NREL
Transforming ENERGY

Energy Resilience Through Grid Modernization and Renewables Integration

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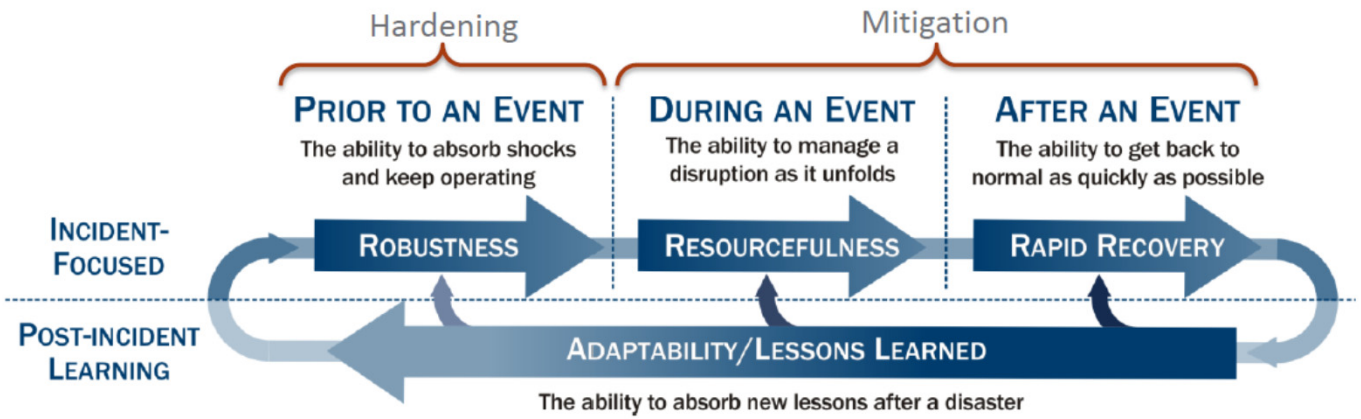
A Definition of Resilience

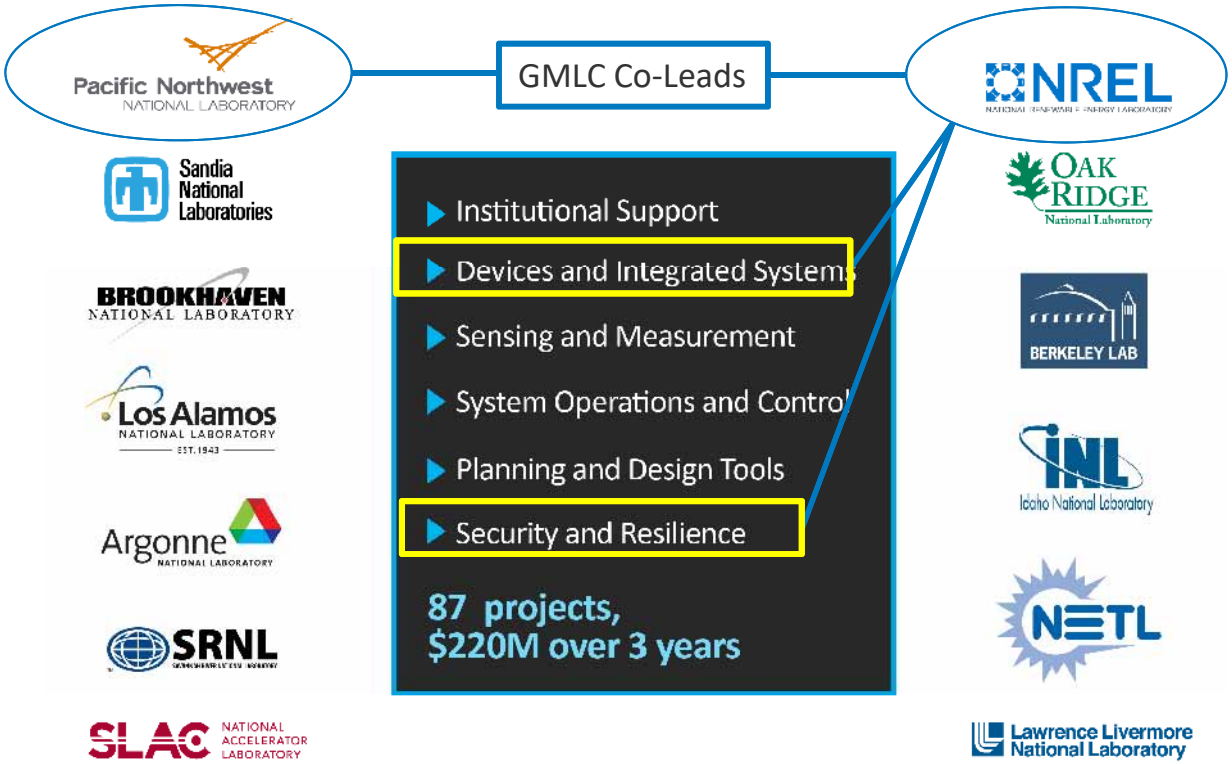
The ability to **anticipate**, **prepare for**, and **adapt** to changing conditions and **withstand**, **respond** to, and **recover** rapidly from disruptions through adaptable and holistic planning and technical solutions.

