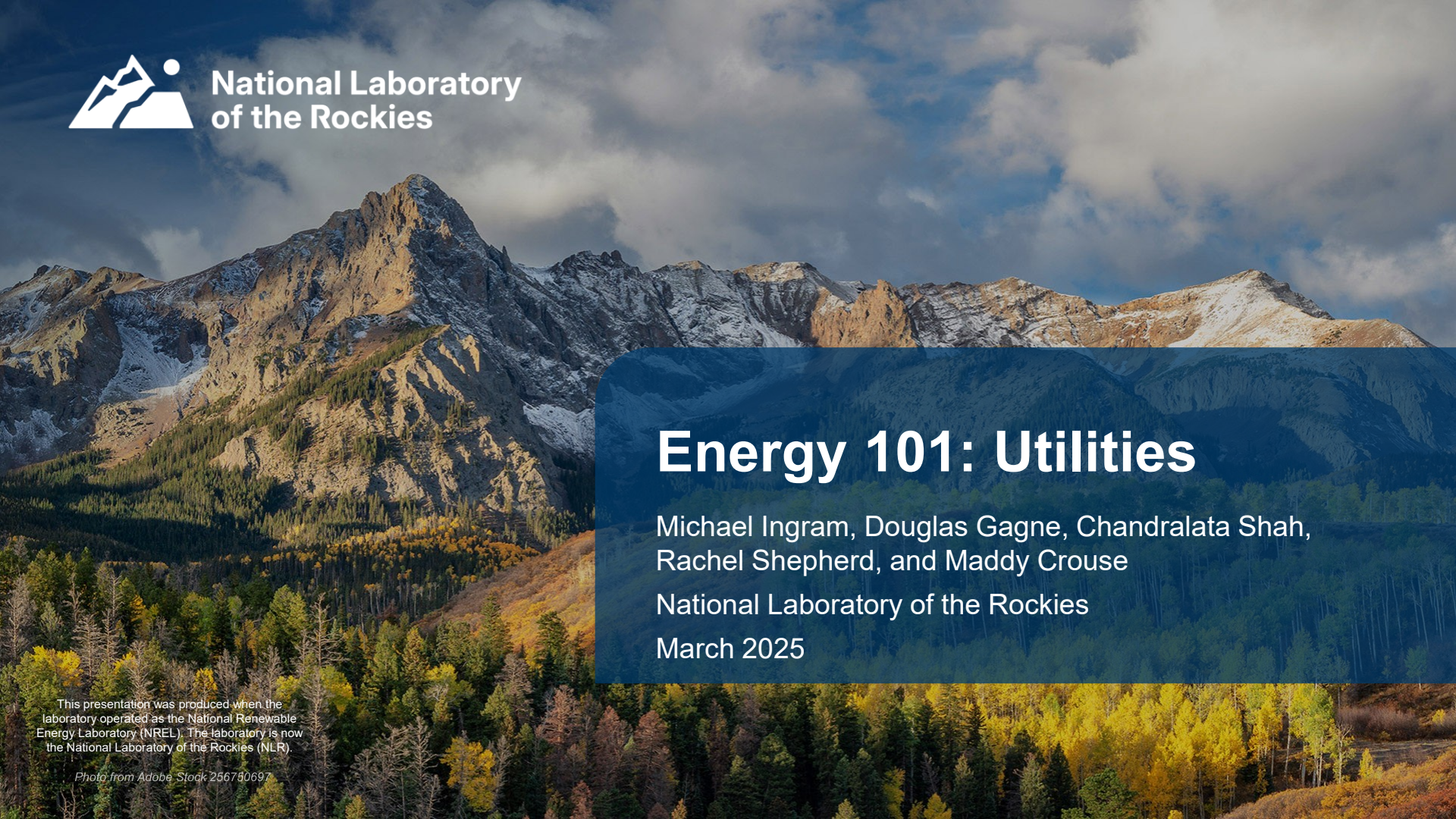

Energy 101: Utilities

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National Laboratory of the Rockies

March 2025

This presentation was produced when the laboratory operated as the National Renewable Energy Laboratory (NREL). The laboratory is now the National Laboratory of the Rockies (NLR).

Photo from Adobe Stock 256750697

The Electric Grid (Overview)

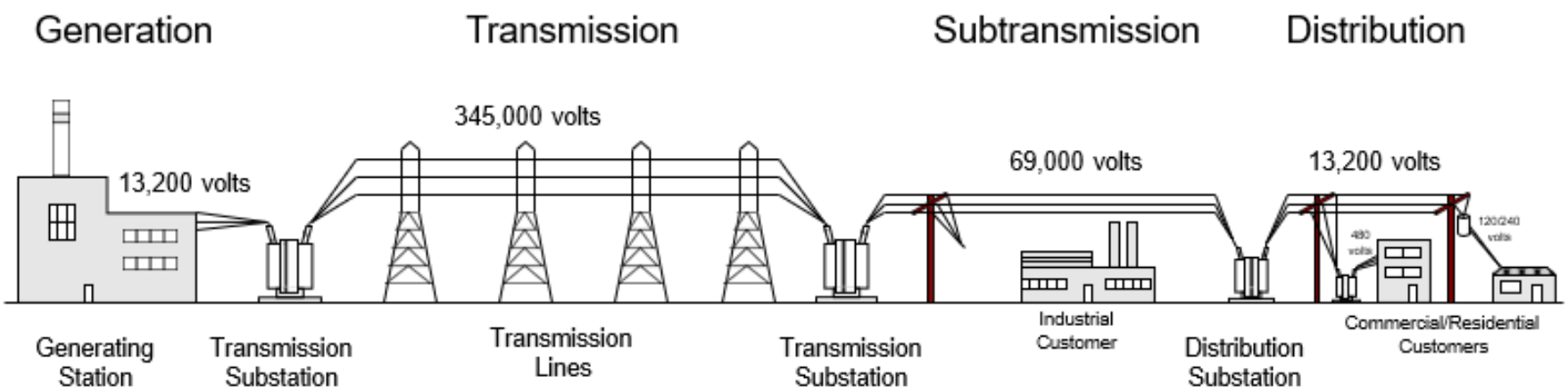


Image: Office of Indian Energy (2012)

Generation, transmission, and distribution voltages vary.

