Sandia National Laboratories

AN INTRODUCTION TO MICROGRIDS AND ENERGY STORAGE

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U.S. DEPARTMENT OF ENERGY | NNSA

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INTRODUCTION - SANDIA

National Nuclear Security Administration labs

Science labs

Nuclear energy lab

Environmental management lab

Fossil energy lab

Energy efficiency and renewable energy lab

Sandia is one of 17 U.S. National Laboratories

Sandia's National Security Mission

- Nuclear Deterrence
- Nuclear Nonproliferation
- National Security Programs
- Energy & Homeland Security
- Advanced Science & Technology

SANDIA HAS FACILITIES ACROSS THE NATION

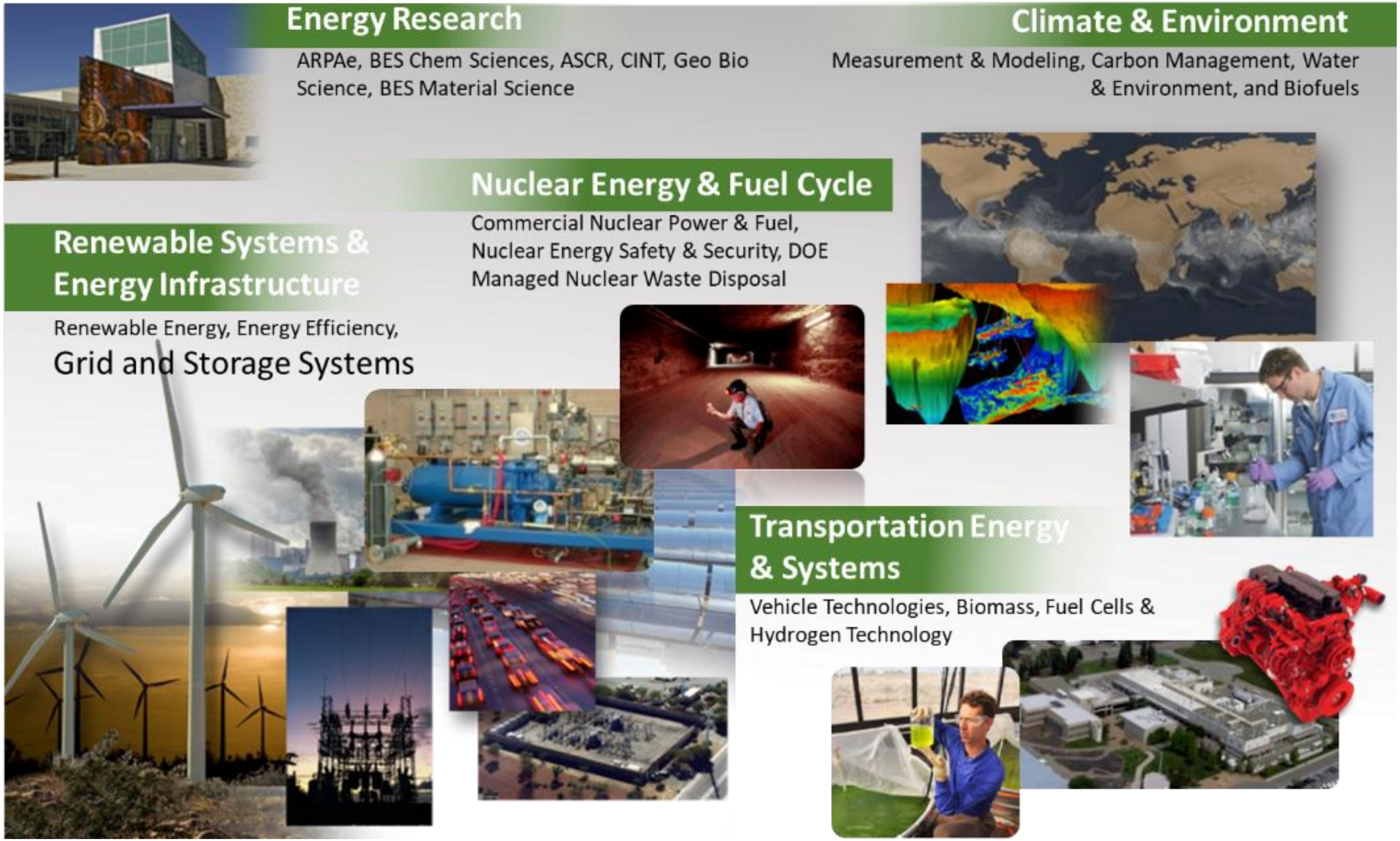
Activity locations

- Kauai, Hawaii
- Waste Isolation Pilot Plant, Carlsbad, New Mexico
- Pantex Plant, Amarillo, Texas
- Tonopah, Nevada

Main sites

- Albuquerque, New Mexico
- Livermore, California

SANDIA ENERGY & CLIMATE



Energy Research

ARPAe, BES Chem Sciences, ASCR, CINT, Geo Bio Science, BES Material Science

Climate & Environment

Measurement & Modeling, Carbon Management, Water & Environment, and Biofuels

Nuclear Energy & Fuel Cycle

Commercial Nuclear Power & Fuel, Nuclear Energy Safety & Security, DOE Managed Nuclear Waste Disposal

Renewable Systems & Energy Infrastructure

Renewable Energy, Energy Efficiency,

Grid and Storage Systems

Transportation Energy & Systems

Vehicle Technologies, Biomass, Fuel Cells & Hydrogen Technology

ENERGY STORAGE R&D AT SANDIA

BATTERY MATERIALS

Large portfolio of R&D projects related to advanced materials, new battery chemistries, electrolyte materials, and membranes.

CELL & MODEULE LEVEL SAFETY

Evaluate safety and performance of electrical energy storage systems down to the module and cell level.

POWER CONVERSION SYSTEMS

Research and development regarding reliability and performance of power electronics and power conversion systems.

SYSTEMS ANALYSIS

Test laboratories evaluate and optimize performance of megawatt-hour class energy storage systems in grid-tied applications.

DEMONSTRATION PROJECTS

Work with industry to develop, install, commission, and operate electrical energy storage systems.

STRATEGIC OUTREACH

Maintain the ESS website and DOE Global Energy Storage Database, organize the annual Peer Review meeting, and host webinars and conferences.

GRID ANALYTICS

Analytical tools model electric grids and microgrids, perform system optimization, plan efficient utilization and optimization of DER on the grid, and understand ROI of energy storage.

Wide ranging R&D covering energy storage technologies with applications in the grid, transportation, and stationary storage

DOE OFFICE OF ELECTRICITY ENERY STORAGE PROGRAM

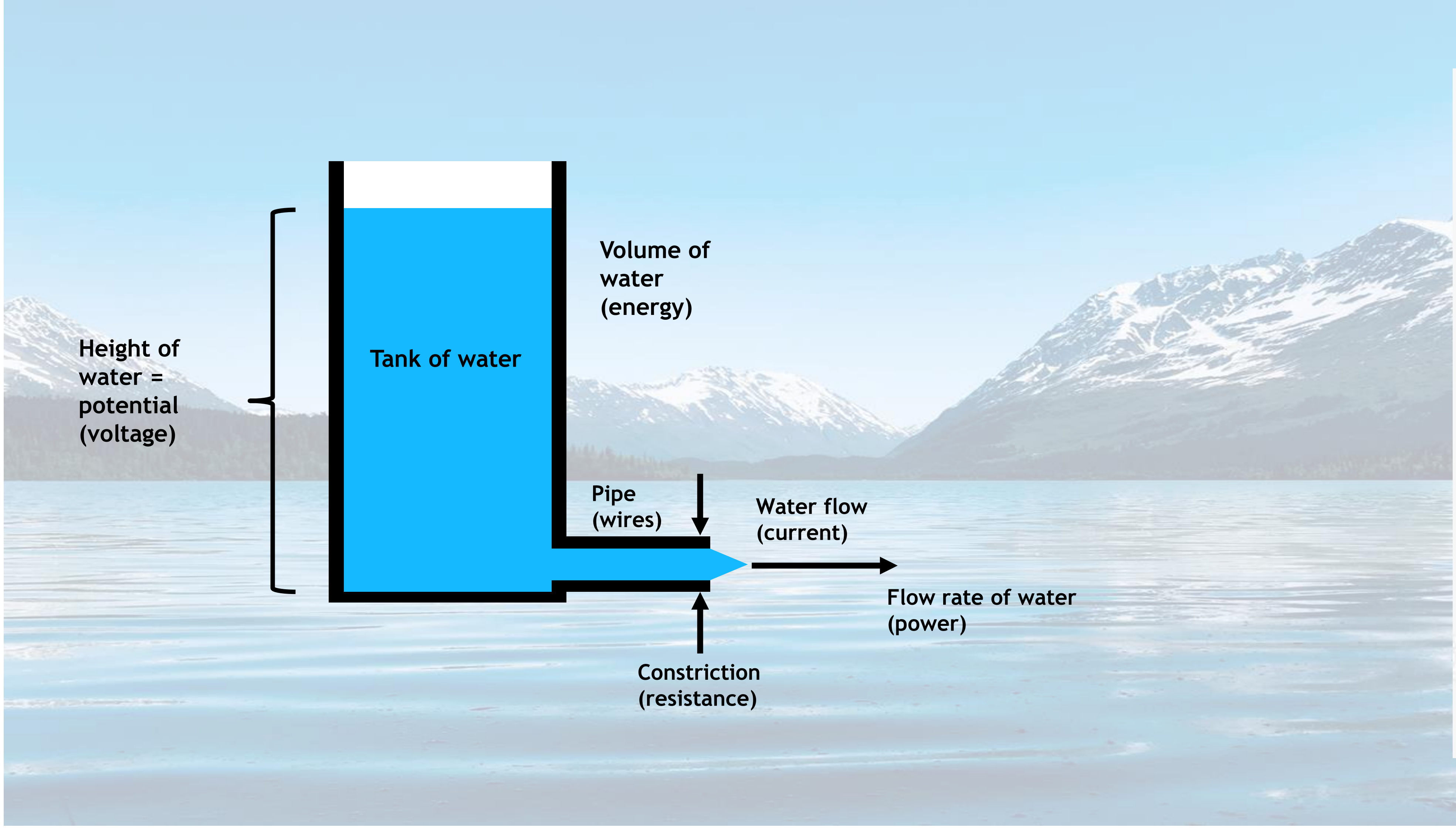
- The goal of the DOE Energy Storage Program is to develop advanced energy storage technologies, systems and power conversion systems in collaboration with industry, academia, and government institutions that will increase the reliability, performance, and sustainability of electricity generation and transmission in the electric grid and in standalone systems. The program also works with utilities, municipalities, States, and tribes to further wide deployment of storage facilities.
- This program is part of the Office of Electricity (OE) under the direction of Dr. Imre Gyuk.