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



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
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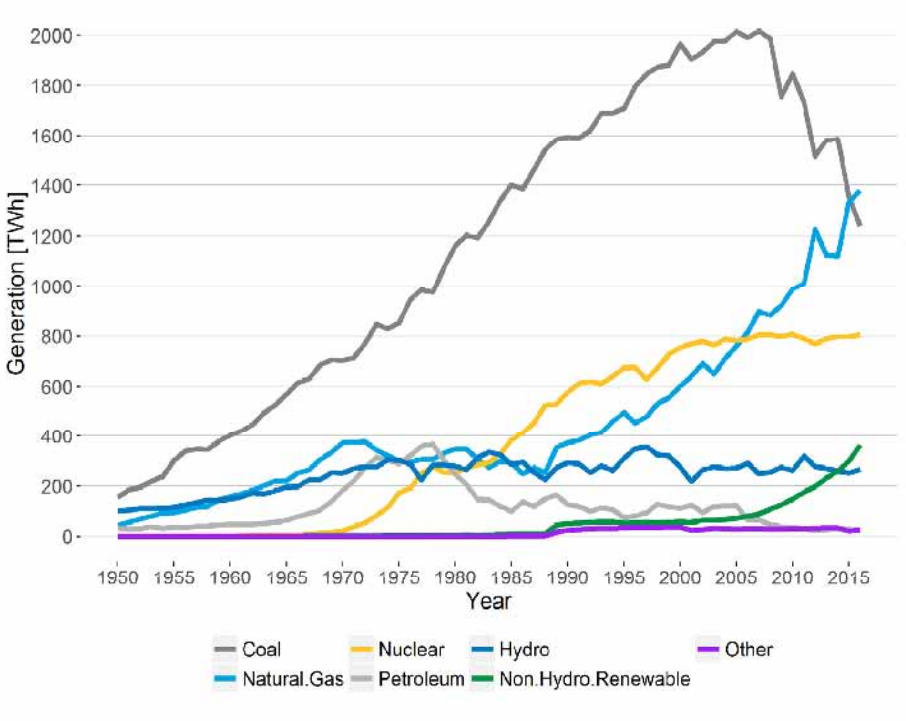
Example GMLC Resilience Projects

