# Energy Resilience Through Grid Modernization and Renewables Integration

Critical Infrastructure Resilience Workshop - December 7, 2018
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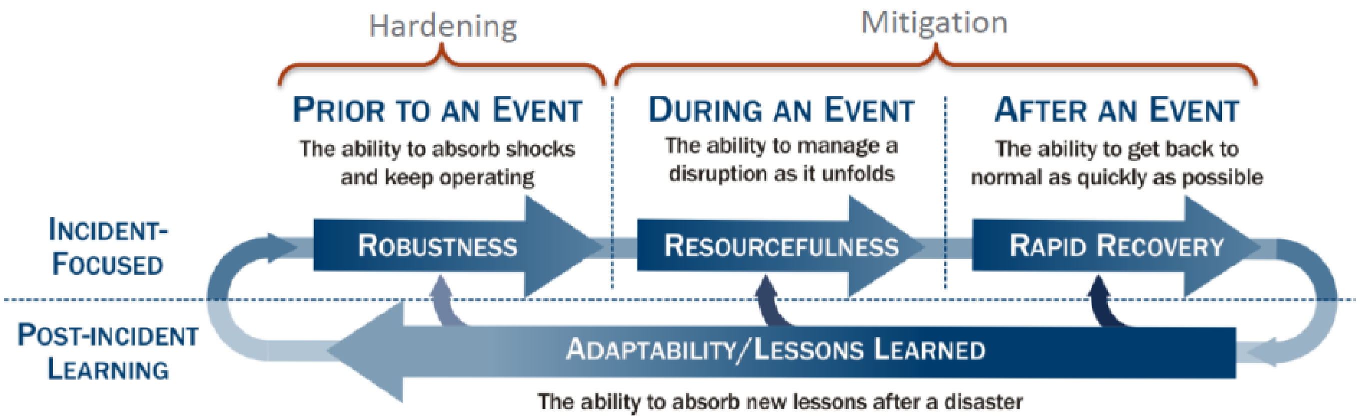
Applied Engineering and Modeling

# A Definition of Resilience

The ability to **anticipate**, **prepare for**, and **adapt** to changing conditions and **withstand**, **respond** to, and **recover** rapidly from disruptions through adaptable and holistic planning and technical solutions.

## Sequence of the NIAC Resilience Construct




"A Framework for Establishing Critical Infrastructure Resilience Goals," National Infrastructure Advisory Council, October 19, 2010

# Grid Modernization Laboratory Consortium

Pacific Northwest NATIONAL LABORATORY

GMLC Co-Leads

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

BROOKHAVEN NATIONAL LABORATORY

Los Alamos NATIONAL LABORATORY EST. 1943

Argonne NATIONAL LABORATORY

SRNL SAVANNAH RIVER NATIONAL LABORATORY

SLAC NATIONAL ACCELERATOR LABORATORY

- Institutional Support
- Devices and Integrated Systems
- Sensing and Measurement
- System Operations and Control
- Planning and Design Tools
- Security and Resilience

**87 projects,**
**$220M over 3 years**

OAK RIDGE National Laboratory

BERKELEY LAB

INL Idaho National Laboratory

NETL

Lawrence Livermore National Laboratory

GRID MODERNIZATION INITIATIVE U.S. Department of Energy

# GMLC Framework for Security and Resilience
## Based on NIST Cybersecurity Framework

**Identify:**

Develop understanding of threats, vulnerabilities, and consequences to all hazards
Outcome: Improved risk management and  streamlined information sharing

**Protect:**

Inherent system-of-systems grid resilience
Outcome: Increase the grid's ability to withstand malicious or natural events

**Detect:**

Real-time system characterization of events and system failures
Outcome: Accelerated state awareness and enhanced event detection

**Respond:**

Maintain critical functionality during events and hazards
Outcome: Advanced system adaptability and graceful degradation