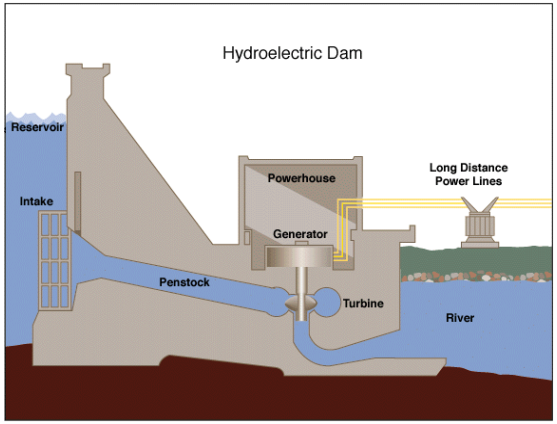
Electricity Grid

- Electricity is generated at power plants and moves through a complex system, sometimes called the *grid*.
- The grid includes electricity substations, transformers, and power lines that connect electricity producers and consumers.
- Most local grids are interconnected to maintain reliability and for commercial purposes, forming larger, more dependable networks that helps suppliers consistently produce the right amount of electricity to meet demand.
- In the United States, the entire electricity grid consists thousands of miles of high-voltage power lines and millions of miles of low-voltage power lines.
- This network of power lines connects thousands of power plants to hundreds of millions of electricity customers across the country.

Photo: Prateek Joshi, NLR

Types of Generation

- Thermal energy can come from resources such as coal, combustion (gas) turbines geothermal, and nuclear.
  - Energy is stored with the source of fuel or the Earth and can be used when needed.
- Non-thermal energy can also come from hydroelectric, pumped-storage hydro, solar, and wind generation.
  - Energy may be used when available (e.g., when water is available, the sun is shining, or the wind is blowing).
- Energy Storage
  - Pumped hydro, compressed air, flywheels, thermal energy storage, and chemical energy (such as Li+).



Images: Office of Indian Energy (2012)

Photo: Office of Indian Energy (n.d.)

U.S. Electricity Generation

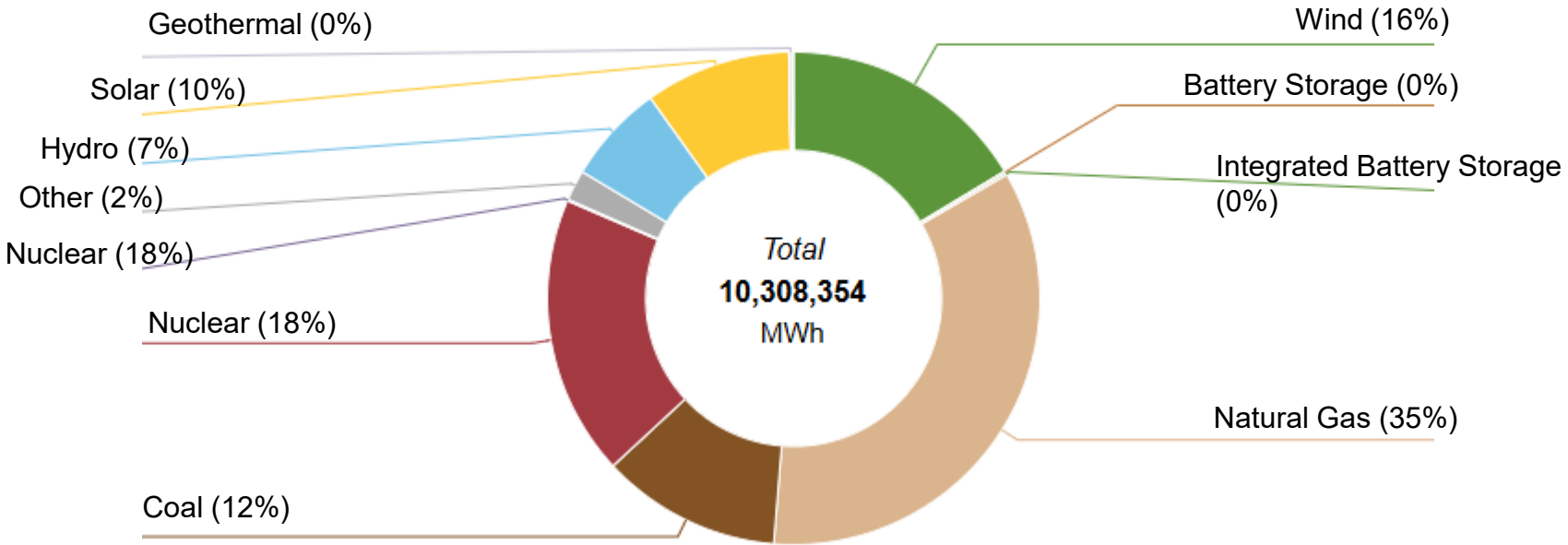
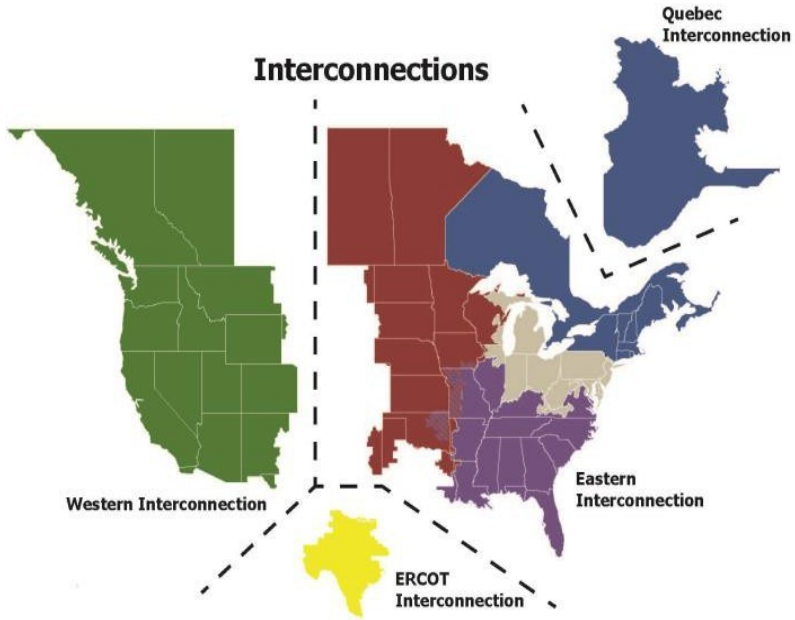


Chart: EIA (2026); Data: U.S Energy Information Administration

Transmission

- Power plants generate the electricity that is delivered to customers through transmission and distribution power lines.
- High-voltage transmission lines, such as those that hang between tall metal towers, carry electricity over long distances.
- Higher voltage electricity is more efficient and less expensive for long-distance electricity transmission. EIA n.d.
- The electric system was originally built as many local or regional grids that were joined to improve reliability and lower costs by sharing generation.
- The United States and Canada grid evolved into three large regional interconnections.