- 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



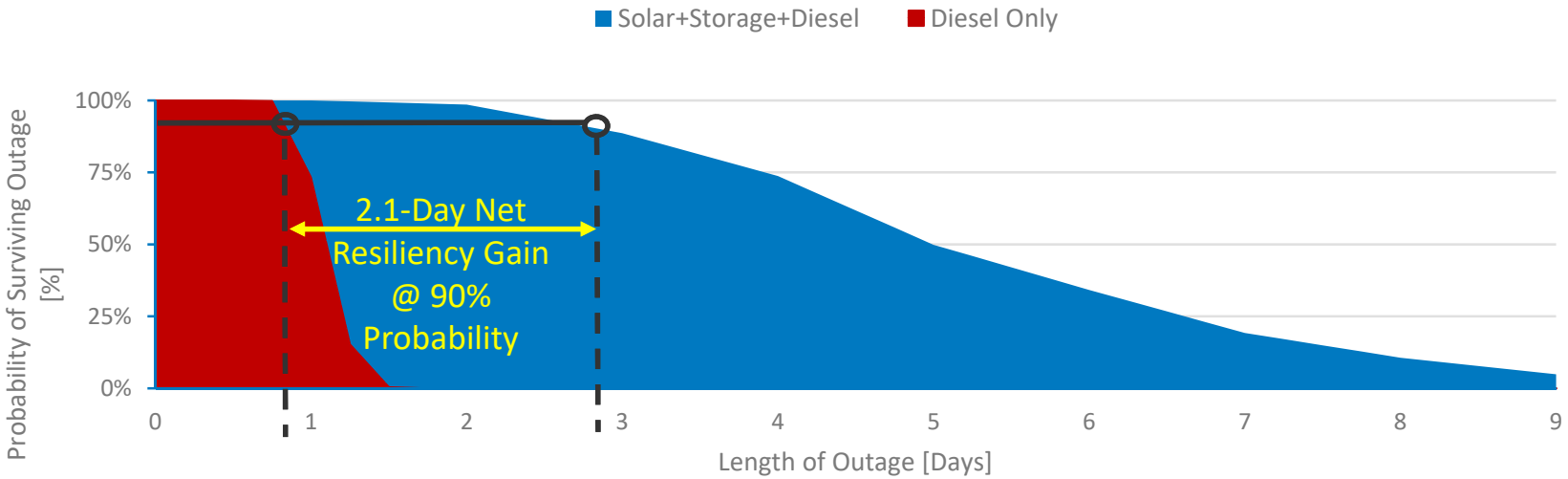
Source: EIA

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



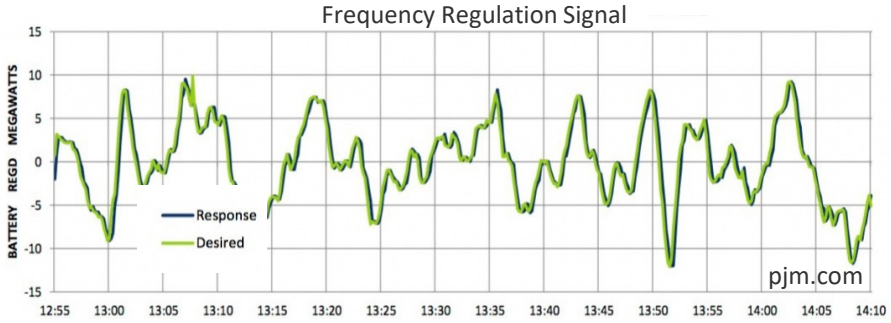
- Diesel sensitivity to fuel supply chains
  - especially in extreme weather events, which along with outages are increasing.
- Diesel back-up often neglected
  - high probability of failure; single point of failure
- RE systems have additional grid-connected benefits
  - diesel usually precluded due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

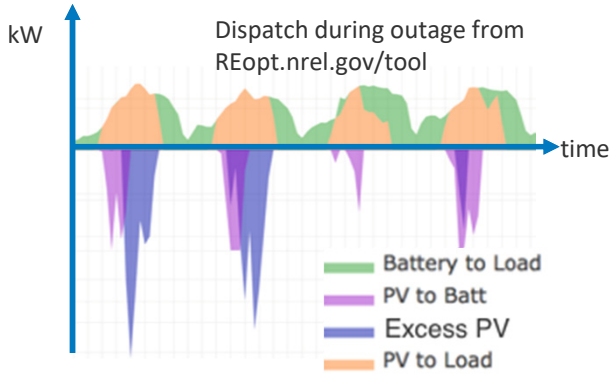
Key Challenge 1: Control Systems

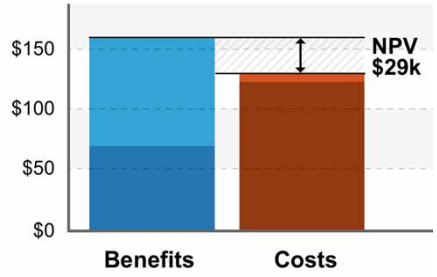
With advanced, autonomous **control systems** we can:

provide grid support services,



meet critical loads during outages,





and reduce operating costs for system owners.