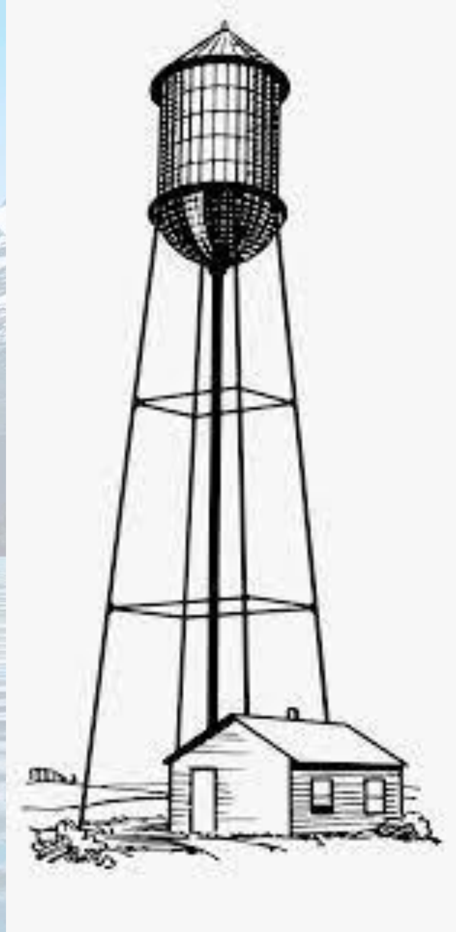
http://www.sandia.gov/ess/

U.S. DEPARTMENT OF ENERGY

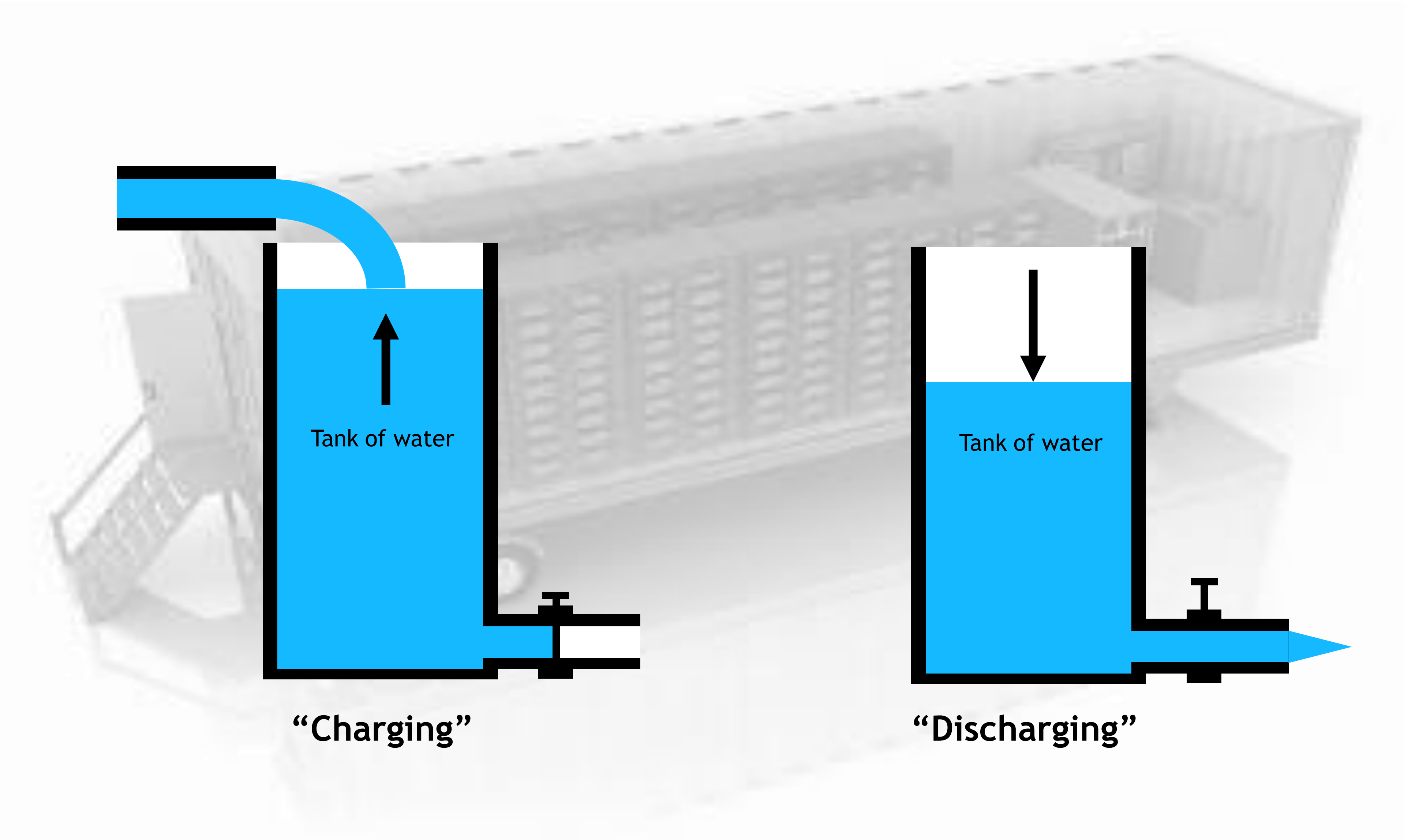
"Working with tribal entities to help them achieve energy sovereignty, is a valuable part of the DOE-OE Energy Storage Program. Storage plus renewables and microgrids are not only viable solutions for the tribes; but are also the way of the future for the U.S. and the world." – Dr. Imre Gyuk

ELECTRICITY BASICS





BATTERY CHARGE AND DISCHARGE EXAMPLE



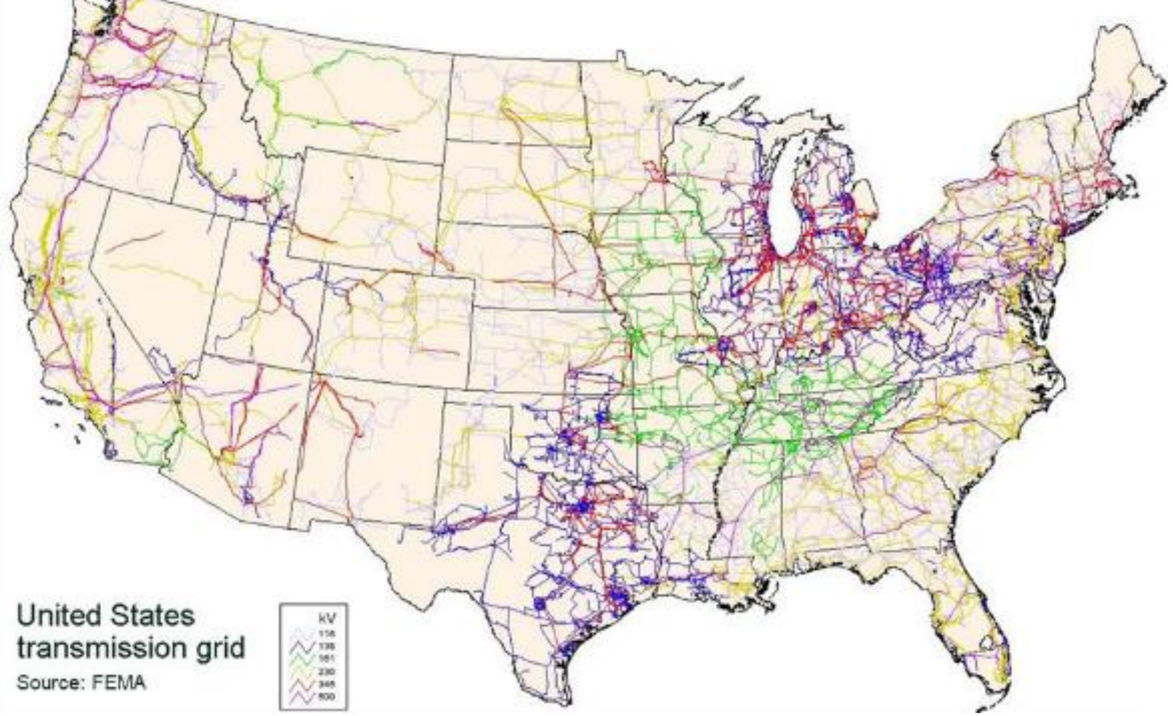
US ELECTRIC INFRUSTRUCTURE – "THE GRID"

Current State

Made up of:

- 7,300 power plants
- Over 150 thousand miles of transmission lines (AC & DC)
- Millions of transformers, relays, and controls
- Millions of miles of low-voltage power lines connecting over 145 million customers
- 100s of billions of dollars in total investments in transmission and distribution
- Sometime referred to as "macrogrid"

First modern electric system developed in 1882 by Thomas Edison's Pearl Street Electric in NYC



	Common AC voltages
Transmission	• 765kV • 500kV • 345kV • 230kV
Sub-Transmission	• 69kV • 30kV
Distribution	• 15kV • 4kV • 2kV • 600V • 480V • 240V • 120V

