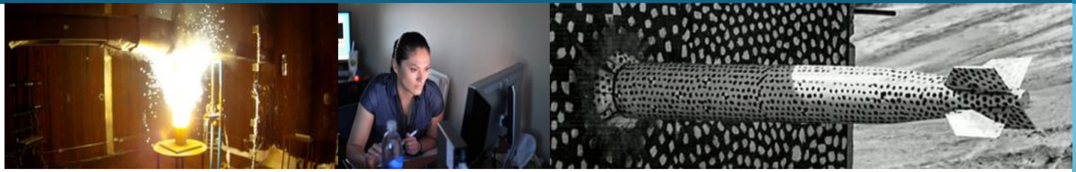
SAND2022-7715C

Sandia National Laboratories

Microgrid Conceptual Design Methodology and Guidebook



Deploying Microgrids in Honduras Workshop | June 14-15, 2022

Organized by U.S. Department of Commerce Commercial Law Development Program (CLDP)

Olga E. Hart, Brooke Marshall Garcia, and Matthew S. Lave

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

The Role of the U.S. Department of Energy in US Energy R&D

17 National Laboratories addressing the worlds large scale, complex research and development challenges

Federal Government

↓

Department of Energy

National Laboratories have served as the leading institutions for scientific innovation in the United States for more than seventy years

National Nuclear Security Administration Laboratories

- Los Alamos National Laboratory
- Lawrence Livermore National Laboratory
- Sandia National Laboratories

Office of Science Laboratories

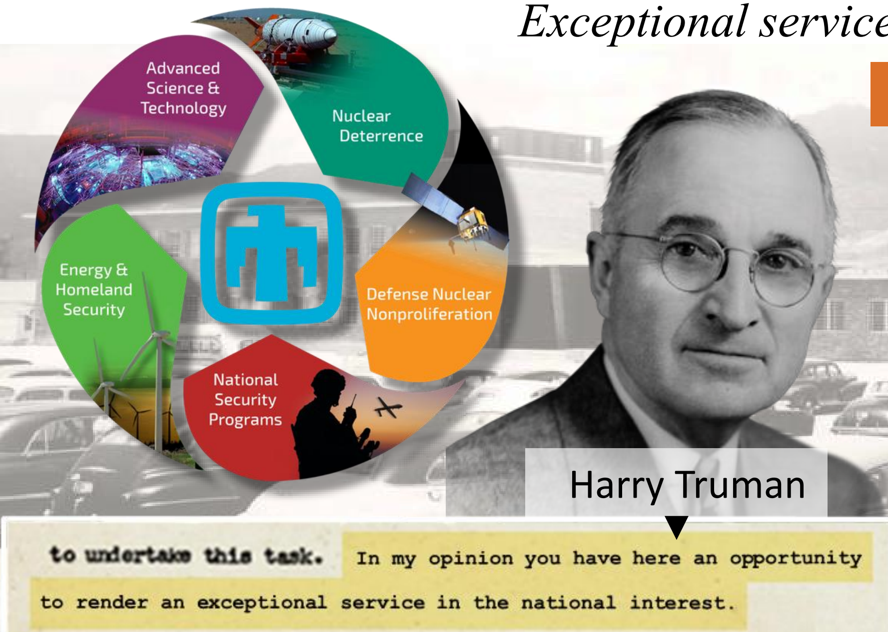
- Ames Laboratory
- Argonne National Laboratory
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory
- PPPL Princeton Plasma Physics Laboratory
- SLAC National Accelerator Laboratory
- Fermilab
- Jefferson Lab
- Brookhaven National Laboratory
- Berkeley Lab

Other Energy Department Office Laboratories

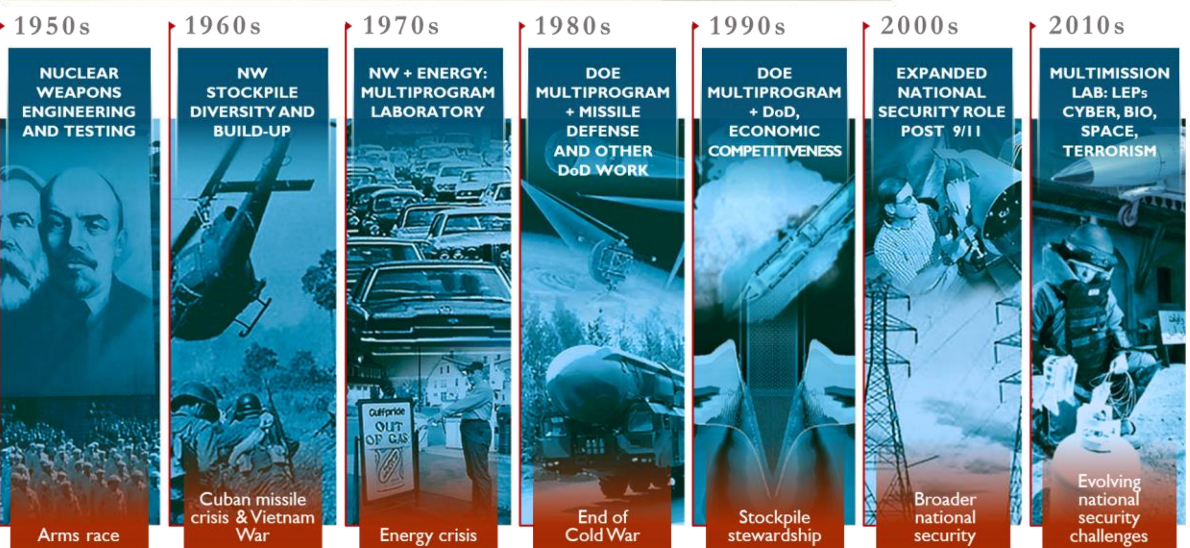
- SRNL Savannah River National Laboratory
- NREL National Renewable Energy Laboratory
- NETL National Energy Technology Laboratory
- INL Idaho National Laboratory

About Sandia National Laboratories

Exceptional service in the national interest

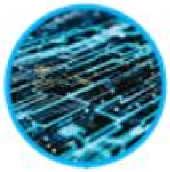


Albuquerque, New Mexico (1949) | **Livermore, California (1956)**



Sandia National Laboratories

Sandia's History of Supporting Grid Modernization Efforts



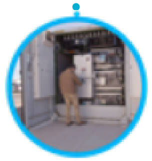
1980s
- Distributed Energy Technology Laboratory (DETL) Opens
- Sandia designs first battery test facility hosted by PSE&G in NJ

1990s/2000s
- Sandia starts interconnected PV systems work
- DOE designates Sandia as US Rep to IEC TC57, (Standards for information exchange for power systems)

2003/04
- Sandia Publishes DOE/EPRI Electricity Storage Handbook
- National SCADA Test Bed (NSTB) established

2009
- R&D 100: SiCPower Module
- DETLY modernized to enable high penetration experimentation on distributed generation
- Energy Surety Microgrid (ESM) Methodology

2010
- Energy Storage Test Pad established as the fist facility to test 1MW class storage systems at a national lab
- Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) established



2011
- R&D100 Award Winners: Ultra-high-voltage Silicon Carbide Thyristor
- R&D100 Award Winners: The Demand Response Inverter
- Secure, Scalable Micrograds Grand Challenge and Hardware Testbed Facility Initiated

