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MICROGRIDS

Benefits, metrics, applications, and state-level programs

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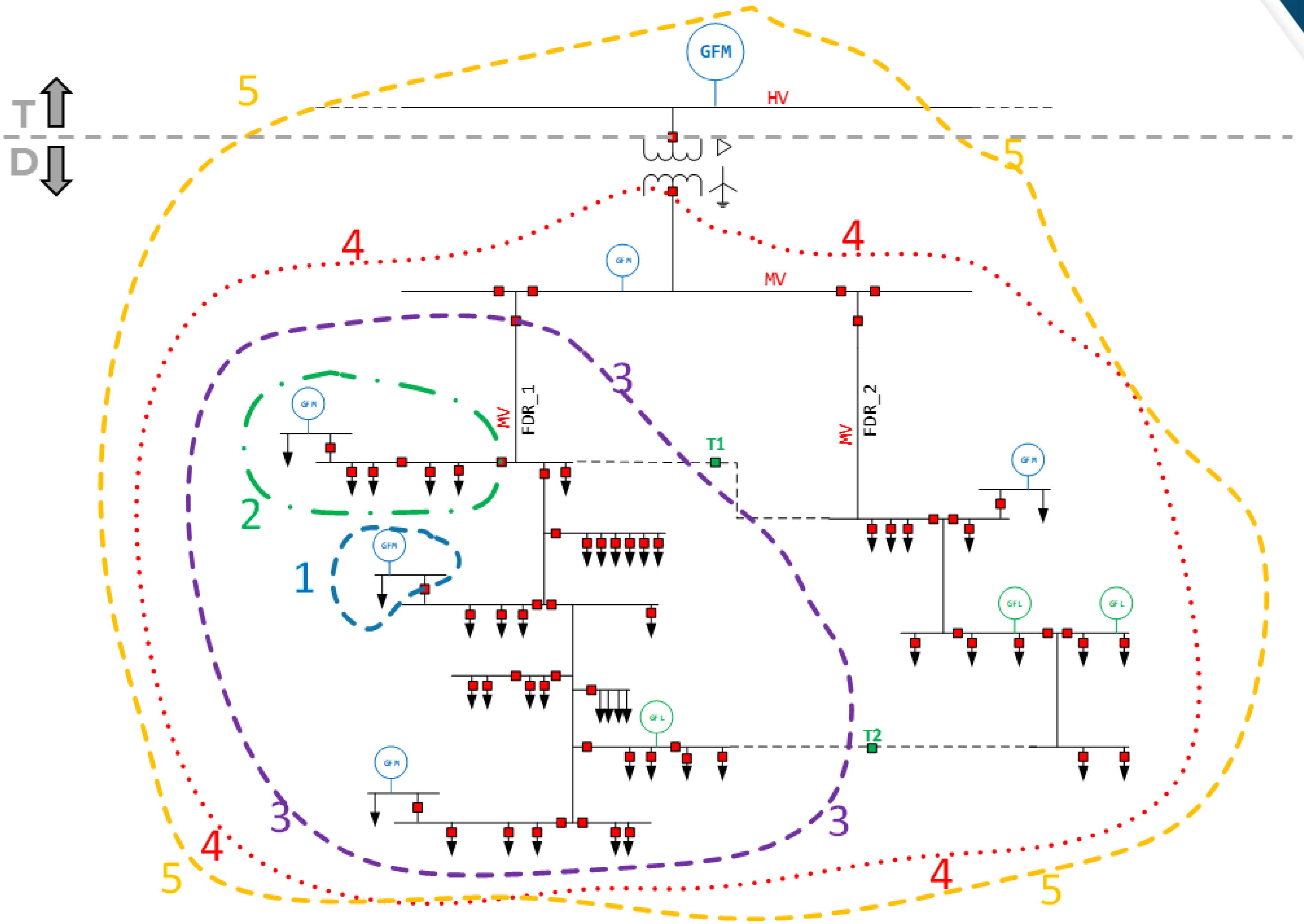
WHAT IS A MICROGRID?

- **From the Oxford English Dictionary:**

Microgrid: a small network of electricity users with a local source of supply that is usually attached to a centralized national grid but is able to function independently.

- **The DoE definition:**

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries **that acts as a single controllable entity with respect to the grid**. **A microgrid can operate in either grid-connected or in island mode**, including entirely off-grid applications.

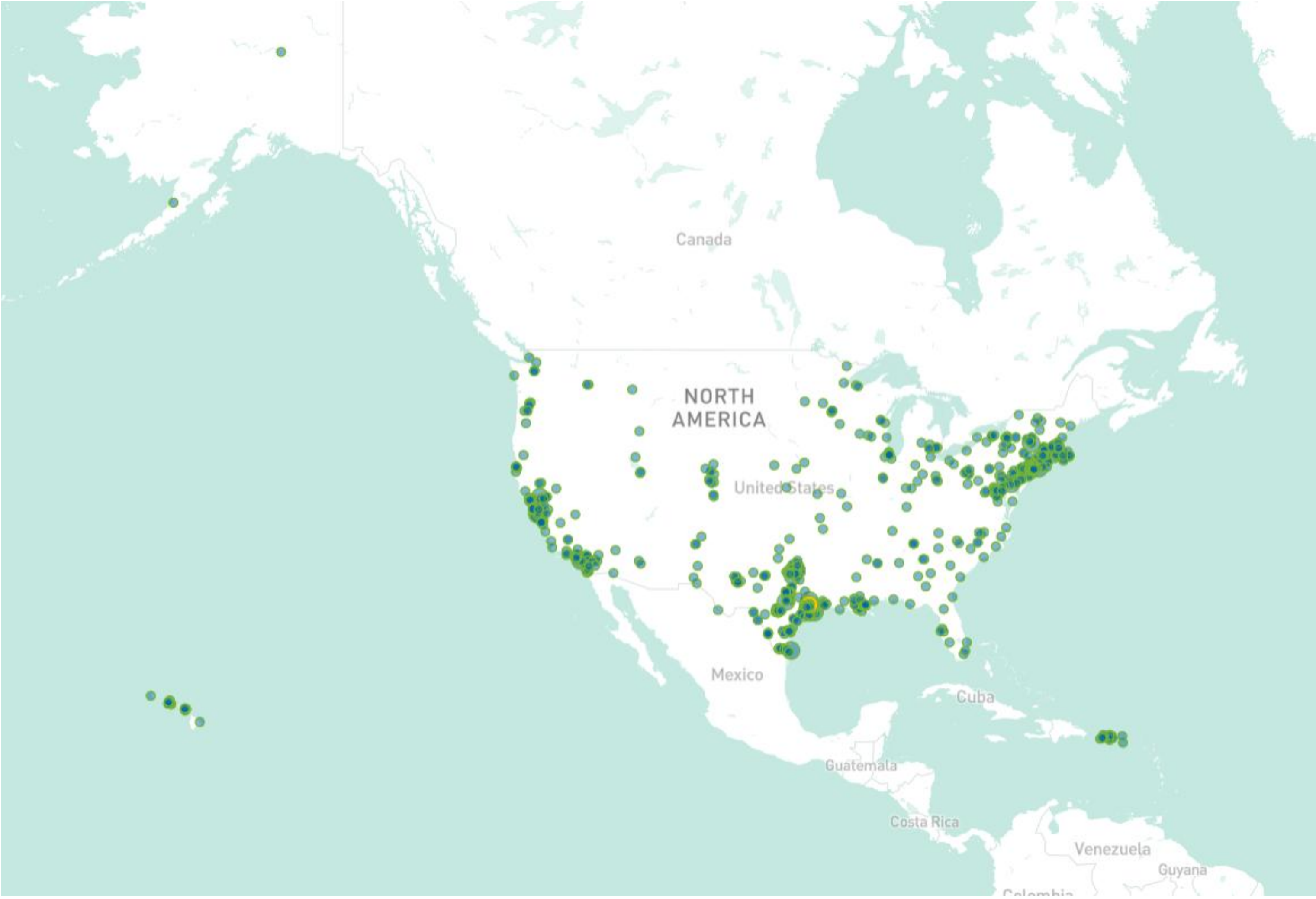


MICROGRIDS IN THE USA

The Microgrid Installation Database includes 461 installations, utilizing a variety of technologies.

