Energy Resilience Return on Investment

EFFICIENCY VERMONT R&D PROJECT: RESILIENCY PAYBACK

Allison Ross

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Executive Summary

Vermont has experienced its share of recent natural disasters that have caused electricity outages, destroyed roads necessary for delivering goods and services, and created financial and personal hardship to people and businesses.

Concurrently, the economy has become increasingly reliant on cyber-connectivity. Innovations have introduced more internet-enabled devices that control everything from a building's mechanical systems to its energy use and management. The Internet of Things—the system of interrelated computing devices and machines—for all its attractions, has opened new avenues for hacking and cyber-crime. Thus, the emerging capability of increasingly intelligent energy systems can also put energy reliability at risk, if malicious actors sabotage energy delivery infrastructure.

Businesses, governments at all levels, and emergency and health services are responding to these threats by seeking ownership of their energy security. Many traditionally rely on generators during a power outage to protect their most critical property and human life. As technology advances, opportunities for supporting critical loads, while using the infrastructure in an economically advantageous way during normal operations, are becoming correspondingly attractive. Systems that include generation, storage, and controls packages allow building owners to use their assets to generate cost savings or income during normal operations; at the same time, these systems can provide energy security in the event of power loss.

Largely absent in the industry, however, are valid and reliable guidance and best practices for building owners who are installing an energy resilience system. That is, to date there has been no single source of guidance for determining how much capital investment results in the most favorable economic return on an energy resilience system.

This paper proposes the formulas and variables necessary for determining the best return on investment in energy resilience assets. It looks at generally accepted payback methods based on the time value of money. The calculations here are applicable to all technologies that might be integrated into a system. It is up to the system owner to define, situationally, what *effective energy resilience* means. That definition will guide the owner in understanding which unique systems are best for meeting energy resilience objectives. The potential cost savings and income streams will depend on factors that will differ by geographic location, the type of enterprise, and the energy management skills and resources available to the owner. The calculation method presented here was designed to be applied across all use cases.

INTRODUCTION

The Problem
Energy assets, whether across the United States or within Vermont, are at increasing risk of damage and destruction from weather events, accidents, and physical or cyber-sabotage.

A single flood event, for example, can wipe out the energy and transportation infrastructure in a community. Residents of Houston, Texas, experienced this in 2017, when Hurricane Harvey devastated the city's infrastructure assets.[1] Tropical storms, blizzards, tornadoes, hurricanes, and deliberate attacks or accidents can destroy the energy resources that communities need to support their population's basic needs. Businesses, municipalities, public safety services, and critical service industries like health care increasingly want to explore ways to take control of their energy access and mitigate the financial effects and the impacts on life safety from an outage.

Possible solutions involve significant capital investment in infrastructure, some of which is relatively new to the energy industry. Other solutions might involve the use of current technologies in new ways to achieve energy assurance for the owner. The unique needs of each enterprise mean owners must find unique energy solutions. This is a challenging prospect for owners, who must also seek optimal returns on their infrastructure investments in climate resilience.

American energy infrastructure assets—power stations, gas and oil pipelines, energy processing plants, coal mines, power lines—are so ubiquitous that it is rare to find them far from areas vulnerable to floods and other severe climate events. The U.S. Energy Information Administration (EIA) has mapped this vulnerability, with street-level information about areas at risk of flooding, and their proximity to energy infrastructure assets. Figure 1 shows the scope of this risk.

[1] Hurricane Harvey lasted four days at the end of August 2017, hitting Houston heavily and costing $126.3 billion in damage and killing 89 people. It is the 30th-worst flood in the history of the United States. Harrington, John. 2018. "What Are the Worst Floods in American History? A Rundown of the Top 30." *USA Today,* September 12. https://www.usatoday.com/story/money/economy/2018/07/24/worst-floods-in-american-history/37070093/.

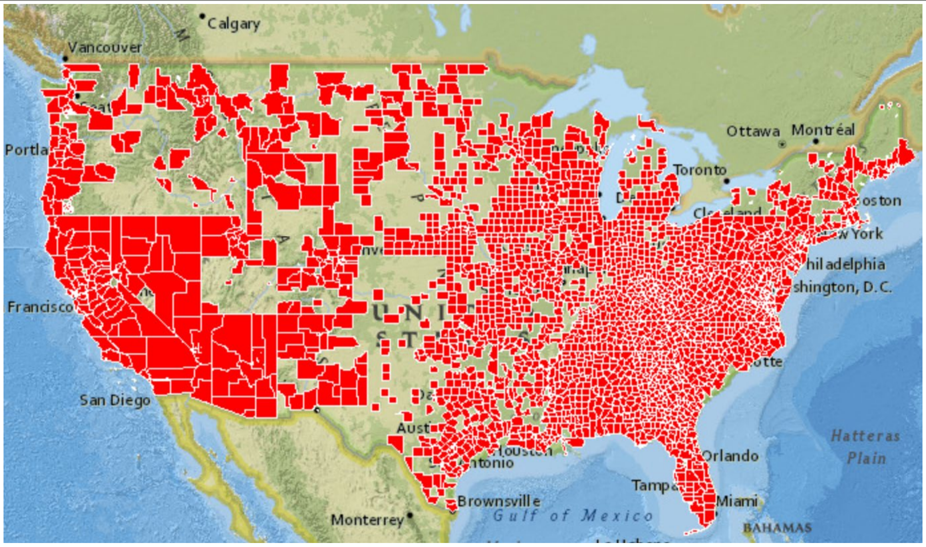

Figure 1. Energy Infrastructure with FEMA National Flood Hazard. The red areas show where energy infrastructure intersects with areas vulnerable to rising sea levels, storm surges, and flash flooding. Source: *EIA, 2020.*[2]

EIA has also mapped energy infrastructure assets with "active storms and other hazards."[3] Together, these and the large amount of data supporting the EIA displays reinforce a single concern: We have multiform vulnerability from climate disruptions, let alone other kinds of infrastructure disruption. But we know where the vulnerability lies. We also know that there is a solution to lessening the effects of that disruption.

The Solution—and an Opportunity for Public and Private Investment

Since 2015, the U.S. Department of Energy (DOE) has made "energy infrastructure resilience" a part of the presidentially mandated *Quadrennial Energy Review*.[4] The term *resilience* encompasses critical infrastructure resilience (linked to national security) and disaster resilience. Resilience is distinct from, and complements, *reliability*, which is achieved through energy "hardening." Hardening is the process of designing systems to withstand adverse events and to operate as normal through an event. Resilience is the contingency plan to support critical loads in the event that energy hardening has not been enough to prevent an outage.

[2] EIA keeps an interactive map on its website, showing flood hazards and energy infrastructure assets at the street level. EIA (U.S. Energy Information Administration), n.d. *Flood Vulnerability Assessment Map*. https://www.eia.gov/special/floodhazard/.
[3] EIA, n.d. "Energy Infrastructure with Active Storms and Other Hazards." https://www.eia.gov/special/disruptions/.
[4] The QER is a long-term policy planning document. Its stakeholder work has lagged in the past three years, but its framework and first two installments are intact and available online: https://www.energy.gov/policy/downloads/quadrennial-energy-review-first-installment. See also President Barack Obama, 2014. "Presidential Memorandum-Establishing a Quadrennial Energy Review," a message for the heads of executive departments and agencies. Washington, DC: The White House. https://obamawhitehouse.archives.gov/the-press-office/2014/01/09/presidential-memorandum-establishing-quadrennial-energy-review.

Resilience against natural disaster and intentional sabotage, grounded in community-level responses, is contingent upon the built environment's ability to "prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions."[5]

This paper analyzes methods for quantifying an investment in energy resilience infrastructure. Its purpose is to help small and medium-sized businesses, large corporations, and community-scale customers evaluate an investment in a system that supports energy resilience.

SPECIFIC AIMS

The threat of natural and human-made catastrophic events on energy systems is becoming increasingly well understood; however, adequately preparing to mitigate those events' effects is not.