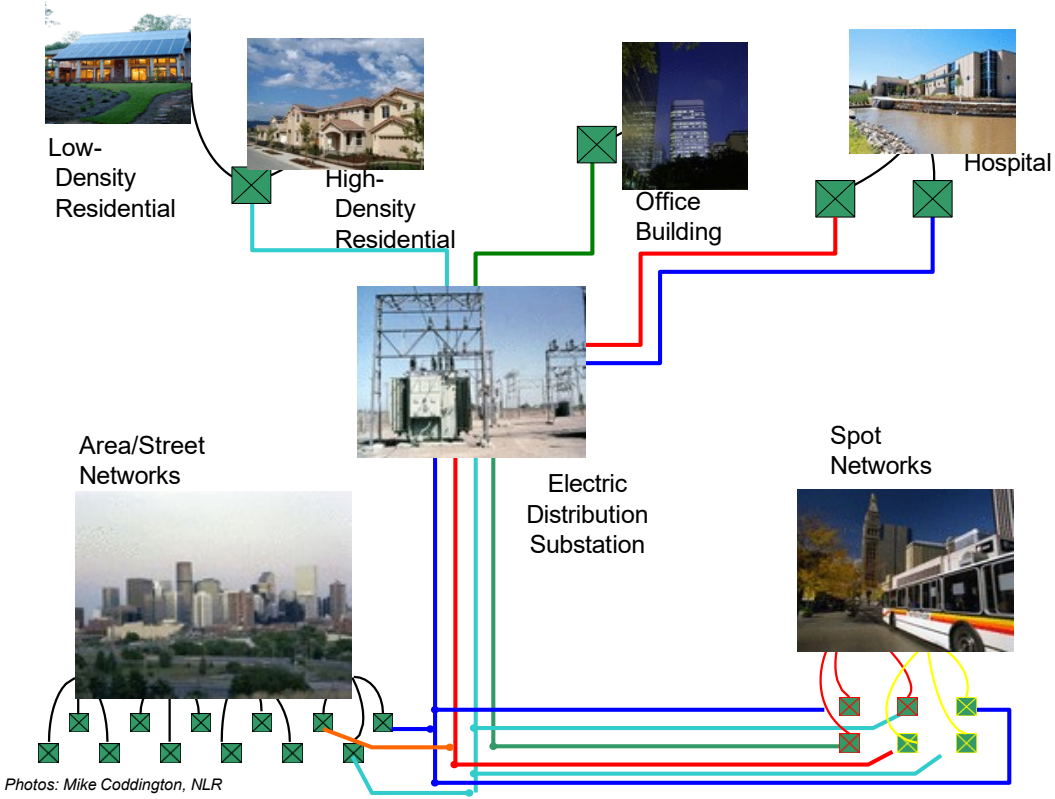


164,000-mile network linking over
75,000 MW of generation to millions of customers served by 3,000 utilities

Image: NERC

Distribution

- Transformers at substations reduce (step down) voltages on long-distance transmission lines to distribution lines that carry electricity to homes and businesses.
- Lower voltage electricity is safer for use in homes and businesses.



Utility Overview

- Electric utilities are responsible for the delivery of electricity to homes and businesses, including metering, billing, and customer service.
- Customers are usually (but not always) assigned to a utility based on the geographic boundaries of the utility franchise agreement and do not have the option to choose among competing retailers.

Photo: Warren Gretz, NLR

Utility Responsibilities

- **Obligation to Serve:** A utility is granted the sole rights to operate in a designated area and in exchange the utility are legally required to provide safe, reliable service to all customers—new and existing — in its territory. A utility's service area may or may not be contiguous.
- **Regulatory Compact**: An implicant agreement or understanding that in exchange for the rights to operate in a specific geographic area, the utility will supply safe, reliable service at a reasonable price.
- **Reliability Standards**: Guidelines and requirements, primarily established by the North American Electric Reliability Corporation (NERC), that ensure the safe and reliable operation of the bulk power system. They cover a wide range of aspects, from cyber security to physical security and operational procedures. All utilities must meet the standards for safety and reliability.
- **Reasonable Rate of Return:** All utility costs including operating and capital expenditures are paid for through the rates the utility charges its customers. For IOUs, regulators set rates that allow the utility to earn a fair return on its investments. Operating costs are subject to regulatory scrutiny and significant capital investments must be approved by the regulatory body and often include public hearings.

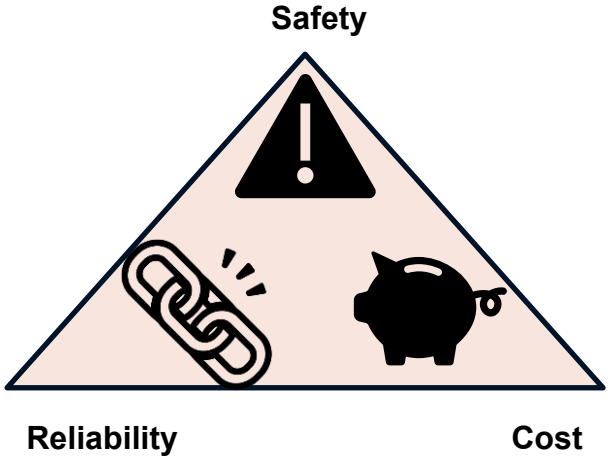


Image: Ingram (2024)