Many are located along the Gulf coast and in New England because of past history with storm-caused outages.

Many are located in California because of a combination of risk factors coupled with relatively high power prices.



https://www.onsite-energy-installations.ornl.gov/?page=1&size=20

Individual facility microgrid: packaged natural gas-driven microgrids built by Enchanted Rock, powering H-E-B stores across Texas.

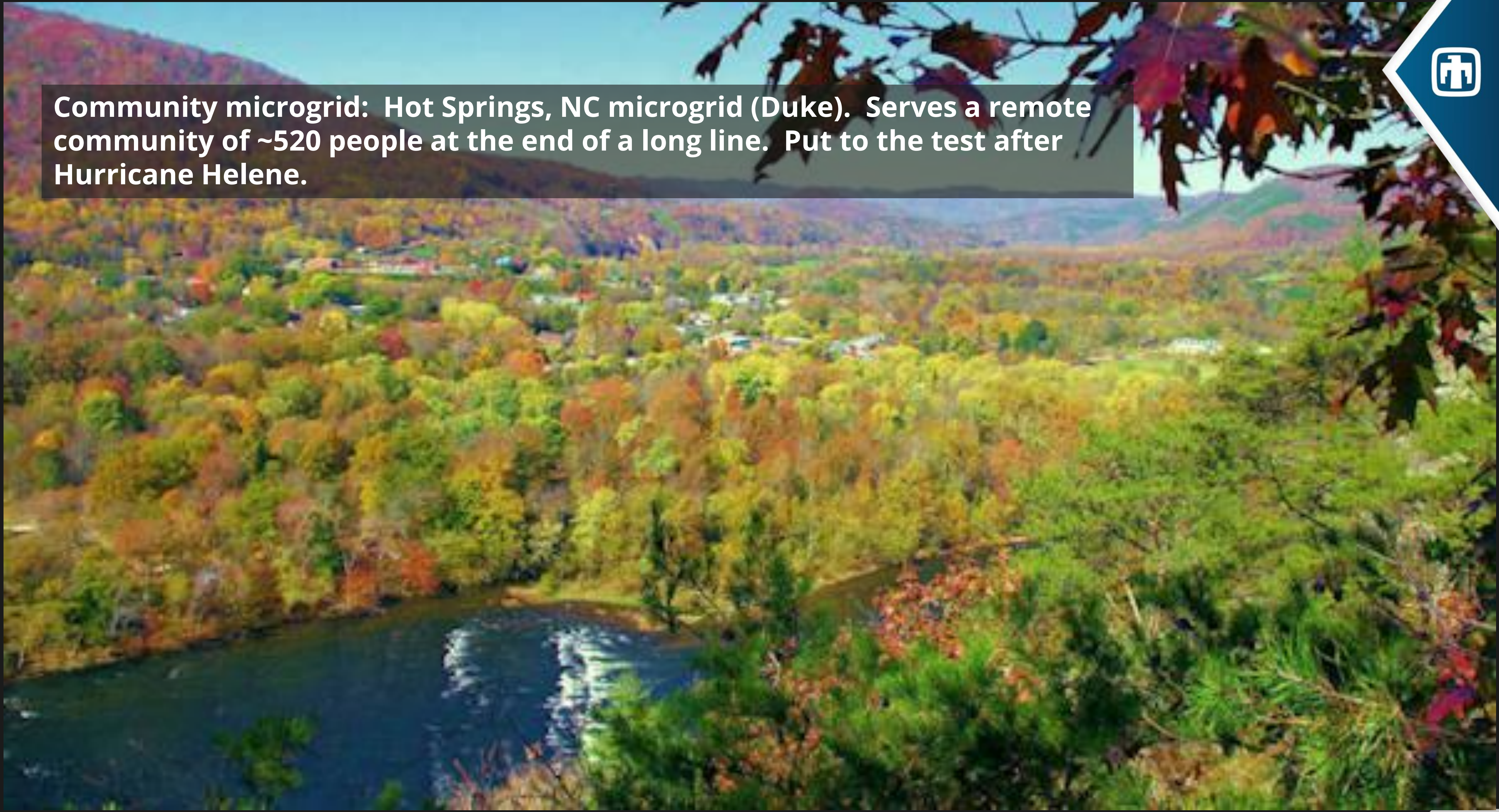
Campus microgrid: Princeton University, gas-fired CHP, thermal and electrical storage. Serves the campus, a highly urban area. Was put to the test during/after Hurricane Sandy.

Campus microgrid: Tulane University. Third-party contract for energy as a service. Centered on campus CHP plant.

Community microgrid: Paradise, CA microgrid (SDG&E). Battery only, serves specific critical loads in the community.

Community microgrid: Redwood Coast Airport Microgrid, McKinleyville, CA (PG&E and Redwood Coast Energy Authority). Front-of-meter, multi-customer microgrid. Serves the airport and the Humboldt Bay Coast Guard station. Commissioned in 2022.

Community microgrid: Borrego Springs, CA (SDG&E). Multi-customer microgrid serving a rural community of about 3000 people at the end of a long line over challenging terrain. Has mitigated many interruptions.



Community microgrid: Hot Springs, NC microgrid (Duke). Serves a remote community of ~520 people at the end of a long line. Put to the test after Hurricane Helene.

AGGREGATION OF DERs (ADER) AND CONTROLLABLE LOADS WHILE ON-GRID

A microgrid's DERs and controllable loads can be aggregated while the microgrid is on-grid.

This aggregate can be controlled to appear to the grid as a single entity. This arrangement can provide a number of services (see graphic at right), which can be economically beneficial depending on how markets are set up. Example:

- **Grid operator requires 500 kW increase from the aggregate**
- **Aggregate responds with +200 kW of energy storage, +150 kW of diesel generation, and -150 kW of controllable load**

(Note: the IEEE definition of DER does *not* include controllable loads, but other definitions, such as the CA Energy Commission's, do. This gets confusing.)

Table 5: ADERs and Bulk Power System Grid Services

			ADERs Capable of Providing the Grid Service[60]		
Type	Bulk Power System Grid Service	ADER Ability	Generation DERs	Storage DERs	Demand DERs
Energy & Capacity	*Energy*: The amount of electricity a resource can provide (measured in megawatt-hours [MWh] or kilowatt-hours [kWh]). Providing energy to the grid is necessary to serve demand.	Individual DERs provide energy at the distribution level (e.g., [redacted]). ADERs can provide energy to the bulk power system (e.g., aggregated EVs).	✔	✔	
	Energy Imbalance: The differential between scheduled and delivered energy over a one-hour time window.	ADERs are able to respond to energy imbalance in the bulk power system.	✔	✔	✔
	Capacity: The potential to generate or reduce electricity when needed (measured in megawatts [MW] or kilowatts [kW]). Grid operators use estimates of available capacity to plan how to supply energy at various increments of time (e.g., a day before, an hour before).	ADERs can meet capacity requirements by agreeing to provide energy needs for a future time. Forward planning is required and may include ADERs "load building" by demanding additional energy from the grid (e.g., charging energy storage) or "load reducing" by reducing ADER electric load (e.g., a smart thermostat demand response program). ADERs may contract months to years in advance for the provision of capacity to the bulk power system, and/or participate in capacity markets.	✔	✔	✔
	Transmission Capacity Infrastructure Relief: The use of grid resources to defer or avoid the reinforcement of the transmission grid.	If ADERs can provide transmission capacity management, they may be able to defer or avoid new transmission infrastructure build out.	✔	✔	✔
Essential Reliability Service[61]	*Regulating Reserve:* Resources with a rapid response time (minute to minute) are leveraged during normal operations to maintain the grid's operating frequency and regulate unintended fluctuations in generator output.	DERs, [redacted] can increase the need for regulating reserves due to impacts on net demand; ADERs can provide this grid service.	✔	✔	

https://connectedcommunities.lbl.gov/sites/default/files/2024-07/NARUC_ADER_Fundamentals_Interactive.pdf

USING AGGREGATED DERs (ADERs)

ADERs are being used to provide some of these services in the US already.

