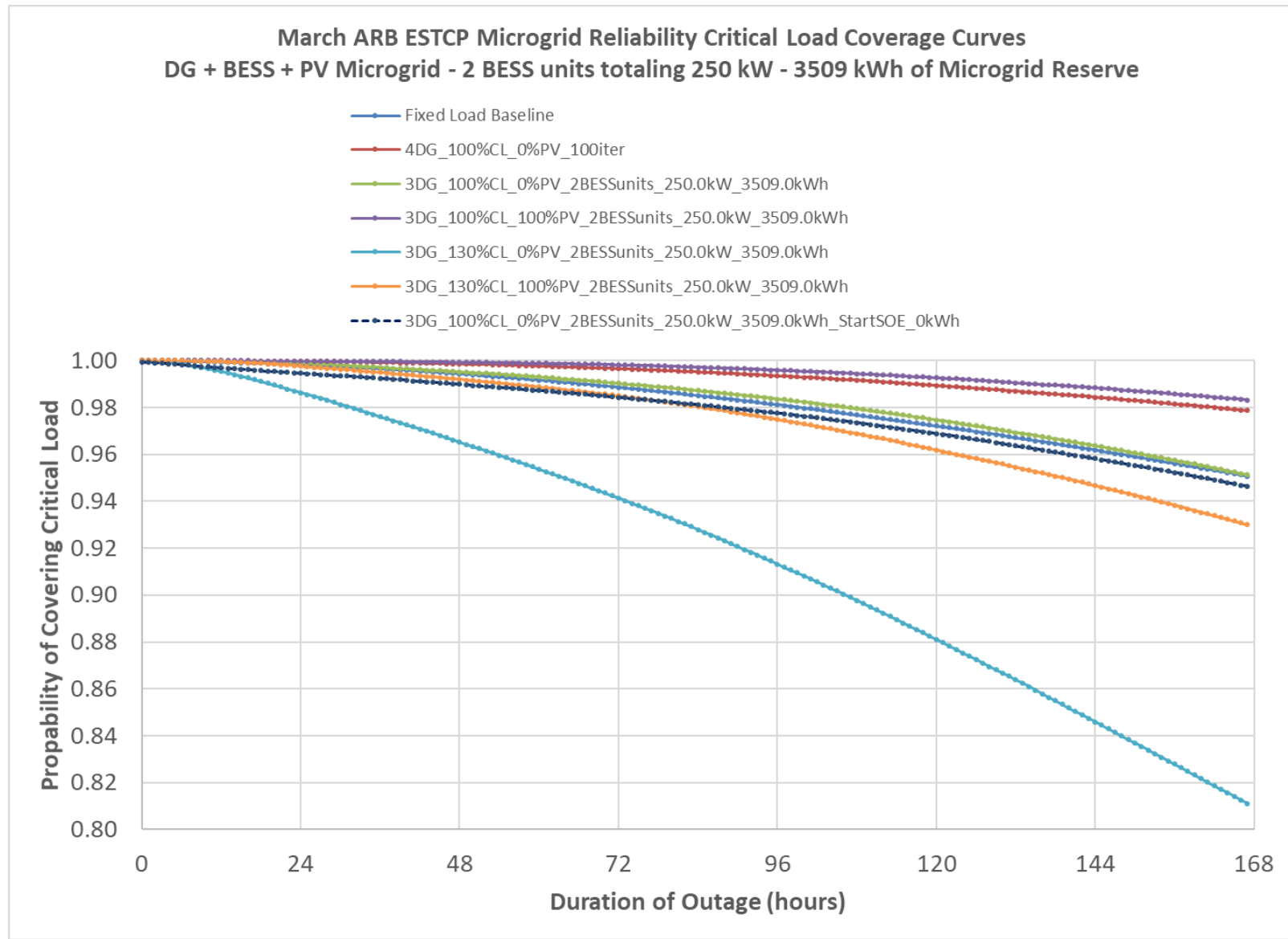
Fort Bliss Critical Load Coverage Charts (1 VRF BESS, 507kW-3574 kWh Microgrid Availability)



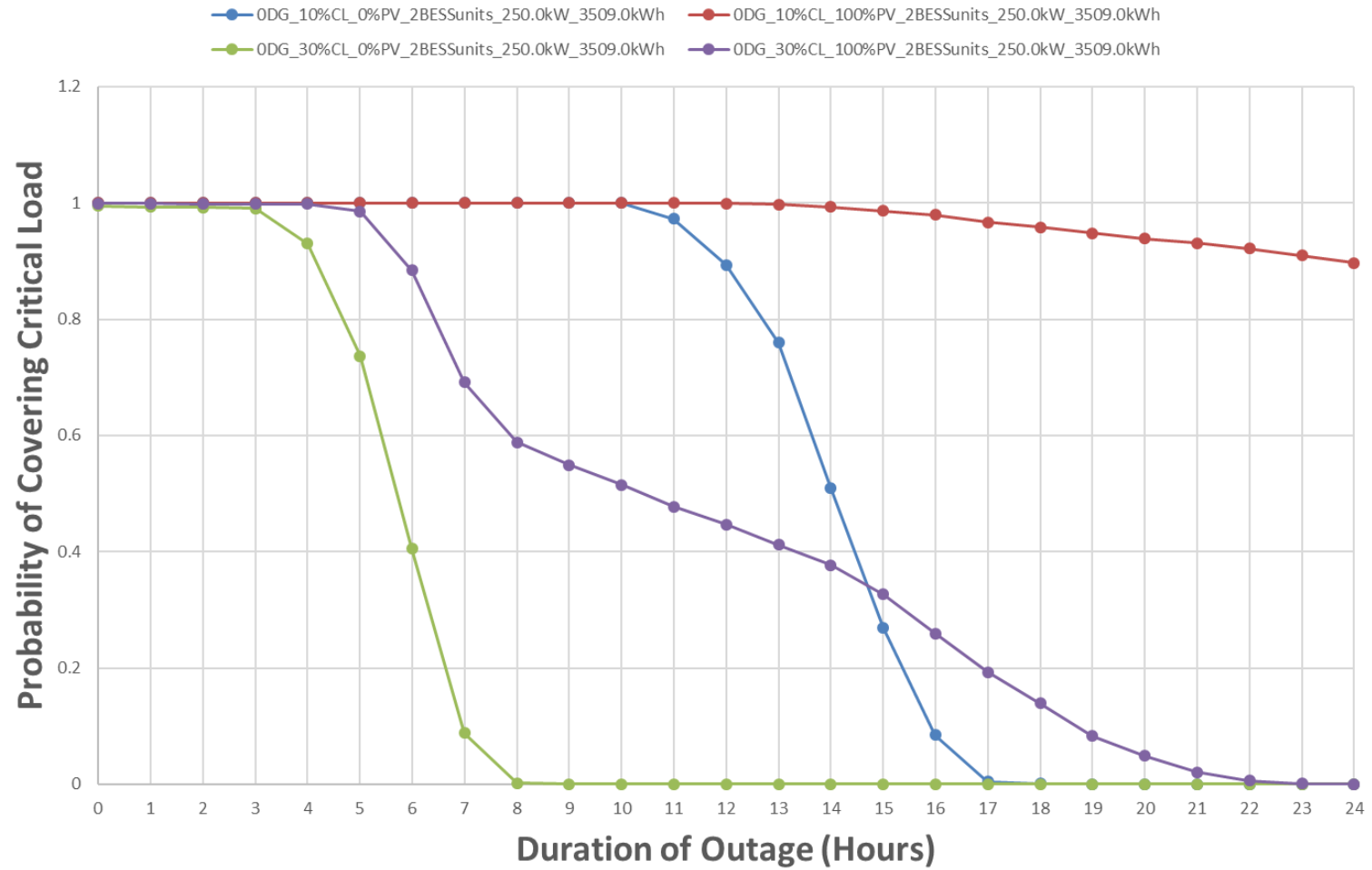
Fort Bliss ESTCP Microgrid Reliability Critical Load Coverage Curves No Diesel Fuel Scenarios



March ARB Critical Load Coverage Charts (2 VRF BESSs, 250kW-3509 kWh Microgrid Availability)



March ARB Microgrid Reliability Critical Load Coverage Curves No Diesel Fuel Scenarios



A.4 COST APPENDIX

The following tables provide the detailed financial pro-forma established for each VRB and Lion BESS system at each of the five installations. For the sake of space, only the first 10 years of the 20-year pro-formas are shown.

MARCH ARB BASELINE MICROGRID

March ARB Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	4
Capacity of Each DG (kW)	250
Capital Cost of Each DG (\$/kW)	\$ 1,100
Year 1 DG O&M Cost Per Unit	\$ 6,500
UPS Quantity	3
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,025	\$ 79,741	\$ 81,495
DG Capital & Annual O&M Cost	\$ 1,100,000	\$ 26,000	\$ 26,572	\$ 27,157	\$ 27,754	\$ 28,365	\$ 28,989	\$ 29,626	\$ 30,278	\$ 30,944	\$ 31,625
DG Demand Response Operating Fuel Cost		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
UPS Capital & Annual O&M Cost	\$ 485,250	\$ 10,246	\$ 10,471	\$ 10,702	\$ 10,937	\$ 11,178	\$ 11,424	\$ 11,675	\$ 11,932	\$ 12,194	\$ 12,463
Total Annual Baseline Capital+O&M Costs	\$ 3,585,250	\$ 103,246	\$ 105,517	\$ 107,839	\$ 110,211	\$ 112,636	\$ 115,114	\$ 117,646	\$ 120,234	\$ 122,880	\$ 125,583
Annual Electricity Costs		\$ 4,400,000	\$ 4,496,800	\$ 4,595,730	\$ 4,696,836	\$ 4,800,166	\$ 4,905,770	\$ 5,013,697	\$ 5,123,998	\$ 5,236,726	\$ 5,351,934
Emergency Demand Response Rev		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 4,400,000	\$ 4,496,800	\$ 4,595,730	\$ 4,696,836	\$ 4,800,166	\$ 4,905,770	\$ 5,013,697	\$ 5,123,998	\$ 5,236,726	\$ 5,351,934

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BASELINE MICROGRID (POST DR AND PS)	\$59,997,761	11	12	13	14	15	16	17	18	19	20
		2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$59,997,761	\$ 83,288	\$ 85,121	\$ 86,993	\$ 88,907	\$ 90,863	\$ 92,862	\$ 94,905	\$ 96,993	\$ 99,127	\$ 101,308
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 4,993,095	\$ 32,321	\$ 33,032	\$ 33,759	\$ 34,501	\$ 35,260	\$ 36,036	\$ 36,829	\$ 37,639	\$ 38,467	\$ 39,313
Years	20	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Installation Peak Annual Load (kW)	7,998	\$ 12,737	\$ 13,017	\$ 13,303	\$ 13,596	\$ 13,895	\$ 14,201	\$ 14,513	\$ 14,832	\$ 15,159	\$ 15,492
Critical Load %	7.5%	\$ 128,346	\$ 131,169	\$ 134,055	\$ 137,004	\$ 140,018	\$ 143,099	\$ 146,247	\$ 149,464	\$ 152,753	\$ 156,113
Peak Annual Critical Load	600	\$ 5,469,676	\$ 5,590,009	\$ 5,712,990	\$ 5,838,675	\$ 5,967,126	\$ 6,098,403	\$ 6,232,568	\$ 6,369,684	\$ 6,509,817	\$ 6,653,033
Energy Security Cost Metric	\$416	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
ESTCP Provided Security Cost Metric	\$416	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Match?	YES	\$ 5,469,676	\$ 5,590,009	\$ 5,712,990	\$ 5,838,675	\$ 5,967,126	\$ 6,098,403	\$ 6,232,568	\$ 6,369,684	\$ 6,509,817	\$ 6,653,033

MARCH ARB Li-Ion 3500 kW – 7000 kWh, CURRENT

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,325,000
	Upfront CMA Purchase	\$ 1,309,000
	Net Initial BESS Purchase	\$ 4,634,000
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,925,000
	Tax	\$ -
	Pre-Markup Subtotal	\$ 6,706,000
	Internal Management and Overhead Estimate	\$ 1,005,900
	Incentive or Grant Value	\$ (1,050,000)
	Total EPC Implementation Cost	\$ 6,661,900
YEAR 1 VALUE	Utility Billing Savings	\$ 180,205
	Wholesale Market Revenue	\$ 172,306
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ 34,461

March ARB Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	3
Capacity of Each DG (kW)	250
Capital Cost of Each DG (\$/kW)	\$ 1,100
Year 1 DG O&M Cost Per Unit	\$ 6,500
UPS Quantity	3
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

SCENARIO	CURRENT
BESS Power Capacity	3500
BESS Energy Capacity	7000
Technology	Li-Ion
Selected Use Case Stack	DCM+WH
Grid Tied Lower SOE	3509

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,025	\$ 79,741	\$ 81,495
BESS Capital & Annual O&M Cost	\$ 6,661,900	\$ 51,261	\$ 52,389	\$ 53,542	\$ 54,719	\$ 55,923	\$ 57,154	\$ 58,411	\$ 59,696	\$ 61,009	\$ 62,351
DG Capital & Annual O&M Cost	\$ 825,000	\$ 19,500	\$ 19,929	\$ 20,367	\$ 20,816	\$ 21,273	\$ 21,741	\$ 22,220	\$ 22,709	\$ 23,208	\$ 23,719
DG Demand Response Operating Fuel Cost		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
UPS Capital & Annual O&M Cost	\$ 485,250	\$ 10,246	\$ 10,471	\$ 10,702	\$ 10,937	\$ 11,178	\$ 11,424	\$ 11,675	\$ 11,932	\$ 12,194	\$ 12,463
Total Annual Baseline Capital+O&M Costs	\$ 9,972,150	\$ 148,007	\$ 151,263	\$ 154,591	\$ 157,992	\$ 161,468	\$ 165,020	\$ 168,651	\$ 172,361	\$ 176,153	\$ 180,028
Annual Electricity Costs Before BESS/DG		\$ 4,400,000	\$ 4,496,800	\$ 4,595,730	\$ 4,696,836	\$ 4,800,166	\$ 4,905,770	\$ 5,013,697	\$ 5,123,998	\$ 5,236,726	\$ 5,351,934
BESS Retail Billing Savings		\$ 180,205	\$ 184,170	\$ 188,221	\$ 192,362	\$ 196,594	\$ 200,919	\$ 205,339	\$ 209,857	\$ 214,474	\$ 219,192
BESS Wholesale Market Value		\$ 172,306	\$ 176,097	\$ 179,971	\$ 183,930	\$ 187,977	\$ 192,112	\$ 196,339	\$ 200,658	\$ 205,073	\$ 209,584
BESS SGIP Payment		\$ 210,000	\$ 210,000	\$ 210,000	\$ 210,000	\$ 210,000	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 3,837,489	\$ 3,926,534	\$ 4,017,538	\$ 4,110,543	\$ 4,205,595	\$ 4,312,738	\$ 4,412,019	\$ 4,513,483	\$ 4,617,180	\$ 4,723,158

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$54,306,376
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$59,997,761
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 11,990,352
Years	20
Installation Peak Annual Load (kW)	7,998
Critical Load %	7.5%
Peak Annual Critical Load	600
Energy Security Cost Metric	\$525
ESTCP Provided Security Cost Metric	\$416

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 83,288	\$ 85,121	\$ 86,993	\$ 88,907	\$ 90,863	\$ 92,862	\$ 94,905	\$ 96,993	\$ 99,127	\$ 101,308
\$ 63,723	\$ 65,125	\$ 66,558	\$ 68,022	\$ 69,519	\$ 71,048	\$ 72,611	\$ 74,209	\$ 75,841	\$ 77,510
\$ 24,241	\$ 24,774	\$ 25,319	\$ 25,876	\$ 26,445	\$ 27,027	\$ 27,622	\$ 28,229	\$ 28,850	\$ 29,485
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 12,737	\$ 13,017	\$ 13,303	\$ 13,596	\$ 13,895	\$ 14,201	\$ 14,513	\$ 14,832	\$ 15,159	\$ 15,492
\$ 183,989	\$ 188,037	\$ 192,173	\$ 196,401	\$ 200,722	\$ 205,138	\$ 209,651	\$ 214,263	\$ 218,977	\$ 223,794
\$ 5,469,676	\$ 5,590,009	\$ 5,712,990	\$ 5,838,675	\$ 5,967,126	\$ 6,098,403	\$ 6,232,568	\$ 6,369,684	\$ 6,509,817	\$ 6,653,033
\$ 224,014	\$ 228,943	\$ 233,979	\$ 239,127	\$ 244,388	\$ 249,764	\$ 255,259	\$ 260,875	\$ 266,614	\$ 272,480
\$ 214,195	\$ 218,907	\$ 223,723	\$ 228,645	\$ 233,675	\$ 238,816	\$ 244,070	\$ 249,440	\$ 254,927	\$ 260,536
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 5,031,467	\$ 5,142,159	\$ 5,255,287	\$ 5,370,903	\$ 5,489,063	\$ 5,609,822	\$ 5,733,239	\$ 5,859,370	\$ 5,988,276	\$ 6,120,018

MARCH ARB Li-Ion 3500 kW – 7000 kWh, FUTURE

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,325,000
	Upfront CMA Purchase	\$ 1,309,000
	Net Initial BESS Purchase	\$ 3,336,480
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,386,000
	Tax	\$ -
	Pre-Markup Subtotal	\$ 4,869,480
	Internal Management and Overhead Estimate	\$ 730,422
	Incentive or Grant Value	\$ (1,050,000)
	Total EPC Implementation Cost	\$ 4,549,902
YEAR 1 VALUE	Utility Billing Savings	\$ 168,620
	Wholesale Market Revenue	\$ 300,858
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ 60,172

March ARB Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	3
Capacity of Each DG (kW)	250
Capital Cost of Each DG (\$/kW)	\$ 1,100
Year 1 DG O&M Cost Per Unit	\$ 6,500
UPS Quantity	3
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	28%

SCENARIO	FUTURE
BESS Power Capacity	3500
BESS Energy Capacity	7000
Technology	Li-Ion
Selected Use Case Scenario	DCM+WH
Grid Tied Lower SOE	3509