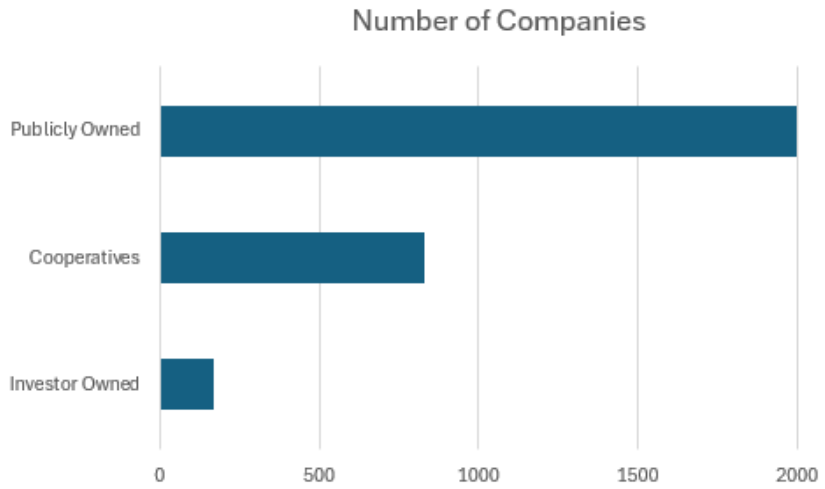
Types of Utilities

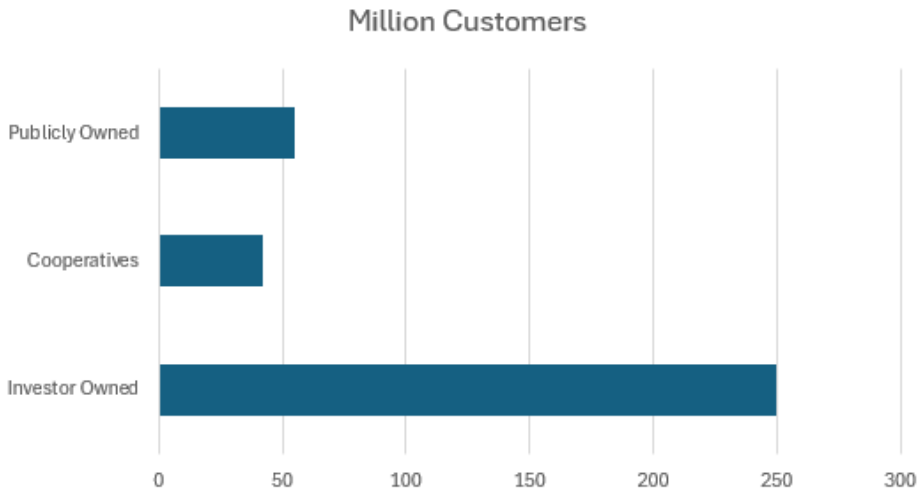
Utility Type	Ownership Structure	Regulatory Body	Examples	Number in the US
Investor-Owned Utilities (IOUs)	These utilities are privately owned and operated for profit, typically by large corporations, and often serve a wide geographic area.	Public Utilities Commission in each state they operate.	Xcel Energy San Diego Gas & Electric, National Grid, Florida Power and Light	There are roughly* 168 investor-owned utilities (IOUs). IOUs are the most common type of electricity provider, serving 72% of customers nationwide. (* varies due to ongoing mergers and acquisitions.) (EIA)
Publicly Owned Utilities: (Municipals (Munis), Public Utilities Districts (PUDs)	Public utilities include federal-, state-, and municipal-run utilities. In addition to government entities, political subdivisions may run POUs, also called public utility districts—utilities that residents vote into existence that operate independently of city or country government. (EIA)	City councils, board of directors, or other elected officials.	Austin Energy Los Angeles Department of Water and Power, Nebraska Public Power District, Tennessee Valley Authority (federal)	There are about 2000 publicly owned utilities in the US serving 55 million people and operating in 49 states and 5 US territories. (APPA)

Types of Utilities Continues

Utility Type	Ownership Structure	Regulatory Body	Examples	Number in the US
Cooperatives (Coops)	These utilities are owned and operated by the customers they serve, often found in rural areas, and are typically non-profit.	Board of directors elected by members.	Roanoke Co-op, Touchstone Energy, Flathead Electric Cooperative, Central Florida Electric Cooperative	Cover 56% of the US area serving 42 million people. There are 832 distribution coops and 64 generation and transmission providing wholesale power to distribution members . (NRECA)
Independent Power Producer (IPP)	An IPP can be corporation, person, agency, authority, or other legal entity that owns or operates electric generation facilities for use primarily by the public, and that is not an electric utility. Often sell into the wholesales markets and often are the deregulated businesses of IOUs.	Depends on the ownership structure.	Vistra Energy, Talen Energy, NRG Energy	There are approximately 570,893 IPPs and CHPs in the Unites States (source: EIA). A CHP is a combined heat and power plant usually co-located at an industrial site. (EIA)

Utilities by Ownership Type





NLR graphs.
Data for Cooperatives are from [NRECA], data for Publicly Owned [APPA], data for Investor Owned [EIA]

Tribal Representation Within Energy Delivery

- Western Area Power Administration (WAPA or Western)
  - Fulfilling requirements for open-access transmission service, reliable operations, and transmission development for renewable energy.
  - DOE and Western include Tribes and stakeholders who play a central role in the electricity system of the future of the country.
- Electric Tribal Utilities
  - Eight Tribal electric utilities
  - One natural gas utility: Southern Ute in Colorado
- Handbook by Leonard S. Gold: *Establishing a Tribal Utility Authority*, 2012 Edition
  - 56-page guide to evaluate the feasibility of forming a Tribal utility.

Utilities Are Stakeholders

- Electric utilities are crucial stakeholders within any community.
  - Utilities have a vested interest in stewarding their investments and protecting consumers from cost increases.
  - They have the final say on the interconnection of renewable energy resources within their service territories.
  - Municipal officials should approach their utilities with a collaborative attitude and keep them informed early on in the planning process regarding any new developments.
- To ensure that stakeholder engagement is effective, it is important to understand:
  - The regulatory environment in which the local utility operates.
  - The utility's ownership structure.
  - The utility's business model.

Use Case: On-Farm Energy Projects

Know Before You Build: On-Farm Energy Projects

1. Land
2. Hire Contractor
3. Hire Accountant and Attorney
4. County Ordinances and Permitting
5. Develop Required Plans (per #4)
6. Construct the Project
7. Educate and Showcase.

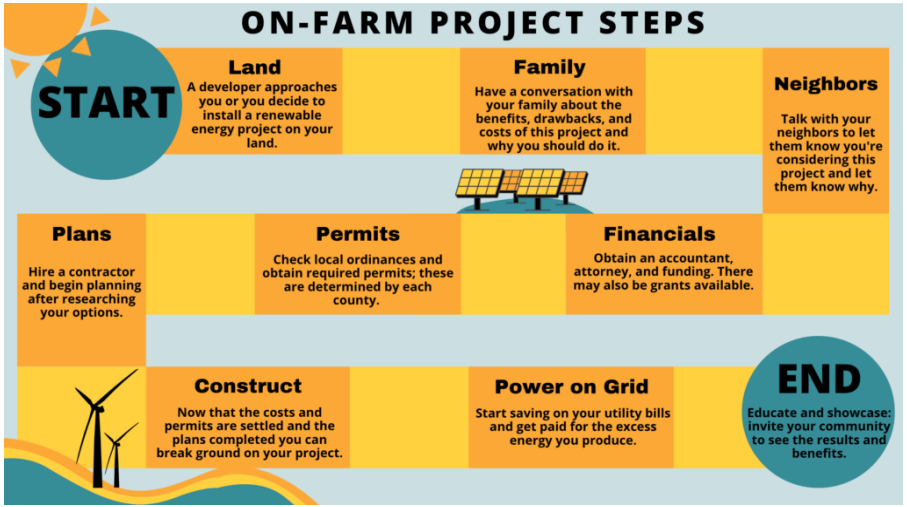


Image: Indiana Agriculture Coalition for Renewable Energy (inacre.org)

Approach

- **What is the community's *relationship* with the utility?**
  - What energy problem is your community trying to solve?
  - How can the utility affect that problem?
  - Is there history?

- **Background research is important to inform engagement.**
  - Browse Database of State Incentives for Renewables and Efficiency (DSIRE).
  - Study the utility's websites.
  - Examine the state(s) websites (if they are regulated).