Service Category	Grid Service	Provided by ADERs in the U.S. as of early 2024?	Example
Bulk Power System Grid Services	Energy	Yes	[redacted]
	Energy Imbalance	No	
	Capacity	Yes	National Grid Connected Solutions Bring Your Own Device (BYOD) Program in Massachusetts[7] Central Hudson NWS in New York[78] Holy Cross Power Plus Program[79]
	Regulated Reserves	No	
	Inertial Response	No[80]	
	Fast Frequency Response	Yes	Hawaiian Electric Power Partners and Energy Scout Programs[81]
	Primary Frequency Response	Yes	ERCOT Demand Response in Texas[82]
	Secondary and Tertiary Frequency Response	Yes	NYISO Demand-Side Ancillary Service Program in New York[83]
	Reactive Power and Voltage Support (System)	Yes	Mosaic Power, Multiple States[84]
	Ramping Reserves	No	
	Black Start	No	Currently being field tested[85]

Service Category	Grid Service	Provided by ADERs in the U.S. as of early 2024?	Example
Distribution Grid Services	Energy	No	Net Energy Metering (NEM)[86]
	Distribution Capacity	Yes	Consumers Energy NWS in Michigan[87]
	Distribution Level Voltage Reactive Power	No	
	Power Quality	No	
	Resilience	Yes	Energy Vault in California[88]
Grid Edge Services	Energy	Yes	[redacted]
	Distribution Voltage-Reactive Power	No	
	Power Quality	No	
	Resilience	Yes	Green Mountain Power (GMP) BYOD Program in Vermont[89]

https://connectedcommunities.lbl.gov/sites/default/files/2024-07/NARUC_ADER_Fundamentals_Interactive.pdf

CASE STUDY: GREEN MOUNTAIN POWER

Green Mountain Power (GMP, state of VT) has a “Bring Your Own Device” (BYOD) and an “Energy Storage System” (ESS) program. BYOD gives customers a cash incentive if they grant GMP permission to control their device. ESS gives customers the opportunity to lease a device from GMP at low cost, with the device being GMP-owned and –controlled.

Element	Green Mountain Power
Cohort	Coral (within an organized market and utilities own some generation assets)
Price or Program?	Program
Incentive Structure[199]	**BYOD:** Up-front incentive of up to $10,500 **ESS:** Leased Powerwall at a reduced cost of $5,500 (or $55/month for a 10-year lease with up to an additional five years at no extra cost)
Load Control Method	Direct control
Program Designed By	Green Mountain Power
Program Implementer	Green Mountain Power
DERMS Provider	**BYOD:** Virtual Peaker **ESS:** Tesla
Customers Served	Residential
Technologies Included	Battery storage
Grid Services Provided	Generation Capacity (through reducing peak loads) • Reduced capacity obligation (ISO-NE Capacity Auction) • Reduced transmission charges for GMP service territory resilience

https://connectedcommunities.lbl.gov/sites/default/files/2024-07/NARUC_ADER_Fundamentals_Interactive.pdf

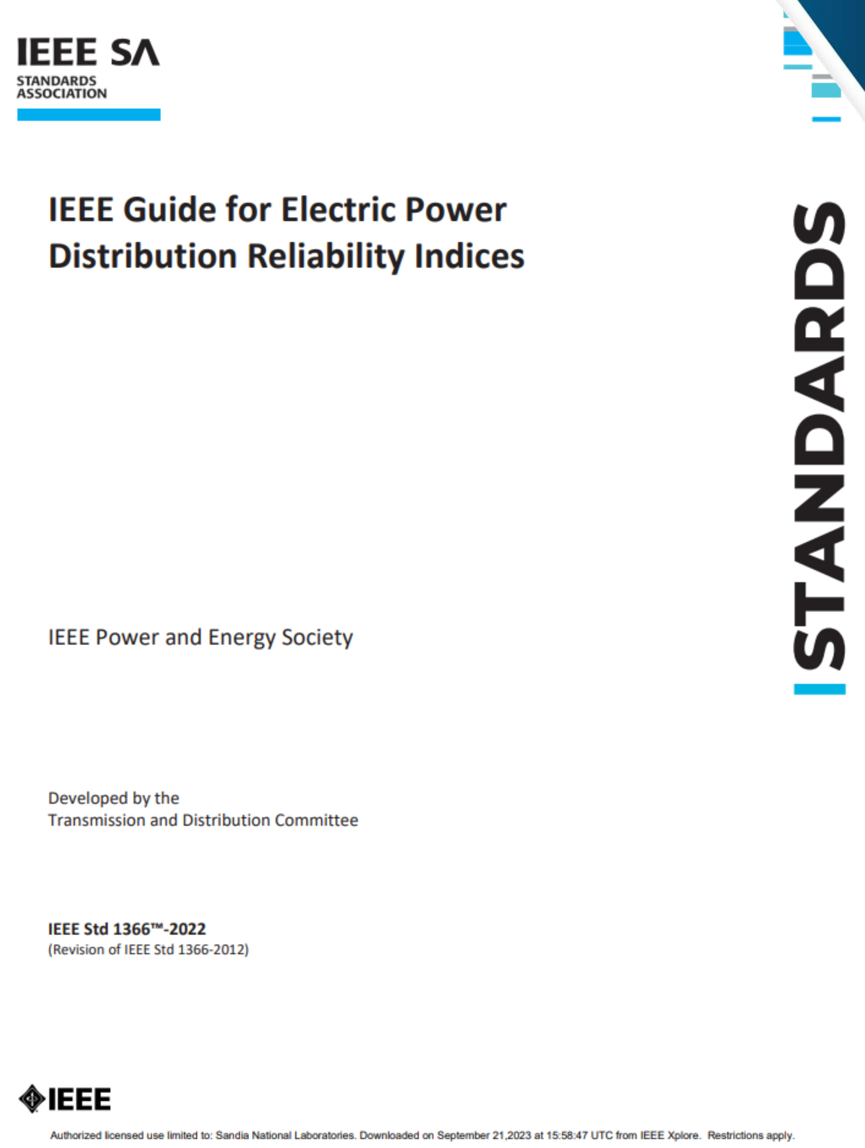
BENEFITS OF MICROGRIDS—WHY BUILD A MICROGRID?

The primary benefits of microgrids are that they improve the electric power system's

- ***Reliability***—ability of the power system to provide power when and where it is needed (related term: availability)
- ***Resilience***—ability of the system to maximally return to normal operations following a disruption

QUANTIFYING RELIABILITY: IEEE STD 1366

- Outage vs Interruption
  - Outage = piece of equipment is out of service (may or may not cause an interruption)
  - Interruption = customer is out of power
- **System Average Interruption Duration Index (SAIDI):** total duration for average customer during a time window.
- **System Average Interruption Frequency Index (SAIFI):** how often an average customer experiences a sustained (not momentary) interruption during a time window.
- **Customer Average Interruption Duration Index (CAIDI):** average time to restore service.
- **Customer Average Interruption Frequency Index (CAIFI):** average frequency of interruptions, for those customers experiencing any interruptions.
- **Average System Availability Index (ASAI):** fraction of time that the power system was available to provide power to a customer during a time window.


IEEE SA
STANDARDS ASSOCIATION

IEEE Guide for Electric Power Distribution Reliability Indices

IEEE Power and Energy Society

Developed by the
Transmission and Distribution Committee

IEEE Std 1366™-2022
(Revision of IEEE Std 1366-2012)

IEEE

STANDARDS

WHAT IS A MAJOR EVENT DAY?

A **Major Event Day (MED)** is a day on which the SAIDI of a system excludes a threshold value, which is called T_{MED}. T_{MED} is calculated using a formula defined in IEEE Std 1366-2022, using a five-year data set of daily SAIDI values.

The process for calculating T_{MED} is designed to provide a uniform reliability assessment across different-sized systems.

System operators typically report their reliability metrics including and excluding MEDs.

When discussing microgrids, we typically start from reliability metric data that includes MEDs, because MEDs are key events during which we want microgrids to benefit us.