This analysis helps readers understand and look for cost savings in their electrically or other fuel-powered built environments, and how to determine a return on investment (ROI) for an energy resilience system that can minimize the effects of catastrophic events on operations. The paper targets building and campus owners in particular—essentially, people or entities responsible for structuring and maintaining resilient energy systems. The analysis contains recommendations for a stepwise approach to building those resilient systems, especially in the sections on **Considerations** and **Economics.**

The study explores definitions of *resilience* and *energy resilience*; places those definitions in the context of Vermont commerce, industry, and government; and recommends their consideration for adoption into the next update of the state's *Comprehensive Energy Plan.* These definitions can be adopted or adapted for other jurisdictions, too. The report also briefly reviews current technologies that contribute to enhancing the state's and an owner's energy resilience, while advocating for a multiform approach to achieving energy resilience goals.

SIGNIFICANCE

Resilience as a Multiform Outcome with Interrelated Benefits
Energy resilience is emerging as a response to growing energy security and reliability threats at governmental levels, as much as among private-sector organizations. Rather than a single solution, energy resilience is an outcome of concerted, community-level considerations for preserving, if not enhancing, energy infrastructure and security.

An energy audit can be a valuable tool for first reducing the overall load, particularly in determining the energy necessary to operate critical loads. The most resilient energy is energy efficiency, because energy that is no longer needed cannot adversely affect loads or hinder critical operations when there is an outage. When energy needs are reduced, all other investments can be reduced. Efficiency reduces the need to serve a load. Small, simpler infrastructure can be sufficient to support a critical load when the load requires minimal energy to operate, thus reducing capital costs and long-term maintenance costs. An owner can also support more loads with the same capital investment if the energy use is first

[5] DOE (U.S. Department of Energy), 2015. "Energy Infrastructure Resilience: Framework and Sector-Specific Metrics." Sandia National Laboratories.
https://www.energy.gov/sites/prod/files/2015/01/f19/SNLResilienceApril29.pdf

reduced through energy efficiency, allowing more facility operations to remain functional during an outage. Efficiency also helps a facility or campus ride through longer outages.

Determining the most effective response requires significant planning. This should start with identifying critical energy and power requirements and evaluating technologies and measures to meet those needs. Whether at the state, campus, or building level, building owners will need to define and design a system that can be effectively operated and maintained. For building or facility owners, this can be accomplished with in-house or contracted skills. Building owners and operators will need to create a budget to accommodate an ideal energy assurance system—with an ROI that meets organizational requirements.

Accurately valuing the ROI poses the greatest challenge to the response. Each entity—whether a single building, a hospital campus, a military installation, or a state government with buildings scattered within its borders—must define *energy resilience* for itself. And because each system will be unique to the use case, the ROI difficult to determine.[6] ROI is easy to determine when someone buys a piece of equipment to replace an aging counterpart; but when there is no counterpart, and the monetary return is not readily apparent, making an investment decision becomes challenging.

The Threat(s)

Severe climate disruptions, including water and fire events, are typically opportunistic, coming without much warning. However, cyberattacks on energy infrastructure are the fastest-growing threat to the electric grid.[7] Hackers attempt to disrupt electricity flow, interrupt information flow, and disable protection systems.

Vermont is not immune to these events. In December 2016, the Burlington Electric Department was the target of Russian hackers linked to presidential election interference. These hackers had installed malware on a utility laptop.[8] Although the electric grid was not compromised at that time, such attackers are likely to continue to attempt to disrupt security and infrastructure assets. At a minimum, the Internet of Things (IoT) is expanding, and thus increasingly interconnecting infrastructure assets.

In a separate type of incident, in April 2020, a biker in Sheldon, Vermont, discovered and reported a transmission line fire that resulted in approximately $70,000 of damage for the Vermont Electric Cooperative. Investigators subsequently discovered that the line had been hit by a bullet, in proximity to the fire.[9]

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[6] For this paper, *ROI* is defined simply as the monetary return that can be expected if the investment is made.

[7] Marqusee, Jeffrey, Craig Schultz, and Dorothy Robyn, 2017. *Power Begins at Home: Assured Energy for U.S. Military Bases.* For the Pew Charitable Trusts. Reston, VA: Noblis. https://noblis.org/wp-content/uploads/2017/11/Power-Begins-at-Home-Noblis-Website-Version-15.pdf.

[8] McCullum, April, 2016. "Russian Hackers Strike Burlington Electric with Malware." *Burlington Free Press,* December 31. https://www.burlingtonfreepress.com/story/news/local/vermont/2016/12/30/russia-hacked-us-grid-through-burlington-electric/96024326/.

[9] WCAX / Channel 3, 2020. "Police: Transmission Line Shot in Area of Fire." May 11. https://www.wcax.com/content/news/Police-Transmission-line-shot-in-area-of-fire-570371991.html.

Whether through cyberattack, acts of vandalism, or severe climate events, infrastructure is at risk of being damaged. In response, corporations and infrastructure operators are becoming increasingly interested in energy security.[10] Their business risk calculations are leading to more investigation of methods for providing greater assurance of energy supply and for reducing risks associated with power loss. Investments in energy resilience do not directly lead to long-term cost savings, but technology allows owners to use assets to mitigate costs, and to ensure access to affordable energy. Determining how to calculate an investment that will lead to optimal financial returns has been, to date, unclear. Owners must make investment decisions without such assurances.

Establishing formulas to estimate financial payback would give owners more confidence in their decisions, thus likely making them more willing to invest—and invest deeply—in a system. This paper provides the formulas to establish the financial data needed to make an investment decision.

CONSIDERATIONS

Getting to the Next Level of Energy Infrastructure Security in Vermont

An acceptable state of energy resilience should be something Vermonters can rely on in the event of a catastrophe, even if the likelihood for such an event is low. Policy makers can agree on the attributes of resilience; in the case of Vermont, the following points would be worth considering:

- Stakeholders have planned and implemented energy hardening features into their energy systems, as a way to prepare for risks.
- Energy infrastructure is designed to adapt when it is unable to supply power normally.
- Building and campus owners will need to identify the loads that support processes preserving life or property that will have catastrophic effects if lost.
- The design incorporates ways to maintain life and property critical loads.

Typical critical load classifications are critical, essential, and normal.[11] "Hardening" an energy system—essentially designing and installing a system capable of maintaining normal operations during adverse events—will strengthen the system's ability to withstand disruptive events. Resilience has greater strategic scope because it has the capacity to respond to low-likelihood events. That is, it is less cost effective to harden against such events (100-year floods, or wildfires in a wet climate, for example), under typical policy and financing norms. And more important, a conventional hardening approach does not provide assurance for critical systems because it has no role in mitigating an event.

Thus, owners of energy systems—whether at the regional or individual-building level—should identify the loads that (1) preserve life or property, and (2) are not likely to ride through a disruption, to target for resilience measures.

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[10] *Energy security,* as it is being used in this report, refers to the relationship between national security and the availability of resources for energy use. This can involve balancing energy demand and supply to avoid economic constraints and make access to energy affordable. It can also involve securing the grid from disruptions.

[11] Vilchuck, Mark, and Bill Chvala, 2019. "T06-S09 Leveraging Audits and Evaluations for Resilience." *Whole Building Design Guide,* Continuing Education presentation, August 22. https://www.wbdg.org/continuing-education/energy-exchange/fempee19t6s9.

Choosing Appropriate Technology for Optimal Resilience

Technologies that support resilience help a system to detect, respond to, or recover from a disruption. The technologies individually do not provide all the necessary functions, but they are worth examining as part of a larger strategy for energy system resilience.

Oil or gas generators. Stand-alone fossil-fuel-fired generators have traditionally provided energy resilience at the building level. That is, they provide energy to critical loads when there is a grid outage.

Distributed energy resources (DER), power supplies located close to the loads they serve, typically involve generation with interconnection to a distribution or sub-transmission system. Examples are solar PV installations, wind turbines, small hydroelectric systems, landfill gas, biomass resources, fuel cell technology, combined heat and power (CHP) facilities, and flywheels.[12] Non-generating sources of DER also contribute to resilience: demand response and energy storage methods using electrochemical, water, compressed air, or thermal resources.