Key Challenge 2: the Value of Resilience

Perspective

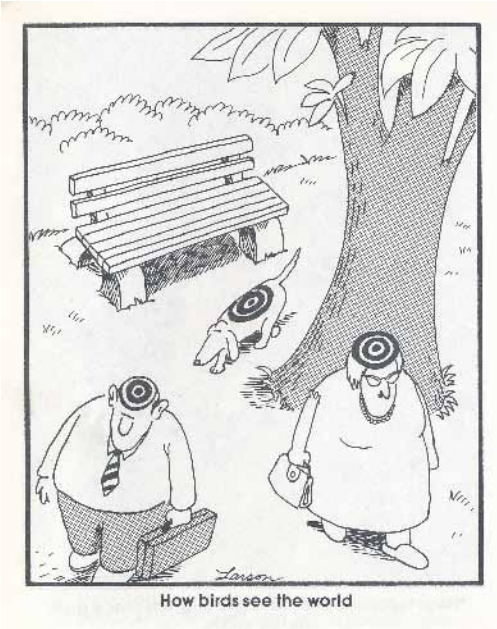
What matters to you?

Metric

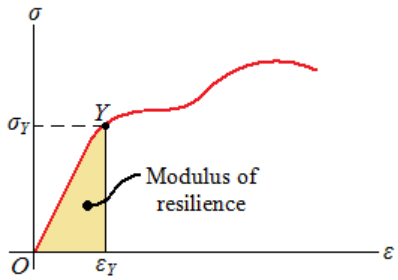
How you *quantify resilience*

Value

How do you *assign value*?



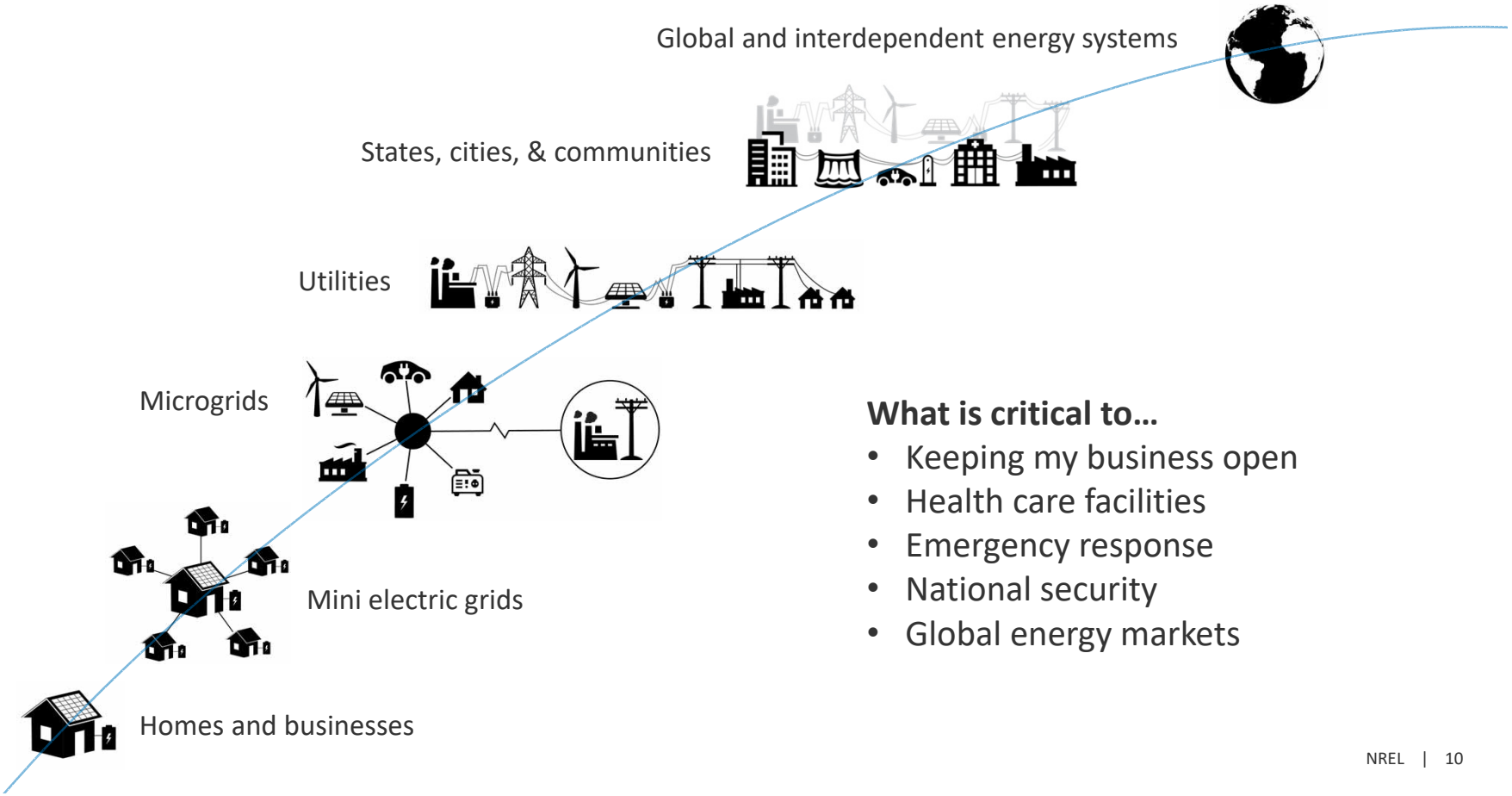
Perspective from Gary Larson.