**Recover:**

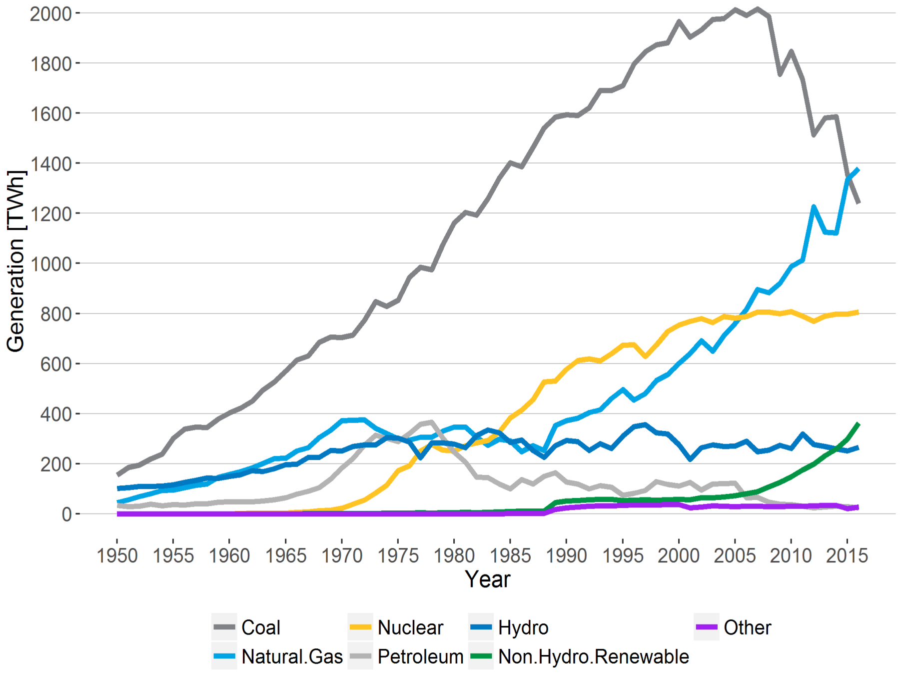
Real-time device management and transformer mobilization
Outcome: Timely post-event recovery of grid and community operations


GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

# Example GMLC Resilience Projects

- Grid Resilience & Intelligence Platform (GRIP) – SLAC, LBNL
- Resilient Alaskan Distribution system Improvements using Automation, Network analysis, Control, and Energy storage (RADIANCE) – INL, PNNL, SNL
- Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB – PNNL, ORNL, NREL
- Integration of Responsive Residential Loads into Distribution Management Systems – ORNL, PNNL
- CleanStart DERMS- LLNL, PNNL, LANL
- Designing Resilient Communities: A consequence-based approach for grid investment - SNL

# The Nation's Electricity Generation Mix is Changing



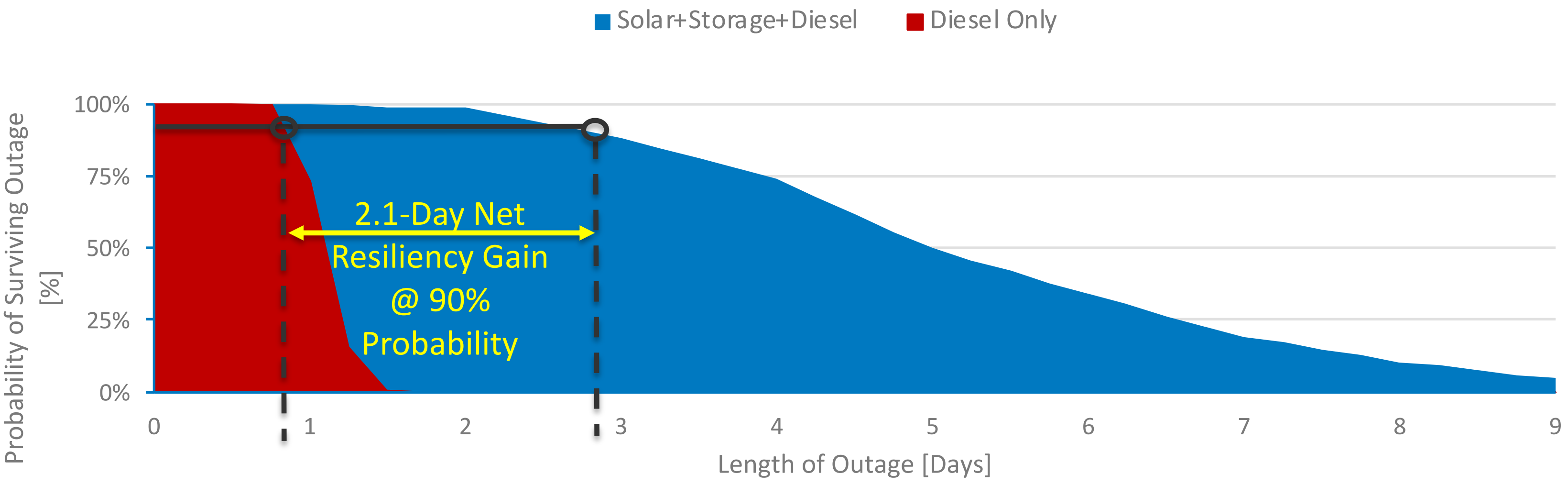

Source: EIA

Changes to the electricity mix: **Natural gas and renewable energy** generated nearly **50% of U.S. electricity** in 2016, up from 30% in 2007