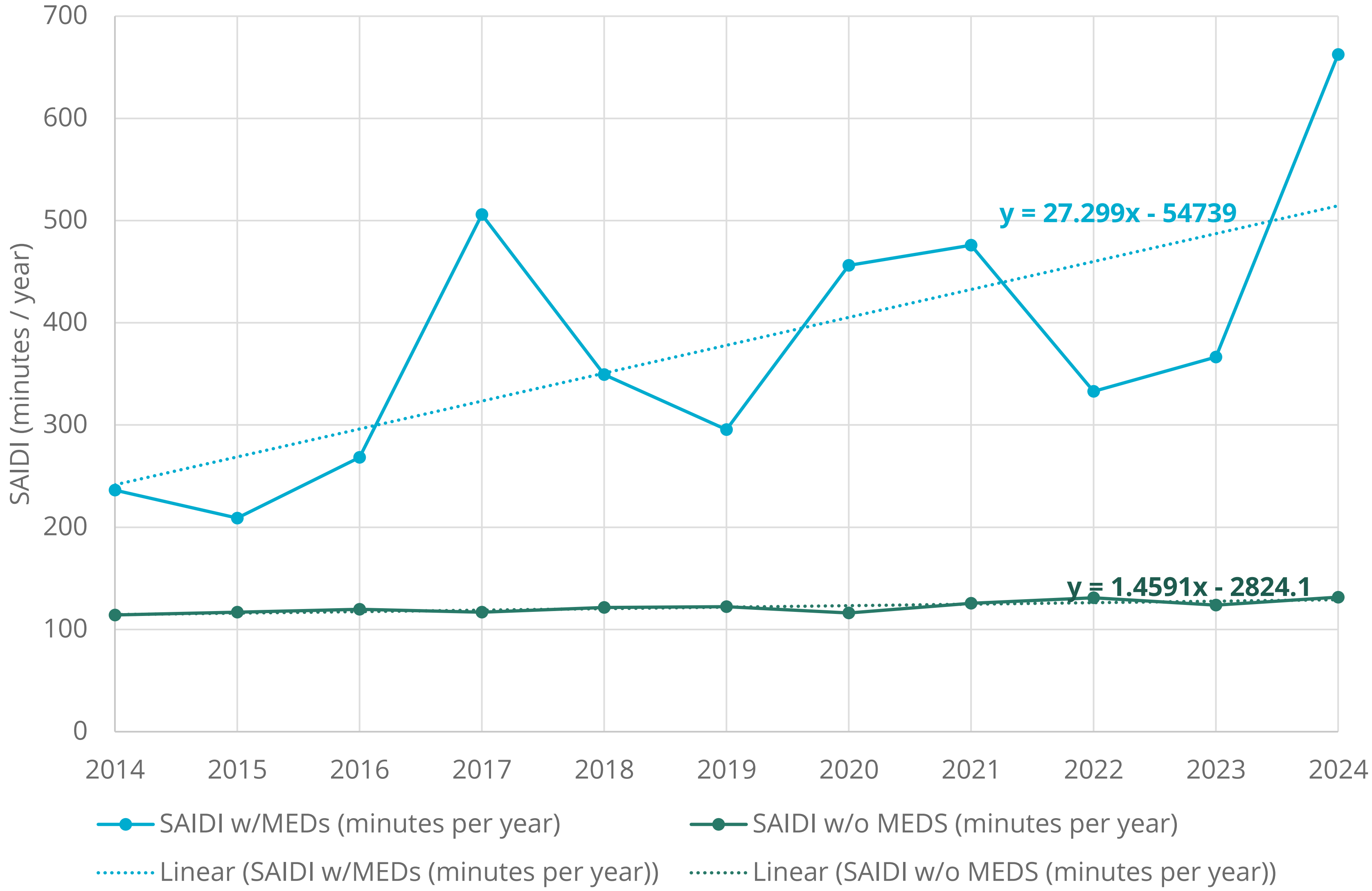
TRENDS IN GRID RELIABILITY

SAIDIs rose steadily over the last ~10 yrs, with or without MEDs included.

Conclusion: interruptions are becoming longer, *especially* during MEDs.

<u>Why?</u>

- Weather trends
- Aging infrastructure

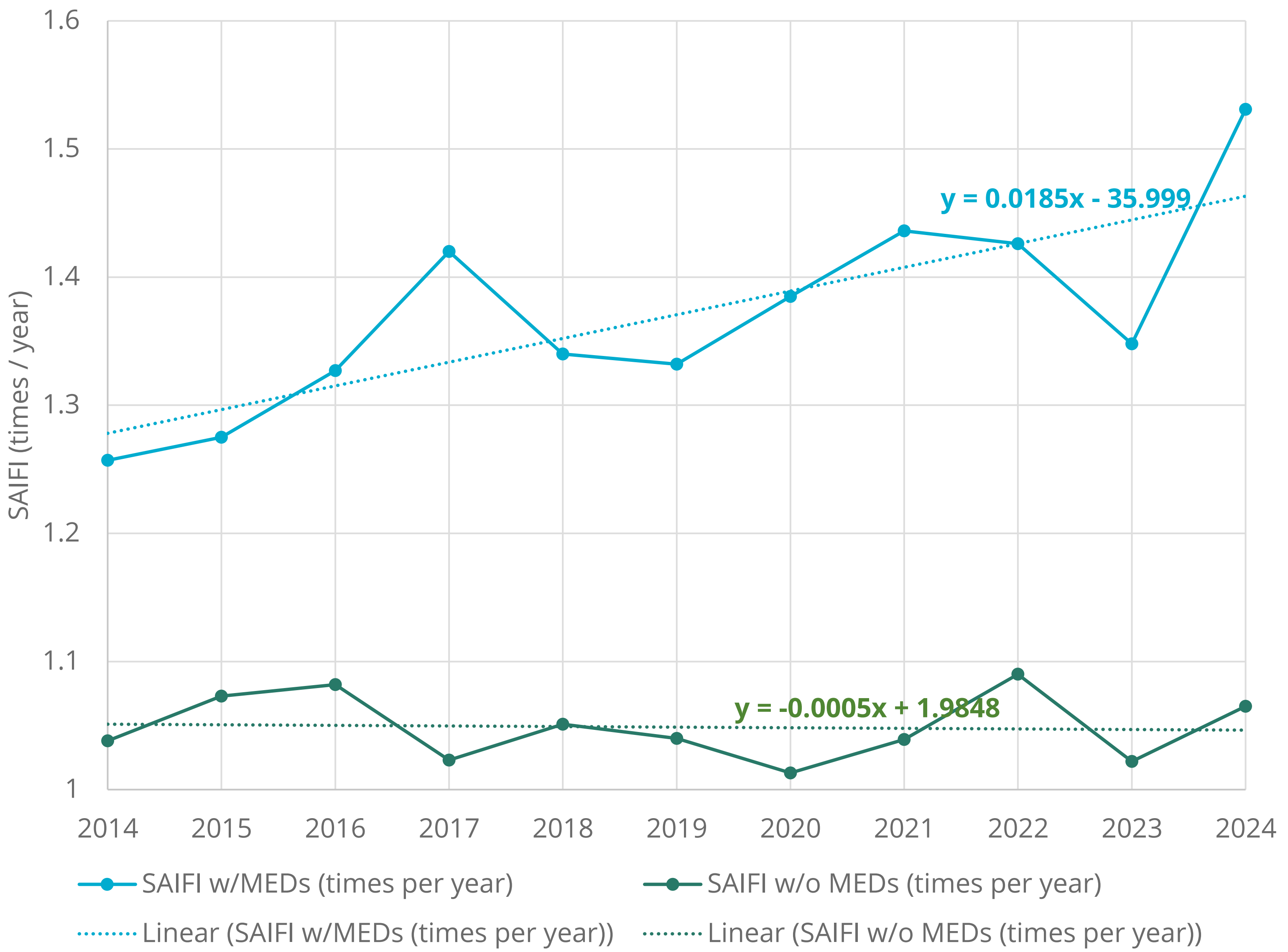


Data from U.S. DoE Energy Information Administration.

TRENDS IN GRID RELIABILITY

SAIFIs are also rising if MEDs are included, but the trend is roughly flat if MEDs are excluded.