CHP. CHP systems provide on-site generation with renewables or fossil fuels and use waste heat for thermal applications. Facilities with a need for electricity and a use for the waste heat can benefit from the local generation control these provide.

Clean renewable generation. Solar and wind are typically tied to a regional grid. This feature renders them unusable during a grid outage. Nevertheless, they can be integrated into a broader system that can "island" them, disconnecting them from the grid, during an outage. This makes them a valuable technology to meet resilience needs.

Energy storage. Storage is important for resilience infrastructure that relies on intermittent generation assets or assets that otherwise are, across the short term, unpredictable in their production. Electrochemical battery technologies such as lithium-ion, lead-acid, or lead-carbon are a few of the chemical combinations in use. They can capture solar or wind production and store it for use when generation is not enough to meet demand—or during grid outages. Other options are thermal storage technologies, which store renewable production or CHP production. Flywheels store kinetic energy as rotational energy, and compressed air can be stored for later use.

Controls. Controls that can detect a fault in the electrical system and initiate an action to mitigate its impact are a vital component of an energy system. They ensure that critical loads are served by bringing critical pieces of the energy infrastructure online to maintain energy supply and prevent disruption to connected loads.

ECONOMICS

Metrics

Common economic analysis metrics traditionally involve net present value (NPV), internal rate of return (IRR), savings-to-investment ratio (SIR), life cycle cost (LCC)—and, although less useful in offering a realistic picture of value, simple payback.

[12] Ameresco, 2019. "Driving Resiliency through Your Organization's Energy Infrastructure." http://www.ameresco.com/wp-content/uploads/2019/08/ameresco-white-paper_driving-resiliency-through-your-organizations-energy-infrastructure.pdf.

Defining a system-level, cost-effective energy resilience investment requires establishing values for capital and operational costs, savings and revenue streams, and rates of return. All the common analytic metrics, except simple payback, involve similar variables, as presented in Table 1.

IRR is the discount rate, and as such is not noted as a variable. These variables can be difficult to identify because resilience infrastructure does not have a direct impact on energy use. At the infrastructure level, it is difficult to quantify a clear reduction in either kilowatt-hours used or in kilowatts of demand; either of these reductions results in a lower monthly utility bill. That cause-and-effect can be easily quantified from an energy efficiency upgrade to a piece of mechanical equipment, for example, but the methods for deriving those savings at the infrastructure level are not suitable. In short, energy savings are a quantitative metric; energy resilience is a qualitative metric.[13]

Table 1. Economic metrics and the variables they influence in deciding on investments in energy infrastructure resilience

Metric	Variables				
NPV	Payments	Savings / revenue	Discount rate	Minimum acceptable rate of return	Lifespan
IRR	Payments	Savings / revenue		Minimum acceptable rate of return	Lifespan
SIR	Payments	Savings / revenue	Discount rate	Minimum acceptable rate of return	Lifespan
LCC	Payments	Savings / revenue	Discount rate	Minimum acceptable rate of return	Lifespan
Simple payback	Payments	Savings / revenue		Minimum acceptable rate of return	Lifespan

Applying the Economic Analysis

The timeline an analysis covers can be associated with the expected lifetime of the energy resilience infrastructure. Components will differ in their lifespans and in their maintenance and upgrade costs. Those costs will depend on individual infrastructure configurations. It is important for owners to consult relevant industry experts for estimated lifespans for each component. An appropriate approach for deriving total infrastructure lifespan for resilience projects is to use the estimated lifespan for the costliest components, and to include replacement costs for less expensive components in the operations and maintenance cost analysis. It is also important to identify components whose capital costs exceed reasonable periodic upgrade costs, and then use the lowest estimated lifespan within that group of components for a realistic estimation of the resilience project's lifetime.

Owners will need to define a baseline condition. Baselines will fall into one of two broad categories: (1) existing conditions, which can assume no resilience in place, or (2) a definable level of resilience practices with several resilience design configurations to meet requirements for economic comparison. Once they determine the baseline condition, owners should then compare proposed resilience configurations against their current site conditions, establishing use cases for each condition. This will help them determine which configuration offers the best investment. Owners should also identify each variable for the baseline condition, as well as those for the proposed resilience technology.

[13] Vilchuck and Chvala, "Leveraging Audits," 2019.

Sources of costs and revenue streams will vary by each technology configuration. These values are the most difficult to derive, but they have the greatest impact on a project decision because they determine the owner's ability to fund the necessary capital expense. They also determine the owner's ability to keep the infrastructure operational throughout its lifespan. Figure 2 offers an overview of how to derive costs and savings, and revenue streams.

Costs

- Initial capital cost for infrastructure upgrades, including all purchases and labor associated with designing and installing the system
- Annual maintenance costs to maintain the system
- Operating costs, considering service contracts and personnel skill sets required
- Lost value to organization from a loss in power

Savings and revenue streams

- Demand cost reduction associated with peak shaving and load shifting (time-of-use pricing), optimized economic operation
- Net metering savings on utility bills
- Avoided losses due to adverse events, value of lost load (VoLL)
- Utility program incentives such as demand response and frequency regulation
- Capital cost reduction and energy and demand cost reductions associated with efficiency measures implemented prior to resilience infrastructure planning
- Insurance premium reductions associated with resilience capabilities
- Savings from equipment no longer needed (generators) and from the fuel used by that equipment, or fuel reductions for systems where generators operated less

Figure 2. Attributes of appropriate costs and relevant savings and revenue streams to be considered in an economic analysis of resilience infrastructure projects.

ANALYSIS METHODS FOR COSTS, SAVINGS, AND REVENUE STREAMS

Costs

Expenditures consist primarily of capital costs, operations costs, maintenance costs, and costs associated with losses due to power failure. Owners must decide what type of technologies they are willing to host and whether the site is suitable for desired technologies—before including them as an option for bidding. Costing data can come from estimates from contractor partners or from industry data on average costs for system components.

$$\text{Costs} = C + E + NPV(N)_n + NPV(M)_n$$

Where

C = Capital cost for implementing infrastructure build

E = Energy efficiency upgrade package costs
N = Operations costs
M = Maintenance costs
n = Infrastructure lifetime

Capital costs will be unique to each project. Owners should firmly define what resilience should accomplish at the site, and which loads are critical to meeting resilience goals. Costs from bids for infrastructure designs provide the most accurate estimate of initial outlays, but projects that have not reached the design stage and whose owners are evaluating whether to pursue a resilience project can use industry-specific capital cost data for components.

Owners should evaluate the extent of energy efficiency improvement opportunities before they design for resilience. Efficiency measures cost-effectively reduce energy and demand requirements. The more efficiency is built into a design, the greater the chances of optimizing the resilience design and its costs. In that step, owners should evaluate capital costs for energy efficiency upgrades that will minimize energy and power requirements in the system, while also limiting costs for any necessary improvements to existing equipment to ensure that the resiliency infrastructure is compatible. Costs should consider energy audits and product and labor costs to implement the recommended upgrades from the audits.

Since overall reduction in energy or demand requirements can result in smaller or simpler resilience systems, owners should evaluate energy efficiency upgrade costs against resilience infrastructure costs. This step will establish an energy efficiency plan to reduce overall energy and demand requirements. As part of this exercise, the analysis should also investigate any changes to utility rate structures, whether those might relate to pending utility rate cases, or to changes that might occur from lower energy use from efficiency and other post-project energy use. The following calculation can determine the effects of an implemented energy efficiency package:

$$C_a + E_1 - R_1 + \sum_n NPV\ (B_a) < C_b + E_2 - R_2 + \sum_n NPV\ (B_b)$$

Where

C_a = Capital costs for infrastructure configuration with energy efficiency incorporated before the resilience design stage
C_b = Capital costs for infrastructure configuration with no energy efficiency upgrades or alternate energy efficiency upgrade package
E = Cost of energy efficiency upgrade package
R = Utility energy efficiency rebates and incentives
B_a = Annual utility bill with energy efficiency incorporated into energy resilience plan
B_b = Annual utility bills with no efficiency upgrades or alternate efficiency upgrade package
n = Infrastructure lifetime

Operating costs for a potentially unfamiliar system should be carefully evaluated to ensure the system operates as intended. It might be necessary to hire new staff with specific skill sets, train existing staff, or execute a contract with a third party to ensure efficient operations that maximize the system's capabilities to benefit the owner. Where relevant, owners should include additional salary costs, training and certification costs, and contract costs. They should also include costs for additional equipment to operate the system.