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

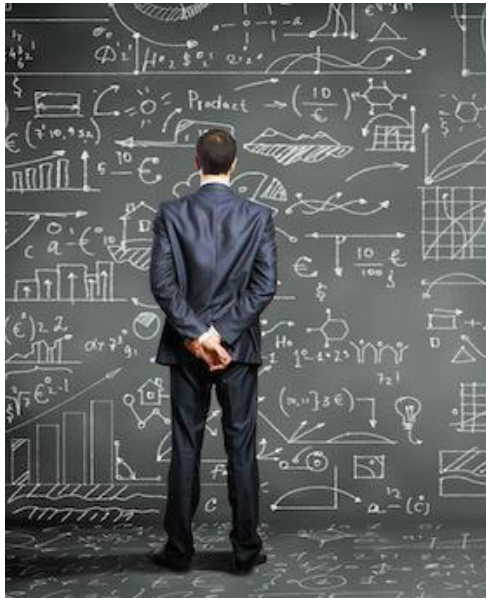


Image credit: 1to1media.com

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

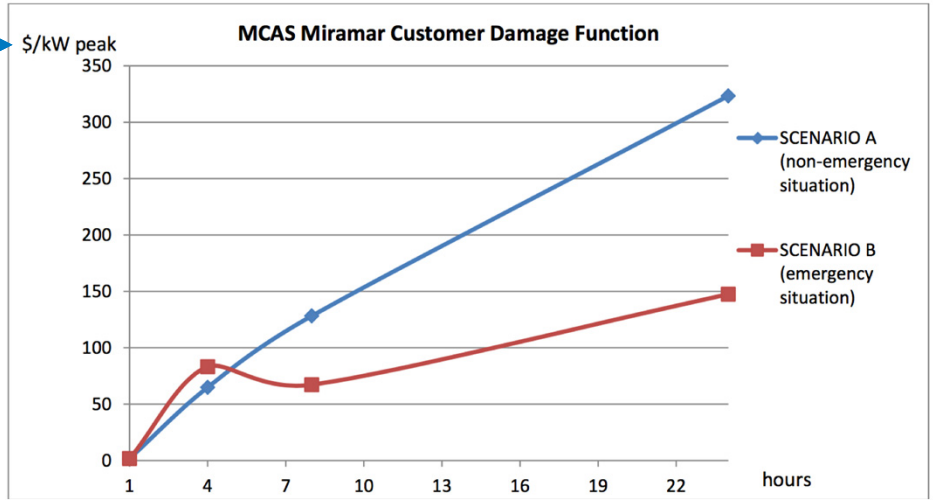
How do you value what matters to you?