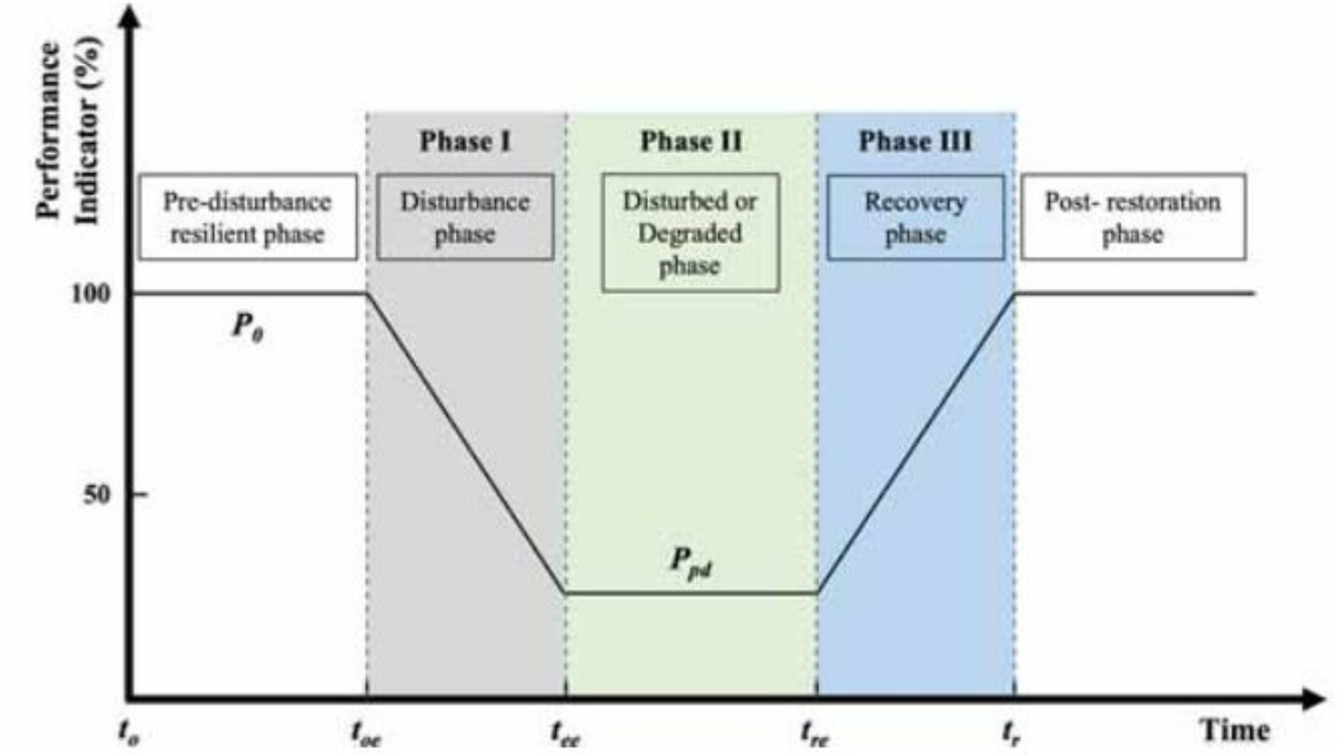
Conclusion: interruptions becoming more ***frequent***, but this increase isn't as marked as the increase in interruption ***duration***.



Data from U.S. DoE Energy Information Administration.

QUANTIFYING RESILIENCE

Quantification of resilience is still somewhat in flux; there's no one method that's been agreed to at present. The most commonly used methos is the "resilience trapezoid":



From Chowdhury et.al., "Toward Reaching a Consensus on the Concept of Power System Resilience: Definitions, Assessment Frameworks, and Metrics", *IEEE Access* vol. 11, 2023.

Quantification of resilience then relies on the parameters of this curve:

P_{pd}, $(P_0 – P_{pd})$, $(t_{re} – t_{ee})$, $(t_r - t_{oe})$, and so forth.

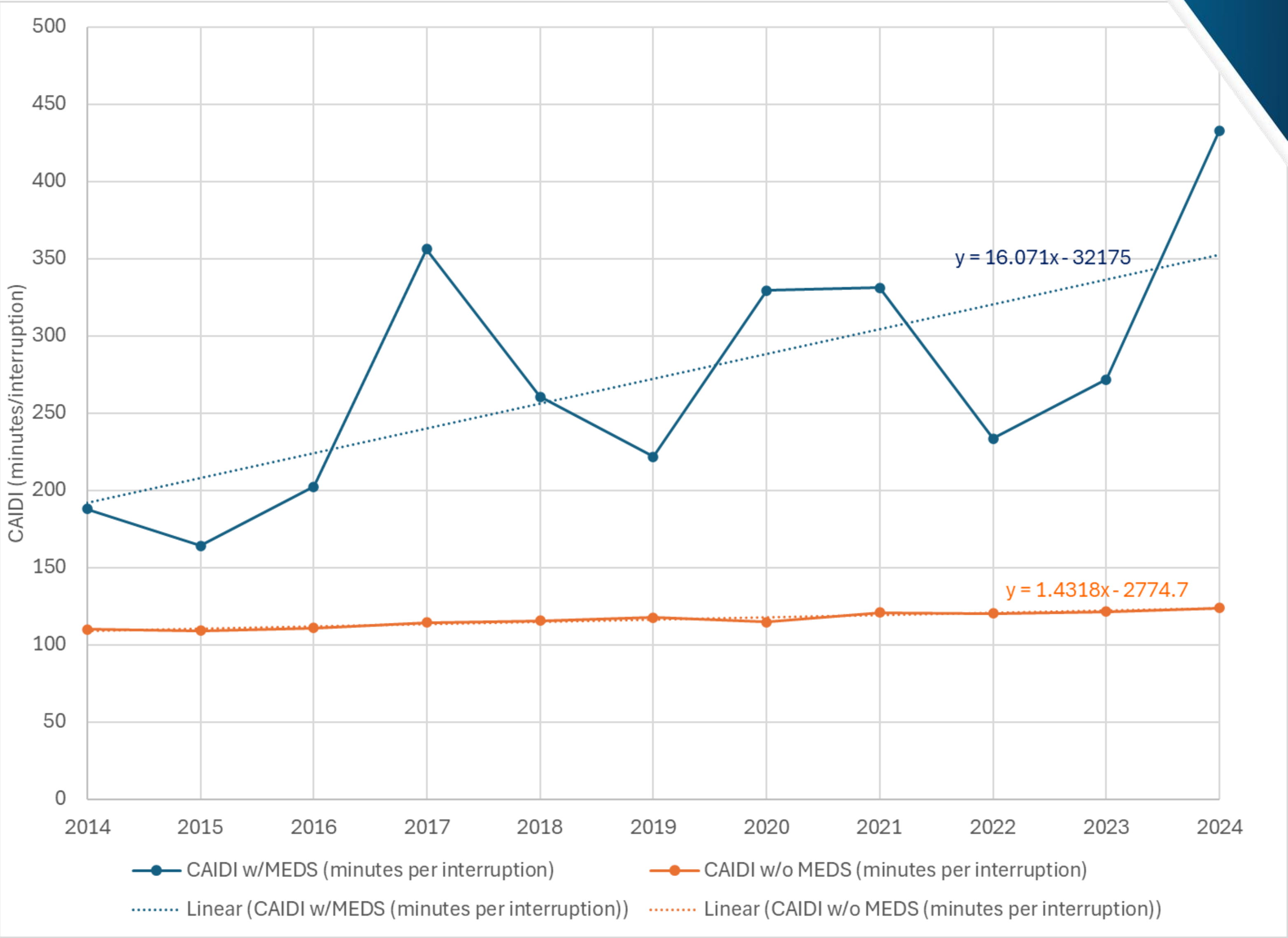
HOW MUCH OFF-GRID AUTONOMY DO WE NEED?

CAIDI gives us the average time to restore service, so it's a starting point for determining how much off-grid autonomy we really need.

CAIDI values have been rising over the years, but with MEDs, the worst CAIDI we've seen is 432.7 min (about 7.2 hours).

So, a common starting point is to assume we need 8 hours' off-grid duration.

This can be adjusted if one has site-specific CAIDI values.



HOW MUCH OFF-GRID AUTONOMY DO WE NEED?

However, maximum interruption durations on the order of days are not at all uncommon anymore. These are data from TX after Hurricane Harvey (August 2017). Max interruption durations were over 9 days.

From a resilience-trapezoid perspective, note that there really isn’t a Phase 2; the recovery starts almost immediately.