Natural gas increased from **22% to 34%**

Renewable energy climbed from **8% to 16%**

# Why Renewable Energy for Resilient Systems



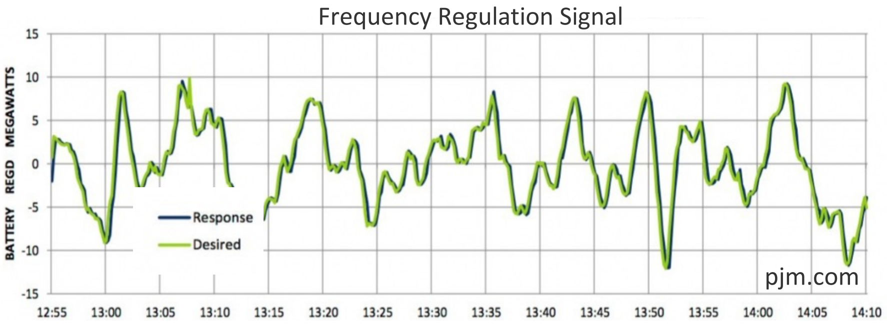

- Diesel sensitivity to fuel supply chains
  - especially in extreme weather events, which along with outages are increasing.
- Diesel back-up often neglected
  - high probability of failure; single point of failure
- RE systems have additional grid-connected benefits
  - diesel usually precluded due to air quality impacts.

Figure source: Kate Anderson et al. **Quantifying and Monetizing Renewable Energy Resiliency.** *Sustainability*, 10(4), 933, 2018, https://doi.org/10.3390/su10040933

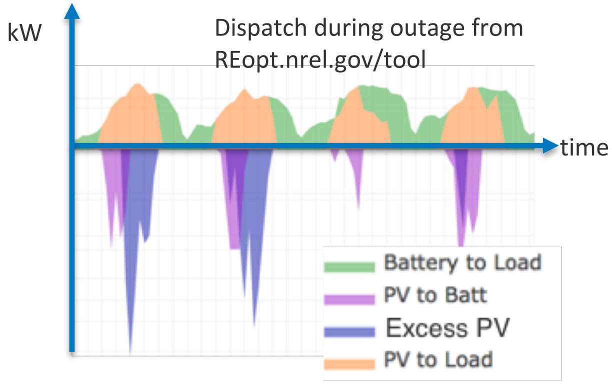
# Key Challenge 1: Control Systems

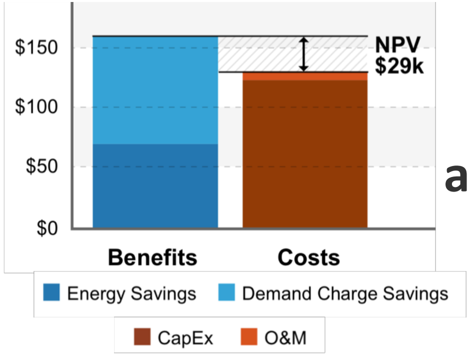
With advanced, autonomous **control systems** we can:

**provide grid support services,**




**meet critical loads during outages,**




**and reduce operating costs for system owners.**

# Key Challenge 2: the Value of Resilience

**Perspective**

*What* matters to you?

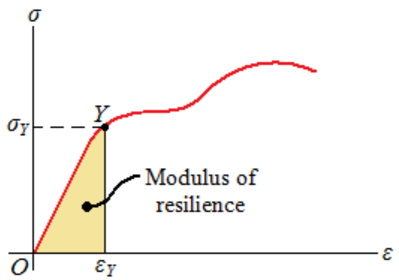
**Metric**

How you *quantify resilience*

**Value**

How do you *assign value*?