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,025	\$ 79,741	\$ 81,495
BESS Capital & Annual O&M Cost	\$ 4,549,902	\$ 62,961	\$ 64,346	\$ 65,762	\$ 67,209	\$ 68,687	\$ 70,198	\$ 71,743	\$ 73,321	\$ 74,934	\$ 76,583
DG Capital & Annual O&M Cost	\$ 825,000	\$ 19,500	\$ 19,929	\$ 20,367	\$ 20,816	\$ 21,273	\$ 21,741	\$ 22,220	\$ 22,709	\$ 23,208	\$ 23,719
DG Demand Response Operating Fuel Cost		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
UPS Capital & Annual O&M Cost	\$ 485,250	\$ 10,246	\$ 10,471	\$ 10,702	\$ 10,937	\$ 11,178	\$ 11,424	\$ 11,675	\$ 11,932	\$ 12,194	\$ 12,463
Total Annual Baseline Capital+O&M Costs	\$ 7,860,152	\$ 159,707	\$ 163,220	\$ 166,811	\$ 170,481	\$ 174,232	\$ 178,065	\$ 181,982	\$ 185,986	\$ 190,077	\$ 194,259
Annual Electricity Costs Before BESS/DG		\$ 4,400,000	\$ 4,496,800	\$ 4,595,730	\$ 4,696,836	\$ 4,800,166	\$ 4,905,770	\$ 5,013,697	\$ 5,123,998	\$ 5,236,726	\$ 5,351,934
BESS Retail Billing Savings		\$ 168,620	\$ 172,330	\$ 176,121	\$ 179,996	\$ 183,955	\$ 188,002	\$ 192,139	\$ 196,366	\$ 200,686	\$ 205,101
BESS Wholesale Market Value		\$ 300,858	\$ 307,477	\$ 314,241	\$ 321,155	\$ 328,220	\$ 335,441	\$ 342,821	\$ 350,363	\$ 358,071	\$ 365,948
BESS SGIP Payment		\$ 210,000	\$ 210,000	\$ 210,000	\$ 210,000	\$ 210,000	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 3,720,522	\$ 3,806,993	\$ 3,895,367	\$ 3,985,685	\$ 4,077,991	\$ 4,382,326	\$ 4,478,737	\$ 4,577,270	\$ 4,677,970	\$ 4,780,885

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$52,711,431
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$59,997,761
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 10,037,891
Years	20
Installation Peak Annual Load (kW)	7,998
Critical Load %	7.5%
Peak Annual Critical Load	600
Energy Security Cost Metric	\$229
ESTCP Provided Security Cost Metric	\$416

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 83,288	\$ 85,121	\$ 86,993	\$ 88,907	\$ 90,863	\$ 92,862	\$ 94,905	\$ 96,993	\$ 99,127	\$ 101,308
\$ 78,267	\$ 79,989	\$ 81,749	\$ 83,547	\$ 85,386	\$ 87,264	\$ 89,184	\$ 91,146	\$ 93,151	\$ 95,200
\$ 24,241	\$ 24,774	\$ 25,319	\$ 25,876	\$ 26,445	\$ 27,027	\$ 27,622	\$ 28,229	\$ 28,850	\$ 29,485
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 12,737	\$ 13,017	\$ 13,303	\$ 13,596	\$ 13,895	\$ 14,201	\$ 14,513	\$ 14,832	\$ 15,159	\$ 15,492
\$ 198,533	\$ 202,901	\$ 207,364	\$ 211,926	\$ 216,589	\$ 221,354	\$ 226,224	\$ 231,200	\$ 236,287	\$ 241,485
\$ 5,469,676	\$ 5,590,009	\$ 5,712,990	\$ 5,838,675	\$ 5,967,126	\$ 6,098,403	\$ 6,232,568	\$ 6,369,684	\$ 6,509,817	\$ 6,653,033
\$ 209,613	\$ 214,224	\$ 218,937	\$ 223,754	\$ 228,677	\$ 233,707	\$ 238,849	\$ 244,104	\$ 249,474	\$ 254,962
\$ 373,999	\$ 382,227	\$ 390,636	\$ 399,230	\$ 408,013	\$ 416,989	\$ 426,163	\$ 435,539	\$ 445,121	\$ 454,913
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 4,886,064	\$ 4,993,558	\$ 5,103,416	\$ 5,215,691	\$ 5,330,436	\$ 5,447,706	\$ 5,567,556	\$ 5,690,042	\$ 5,815,223	\$ 5,943,158

MARCH ARB VRF 875 kW – 7000 kWh, CURRENT

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,578,750
	Electrolyte Value	\$ (1,680,000)
	Net Initial BESS Purchase	\$ 1,898,750
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,925,000
	Tax	\$ -
	Pre-Markup Subtotal	\$ 3,970,750
	Internal Management and Overhead Estimate	\$ 595,613
	Incentive or Grant Value	\$ (1,050,000)
	Total EPC Implementation Cost	\$ 3,516,363
YEAR 1 VALUE	Utility Billing Savings	\$ 146,984
	Wholesale Market Revenue	\$ 57,635
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Electrolyte Lease Annual Cost	\$ 100,800
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ 11,527

March ARB Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	3
Capacity of Each DG (kW)	250
Capital Cost of Each DG (\$/kW)	\$ 1,100
Year 1 DG O&M Cost Per Unit	\$ 6,500
UPS Quantity	3
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	0%

SCENARIO	CURRENT
BESS Power Capacity	875
BESS Energy Capacity	7000
Technology	VRF
Selected Use Case Stack	DCM+WH
Grid Tied Lower SOE	3509

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,025	\$ 79,741	\$ 81,495
BESS Capital & Annual O&M Cost	\$ 3,516,363	\$ 129,127	\$ 131,968	\$ 134,871	\$ 137,838	\$ 140,871	\$ 143,970	\$ 147,137	\$ 150,374	\$ 153,682	\$ 157,063
DG Capital & Annual O&M Cost	\$ 825,000	\$ 19,500	\$ 19,929	\$ 20,367	\$ 20,816	\$ 21,273	\$ 21,741	\$ 22,220	\$ 22,709	\$ 23,208	\$ 23,719
DG Demand Response Operating Fuel Cost		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
UPS Capital & Annual O&M Cost	\$ 485,250	\$ 10,246	\$ 10,471	\$ 10,702	\$ 10,937	\$ 11,178	\$ 11,424	\$ 11,675	\$ 11,932	\$ 12,194	\$ 12,463
Total Annual Baseline Capital+O&M Costs	\$ 6,826,613	\$ 225,873	\$ 230,842	\$ 235,921	\$ 241,111	\$ 246,415	\$ 251,836	\$ 257,377	\$ 263,039	\$ 268,826	\$ 274,740
Annual Electricity Costs Before BESS/DG		\$ 4,400,000	\$ 4,496,800	\$ 4,595,730	\$ 4,696,836	\$ 4,800,166	\$ 4,905,770	\$ 5,013,697	\$ 5,123,998	\$ 5,236,726	\$ 5,351,934
BESS Retail Billing Savings		\$ 146,984	\$ 150,218	\$ 153,522	\$ 156,900	\$ 160,352	\$ 163,879	\$ 167,485	\$ 171,169	\$ 174,935	\$ 178,784
BESS Wholesale Market Value		\$ 57,635	\$ 58,903	\$ 60,199	\$ 61,523	\$ 62,877	\$ 64,260	\$ 65,674	\$ 67,119	\$ 68,595	\$ 70,104
BESS SGIP Payment		\$ 210,000	\$ 210,000	\$ 210,000	\$ 210,000	\$ 210,000	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 3,985,381	\$ 4,077,679	\$ 4,172,008	\$ 4,268,413	\$ 4,366,938	\$ 4,467,630	\$ 4,570,538	\$ 4,675,710	\$ 4,783,196	\$ 4,892,046

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$56,323,010
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$59,997,761
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 9,906,582
Years	20
Installation Peak Annual Load (kW)	7,998
Critical Load %	7.5%
Peak Annual Critical Load	600
Energy Security Cost Metric	\$519
ESTCP Provided Security Cost Metric	\$416

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 83,288	\$ 85,121	\$ 86,993	\$ 88,907	\$ 90,863	\$ 92,862	\$ 94,905	\$ 96,993	\$ 99,127	\$ 101,308
\$ 160,519	\$ 164,050	\$ 167,659	\$ 171,348	\$ 175,118	\$ 178,970	\$ 182,907	\$ 186,931	\$ 191,044	\$ 195,247
\$ 24,241	\$ 24,774	\$ 25,319	\$ 25,876	\$ 26,445	\$ 27,027	\$ 27,622	\$ 28,229	\$ 28,850	\$ 29,485
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 12,737	\$ 13,017	\$ 13,303	\$ 13,596	\$ 13,895	\$ 14,201	\$ 14,513	\$ 14,832	\$ 15,159	\$ 15,492
\$ 280,784	\$ 286,962	\$ 293,275	\$ 299,727	\$ 306,321	\$ 313,060	\$ 319,947	\$ 326,986	\$ 334,180	\$ 341,532
\$ 5,469,676	\$ 5,590,009	\$ 5,712,990	\$ 5,838,675	\$ 5,967,126	\$ 6,098,403	\$ 6,232,568	\$ 6,369,684	\$ 6,509,817	\$ 6,653,033
\$ 182,717	\$ 186,737	\$ 190,845	\$ 195,044	\$ 199,335	\$ 203,720	\$ 208,202	\$ 212,782	\$ 217,463	\$ 222,248
\$ 71,647	\$ 73,223	\$ 74,834	\$ 76,480	\$ 78,163	\$ 79,882	\$ 81,640	\$ 83,436	\$ 85,271	\$ 87,147
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 5,215,313	\$ 5,330,050	\$ 5,447,311	\$ 5,567,152	\$ 5,689,629	\$ 5,814,801	\$ 5,942,726	\$ 6,073,466	\$ 6,207,083	\$ 6,343,639

MARCH ARB VRF 875 kW – 7000 kWh, FUTURE

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,578,750
	Electrolyte Value	\$ (1,680,000)
	Net Initial BESS Purchase	\$ 2,218,825
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,193,500
	Tax	\$ -
	Pre-Markup Subtotal	\$ 3,559,325
	Internal Management and Overhead Estimate	\$ 533,899
	Incentive or Grant Value	\$ (1,023,306)
Total EPC Implementation Cost		\$ 3,069,918
YEAR 1 VALUE	Utility Billing Savings	\$ 140,135
	Wholesale Market Revenue	\$ 123,603
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Electrolyte Lease Annual Cost	\$ -
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ 24,721

March ARB Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	3
Capacity of Each DG (kW)	250
Capital Cost of Each DG (\$/kW)	\$ 1,100
Year 1 DG O&M Cost Per Unit	\$ 6,500
UPS Quantity	3
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	38%

SCENARIO	FUTURE
BESS Power Capacity	875
BESS Energy Capacity	7000
Technology	VRF
Selected Use Case Stage	DCM+WH
Grid Tied Lower SOE	3509

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,025	\$ 79,741	\$ 81,495
BESS Capital & Annual O&M Cost	\$ 3,069,918	\$ 41,521	\$ 42,434	\$ 43,368	\$ 44,322	\$ 45,297	\$ 46,293	\$ 47,312	\$ 48,353	\$ 49,416	\$ 50,504
DG Capital & Annual O&M Cost	\$ 825,000	\$ 19,500	\$ 19,929	\$ 20,367	\$ 20,816	\$ 21,273	\$ 21,741	\$ 22,220	\$ 22,709	\$ 23,208	\$ 23,719
DG Demand Response Operating Fuel Cost		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
UPS Capital & Annual O&M Cost	\$ 485,250	\$ 10,246	\$ 10,471	\$ 10,702	\$ 10,937	\$ 11,178	\$ 11,424	\$ 11,675	\$ 11,932	\$ 12,194	\$ 12,463
Total Annual Baseline Capital+O&M Costs	\$ 6,380,168	\$ 138,266	\$ 141,308	\$ 144,417	\$ 147,594	\$ 150,841	\$ 154,160	\$ 157,551	\$ 161,017	\$ 164,560	\$ 168,180
Annual Electricity Costs Before BESS/DG		\$ 4,400,000	\$ 4,496,800	\$ 4,595,730	\$ 4,696,836	\$ 4,800,166	\$ 4,905,770	\$ 5,013,697	\$ 5,123,998	\$ 5,236,726	\$ 5,351,934
BESS Retail Billing Savings		\$ 140,135	\$ 143,218	\$ 146,369	\$ 149,589	\$ 152,880	\$ 156,243	\$ 159,681	\$ 163,194	\$ 166,784	\$ 170,453
BESS Wholesale Market Value		\$ 123,603	\$ 126,322	\$ 129,101	\$ 131,942	\$ 134,844	\$ 137,811	\$ 140,843	\$ 143,941	\$ 147,108	\$ 150,344
BESS SGIP Payment		\$ 204,661	\$ 204,661	\$ 204,661	\$ 204,661	\$ 204,661	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 3,931,601	\$ 4,022,599	\$ 4,115,598	\$ 4,210,644	\$ 4,307,781	\$ 4,406,716	\$ 4,507,517	\$ 4,610,173	\$ 4,714,784	\$ 4,821,337

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$55,539,361
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$59,997,761
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 8,265,549
Years	20
Installation Peak Annual Load (kW)	7,998
Critical Load %	7.5%
Peak Annual Critical Load	600
Energy Security Cost Metric	\$317
ESTCP Provided Security Cost Metric	\$416

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 83,288	\$ 85,121	\$ 86,993	\$ 88,907	\$ 90,863	\$ 92,862	\$ 94,905	\$ 96,993	\$ 99,127	\$ 101,308
\$ 51,615	\$ 52,750	\$ 53,911	\$ 55,097	\$ 56,309	\$ 57,548	\$ 58,814	\$ 60,108	\$ 61,430	\$ 62,781
\$ 24,241	\$ 24,774	\$ 25,319	\$ 25,876	\$ 26,445	\$ 27,027	\$ 27,622	\$ 28,229	\$ 28,850	\$ 29,485
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 12,737	\$ 13,017	\$ 13,303	\$ 13,596	\$ 13,895	\$ 14,201	\$ 14,513	\$ 14,832	\$ 15,159	\$ 15,492
\$ 171,880	\$ 175,662	\$ 179,526	\$ 183,476	\$ 187,512	\$ 191,637	\$ 195,853	\$ 200,162	\$ 204,566	\$ 209,066
\$ 5,469,676	\$ 5,590,009	\$ 5,712,990	\$ 5,838,675	\$ 5,967,126	\$ 6,098,403	\$ 6,232,568	\$ 6,369,684	\$ 6,509,817	\$ 6,653,033
\$ 174,203	\$ 178,035	\$ 181,952	\$ 185,955	\$ 190,046	\$ 194,227	\$ 198,500	\$ 202,867	\$ 207,330	\$ 211,892
\$ 153,652	\$ 157,032	\$ 160,487	\$ 164,018	\$ 167,626	\$ 171,314	\$ 175,083	\$ 178,935	\$ 182,871	\$ 186,894
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 5,141,822	\$ 5,254,942	\$ 5,370,550	\$ 5,488,702	\$ 5,609,454	\$ 5,732,862	\$ 5,858,985	\$ 5,987,882	\$ 6,119,616	\$ 6,254,247

FORT BLISS BASELINE MICROGRID

Fort Bliss Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	8
Capacity of Each DG (kW)	2000
Capital Cost of Each DG (\$/kW)	\$ 600
Year 1 DG O&M Cost Per Unit	\$ 20,000
UPS Quantity	4
Capacity of Each UPS (kVA)	2000
Energy Capacity of Each UPS (kWh)	500
Capital Cost of Each UPS (\$/kVA)	\$ 486
Fixed O&M Cost of UPS (\$/kVA)	\$ 5.98
Variable O&M Cost of UPS (\$/MWh)	\$ 1.21

	Operating Yr.	1	2	3	4	5	6	7	8	9	10
Line Item	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 3,000,000	\$ 100,000	\$ 102,200	\$ 104,448	\$ 106,746	\$ 109,095	\$ 111,495	\$ 113,948	\$ 116,454	\$ 119,016	\$ 121,635
DG Capital & Annual O&M Cost	\$ 9,600,000	\$ 160,000	\$ 163,520	\$ 167,117	\$ 170,794	\$ 174,551	\$ 178,392	\$ 182,316	\$ 186,327	\$ 190,426	\$ 194,616
DG Demand Response Operating Fuel Cost		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
UPS Capital & Annual O&M Cost	\$ 3,888,000	\$ 47,842	\$ 48,895	\$ 49,971	\$ 51,070	\$ 52,194	\$ 53,342	\$ 54,515	\$ 55,715	\$ 56,940	\$ 58,193
Total Annual Baseline Capital+O&M Costs	\$ 16,488,000	\$ 307,842	\$ 314,615	\$ 321,536	\$ 328,610	\$ 335,840	\$ 343,228	\$ 350,779	\$ 358,496	\$ 366,383	\$ 374,444
		\$ 207,842	\$ 212,415	\$ 217,088	\$ 221,864	\$ 226,745	\$ 231,733	\$ 236,832	\$ 242,042	\$ 247,367	\$ 252,809
Annual Electricity Costs		\$ 20,700,000	\$ 21,155,400	\$ 21,620,819	\$ 22,096,477	\$ 22,582,599	\$ 23,079,416	\$ 23,587,164	\$ 24,106,081	\$ 24,636,415	\$ 25,178,416
Emergency Demand Response Rev		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 20,700,000	\$ 21,155,400	\$ 21,620,819	\$ 22,096,477	\$ 22,582,599	\$ 23,079,416	\$ 23,587,164	\$ 24,106,081	\$ 24,636,415	\$ 25,178,416

	11	12	13	14	15	16	17	18	19	20
	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BASELINE MICROGRID (POST DR AND PS)	\$ 124,311	\$ 127,046	\$ 129,841	\$ 132,697	\$ 135,617	\$ 138,600	\$ 141,649	\$ 144,766	\$ 147,950	\$ 151,205
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$ 198,897	\$ 203,273	\$ 207,745	\$ 212,315	\$ 216,986	\$ 221,760	\$ 226,639	\$ 231,625	\$ 236,721	\$ 241,928
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
	\$ 59,473	\$ 60,782	\$ 62,119	\$ 63,486	\$ 64,882	\$ 66,310	\$ 67,768	\$ 69,259	\$ 70,783	\$ 72,340
Years	\$ 382,681	\$ 391,100	\$ 399,705	\$ 408,498	\$ 417,485	\$ 426,670	\$ 436,057	\$ 445,650	\$ 455,454	\$ 465,474
Installation Peak Annual Load (kW)	\$ 258,371	\$ 264,055	\$ 269,864	\$ 275,801	\$ 281,869	\$ 288,070	\$ 294,407	\$ 300,884	\$ 307,504	\$ 314,269
Critical Load %										
Peak Annual Critical Load	\$ 25,732,341	\$ 26,298,453	\$ 26,877,019	\$ 27,468,313	\$ 28,072,616	\$ 28,690,214	\$ 29,321,398	\$ 29,966,469	\$ 30,625,731	\$ 31,299,498
	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Energy Security Cost Metric	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
ESTCP Provided Security Cost Metric	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Match?	\$ 25,732,341	\$ 26,298,453	\$ 26,877,019	\$ 27,468,313	\$ 28,072,616	\$ 28,690,214	\$ 29,321,398	\$ 29,966,469	\$ 30,625,731	\$ 31,299,498