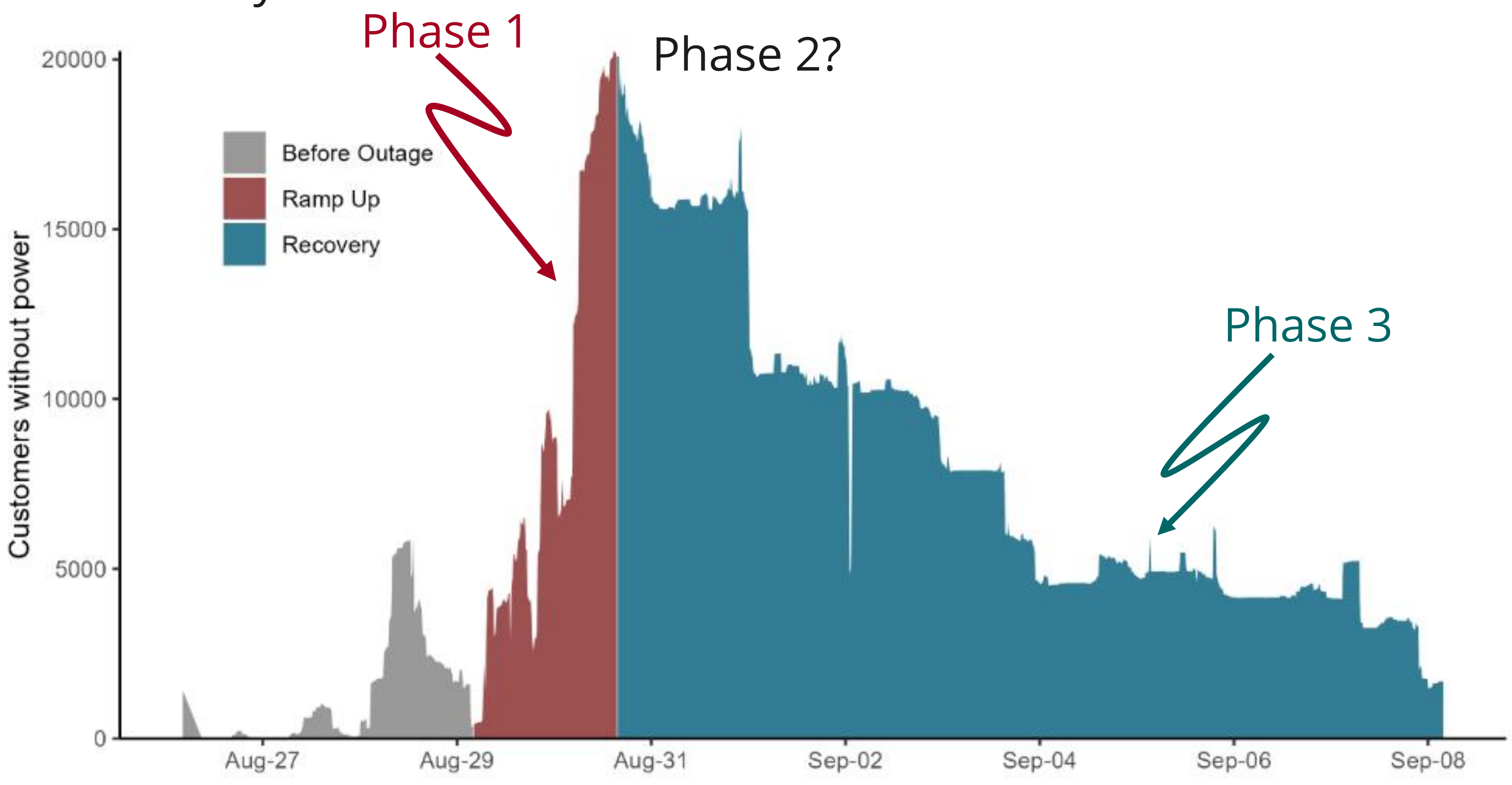


Figure 3. Customer outages for Jefferson County, Texas, during Hurricane Harvey

HOT SPRINGS MICROGRID DURING HURRICANE HELENE

- Helene hit on September 27, 2024
- Community's substation was almost entirely destroyed
- Community microgrid was able to restore service ~2 days later (comms were damaged and had to be restored first)
- Grid service was restored in about 10 days using a mobile substation
- The microgrid reduced the outage time to the community by about 8 days, in the aftermath of one of the worst storms to hit the area in many years.
- This would significantly reduce the SAIDI and CAIDI (w/MEDs) for this part of the system and these customers.
- **What is the value of that electricity?**

LONGER-DURATION MICROGRIDS HAVE HIGHER COST

- To go from 4 h off-grid autonomy to 8 hr can increase $/MW costs by ~50%, and to go from 4 to 12 h can raise costs by ~85%.
- **Common high-resilience microgrid endurance target: 14 days off-grid.**
- **US DoD microgrid endurance target: 30 days off-grid. (!!!)**
- Reaching these longer durations can be costly. One must also consider the importance of maintaining long off-grid duration intervals when fuel delivery infrastructure is disrupted (as in the Hot Springs NC case).

COSTS

- Li-ion short-duration storage costs ~$1500/kWh of capacity, installed.
- For longer off-grid duration:
  - The average cost of electricity from the grid in CONUS is $0.18/kWh. That's the AVERAGE; in places like NE and SD it is ~ $0.06/kWh, and in some parts of CA can reach $0.60/kWh.
  - The cost of off-grid electricity can be as low as $0.25/kWh on a good site and with relatively little off-grid duration, but with > 8 hrs off-grid duration, it can easily climb above $0.80/kWh.

Thus, *on average*, electricity from microgrids with more than 8 hr of off-grid duration capability is more costly than that from the grid on a $/kWh basis.

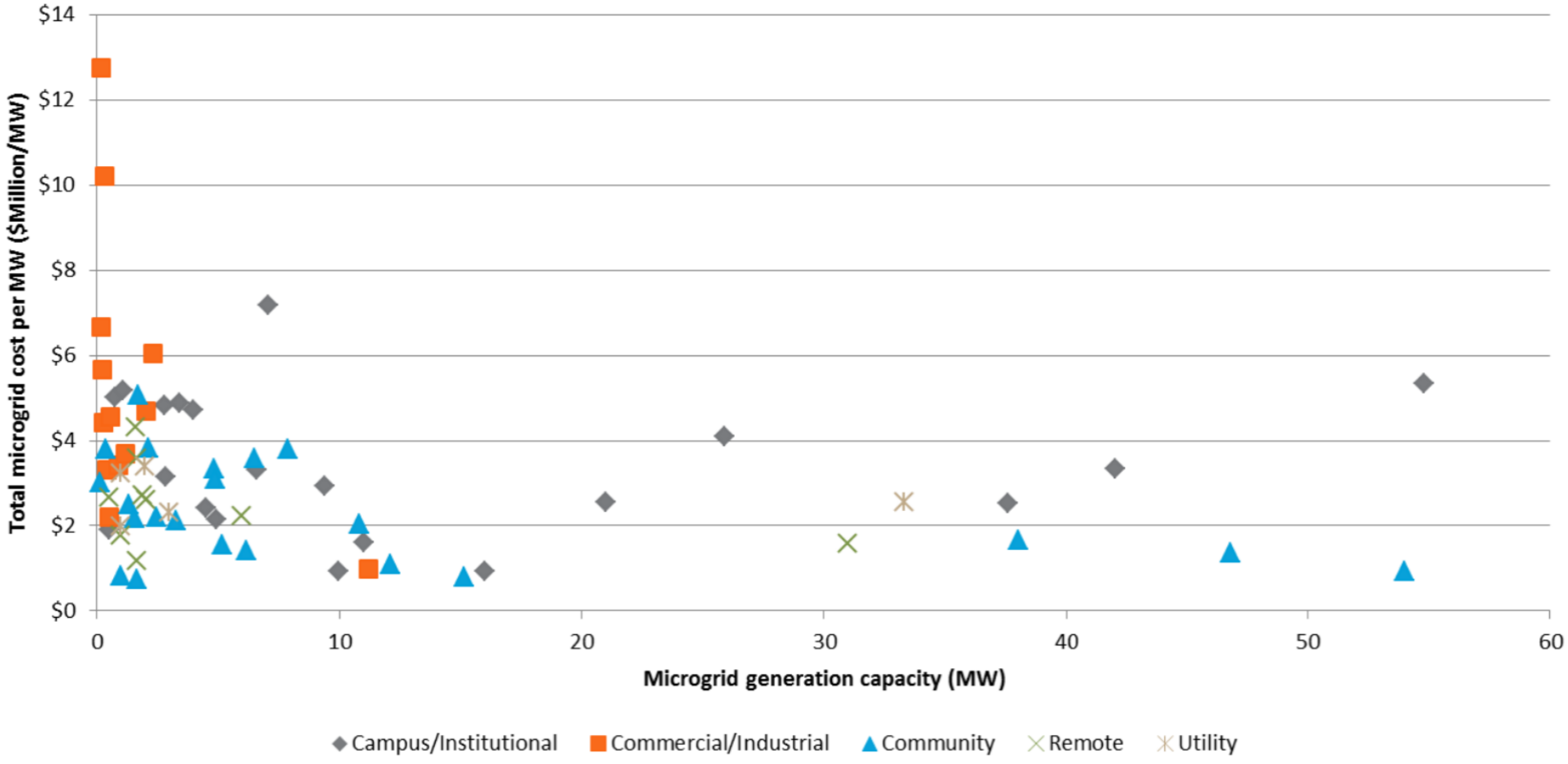
Can these costs be reduced or justified?