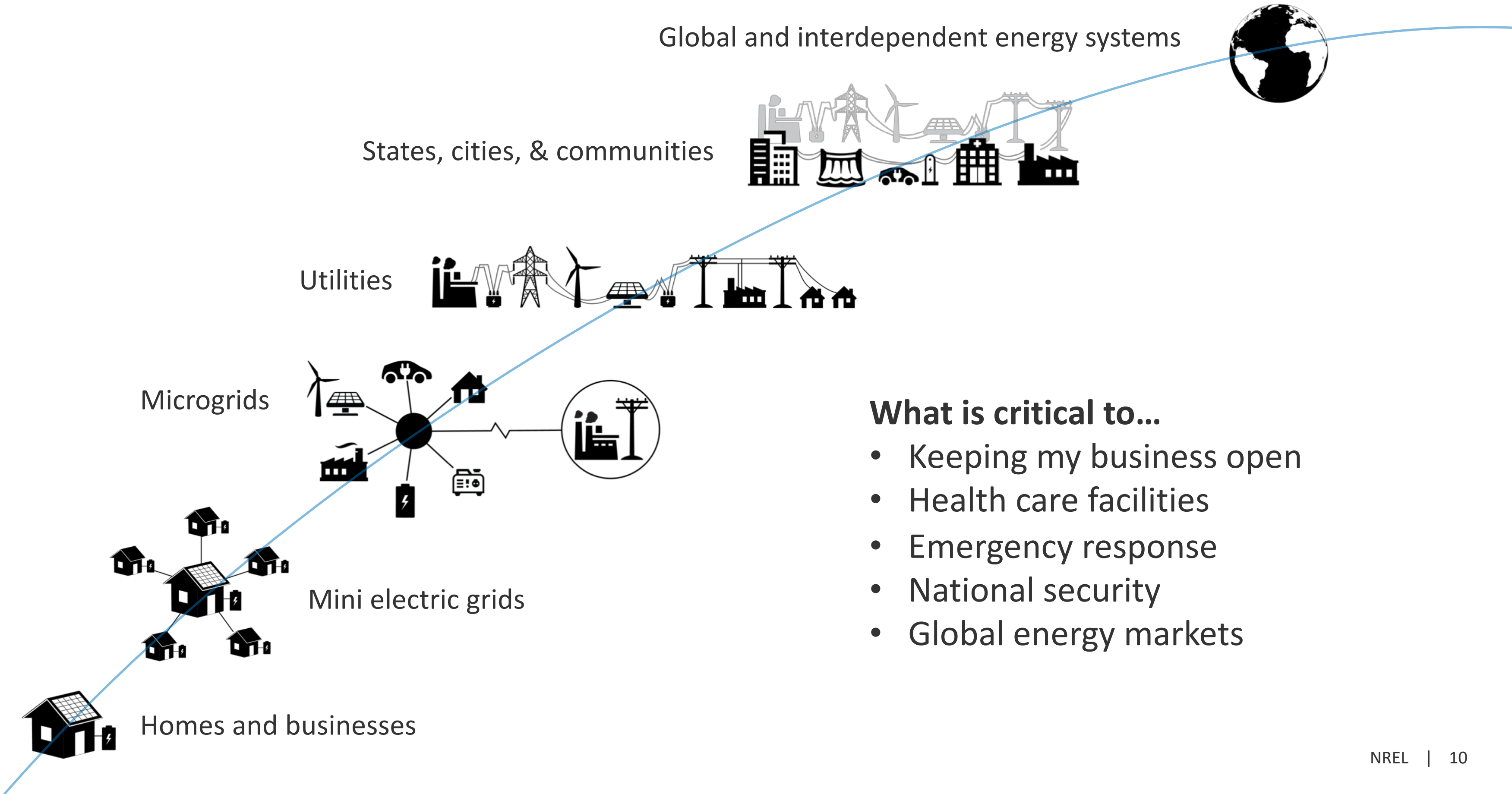

Perspective from Gary Larson.




Example of quantifying resilience from materials science (image credit: engineeringarchives.com)

# Step 1: Perspective

*What* matters to you?




**What is critical to…**

- Keeping my business open
- Health care facilities
- Emergency response
- National security
- Global energy markets

# Step 2: Metrics for Resilience

*Depends on your perspective*

## Many metrics have been proposed, but no agreement on the best measures.

A few examples:

**Utility** perspective

- Customer-hours of outages
- Customer energy not served
- Avg (or %) customers experiencing an outage during a specific time period
- Cost of damages

**Community** perspective

- Critical services without power after backup fails
- Key military facilities w/o power