FORT BLISS Li-Ion 2000 kW – 4000 kWh, CURRENT

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 1,900,000
	Upfront CMA Purchase	\$ 748,000
	Net Initial BESS Purchase	\$ 2,648,000
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ -
	Market Participation Telemetry Setup	\$ -
	Market Participation SoC Management Setup	\$ -
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,100,000
	Tax	\$ -
	Pre-Markup Subtotal	\$ 3,878,000
	Internal Management and Overhead Estimate	\$ 581,700
	Incentive or Grant Value	
	Total EPC Implementation Cost	\$ 4,459,700
YEAR 1 VALUE	Utility Billing Savings	\$ 112,853
	Wholesale Market Revenue	\$ -
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ -

Fort Bliss Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	7
Capacity of Each DG (kW)	2000
Capital Cost of Each DG (\$/kW)	\$ 600
Year 1 DG O&M Cost Per Unit	\$ 20,000
UPS Quantity	4
Capacity of Each UPS (kVA)	2000
Energy Capacity of Each UPS (kWh)	500
Capital Cost of Each UPS (\$/kVA)	\$ 486
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

SCENARIO	CURRENT
BESS Power Capacity	2000
BESS Energy Capacity	4000
Technology	Li-Ion
Selected Use Case Stack	DCM
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 3,000,000	\$ 100,000	\$ 102,200	\$ 104,448	\$ 106,746	\$ 109,095	\$ 111,495	\$ 113,948	\$ 116,454	\$ 119,016	\$ 121,635
BESS Capital & Annual O&M Cost	\$ 4,459,700	\$ 16,800	\$ 17,170	\$ 17,547	\$ 17,933	\$ 18,328	\$ 18,731	\$ 19,143	\$ 19,564	\$ 19,995	\$ 20,435
DG Capital & Annual O&M Cost	\$ 8,400,000	\$ 140,000	\$ 143,080	\$ 146,228	\$ 149,445	\$ 152,733	\$ 156,093	\$ 159,527	\$ 163,036	\$ 166,623	\$ 170,289
DG Demand Response Operating Fuel Cost		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
UPS Capital & Annual O&M Cost	\$ 3,888,000	\$ 109,289	\$ 111,693	\$ 114,150	\$ 116,662	\$ 119,228	\$ 121,851	\$ 124,532	\$ 127,272	\$ 130,072	\$ 132,933
Total Annual Baseline Capital+O&M Costs	\$ 19,747,700	\$ 366,089	\$ 374,143	\$ 382,374	\$ 390,786	\$ 399,383	\$ 408,170	\$ 417,150	\$ 426,327	\$ 435,706	\$ 445,292
Annual Electricity Costs Before BESS/DG		\$ 20,700,000	\$ 21,155,400	\$ 21,620,819	\$ 22,096,477	\$ 22,582,599	\$ 23,079,416	\$ 23,587,164	\$ 24,106,081	\$ 24,636,415	\$ 25,178,416
BESS Retail Billing Savings		\$ 112,853	\$ 115,336	\$ 117,873	\$ 120,466	\$ 123,117	\$ 125,825	\$ 128,593	\$ 131,422	\$ 134,314	\$ 137,269
BESS Wholesale Market Value		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 20,587,147	\$ 21,040,064	\$ 21,502,946	\$ 21,976,010	\$ 22,459,483	\$ 22,953,591	\$ 23,458,570	\$ 23,974,659	\$ 24,502,101	\$ 25,041,148

		11	12	13	14	15	16	17	18	19	20
		2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$280,723,348	\$ 124,311	\$ 127,046	\$ 129,841	\$ 132,697	\$ 135,617	\$ 138,600	\$ 141,649	\$ 144,766	\$ 147,950	\$ 151,205
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$282,262,196	\$ 20,884	\$ 21,344	\$ 21,813	\$ 22,293	\$ 22,784	\$ 23,285	\$ 23,797	\$ 24,321	\$ 24,856	\$ 25,402
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 24,739,633	\$ 174,035	\$ 177,864	\$ 181,777	\$ 185,776	\$ 189,863	\$ 194,040	\$ 198,309	\$ 202,672	\$ 207,131	\$ 211,687
Years	20	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Installation Peak Annual Load (kW)	67,605	\$ 135,858	\$ 138,847	\$ 141,901	\$ 145,023	\$ 148,214	\$ 151,474	\$ 154,807	\$ 158,213	\$ 161,693	\$ 165,250
Critical Load %	18.5%	\$ 455,088	\$ 465,100	\$ 475,332	\$ 485,789	\$ 496,477	\$ 507,399	\$ 518,562	\$ 529,970	\$ 541,630	\$ 553,546
Peak Annual Critical Load	12,507	\$ 25,732,341	\$ 26,298,453	\$ 26,877,019	\$ 27,468,313	\$ 28,072,616	\$ 28,690,214	\$ 29,321,398	\$ 29,966,469	\$ 30,625,731	\$ 31,299,498
		\$ 140,288	\$ 143,375	\$ 146,529	\$ 149,753	\$ 153,047	\$ 156,414	\$ 159,855	\$ 163,372	\$ 166,966	\$ 170,640
		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Energy Security Cost Metric	\$93	\$ 25,592,053	\$ 26,155,078	\$ 26,730,490	\$ 27,318,560	\$ 27,919,569	\$ 28,533,799	\$ 29,161,543	\$ 29,803,097	\$ 30,458,765	\$ 31,128,858
ESTCP Provided Security Cost Metric	\$83										

FORT BLISS Li-Ion 2000 kW – 4000 kWh, FUTURE

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 1,900,000
	Upfront CMA Purchase	\$ 748,000
	Net Initial BESS Purchase	\$ 1,906,560
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ -
	Market Participation Telemetry Setup	\$ -
	Market Participation SoC Management Setup	\$ -
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 792,000
	Tax	\$ -
	Pre-Markup Subtotal	\$ 2,828,560
	Internal Management and Overhead Estimate	\$ 424,284
	Incentive or Grant Value	
	Total EPC Implementation Cost	\$ 3,252,844
YEAR 1 VALUE	Utility Billing Savings	\$ 112,853
	Wholesale Market Revenue	\$ -
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ -

Fort Bliss Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	7
Capacity of Each DG (kW)	2000
Capital Cost of Each DG (\$/kW)	\$ 600
Year 1 DG O&M Cost Per Unit	\$ 20,000
UPS Quantity	4
Capacity of Each UPS (kVA)	2000
Energy Capacity of Each UPS (kWh)	500
Capital Cost of Each UPS (\$/kVA)	\$ 486
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	28%

SCENARIO	FUTURE
BESS Power Capacity	2000
BESS Energy Capacity	4000
Technology	Li-Ion
Selected Use Case Stack	DCM
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 3,000,000	\$ 100,000	\$ 102,200	\$ 104,448	\$ 106,746	\$ 109,095	\$ 111,495	\$ 113,948	\$ 116,454	\$ 119,016	\$ 121,635
BESS Capital & Annual O&M Cost	\$ 3,252,844	\$ 16,800	\$ 17,170	\$ 17,547	\$ 17,933	\$ 18,328	\$ 18,731	\$ 19,143	\$ 19,564	\$ 19,995	\$ 20,435
DG Capital & Annual O&M Cost	\$ 8,400,000	\$ 140,000	\$ 143,080	\$ 146,228	\$ 149,445	\$ 152,733	\$ 156,093	\$ 159,527	\$ 163,036	\$ 166,623	\$ 170,289
DG Demand Response Operating Fuel Cost		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
UPS Capital & Annual O&M Cost	\$ 3,888,000	\$ 109,289	\$ 111,693	\$ 114,150	\$ 116,662	\$ 119,228	\$ 121,851	\$ 124,532	\$ 127,272	\$ 130,072	\$ 132,933
Total Annual Baseline Capital+O&M Costs	\$ 18,540,844	\$ 366,089	\$ 374,143	\$ 382,374	\$ 390,786	\$ 399,383	\$ 408,170	\$ 417,150	\$ 426,327	\$ 435,706	\$ 445,292
Annual Electricity Costs Before BESS/DG		\$ 20,700,000	\$ 21,155,400	\$ 21,620,819	\$ 22,096,477	\$ 22,582,599	\$ 23,079,416	\$ 23,587,164	\$ 24,106,081	\$ 24,636,415	\$ 25,178,416
BESS Retail Billing Savings		\$ 112,853	\$ 115,336	\$ 117,873	\$ 120,466	\$ 123,117	\$ 125,825	\$ 128,593	\$ 131,422	\$ 134,314	\$ 137,269
BESS Wholesale Market Value		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 20,587,147	\$ 21,040,064	\$ 21,502,946	\$ 21,976,010	\$ 22,459,483	\$ 22,953,591	\$ 23,458,570	\$ 23,974,659	\$ 24,502,101	\$ 25,041,148

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$280,723,348
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$282,262,196
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 23,532,777
Years	20
Installation Peak Annual Load (kW)	67,605
Critical Load %	18.5%
Peak Annual Critical Load	12,507
Energy Security Cost Metric	\$88
ESTCP Provided Security Cost Metric	\$83

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 124,311	\$ 127,046	\$ 129,841	\$ 132,697	\$ 135,617	\$ 138,600	\$ 141,649	\$ 144,766	\$ 147,950	\$ 151,205
\$ 20,884	\$ 21,344	\$ 21,813	\$ 22,293	\$ 22,784	\$ 23,285	\$ 23,797	\$ 24,321	\$ 24,856	\$ 25,402
\$ 174,035	\$ 177,864	\$ 181,777	\$ 185,776	\$ 189,863	\$ 194,040	\$ 198,309	\$ 202,672	\$ 207,131	\$ 211,687
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 135,858	\$ 138,847	\$ 141,901	\$ 145,023	\$ 148,214	\$ 151,474	\$ 154,807	\$ 158,213	\$ 161,693	\$ 165,250
\$ 455,088	\$ 465,100	\$ 475,332	\$ 485,789	\$ 496,477	\$ 507,399	\$ 518,562	\$ 529,970	\$ 541,630	\$ 553,546
\$ 25,732,341	\$ 26,298,453	\$ 26,877,019	\$ 27,468,313	\$ 28,072,616	\$ 28,690,214	\$ 29,321,398	\$ 29,966,469	\$ 30,625,731	\$ 31,299,498
\$ 140,288	\$ 143,375	\$ 146,529	\$ 149,753	\$ 153,047	\$ 156,414	\$ 159,855	\$ 163,372	\$ 166,966	\$ 170,640
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 25,592,053	\$ 26,155,078	\$ 26,730,490	\$ 27,318,560	\$ 27,919,569	\$ 28,533,799	\$ 29,161,543	\$ 29,803,097	\$ 30,458,765	\$ 31,128,858

FORT BLISS VRF 2000 kW – 12000 kWh, CURRENT

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 6,260,000
	Electrolyte Value	\$ (2,880,000)
	Net Initial BESS Purchase	\$ 3,380,000
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ -
	Market Participation Telemetry Setup	\$ -
	Market Participation SoC Management Setup	\$ -
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 3,300,000
	Tax	\$ -
	Pre-Markup Subtotal	\$ 6,810,000
	Internal Management and Overhead Estimate	\$ 1,021,500
	Incentive or Grant Value	
	Total EPC Implementation Cost	\$ 7,831,500
YEAR 1 VALUE	Utility Billing Savings	\$ 95,152
	Wholesale Market Revenue	\$ -
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Electrolyte Lease Annual Cost	\$ 172,800
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ -

Fort Bliss Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	7
Capacity of Each DG (kW)	2000
Capital Cost of Each DG (\$/kW)	\$ 600
Year 1 DG O&M Cost Per Unit	\$ 20,000
UPS Quantity	4
Capacity of Each UPS (kVA)	2000
Energy Capacity of Each UPS (kWh)	500
Capital Cost of Each UPS (\$/kVA)	\$ 486
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

SCENARIO	CURRENT
BESS Power Capacity	2000
BESS Energy Capacity	12000
Technology	VRF
Selected Use Case Stack	DCM
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 3,000,000	\$ 100,000	\$ 102,200	\$ 104,448	\$ 106,746	\$ 109,095	\$ 111,495	\$ 113,948	\$ 116,454	\$ 119,016	\$ 121,635
BESS Capital & Annual O&M Cost	\$ 7,831,500	\$ 189,600	\$ 193,771	\$ 198,034	\$ 202,391	\$ 206,844	\$ 211,394	\$ 216,045	\$ 220,798	\$ 225,655	\$ 230,620
DG Capital & Annual O&M Cost	\$ 8,400,000	\$ 140,000	\$ 143,080	\$ 146,228	\$ 149,445	\$ 152,733	\$ 156,093	\$ 159,527	\$ 163,036	\$ 166,623	\$ 170,289
DG Demand Response Operating Fuel Cost		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
UPS Capital & Annual O&M Cost	\$ 3,888,000	\$ 109,289	\$ 111,693	\$ 114,150	\$ 116,662	\$ 119,228	\$ 121,851	\$ 124,532	\$ 127,272	\$ 130,072	\$ 132,933
Total Annual Baseline Capital+O&M Costs	\$ 23,119,500	\$ 538,889	\$ 550,744	\$ 562,861	\$ 575,244	\$ 587,899	\$ 600,833	\$ 614,051	\$ 627,560	\$ 641,367	\$ 655,477
Annual Electricity Costs Before BESS/DG		\$ 20,700,000	\$ 21,155,400	\$ 21,620,819	\$ 22,096,477	\$ 22,582,599	\$ 23,079,416	\$ 23,587,164	\$ 24,106,081	\$ 24,636,415	\$ 25,178,416
BESS Retail Billing Savings		\$ 95,152	\$ 97,245	\$ 99,385	\$ 101,571	\$ 103,806	\$ 106,089	\$ 108,423	\$ 110,809	\$ 113,247	\$ 115,738
BESS Wholesale Market Value		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 20,604,848	\$ 21,058,155	\$ 21,521,434	\$ 21,994,906	\$ 22,478,794	\$ 22,973,327	\$ 23,478,740	\$ 23,995,272	\$ 24,523,168	\$ 25,062,678

		11	12	13	14	15	16	17	18	19	20
		2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$280,964,717	\$ 124,311	\$ 127,046	\$ 129,841	\$ 132,697	\$ 135,617	\$ 138,600	\$ 141,649	\$ 144,766	\$ 147,950	\$ 151,205
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$282,262,196	\$ 235,693	\$ 240,879	\$ 246,178	\$ 251,594	\$ 257,129	\$ 262,786	\$ 268,567	\$ 274,475	\$ 280,514	\$ 286,685
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 30,467,709	\$ 174,035	\$ 177,864	\$ 181,777	\$ 185,776	\$ 189,863	\$ 194,040	\$ 198,309	\$ 202,672	\$ 207,131	\$ 211,687
Years	20	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Installation Peak Annual Load (kW)	67,605	\$ 135,858	\$ 138,847	\$ 141,901	\$ 145,023	\$ 148,214	\$ 151,474	\$ 154,807	\$ 158,213	\$ 161,693	\$ 165,250
Critical Load %	18.5%	\$ 669,897	\$ 684,635	\$ 699,697	\$ 715,090	\$ 730,822	\$ 746,900	\$ 763,332	\$ 780,125	\$ 797,288	\$ 814,828
Peak Annual Critical Load	12,507	\$ 25,732,341	\$ 26,298,453	\$ 26,877,019	\$ 27,468,313	\$ 28,072,616	\$ 28,690,214	\$ 29,321,398	\$ 29,966,469	\$ 30,625,731	\$ 31,299,498
Energy Security Cost Metric	\$117	\$ 118,284	\$ 120,886	\$ 123,546	\$ 126,264	\$ 129,042	\$ 131,881	\$ 134,782	\$ 137,747	\$ 140,778	\$ 143,875
ESTCP Provided Security Cost Metric	\$83	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
		\$ 25,614,057	\$ 26,177,566	\$ 26,753,473	\$ 27,342,049	\$ 27,943,574	\$ 28,558,333	\$ 29,186,616	\$ 29,828,722	\$ 30,484,954	\$ 31,155,623

FORT BLISS VRF 2000 kW – 12000 kWh, FUTURE

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 6,260,000
	Electrolyte Value	\$ (2,880,000)
	Net Initial BESS Purchase	\$ 3,881,200
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ -
	Market Participation Telemetry Setup	\$ -
	Market Participation SoC Management Setup	\$ -
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 2,046,000
	Tax	\$ -
	Pre-Markup Subtotal	\$ 6,057,200
	Internal Management and Overhead Estimate	\$ 908,580
	Incentive or Grant Value	
	Total EPC Implementation Cost	\$ 6,965,780
YEAR 1 VALUE	Utility Billing Savings	\$ 95,152
	Wholesale Market Revenue	\$ -
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Electrolyte Lease Annual Cost	\$ -
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ -

Fort Bliss Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	7
Capacity of Each DG (kW)	2000
Capital Cost of Each DG (\$/kW)	\$ 600
Year 1 DG O&M Cost Per Unit	\$ 20,000
UPS Quantity	4
Capacity of Each UPS (kVA)	2000
Energy Capacity of Each UPS (kWh)	500
Capital Cost of Each UPS (\$/kVA)	\$ 486
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	38%

SCENARIO	FUTURE
BESS Power Capacity	2000
BESS Energy Capacity	12000
Technology	VRF
Selected Use Case Stack	DCM
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 3,000,000	\$ 100,000	\$ 102,200	\$ 104,448	\$ 106,746	\$ 109,095	\$ 111,495	\$ 113,948	\$ 116,454	\$ 119,016	\$ 121,635
BESS Capital & Annual O&M Cost	\$ 6,965,780	\$ 16,800	\$ 17,170	\$ 17,547	\$ 17,933	\$ 18,328	\$ 18,731	\$ 19,143	\$ 19,564	\$ 19,995	\$ 20,435
DG Capital & Annual O&M Cost	\$ 8,400,000	\$ 140,000	\$ 143,080	\$ 146,228	\$ 149,445	\$ 152,733	\$ 156,093	\$ 159,527	\$ 163,036	\$ 166,623	\$ 170,289
DG Demand Response Operating Fuel Cost		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
UPS Capital & Annual O&M Cost	\$ 3,888,000	\$ 109,289	\$ 111,693	\$ 114,150	\$ 116,662	\$ 119,228	\$ 121,851	\$ 124,532	\$ 127,272	\$ 130,072	\$ 132,933
Total Annual Baseline Capital+O&M Costs	\$ 22,253,780	\$ 366,089	\$ 374,143	\$ 382,374	\$ 390,786	\$ 399,383	\$ 408,170	\$ 417,150	\$ 426,327	\$ 435,706	\$ 445,292
Annual Electricity Costs Before BESS/DG		\$ 20,700,000	\$ 21,155,400	\$ 21,620,819	\$ 22,096,477	\$ 22,582,599	\$ 23,079,416	\$ 23,587,164	\$ 24,106,081	\$ 24,636,415	\$ 25,178,416
BESS Retail Billing Savings		\$ 95,152	\$ 97,245	\$ 99,385	\$ 101,571	\$ 103,806	\$ 106,089	\$ 108,423	\$ 110,809	\$ 113,247	\$ 115,738
BESS Wholesale Market Value		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 20,604,848	\$ 21,058,155	\$ 21,521,434	\$ 21,994,906	\$ 22,478,794	\$ 22,973,327	\$ 23,478,740	\$ 23,995,272	\$ 24,523,168	\$ 25,062,678