Those costs might involve required testing equipment, tools, and system-external hardware or software that will communicate or be affected by it. Owners should establish the NPV of operations contracts or an increase in personnel costs to operate the infrastructure, as designed, over the life of the system.

Another cost consideration is system maintenance. This involves component replacements at appropriate intervals and routine system tuning to ensure continued optimal operation. The analysis should evaluate ancillary equipment for operating the system in terms of the equipment lifetime, with replacement costs at appropriate intervals, and calibration requirements for any equipment. The analysis should determine costs and frequency of required maintenance on system components. Manufacturers typically specify maintenance requirements, or they can come from industry data. In either case, the analysis should also include consumable supplies for system maintenance. This calculation will need to establish the NPV of maintenance costs for the life of the system.

Savings and Revenue Streams

Resilience infrastructure can create monetary benefits. They come from energy and operational cost savings and revenue streams from the grid services the assets can provide. Options for each will depend on utility partner offerings, individual resilience needs, and facility functions. These are summarized as “income” in the equation.

$$\text{Income over life of infrastructure} = U + Z + Y + VLL$$

Where

- U = Utility bill savings
- Z = Value of utility programs
- Y = Ancillary cost savings
- VLL = Value of lost load

Utility bills can be optimized by designing a system to maximize economic operations. The system should continue to provide benefits, even when it is not providing resilience support. Owners can evaluate the utility rate structures and determine how utilities charge for demand, time-of-use, and demand response rates. They can then estimate potential demand savings when assets are able to shave peak loads or support base loads. Owners should evaluate net metering options through the utility, if renewable energy options are in a bid package to estimate utility bill offsets. Owners can estimate reductions in demand charges and changes in energy billing due to energy arbitrage.

$$U = NPV(D + T + B)_n$$

Where

- U = Utility bill savings over life of infrastructure
- D = Yearly demand charge reduction
- T = Yearly energy charge reduction
- B = Yearly net metering credit
- n = Life of resilience infrastructure

Utility programs offer payment in exchange for services an owner is willing to provide to the grid, via the resilience infrastructure. Owners should determine the utility programs that are available for the infrastructure configuration. Resilience infrastructure can shift either to island mode or to a grid-integrated asset, as necessary, to participate in a demand response program. Independent System Operators (ISOs; also known as Regional Transmission Operators or RTOs) might also have programs such as frequency regulation, capacity markets, voltage support, and upgrade deferral. Each of these provides an income stream in exchange for services the resilience infrastructure can provide to the grid. Owners should consider partnering with the utilities and ISO / RTO to determine whether the program is a fit for the resilience design and what the value stream will be.

$$Z = \sum_x NPV(A)$$

Where
- Z = Utility program value over life of infrastructure
- A = Utility program yearly value
- x = Each instance of variable A

Ancillary cost savings come from cost reductions on a site, in expense categories that are not directly related to energy but are affected by energy use. For example, a site might carry insurance to protect against financial implications of lost power. Owners should therefore evaluate any insurance policies and determine what premium reductions might be available when they protect critical loads. Owners should also investigate where other tangential savings might occur. These could involve workers' compensation insurance, storage and maintenance for spare equipment parts, procuring and maintaining supply reserves or emergency equipment, labor to restart equipment, or repurposing space that can add to business value or additional services.

$$Y = \sum_x \Delta B$$

Where
- Y = Ancillary cost savings
- ∆B = Ancillary item yearly incremental cost (current yearly cost minus estimated cost with resilience)
- X = Each instance of variable Y

The VoLL estimates the costs owners incur to respond to and recover from a loss of power. Costs will be either tangible, such as destroyed products or assets, or intangible, such as redirecting staff time to respond to an outage, or lost sales. Operations that are new and have no historical data can consult the IEEE Gold Book[14] or other industry data for associated cost estimates. Established entities should evaluate building automation system (BAS) or historical data on frequency and duration of power outages to estimate a timeframe for drawing out the loss.

Availability is the percent of the year the system is operational by weighted average of critical equipment importance. Using hours of outage for both planned and unplanned events, owners can calculate percentage of availability of power. For example, for a hypothetical pump that is not operational when it is planned to be "on" for 175 hours per year:

(8760-175)/8760=98% availability[15]

Lost load costs encompass a broad range of possible consequences to downtime. Owners should evaluate how the facility responds to an outage and the resources dedicated to bringing a system back online. Owners should also estimate the value of staff production lost

[14] IEEE Standards Association, 2007. *493-2007 – IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems.* Known as the *Gold Book.* Piscataway, NJ: IEEE. https://standards.ieee.org/standard/493-2007.html
[15] Vilchuck and Chvala, "Leveraging Audits," 2019.

when those employees are not performing their typical tasks; this might involve time spent idling and time spent responding to the outage.
The next step is to apply the "percent availability" metric to estimate lost time across staff who would be idle during an outage. Staff time should be associated with restarting equipment or performing manual tasks to prevent a critical loss—for example, life support systems for patients, or guarding a restricted area normally protected with an alarm. Owners can base such costs on hourly pay rate and indirect costs for each staff member.

Owners should estimate income losses from a pause in normal function. Sales that might normally occur but are hindered by a lack of power can be estimated by each industry function. Owners who have data to show what sales tasks were canceled by outages can use the value of the sales that were to take place. Owners with less predictable sales values can apply the "percent availability" metric to approximate average sales data.

Lost load costs are those associated with material losses, such as a product that is destroyed in the production process when power is cut, or a refrigerated product that must be disposed of. In some cases, there could be additional costs if destroyed material is considered hazardous or needs special handling for disposal. These costs also involve materials that must be re-consumed when processes re-start after power returns. For example, a bakery might have to reproduce baked goods after a power loss.

$$\text{VLL} = \sum_x NPV(P + R + S)$$

Where
- P = Yearly cost of staff hours lost to regular job tasks
- R = Yearly cost of material losses
- S = Yearly value of lost sales
- x = Each instance of power failure

The resilience infrastructure configuration investment that results in the highest income-to-cost ratio offers the greatest monetary benefit.

DISCUSSION

Many Definitions, But All Pointing to Similar Needs
A comprehensive characterization of *energy resilience* should encompass threat mitigation from three sources:

- Physical and cyber vandalism
- Natural weather events
- Accidents

The term should not be construed to mean that these events can be prevented entirely, but that mechanisms are in place to minimize them to the extent possible, and to bring an energy system back online enough to continue critical functions without interruption. Energy infrastructure can be systemically hardened to mitigate risks and be resilient in responding to interruptions from adverse events. Supporting critical loads will likely mean that some non-critical loads will not be served until the system returns to normal operations; nevertheless, an energy resilience strategy plans for service to all loads that preserve life and property.

The Presidential Policy Directive on Critical Infrastructure Security and Resilience from the Obama Administration defines *resilience* as "the ability to prepare for and adapt to changing conditions and withstand and recover quickly from disruptions." These disruptions can stem from deliberate attack, accidents, or natural events.[16] These events are typically very costly.

Industry loses products or labor to produce products; commercial companies lose sales, and service organizations cannot provide critical services such as health care or public safety. One solution is to take more control over energy production and procurement.

DOE defines *hardening* of a system as physically changing infrastructure to improve durability and stability to withstand physical impacts. DOE, seeing resilience through a sector-specific lens, defines *resilience* as the ability of an energy facility to recover quickly from damage to a component or other external system. They distinguish *resilience* from *hardening,* relating it to physically designing infrastructure to decrease susceptibility to damage from extreme weather.[17]

Closer to home, and in today's IoT environment, Vermont should harden energy infrastructure against cyber risks and design cyber-resilience into its energy systems.

How Those Definitions Apply to This Discussion
The federal government and some federal agencies have recognized a need to research energy resilience's impact on the national energy infrastructure and the services they provide. Federal agencies, including DOE and all branches of the Armed Forces, have issued policies and directives that establish a definition that informs federal investment and research efforts.