**Business** perspective

- Lost revenues, assets, and/or perishables

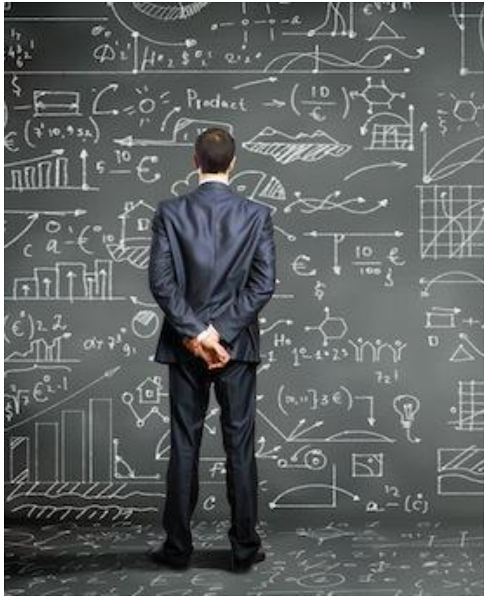


Image credit: 1to1media.com

Credit to: Caitlin Murphy at NREL for summary of existing metrics (only a cross-sample shown here).
See https://gridmod.labworks.org/sites/default/files/resources/GMLC1%201_Reference_Manual_2%201_final_2017_06_01_v4_wPNNLNo_1.pdf for more.

# Step 3: Value of Resilience

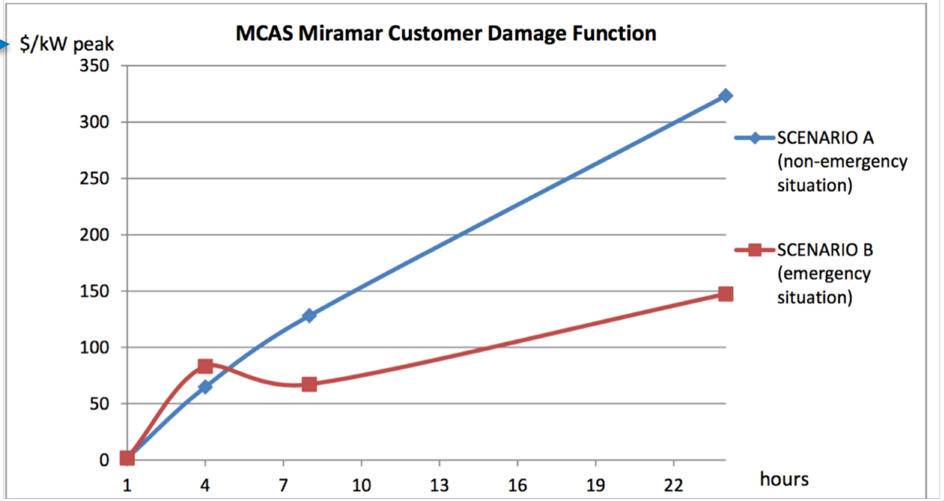
*How do you value what matters to you?*

## Macroscopic example

$$Outage\ Cost\left[\frac{\$}{kWh}\right] = \frac{GNP\ (or\ GDP)\ in\ \$}{Total\ Annual\ Energy\ Consumption\ in\ kWh}$$

$/metric

## Microscopic example




**Note the time varying value – currently integrating into REopt**

J. Giraldez, S. Booth, K. Anderson, and K. Massey, "Valuing Energy Security: Customer Damage Function Methodology and Case Studies at DoD Installations". NREL/ TP-7A30-55913, October 2012

# Key Challenge 2: the Value of Resilience

**Perspective**

*What* matters to you?

**Metric**

How you *quantify resilience*

**Value**

How do you *assign value*?

We made this problem tractable by considering:

1. **Perspective =** commercial building
2. **Metric =** unmet critical load [kWh]
3. **Value = Value of Lost Load** (VoLL) [$/kWh] ~willingness-to-pay

(And addressed the control challenge using REopt)