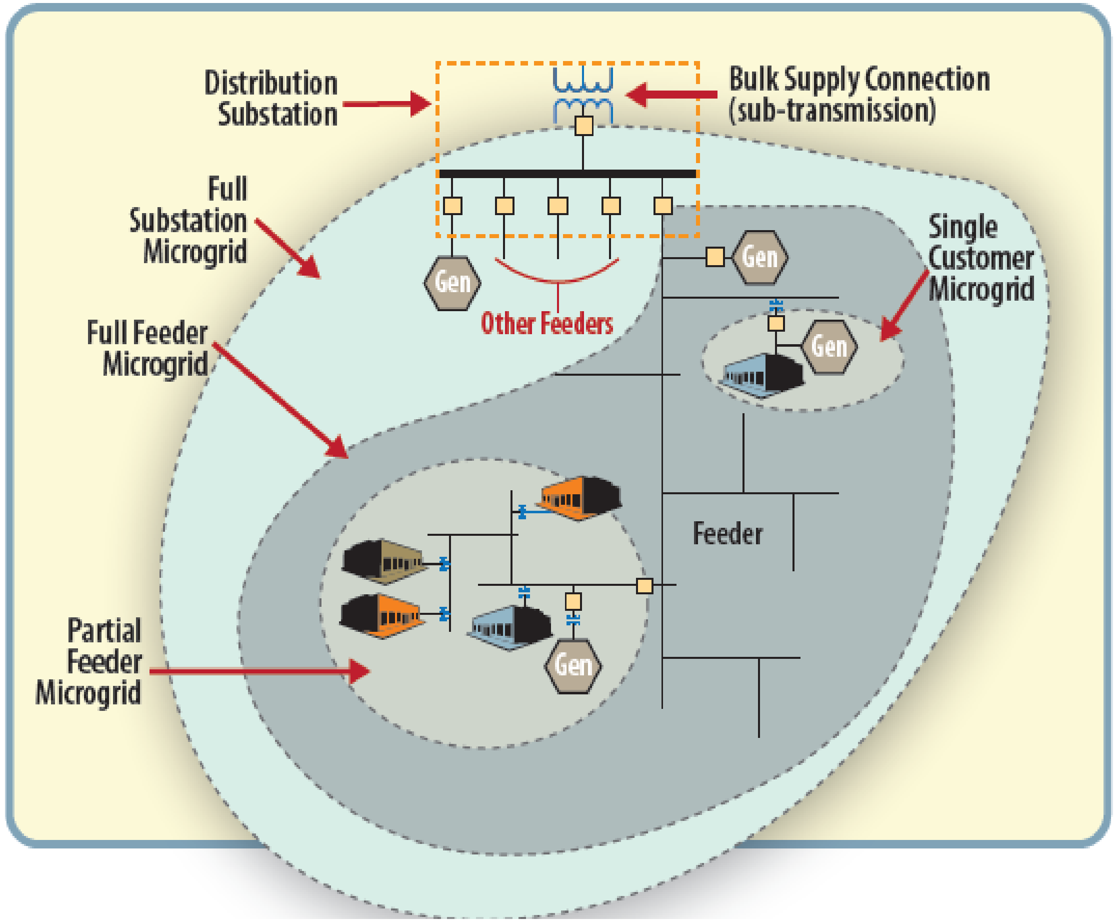
Trends challenging the grid:

- Changing generation mix
- Aging infrastructure
- Increased variable generation and load mix
- Increased cyber and physical attacks
- Changing demands

SO WHAT IS A "MICROGRID"?

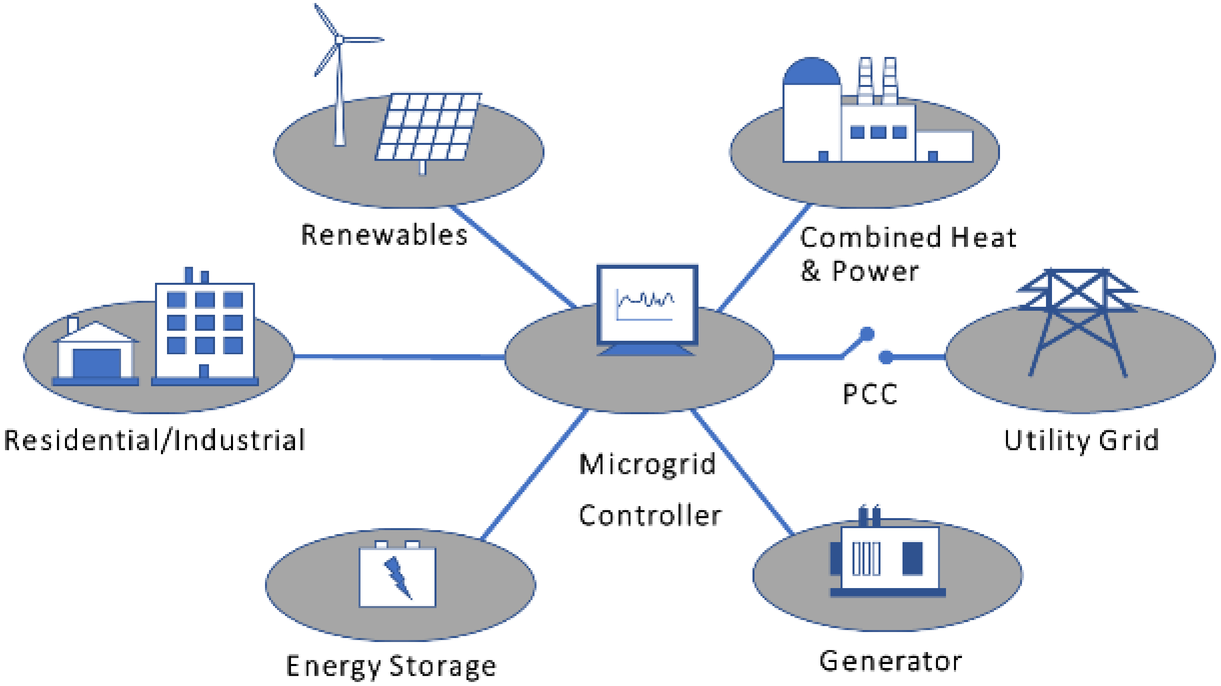
Definition

- A microgrid is a small power system that has the ability to operate connected to the larger grid, or by itself in stand-alone mode.
- Microgrids may be small, powering only a few buildings; or large, powering entire neighborhoods, college campuses, or military bases.
- Many microgrids today are formed around the existing combined-heat-and-power plants ("steam plants") on college campuses or industrial facilities.
- However, increasingly, microgrids are being based on energy storage systems combined with renewable energy sources (solar, wind, small hydro), usually backed up by a fossil fuel-powered generator.



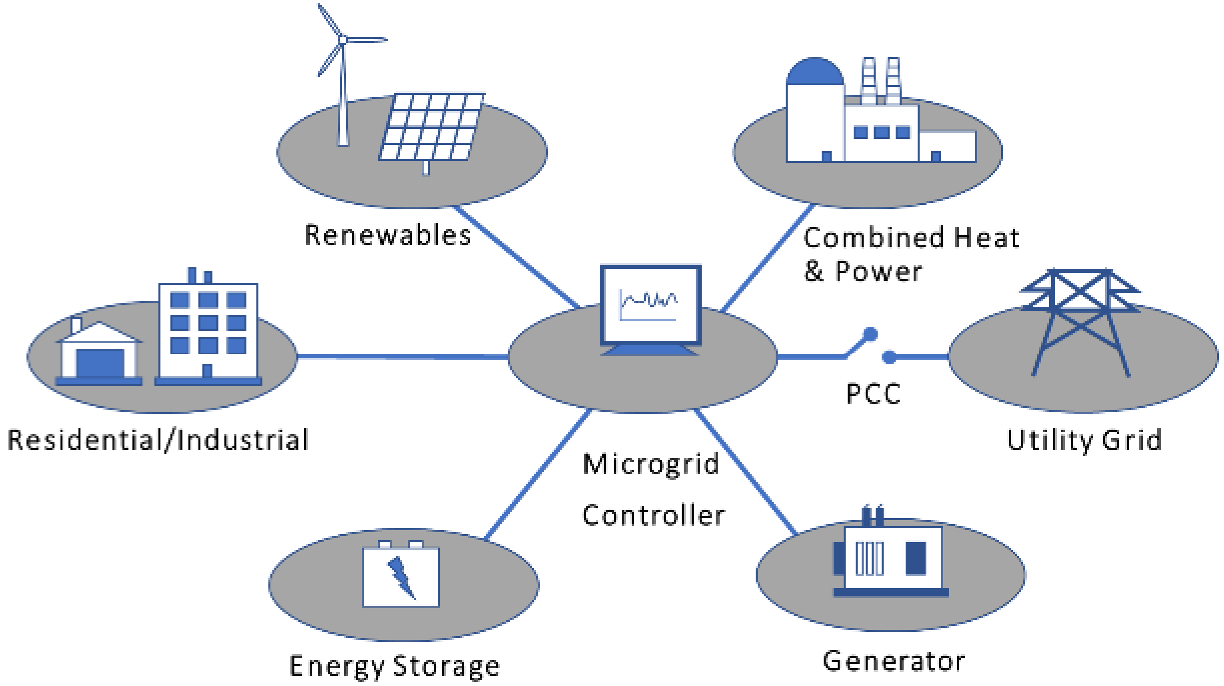
KEY MICROGRID COMPONENTS

- **A microgrid has five key components:**
  - Energy sources (generators and storage)
  - Energy sinks (loads)
  - A means for connecting to/disconnecting from a larger power system
  - Means for controlling ("regulating") the microgrid
  - Appropriate safety-assurance systems ("protection")
- **The energy sources must have the ability to provide certain critical functions that are usually provided by the larger grid, such as:**
  - "Black start"—starting up the microgrid by themselves, after a full outage/blackout
  - Surge capability—some loads when they turn on draw big pulses of power, and the microgrid sources have to be able to supply those
  - Voltage and frequency regulation—keeping the voltage at your outlets within specified ranges (i.e., "grid forming" versus "grid following")