Macroscopic example

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

$/metric

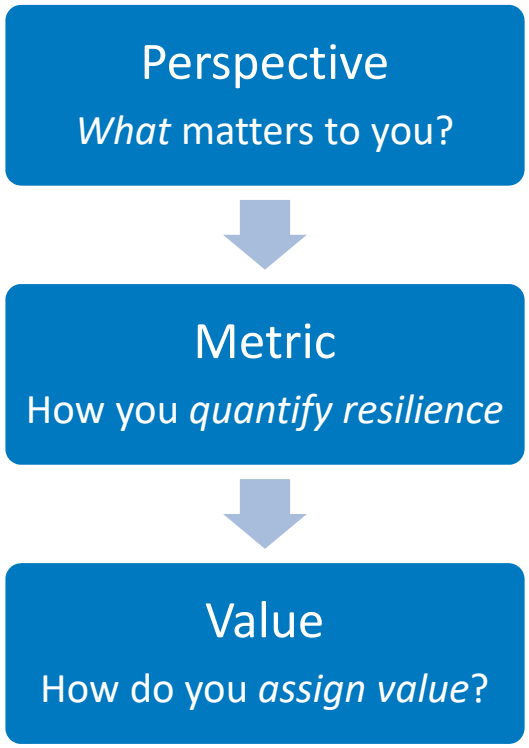
Microscopic example



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



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 ...

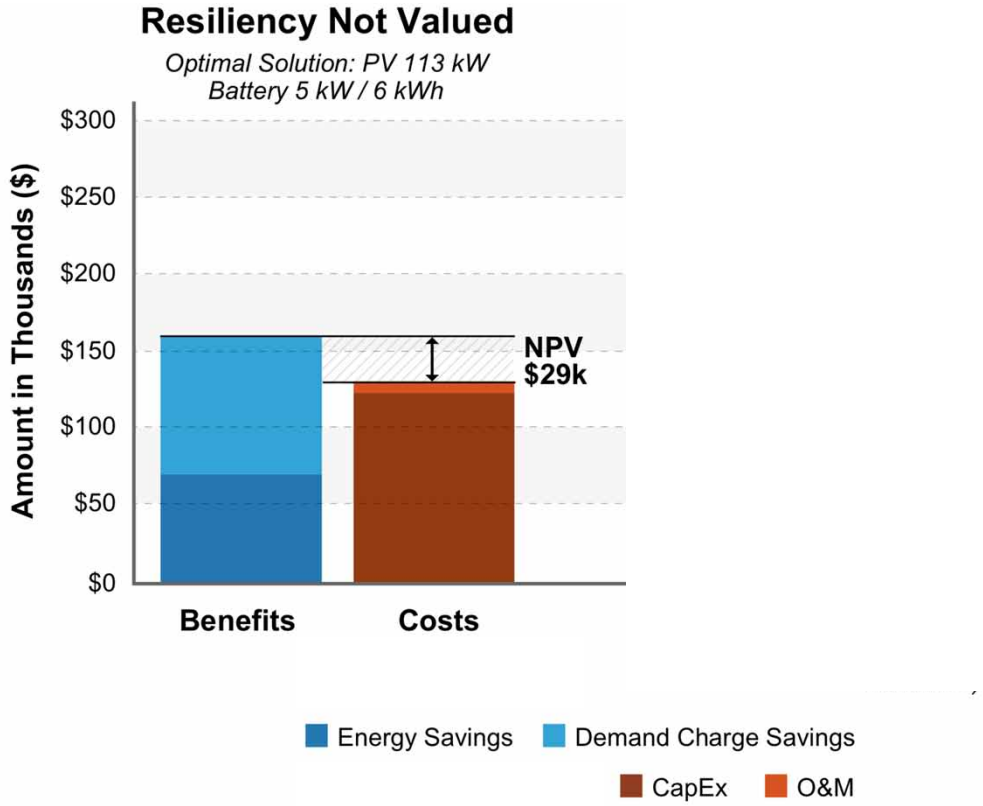


Figure source: Laws, Nicholas D., Kate Anderson, Nicholas A. DiOrio, Xiangkun Li, and Joyce McLaren. "**Impacts of Valuing Resilience on Cost-Optimal PV and Storage Systems for Commercial Buildings**." Renewable Energy, Volume 127, **2018**, Pages 896-909, https://doi.org/10.1016/j.renene.2018.05.011.