Preparation

- When and/or why should the utility be involved?
  - Does your project potentially affect safety, reliability, or cost of electricity?
  - In which cases is engaging with your utility a critical path item?
- Non-disclosure agreements (NDAs) may be an essential step for gathering essential data
  - Controlled unclassified information (CUI) or business-sensitive information
    - Load data (billing, metering, or Supervisory Control and Data Acquisition (SCADA) information
    - Reliability data (System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), etc.)
    - Geographic Information System (GIS)
    - Power system model

Initial discussions about the high-level potential partnership are encouraged prior to requesting an NDA.

Utility Engagement

Clearly state your issue	Briefly explain the goal the community is trying to achieve or the issues it is facing and trying to solve.
Focus on facts and data	Provide a shared understanding of the situation, facts, and data.
Ask specific questions	Seek clarification and request data to better understand everyone's position.
Propose options	Don't just point out problems; ask for options and come with suggestions for how to improve the option-set.
Encourage respect and professionalism	Utilities may not always be able to be forthcoming due to limitations on data sharing or making public-facing statements.
What to say, what not to say	Seek to inform community positions or arguments with evidence and research.
Key questions to ask a utility stakeholder at the outset of your project	Ask questions from background research (utility website, etc.).

Manage Expectations

Utilities are not a single, uniform entity but are complex and diverse systems.

- You may have a very different experience depending on which part of the utility you're working with and in what context.

Sharing utility data may present challenges.

- Utilities may be prohibited by law from sharing the data you are requesting.
- Utilities may not have the staff capability or bandwidth to meet your request.
  - E.g. data may take time to format so it is anonymous.
- Utilities may not have the data you are seeking. For example:
  - Utilities may not have smart meters and therefor cannot share load data.
  - Information may not be collected at the intervals needed.
  - Data sets may be very large so utilities may not collect or store this data.

What types of analyses are practical to do in collaboration with utilities?

Utility Coordination: Other Topics

- **Available incentives, application process, other requirements**
- **Understand rate structure so that distributed energy project cost effectiveness can be accurately evaluated**:
  - Demand charge
  - Time-of-use rates
  - Seasonal rates, etc.
- **Also discuss with utility:**
  - Any expected tariff change due to reduced energy import from utility (the site load does not change)
  - Any standby, departing load, or other applicable charges?

What is Interconnection?

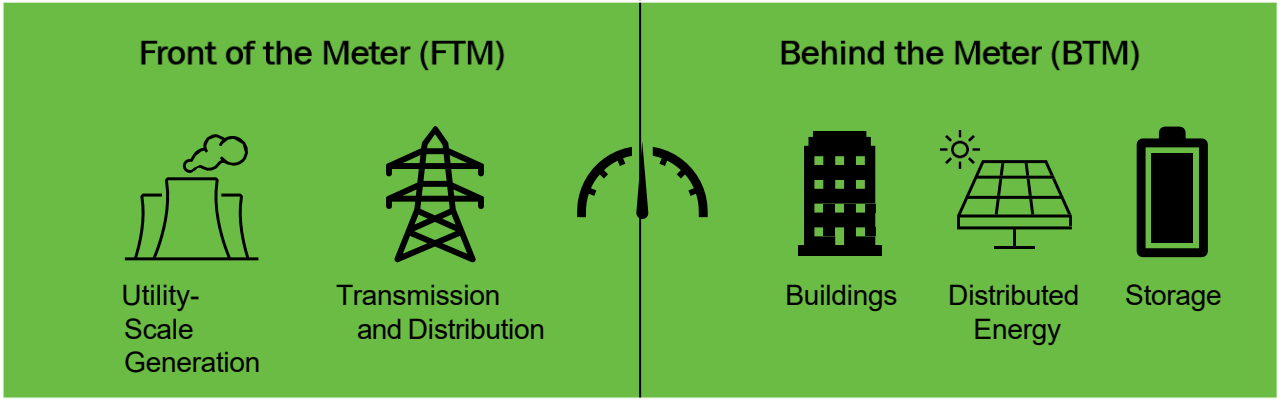
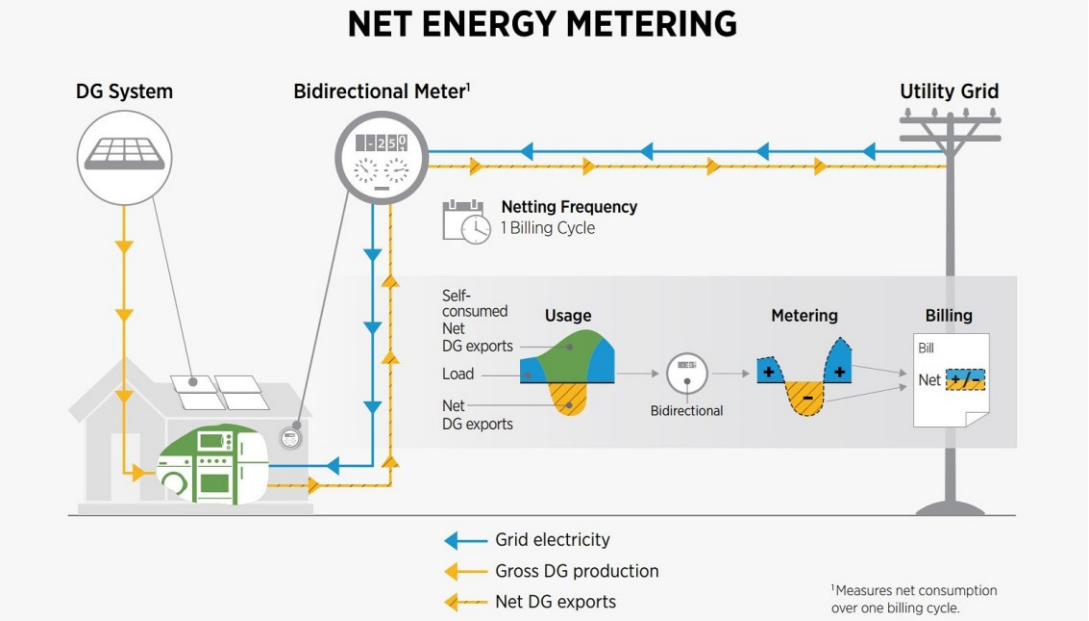


Image: Shepherd, Gagne, and Shah (2021)

- Distributed energy systems, like solar panels or wind turbines, are often connected to an existing utility grid in a process called interconnection.
- For safety, grid reliability, and economics, the utility has a set of requirements for customers installing distributed energy systems on their grid.

Net Metering

- Net metering lets owners of energy systems send excess power back to the grid and earn credits. These credits can be used to reduce their electricity bill.
- In most states, electric utilities allow net metering.
- If you use more power than your system produces in a month, you only pay for the difference.