# Solar PV & Storage for Resilience

Balance
cost of system
with
grid-connected
benefits …

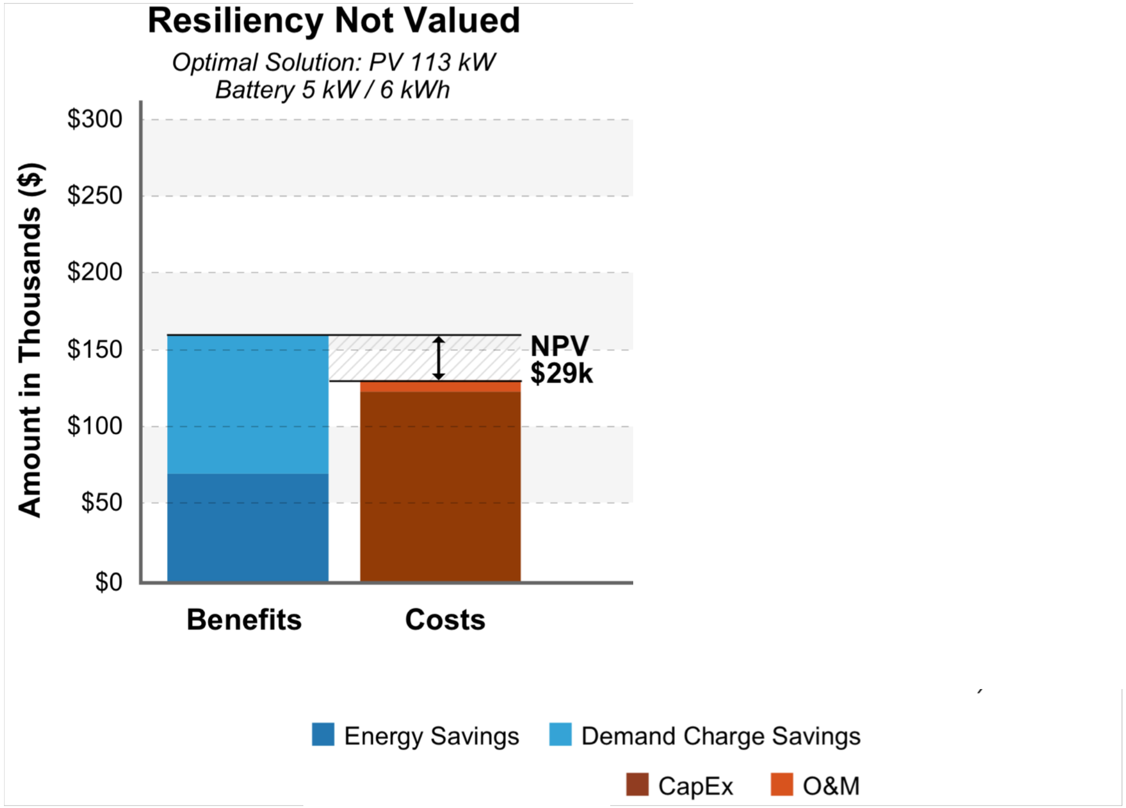



Figure source: Laws, Nicholas D., Kate Anderson, Nicholas A. DiOrio, Xiangkun Li, and Joyce McLaren. "**Impacts of Valuing Resilience on Cost-Optimal PV and Storage Systems for Commercial Buildings**." Renewable Energy, Volume 127, **2018**, Pages 896-909, https://doi.org/10.1016/j.renene.2018.05.011.

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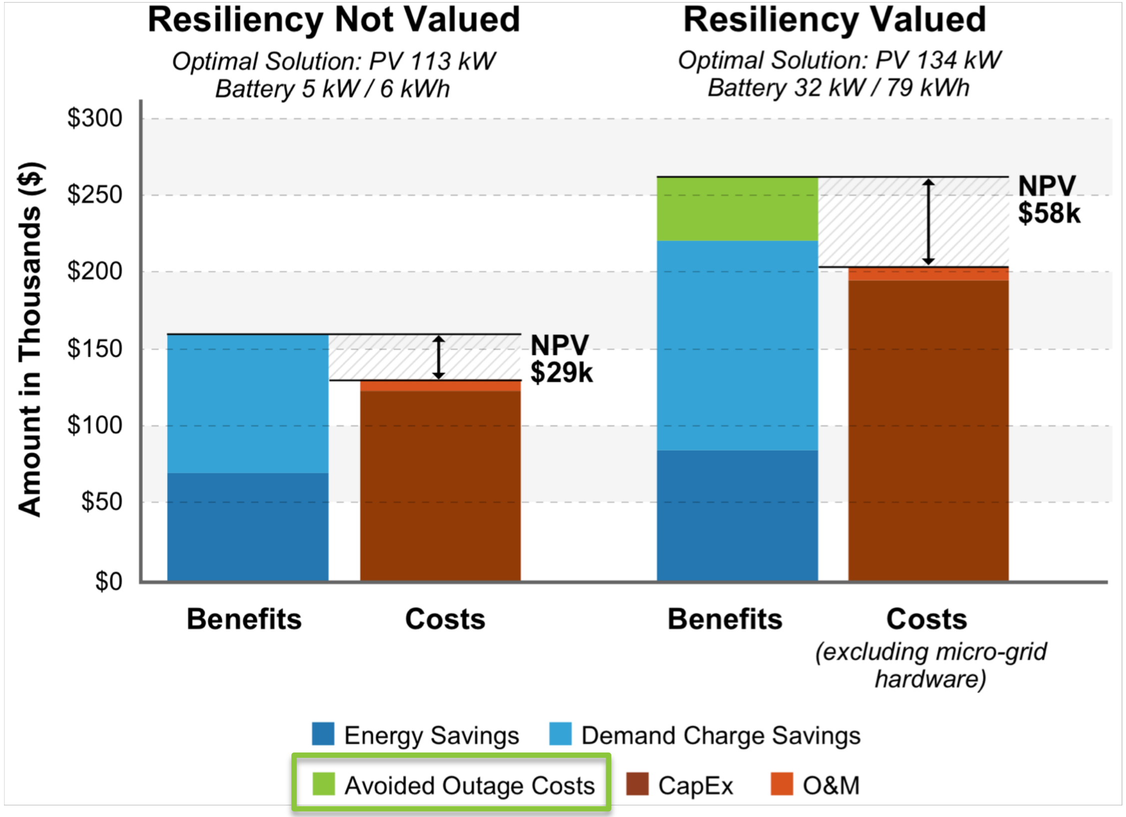