2013
- Sandia developed the DOE/SNL Global Energy Storage Database

2014
- Grid Modernization Laboratory Consortium established & Sandia participates in 29 GMLC projects

2015
- Smart Grid International Research Facility Network (SIRFN) established
- R&D 100: Sandia and United Silicon Carbide, Inc. create new high voltage switch

2016
- Resilience Node Cluster Analysis Tool (ReINCAT) developed
- Control and Optimization of Networked Energy Technologies (CONET) Laboratory established
- First version of WNTR – Water Network Tool for Resilience

2017
- R&D 100: Control System for Active Damping of Inter-area Oscillations

2018
- QuESt, an open source energy storage simulation and analysis suite, publicly released
- Energy Storage controls and Analytics Laboratory (ESCAL) created

2019
- Sandia-developed Grid Damping Control Strategy at CONET

2020
- Advanced Power Electronics Conversion Systems (APEX) Laboratory established

2021
- Resilient Energy Systems Mission Campaign: Corporate internal research investment in energy resilience begins

Resilience Science at Sandia

A resilient energy system **supports critical community functions** by preparing for, withstanding, adapting to, and recovering from disruptions

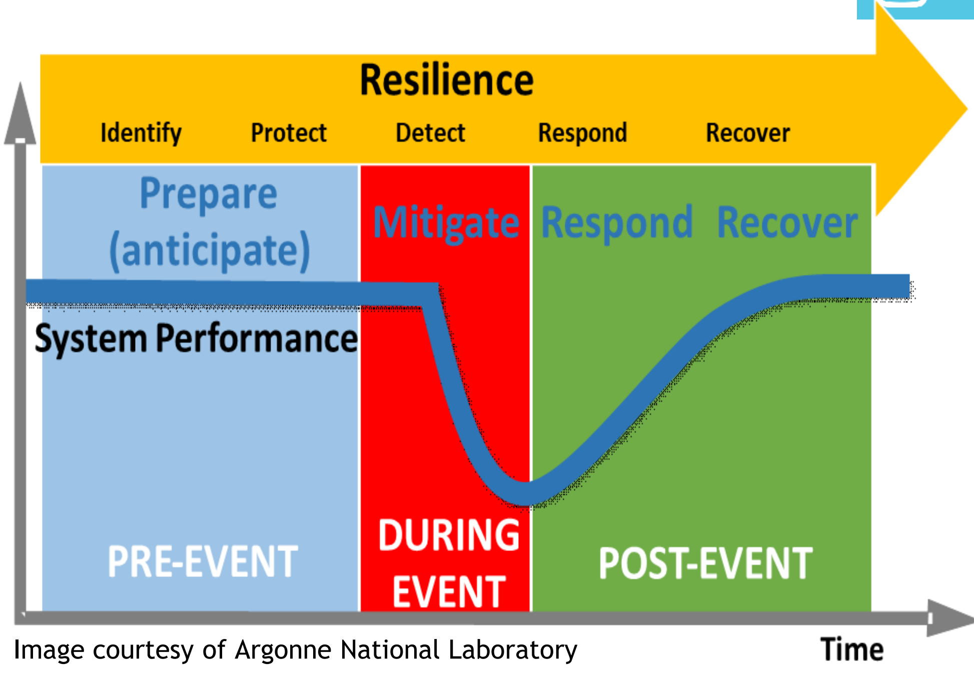


Image courtesy of Argonne National Laboratory

1. Includes hazards with low probability but potential for high consequence

   Naturally fits within a risk-based planning approach…

   …but difficult to capture this type of risk with high confidence

2. Resilience is contextual – defined in terms of threats or hazards

   A system resilient to hurricanes may not be resilient to earthquakes

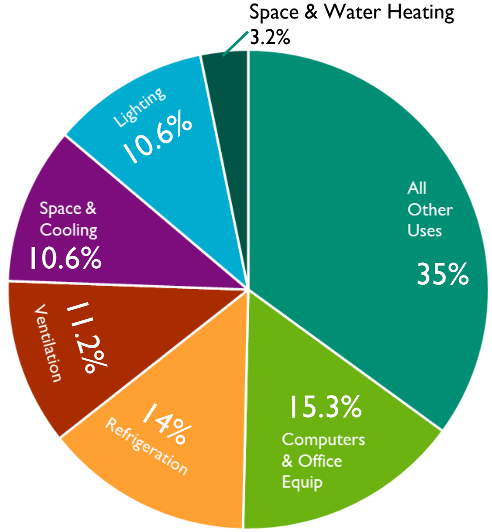
Need for Reliable Electric Power

Our society is highly dependent on electric power

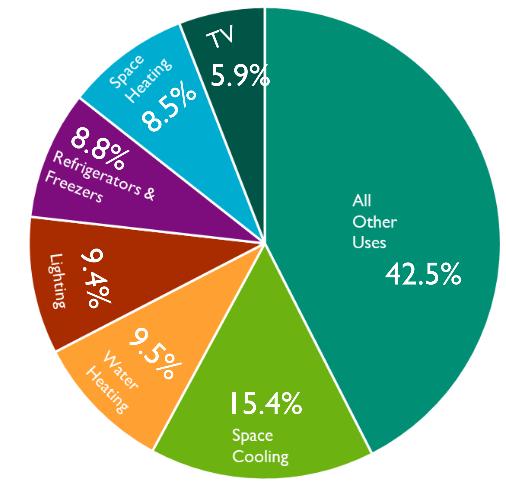
Power outages have severe consequences:

1. Productivity:
   - Damage to equipment
   - Loss of perishables
   - Lost computing time
   - Unsafe work conditions
2. Daily Life
   - Communications challenges
   - Cooking difficult
   - Entertainment unavailable
3. Health