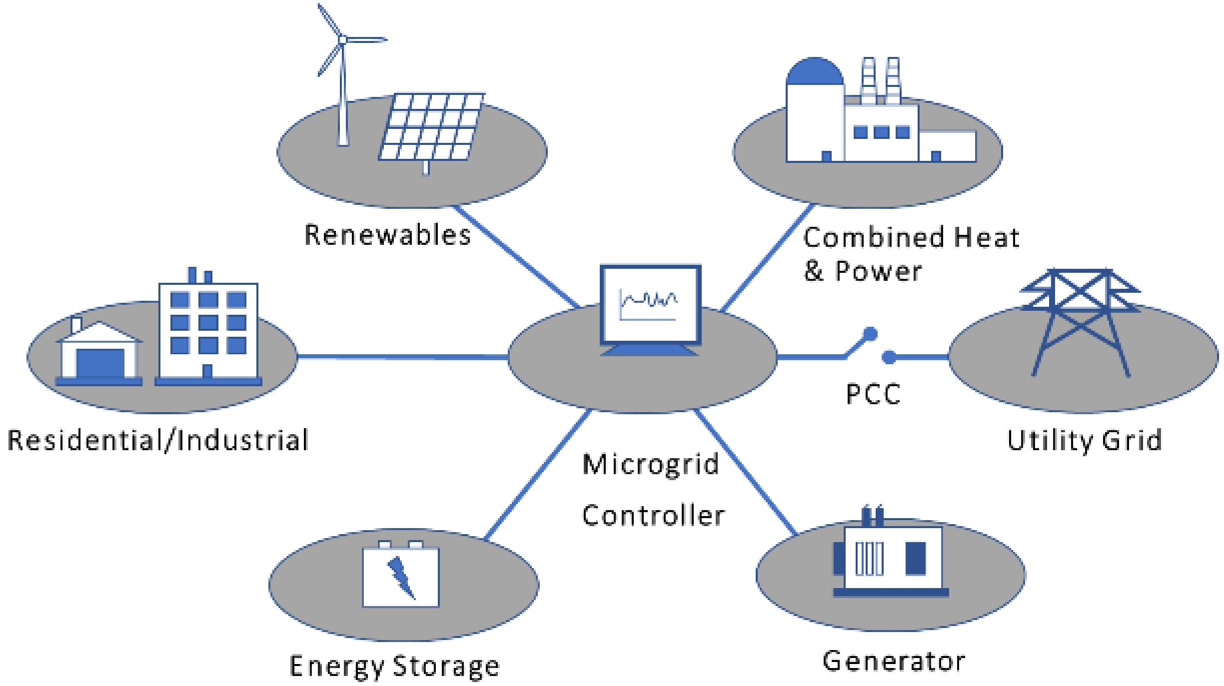
ADVANTAGES OF MICROGRIDS

- **The main advantage of a microgrid: higher reliability.** The microgrid has sources close to loads, and is thus less vulnerable to disruption in transmission caused by storms or other natural disasters. *Most* microgrids installed commercially today were installed for reliability-enhancement reasons.
- **Eventually, microgrids may be lower-cost.** Large-scale mass production of microgrid equipment, improvements in energy storage and renewable energy technology, and standardization of design and operations may eventually make microgrids a low-cost option.
- **Other potential advantages:**
  - Can take advantage of local resources, such as the aforementioned "steam plant", a local hydropower resource, or strong solar resources.
  - Power is produced locally, so losses in the transmission system are avoided.
  - Microgrids can take maximum advantage of DC power, which could ultimately improve overall energy efficiency and simplify system control.



CHALLENGES FACING MICROGRIDS

- **High cost.** *In general*, power from a microgrid today is more expensive than power from the main grid. Cost drivers:
  - Need for redundancy to achieve high reliability.
  - Most microgrids are built around existing distribution circuits, which were not designed for microgrids. Upgrades are usually needed.
  - Communications systems. Many microgrid controllers require high-bandwidth networked communications.
  - Safety-assurance systems. Safety assurance requires additional equipment, or oversizing of energy sources.
- **Regulatory hurdles.** In most jurisdictions, only the local utility is allowed to sell power to customers (regulated monopoly). Microgrid asset owners are forbidden from selling power to other customers, which complicates creation of multi-customer microgrids.



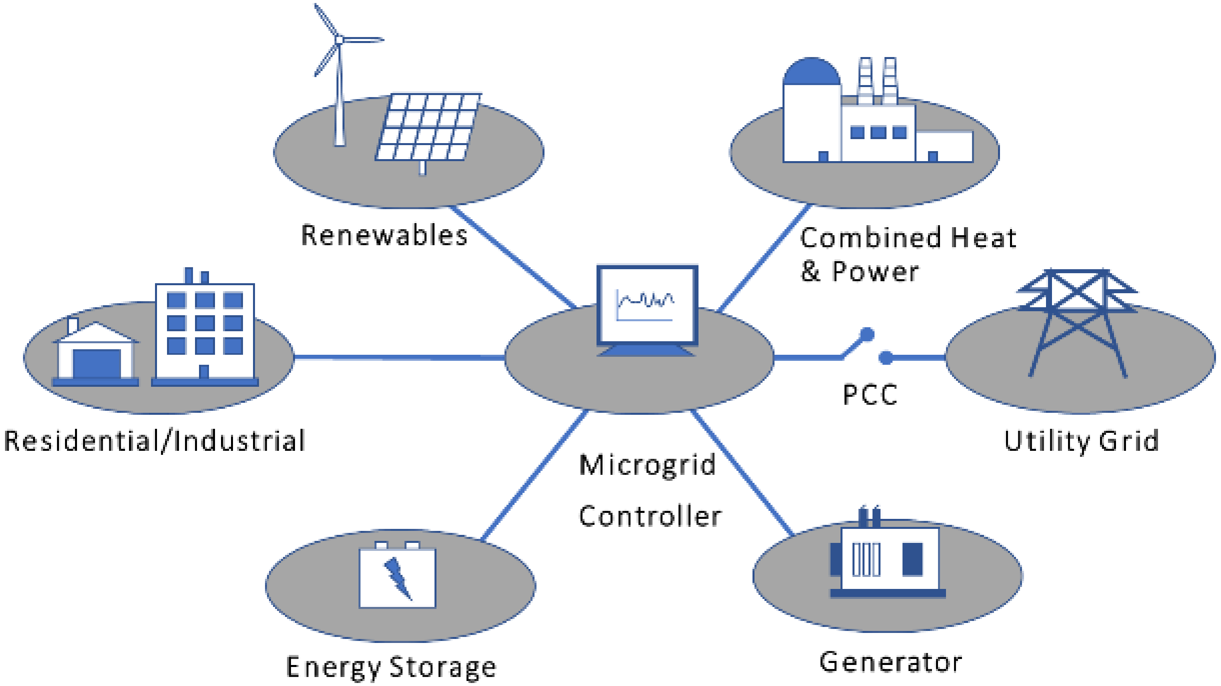
FUTURE OF MICROGRIDS

- Major outages have led to a public perception that the grid is becoming less reliable.
  - Recent major outage events in CA and TX have reinforced this perception.
  - Grid operators usually exclude "major events" from their reliability metrics. This hides the impact of these major events on the true reliability of the grid.
- For this reason, load-sited generation to improve reliability is becoming increasingly common. However, *most* of these are not true microgrids because they do not have an on-grid mode; "backup power" only.
- **The future of microgrids will largely depend on two factors:**
  - The cost advantages of having an on-grid mode for one's load-sited generation; and
  - The ability of customers to share resources with each other over the distribution network (regulatory hurdle).


Source: Reuters / Gene


Source: Greentech Media


Source: Entergy Texas, Inc/Flicker

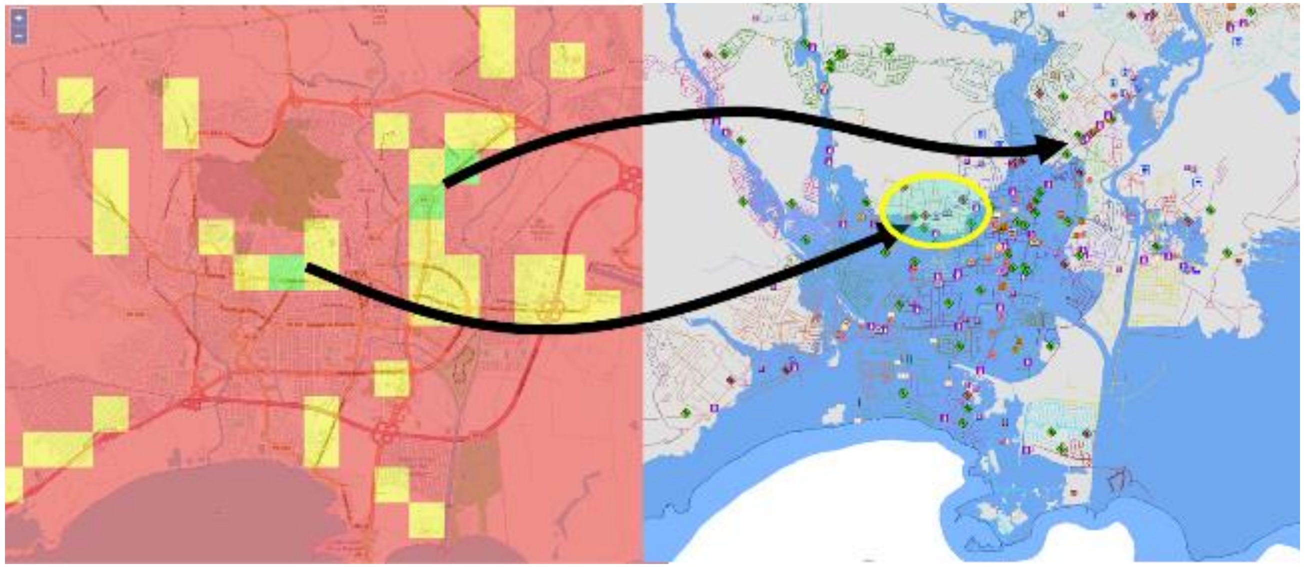


SANDIA ISLANDED POWER SYSTEM SYSTEM R&D

Tool: ReNCAT   Tool: MPEx

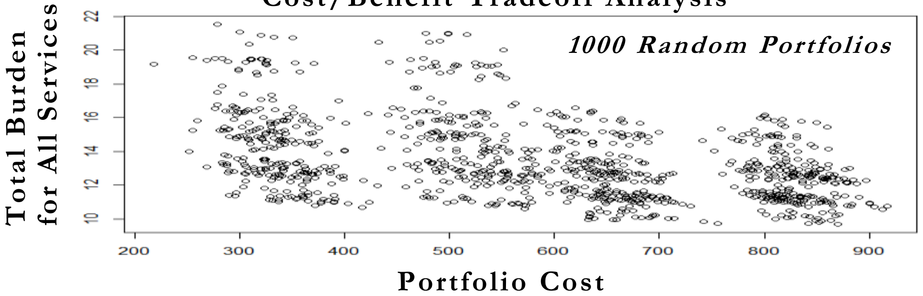
Sandia Microgrid Analysis Process

Example Threat Analysis (e.g., wind, flooding, landslide, earthquakes, etc.)