WESTOVER BASELINE MICROGRID

Westover Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	4
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	5
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

Demand Response (DR)

DR Capacity	1.5	MW
Current Daily Capacity Payment	\$ 152.00	\$/MW-day
Future Volatile Daily Capacity Payment	\$ 231.00	\$/MW-day
DR Days Per Year	365	This was back calculated
DR Hours Per Year	6	
DR Energy Payments	250	\$/MWh
Installation Share	0.8	
Year 1 DR Revenue	\$ 68,376.00	
Future Volatile Year 1 DR Revenue	\$ 102,978.00	
MWh of Generation	9	MWh
Heat Rate	12,040,000	BTU/MWh
Fuel Gallons	779.57	Gallons
Fuel Cost	2.65	\$/gallon of Diesel Fuel

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,025	\$ 79,741	\$ 81,495
DG Capital & Annual O&M Cost	\$ 2,250,000	\$ 28,000	\$ 28,616	\$ 29,246	\$ 29,889	\$ 30,547	\$ 31,219	\$ 31,905	\$ 32,607	\$ 33,325	\$ 34,058
DG Demand Response Operating Fuel Cost		\$ 2,066	\$ 2,111	\$ 2,158	\$ 2,205	\$ 2,254	\$ 2,303	\$ 2,354	\$ 2,406	\$ 2,459	\$ 2,513
UPS Capital & Annual O&M Cost	\$ 808,750	\$ 17,076	\$ 17,452	\$ 17,836	\$ 18,228	\$ 18,629	\$ 19,039	\$ 19,458	\$ 19,886	\$ 20,324	\$ 20,771
Total Annual Baseline Capital+O&M Costs	\$ 5,058,750	\$ 114,142	\$ 116,653	\$ 119,220	\$ 121,843	\$ 124,523	\$ 127,263	\$ 130,062	\$ 132,924	\$ 135,848	\$ 138,837
Annual Electricity Costs		\$1,500,000	\$1,533,000	\$1,566,726	\$1,601,194	\$1,636,420	\$1,672,421	\$1,709,215	\$1,746,817	\$1,785,247	\$1,824,523
Emergency Demand Response Rev		\$ 68,376	\$ 69,880	\$ 71,418	\$ 72,989	\$ 74,595	\$ 76,236	\$ 77,913	\$ 79,627	\$ 81,379	\$ 83,169
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$1,431,624	\$1,463,120	\$1,495,308	\$1,528,205	\$1,561,826	\$1,596,186	\$1,631,302	\$1,667,191	\$1,703,869	\$1,741,354

		11	12	13	14	15	16	17	18	19	20
		2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BASELINE MICROGRID (POST DR AND PS)	\$19,521,417	\$ 83,288	\$ 85,121	\$ 86,993	\$ 88,907	\$ 90,863	\$ 92,862	\$ 94,905	\$ 96,993	\$ 99,127	\$ 101,308
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$20,453,782	\$ 34,807	\$ 35,573	\$ 36,355	\$ 37,155	\$ 37,973	\$ 38,808	\$ 39,662	\$ 40,534	\$ 41,426	\$ 42,337
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 6,615,177	\$ 2,568	\$ 2,625	\$ 2,682	\$ 2,741	\$ 2,802	\$ 2,863	\$ 2,926	\$ 2,991	\$ 3,056	\$ 3,124
Years	20	\$ 21,228	\$ 21,695	\$ 22,172	\$ 22,660	\$ 23,158	\$ 23,668	\$ 24,189	\$ 24,721	\$ 25,265	\$ 25,820
Installation Peak Annual Load (kW)	3414	\$ 141,891	\$ 145,013	\$ 148,203	\$ 151,464	\$ 154,796	\$ 158,201	\$ 161,682	\$ 165,239	\$ 168,874	\$ 172,589
Critical Load %	50.0%										
Peak Annual Critical Load	1707	\$1,864,662	\$1,905,685	\$1,947,610	\$1,990,457	\$2,034,248	\$2,079,001	\$2,124,739	\$2,171,483	\$2,219,256	\$2,268,080
		\$ 84,999	\$ 86,869	\$ 88,780	\$ 90,733	\$ 92,729	\$ 94,769	\$ 96,854	\$ 98,985	\$ 101,163	\$ 103,388
Energy Security Cost Metric	\$166	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
ESTCP Provided Security Cost Metric	\$166										
Match?	YES	\$1,779,664	\$1,818,816	\$1,858,830	\$1,899,724	\$1,941,518	\$1,984,232	\$2,027,885	\$2,072,498	\$2,118,093	\$2,164,691

WESTOVER Li-Ion 750 kW – 750 kWh, CURRENT

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 450,000
	Upfront CMA Purchase	\$ 140,250
	Net Initial BESS Purchase	\$ 590,250
	Peak Shaving Controls Equipment	\$ -
	Peak Shaving Controls Initial Setup	\$ -
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 206,250
	Tax	\$ -
	Pre-Markup Subtotal	\$ 928,500
	Internal Management and Overhead Estimate	\$ 139,275
	Incentive or Grant Value	
	Total EPC Implementation Cost	\$1,067,775
YEAR 1 VALUE	Utility Billing Savings	\$ (9,509)
	Wholesale Market Revenue	\$ 94,930
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Controls Software Licensing and Support	\$ -
	Cellular Data Plan for Peak Shaving Operation	\$ -
	Wholesale Market CSP Services	\$ 18,986

Westover Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	3
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	5
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

SCENARIO	CURRENT
BESS Power Capacity	750
BESS Energy Capacity	750
Technology	Li-Ion
Selected Use Case Stack	FR
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,025	\$ 79,741	\$ 81,495
BESS Capital & Annual O&M Cost	\$ 1,067,775	\$ 28,986	\$ 29,624	\$ 30,275	\$ 30,941	\$ 31,622	\$ 32,318	\$ 33,029	\$ 33,756	\$ 34,498	\$ 35,257
DG Capital & Annual O&M Cost	\$ 1,687,500	\$ 21,000	\$ 21,462	\$ 21,934	\$ 22,417	\$ 22,910	\$ 23,414	\$ 23,929	\$ 24,455	\$ 24,993	\$ 25,543
DG Demand Response Operating Fuel Cost		\$ 2,066	\$ 2,111	\$ 2,158	\$ 2,205	\$ 2,254	\$ 2,303	\$ 2,354	\$ 2,406	\$ 2,459	\$ 2,513
UPS Capital & Annual O&M Cost	\$ 808,750	\$ 17,076	\$ 17,452	\$ 17,836	\$ 18,228	\$ 18,629	\$ 19,039	\$ 19,458	\$ 19,886	\$ 20,324	\$ 20,771
Total Annual Baseline Capital+O&M Costs	\$ 5,564,025	\$ 136,128	\$ 139,123	\$ 142,184	\$ 145,312	\$ 148,509	\$ 151,776	\$ 155,115	\$ 158,527	\$ 162,015	\$ 165,579
Annual Electricity Costs Before BESS/DG		\$ 1,500,000	\$ 1,533,000	\$ 1,566,726	\$ 1,601,194	\$ 1,636,420	\$ 1,672,421	\$ 1,709,215	\$ 1,746,817	\$ 1,785,247	\$ 1,824,523
BESS Retail Billing Savings		\$ (9,509)	\$ (9,718)	\$ (9,932)	\$ (10,151)	\$ (10,374)	\$ (10,602)	\$ (10,835)	\$ (11,074)	\$ (11,317)	\$ (11,566)
BESS Wholesale Market Value		\$ 94,930	\$ 97,018	\$ 99,153	\$ 101,334	\$ 103,564	\$ 105,842	\$ 108,171	\$ 110,550	\$ 112,982	\$ 115,468
Emergency Demand Response Rev		\$ 68,376	\$ 69,880	\$ 71,418	\$ 72,989	\$ 74,595	\$ 76,236	\$ 77,913	\$ 79,627	\$ 81,379	\$ 83,169
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 1,346,203	\$ 1,375,819	\$ 1,406,087	\$ 1,437,021	\$ 1,468,636	\$ 1,500,946	\$ 1,533,967	\$ 1,567,714	\$ 1,602,204	\$ 1,637,452

		11	12	13	14	15	16	17	18	19	20
		2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$18,356,629	\$ 83,288	\$ 85,121	\$ 86,993	\$ 88,907	\$ 90,863	\$ 92,862	\$ 94,905	\$ 96,993	\$ 99,127	\$ 101,308
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$20,453,782	\$ 36,033	\$ 36,825	\$ 37,636	\$ 38,464	\$ 39,310	\$ 40,175	\$ 41,058	\$ 41,962	\$ 42,885	\$ 43,828
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 7,420,250	\$ 26,105	\$ 26,680	\$ 27,267	\$ 27,866	\$ 28,479	\$ 29,106	\$ 29,746	\$ 30,401	\$ 31,070	\$ 31,753
Years	20	\$ 2,568	\$ 2,625	\$ 2,682	\$ 2,741	\$ 2,802	\$ 2,863	\$ 2,926	\$ 2,991	\$ 3,056	\$ 3,124
Installation Peak Annual Load (kW)	3414	\$ 21,228	\$ 21,695	\$ 22,172	\$ 22,660	\$ 23,158	\$ 23,668	\$ 24,189	\$ 24,721	\$ 25,265	\$ 25,820
Critical Load %	50.0%	\$ 169,222	\$ 172,945	\$ 176,750	\$ 180,638	\$ 184,612	\$ 188,674	\$ 192,825	\$ 197,067	\$ 201,402	\$ 205,833
Peak Annual Critical Load	1707										
		\$1,864,662	\$1,905,685	\$1,947,610	\$1,990,457	\$2,034,248	\$2,079,001	\$2,124,739	\$2,171,483	\$2,219,256	\$2,268,080
		\$ (11,821)	\$ (12,081)	\$ (12,347)	\$ (12,618)	\$ (12,896)	\$ (13,179)	\$ (13,469)	\$ (13,766)	\$ (14,069)	\$ (14,378)
		\$ 118,008	\$ 120,604	\$ 123,258	\$ 125,969	\$ 128,741	\$ 131,573	\$ 134,468	\$ 137,426	\$ 140,449	\$ 143,539
		\$ 84,999	\$ 86,869	\$ 88,780	\$ 90,733	\$ 92,729	\$ 94,769	\$ 96,854	\$ 98,985	\$ 101,163	\$ 103,388
		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Energy Security Cost Metric	\$156	\$1,673,476	\$1,710,293	\$1,747,919	\$1,786,373	\$1,825,673	\$1,865,838	\$1,906,887	\$1,948,838	\$1,991,713	\$2,035,530
ESTCP Provided Security Cost Metric	\$166										

WESTOVER Li-Ion 750 kW – 750 kWh, FUTURE

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 450,000
	Upfront CMA Purchase	\$ 140,250
	Net Initial BESS Purchase	\$ 424,980
	Peak Shaving Controls Equipment	\$ -
	Peak Shaving Controls Initial Setup	\$ -
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 148,500
	Tax	\$ -
	Pre-Markup Subtotal	\$ 705,480
	Internal Management and Overhead Estimate	\$ 105,822
	Incentive or Grant Value	
	Total EPC Implementation Cost	\$ 811,302
YEAR 1 VALUE	Utility Billing Savings	\$ (9,509)
	Wholesale Market Revenue	\$ 111,996
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Controls Software Licensing and Support	\$ -
	Cellular Data Plan for Peak Shaving Operation	\$ -
	Wholesale Market CSP Services	\$ 22,399

Westover Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	3
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	5
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	28%

SCENARIO	FUTURE
BESS Power Capacity	750
BESS Energy Capacity	750
Technology	Li-Ion
Selected Use Case Sta	FR
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,025	\$ 79,741	\$ 81,495
BESS Capital & Annual O&M Cost	\$ 811,302	\$ 32,399	\$ 33,112	\$ 33,840	\$ 34,585	\$ 35,346	\$ 36,123	\$ 36,918	\$ 37,730	\$ 38,560	\$ 39,409
DG Capital & Annual O&M Cost	\$ 1,687,500	\$ 21,000	\$ 21,462	\$ 21,934	\$ 22,417	\$ 22,910	\$ 23,414	\$ 23,929	\$ 24,455	\$ 24,993	\$ 25,543
DG Demand Response Operating Fuel Cost		\$ 2,066	\$ 2,111	\$ 2,158	\$ 2,205	\$ 2,254	\$ 2,303	\$ 2,354	\$ 2,406	\$ 2,459	\$ 2,513
UPS Capital & Annual O&M Cost	\$ 808,750	\$ 17,076	\$ 17,452	\$ 17,836	\$ 18,228	\$ 18,629	\$ 19,039	\$ 19,458	\$ 19,886	\$ 20,324	\$ 20,771
Total Annual Baseline Capital+O&M Costs	\$ 5,307,552	\$ 139,541	\$ 142,611	\$ 145,749	\$ 148,955	\$ 152,232	\$ 155,581	\$ 159,004	\$ 162,502	\$ 166,077	\$ 169,731
Annual Electricity Costs Before BESS/DG		\$ 1,500,000	\$ 1,533,000	\$ 1,566,726	\$ 1,601,194	\$ 1,636,420	\$ 1,672,421	\$ 1,709,215	\$ 1,746,817	\$ 1,785,247	\$ 1,824,523
BESS Retail Billing Savings		\$ (9,509)	\$ (9,718)	\$ (9,932)	\$ (10,151)	\$ (10,374)	\$ (10,602)	\$ (10,835)	\$ (11,074)	\$ (11,317)	\$ (11,566)
BESS Wholesale Market Value		\$ 111,996	\$ 114,460	\$ 116,978	\$ 119,552	\$ 122,182	\$ 124,870	\$ 127,617	\$ 130,424	\$ 133,294	\$ 136,226
Emergency Demand Response Rev		\$ 102,978	\$ 105,244	\$ 107,559	\$ 109,925	\$ 112,344	\$ 114,815	\$ 117,341	\$ 119,923	\$ 122,561	\$ 125,257
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 1,294,535	\$ 1,323,015	\$ 1,352,121	\$ 1,381,868	\$ 1,412,269	\$ 1,443,339	\$ 1,475,092	\$ 1,507,544	\$ 1,540,710	\$ 1,574,606

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$17,652,091
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$20,453,782
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 7,210,319
Years	20
Installation Peak Annual Load (kW)	3414
Critical Load %	50.0%
Peak Annual Critical Load	1707
Energy Security Cost Metric	\$129
ESTCP Provided Security Cost Metric	\$166

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 83,288	\$ 85,121	\$ 86,993	\$ 88,907	\$ 90,863	\$ 92,862	\$ 94,905	\$ 96,993	\$ 99,127	\$ 101,308
\$ 40,276	\$ 41,162	\$ 42,067	\$ 42,993	\$ 43,939	\$ 44,905	\$ 45,893	\$ 46,903	\$ 47,935	\$ 48,989
\$ 26,105	\$ 26,680	\$ 27,267	\$ 27,866	\$ 28,479	\$ 29,106	\$ 29,746	\$ 30,401	\$ 31,070	\$ 31,753
\$ 2,568	\$ 2,625	\$ 2,682	\$ 2,741	\$ 2,802	\$ 2,863	\$ 2,926	\$ 2,991	\$ 3,056	\$ 3,124
\$ 21,228	\$ 21,695	\$ 22,172	\$ 22,660	\$ 23,158	\$ 23,668	\$ 24,189	\$ 24,721	\$ 25,265	\$ 25,820
\$ 173,465	\$ 177,281	\$ 181,182	\$ 185,168	\$ 189,241	\$ 193,405	\$ 197,659	\$ 202,008	\$ 206,452	\$ 210,994
\$ 1,864,662	\$ 1,905,685	\$ 1,947,610	\$ 1,990,457	\$ 2,034,248	\$ 2,079,001	\$ 2,124,739	\$ 2,171,483	\$ 2,219,256	\$ 2,268,080
\$ (11,821)	\$ (12,081)	\$ (12,347)	\$ (12,618)	\$ (12,896)	\$ (13,179)	\$ (13,469)	\$ (13,766)	\$ (14,069)	\$ (14,378)
\$ 139,223	\$ 142,286	\$ 145,416	\$ 148,616	\$ 151,885	\$ 155,227	\$ 158,642	\$ 162,132	\$ 165,699	\$ 169,344
\$ 128,013	\$ 130,829	\$ 133,707	\$ 136,649	\$ 139,655	\$ 142,728	\$ 145,868	\$ 149,077	\$ 152,356	\$ 155,708
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 1,609,247	\$ 1,644,651	\$ 1,680,833	\$ 1,717,811	\$ 1,755,603	\$ 1,794,226	\$ 1,833,699	\$ 1,874,041	\$ 1,915,270	\$ 1,957,406

WESTOVER VRF 750 kW – 4500 kWh, CURRENT

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 2,347,500
	Electrolyte Value	\$ (1,080,000)
	Net Initial BESS Purchase	\$ 1,267,500
	Peak Shaving Controls Equipment	\$ -
	Peak Shaving Controls Initial Setup	\$ -
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,237,500
	Tax	\$ -
	Pre-Markup Subtotal	\$ 2,637,000
	Internal Management and Overhead Estimate	\$ 395,550
	Incentive or Grant Value	\$ (165,513)
Total EPC Implementation Cost		\$ 2,867,037
YEAR 1 VALUE	Utility Billing Savings	\$ (51,580)
	Wholesale Market Revenue	\$ 95,704
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Electrolyte Lease Annual Cost	\$ 64,800
	Controls Software Licensing and Support	\$ -
	Cellular Data Plan for Peak Shaving Operation	\$ -
	Wholesale Market CSP Services	\$ 19,141

Westover Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	3
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	5
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