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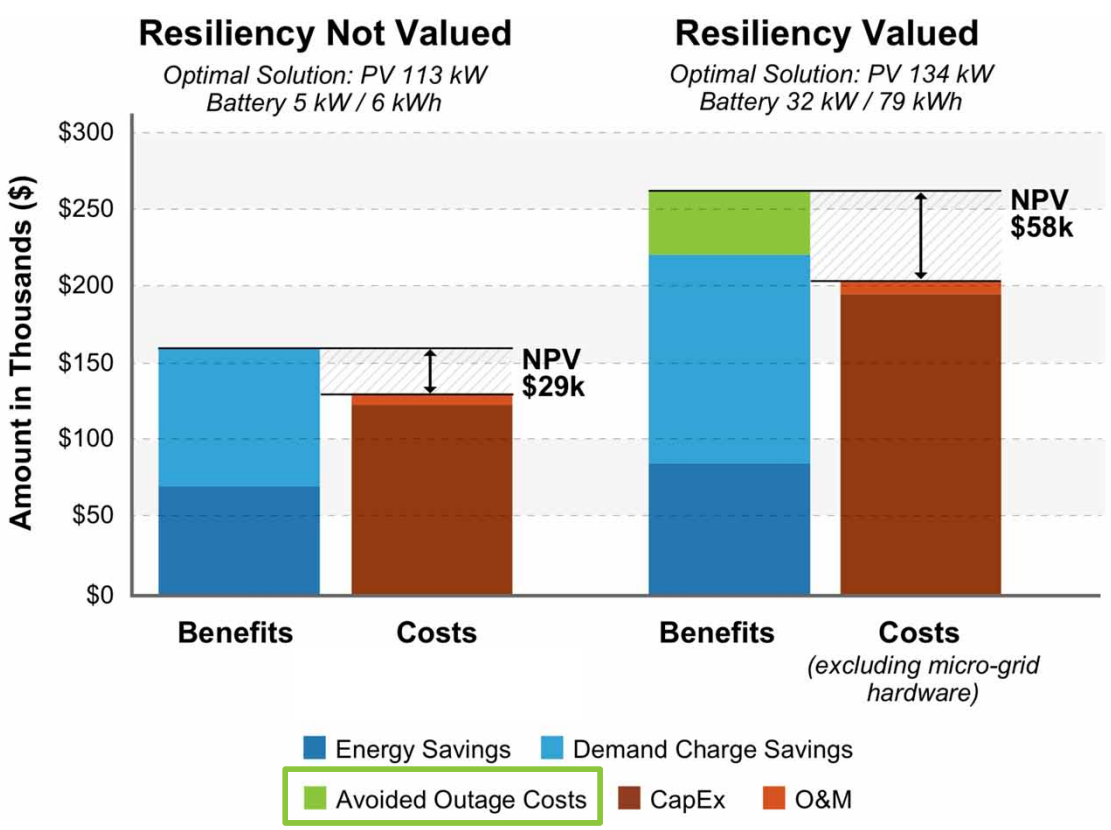

... and
resiliency benefits.

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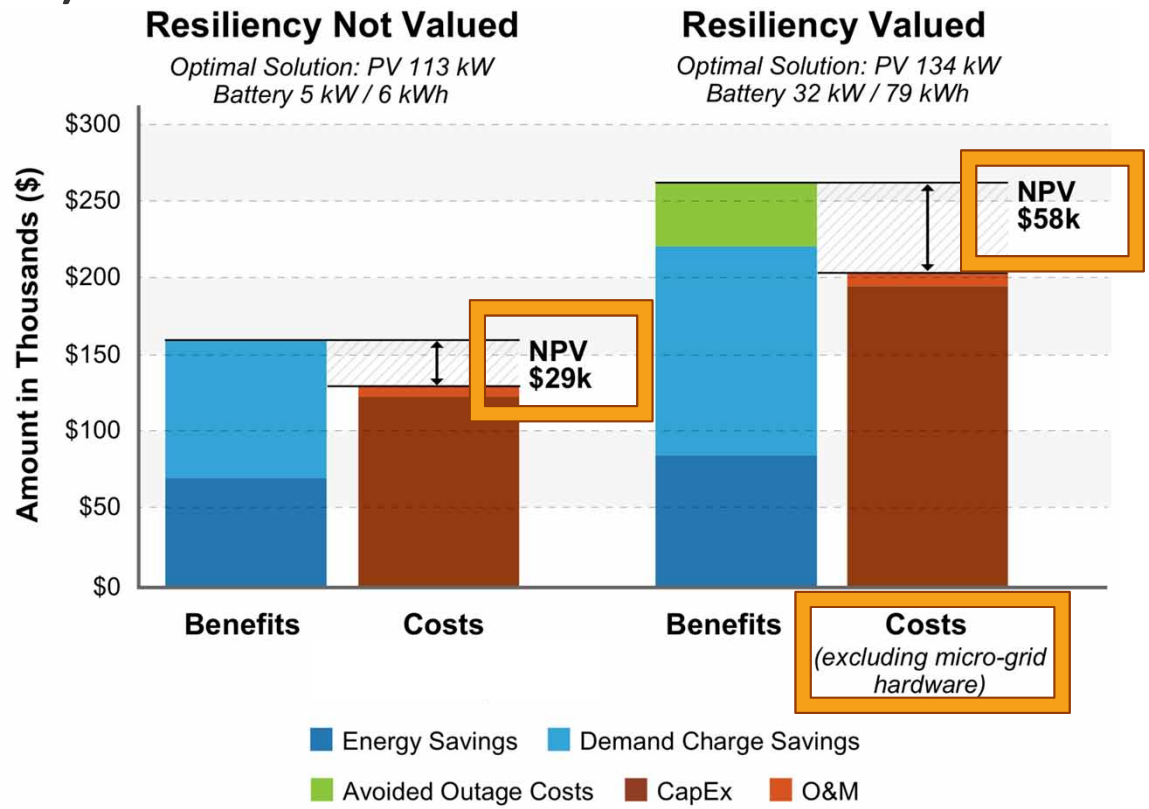
Solar PV & Storage for Resilience