... *and* **resiliency benefits.**

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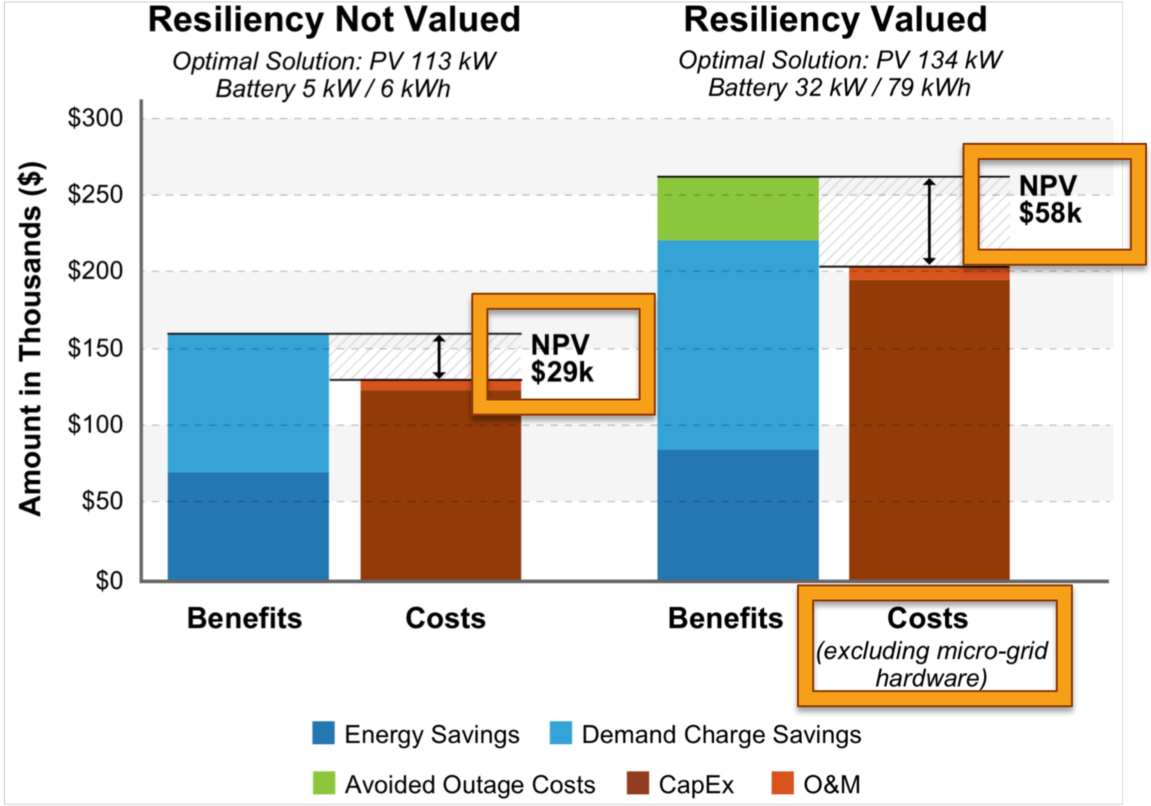
# Solar PV & Storage for Resilience