SCENARIO	CURRENT
BESS Power Capacity	750
BESS Energy Capacity	4500
Technology	VRF
Selected Use Case Stack	FR
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,025	\$ 79,741	\$ 81,495
BESS Capital & Annual O&M Cost	\$ 2,867,037	\$ 93,941	\$ 96,007	\$ 98,120	\$ 100,278	\$ 102,484	\$ 104,739	\$ 107,043	\$ 109,398	\$ 111,805	\$ 114,265
DG Capital & Annual O&M Cost	\$ 1,687,500	\$ 21,000	\$ 21,462	\$ 21,934	\$ 22,417	\$ 22,910	\$ 23,414	\$ 23,929	\$ 24,455	\$ 24,993	\$ 25,543
DG Demand Response Operating Fuel Cost		\$ 2,066	\$ 2,111	\$ 2,158	\$ 2,205	\$ 2,254	\$ 2,303	\$ 2,354	\$ 2,406	\$ 2,459	\$ 2,513
UPS Capital & Annual O&M Cost	\$ 808,750	\$ 17,076	\$ 17,452	\$ 17,836	\$ 18,228	\$ 18,629	\$ 19,039	\$ 19,458	\$ 19,886	\$ 20,324	\$ 20,771
Total Annual Baseline Capital+O&M Costs	\$ 7,363,287	\$ 201,083	\$ 205,507	\$ 210,028	\$ 214,649	\$ 219,371	\$ 224,197	\$ 229,129	\$ 234,170	\$ 239,322	\$ 244,587
Annual Electricity Costs Before BESS/DG		\$ 1,500,000	\$ 1,533,000	\$ 1,566,726	\$ 1,601,194	\$ 1,636,420	\$ 1,672,421	\$ 1,709,215	\$ 1,746,817	\$ 1,785,247	\$ 1,824,523
BESS Retail Billing Savings		\$ (51,580)	\$ (52,715)	\$ (53,874)	\$ (55,060)	\$ (56,271)	\$ (57,509)	\$ (58,774)	\$ (60,067)	\$ (61,389)	\$ (62,739)
BESS Wholesale Market Value		\$ 95,704	\$ 97,809	\$ 99,961	\$ 102,160	\$ 104,408	\$ 106,705	\$ 109,052	\$ 111,452	\$ 113,904	\$ 116,409
Emergency Demand Response Rev		\$ 68,376	\$ 69,880	\$ 71,418	\$ 72,989	\$ 74,595	\$ 76,236	\$ 77,913	\$ 79,627	\$ 81,379	\$ 83,169
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 1,387,500	\$ 1,418,025	\$ 1,449,222	\$ 1,481,104	\$ 1,513,689	\$ 1,546,990	\$ 1,581,024	\$ 1,615,806	\$ 1,651,354	\$ 1,687,684

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$18,919,749
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$20,453,782
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 10,105,226
Years	20
Installation Peak Annual Load (kW)	3414
Critical Load %	50.0%
Peak Annual Critical Load	1707
Energy Security Cost Metric	\$251
ESTCP Provided Security Cost Metric	\$166

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 83,288	\$ 85,121	\$ 86,993	\$ 88,907	\$ 90,863	\$ 92,862	\$ 94,905	\$ 96,993	\$ 99,127	\$ 101,308
\$ 116,779	\$ 119,348	\$ 121,973	\$ 124,657	\$ 127,399	\$ 130,202	\$ 133,066	\$ 135,994	\$ 138,986	\$ 142,043
\$ 26,105	\$ 26,680	\$ 27,267	\$ 27,866	\$ 28,479	\$ 29,106	\$ 29,746	\$ 30,401	\$ 31,070	\$ 31,753
\$ 2,568	\$ 2,625	\$ 2,682	\$ 2,741	\$ 2,802	\$ 2,863	\$ 2,926	\$ 2,991	\$ 3,056	\$ 3,124
\$ 21,228	\$ 21,695	\$ 22,172	\$ 22,660	\$ 23,158	\$ 23,668	\$ 24,189	\$ 24,721	\$ 25,265	\$ 25,820
\$ 249,968	\$ 255,467	\$ 261,088	\$ 266,831	\$ 272,702	\$ 278,701	\$ 284,833	\$ 291,099	\$ 297,503	\$ 304,048
\$1,864,662	\$1,905,685	\$1,947,610	\$1,990,457	\$2,034,248	\$2,079,001	\$2,124,739	\$2,171,483	\$2,219,256	\$2,268,080
\$ (64,120)	\$ (65,530)	\$ (66,972)	\$ (68,445)	\$ (69,951)	\$ (71,490)	\$ (73,063)	\$ (74,670)	\$ (76,313)	\$ (77,992)
\$ 118,970	\$ 121,588	\$ 124,263	\$ 126,996	\$ 129,790	\$ 132,646	\$ 135,564	\$ 138,546	\$ 141,594	\$ 144,710
\$ 84,999	\$ 86,869	\$ 88,780	\$ 90,733	\$ 92,729	\$ 94,769	\$ 96,854	\$ 98,985	\$ 101,163	\$ 103,388
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$1,724,813	\$1,762,759	\$1,801,539	\$1,841,173	\$1,881,679	\$1,923,076	\$1,965,384	\$2,008,622	\$2,052,812	\$2,097,974

WESTOVER VRF 750 kW – 4500 kWh, FUTURE

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 2,347,500
	Electrolyte Value	\$ (1,080,000)
	Net Initial BESS Purchase	\$ 1,455,450
	Peak Shaving Controls Equipment	\$ -
	Peak Shaving Controls Initial Setup	\$ -
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 767,250
	Tax	\$ -
	Pre-Markup Subtotal	\$ 2,354,700
	Internal Management and Overhead Estimate	\$ 353,205
	Incentive or Grant Value	\$ (165,513)
YEAR 1 VALUE	Total EPC Implementation Cost	\$ 2,542,392
	Utility Billing Savings	\$ (51,580)
	Wholesale Market Revenue	\$ 112,867
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Electrolyte Lease Annual Cost	\$ -
	Controls Software Licensing and Support	\$ -
	Cellular Data Plan for Peak Shaving Operation	\$ -
	Wholesale Market CSP Services	\$ 22,573

Westover Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	3
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	5
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	38%

SCENARIO	FUTURE
BESS Power Capacity	750
BESS Energy Capacity	4500
Technology	VRF
Selected Use Case Stack	FR
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 2,000,000	\$ 67,000	\$ 68,474	\$ 69,980	\$ 71,520	\$ 73,093	\$ 74,701	\$ 76,345	\$ 78,025	\$ 79,741	\$ 81,495
BESS Capital & Annual O&M Cost	\$ 2,542,392	\$ 32,573	\$ 33,290	\$ 34,022	\$ 34,771	\$ 35,536	\$ 36,318	\$ 37,117	\$ 37,933	\$ 38,768	\$ 39,621
DG Capital & Annual O&M Cost	\$ 1,687,500	\$ 21,000	\$ 21,462	\$ 21,934	\$ 22,417	\$ 22,910	\$ 23,414	\$ 23,929	\$ 24,455	\$ 24,993	\$ 25,543
DG Demand Response Operating Fuel Cost		\$ 2,066	\$ 2,111	\$ 2,158	\$ 2,205	\$ 2,254	\$ 2,303	\$ 2,354	\$ 2,406	\$ 2,459	\$ 2,513
UPS Capital & Annual O&M Cost	\$ 808,750	\$ 17,076	\$ 17,452	\$ 17,836	\$ 18,228	\$ 18,629	\$ 19,039	\$ 19,458	\$ 19,886	\$ 20,324	\$ 20,771
Total Annual Baseline Capital+O&M Costs	\$ 7,038,642	\$ 139,716	\$ 142,789	\$ 145,931	\$ 149,141	\$ 152,422	\$ 155,776	\$ 159,203	\$ 162,705	\$ 166,285	\$ 169,943
Annual Electricity Costs Before BESS/DG		\$ 1,500,000	\$ 1,533,000	\$ 1,566,726	\$ 1,601,194	\$ 1,636,420	\$ 1,672,421	\$ 1,709,215	\$ 1,746,817	\$ 1,785,247	\$ 1,824,523
BESS Retail Billing Savings		\$ (51,580)	\$ (52,715)	\$ (53,874)	\$ (55,060)	\$ (56,271)	\$ (57,509)	\$ (58,774)	\$ (60,067)	\$ (61,389)	\$ (62,739)
BESS Wholesale Market Value		\$ 112,867	\$ 115,350	\$ 117,888	\$ 120,481	\$ 123,132	\$ 125,841	\$ 128,609	\$ 131,439	\$ 134,330	\$ 137,286
Emergency Demand Response Rev		\$ 102,978	\$ 105,244	\$ 107,559	\$ 109,925	\$ 112,344	\$ 114,815	\$ 117,341	\$ 119,923	\$ 122,561	\$ 125,257
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 1,335,735	\$ 1,365,121	\$ 1,395,154	\$ 1,425,847	\$ 1,457,216	\$ 1,489,275	\$ 1,522,039	\$ 1,555,523	\$ 1,589,745	\$ 1,624,719

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$18,213,889
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$20,453,782
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 8,943,784
Years	20
Installation Peak Annual Load (kW)	3414
Critical Load %	50.0%
Peak Annual Critical Load	1707
Energy Security Cost Metric	\$196
ESTCP Provided Security Cost Metric	\$166

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 83,288	\$ 85,121	\$ 86,993	\$ 88,907	\$ 90,863	\$ 92,862	\$ 94,905	\$ 96,993	\$ 99,127	\$ 101,308
\$ 40,492	\$ 41,383	\$ 42,294	\$ 43,224	\$ 44,175	\$ 45,147	\$ 46,140	\$ 47,155	\$ 48,192	\$ 49,253
\$ 26,105	\$ 26,680	\$ 27,267	\$ 27,866	\$ 28,479	\$ 29,106	\$ 29,746	\$ 30,401	\$ 31,070	\$ 31,753
\$ 2,568	\$ 2,625	\$ 2,682	\$ 2,741	\$ 2,802	\$ 2,863	\$ 2,926	\$ 2,991	\$ 3,056	\$ 3,124
\$ 21,228	\$ 21,695	\$ 22,172	\$ 22,660	\$ 23,158	\$ 23,668	\$ 24,189	\$ 24,721	\$ 25,265	\$ 25,820
\$ 173,682	\$ 177,503	\$ 181,408	\$ 185,399	\$ 189,477	\$ 193,646	\$ 197,906	\$ 202,260	\$ 206,710	\$ 211,257
\$ 1,864,662	\$ 1,905,685	\$ 1,947,610	\$ 1,990,457	\$ 2,034,248	\$ 2,079,001	\$ 2,124,739	\$ 2,171,483	\$ 2,219,256	\$ 2,268,080
\$ (64,120)	\$ (65,530)	\$ (66,972)	\$ (68,445)	\$ (69,951)	\$ (71,490)	\$ (73,063)	\$ (74,670)	\$ (76,313)	\$ (77,992)
\$ 140,306	\$ 143,393	\$ 146,547	\$ 149,771	\$ 153,066	\$ 156,434	\$ 159,875	\$ 163,393	\$ 166,987	\$ 170,661
\$ 128,013	\$ 130,829	\$ 133,707	\$ 136,649	\$ 139,655	\$ 142,728	\$ 145,868	\$ 149,077	\$ 152,356	\$ 155,708
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 1,660,463	\$ 1,696,993	\$ 1,734,327	\$ 1,772,482	\$ 1,811,477	\$ 1,851,330	\$ 1,892,059	\$ 1,933,684	\$ 1,976,225	\$ 2,019,702

NAS CORPUS CHRISTI BASELINE MICROGRID

NAS Corpus Christi Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	7
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	9
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

Demand Response (DR)

DR Capacity	4.5 MW
Daily Capacity Payment	\$ 230.00 This was back calculated
DR Days Per Year	150 This was back calculated
DR Hours Per Year	6
DR Energy Payments	6.86 \$/MWh
Installation Share	0.8
Year 1 DR Revenue	\$ 124,348.18
MWh of Generation	82.5
Heat Rate	12,040,000 BTU/MWh
Fuel Gallons	7146.04 Gallons
Fuel Cost	2.42 \$/gallon of Diesel Fuel

Peak Shaving

Peak Shaving Capacity	750 kW
Peak Shaving Hours Per Year	74 hr
Peak Shaving Months	12
Peak Shaving Demand Payment	\$12.057577 \$/kW
Peak Shaving Energy Payment	\$0.036172 \$/kWh
Year 1 Peak Shaving Revenue	\$110,525.74

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 3,000,000	\$ 100,000	\$ 102,200	\$ 104,448	\$ 106,746	\$ 109,095	\$ 111,495	\$ 113,948	\$ 116,454	\$ 119,016	\$ 121,635
DG Capital & Annual O&M Cost	\$ 3,937,500	\$ 49,000	\$ 50,078	\$ 51,180	\$ 52,306	\$ 53,456	\$ 54,632	\$ 55,834	\$ 57,063	\$ 58,318	\$ 59,601
DG Demand Response Operating Fuel Cost		\$ 17,293	\$ 17,674	\$ 18,063	\$ 18,460	\$ 18,866	\$ 19,281	\$ 19,705	\$ 20,139	\$ 20,582	\$ 21,035
UPS Capital & Annual O&M Cost	\$ 1,455,750	\$ 30,737	\$ 31,414	\$ 32,105	\$ 32,811	\$ 33,533	\$ 34,271	\$ 35,025	\$ 35,795	\$ 36,583	\$ 37,388
Total Annual Baseline Capital+O&M Costs	\$ 8,393,250	\$ 197,031	\$ 201,366	\$ 205,796	\$ 210,323	\$ 214,950	\$ 219,679	\$ 224,512	\$ 229,451	\$ 234,499	\$ 239,658
		\$ 79,737	\$ 81,492	\$ 83,285	\$ 85,117	\$ 86,989	\$ 88,903	\$ 90,859	\$ 92,858	\$ 94,901	\$ 96,989
Annual Electricity Costs		\$ 7,100,000	\$ 7,256,200	\$ 7,415,836	\$ 7,578,985	\$ 7,745,722	\$ 7,916,128	\$ 8,090,283	\$ 8,268,269	\$ 8,450,171	\$ 8,636,075
Emergency Demand Response Rev		\$ 124,348	\$ 127,084	\$ 129,880	\$ 132,737	\$ 135,657	\$ 138,642	\$ 141,692	\$ 144,809	\$ 147,995	\$ 151,251
Peak Shaving Rev from DG Assets		\$ 110,526	\$ 112,957	\$ 115,442	\$ 117,982	\$ 120,578	\$ 123,230	\$ 125,941	\$ 128,712	\$ 131,544	\$ 134,438
Net Annual Electricity Costs		\$ 6,865,126	\$ 7,016,159	\$ 7,170,514	\$ 7,328,266	\$ 7,489,488	\$ 7,654,256	\$ 7,822,650	\$ 7,994,748	\$ 8,170,633	\$ 8,350,387

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BASELINE MICROGRID (POST DR AND PS)	\$93,611,863
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$96,814,570
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 11,079,935
Years	20
Installation Peak Annual Load (kW)	23,965
Critical Load %	18.4%
Peak Annual Critical Load	4,410
Energy Security Cost Metric	\$89
ESTCP Provided Security Cost Metric	\$89
Match?	YES

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 124,311	\$ 127,046	\$ 129,841	\$ 132,697	\$ 135,617	\$ 138,600	\$ 141,649	\$ 144,766	\$ 147,950	\$ 151,205
\$ 60,912	\$ 62,252	\$ 63,622	\$ 65,022	\$ 66,452	\$ 67,914	\$ 69,408	\$ 70,935	\$ 72,496	\$ 74,091
\$ 21,498	\$ 21,971	\$ 22,454	\$ 22,948	\$ 23,453	\$ 23,969	\$ 24,496	\$ 25,035	\$ 25,586	\$ 26,149
\$ 38,210	\$ 39,051	\$ 39,910	\$ 40,788	\$ 41,685	\$ 42,602	\$ 43,539	\$ 44,497	\$ 45,476	\$ 46,477
\$ 244,931	\$ 250,319	\$ 255,826	\$ 261,454	\$ 267,206	\$ 273,085	\$ 279,093	\$ 285,233	\$ 291,508	\$ 297,921
\$ 99,122	\$ 101,303	\$ 103,532	\$ 105,809	\$ 108,137	\$ 110,516	\$ 112,948	\$ 115,432	\$ 117,972	\$ 120,567
\$ 8,826,069	\$ 9,020,242	\$ 9,218,688	\$ 9,421,499	\$ 9,628,772	\$ 9,840,605	\$ 10,057,098	\$ 10,278,354	\$ 10,504,478	\$ 10,735,576
\$ 154,578	\$ 157,979	\$ 161,455	\$ 165,007	\$ 168,637	\$ 172,347	\$ 176,138	\$ 180,013	\$ 183,974	\$ 188,021
\$ 137,395	\$ 140,418	\$ 143,507	\$ 146,665	\$ 149,891	\$ 153,189	\$ 156,559	\$ 160,003	\$ 163,523	\$ 167,121
\$ 8,534,095	\$ 8,721,845	\$ 8,913,726	\$ 9,109,828	\$ 9,310,244	\$ 9,515,069	\$ 9,724,401	\$ 9,938,338	\$ 10,156,981	\$ 10,380,435

NAS CORPUS CHRISTI Li-Ion 3650 kW – 7300 kWh, CURRENT

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,467,500
	Upfront CMA Purchase	\$ 1,365,100
	Net Initial BESS Purchase	\$ 4,832,600
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ -
	Market Participation Telemetry Setup	\$ -
	Market Participation SoC Management Setup	\$ -
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 2,007,500
	Tax	\$ -
	Pre-Markup Subtotal	\$ 6,970,100
	Internal Management and Overhead Estimate	\$ 1,045,515
	Incentive or Grant Value	\$ -
	Total EPC Implementation Cost	\$ 8,015,615
YEAR 1 VALUE	Utility Billing Savings	\$ 387,245
	Wholesale Market Revenue	\$ -
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ -

NAS Corpus Christi Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	6
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	9
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