U.S. Commercial Sector Electricity Consumption By Major End Uses, 2017



U.S. Residential Sector Electricity Consumption By Major End Uses, 2017



Electric Power Interdependencies

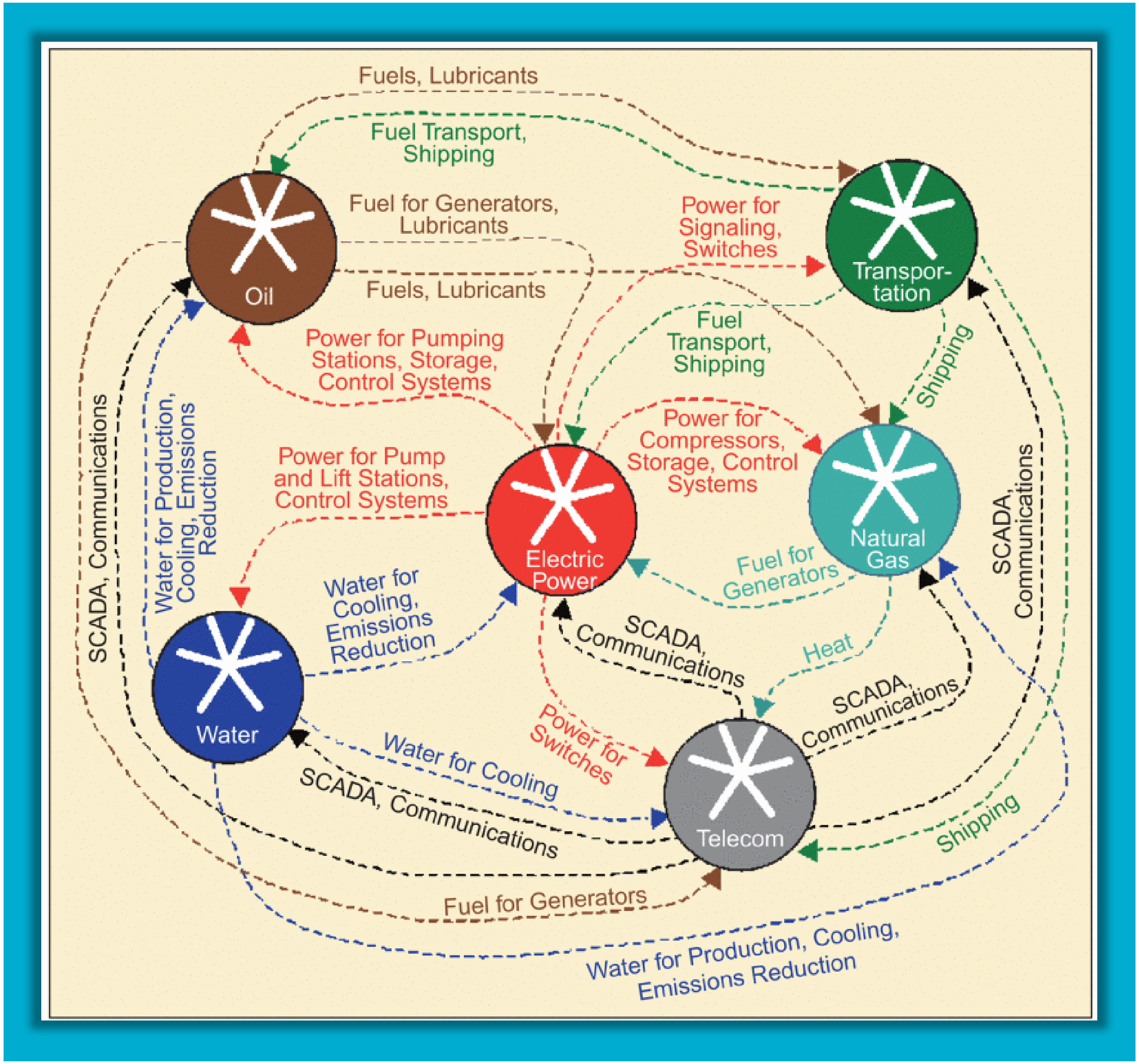


Image from: "Identifying, understanding, and analyzing critical infrastructure interdependencies," S.M. Rinaldi, J.P. Peerenboom, T.K. Kelley, IEEE Control Systems Magazine, Volume 21, Issue 6, Dec. 2001: https://ieeexplore.ieee.org/document/969131

Main Electric Grid

Transmission

- Move bulk electricity from generation to load centers
- Longer distance (10s to 100s of miles), high capacity, high voltage

Distribution

- Distribute electricity to end users
- Shorter distance (up to several miles), lower capacity, lower voltage

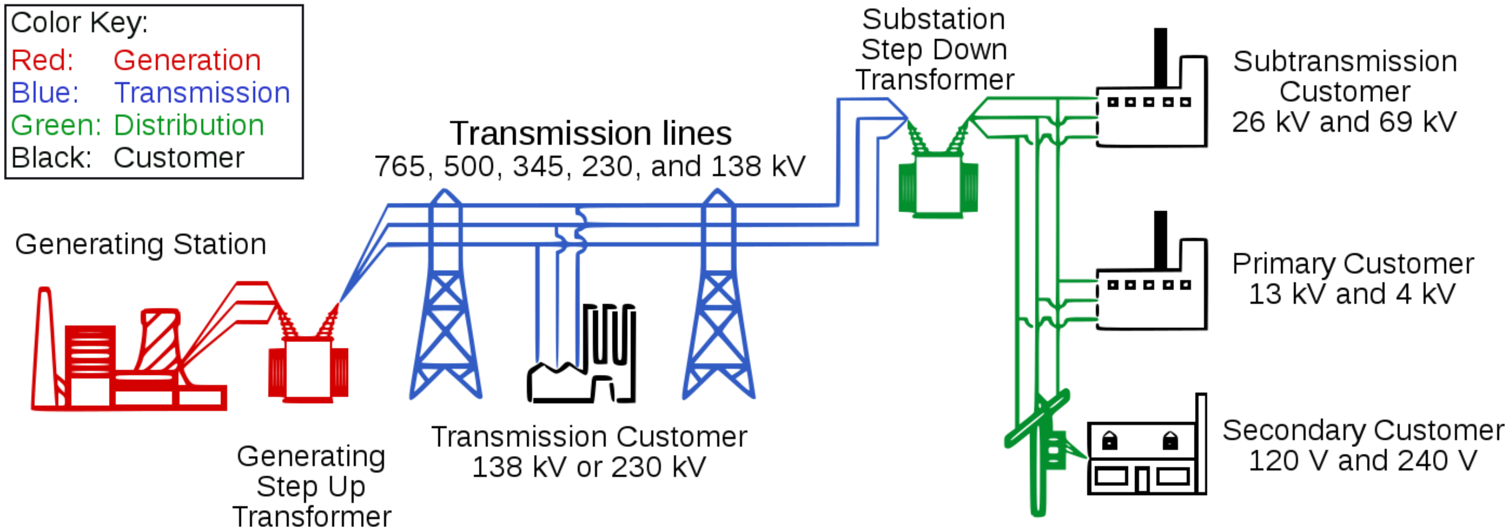
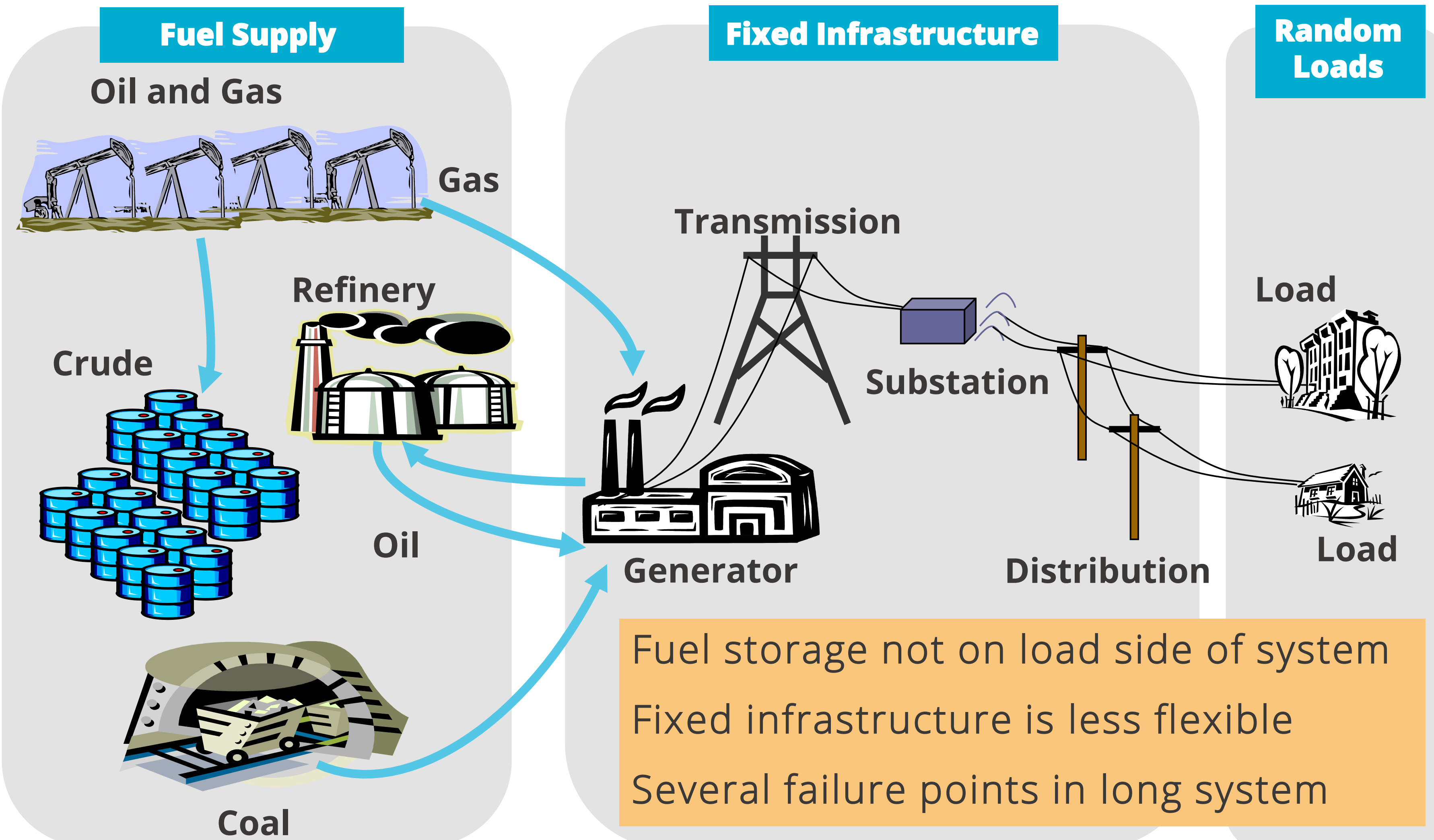