- Somewhat. Microgrids while on-grid can reduce demand charges and provide grid services, but the value of these services is highly location-specific.
- Microgrids can make good use of combined heat and power (CHP) facilities. This can be economical. Many campus microgrids are based on an existing CHP plant, e.g. Princeton.
- What is the value of electricity during an especially long outage?

LARGER MICROGRIDS TEND TO HAVE LOWER UP-FRONT COSTS

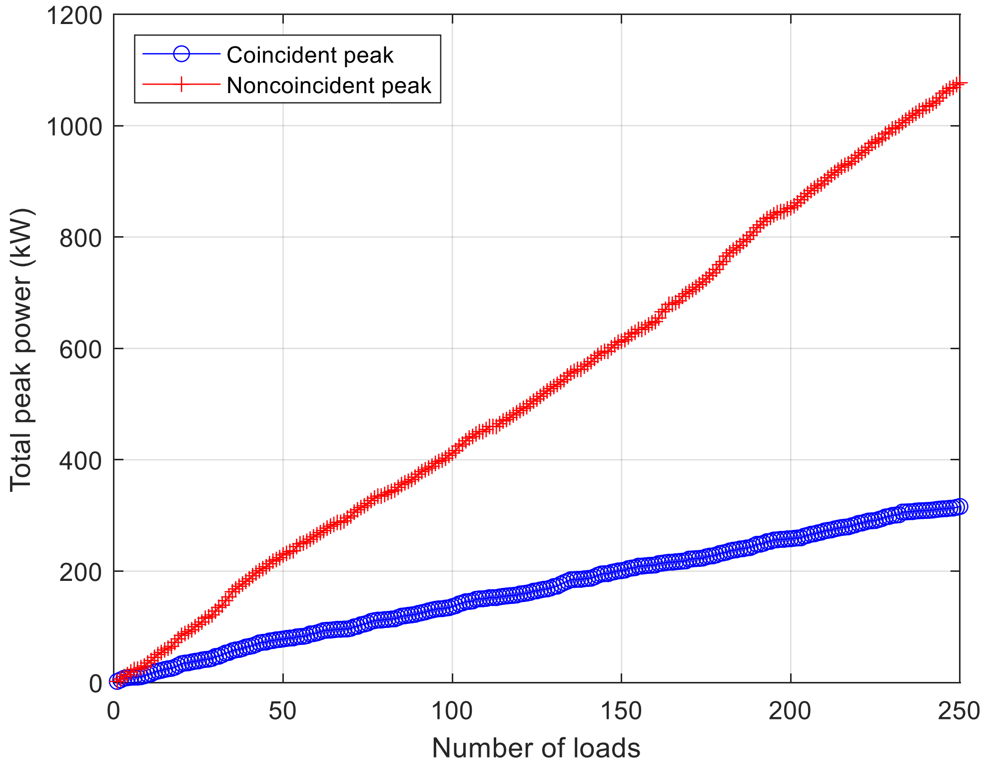
Why?

- Lower overhead costs per MW
- Generator costs drop
- Better able to take advantage of load diversity

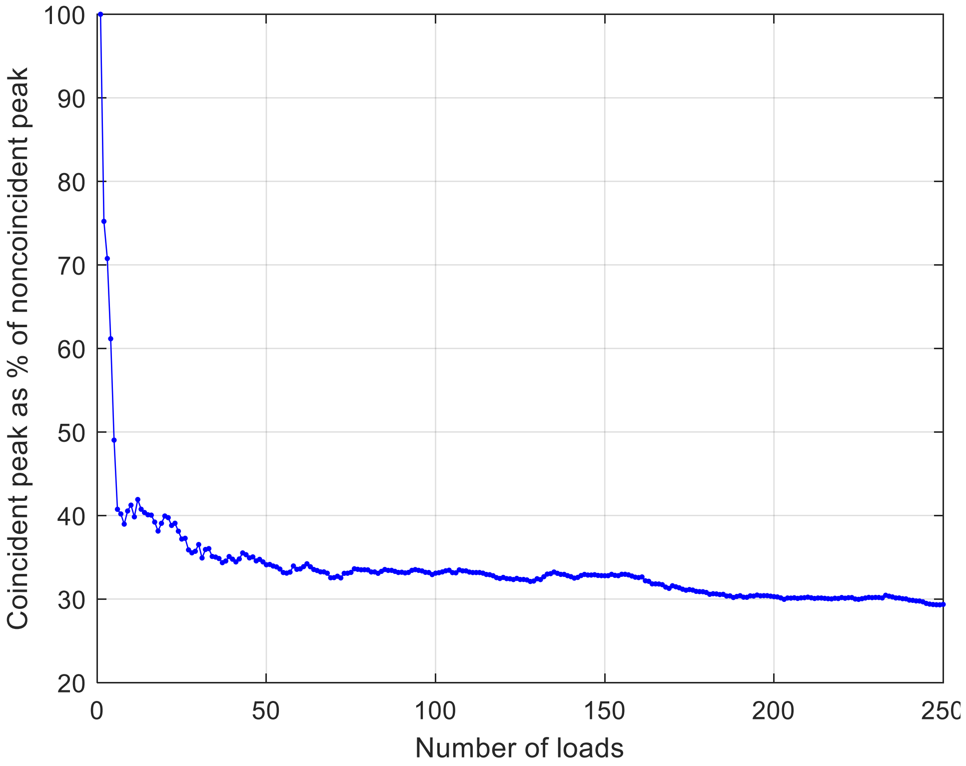


From "Phase I Microgrid Cost Study: Data Collection and Analysis of Microgrid Costs in the United States", NREL/TP-5D00-67821.

THE IMPORTANCE OF LOAD DIVERSITY IN COST REDUCTION



This shows noncoincident peaks (red) and coincident peaks (blue) as a function of the number of residential loads, using a real-world data set from Ota City, Japan.



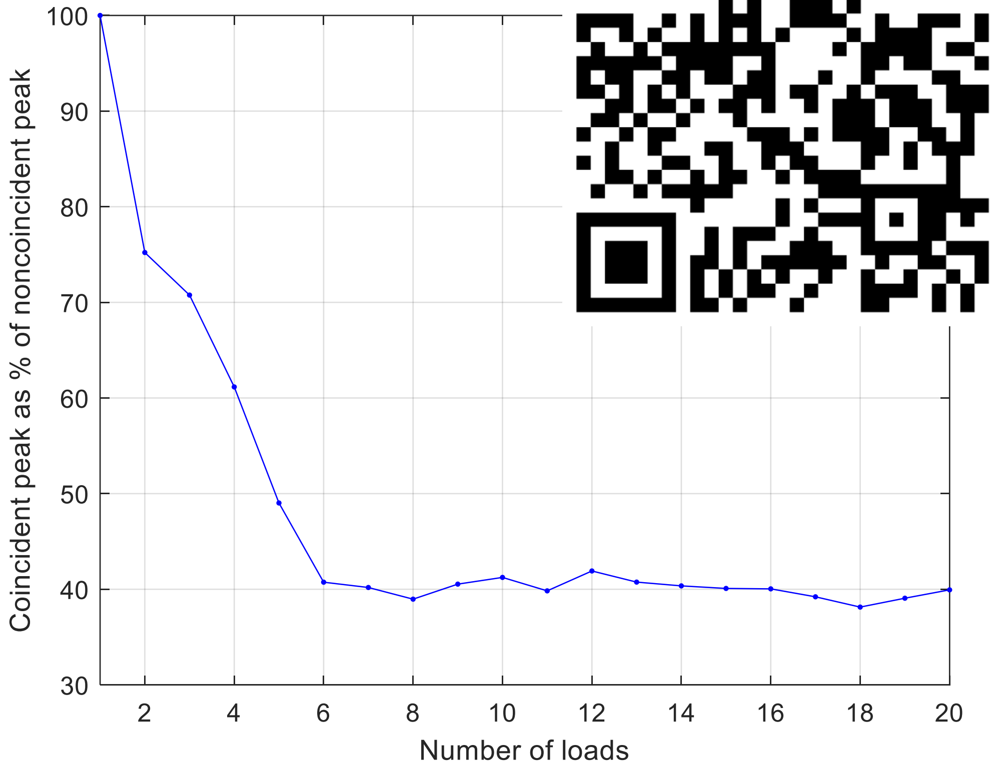
This shows the coincident peak as a fraction of noncoincident peak, for the same Ota City data set.