SCENARIO	CURRENT
BESS Power Capacity	3650
BESS Energy Capacity	7300
Technology	Li-Ion
Selected Use Case Stack	DCM
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 3,000,000	\$ 100,000	\$ 102,200	\$ 104,448	\$ 106,746	\$ 109,095	\$ 111,495	\$ 113,948	\$ 116,454	\$ 119,016	\$ 121,635
BESS Capital & Annual O&M Cost	\$ 8,015,615	\$ 16,800	\$ 17,170	\$ 17,547	\$ 17,933	\$ 18,328	\$ 18,731	\$ 19,143	\$ 19,564	\$ 19,995	\$ 20,435
DG Capital & Annual O&M Cost	\$ 3,375,000	\$ 42,000	\$ 42,924	\$ 43,868	\$ 44,833	\$ 45,820	\$ 46,828	\$ 47,858	\$ 48,911	\$ 49,987	\$ 51,087
DG Demand Response Operating Fuel Cost		\$ 17,293	\$ 17,674	\$ 18,063	\$ 18,460	\$ 18,866	\$ 19,281	\$ 19,705	\$ 20,139	\$ 20,582	\$ 21,035
UPS Capital & Annual O&M Cost	\$ 1,455,750	\$ 30,737	\$ 31,414	\$ 32,105	\$ 32,811	\$ 33,533	\$ 34,271	\$ 35,025	\$ 35,795	\$ 36,583	\$ 37,388
Total Annual Baseline Capital+O&M Costs	\$ 15,846,365	\$ 206,831	\$ 211,381	\$ 216,032	\$ 220,784	\$ 225,642	\$ 230,606	\$ 235,679	\$ 240,864	\$ 246,163	\$ 251,578
Annual Electricity Costs Before BESS/DG		\$ 7,100,000	\$ 7,256,200	\$ 7,415,836	\$ 7,578,985	\$ 7,745,722	\$ 7,916,128	\$ 8,090,283	\$ 8,268,269	\$ 8,450,171	\$ 8,636,075
BESS Retail Billing Savings		\$ 387,245	\$ 395,764	\$ 404,471	\$ 413,370	\$ 422,464	\$ 431,758	\$ 441,257	\$ 450,964	\$ 460,885	\$ 471,025
BESS Wholesale Market Value		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ 124,348	\$ 127,084	\$ 129,880	\$ 132,737	\$ 135,657	\$ 138,642	\$ 141,692	\$ 144,809	\$ 147,995	\$ 151,251
Peak Shaving Rev from DG Assets		\$ 110,526	\$ 112,957	\$ 115,442	\$ 117,982	\$ 120,578	\$ 123,230	\$ 125,941	\$ 128,712	\$ 131,544	\$ 134,438
Net Annual Electricity Costs		\$ 6,477,881	\$ 6,620,394	\$ 6,766,043	\$ 6,914,896	\$ 7,067,024	\$ 7,222,498	\$ 7,381,393	\$ 7,543,784	\$ 7,709,747	\$ 7,879,362

		11	12	13	14	15	16	17	18	19	20
		2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$88,331,446	\$ 124,311	\$ 127,046	\$ 129,841	\$ 132,697	\$ 135,617	\$ 138,600	\$ 141,649	\$ 144,766	\$ 147,950	\$ 151,205
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$96,814,570	\$ 20,884	\$ 21,344	\$ 21,813	\$ 22,293	\$ 22,784	\$ 23,285	\$ 23,797	\$ 24,321	\$ 24,856	\$ 25,402
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 18,666,681	\$ 52,211	\$ 53,359	\$ 54,533	\$ 55,733	\$ 56,959	\$ 58,212	\$ 59,493	\$ 60,802	\$ 62,139	\$ 63,506
Years	20	\$ 21,498	\$ 21,971	\$ 22,454	\$ 22,948	\$ 23,453	\$ 23,969	\$ 24,496	\$ 25,035	\$ 25,586	\$ 26,149
Installation Peak Annual Load (kW)	23,965	\$ 38,210	\$ 39,051	\$ 39,910	\$ 40,788	\$ 41,685	\$ 42,602	\$ 43,539	\$ 44,497	\$ 45,476	\$ 46,477
Critical Load %	18.4%	\$ 257,113	\$ 262,770	\$ 268,551	\$ 274,459	\$ 280,497	\$ 286,668	\$ 292,974	\$ 299,420	\$ 306,007	\$ 312,739
Peak Annual Critical Load	4,410										
		\$ 8,826,069	\$ 9,020,242	\$ 9,218,688	\$ 9,421,499	\$ 9,628,772	\$ 9,840,605	\$ 10,057,098	\$ 10,278,354	\$ 10,504,478	\$ 10,735,576
Energy Security Cost Metric	\$115	\$ 481,387	\$ 491,978	\$ 502,802	\$ 513,863	\$ 525,168	\$ 536,722	\$ 548,530	\$ 560,597	\$ 572,931	\$ 585,535
ESTCP Provided Security Cost Metric	\$89	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
		\$ 154,578	\$ 157,979	\$ 161,455	\$ 165,007	\$ 168,637	\$ 172,347	\$ 176,138	\$ 180,013	\$ 183,974	\$ 188,021
		\$ 137,395	\$ 140,418	\$ 143,507	\$ 146,665	\$ 149,891	\$ 153,189	\$ 156,559	\$ 160,003	\$ 163,523	\$ 167,121
		\$ 8,052,708	\$ 8,229,867	\$ 8,410,924	\$ 8,595,965	\$ 8,785,076	\$ 8,978,347	\$ 9,175,871	\$ 9,377,740	\$ 9,584,051	\$ 9,794,900

NAS CORPUS CHRISTI Li-Ion 3650 kW – 7300 kWh, FUTURE

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,467,500
	Upfront CMA Purchase	\$ 1,365,100
	Net Initial BESS Purchase	\$ 3,479,472
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ -
	Market Participation Telemetry Setup	\$ -
	Market Participation SoC Management Setup	\$ -
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,445,400
	Tax	\$ -
	Pre-Markup Subtotal	\$ 5,054,872
	Internal Management and Overhead Estimate	\$ 758,231
	Incentive or Grant Value	\$ -
Total EPC Implementation Cost		\$ 5,813,103
YEAR 1 VALUE	Utility Billing Savings	\$ 387,245
	Wholesale Market Revenue	\$ -
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ -

NAS Corpus Christi Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	6
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	9
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	28%

SCENARIO	FUTURE
BESS Power Capacity	3650
BESS Energy Capacity	7300
Technology	Li-Ion
Selected Use Case Stack	DCM
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 3,000,000	\$ 100,000	\$ 102,200	\$ 104,448	\$ 106,746	\$ 109,095	\$ 111,495	\$ 113,948	\$ 116,454	\$ 119,016	\$ 121,635
BESS Capital & Annual O&M Cost	\$ 5,813,103	\$ 16,800	\$ 17,170	\$ 17,547	\$ 17,933	\$ 18,328	\$ 18,731	\$ 19,143	\$ 19,564	\$ 19,995	\$ 20,435
DG Capital & Annual O&M Cost	\$ 3,375,000	\$ 42,000	\$ 42,924	\$ 43,868	\$ 44,833	\$ 45,820	\$ 46,828	\$ 47,858	\$ 48,911	\$ 49,987	\$ 51,087
DG Demand Response Operating Fuel Cost		\$ 17,293	\$ 17,674	\$ 18,063	\$ 18,460	\$ 18,866	\$ 19,281	\$ 19,705	\$ 20,139	\$ 20,582	\$ 21,035
UPS Capital & Annual O&M Cost	\$ 1,455,750	\$ 30,737	\$ 31,414	\$ 32,105	\$ 32,811	\$ 33,533	\$ 34,271	\$ 35,025	\$ 35,795	\$ 36,583	\$ 37,388
Total Annual Baseline Capital+O&M Costs	\$ 13,643,853	\$ 206,831	\$ 211,381	\$ 216,032	\$ 220,784	\$ 225,642	\$ 230,606	\$ 235,679	\$ 240,864	\$ 246,163	\$ 251,578
Annual Electricity Costs Before BESS/DG		\$ 7,100,000	\$ 7,256,200	\$ 7,415,836	\$ 7,578,985	\$ 7,745,722	\$ 7,916,128	\$ 8,090,283	\$ 8,268,269	\$ 8,450,171	\$ 8,636,075
BESS Retail Billing Savings		\$ 387,245	\$ 395,764	\$ 404,471	\$ 413,370	\$ 422,464	\$ 431,758	\$ 441,257	\$ 450,964	\$ 460,885	\$ 471,025
BESS Wholesale Market Value		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ 124,348	\$ 127,084	\$ 129,880	\$ 132,737	\$ 135,657	\$ 138,642	\$ 141,692	\$ 144,809	\$ 147,995	\$ 151,251
Peak Shaving Rev from DG Assets		\$ 110,526	\$ 112,957	\$ 115,442	\$ 117,982	\$ 120,578	\$ 123,230	\$ 125,941	\$ 128,712	\$ 131,544	\$ 134,438
Net Annual Electricity Costs		\$ 6,477,881	\$ 6,620,394	\$ 6,766,043	\$ 6,914,896	\$ 7,067,024	\$ 7,222,498	\$ 7,381,393	\$ 7,543,784	\$ 7,709,747	\$ 7,879,362

		11	12	13	14	15	16	17	18	19	20
		2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$88,331,446	\$ 124,311	\$ 127,046	\$ 129,841	\$ 132,697	\$ 135,617	\$ 138,600	\$ 141,649	\$ 144,766	\$ 147,950	\$ 151,205
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$96,814,570	\$ 20,884	\$ 21,344	\$ 21,813	\$ 22,293	\$ 22,784	\$ 23,285	\$ 23,797	\$ 24,321	\$ 24,856	\$ 25,402
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 16,464,169	\$ 52,211	\$ 53,359	\$ 54,533	\$ 55,733	\$ 56,959	\$ 58,212	\$ 59,493	\$ 60,802	\$ 62,139	\$ 63,506
Years	20	\$ 21,498	\$ 21,971	\$ 22,454	\$ 22,948	\$ 23,453	\$ 23,969	\$ 24,496	\$ 25,035	\$ 25,586	\$ 26,149
Installation Peak Annual Load (kW)	23,965	\$ 38,210	\$ 39,051	\$ 39,910	\$ 40,788	\$ 41,685	\$ 42,602	\$ 43,539	\$ 44,497	\$ 45,476	\$ 46,477
Critical Load %	18.4%	\$ 257,113	\$ 262,770	\$ 268,551	\$ 274,459	\$ 280,497	\$ 286,668	\$ 292,974	\$ 299,420	\$ 306,007	\$ 312,739
Peak Annual Critical Load	4,410	\$ 8,826,069	\$ 9,020,242	\$ 9,218,688	\$ 9,421,499	\$ 9,628,772	\$ 9,840,605	\$10,057,098	\$10,278,354	\$10,504,478	\$10,735,576
		\$ 481,387	\$ 491,978	\$ 502,802	\$ 513,863	\$ 525,168	\$ 536,722	\$ 548,530	\$ 560,597	\$ 572,931	\$ 585,535
		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
		\$ 154,578	\$ 157,979	\$ 161,455	\$ 165,007	\$ 168,637	\$ 172,347	\$ 176,138	\$ 180,013	\$ 183,974	\$ 188,021
		\$ 137,395	\$ 140,418	\$ 143,507	\$ 146,665	\$ 149,891	\$ 153,189	\$ 156,559	\$ 160,003	\$ 163,523	\$ 167,121
Energy Security Cost Metric	\$90	\$ 8,052,708	\$ 8,229,867	\$ 8,410,924	\$ 8,595,965	\$ 8,785,076	\$ 8,978,347	\$ 9,175,871	\$ 9,377,740	\$ 9,584,051	\$ 9,794,900
ESTCP Provided Security Cost Metric	\$89										

NAS CORPUS CHRISTI VRF 1217 kW – 7300 kWh, CURRENT

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,808,250
	Electrolyte Value	\$ (1,752,000)
	Net Initial BESS Purchase	\$ 2,056,250
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ -
	Market Participation Telemetry Setup	\$ -
	Market Participation SoC Management Setup	\$ -
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 2,007,500
	Tax	\$ -
	Pre-Markup Subtotal	\$ 4,193,750
	Internal Management and Overhead Estimate	\$ 629,063
	Incentive or Grant Value	\$ -
	Total EPC Implementation Cost	\$ 4,822,813
YEAR 1 VALUE	Utility Billing Savings	\$ 153,752
	Wholesale Market Revenue	\$ -
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Electrolyte Lease Annual Cost	\$ 105,120
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ -

NAS Corpus Christi Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	6
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	9
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

SCENARIO	CURRENT
BESS Power Capacity	1217
BESS Energy Capacity	7300
Technology	VRF
Selected Use Case Stack	DCM
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 3,000,000	\$ 100,000	\$ 102,200	\$ 104,448	\$ 106,746	\$ 109,095	\$ 111,495	\$ 113,948	\$ 116,454	\$ 119,016	\$ 121,635
BESS Capital & Annual O&M Cost	\$ 4,822,813	\$ 121,920	\$ 124,602	\$ 127,343	\$ 130,145	\$ 133,008	\$ 135,934	\$ 138,925	\$ 141,981	\$ 145,105	\$ 148,297
DG Capital & Annual O&M Cost	\$ 3,375,000	\$ 42,000	\$ 42,924	\$ 43,868	\$ 44,833	\$ 45,820	\$ 46,828	\$ 47,858	\$ 48,911	\$ 49,987	\$ 51,087
DG Demand Response Operating Fuel Cost		\$ 17,293	\$ 17,674	\$ 18,063	\$ 18,460	\$ 18,866	\$ 19,281	\$ 19,705	\$ 20,139	\$ 20,582	\$ 21,035
UPS Capital & Annual O&M Cost	\$ 1,455,750	\$ 30,737	\$ 31,414	\$ 32,105	\$ 32,811	\$ 33,533	\$ 34,271	\$ 35,025	\$ 35,795	\$ 36,583	\$ 37,388
Total Annual Baseline Capital+O&M Costs	\$ 12,653,563	\$ 311,951	\$ 318,814	\$ 325,828	\$ 332,996	\$ 340,322	\$ 347,809	\$ 355,461	\$ 363,281	\$ 371,273	\$ 379,441
Annual Electricity Costs Before BESS/DG		\$ 7,100,000	\$ 7,256,200	\$ 7,415,836	\$ 7,578,985	\$ 7,745,722	\$ 7,916,128	\$ 8,090,283	\$ 8,268,269	\$ 8,450,171	\$ 8,636,075
BESS Retail Billing Savings		\$ 153,752	\$ 157,135	\$ 160,592	\$ 164,125	\$ 167,735	\$ 171,425	\$ 175,197	\$ 179,051	\$ 182,990	\$ 187,016
BESS Wholesale Market Value		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ 124,348	\$ 127,084	\$ 129,880	\$ 132,737	\$ 135,657	\$ 138,642	\$ 141,692	\$ 144,809	\$ 147,995	\$ 151,251
Peak Shaving Rev from DG Assets		\$ 110,526	\$ 112,957	\$ 115,442	\$ 117,982	\$ 120,578	\$ 123,230	\$ 125,941	\$ 128,712	\$ 131,544	\$ 134,438
Net Annual Electricity Costs		\$ 6,711,374	\$ 6,859,024	\$ 7,009,923	\$ 7,164,141	\$ 7,321,752	\$ 7,482,831	\$ 7,647,453	\$ 7,815,697	\$ 7,987,642	\$ 8,163,371

		11	12	13	14	15	16	17	18	19	20
		2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$91,515,323	\$ 124,311	\$ 127,046	\$ 129,841	\$ 132,697	\$ 135,617	\$ 138,600	\$ 141,649	\$ 144,766	\$ 147,950	\$ 151,205
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$96,814,570	\$ 151,560	\$ 154,894	\$ 158,302	\$ 161,784	\$ 165,344	\$ 168,981	\$ 172,699	\$ 176,498	\$ 180,381	\$ 184,350
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 16,907,280	\$ 52,211	\$ 53,359	\$ 54,533	\$ 55,733	\$ 56,959	\$ 58,212	\$ 59,493	\$ 60,802	\$ 62,139	\$ 63,506
Years	20	\$ 21,498	\$ 21,971	\$ 22,454	\$ 22,948	\$ 23,453	\$ 23,969	\$ 24,496	\$ 25,035	\$ 25,586	\$ 26,149
Installation Peak Annual Load (kW)	23,965	\$ 38,210	\$ 39,051	\$ 39,910	\$ 40,788	\$ 41,685	\$ 42,602	\$ 43,539	\$ 44,497	\$ 45,476	\$ 46,477
Critical Load %	18.4%	\$ 387,789	\$ 396,320	\$ 405,039	\$ 413,950	\$ 423,057	\$ 432,364	\$ 441,876	\$ 451,597	\$ 461,533	\$ 471,686
Peak Annual Critical Load	4,410										
		\$ 8,826,069	\$ 9,020,242	\$ 9,218,688	\$ 9,421,499	\$ 9,628,772	\$ 9,840,605	\$ 10,057,098	\$ 10,278,354	\$ 10,504,478	\$ 10,735,576
		\$ 191,130	\$ 195,335	\$ 199,633	\$ 204,025	\$ 208,513	\$ 213,100	\$ 217,789	\$ 222,580	\$ 227,477	\$ 232,481
		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
		\$ 154,578	\$ 157,979	\$ 161,455	\$ 165,007	\$ 168,637	\$ 172,347	\$ 176,138	\$ 180,013	\$ 183,974	\$ 188,021
		\$ 137,395	\$ 140,418	\$ 143,507	\$ 146,665	\$ 149,891	\$ 153,189	\$ 156,559	\$ 160,003	\$ 163,523	\$ 167,121
Energy Security Cost Metric	\$132	\$ 8,342,965	\$ 8,526,510	\$ 8,714,093	\$ 8,905,803	\$ 9,101,731	\$ 9,301,969	\$ 9,506,612	\$ 9,715,758	\$ 9,929,504	\$ 10,147,953
ESTCP Provided Security Cost Metric	\$89										

NAS CORPUS CHRISTI VRF 1217 kW – 7300 kWh, FUTURE

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,808,250
	Electrolyte Value	\$ (1,752,000)
	Net Initial BESS Purchase	\$ 2,361,115
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ -
	Market Participation Telemetry Setup	\$ -
	Market Participation SoC Management Setup	\$ -
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,244,650
	Tax	\$ -
	Pre-Markup Subtotal	\$ 3,735,765
	Internal Management and Overhead Estimate	\$ 560,365
	Incentive or Grant Value	\$ -
	Total EPC Implementation Cost	\$ 4,296,130
YEAR 1 VALUE	Utility Billing Savings	\$ 153,752
	Wholesale Market Revenue	\$ -
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Electrolyte Lease Annual Cost	\$ -
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ -

NAS Corpus Christi Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	6
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	9
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	38%

SCENARIO	FUTURE
BESS Power Capacity	1217
BESS Energy Capacity	7300
Technology	VRF
Selected Use Case Stack	DCM
Grid Tied Lower SOE	0