President Obama's Presidential Policy Directive was followed by the now-rescinded Executive Order 13693, Planning for Federal Sustainability in the Next Decade (2015), which essentially reiterated his 2013 Directive's *resilience* definition.[18]

Implications for Vermont

Vermont created the Vermont Energy Assurance Plan to address the challenge of securing energy supply with goals to avoid or reduce energy disruptions, reduce the number or severity of impacts, and reduce time to return to normal supply conditions. Its approach reflects DOE's definition of energy *hardening*. The *energy assurance* definition stops short of *resilience,* as defined elsewhere, by calling for an "acceptably reliable" and "economically viable" energy supply without "significant impacts due to energy supply disruption events or the potential for such events."[19]

Although Vermont recognizes that supply disruption risks exist and there is a need to mitigate them, the State stops short of planning for meeting critical needs during catastrophic

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[16] Office of the Press Secretary, 2013. "Presidential Policy Directive—Critical Infrastructure Security and Resilience." February 12. Washington, DC: The White House. https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil.
[17] DOE (U.S. Department of Energy), 2010. *Hardening and Resiliency: U.S. Energy Industry Response to Recent Hurricane Seasons*. https://www.hsdl.org/?abstract&did=4496.
[18] President Barack Obama, 2015. *Planning for Federal Sustainability in the Next Decade,* Executive Order 13963, March 19. Washington, DC: Federal Register. https://www.govinfo.gov/content/pkg/FR-2015-03-25/pdf/2015-07016.pdf.
[19] St. Peter, Allan, 2013. *State of Vermont Energy Assurance Plan, Rev. 1.0.* Montpelier, VT: Vermont Public Service Department. https://publicservice.vermont.gov/sites/dps/files/documents/VT%20Energy%20Assurance%20Plan%20August%202013.pdf.

outages. The State does consider the time required to return to full energy supply services. Vermont's Plan evaluates the energy resources, risks to those resources, and ways to mitigate those risks, whereas the term *energy resilience* addresses the ability to quickly and seamlessly respond to a disturbance without compromising loads that support life and property.

Vermont has made significant strides in planning for energy challenges. Although it is possible to mitigate the risks, it is not possible to eliminate them entirely. The state has evaluated resilience in the context of natural disaster and climate change impacts on economic and social well-being in Vermont.[20]

Recommendation. Including a working definition of *energy resilience* in the state's resources will help ensure that Vermont can both reduce risk and respond to and recover from events that affect energy access. The *2016 Comprehensive Energy Plan* calls for emphasizing energy efficiency and conservation for both energy demand and supply. It calls out strategic electrification to increase resilience and to lower infrastructure costs. Further, the *Comprehensive Energy Plan* recognizes the risks of storms and other natural events to the energy supply infrastructure, specifically recommending monitoring microgrid technology development particularly to support critical infrastructure.[21]

Implications for the Nation's Military

Energy resilience is a very important consideration within the U.S. Department of Defense (DoD), because military operations rely heavily on energy accessibility, and the risks to national defense can be enormous. DoD considers resilience to be intertwined with energy security, and thus is a critical investment.

The Department defines *energy resilience* in section 101(e) of Title 10, United States Code (U.S.C.) as

> the ability to avoid, prepare for, minimize, adapt to, and recover from anticipated and unanticipated energy disruptions in order to ensure energy availability and reliability sufficient to provide for mission assurance and readiness, including task critical assets and other mission essential operations related to readiness, and to execute or rapidly reestablish mission essential requirements.[22]

The military branches have each based their own interpretations on their mission needs. The Air Force Energy Flight Plan, for example, defines *energy resilience* as "the ability to prepare

[20] Institute for Sustainable Communities, n.d. *Vermont's Roadmap to Resilience: Preparing for Natural Disasters and the Effects of Climate Change in the Green Mountain State."* Montpelier, VT: ISC. https://resilientvt.files.wordpress.com/2013/12/vermonts-roadmap-to-resilience-web.pdf.

[21] State of Vermont, 2016. *Comprehensive Energy Plan 2016.* December 31. Montpelier, VT: Vermont Department of Public Service. https://outside.vermont.gov/sov/webservices/Shared%20Documents/2016CEP_Final.pdf.

[22] Office of the Assistant Secretary of Defense for Energy Installations and Environment, 2017. *Department of Defense Annual Energy Management and Resilience Report (AEMRR), Fiscal Year 2017.* July. https://www.acq.osd.mil/eie/Downloads/IE/FY%202017%20AEMR.pdf. Also: *2018 AEMRR*, https://www.acq.osd.mil/eie/Downloads/IE/FY%202018%20AEMR.pdf. And Judson, N., A.L. Pina, E.V. Dydek, S. B. van Broekhoven, and A.S. Castillo, 2016. "Application of a Resilience Framework to Military Installations: A Methodology for Energy Resilience Business Case Decisions." Technical Report 1216. Lexington, MA: Lincoln Laboratory, Massachusetts Institute of Technology. https://apps.dtic.mil/dtic/tr/fulltext/u2/1024805.pdf

for and recover from energy disruptions that impact mission assurance on military installations."[23]

Technologies Providing Resilience

For many people, energy resilience calls to mind microgrids, and a microgrid system will certainly provide local energy control. But energy resilience is not limited to the typical renewable resource with an electrochemical battery combination. Individual technology components alone do not provide resilience. They must be combined into a system with appropriate controls to ensure the system can detect disturbances and respond quickly enough for the critical loads to remain in service.

Research and development in the component technologies have progressed—especially investigation into how these components can combine to create the ideal system for the application. This discussion of current technologies is relevant now. But given the increasing interest in energy resilience across industries, available technologies might change as new products enter the market, or as new ways of applying existing concepts emerge.

Lessons from the Military on Responding to Power Loss

An emergency backup generator meets the definition of *energy resilience* by providing energy to loads when grid resources are unavailable. Backup generators are the military's current approach to energy resilience. They typically connect critical loads to fossil-fuel-fired generators that can serve loads of approximately 20 MW.[24] The strategy allows local control of installation building assets and provides assurance that critical functions will remain operational if the grid cannot serve the loads. Generators also provide support for broader microgrids, as Otis Air National Guard Base is doing in Barnstable, Massachusetts. Their generators support critical loads in the event that their microgrid cannot.[25] Fort Sill uses two natural gas generators paired with storage to support a microgrid system that can island and support loads during grid disturbances.[26]

Other Types of Response: Fuel Cells and Load Shifting

Home Depot stores in New York State rode through utility outages in the summer of 2019 with fuel cell backup systems. Outages lasted up to 6 hours, but stores could continue to serve customers throughout the duration.[27] Fuel cell technology offers a power source close to the critical loads, as long as there is a hydrocarbon source such as natural gas to operate the fuel cell. The technology uses hydrogen to catalyze the chemical reaction, which produces electricity. Renewable sources can also integrate into a system to supply hydrogen. Fuel cells are not batteries and do not store energy, but they can supply electricity via a chemical reaction.

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[23] U.S. Air Force, 2017. *Energy Flight Plan: 2017 – 2036.* https://www.safie.hq.af.mil/Portals/78/AFEnergyFlightPlan2017.pdf?ver=2017-01-13-133958-503.

[24] Marqusee et al., *Power Begins at Home,* 2017.

[25] Major Shawn Doyle, personal communication, November 20, 2018.

[26] Paquette, Andrew D., Deepak M. Divan, 2015. "Virtual Impedance Current Limiting for Inverters in Microgrids with Synchronous Generators." *IEEE Transaction on Industry Applications 51*(2): 1630-38. https://ieeexplore.ieee.org/abstract/document/6872529.

[27] Hussain, Asim, 2019. "Fuel-Cell Powered Microgrids Keep Home Depot Stores Open through New York Power Outages." Bloom Energy Blog. https://www.bloomenergy.com/blog/fuel-cell-powered-microgrids-keep-home-depot-stores-open-through-new-york-power-outages.