Examine Candidate Microgrid Locations   Finalize Candidate Microgrid Locations

Cost/Benefit Tradeoff Analysis

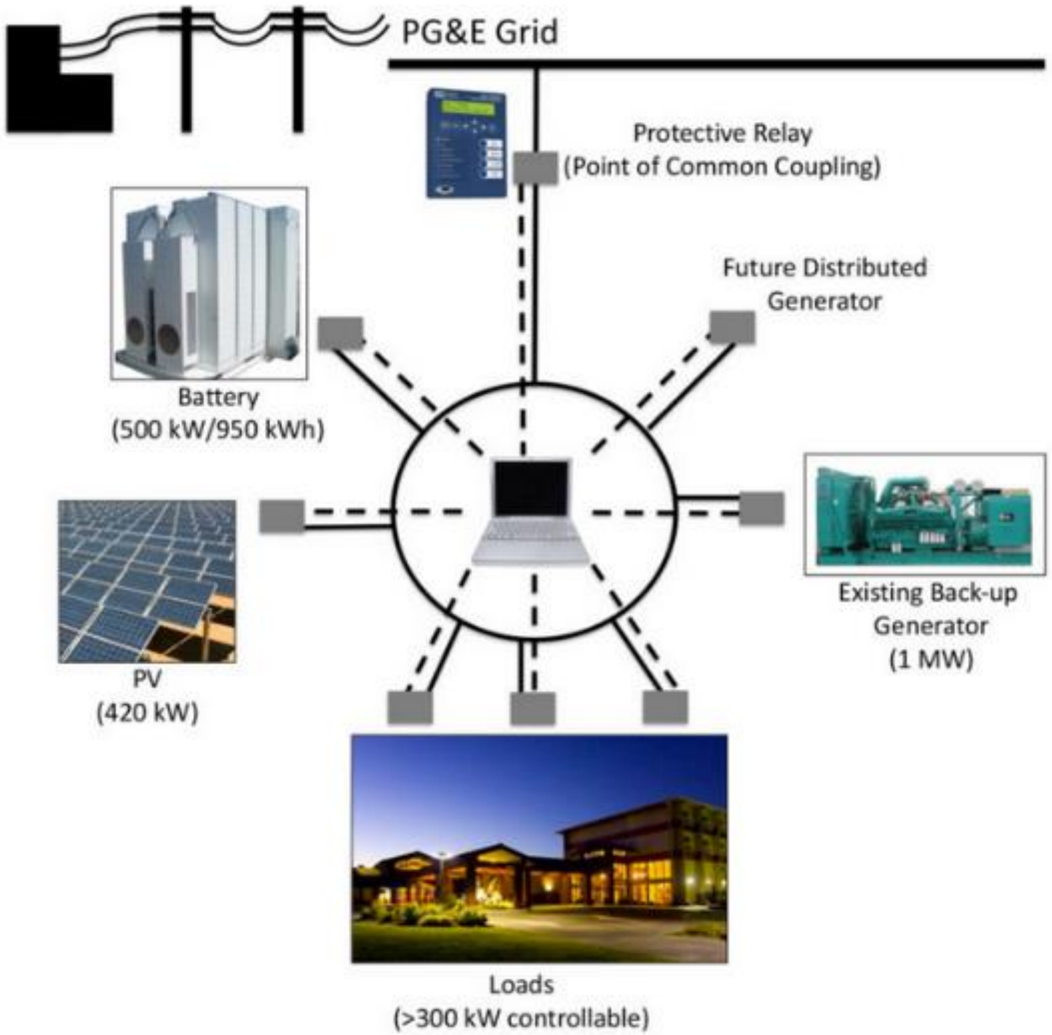


Jeffers et al. (2018) Analysis of Microgrid Locations Benefitting Community Resilience for Puerto Rico. SAND2018-11145

BLUE LAKE RANCHERIA MICROGRID EXAMPLE

- Functioning example of a secure, reliable, low-carbon microgrid for a Native American tribe
- Has single point of common coupling between the microgrid and the main utility grid for seamless islanded if main utility grid losses power
- Can optimally dispatch battery power under normal conditions by using energy load and PV availability forecasting and rate schedule
- Increases use of local renewable energy, thus reducing CO2 emissions
- Designated American Red Cross evacuation center

Source: Schatz Energy Research Cer



Source: Schatz Energy Research Center

GRID ENERGY STORAGE TECHNOLOGIES

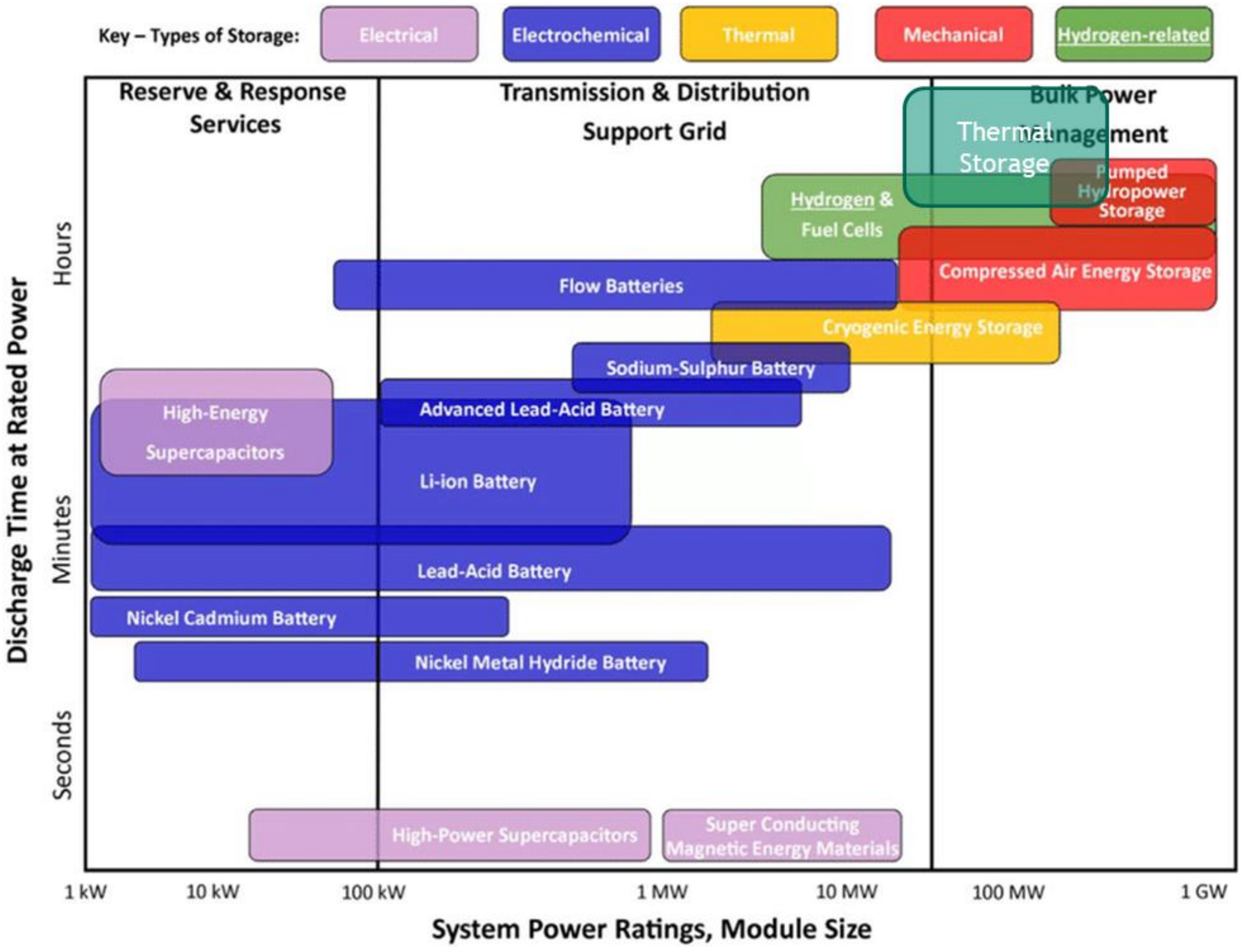
- Electrical
  - Electrochemical Capacitor
- Electromagnetic
  - Superconducting Magnetic Storage
- Mechanical
  - Hydroelectric, Pumped Hydro
  - Compressed Air
  - Flywheel
- Thermal
  - High Temperature
    - Molten Salt
  - Low Temperature
    - Ice Storage, etc.
- Hybrid Energy Storage
  - Coupling of two or more energy storage technologies
- Electrochemical
  - Non-flow Rechargeable Batteries
    - Lead Acid, Lithium ion, nickel-cadmium, etc..
  - Flow Batteries
    - Zinc-Bromine, Vanadium Redox, etc.
  - Fuel Cells
    - Hydrogen, Direct Methanol, etc.