## The maximum islandable premium is the difference of the Net Present Values (NPV).

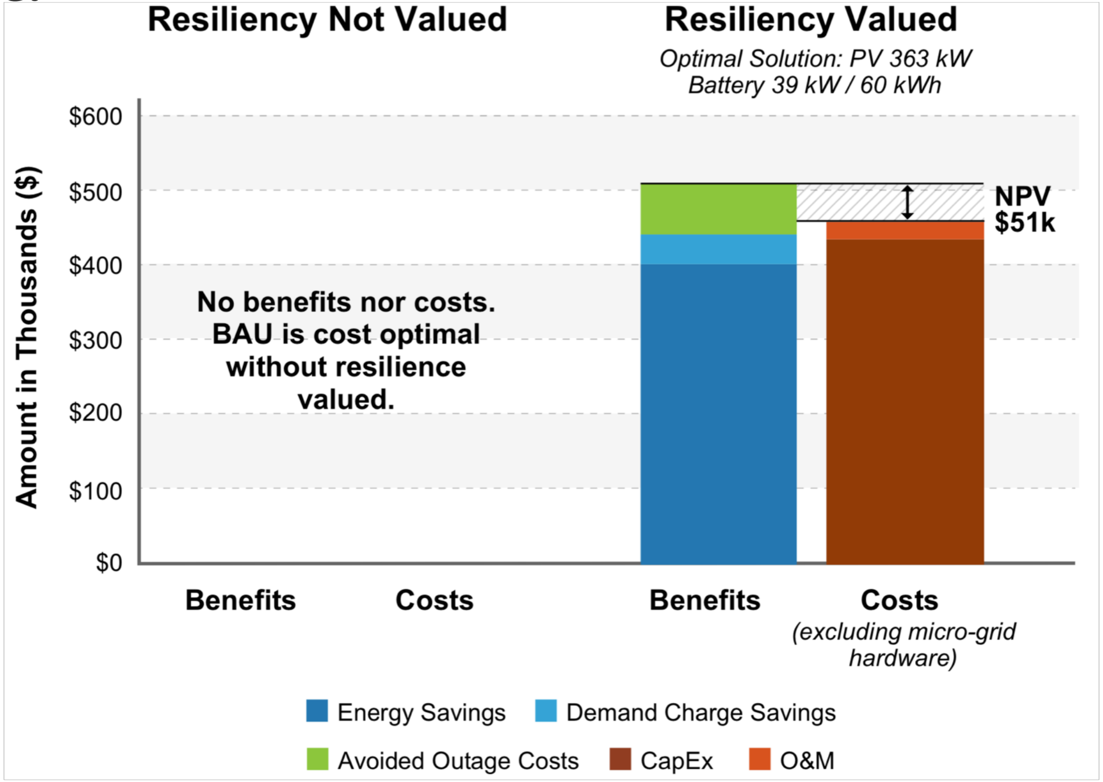



$$I_{max} = \text{NPV}_{resilient} - \text{NPV}$$

Figure source: Laws, Nicholas D., Kate Anderson, Nicholas A. DiOrio, Xiangkun Li, and Joyce McLaren. "**Impacts of Valuing Resilience on Cost-Optimal PV and Storage Systems for Commercial Buildings**." Renewable Energy, Volume 127, **2018**, Pages 896-909, https://doi.org/10.1016/j.renene.2018.05.011.

# Solar PV & Storage for Resilience

**In some cases, valuing resilience can make PV and storage cost effective where it was not before.**

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# Ongoing work

How can we ***monetize*** the Value of Resilience?

Banking, Insurance

- lower rates for lower risk assets

Government incentives

- ITC could include islandable premium

# Thank you

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# Back up slides

# Methods for Determining VoLL

## Direct (survey)

- Blackout studies
  - record real damage costs after event
- Willingness to pay for avoidance
- Direct costs
  - from hypothetical scenarios

## Indirect

- Production function
  - estimate costs from lost production (commercial/industrial) or lost time (residential, using household income)
- Revealed preferences
  - equivocate outage costs with money spent on mitigation measures, such as backup power supply and interruptible supply contracts

Schroder and Kuckshinrichs. "Value of Lost Load: An efficient economic indicator for Power Supply Security? A Literature Review ". Frontiers in Energy Research (2015) **3.**
de Nooij *et al.* "The value of supply security; The costs of power interruptions: Economic input for damage reduction and investment in networks". Energy Economics (2007) **29** 77-295.