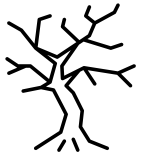
DG = Distributed Generation

Image: NREL, 2017

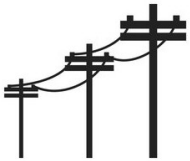
What is a Public Safety Power Shutoff (PSPS)?

High Winds

Low Humidity



Dry Vegetation



Fire Threat

Public Safety Risk

"High winds and other adverse weather conditions combine to increase the risk of wildfire. During windy conditions, flying debris can damage our power lines and create sparks that could cause ignition...a PSPS may be necessary to ensure the safety of our communities and employees."

[SDGE, https://www.sdgenews.com/article/what-psps-public-safety-power-shutoffs-explained]

Resources

- **Resources**
  - U.S. Energy Information Administration (EIA): https://www.eia.gov/electricity/
  - Paper: *Case Studies: The Conversion of On-Reservation Electric Utilities to Tribal Ownership and Operation by Western Area Power Administration*; Sept, 2010: https://www.energy.gov/sites/prod/files/2016/04/f30/tribal_authority_case_studies_report.pdf
  - Handbook: *Establishing a Tribal Utility Authority*; by Leonard S. Gold, President, Utility Strategies Consulting Group, LLC: https://www.bia.gov/sites/default/files/dup/assets/as-ia/ieed/ieed/pdf/tribalutility_handbook.pdf
- **Policy**
  - American Council for an Energy-Efficient Economy: https://www.aceee.org/
  - Western Electric Coordinating Council has two Tribal reps for policy deliberations: https://www.wecc.org/
  - Inter-Tribal Council on Utility Policy: https://www.energy.gov/sites/prod/files/2016/01/f28/0510review_03spears.pdf
- **Technology**
  - Occupational Safety & Health Administration (OSHA) offers reliable grid information: http://www.osha.gov/SLTC/etools/electric_power/illustrated_glossary/
- **Key Interconnection Resources**
  - Your Utility's Website
  - DSIRE
  - Overview of DER Interconnection
  - Review of Interconnection Practices and Costs in the Western States

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Thank You

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NLR/PR-7A40-93269

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National Laboratory of the Rockies

Appendix

Dispatchable vs. Nondispatchable Generation

Dispatchable

- Can reliably be called on to meet power demand when needed by the grid. (EIA, 2024)

Images: Office of Indian Energy (2012)

Nondispatchable

- Depend on the resource availability, such as when the sun is shining or the wind is blowing.
- As a result, these technologies have limited capability to respond to generation dispatch signals. (EIA, 2018)

Transmission vs. Distribution

Transmission:

- Bulk transfer of electrical energy over long distances.
- About 10% of customer outage minutes due to Generation and Transmission system problems—which are big outage events.

Distribution:

- Limited quantity of energy transferred over short distances.
- About 90% of customer outage minutes due to distribution system, in small local events.

Role of Transmission

- Interconnect new generation and resource areas to the grid
- Improve reliability by strengthening the grid
- Improve reliability and manage risk by providing access to additional generation resources
- Reduce energy cost by providing access to diverse generation resources
- Reduce congestion by creating new flow paths and system capacity
- Increase efficiency by reducing line losses
- Make wholesale markets more competitive and efficient.

All Transmission, 69 kV and Above

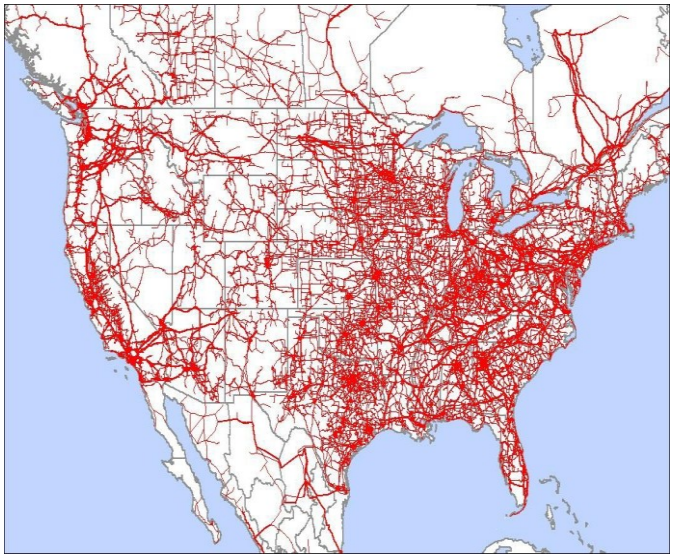


Image: Ingram (2022)

Renewables Integration

Studies on renewable generation goals and development potential within the United States have concluded that:

- High-penetration renewables development is technically feasible, if the transmission system is expanded.
- Significant amounts of new transmission are needed for major future wind development scenarios in the eastern and western interconnections.
- Costs for integrating large amounts of renewables are manageable with large amounts of transmission and regional operating pools to facilitate ancillary services.

Transmission Planning Considerations

- Planning period—often 10 or more years out
- Load forecast and transmission usage projections
- Generation resources (location, type, etc.)
- Economic and financial constraints
- New and emerging technologies
- Uncertainties and risks
- Institutional and government regulations
- Discrete transmission capacities
- Alternative solutions—e.g., distributed generation, demand reductions
- Right-of-way (ROW) limitations *(The ROW is the strip of land immediately below and adjacent to a transmission line.)*

Photo: Mike Coddington, NLR

Overhead vs. Underground Lines

Overhead:

- Accessible for maintenance and problem-spotting
- Right-of-way
- Long life (>80 years)
- Visually obtrusive
- Environmental concerns
- Electromagnetic field/electromagnetic interference concerns
- Exposure to storm, accident, or attack
- Lower installation and maintenance cost.

Underground:

- Harder to access for maintenance and repair
- Narrower right-of-way
- Shorter life (~40 years)
- Visually inconspicuous
- Some environmental concerns
- Necessary for certain conditions (i.e., submarine)
- Higher installation and maintenance costs (up to 10x cost differential).

Regional Transmission Organizations and Independent System Operators

- Facilitate competition among wholesale electricity suppliers
- Provide non-discriminatory access to transmission by scheduling and monitoring the use of transmission
- Perform planning and operations of the grid to ensure reliability
- Manage the interconnection of new generation
- Oversee competitive energy markets to guard against market power and manipulation
- Provide greater transparency of transactions on the system
- No standard market design for every ISO/RTO
- About half of the United States (by area) is not in an ISO/RTO.

Power Marketing Administrations

U.S. Department of Energy operates four regional PMAs:

1. Bonneville Power Administration (BPA),
2. Southeastern Power Administration (SEPA),
3. Southwestern Power Administration (SWPA),
4. Western Area Power Administration (WAPA).