ENERGY STORAGE TECHNOLOGY COMPARISON

Energy

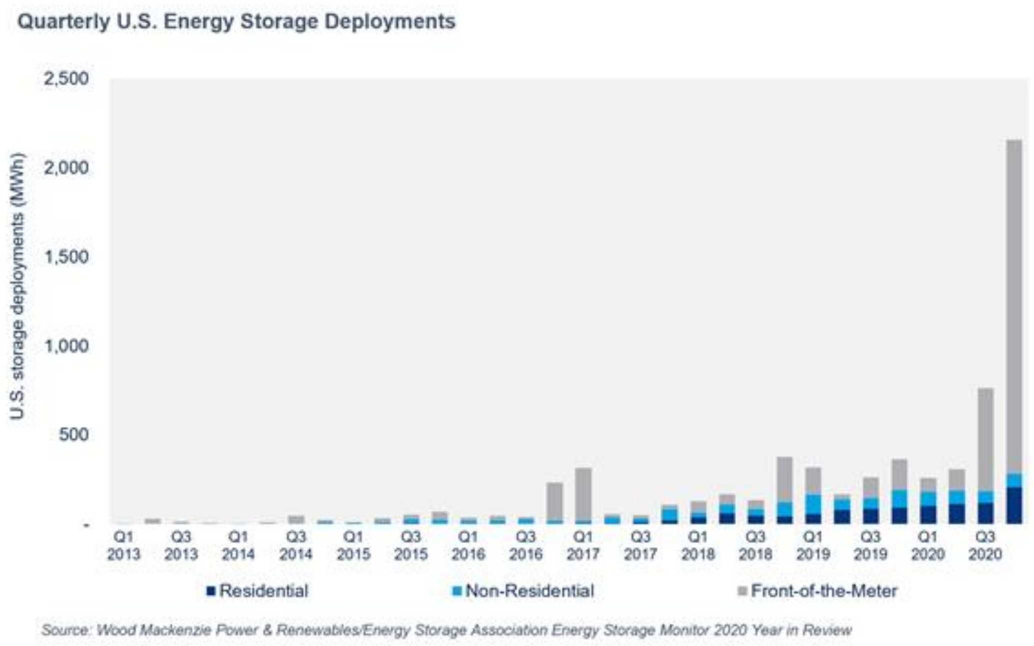
- Pumped Hydro
- Compressed Air Energy Storage
- Batteries
    - Lithium Ion
    - Lead Acid
    - Advanced Lead Carbon
    - Flow Batteries
    - Sodium Sulfur
- Flywheels
- Superconducting Magnetic Energy Storage
- Electrochemical Capacitors

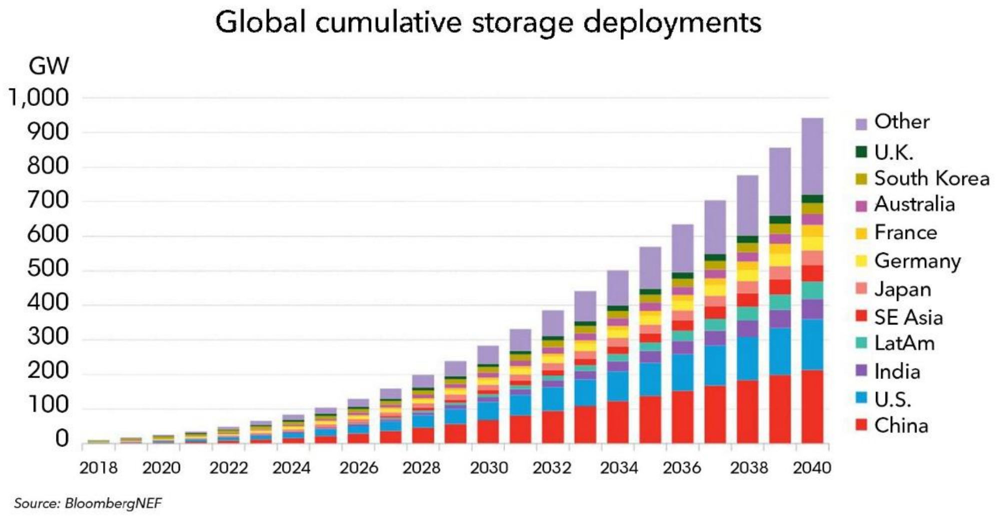
Power



https://www.researchgate.net/figure/Comparison-of-key-type-energy-storage-technologies-in-sense-of-storage-capacity-and_fig1_312870399

DOE GLOBAL ENERGY STORAGE DATABASE





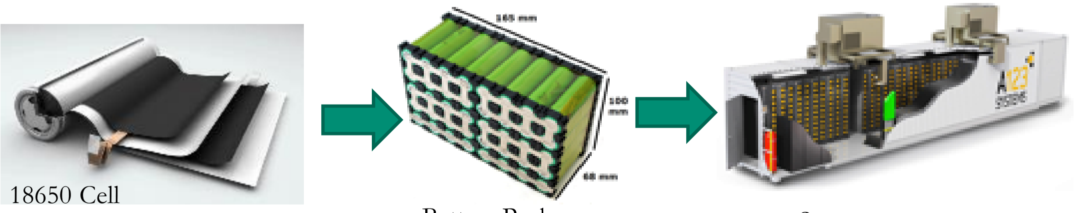
DOE Energy Storage Database
www.energystorageexchange.org

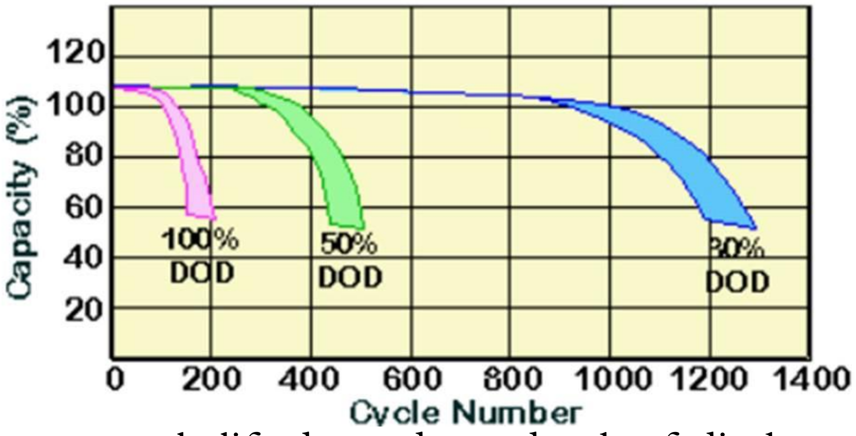
DOE Database (since 2019)

- Over 1,600 Projects
- More than 21 Polices
- Users in over 189 Countries
- 50+ Energy Storage Technologies

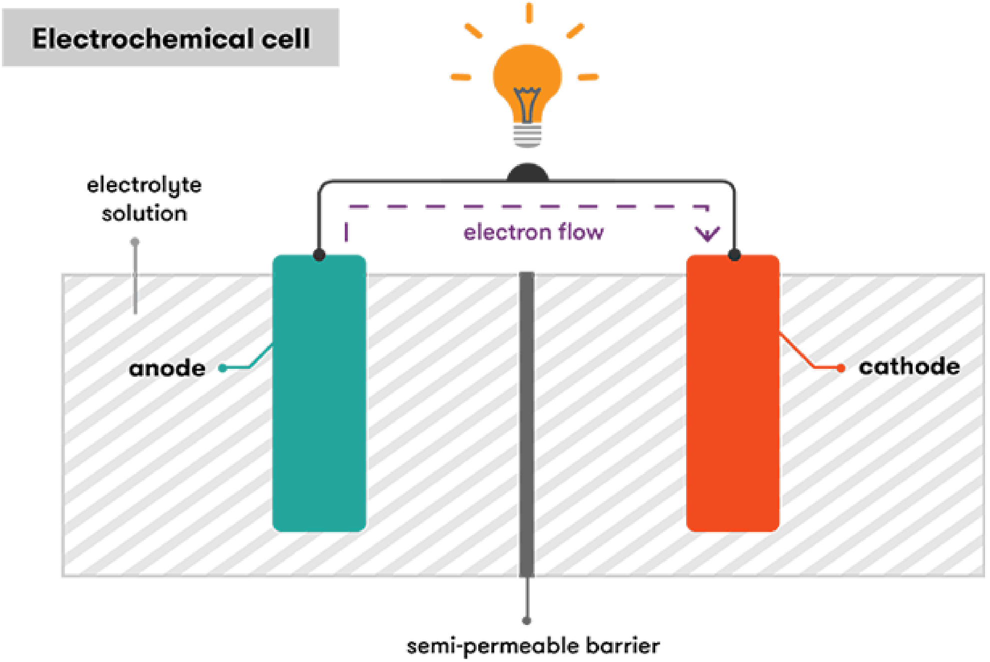
BATTERY STORAGE INTRODUCTION

- A battery is a device that stores chemical energy and converts it to electrical energy
- The chemical reactions in a battery involve the flow of electrons from one material (electrode) to another, through an external circuit
- The flow of electrons provides an electric current that can be used to do work
- Lead acid, lithium ion, nickel cadmium, etc.