Although load shifting is not a piece of technology equipment, an option to shift loads to other locations can provide the energy resilience that meets process needs. A data center, for example, that can "fail over" or transfer a data process to a facility outside the affected area can provide the resilience necessary for maintaining critical operations, even as the local facility loses the ability to operate.[28]

Benefits of Resilient Technologies

Resilient technologies offer users control over their energy supply and the loads served. Users can be individual homes, small to medium-sized businesses, large corporations with campuses, communities, or distribution utilities. Each must define *critical loads* for themselves. A hospital must continue to provide critical patient care, for example, and a manufacturer must ensure that its product is not destroyed because of an unexpected stop in the manufacturing process.

Economics

Recent developments in technology, the risks associated with climate change and security, and aging electrical grid infrastructure have all prompted a significant interest in energy resilience. Researchers and practitioners alike are exploring the potential for using assets to benefit the owner beyond simply responding to emergencies. New opportunities to use emergency assets for managing energy costs have begun to emerge.

These opportunities provide energy management benefits during normal operations—essentially improving building energy performance while also making the building more energy resilient. A report commissioned by the Pew Charitable Trusts introduced five advantages of microgrid infrastructure over stand-alone generators in providing resilience:[29]

1. Where generators are sized for the peak loads at each building, a microgrid system can serve a conglomeration of buildings, thus reducing the power volume by integrating a combination of differing peak loads.
2. Microgrid infrastructure is standardized enhancing maintenance over a mix of generator sizes, models, and vintages.
3. Microgrids offer flexibility in load profiles through their networks where generators must be physically relocated if power needs change.
4. Excess microgrid generation is available for non-critical loads where generators are limited in their coverage areas.
5. Microgrids increase reliability through networking that allows components to take over for portions that fail. Generators must have individual backup plans.

Hospitals and military bases have been among the first to adopt energy resilience because their operations are of paramount importance to human health and national security.[30] They are more willing to invest in infrastructure without regard to payback because the consequences of hindering operations are catastrophic. DoD typically employs backup

[28] Shepherd, Rachel, Dale Sartor, Rish Ghatikar, Bruce Myatt, Mukesh Khattar, and Russell Carr, 2019. "Designing and Managing Data Centers for Resilience: Demand Response and Microgrids." Webinar. Washington, DC: DOE, Office of Energy Efficiency and Renewable Energy. https://datacenters.lbl.gov/sites/default/files/Designing%20and%20Managing%20Data%20Centers%20for%20Resilience%20-%20Demand%20Response%20and%20Microgrids_3Dec2019.pdf

[29] Marqusee et al., *Power Begins at Home,* 2017.

[30] Ameresco, "Driving Resiliency," 2019.

generators to serve critical loads. It incurs the costs of maintenance and fuel to maintain the assets so that they are available whenever needed. An installation with an average of 20 MW of critical load will spend approximately $16 million to buy 40 MW of generator capacity (DoD requires generators to be sized at two times the estimated peak load). That installation will also spend $1 million a year to maintain these generators.[31]

The Value-Add of Energy Efficiency and Renewables in Providing Resilience

An energy resilience system will need to provide support only to critical loads during infrequent but catastrophic events. Systems that have been hardened against anticipated potential events will be called to support loads only when events beyond those in a contingency plan occur. Therefore, systems can be used for other services to continue to provide benefits to the owner and to the energy system.

Energy efficiency is a reliable resilience strategy that offers lower energy and demand costs across energy procurement plans. Energy resilience planning should always start with an evaluation of opportunities for energy efficiency improvements.[32] In addition to the other benefits of "efficiency first," described in Significance, unneeded energy cannot pose a risk to critical operations and requires no backup plan to replace a lost resource. Minimizing energy and demand requirements also facilitates the design of smaller, simpler, and cheaper energy resilience systems. This reduces capital costs and operations and maintenance costs. A simpler system is easier to maintain and operate as intended.

The cost of providing energy security is a function of peak power required for protected loads, so energy efficiency and conservation drop costs.[33] When energy needs decrease, existing infrastructure can better support critical loads without risk of exceeding capacity. To achieve optimal resilience, system owners and operators should evaluate ways to minimize energy needs before planning to support critical systems, to minimize costs and complexity. Another example of this is net metering for solar installations. The owner uses the solar generation during normal production, thus eliminating the need to purchase electricity; with net metering, the owner can send unused generated energy back to the grid and receive compensation for it.

In defining *resilience* and establishing goals for energy resilience, system owners should recognize that all cost and benefit metrics will depend on the system's goals, because the infrastructure—to be viable—must meet the requirements. Thus, resilience metrics should distinguish between reliability and the low-likelihood-but-catastrophic events.[34]

Reliability vs. Availability

The IEEE Gold Book defines *reliability* as the ability of a component to perform required functions under defined conditions over defined period of time, and *availability* as the ability of equipment to perform intended functions at an instant in time over defined period of time. Resilience is intended to mitigate low-likelihood-but-catastrophic events, so costs must include probability metrics to define how much risk an event might pose.

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[31] Marqusee et al., *Power Begins at Home,* 2017.
[32] Shepherd et al., "Designing and Managing Data Centers," 2019.
[33] Marqusee et al., *Power Begins at Home,* 2017.
[34] Vugrin, Eric, Anya Castillo, and Cesar Silva-Monroy, 2017. *Resilience Metrics for the Electric Power System: A Performance-Based Approach.* Sandia Report SAND2017-1493. Albuquerque, NM, and Livermore, CA: Sandia National Laboratories. https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2017/171493.pdf.

For example, a study at the Massachusetts Institute of Technology (MIT) measured *availability* as annual unserved kWh.[35] Establishing definitions of a system's availability and reliability needs will set the parameters for the functions that the resilience assets must support.

Availability metrics are important only for components identified as critical to a process—in other words, a process that supports life or property preservation. A system that can transfer tasks to another system and fail without impacts is resilient—without the primary system having availability. A data center capable of transferring its processes to another site before going offline illustrates the concept.[36]

Costs and Benefits in Deriving What the Investment in Infrastructure Can Look Like

The resilience planning process is critical to defining the costs and benefits of infrastructure investment because it sets the baseline for assessing the cost of the status quo. It also creates the path for determining what is necessary for mitigating risks. Centralizing generation within a system allows for redundancy for each critical load, by providing connectivity to onsite generation, or a storage option and controls, further enhancing resilience.[37]

Sandia National Laboratories has proposed a 7-step planning process for utilities; it can be adapted for facilities and communities to create goals and criteria for risk identification and mitigation, as shown in Figure 3.

[35] Judson et al., "Application of a Resilience Framework," 2016.
[36] Shepherd et al., "Designing and Managing Data Centers," 2019.
[37] Judson et al., "Application of a Resilience Framework," 2016.

Figure 3. Seven steps for planning an energy resilience process for utiities, facilities, and communities. Source: *Sandia National Laboratories.*[38]

Quantifying the total costs and benefits for resilience infrastructure investment is challenging. Until recently, decision makers and researchers have limited the concept of *energy resilience* to backup generators. Now, technology advances in onsite generation, energy storage, and advanced controls have emerged as positive market developments. However, building and system owners must find ways to successfully use those options to respond to threats from extreme weather events and an ever-expanding IoT environment.

Fortunately, owners now have more ways to use backup power systems that can bring benefits during both normal and emergency operations. Further, diversifying system use can offer owners a way to offset their capital investments in resilience by using the assets in several ways. Largely undefined, however, is how owners can determine the optimal capital investment amount, and how to quantify potential income streams that such investments can produce.

An analysis several years ago evaluated the cost per kW of critical load for supporting critical loads on military installations.[39] This metric allows direct comparison to stand-alone generators sized for peak demand. The analysts compared stand-alone generators to centralized generators in a microgrid configuration across three regions of the United States.

[38] Vugrin et al., *Resilience Metrics,* 2017.
[39] Marqusee et al., *Power Begins at Home,* 2017.

They found that the cost per kW was lower for the microgrid configuration using diesel generators. This was primarily because of the operation and maintenance costs associated with stand-alone generators and the ability to use the microgrid configuration for peak shaving. Alternatively, adding natural gas generators to the microgrid configuration to handle baseload resulted in higher costs for some regions, but negative costs in others. The *system value* is defined as the annual cost of protecting each kW of critical load.