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

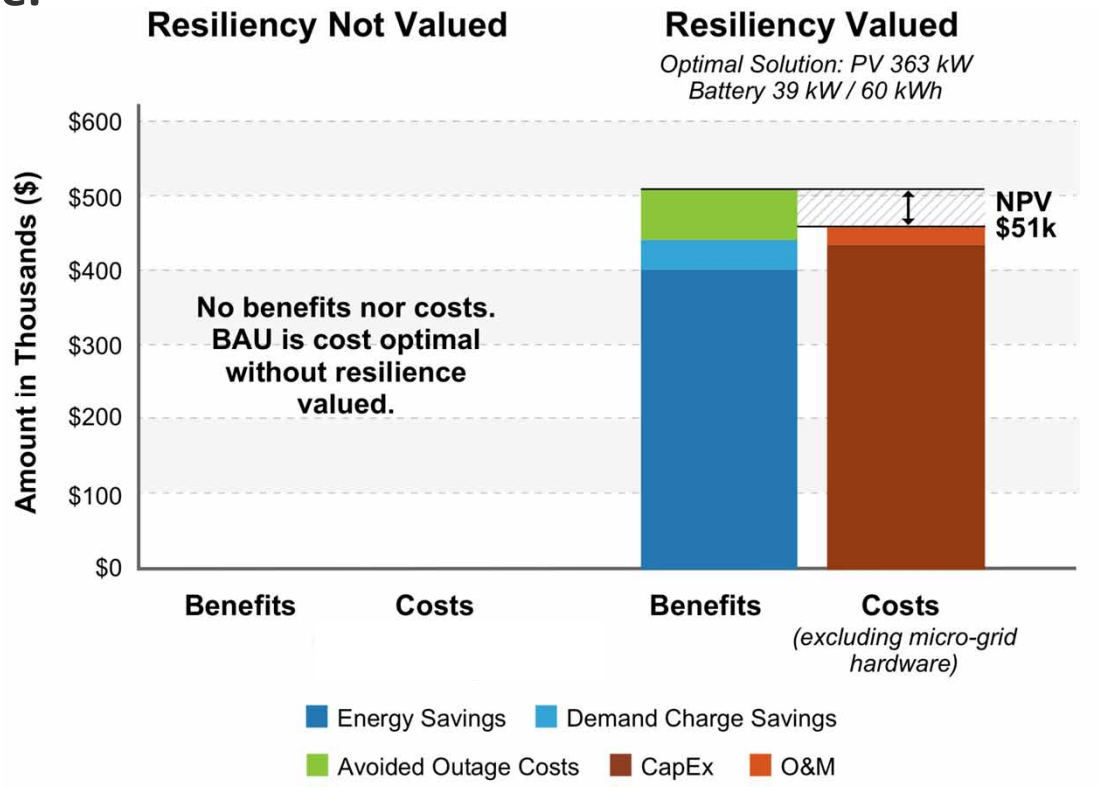


$$I_{max} = \text{NPV}_{resilient} - \text{NPV}$$

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.