Image from FERC report: https://www.ferc.gov/industries/electric/indus-act/reliability/blackout/ch1-3.pdf

Electric Grid is Limited in Ability to Meet Energy Assurance Requirements



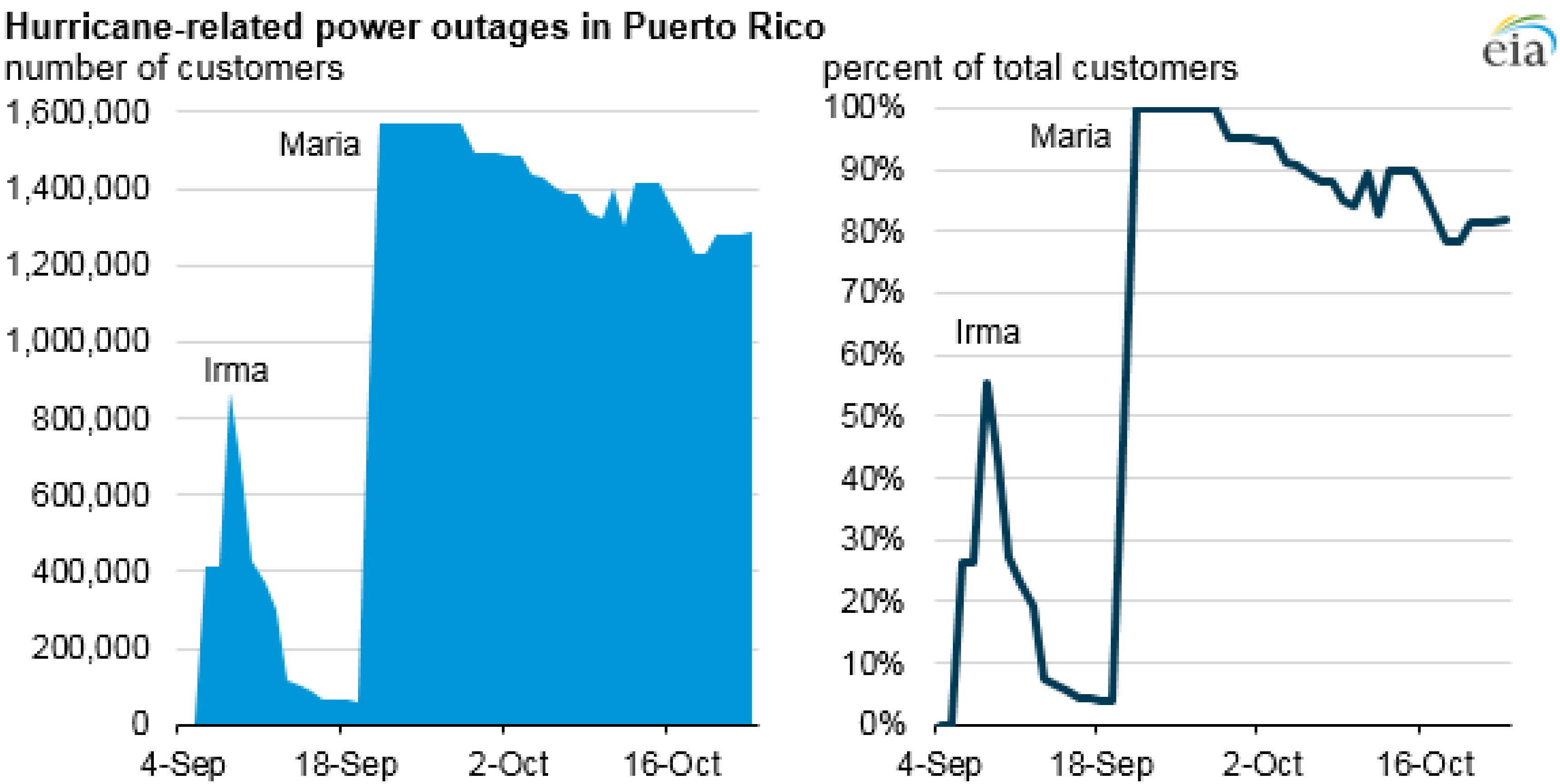
Fuel storage not on load side of system

Fixed infrastructure is less flexible

Several failure points in long system

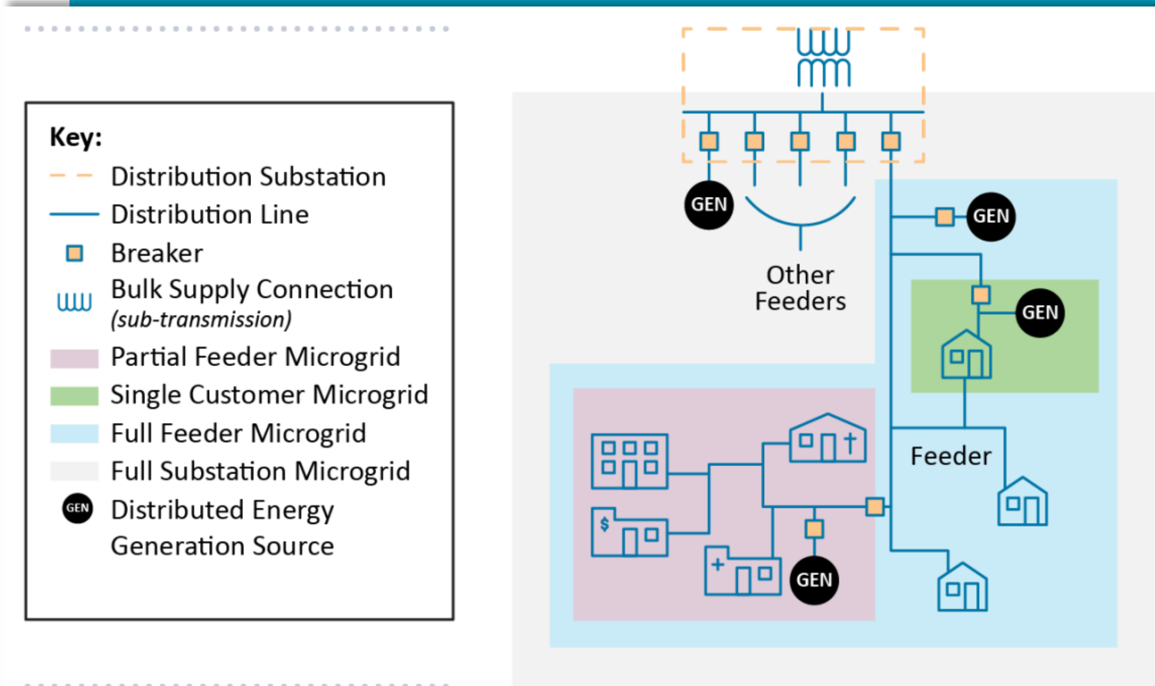
Slow Restoration

Outage-causing event may disrupt fuel supplies, transportation, communication, etc., leading to a long restoration period.



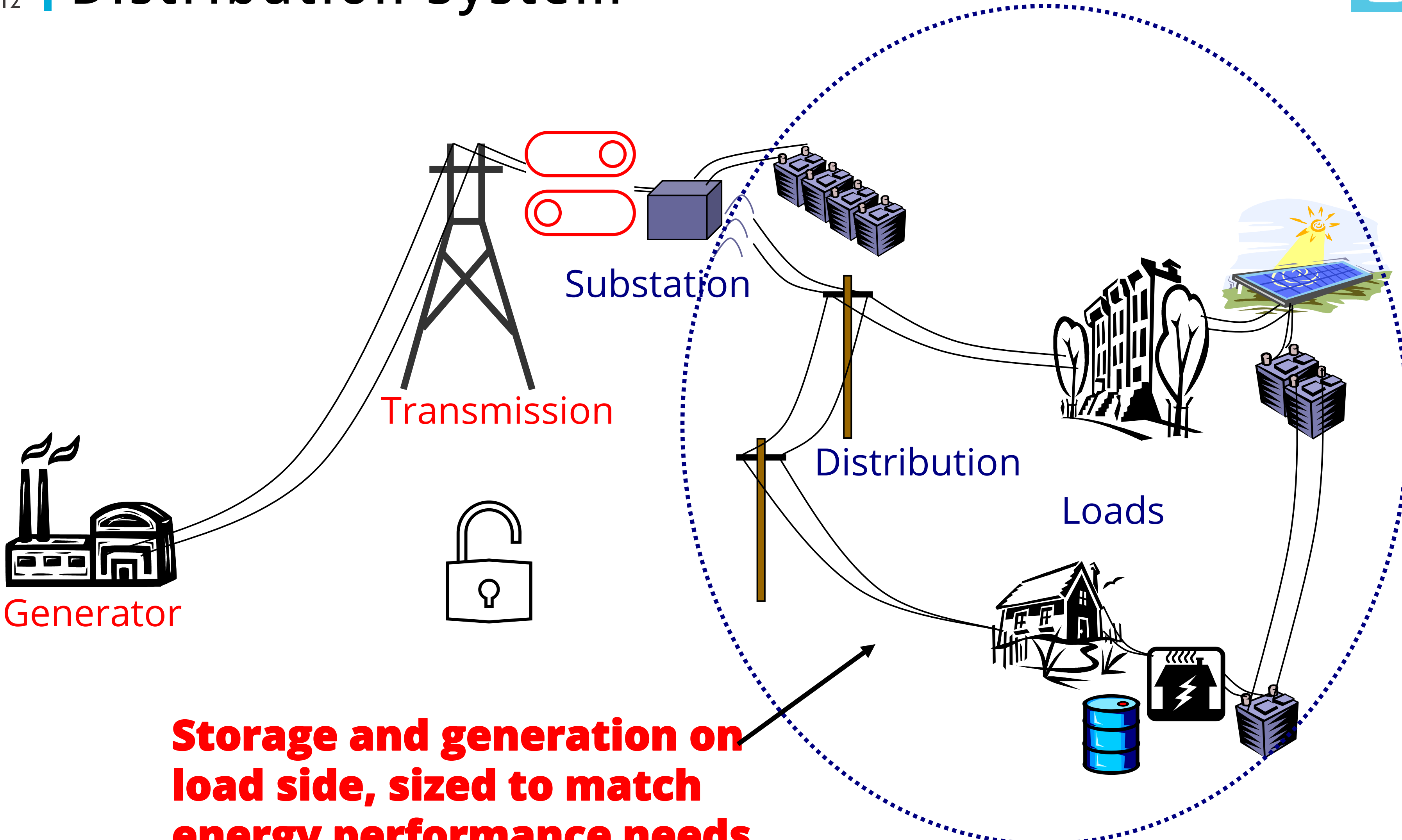
What is a microgrid?

"**microgrid**" – A set of loads with local generation that can be isolated form the main electric grid



- Motivation for "micro" based on size
  - Generating capacity of very large electric grids (United States, Europe, China, India, etc.) is 100s of GW to 1TW
    - grid" $\sim\mathcal{O}(1\text{TW})$
    - "micro" grid ≈ 10^(−6)×grid → microgrid $\sim\mathcal{O}(1MW)$
- However, microgrids can be much less than or much greater than 1MW

Microgrids are Associated with the Distribution System



Storage and generation on load side, sized to match energy performance needs

Opportunity for Microgrids

1. Reliable electric power is critical to health, safety, and productivity

2. Historical practice of providing power security based on back-up generators has been problematic
   - *Frequently over-sized and under-maintained, low probability of start (<60%)*
   - *Dedicated to one building or facility*
   - *Operations for extended periods problematic*

3. Advanced microgrids are an energy assurance solution
   - Advanced microgrids improve energy surety – safety, security, reliability, sustainability, cost-effectiveness, and resiliency of electric power
     - *Local generation reduces possible nodes of failure*
     - *Renewable energy can be incorporated, improving sustainability and reducing fuel dependencies*
     - *Generation matches load, reducing costs*
     - *Designs considering threats can improve resilience*