Battery cycle life depends on depth of discharge (DOD)



https://www.science.org.au/curious/technology-future/batteries

BATTERY ENERGY STORAGE SYSTEM ELEMENTS

Battery Storage
- Modules
- Racks
- $/KWh

Battery Management System (BMS)
- Battery Management & BESS Protection

Power Control System (PCS)
- Bi-directional Inverter
- Inverter control
- Interconnection / Switchgear
- $/KW

Energy Management System (EMS)
- Charge / Discharge
- Load Management
- Ramp rate control
- Grid Stability
- Monitoring
- $ / ESS

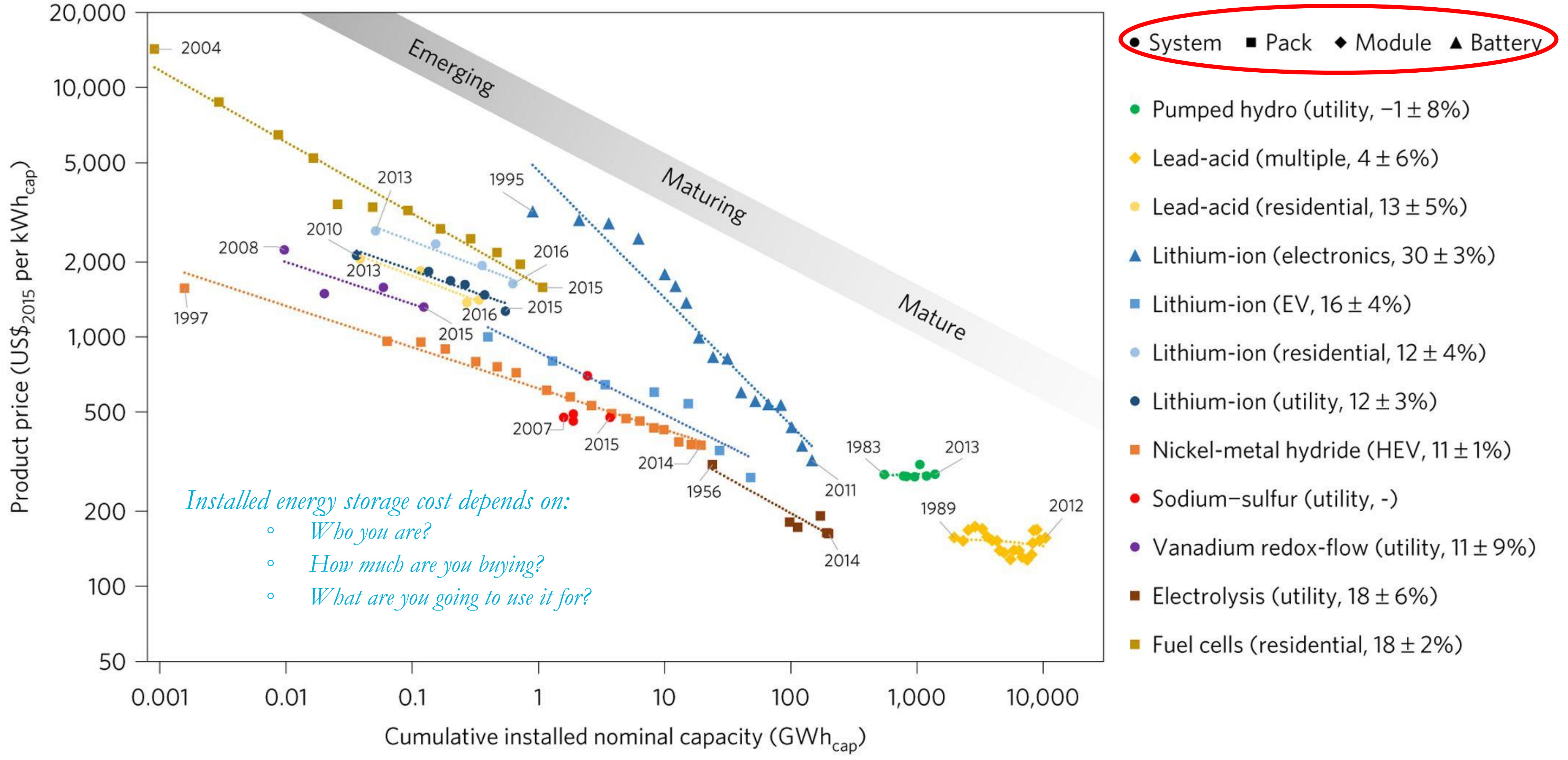
Site Management System (SMS)
- Distributed Energy Resources (DER) control
- Synchronization
- Islanding and microgrid control
- $ / microgrid

Balance of Plant
- Transformer/ POC switchgear
- BESS container
- Climate control
- <u>**Fire protection**</u>
- Construction and Permitting
- $ / project

NOTE: Important to have single entity responsible for the ESS integration.

Source: UtilityDrive

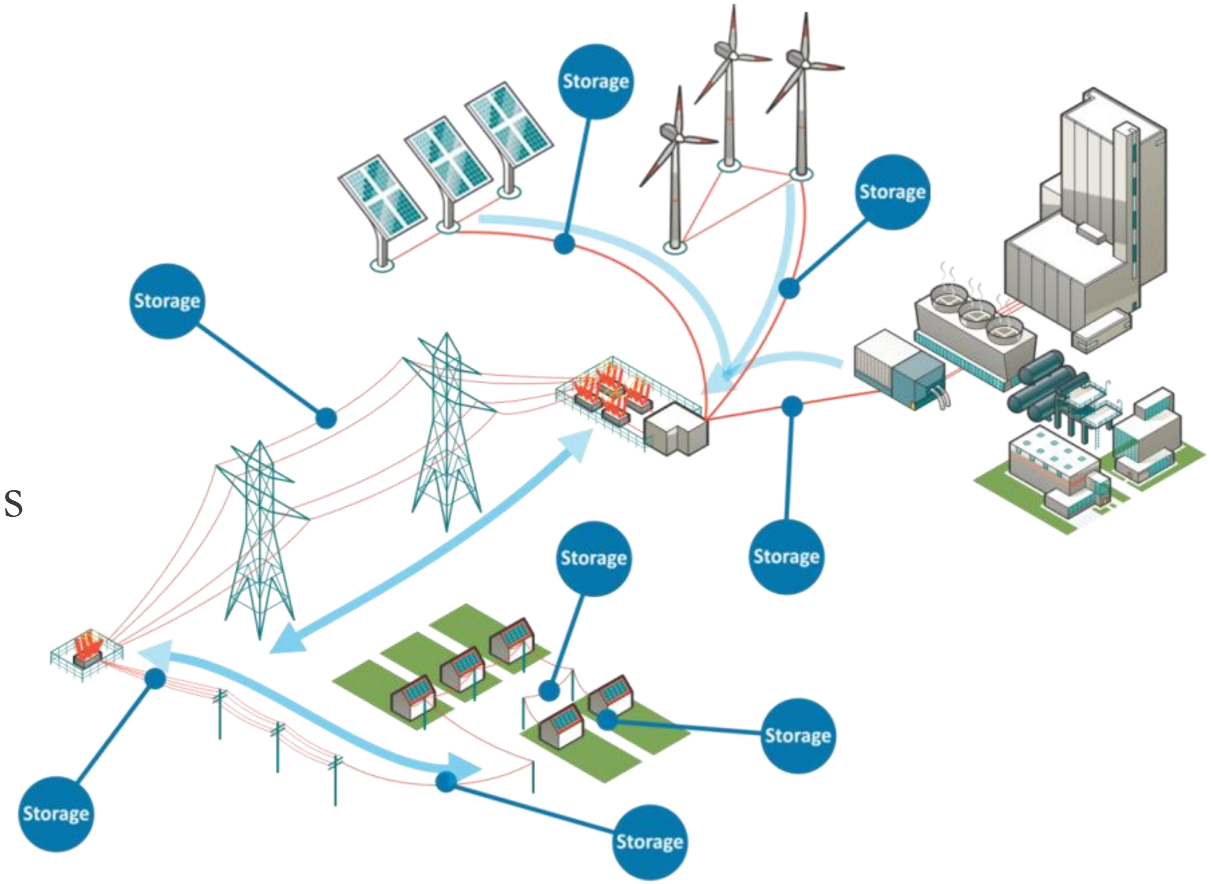
ENERGY STORAGE COSTS ($/kWh$_{cap}$) vs. INSTALLED CAPACITY



Nature Energy **volume 2**, Article number: 17110 (2017)
https://www.nature.com/articles/nenergy2017110

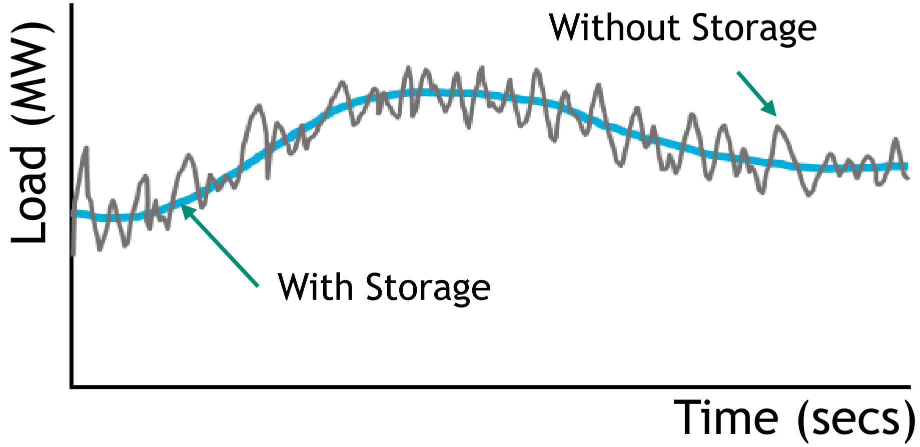
BENEFITS OF ELECTRICITY STORAGE

- Maintain quality power and reliability
- Provide customer services — cost control, flexibility, and convenience
- Improve T&D stability
- Enhance asset utilization and defer upgrades
- Increase the value of variable renewable generation