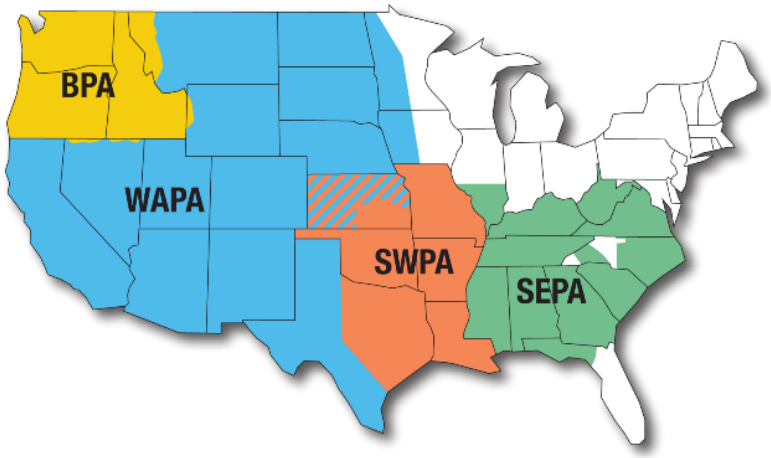


Image: Ingram (2024)

- Generally, PMAs market the power produced by federal dams owned and operated by the U.S. Army Corps of Engineers and the Bureau of Reclamation.
- By statute, PMAs must give preference to PUDs and co-ops and sell their power at FERC-regulated, cost-based rates (additionally, WAPA gives preference to Native American Tribes).

Independent System Operators (ISOs) and Regional Transmission Operators (RTOs)

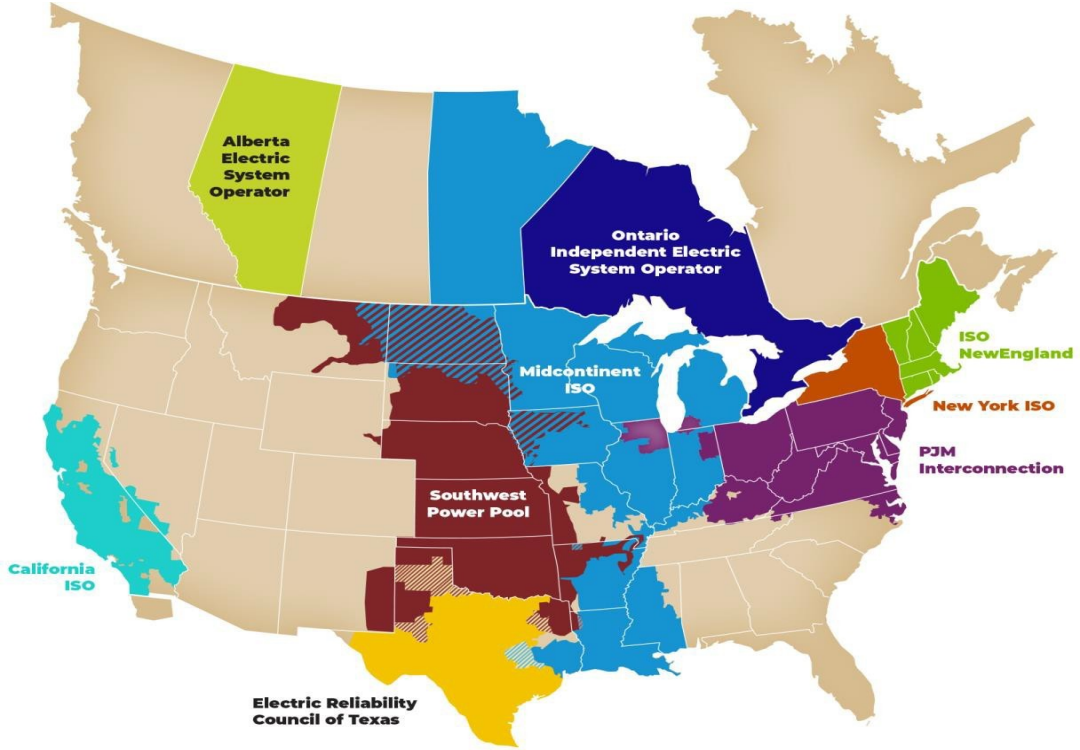


Image: ISO/RTO Council

North American Balancing Authorities

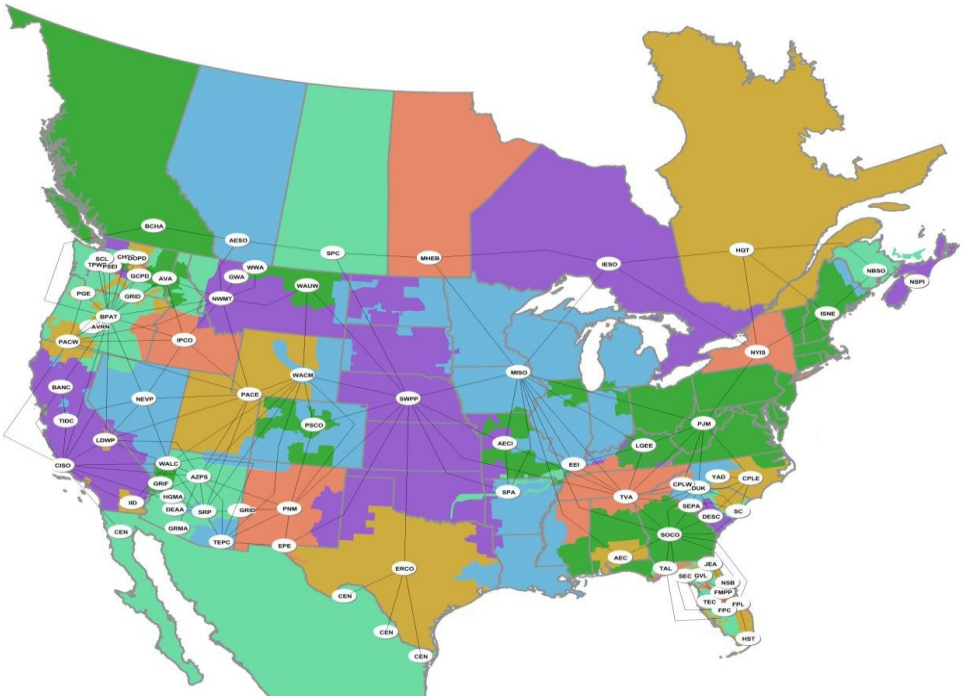


Image: NERC

Balancing authorities ensure, **in real time**, that power system demand and supply are finely balanced.

Distribution

Distribution is the final phase of electricity's journey to the consumer.