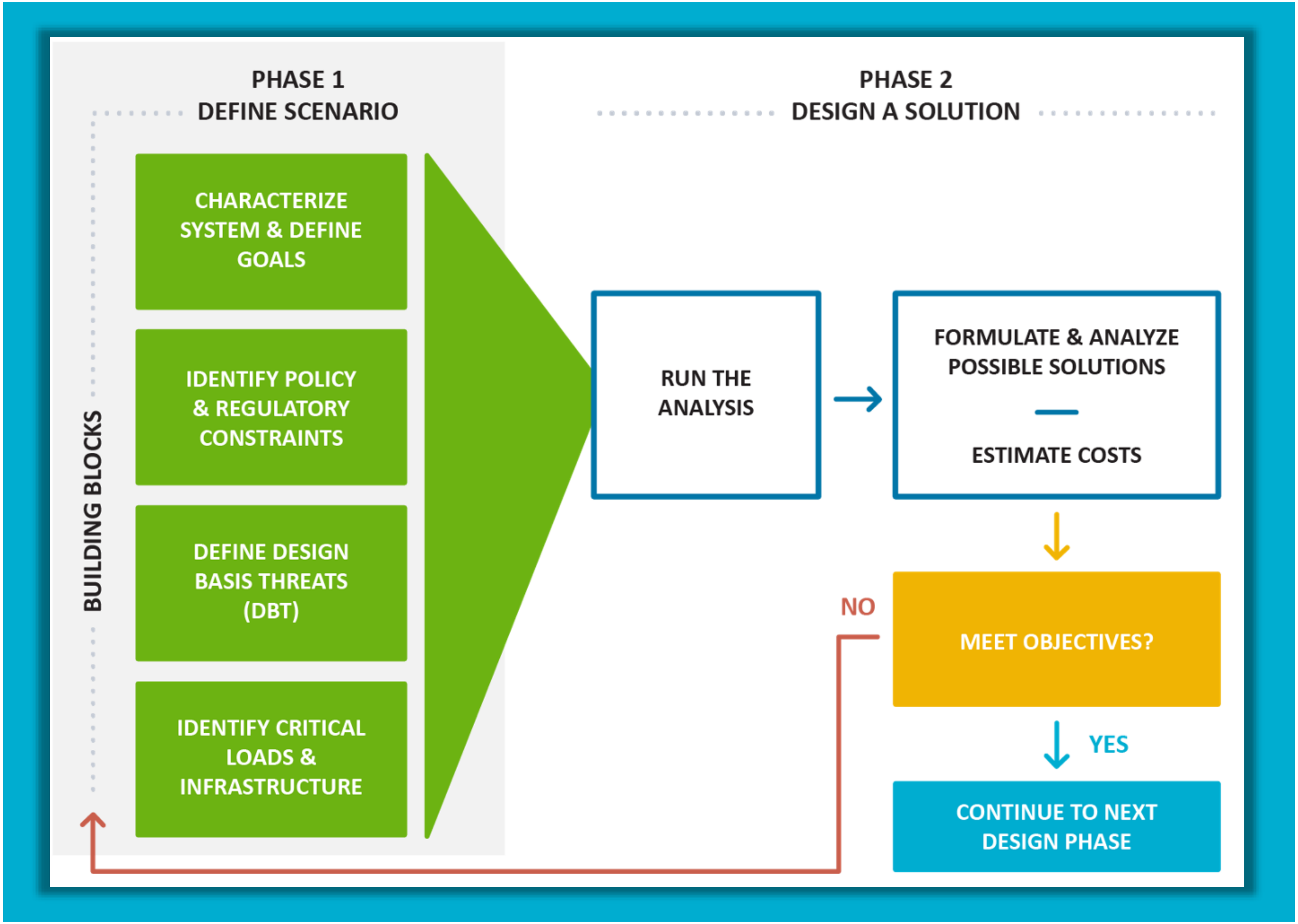
Audience Participation

Q: **What is your primary GOAL for your microgrid?**

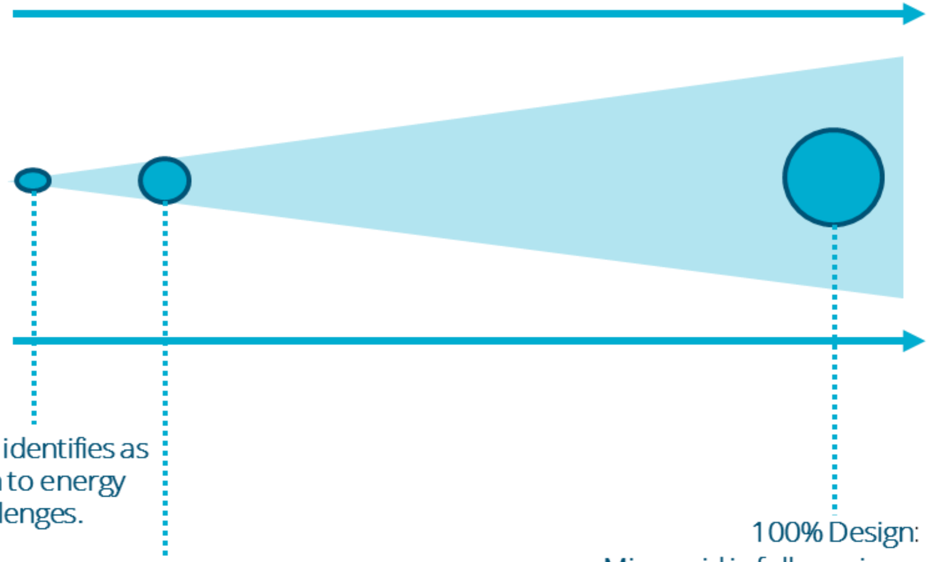
A) Primary source of power
B) Backup source of power
C) Assist with renewable energy goals
D) Other

Sandia's Microgrid Conceptual Design Methodology Framework

Microgrid Conceptual Design Methodology Framework



Scope



Microgrid identifies as solution to energy challenges.

10% to 20% Conceptual Design:
Site-specific needs are estimated and a microgrid solution is conceptualized including generation type, scale, and distribution.

100% Design:
Microgrid is fully engineered with final specifications, it is environmentally permitted, and ready to be built.

RESILENCE

Includes ***low probability, high consequence*** event.
Not standardized. Still working on methods, ***metrics, and tools***

RELIABILITY

Focuses on system performance with respect to ***commonly expected events*** (component failure, etc.)

Widely adopted for infrastructure investment decision-making

Standardized methods, metrics and tools exist to evaluate reliability

Microgrid Conceptual Design Methodology: Phase 1

Defining the Scenario

Define Boundaries

BEGIN ASSESSMENT OF SITE BOUNDARIES

Evaluate:

- What is the **geographic footprint**?
- What types of **services and assets** do we want to provide energy resilience?
- For what **duration of time** (days, weeks, longer) do we want to provide these services and assets?
- What types of **generation resources** should we consider (e.g., diesel, gas, generators, cogeneration, renewables like PV or wind)?
- In addition to providing emergency services, do we want to consider **ancillary benefits** like selling power back to the utility, meeting renewable energy goals, etc.?
- What **funding sources** are available (federal, city, state, private purchase agreements, etc.)?

PHASE 1
DEFINE SCENARIO

CHARACTERIZE SYSTEM & DEFINE GOALS

IDENTIFY POLICY & REGULATORY CONSTRAINTS

DEFINE DESIGN BASIS THREATS (DBT)

IDENTIFY CRITICAL LOADS & INFRASTRUCTURE

Assess Critical Loads & Interdependencies

EVALUATE THE CRITICAL INFRASTRUCTURE PRIORITIZATION

Evaluate:

- Develop a rubric for evaluating critical infrastructure.
- Consider outage duration as a factor in critical ranking.
- Get community input and feedback for enhanced resiliency and equitable outcomes.

ENERGY TRANSITIONS INITIATIVE
U.S. Department of Energy

Handout 3: Powering Critical Infrastructure

Assign the following general services and facilities high, medium, or low priorities. Assign each facility a category of service (e.g., grocery stores apply to the category of "Food" service) to help map facility priorities to service priorities.