Line Item	Operating Yr. 2019	1 2020	2 2021	3 2022	4 2023	5 2024	6 2025	7 2026	8 2027	9 2028	10 2029
Microgrid Capital & Annual O&M Cost	\$ 3,000,000	\$ 100,000	\$ 102,200	\$ 104,448	\$ 106,746	\$ 109,095	\$ 111,495	\$ 113,948	\$ 116,454	\$ 119,016	\$ 121,635
BESS Capital & Annual O&M Cost	\$ 4,296,130	\$ 16,800	\$ 17,170	\$ 17,547	\$ 17,933	\$ 18,328	\$ 18,731	\$ 19,143	\$ 19,564	\$ 19,995	\$ 20,435
DG Capital & Annual O&M Cost	\$ 3,375,000	\$ 42,000	\$ 42,924	\$ 43,868	\$ 44,833	\$ 45,820	\$ 46,828	\$ 47,858	\$ 48,911	\$ 49,987	\$ 51,087
DG Demand Response Operating Fuel Cost		\$ 17,293	\$ 17,674	\$ 18,063	\$ 18,460	\$ 18,866	\$ 19,281	\$ 19,705	\$ 20,139	\$ 20,582	\$ 21,035
UPS Capital & Annual O&M Cost	\$ 1,455,750	\$ 30,737	\$ 31,414	\$ 32,105	\$ 32,811	\$ 33,533	\$ 34,271	\$ 35,025	\$ 35,795	\$ 36,583	\$ 37,388
Total Annual Baseline Capital+O&M Costs	\$ 12,126,880	\$ 206,831	\$ 211,381	\$ 216,032	\$ 220,784	\$ 225,642	\$ 230,606	\$ 235,679	\$ 240,864	\$ 246,163	\$ 251,578
Annual Electricity Costs Before BESS/DG		\$ 7,100,000	\$ 7,256,200	\$ 7,415,836	\$ 7,578,985	\$ 7,745,722	\$ 7,916,128	\$ 8,090,283	\$ 8,268,269	\$ 8,450,171	\$ 8,636,075
BESS Retail Billing Savings		\$ 153,752	\$ 157,135	\$ 160,592	\$ 164,125	\$ 167,735	\$ 171,425	\$ 175,197	\$ 179,051	\$ 182,990	\$ 187,016
BESS Wholesale Market Value		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Emergency Demand Response Rev		\$ 124,348	\$ 127,084	\$ 129,880	\$ 132,737	\$ 135,657	\$ 138,642	\$ 141,692	\$ 144,809	\$ 147,995	\$ 151,251
Peak Shaving Rev from DG Assets		\$ 110,526	\$ 112,957	\$ 115,442	\$ 117,982	\$ 120,578	\$ 123,230	\$ 125,941	\$ 128,712	\$ 131,544	\$ 134,438
Net Annual Electricity Costs		\$ 6,711,374	\$ 6,859,024	\$ 7,009,923	\$ 7,164,141	\$ 7,321,752	\$ 7,482,831	\$ 7,647,453	\$ 7,815,697	\$ 7,987,642	\$ 8,163,371

		11	12	13	14	15	16	17	18	19	20
		2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$91,515,323	\$ 124,311	\$ 127,046	\$ 129,841	\$ 132,697	\$ 135,617	\$ 138,600	\$ 141,649	\$ 144,766	\$ 147,950	\$ 151,205
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$96,814,570	\$ 20,884	\$ 21,344	\$ 21,813	\$ 22,293	\$ 22,784	\$ 23,285	\$ 23,797	\$ 24,321	\$ 24,856	\$ 25,402
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 14,947,196	\$ 52,211	\$ 53,359	\$ 54,533	\$ 55,733	\$ 56,959	\$ 58,212	\$ 59,493	\$ 60,802	\$ 62,139	\$ 63,506
Years	20	\$ 21,498	\$ 21,971	\$ 22,454	\$ 22,948	\$ 23,453	\$ 23,969	\$ 24,496	\$ 25,035	\$ 25,586	\$ 26,149
Installation Peak Annual Load (kW)	23,965	\$ 38,210	\$ 39,051	\$ 39,910	\$ 40,788	\$ 41,685	\$ 42,602	\$ 43,539	\$ 44,497	\$ 45,476	\$ 46,477
Critical Load %	18.4%	\$ 257,113	\$ 262,770	\$ 268,551	\$ 274,459	\$ 280,497	\$ 286,668	\$ 292,974	\$ 299,420	\$ 306,007	\$ 312,739
Peak Annual Critical Load	4,410										
		\$ 8,826,069	\$ 9,020,242	\$ 9,218,688	\$ 9,421,499	\$ 9,628,772	\$ 9,840,605	\$10,057,098	\$10,278,354	\$10,504,478	\$10,735,576
Energy Security Cost Metric	\$109	\$ 191,130	\$ 195,335	\$ 199,633	\$ 204,025	\$ 208,513	\$ 213,100	\$ 217,789	\$ 222,580	\$ 227,477	\$ 232,481
ESTCP Provided Security Cost Metric	\$89	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
		\$ 154,578	\$ 157,979	\$ 161,455	\$ 165,007	\$ 168,637	\$ 172,347	\$ 176,138	\$ 180,013	\$ 183,974	\$ 188,021
		\$ 137,395	\$ 140,418	\$ 143,507	\$ 146,665	\$ 149,891	\$ 153,189	\$ 156,559	\$ 160,003	\$ 163,523	\$ 167,121
		\$ 8,342,965	\$ 8,526,510	\$ 8,714,093	\$ 8,905,803	\$ 9,101,731	\$ 9,301,969	\$ 9,506,612	\$ 9,715,758	\$ 9,929,504	\$10,147,953

NAS PATUXENT RIVER BASELINE MICROGRID

NAS Pax Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	12
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	17
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

Demand Response (DR)

DR Capacity	2.25	MW
Daily Capacity Payment	\$ 166.00	\$/MW-day
Future Volatile Daily Capacity Payme	\$ 226.00	\$/MW-day
DR Days Per Year	200	This was back calculated
DR Hours Per Year	6	
DR Energy Payments	250	\$/MWh
Installation Share	0.8	
Year 1 DR Revenue	\$ 62,460.00	
Future Volatile Year 1 DR Revenue	\$ 84,060.00	
MWh of Generation	13.5	
Heat Rate	12,040,000	BTU/MWh
Fuel Gallons	1169.35	Gallons
Fuel Cost	2.74	\$/gallon of Diesel Fuel

Line Item	Operating Yr. 2019	1 2020	2 2021	3 2022	4 2023	5 2024	6 2025	7 2026	8 2027	9 2028	10 2029
Microgrid Capital & Annual O&M Cost	\$ 4,000,000	\$ 133,000	\$ 135,926	\$ 138,916	\$ 141,973	\$ 145,096	\$ 148,288	\$ 151,550	\$ 154,884	\$ 158,292	\$ 161,774
DG Capital & Annual O&M Cost	\$ 6,750,000	\$ 28,000	\$ 28,616	\$ 29,246	\$ 29,889	\$ 30,547	\$ 31,219	\$ 31,905	\$ 32,607	\$ 33,325	\$ 34,058
DG Demand Response Operating Fuel Cost		\$ 3,204	\$ 3,275	\$ 3,347	\$ 3,420	\$ 3,495	\$ 3,572	\$ 3,651	\$ 3,731	\$ 3,813	\$ 3,897
UPS Capital & Annual O&M Cost	\$ 2,749,750	\$ 58,060	\$ 59,337	\$ 60,642	\$ 61,977	\$ 63,340	\$ 64,734	\$ 66,158	\$ 67,613	\$ 69,101	\$ 70,621
Total Annual Baseline Capital+O&M Costs	\$ 13,499,750	\$ 222,264	\$ 227,154	\$ 232,151	\$ 237,258	\$ 242,478	\$ 247,812	\$ 253,264	\$ 258,836	\$ 264,531	\$ 270,350
		\$ 86,060	\$ 87,953	\$ 89,888	\$ 91,866	\$ 93,887	\$ 95,952	\$ 98,063	\$ 100,220	\$ 102,425	\$ 104,679
Annual Electricity Costs		\$ 17,800,000	\$ 18,191,600	\$ 18,591,815	\$ 19,000,835	\$ 19,418,854	\$ 19,846,068	\$ 20,282,682	\$ 20,728,901	\$ 21,184,937	\$ 21,651,005
Emergency Demand Response Rev		\$ 62,460	\$ 63,834	\$ 65,238	\$ 66,674	\$ 68,141	\$ 69,640	\$ 71,172	\$ 72,737	\$ 74,338	\$ 75,973
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 17,737,540	\$ 18,127,766	\$ 18,526,577	\$ 18,934,161	\$ 19,350,713	\$ 19,776,429	\$ 20,211,510	\$ 20,656,163	\$ 21,110,599	\$ 21,575,032

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BASELINE MICROGRID (POST DR AND PS)	\$241,866,521
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$242,718,216
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 16,530,506
Years	20
Installation Peak Annual Load (kW)	33,958
Critical Load %	23.6%
Peak Annual Critical Load	8,014
Energy Security Cost Metric	\$98
ESTCP Provided Security Cost Metric	\$98
Match?	YES

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 165,333	\$ 168,971	\$ 172,688	\$ 176,487	\$ 180,370	\$ 184,338	\$ 188,394	\$ 192,538	\$ 196,774	\$ 201,103
\$ 34,807	\$ 35,573	\$ 36,355	\$ 37,155	\$ 37,973	\$ 38,808	\$ 39,662	\$ 40,534	\$ 41,426	\$ 42,337
\$ 3,983	\$ 4,071	\$ 4,160	\$ 4,252	\$ 4,345	\$ 4,441	\$ 4,538	\$ 4,638	\$ 4,740	\$ 4,845
\$ 72,174	\$ 73,762	\$ 75,385	\$ 77,044	\$ 78,739	\$ 80,471	\$ 82,241	\$ 84,050	\$ 85,900	\$ 87,789
\$ 276,298	\$ 282,376	\$ 288,589	\$ 294,938	\$ 301,426	\$ 308,058	\$ 314,835	\$ 321,761	\$ 328,840	\$ 336,075
\$ 106,982	\$ 109,335	\$ 111,740	\$ 114,199	\$ 116,711	\$ 119,279	\$ 121,903	\$ 124,585	\$ 127,326	\$ 130,127
\$ 22,127,327	\$ 22,614,129	\$ 23,111,639	\$ 23,620,095	\$ 24,139,738	\$ 24,670,812	\$ 25,213,570	\$ 25,768,268	\$ 26,335,170	\$ 26,914,544
\$ 77,645	\$ 79,353	\$ 81,098	\$ 82,883	\$ 84,706	\$ 86,570	\$ 88,474	\$ 90,421	\$ 92,410	\$ 94,443
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 22,049,683	\$ 22,534,776	\$ 23,030,541	\$ 23,537,213	\$ 24,055,031	\$ 24,584,242	\$ 25,125,095	\$ 25,677,848	\$ 26,242,760	\$ 26,820,101

NAS PATUXENT RIVER Li-Ion 3500 kW – 7000 kWh, CURRENT

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,325,000
	Upfront CMA Purchase	\$ 1,309,000
	Net Initial BESS Purchase	\$ 4,634,000
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,925,000
	Tax	\$ -
	Pre-Markup Subtotal	\$ 6,706,000
	Internal Management and Overhead Estimate	\$ 1,005,900
	Incentive or Grant Value	\$ (75,000)
	Total EPC Implementation Cost	\$ 7,636,900
YEAR 1 VALUE	Utility Billing Savings	\$ 233,449
	Wholesale Market Revenue	\$ 93,308
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ 18,662

NAS Pax Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	11
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	17
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

SCENARIO	CURRENT
BESS Power Capacity	3500
BESS Energy Capacity	7000
Technology	Li-Ion
Selected Use Case Stack	DCM+Wholesale
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 4,000,000	\$ 133,000	\$ 135,926	\$ 138,916	\$ 141,973	\$ 145,096	\$ 148,288	\$ 151,550	\$ 154,884	\$ 158,292	\$ 161,774
BESS Capital & Annual O&M Cost	\$ 7,636,900	\$ 35,462	\$ 36,242	\$ 37,039	\$ 37,854	\$ 38,687	\$ 39,538	\$ 40,408	\$ 41,297	\$ 42,205	\$ 43,134
DG Capital & Annual O&M Cost	\$ 6,187,500	\$ 77,000	\$ 78,694	\$ 80,425	\$ 82,195	\$ 84,003	\$ 85,851	\$ 87,740	\$ 89,670	\$ 91,643	\$ 93,659
DG Demand Response Operating Fuel Cost		\$ 3,204	\$ 3,275	\$ 3,347	\$ 3,420	\$ 3,495	\$ 3,572	\$ 3,651	\$ 3,731	\$ 3,813	\$ 3,897
UPS Capital & Annual O&M Cost	\$ 2,749,750	\$ 58,060	\$ 59,337	\$ 60,642	\$ 61,977	\$ 63,340	\$ 64,734	\$ 66,158	\$ 67,613	\$ 69,101	\$ 70,621
Total Annual Baseline Capital+O&M Costs	\$ 20,574,150	\$ 306,725	\$ 313,473	\$ 320,370	\$ 327,418	\$ 334,621	\$ 341,983	\$ 349,506	\$ 357,195	\$ 365,054	\$ 373,085
Annual Electricity Costs Before BESS/DG		\$ 17,800,000	\$ 18,191,600	\$ 18,591,815	\$ 19,000,835	\$ 19,418,854	\$ 19,846,068	\$ 20,282,682	\$ 20,728,901	\$ 21,184,937	\$ 21,651,005
BESS Retail Billing Savings		\$ 233,449	\$ 238,585	\$ 243,834	\$ 249,198	\$ 254,680	\$ 260,283	\$ 266,010	\$ 271,862	\$ 277,843	\$ 283,955
BESS Wholesale Market Value		\$ 93,308	\$ 95,361	\$ 97,459	\$ 99,603	\$ 101,794	\$ 104,034	\$ 106,322	\$ 108,661	\$ 111,052	\$ 113,495
Emergency Demand Response Rev		\$ 62,460	\$ 63,834	\$ 65,238	\$ 66,674	\$ 68,141	\$ 69,640	\$ 71,172	\$ 72,737	\$ 74,338	\$ 75,973
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 17,410,783	\$ 17,793,820	\$ 18,185,284	\$ 18,585,361	\$ 18,994,238	\$ 19,412,112	\$ 19,839,178	\$ 20,275,640	\$ 20,721,704	\$ 21,177,582

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$237,410,910
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$242,718,216
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 24,756,612
Years	20
Installation Peak Annual Load (kW)	33,958
Critical Load %	23.6%
Peak Annual Critical Load	8,014
Energy Security Cost Metric	\$121
ESTCP Provided Security Cost Metric	\$98

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 165,333	\$ 168,971	\$ 172,688	\$ 176,487	\$ 180,370	\$ 184,338	\$ 188,394	\$ 192,538	\$ 196,774	\$ 201,103
\$ 44,083	\$ 45,052	\$ 46,044	\$ 47,057	\$ 48,092	\$ 49,150	\$ 50,231	\$ 51,336	\$ 52,466	\$ 53,620
\$ 95,719	\$ 97,825	\$ 99,977	\$ 102,177	\$ 104,425	\$ 106,722	\$ 109,070	\$ 111,469	\$ 113,922	\$ 116,428
\$ 3,983	\$ 4,071	\$ 4,160	\$ 4,252	\$ 4,345	\$ 4,441	\$ 4,538	\$ 4,638	\$ 4,740	\$ 4,845
\$ 72,174	\$ 73,762	\$ 75,385	\$ 77,044	\$ 78,739	\$ 80,471	\$ 82,241	\$ 84,050	\$ 85,900	\$ 87,789
\$ 381,293	\$ 389,681	\$ 398,254	\$ 407,016	\$ 415,970	\$ 425,122	\$ 434,474	\$ 444,033	\$ 453,801	\$ 463,785
\$ 22,127,327	\$ 22,614,129	\$ 23,111,639	\$ 23,620,095	\$ 24,139,738	\$ 24,670,812	\$ 25,213,570	\$ 25,768,268	\$ 26,335,170	\$ 26,914,544
\$ 290,202	\$ 296,587	\$ 303,112	\$ 309,780	\$ 316,595	\$ 323,560	\$ 330,679	\$ 337,954	\$ 345,389	\$ 352,987
\$ 115,992	\$ 118,544	\$ 121,152	\$ 123,817	\$ 126,541	\$ 129,325	\$ 132,170	\$ 135,078	\$ 138,050	\$ 141,087
\$ 77,645	\$ 79,353	\$ 81,098	\$ 82,883	\$ 84,706	\$ 86,570	\$ 88,474	\$ 90,421	\$ 92,410	\$ 94,443
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 21,643,488	\$ 22,119,645	\$ 22,606,277	\$ 23,103,615	\$ 23,611,895	\$ 24,131,357	\$ 24,662,247	\$ 25,204,816	\$ 25,759,322	\$ 26,326,027

NAS PATUXENT RIVER Li-Ion 3500 kW – 7000 kWh, FUTURE

BUDGETARY ESTIMATES ONLY

	Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)
	\$ 3,325,000
	Upfront CMA Purchase
	\$ 1,309,000
	Net Initial BESS Purchase
	\$ 3,336,480
	Peak Shaving Controls Equipment
	\$ 5,000
	Peak Shaving Controls Initial Setup
	\$ 10,000
	Market Participation Router/RTU Equipment
	\$ 8,500
	Market Participation Telemetry Setup
	\$ 5,000
	Market Participation SoC Management Setup
	\$ 3,500
	Revenue-Grade Meter(s)
	\$ 15,000
	Issue for Construction Design Engineering
	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation
	\$ 1,386,000
	Tax
	\$ -
	Pre-Markup Subtotal
	\$ 4,869,480
	Internal Management and Overhead Estimate
	\$ 730,422
	Incentive or Grant Value
	\$ (75,000)
	Total EPC Implementation Cost
	\$ 5,524,902
YEAR 1 VALUE	Utility Billing Savings
	\$ 214,077
	Wholesale Market Revenue
	\$ 279,596
Year 1 O&M	Annual Equipment Preventative Maintenance
	\$ 10,000
	Controls Software Licensing and Support
	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation
	\$ 1,800
	Wholesale Market CSP Services
	\$ 55,919

NAS Pax Microgrid Economics

Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	11
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	17
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	28%