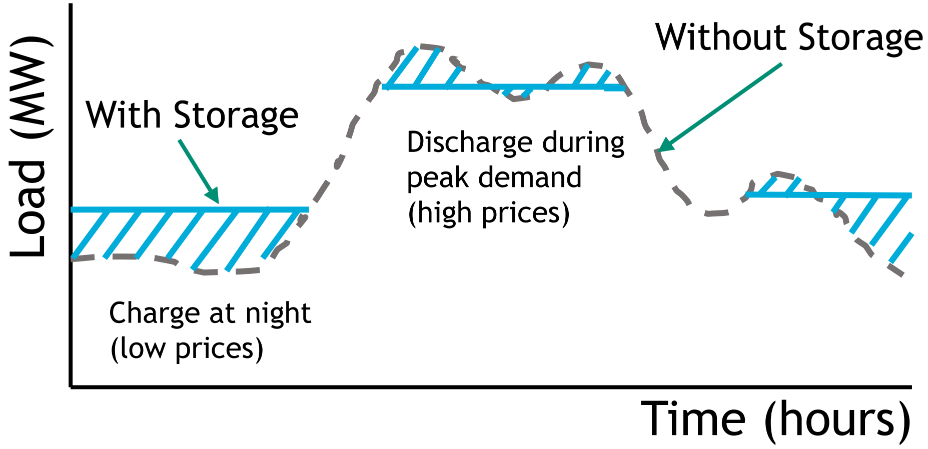


EXAMPLES OF ENERGY STORAGE BENEFITS TO GRID

- Frequency Control
  - Electric utility grid can experience frequency instability
  - If not managed, frequency instability can damage critical components
  - Energy storage injects power into the grid to keep the grid's frequency stable



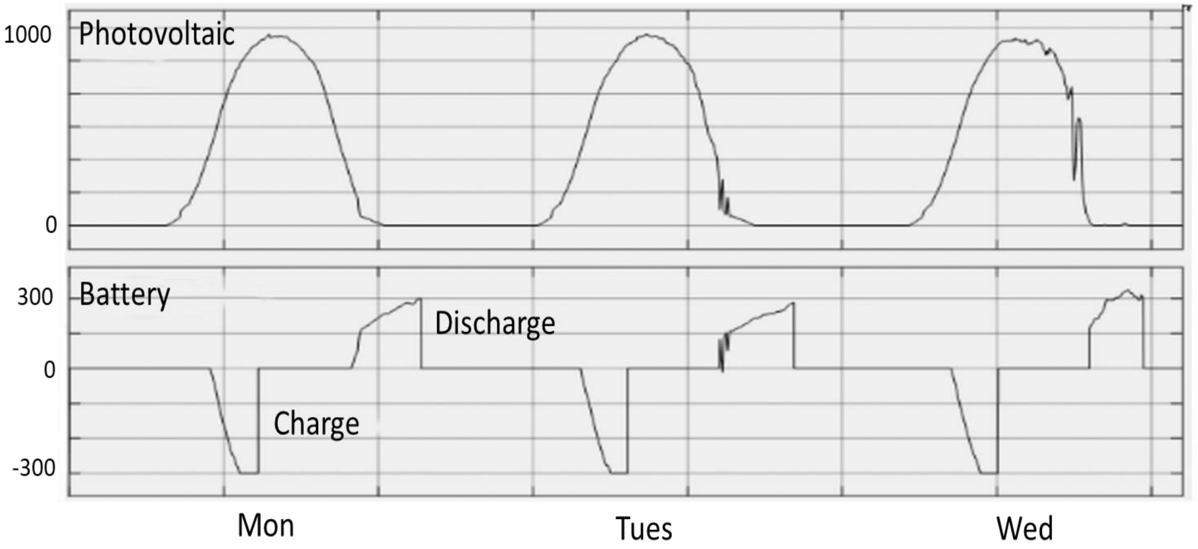
- Peak Shaving
  - Energy storage is charged when electricity rates are at its lowest
  - Energy storage is discharged to avoid paying peak prices during expensive times of the day

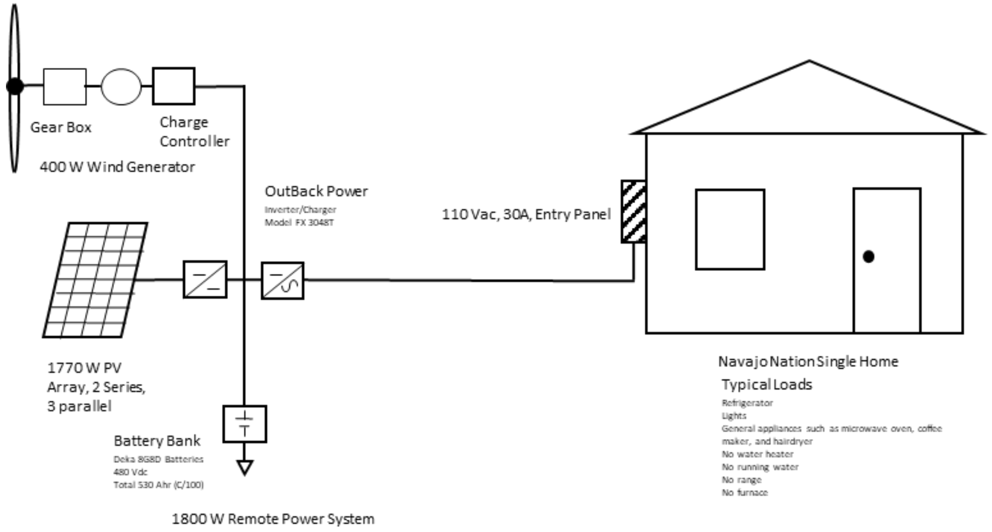


ENERGY STORAGE BENEFITS TO NAVAJO NATION

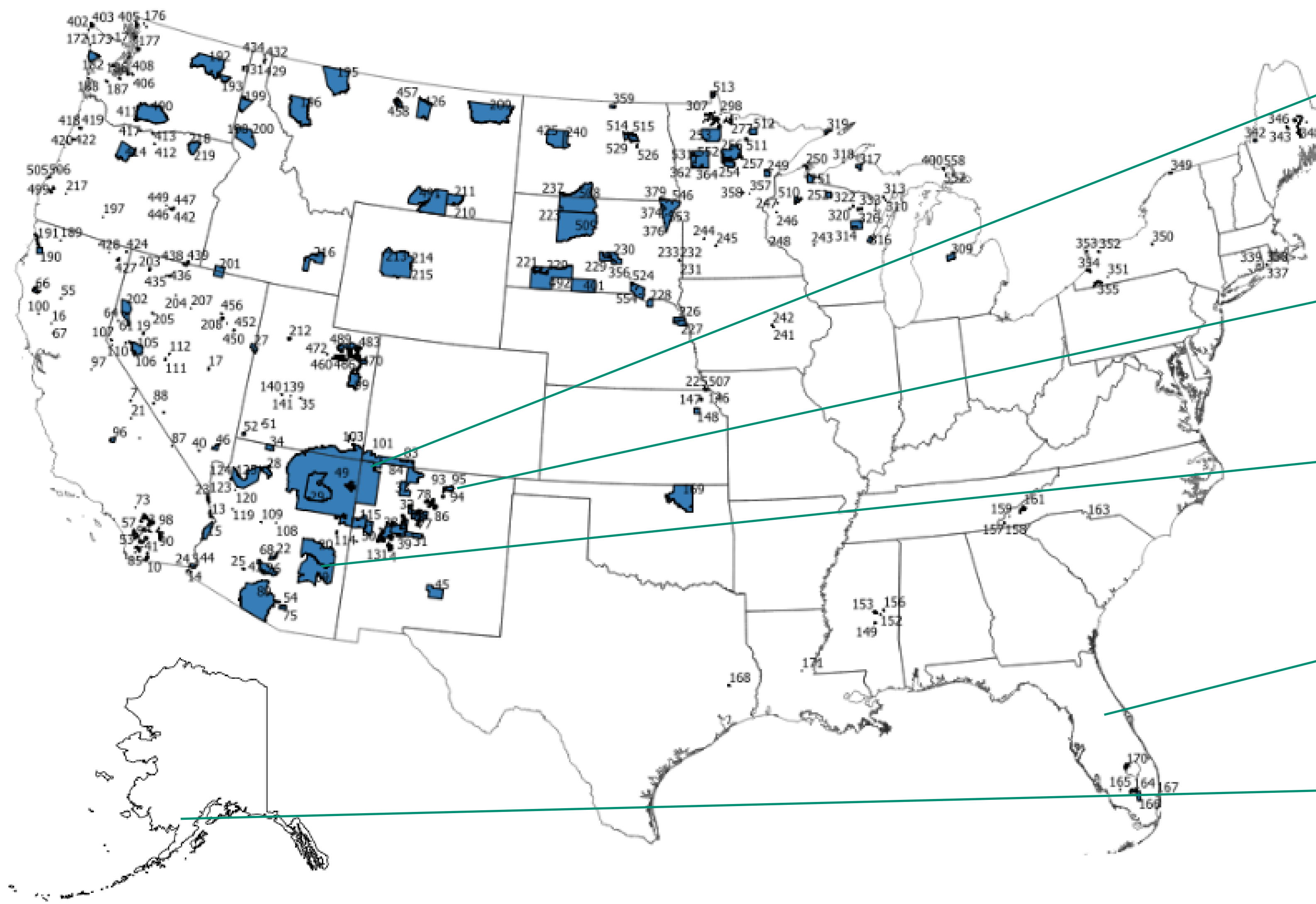
- Navajo Tribal Utility Authority provides utility services (electricity, natural gas, water, wastewater, and photovoltaic systems) within 27k sq. mi. service territory
- NTUA promotes the use of renewable energy by providing off-grid residential power (640W to 1800W rated turnkey PV-battery-wind turbine systems)

Source: NTUA





DOE OE ENERGY STORAGE TRIBAL ENERGY PROJECTS



Navajo Nation, Navajo Tribal Utility Authority (NTUA), Energy Storage and Power Conversion System Project

Picuris Pueblo Energy Storage Microgrid Project

San Carlos Apache Tribe Energy Storage Microgrid Project

Seminole Tribe of Florida Energy Storage Microgrid Project

Levelock Village of Alaska Energy Storage Project

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Questions?

Ahéhee’ (Thank You!)