	Service	Tolerance (hours)	Priorities (H, M, L)
1	Communications	<1 day	H
2	Medicine/Supplies	<1 day	H
3	Ambulance	<1 hour	H
4	Fire response	<1 hour	H
5	Road Clearing	days	M
6	Clean water	<1 day	H
7	Food	<3 day	H
8	Wastewater	<1 day	H
9	Flood Control	days	M
10	Shelter	<1 day	H
11	Trash collection	Many days	L
12	Police	<1 day	H
13	Mail delivery	Many days	L
14	Hospital	<1 hour	H
15	Heating/Cooling	days	M
16	Transportation	days	M
17	Fuel	<2 day	H
18	ATMs/money	days	M

Audience Participation

Q: What are the critical *services* in your study area?

Example Critical Services Prioritization

Grouping critical services and associated assets in terms of priorities of the needs of the community for the impacts of the DBT event helps define how resilience improvements can be targeted to needs and be cost-effective

Critical Services Hierarchy

Tier 1	Tier 2	Tier 3
Cell Tower Emergency Operations Hospital Water Pump	Shelter Grocery Store	Banks Sewer Treatment

Design Basis Threat

BEGIN ASSESSMENT OF DESIGN BASIS THREATS.
COME OUT OF THIS STEP WITH PERFORMANCE GOALS IN RESPONSE TO DESIGN THREATS.

Evaluate:

- Discuss natural, manmade, and other threats – make comprehensive list from which to down select design parameters.
- Discuss likelihood v. severity
- Look at maps and other material to identify consequences (e.g., flood mapping, risk indices, news reports)
- Discuss consequence-based evaluation (i.e., what do we lose, and who loses it, when we lose power)

Example Threats

Natural

Earthquakes
Flooding
Hurricanes
Wildfires
Drought

Direct Intentional

Cyberattack
Electromagnetic Attack
Kinetic/Physical Attack

Structural/Other

Economic/Market Shocks
Regulatory/Policy Changes
Aging infrastructure
Capacity constraints
Workforce turnover
Supply chain interruptions
Human error

Audience Participation

Match the DBT with the typical distribution system outage duration

?

MONTHS

WEEKS

DAYS

Audience Participation

WEEKS | MONTHS

DAYS

DAYS | WEEKS | MONTHS

WEEKS

Audience Participation

Match the DBT with the typical impact level

?

HIGH

MEDIUM

LOW

Audience Participation

HIGH

HIGH

LOW | MEDIUM | HIGH

LOW | MEDIUM

Policy and Regulatory Constraints

CAPTURE THE POLICY AND REGULATORY CONSTRAINTS WITHIN THE JURISDICTION OF THIS MICROGRID LOCATION

Evaluate:

- **Regulatory requirements and limitations** to grid-tied microgrids (e.g., Puerto Rico "Microgrid Rule" 75% to be independent of PREPA ← will determine footprint)
- Consider audience: utility, regulator, developer
- Consider **funding requirements** if known

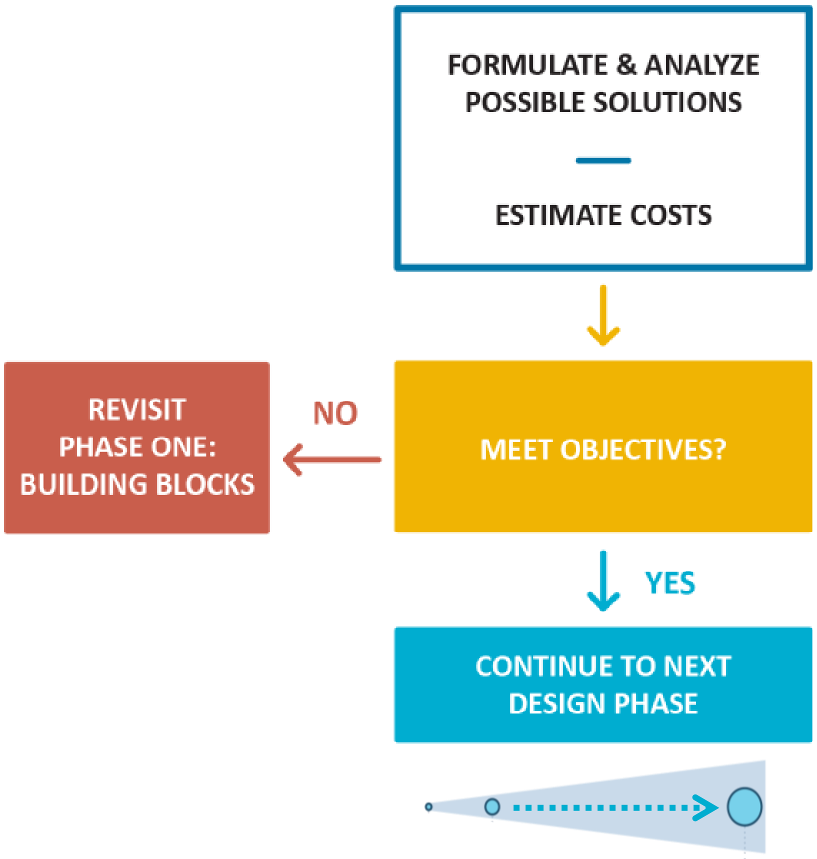
Microgrid Conceptual Design Methodology: Phase 2

Design and Evaluate Solutions

Formulate and Analyze Solutions

START TO FORMULATE AND ANALYZE SOLUTIONS

- **Site generation sources and capacity** goals
- Potential **tie-in points** if microgrid is not stand-alone
- Groups of users – **look at clusters that might yield higher resilience** opportunities (economies of scale, impacting the most users with a single microgrid)
- Sketch **proposed feeders and switch locations**
- Estimate **DER options**, consider fuel, assess equipment types and quantities



Estimate Up-Front Costs

DEVELOP A COST ESTIMATE

Evaluate:

- Variability as a function of generation type, be sure to include fuel costs
- Cost per MW
- Hardware upgrades and investments
- As time permits evaluate trade-offs and how maximize return on investment.

Based on a survey done in 2018, Micrograds in the Continental U.S. average [21]:

$2M to $5M / per MW

Source: "Phase I Microgrid Cost Study: Data Collection and Analysis of Microgrid Costs in the United States," National Renewable Energy Laboratory, Golden, CO, 2018