SCENARIO	FUTURE
BESS Power Capacity	3500
BESS Energy Capacity	7000
Technology	Li-Ion
Selected Use Case Stack	DCM+Wholesale
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 4,000,000	\$ 133,000	\$ 135,926	\$ 138,916	\$ 141,973	\$ 145,096	\$ 148,288	\$ 151,550	\$ 154,884	\$ 158,292	\$ 161,774
BESS Capital & Annual O&M Cost	\$ 5,524,902	\$ 72,719	\$ 74,319	\$ 75,954	\$ 77,625	\$ 79,333	\$ 81,078	\$ 82,862	\$ 84,685	\$ 86,548	\$ 88,452
DG Capital & Annual O&M Cost	\$ 6,187,500	\$ 77,000	\$ 78,694	\$ 80,425	\$ 82,195	\$ 84,003	\$ 85,851	\$ 87,740	\$ 89,670	\$ 91,643	\$ 93,659
DG Demand Response Operating Fuel Cost		\$ 3,204	\$ 3,275	\$ 3,347	\$ 3,420	\$ 3,495	\$ 3,572	\$ 3,651	\$ 3,731	\$ 3,813	\$ 3,897
UPS Capital & Annual O&M Cost	\$ 2,749,750	\$ 58,060	\$ 59,337	\$ 60,642	\$ 61,977	\$ 63,340	\$ 64,734	\$ 66,158	\$ 67,613	\$ 69,101	\$ 70,621
Total Annual Baseline Capital+O&M Costs	\$ 18,462,152	\$ 343,983	\$ 351,551	\$ 359,285	\$ 367,189	\$ 375,267	\$ 383,523	\$ 391,960	\$ 400,584	\$ 409,396	\$ 418,403
Annual Electricity Costs Before BESS/DG		\$ 17,800,000	\$ 18,191,600	\$ 18,591,815	\$ 19,000,835	\$ 19,418,854	\$ 19,846,068	\$ 20,282,682	\$ 20,728,901	\$ 21,184,937	\$ 21,651,005
BESS Retail Billing Savings		\$ 214,077	\$ 218,787	\$ 223,600	\$ 228,519	\$ 233,547	\$ 238,685	\$ 243,936	\$ 249,302	\$ 254,787	\$ 260,392
BESS Wholesale Market Value		\$ 279,596	\$ 285,747	\$ 292,034	\$ 298,458	\$ 305,024	\$ 311,735	\$ 318,593	\$ 325,602	\$ 332,765	\$ 340,086
Emergency Demand Response Rev		\$ 84,060	\$ 85,909	\$ 87,799	\$ 89,731	\$ 91,705	\$ 93,722	\$ 95,784	\$ 97,892	\$ 100,045	\$ 102,246
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 17,222,267	\$ 17,601,157	\$ 17,988,382	\$ 18,384,127	\$ 18,788,578	\$ 19,201,926	\$ 19,624,369	\$ 20,056,105	\$ 20,497,339	\$ 20,948,280

		11	12	13	14	15	16	17	18	19	20
		2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$234,840,333	\$ 165,333	\$ 168,971	\$ 172,688	\$ 176,487	\$ 180,370	\$ 184,338	\$ 188,394	\$ 192,538	\$ 196,774	\$ 201,103
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$242,718,216	\$ 90,398	\$ 92,387	\$ 94,419	\$ 96,496	\$ 98,619	\$ 100,789	\$ 103,006	\$ 105,272	\$ 107,588	\$ 109,955
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 23,152,653	\$ 95,719	\$ 97,825	\$ 99,977	\$ 102,177	\$ 104,425	\$ 106,722	\$ 109,070	\$ 111,469	\$ 113,922	\$ 116,428
Years	20	\$ 3,983	\$ 4,071	\$ 4,160	\$ 4,252	\$ 4,345	\$ 4,441	\$ 4,538	\$ 4,638	\$ 4,740	\$ 4,845
Installation Peak Annual Load (kW)	33,958	\$ 72,174	\$ 73,762	\$ 75,385	\$ 77,044	\$ 78,739	\$ 80,471	\$ 82,241	\$ 84,050	\$ 85,900	\$ 87,789
Critical Load %	23.6%	\$ 427,608	\$ 437,015	\$ 446,630	\$ 456,456	\$ 466,498	\$ 476,761	\$ 487,249	\$ 497,969	\$ 508,924	\$ 520,120
Peak Annual Critical Load	8,014	\$ 22,127,327	\$ 22,614,129	\$ 23,111,639	\$ 23,620,095	\$ 24,139,738	\$ 24,670,812	\$ 25,213,570	\$ 25,768,268	\$ 26,335,170	\$ 26,914,544
		\$ 266,121	\$ 271,976	\$ 277,959	\$ 284,074	\$ 290,324	\$ 296,711	\$ 303,239	\$ 309,910	\$ 316,728	\$ 323,696
		\$ 347,568	\$ 355,215	\$ 363,029	\$ 371,016	\$ 379,178	\$ 387,520	\$ 396,046	\$ 404,759	\$ 413,663	\$ 422,764
		\$ 104,496	\$ 106,795	\$ 109,144	\$ 111,545	\$ 113,999	\$ 116,507	\$ 119,070	\$ 121,690	\$ 124,367	\$ 127,103
Energy Security Cost Metric	\$95	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
ESTCP Provided Security Cost Metric	\$98	\$ 21,409,143	\$ 21,880,144	\$ 22,361,507	\$ 22,853,460	\$ 23,356,236	\$ 23,870,073	\$ 24,395,215	\$ 24,931,910	\$ 25,480,412	\$ 26,040,981

NAS PATUXENT RIVER VRF 1167 kW – 7000 kWh, CURRENT

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,651,750
	Electrolyte Value	\$ (1,680,000)
	Net Initial BESS Purchase	\$ 1,971,750
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,925,000
	Tax	\$ -
	Pre-Markup Subtotal	\$ 4,043,750
	Internal Management and Overhead Estimate	\$ 606,563
	Incentive or Grant Value	\$ (75,000)
	Total EPC Implementation Cost	\$ 4,575,313
YEAR 1 VALUE	Utility Billing Savings	\$ 91,020
	Wholesale Market Revenue	\$ 35,821
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Electrolyte Lease Annual Cost	\$ 100,800
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ 7,164

NAS Pax Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	11
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	17
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39

SCENARIO	CURRENT
BESS Power Capacity	1167
BESS Energy Capacity	7000
Technology	VRF
Selected Use Case Stack	DCM+WHOLESALE
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 4,000,000	\$ 133,000	\$ 135,926	\$ 138,916	\$ 141,973	\$ 145,096	\$ 148,288	\$ 151,550	\$ 154,884	\$ 158,292	\$ 161,774
BESS Capital & Annual O&M Cost	\$ 4,575,313	\$ 124,764	\$ 127,509	\$ 130,314	\$ 133,181	\$ 136,111	\$ 139,106	\$ 142,166	\$ 145,294	\$ 148,490	\$ 151,757
DG Capital & Annual O&M Cost	\$ 6,187,500	\$ 77,000	\$ 78,694	\$ 80,425	\$ 82,195	\$ 84,003	\$ 85,851	\$ 87,740	\$ 89,670	\$ 91,643	\$ 93,659
DG Demand Response Operating Fuel Cost		\$ 3,204	\$ 3,275	\$ 3,347	\$ 3,420	\$ 3,495	\$ 3,572	\$ 3,651	\$ 3,731	\$ 3,813	\$ 3,897
UPS Capital & Annual O&M Cost	\$ 2,749,750	\$ 58,060	\$ 59,337	\$ 60,642	\$ 61,977	\$ 63,340	\$ 64,734	\$ 66,158	\$ 67,613	\$ 69,101	\$ 70,621
Total Annual Baseline Capital+O&M Costs	\$ 17,512,563	\$ 396,028	\$ 404,741	\$ 413,645	\$ 422,745	\$ 432,045	\$ 441,550	\$ 451,265	\$ 461,192	\$ 471,339	\$ 481,708
Annual Electricity Costs Before BESS/DG		\$ 17,800,000	\$ 18,191,600	\$ 18,591,815	\$ 19,000,835	\$ 19,418,854	\$ 19,846,068	\$ 20,282,682	\$ 20,728,901	\$ 21,184,937	\$ 21,651,005
BESS Retail Billing Savings		\$ 91,020	\$ 93,022	\$ 95,069	\$ 97,160	\$ 99,298	\$ 101,483	\$ 103,715	\$ 105,997	\$ 108,329	\$ 110,712
BESS Wholesale Market Value		\$ 35,821	\$ 36,609	\$ 37,414	\$ 38,238	\$ 39,079	\$ 39,939	\$ 40,817	\$ 41,715	\$ 42,633	\$ 43,571
Emergency Demand Response Rev		\$ 62,460	\$ 63,834	\$ 65,238	\$ 66,674	\$ 68,141	\$ 69,640	\$ 71,172	\$ 72,737	\$ 74,338	\$ 75,973
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 17,610,699	\$ 17,998,134	\$ 18,394,093	\$ 18,798,763	\$ 19,212,336	\$ 19,635,008	\$ 20,066,978	\$ 20,508,451	\$ 20,959,637	\$ 21,420,749

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$240,136,936
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$242,718,216
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 22,912,742
Years	20
Installation Peak Annual Load (kW)	33,958
Critical Load %	23.6%
Peak Annual Critical Load	8,014
Energy Security Cost Metric	\$127
ESTCP Provided Security Cost Metric	\$98

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 165,333	\$ 168,971	\$ 172,688	\$ 176,487	\$ 180,370	\$ 184,338	\$ 188,394	\$ 192,538	\$ 196,774	\$ 201,103
\$ 155,095	\$ 158,508	\$ 161,995	\$ 165,559	\$ 169,201	\$ 172,923	\$ 176,728	\$ 180,616	\$ 184,589	\$ 188,650
\$ 95,719	\$ 97,825	\$ 99,977	\$ 102,177	\$ 104,425	\$ 106,722	\$ 109,070	\$ 111,469	\$ 113,922	\$ 116,428
\$ 3,983	\$ 4,071	\$ 4,160	\$ 4,252	\$ 4,345	\$ 4,441	\$ 4,538	\$ 4,638	\$ 4,740	\$ 4,845
\$ 72,174	\$ 73,762	\$ 75,385	\$ 77,044	\$ 78,739	\$ 80,471	\$ 82,241	\$ 84,050	\$ 85,900	\$ 87,789
\$ 492,306	\$ 503,136	\$ 514,205	\$ 525,518	\$ 537,079	\$ 548,895	\$ 560,971	\$ 573,312	\$ 585,925	\$ 598,815
\$ 22,127,327	\$ 22,614,129	\$ 23,111,639	\$ 23,620,095	\$ 24,139,738	\$ 24,670,812	\$ 25,213,570	\$ 25,768,268	\$ 26,335,170	\$ 26,914,544
\$ 113,148	\$ 115,637	\$ 118,181	\$ 120,781	\$ 123,438	\$ 126,154	\$ 128,929	\$ 131,766	\$ 134,664	\$ 137,627
\$ 44,529	\$ 45,509	\$ 46,510	\$ 47,533	\$ 48,579	\$ 49,648	\$ 50,740	\$ 51,856	\$ 52,997	\$ 54,163
\$ 77,645	\$ 79,353	\$ 81,098	\$ 82,883	\$ 84,706	\$ 86,570	\$ 88,474	\$ 90,421	\$ 92,410	\$ 94,443
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 21,892,006	\$ 22,373,630	\$ 22,865,850	\$ 23,368,898	\$ 23,883,014	\$ 24,408,440	\$ 24,945,426	\$ 25,494,225	\$ 26,055,098	\$ 26,628,311

NAS PATUXENT RIVER VRF 1167 kW – 7000 kWh, FUTURE

BUDGETARY ESTIMATES ONLY		Amount (\$USD)
EPC Costs	Initial BESS Purchase (DC BESS, PCS, BMS, FSS, HVAC, Shipping, Tariffs, Cx and Training)	\$ 3,651,750
	Electrolyte Value	\$ (1,680,000)
	Net Initial BESS Purchase	\$ 2,264,085
	Peak Shaving Controls Equipment	\$ 5,000
	Peak Shaving Controls Initial Setup	\$ 10,000
	Market Participation Router/RTU Equipment	\$ 8,500
	Market Participation Telemetry Setup	\$ 5,000
	Market Participation SoC Management Setup	\$ 3,500
	Revenue-Grade Meter(s)	\$ 15,000
	Issue for Construction Design Engineering	\$ 100,000
	Electrical, Civil, Mechanical Construction Materials & Installation	\$ 1,193,500
	Tax	\$ -
	Pre-Markup Subtotal	\$ 3,604,585
	Internal Management and Overhead Estimate	\$ 540,688
	Incentive or Grant Value	\$ (75,000)
	Total EPC Implementation Cost	\$ 4,070,273
YEAR 1 VALUE	Utility Billing Savings	\$ 72,300
	Wholesale Market Revenue	\$ 113,759
Year 1 O&M	Annual Equipment Preventative Maintenance	\$ 10,000
	Electrolyte Lease Annual Cost	\$ -
	Controls Software Licensing and Support	\$ 5,000
	Cellular Data Plan for Peak Shaving Operation	\$ 1,800
	Wholesale Market CSP Services	\$ 22,752

NAS Pax Microgrid Economics	
Inflation Rate	2.2%
Investment Rate	6.0%
DG Quantity	11
Capacity of Each DG (kW)	750
Capital Cost of Each DG (\$/kW)	\$ 750
Year 1 DG O&M Cost Per Unit	\$ 7,000
UPS Quantity	17
Capacity of Each UPS (kVA)	250
Energy Capacity of Each UPS (kWh)	63
Capital Cost of Each UPS (\$/kVA)	\$ 647
Fixed O&M Cost of UPS (\$/kVA)	\$ 13.66
Variable O&M Cost of UPS (\$/MWh)	\$ 4.39
5 Year Future Pricing Reduction	38%

SCENARIO	FUTURE
BESS Power Capacity	1167
BESS Energy Capacity	7000
Technology	VRF
Selected Use Case Stack	DCM+WHOLESALE
Grid Tied Lower SOE	0

Line Item	Operating Yr.	1	2	3	4	5	6	7	8	9	10
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Microgrid Capital & Annual O&M Cost	\$ 4,000,000	\$ 133,000	\$ 135,926	\$ 138,916	\$ 141,973	\$ 145,096	\$ 148,288	\$ 151,550	\$ 154,884	\$ 158,292	\$ 161,774
BESS Capital & Annual O&M Cost	\$ 4,070,273	\$ 39,552	\$ 40,422	\$ 41,311	\$ 42,220	\$ 43,149	\$ 44,098	\$ 45,068	\$ 46,060	\$ 47,073	\$ 48,109
DG Capital & Annual O&M Cost	\$ 6,187,500	\$ 77,000	\$ 78,694	\$ 80,425	\$ 82,195	\$ 84,003	\$ 85,851	\$ 87,740	\$ 89,670	\$ 91,643	\$ 93,659
DG Demand Response Operating Fuel Cost		\$ 3,204	\$ 3,275	\$ 3,347	\$ 3,420	\$ 3,495	\$ 3,572	\$ 3,651	\$ 3,731	\$ 3,813	\$ 3,897
UPS Capital & Annual O&M Cost	\$ 2,749,750	\$ 58,060	\$ 59,337	\$ 60,642	\$ 61,977	\$ 63,340	\$ 64,734	\$ 66,158	\$ 67,613	\$ 69,101	\$ 70,621
Total Annual Baseline Capital+O&M Costs	\$ 17,007,523	\$ 310,816	\$ 317,653	\$ 324,642	\$ 331,784	\$ 339,083	\$ 346,543	\$ 354,167	\$ 361,959	\$ 369,922	\$ 378,060
Annual Electricity Costs Before BESS/DG		\$ 17,800,000	\$ 18,191,600	\$ 18,591,815	\$ 19,000,835	\$ 19,418,854	\$ 19,846,068	\$ 20,282,682	\$ 20,728,901	\$ 21,184,937	\$ 21,651,005
BESS Retail Billing Savings		\$ 72,300	\$ 73,891	\$ 75,516	\$ 77,178	\$ 78,875	\$ 80,611	\$ 82,384	\$ 84,197	\$ 86,049	\$ 87,942
BESS Wholesale Market Value		\$ 113,759	\$ 116,262	\$ 118,819	\$ 121,433	\$ 124,105	\$ 126,835	\$ 129,626	\$ 132,477	\$ 135,392	\$ 138,371
Emergency Demand Response Rev		\$ 84,060	\$ 85,909	\$ 87,799	\$ 89,731	\$ 91,705	\$ 93,722	\$ 95,784	\$ 97,892	\$ 100,045	\$ 102,246
Peak Shaving Rev from DG Assets		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Net Annual Electricity Costs		\$ 17,529,881	\$ 17,915,538	\$ 18,309,680	\$ 18,712,493	\$ 19,124,168	\$ 19,544,900	\$ 19,974,888	\$ 20,414,335	\$ 20,863,450	\$ 21,322,446

20 YR NPV OF INSTALLATION ELECTRICITY COSTS IN BESS ENABLED MICROGRID	\$239,034,913
20 YR NPV OF INSTALLATION ELECTRICITY COSTS WITHOUT MICROGRID	\$242,718,216
20 YR NPV OF CAPITAL AND O&M COSTS OF BASELINE MICROGRID	\$ 21,245,758
Years	20
Installation Peak Annual Load (kW)	33,958
Critical Load %	23.6%
Peak Annual Critical Load	8,014
Energy Security Cost Metric	\$110
ESTCP Provided Security Cost Metric	\$98

11	12	13	14	15	16	17	18	19	20
2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
\$ 165,333	\$ 168,971	\$ 172,688	\$ 176,487	\$ 180,370	\$ 184,338	\$ 188,394	\$ 192,538	\$ 196,774	\$ 201,103
\$ 49,167	\$ 50,249	\$ 51,354	\$ 52,484	\$ 53,639	\$ 54,819	\$ 56,025	\$ 57,257	\$ 58,517	\$ 59,804
\$ 95,719	\$ 97,825	\$ 99,977	\$ 102,177	\$ 104,425	\$ 106,722	\$ 109,070	\$ 111,469	\$ 113,922	\$ 116,428
\$ 3,983	\$ 4,071	\$ 4,160	\$ 4,252	\$ 4,345	\$ 4,441	\$ 4,538	\$ 4,638	\$ 4,740	\$ 4,845
\$ 72,174	\$ 73,762	\$ 75,385	\$ 77,044	\$ 78,739	\$ 80,471	\$ 82,241	\$ 84,050	\$ 85,900	\$ 87,789
\$ 386,377	\$ 394,878	\$ 403,565	\$ 412,443	\$ 421,517	\$ 430,791	\$ 440,268	\$ 449,954	\$ 459,853	\$ 469,970
\$ 22,127,327	\$ 22,614,129	\$ 23,111,639	\$ 23,620,095	\$ 24,139,738	\$ 24,670,812	\$ 25,213,570	\$ 25,768,268	\$ 26,335,170	\$ 26,914,544
\$ 89,877	\$ 91,854	\$ 93,875	\$ 95,940	\$ 98,051	\$ 100,208	\$ 102,412	\$ 104,665	\$ 106,968	\$ 109,321
\$ 141,415	\$ 144,526	\$ 147,705	\$ 150,955	\$ 154,276	\$ 157,670	\$ 161,139	\$ 164,684	\$ 168,307	\$ 172,010
\$ 104,496	\$ 106,795	\$ 109,144	\$ 111,545	\$ 113,999	\$ 116,507	\$ 119,070	\$ 121,690	\$ 124,367	\$ 127,103
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 21,791,540	\$ 22,270,954	\$ 22,760,915	\$ 23,261,655	\$ 23,773,412	\$ 24,296,427	\$ 24,830,948	\$ 25,377,229	\$ 25,935,528	\$ 26,506,110