The value of resilience currently uses the value of avoided power disruptions as an estimate. The National Association of Regulatory Utility Commissioners (NARUC) studied four methods of valuing resilience in DER: contingent valuation, defensive behavior method, damage cost method, and input-output modeling.[40]

Contingent valuation elicits values for non-market goods such as avoiding power disruptions.[41] Owners must determine how much they are hypothetically willing to pay to avoid a power outage or to guarantee a level of security. In the NARUC study, the project derived the resilience value from the Lawrence Berkley National Laboratory's (LBNL) Interruption Cost Estimate (ICE) Calculator tool.[42] The Calculator bases the avoided cost of power interruptions on the system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), and customer average interruption duration index (CAIDI). The metrics are typically utility level indices. Generalizing the costs of disruptions would not serve an owner well, because each owner's enterprise is unique. Some owners might have assessed how much their budgets can cover a cost of avoiding an outage, but the value is hypothetical and does not result in actual costs or savings from a capital investment.

Damage cost method and *defensive behavior method* identify how much owners have paid to avoid negative consequences of a disruption.[43] Damage cost calculates the actual costs that might occur during a disruption. These might be injuries or lost product. Defensive behavior costs can be the cost of purchasing and maintaining a backup diesel generator.

The NARUC study used the Federal Emergency Management Agency's (FEMA) Benefit-Cost Analysis (BCA) calculator[44] to estimate damage costs. The study also combined the output with ICE output to evaluate the overall value of resilience. The BCA calculator estimates the cost-to-benefit ratio for investment that mitigates natural hazard risks. The calculator can be useful to an owner who does not have historical data to inform cost estimates for natural disasters in the local area. However, it is not readily applicable to the value of lost load estimate, so the output must be analyzed with other relevant resilience data to determine if it is an effective tool for the use case.

The input-output model assesses the broader economic impacts in the region of a disruption. The NARUC study used IMPLAN's economic modeling platform[45] to run the

[40] Rickerson, Wilson, Jonathan Gillis, Marisa Bulkeley, 2019. *The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices.* Prepared by Converge Strategies for the National Association of Regulatory Utility Commissioners. April. https://pubs.naruc.org/pub/531AD059-9CC0-BAF6-127B-99BCB5F02198).
[41] Rickerson et al., *Value of Resilience,* 2019.
[42] DOE (U.S. Department of Energy), Berkeley Lab, and Nexant, n.d. *Interuption Cost Estimate (ICE) Calculator.* (https://icecalculator.com/home.
[43] Rickerson et al., *Value of Resilience,* 2019.
[44] DHS (U.S. Department of Homeland Security), n.d. *Benefit-Cost Analysis.* https://www.fema.gov/grants/guidance-tools/benefit-cost-analysis.
[45] IMPLAN, n.d. "Technology for Unlocking Economic Opportunity." https://www.implan.com/.

analysis. The model can be useful for state and local governments that are assessing the costs and benefits of resilience plans. It can also give business owners an overview of what a disruption might do to the local economy. It is too broad for a business owner to use to estimate the individual value of lost load, because the loads will be unique to the business. Thus, the model should not be used alone to estimate the value of lost load. State and local governments should also consider the economic activities within their regions, the population's government and emergency service needs, and the specific natural or man-made risks in the region.

NARUC also studied a comparison between a baseline diesel generator and a microgrid using a dollar-per-protected-kilowatt-hour metric[46] on a life cycle cost basis to define a value of lost load. This method allows for simple comparison between two resilience capital and maintenance cost options. It also assumes that the protected load is the critical load and that the assets are protecting the load—which, if disrupted, can result in loss of life or property. It provides a simpler way to compare two resilience configurations, but it leaves out the tangential losses that increase business or government costs during an outage. These losses might be lost labor hours, diverted emergency resources, or destroyed products. Another proposed method for calculating the value of resilience (VoR) can be derived this way:[47]

$$\text{VoR} = \text{VoLL} \int_0^T L_c(T)\,dt$$

Where

L_c = additional critical load the resilience assets can serve over the baseline in kilowatts

T = the time over which the assets can carry the critical load

This method can also compare a proposed configuration to an existing or baseline proposal, but it does not consider other factors such as income streams. It relies entirely on the lost load value to estimate the resilience value.

The Context for Vermont

This analysis uses traditional methods for assessing cost effectiveness, because these are familiar concepts to Vermont regulators who review Efficiency Vermont's cost savings and payback metrics for customers' energy efficiency investments. Nearly all industries doing business in Vermont understand them, and they are applicable to all technologies and technology configurations.

The calculation method provides the variables within those formulas. But deriving the values for the variables requires working closely with design engineers, facilities staff, utility representatives, and business decision makers to identify their respective resilience needs. Through such a process, owners can better understand where opportunities lie to reduce energy costs and take advantage of market participation. Opportunities will be unique to locations, owner requirements, and energy needs—during both normal and emergency operations. The process for designing resilience measures can be incorporated into the engineering design phase, when teams can model systems and identify infrastructure components. But owners should expect to provide partners with guidance on their (the

[46] Rickerson et al., *Value of Resilience,* 2019.

[47] Anderson, Kate, Nicholas D. Laws, Spencer Marr, Lars Lisell, Tony Jimenez, Tria Case, Xiangkun Li, Dag Lohmann, and Dylan Cutler, 2018. "Quantifying and Monetizing Renewable Energy Resiliency." *Sustainability 10* (933). Basel, Switzerland: MDPI (Multidisciplinary Digital Publishing Institute). https://www.nrel.gov/docs/fy18osti/71143.pdf.

owners') appetites for managing energy use and complying with program participation requirements—and defining what financial metrics are a priority.

Designing a Comprehensive System

Designing an energy resilience system should involve a plan for the entire value proposition. Resilience infrastructure such as microgrids can be designed to optimize resilience, economics, sustainability, or a combination of those elements.[48] Although a system's primary purpose is to support critical loads, it can also be a tool for minimizing energy costs. Value streams can come from utility programs and rate structures that allow an owner to opt for time-of-use rate structures that produce income or lower bills. Owners and project partners should determine how to optimize a design to include tools to optimize energy cost savings or environmental benefits.[49]

A Rocky Mountain Institute report found 13 services that energy storage can provide, as shown in Figure 4. These services ultimately return value to the owner, even though they benefit customers, utilities, and grid operators.[50] ISO / RTO services are primarily ancillary services that can benefit infrastructure owners if they participate in those operators' capacity markets and other mechanisms through which the owners can receive payments for reliably bringing demand resources to the grid. ISO New England notes that its Ancillary Services program is one component of the operator's market participation programs and does not comprise a large budget concern for them.[51] Ancillary services can offer significant financial incentives for owners, however. Major Shawn Doyle (Otis Air National Guard Base) indicated that the ISO New England frequency regulation program offered a significant incentive that they used to help cover the battery maintenance costs for the microgrid on base.[52]

[48] Shepherd et al., "Designing and Managing Data Centers," 2019.
[49] Ameresco, "Driving Resiliency," 2019.
[50] Fitzgerald, Garrett, James Mandel, Jesse Morris, and Hervé Touati, 2015. *The Economics of Battery Energy Storage: How Multi-Use, Customer-Sited Batteries Deliver the Most Services and Value to Customers and the Grid.* Aspen, CO: RMI (Rocky Mountain Institute). https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf.
[51] Pete Brandien, Vice President, System Operations & Market Administration, personal communication, May 22, 2019.
[52] Major Shawn Doyle, personal communication, November 20, 2018.