Microgrid Conceptual Design Guidebook 2022

The 2022 Guidebook

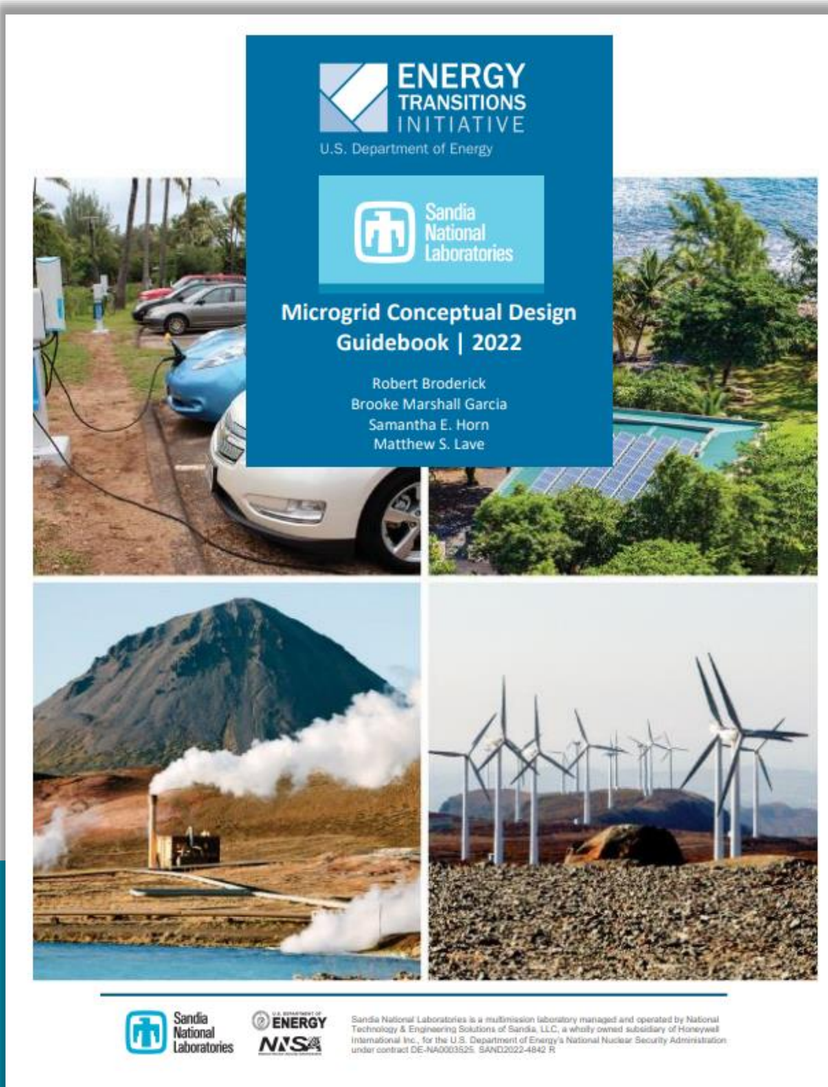


Table of Contents:

Available at: https://energy.sandia.gov/wp-content/uploads/2022/04/ETI_SNL_Microgrid_Guidebook_2022_SAND2022-4842-R_FINAL.pdf

Additional Content – DOE Lab Tools Sampling

Microgrid Design Toolkit (MDT) The MDT is a decision-support tool that aids microgrid planners and designers in quantitative analysis to meet objectives and constraints for efficiency, cost, reliability, and environmental emissions. https://www.sandia.gov/CSR/tools/mdt.html	**Technology Management Optimization (TMO)** TMO software optimizes user-defined problems using a genetic algorithm. It can be used to determine optimal design for power generation and distribution systems. https://www.sandia.gov/CSR/tools/tmo.html
Performance Reliability Model (PRM) The PRM evaluates the performance of a microgrid design, focusing on the behavior of a microgrid when operating in islanded modes following extreme weather events. PRM and TMO are embedded in the MDT tool. https://www.sandia.gov/CSR/tools/mdt.html	**The Distributed Energy Resources Customer Adoption Model (DER-CAM)** DER-CAM answers several important questions related to optimal distributed energy resource solutions for microgrids including: the optimal portfolio, the ideal installed capacity, energy bill considerations, where in distributed energy resources should be installed and how should they be operated to ensure voltage stability, and what is the optimal DER solution that minimizes costs while ensuring resilience targets. https://gridintegration.lbl.gov/der-cam
EPRI's Open DSS Power distribution system simulation and analysis. https://smartgrid.epri.com/SimulationTool.aspx	**GridLab-D** Power distribution system simulation and analysis https://www.gridlabd.org/
System Advisor Model (SAM) Techno-economic software model that facilitates decision-making. Can model renewable energy systems and their financials. https://sam.nrel.gov/	**ETI Islands Playbook** Information and resources to help you initiate, plan, and complete an energy transition that relies on local resources and eliminates dependence on imported fuels. https://www.eere.energy.gov/islandsplaybook/
REOpt Techno-economic design support platform to optimize energy systems. Recommends optimal mix of renewable energy, conventional generation, and energy storage technologies to meet cost savings, resilience, and energy performance goals. https://reopt.nrel.gov/	**ReNCAT** Resilience Node Cluster Analysis Tool (ReNCAT) sites microgrids for optimal cost versus social burden performance subject to outage conditions. Not yet publicly available, contact this group for more information: https://energy.sandia.gov/programs/electric-grid/renewable-energy-integration/

Additional Content – The Basics of Business Models

5. Business Models

A business model designed to support new microgrid systems remains a critical factor in its viability. Though the regulation and management of these systems is no doubt a primary driver, this guide focuses primarily on the technical factors including sizing, operational costs, and developing metrics to quantify overall benefits. We will not be exploring or comparing models. This section is intended to present a high-level overview and structure discussion.

There are three basic models in use today:

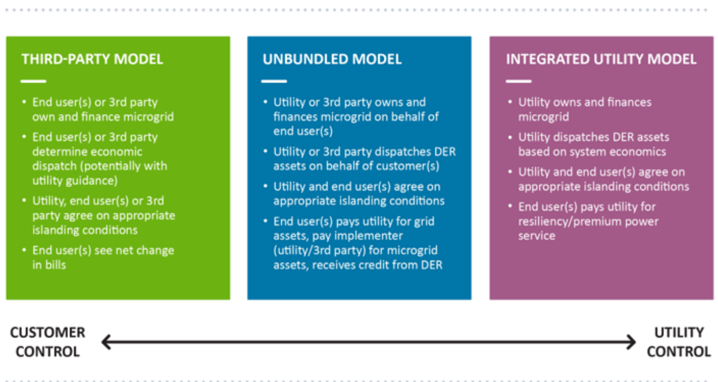


Figure 17: Description of various microgrid operation models in use.

At present, there is no single "best" microgrid business model. End-user ownership still largely dominates the business models in practice, but there are innovative third-party and mixed ownership models that are emerging (**Figure 17**).

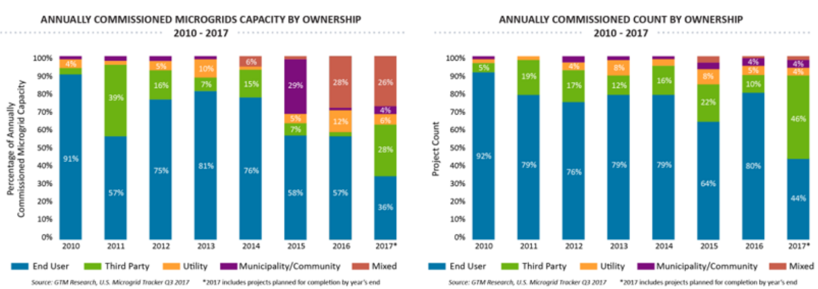


Figure 18: Ownership of Microgrids by Capacity and Count 2010-2017 [10]Case Studies

Summary

Summary

1. Reliable power is the backbone of infrastructure and enables the provision of critical services.
2. A resilient energy system supports critical community functions by preparing for, withstanding, adapting to, and recovering from disruptions.
3. Microgrids are one option to enhance reliability and resilience to power outages.
4. Sandia’s Microgrid Conceptual Design Methodology developed to guide communities through developing and evaluation their vision for microgrids as solutions for their particular energy needs.
5. Sandia’s latest Microgrid Conceptual Design Guidebook released in April 2022, publicly available to provide communities a starting place to investigate microgrid design.

Thank You
Questions | Comments

oehart@sandia.gov