From "An exploration of how the geographic distribution of power sources impacts power system resilience", SAND2025-00453, https://www.osti.gov/servlets/purl/2516820.

THE IMPORTANCE OF LOAD DIVERSITY IN COST REDUCTION

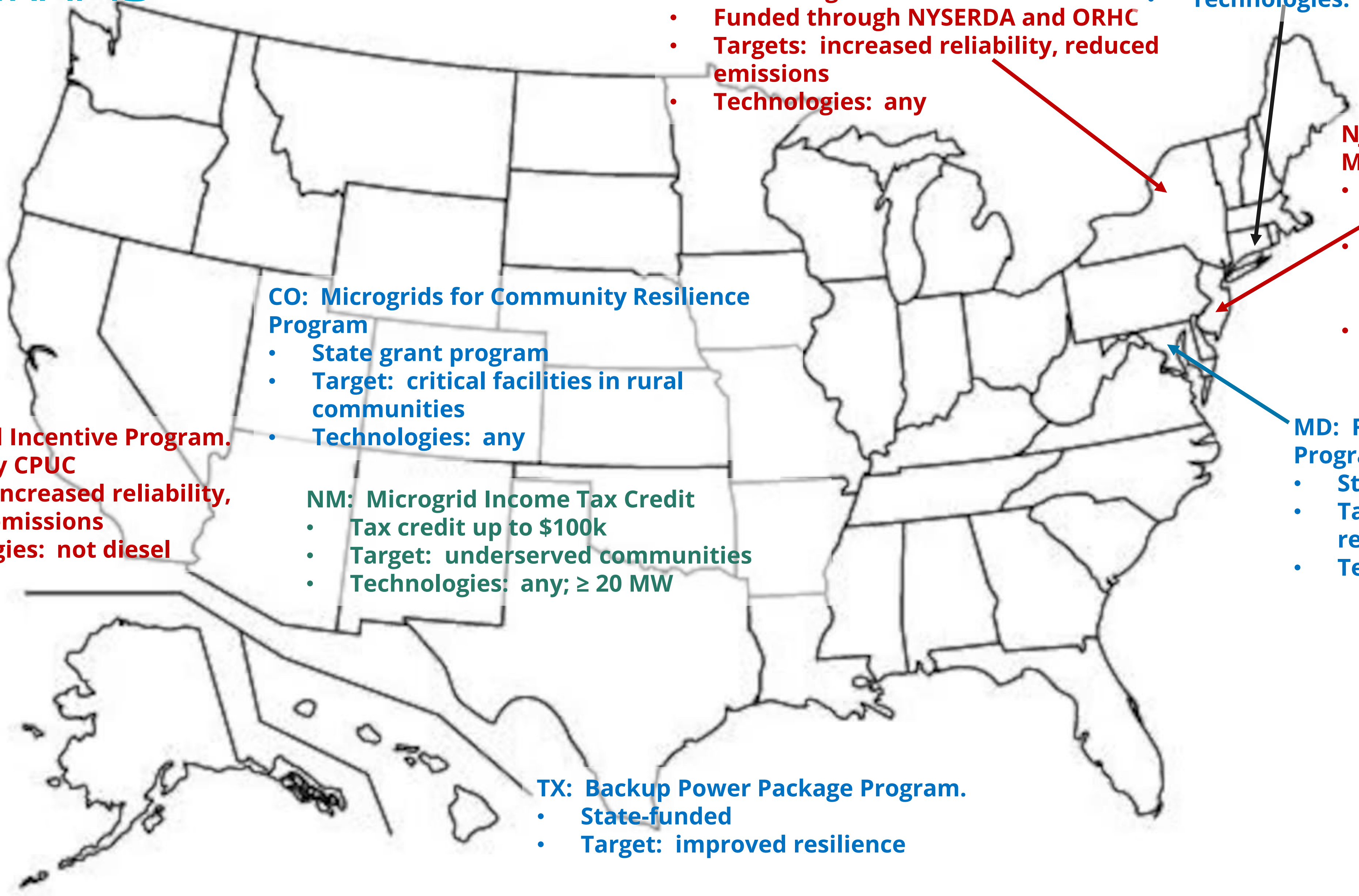
Generally speaking, what this means is that a community microgrid can have lower overall costs than a large number of individual facility backup sources, because the community microgrid has to serve the coincident peak.

The ratio of coincident to noncoincident peak drops fairly quickly as the number of loads rises from 1—see at right. With as few as six loads being served, the coincident peak is less than half the noncoincident peak, which (roughly) halves the generation capacity we need. At 250 loads, the coincident peak is about a third of the noncoincident peak.



From "An exploration of how the geographic distribution of power sources impacts power system resilience", SAND2025-00453, https://www.osti.gov/servlets/purl/2516820.

EXAMPLE STATE-LEVEL MICROGRID PROGRAMS



CT: Microgrid Program.
- State-funded
- Targets: increased reliability for critical facilities
- Technologies: any

NY: Prize Program.
- Funded through NYSERDA and ORHC
- Targets: increased reliability, reduced emissions
- Technologies: any

NJ: Town Center DER Microgrid Program
- State-funded through the BPU
- Targets: critical facilities power reliability
- Technologies: any

CO: Microgrids for Community Resilience Program
- State grant program
- Target: critical facilities in rural communities
- Technologies: any

CA: Microgrid Incentive Program.
- Funded by CPUC
- Targets: increased reliability, reduced emissions
- Technologies: not diesel

NM: Microgrid Income Tax Credit
- Tax credit up to $100k
- Target: underserved communities
- Technologies: any; ≥ 20 MW

MD: Resilient Maryland Program
- State-funded
- Targets: increased reliability/resilience
- Technologies: any

TX: Backup Power Package Program.
- State-funded
- Target: improved resilience

KEY FACTORS IN STATE-LEVEL MICROGRID PROGRAMS

- Generally, non-utility generators (NUGs) cannot sell power to other microgrid customers. NUGs have to sell power into the utility, which then transports it over the wires to other customers and sells it. In some states, there are regulatory policies that may complicate this process. Perhaps there are innovations that can help.
- Microgrid programs that target specific technologies *may* have higher costs, and *may* in some cases lead to suboptimal resource usage, than technology-agnostic microgrid programs that target higher resilience/reliability more generally. However, there are few data points to support this because *most* state programs are technology-agnostic.
- It is not yet clear how the effectiveness of microgrid programs is impacted by targeting specific communities ("rural", "underserved"). This may depend on how "underserved" overlaps with "low reliability of electric power service".
- It is not yet clear how outcomes are impacted by the specific funding mechanism (tax credits vs loans vs grants vs…).

CONCLUSIONS

- Overall, the US electric power grid is becoming less reliable over time. Reasons include aging infrastructure, and more frequent and stronger weather events.
- Microgrids are an important, proven tool for enhancing electric power reliability, and electric power system resilience.
- The cost of energy from a microgrid is *generally* higher than that from the grid, but costs vary widely and are situationally specific.
- Microgrid economics can be helped via on-grid savings.
- Quantifying reliability is somewhat straightforward; quantifying resilience is an ongoing conversation.
- Several state programs have been successful in driving increased microgrid deployment.

THANK YOU!

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