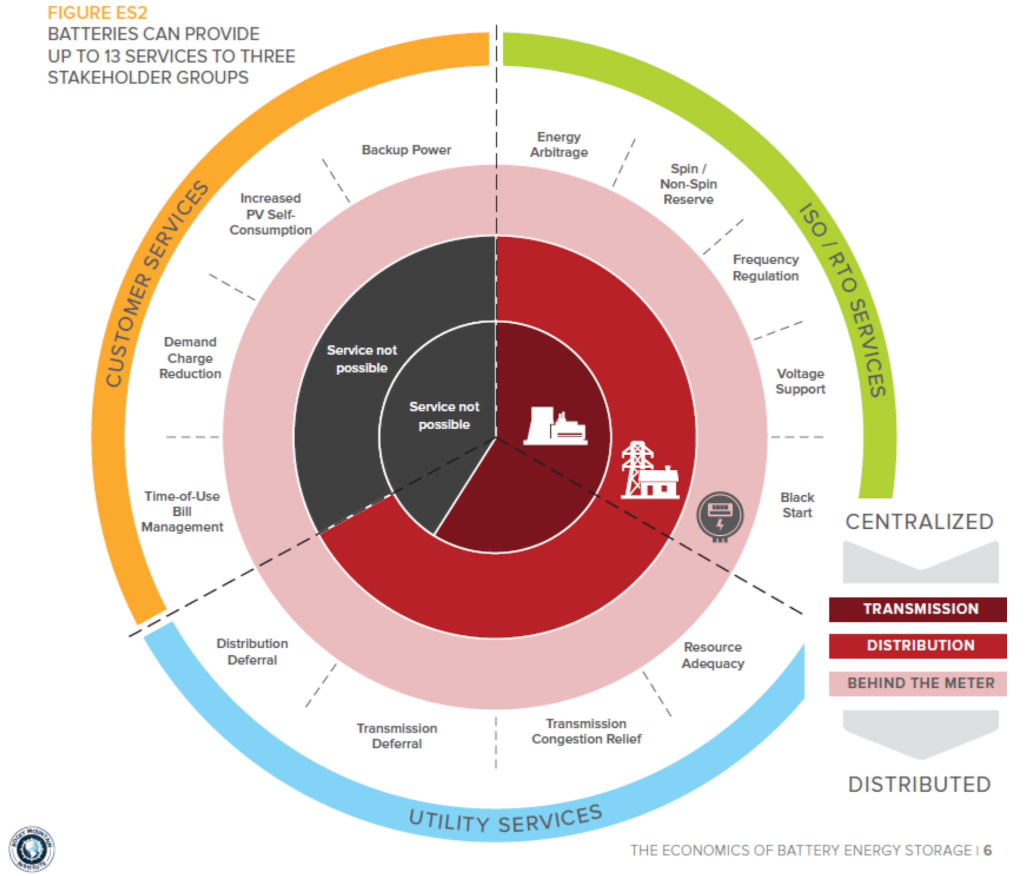

Figure 4. The services that battery storage can provide to grid operators, utilities, and customers. Source: *RMI, Garrett Fitzgerald et al., 2015.*

Determining the value of lost load is likely the most challenging variable for an owner to define. It requires analyzing business practices to determine the costs each enterprise incurs due to power loss. Losses might not seem related to the outage, or their causes might be tangential and not readily obvious. The value of the loss depends on the owner's operations and the nature of the business.

In cases of medical providers, where loads are all about life support systems, the determination might be particularly difficult because it is unethical to put a value on life. Others can value the costs they incur as a result of lost load; this might involve the cost of lost product, employees' unproductive labor hours, and time and materials dedicated to bringing operations back to normal. There might also be added costs from a need to divert labor hours from normal staff tasks to outage mitigation tasks. Avoided outage costs can significantly enhance the overall NPV for a project.

The National Renewable Energy Laboratory (NREL) found that assessing the lost load value can have a significant effect on the design and size of a resilience system, as well as on the overall NPV.[53] Longer outages make the VoLL estimate more difficult, because of cumulative

[53] Elgqvist, Emma, and Nicholas DeForest, 2020. "Save Money and Build Resilience with Distributed Energy Technologies." U.S. Department of Energy Better Buildings® webinar. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/slides/Save%20Money%20and%20Build%20Resilience%20with%20Distributed%20Energy%20Technologies.pdf.

impacts and spillover impacts from the greater economy. The VoLL estimate might also depend on time of day or season, adding a greater challenge to determining an accurate metric.[54]

Estimating how long a system can survive an outage from the grid is an important metric.[55] Traditional diesel generator backup relies on a ready supply of fuel; if it runs out or the local situation precludes procuring sufficient supply, the generator can support survivability only for as long as there is fuel. Resilience infrastructure designed and sized to maintain energy production on site can offer longer-term survivability solutions. Survivability affects the VoLL calculation because long-term outages can outlast a resilience plan and result in losses.

Determining Necessary Insurance Coverage and Accounting for Insurance Costs

Outages affect three types of insurance coverage: property, contents, and business interruption. Property and content coverages address physical damage and losses. Business interruption covers losses associated with disruptions to operations. Energy resilience can mitigate all of these types of losses by ensuring power supply when there is a large outage, thus preserving buildings and processes to prevent losses.[56] Locations at high risk of outages—flood zones, hurricane paths, or earthquake centers, for example—could reduce losses during such events with resilience assets. It is therefore important for owners to evaluate waiting periods, deductibles, and payment time limits when assessing costs of insurance premiums and resilience costs.

Financing Options

There are several large-project financing options that offer energy resilience or other grid benefits. A public-private partnership (PPP) allows a public-sector authority to partner with a third party to develop and finance resilience infrastructure. The cost of this is then repaid over time, following pre-determined procedures and criteria. The model shifts the risk to the private partner, while minimizing taxpayer commitment.

Similarly, design-build-own-operate-maintain (DBOOM) mechanisms involve a third party that designs, builds, carries out operations and maintenance (O&M) functions, and maintains ownership of a system across a long-term contract. Reducing energy use and implementing energy reduction measures before designing a resilience plan can be costly, if the scope is large. But it can also offer significant savings over the life of the equipment if the resilience infrastructure is cost-effectively scoped.

An energy savings performance contract (ESPC) through an energy services company (ESCO) offers an energy performance guarantee based on an energy audit and agreed-upon retrofits to achieve identified savings. The owner pays for the services through the energy savings achieved over the course of the contract. Ameresco has completed projects under these financing models at both Portsmouth Naval Shipyard and Marine Corps Recruit Depot in Parris Island.[57]

[54] Kate Anderson et al., "Quantifying and Monetizing Renewable Energy Resiliency," 2018.
[55] Kate Anderson et al., "Quantifying and Monetizing Renewable Energy Resiliency," 2018.
[56] Kate Anderson et al., "Quantifying and Monetizing Renewable Energy Resiliency," 2018.
[57] Ameresco, "Driving Resiliency," 2019.

CONCLUSION

The analysis method offered in this paper covers the sources of costs and revenue streams for nearly any combination of energy resilience infrastructure configuration. The sources applicable to costs and revenue can be broad and require owners to carefully evaluate them, whether they are direct or ancillary costs and revenues, for each unique system. As technology options continue to evolve in the market, the opportunities for using assets to mitigate the costs of normal operations and to take advantage of possible revenue streams will also evolve.

As other researchers and owners involved in pilot projects publish their economic analysis proposals, comparing the economic analysis output between those proposed methods and this NPV method will lend strength to the data they produce. This should give owners and operators more confidence in making large capital investments in energy resilience.

Additional data will refine the formulas established here to account for variables that are not yet identified and to develop more precision.

Recommendation: Further real-world research. Further research should investigate energy efficiency utility program pilot projects, evaluating them with the analytical methods described here—to confirm where costs and revenue opportunities lie, and to identify whether there are other factors that can refine the economic analysis. Data from such projects can inform the accuracy of the mathematical equations here and provide justifications for adjusting these formulas, to increase their precision.

As more energy resilience pilot projects come online, they will offer opportunities for comparing different financial analysis methods—not only to support, but perhaps to prove the value of the expected financial outcomes.

Recommendation: Thinking in terms of joint responses. The threats to American energy infrastructure are not likely to diminish in the coming decades. However, the most effective mitigation approach appears to be a joint response to those threats, using resilience as a guide for the application of appropriate and cost-effective strategies to individual buildings, community energy systems, and large-scale energy infrastructure. Determining the costs and benefits of such an approach and finding ways to finance appropriately scaled projects at each of those levels, is perhaps the single most important task for ensuring Vermont's and the nation's energy security.