Distribution transformers convert the primary voltage levels to secondary voltage levels for utilization by customers.

Three-Phase Pad-Mount (13.2 kV to 277/480 V)

Photos: Mike Coddington, NLR

Distribution Substation

Photo: Ravel F. Ammerman, NLR

13.2-kV Side

13.2–230-kV Transformer

230-kV Side

Operational Structure

Utilities may be "vertically integrated" (all-of-the-above) or have various structures, such as distribution-only.

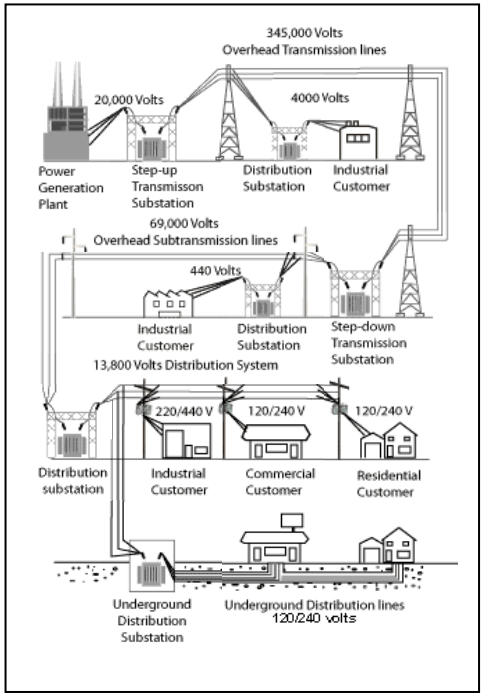


Image: Ingram (2024)

Provides generation, transmission, and distribution services

Utilities also play the role of the "system operator" for the grid, ensuring that demand and supply are matched on a second-by-second basis; this structure predominates in large parts of the western and southeastern United States

Customers are usually (but not always) assigned to a utility based on the geographic boundaries of the utility franchise agreement and do not have the option to choose among competing retailers

Utility Regulation

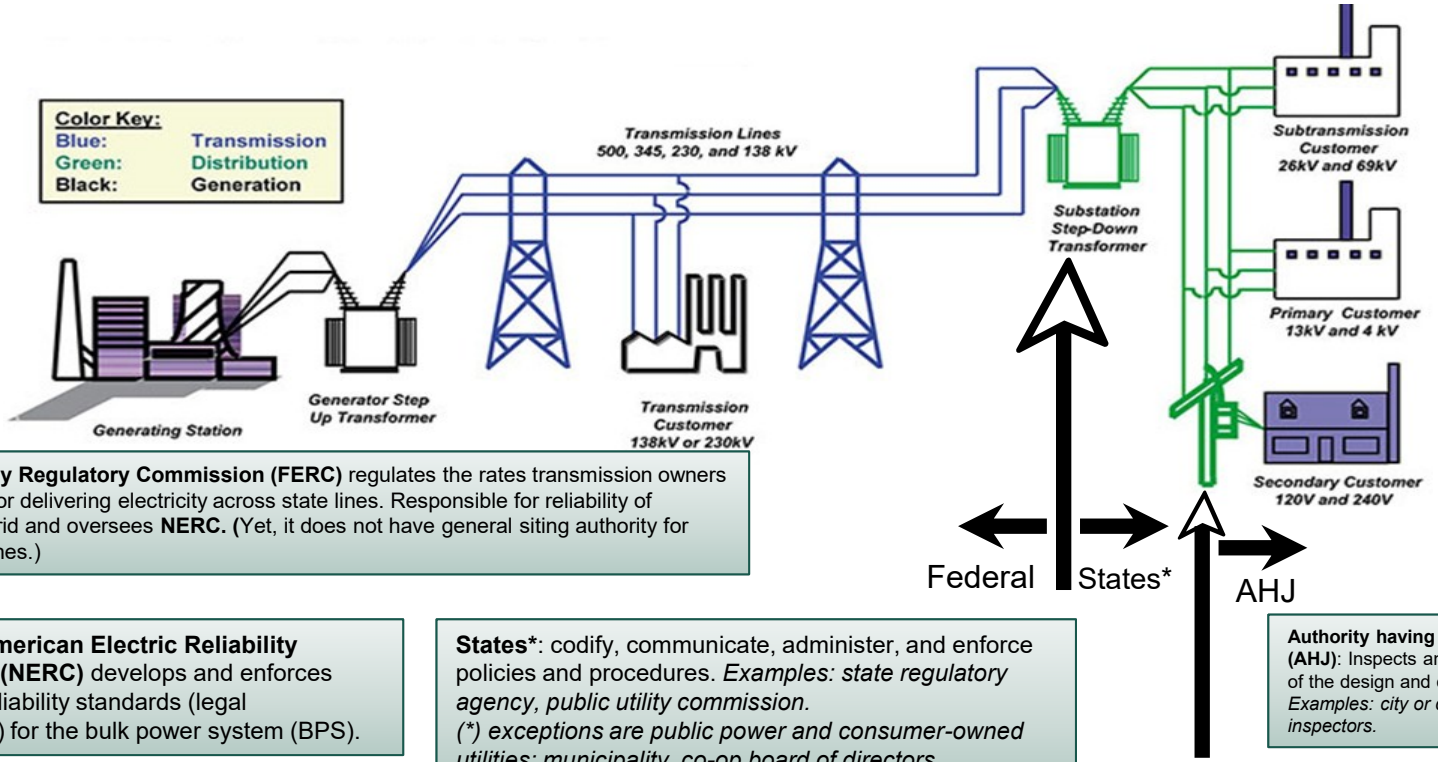
Federal Regulation – Federal Energy Regulatory Commission

- Transmission of electricity in interstate commerce
- Wholesale sales of electricity for resale in interstate commerce
- Limited transmission siting authority
- Reliability of transmission grid and oversees NERC.

State Regulation – Public Utility Commissions

- Retail sales to end users
- Low-voltage distribution
- Siting of power plants and transmission lines
- Utility resource planning (generation mix).

Utility Structure: Regulatory



Federal Energy Regulatory Commission (FERC) regulates the rates transmission owners (TOs) charge for delivering electricity across state lines. Responsible for reliability of transmission grid and oversees **NERC. (**Yet, it does not have general siting authority for transmission lines.)

The **North American Electric Reliability Corporation (NERC)** develops and enforces mandatory reliability standards (legal requirements) for the bulk power system (BPS).

States*: codify, communicate, administer, and enforce policies and procedures. *Examples: state regulatory agency, public utility commission.*
(*) exceptions are public power and consumer-owned utilities: municipality, co-op board of directors.

Authority having jurisdiction (AHJ): Inspects and approves of the design and construction. *Examples: city or county inspectors.*

Image: Ingram (2024)

Interconnection (IC) Process

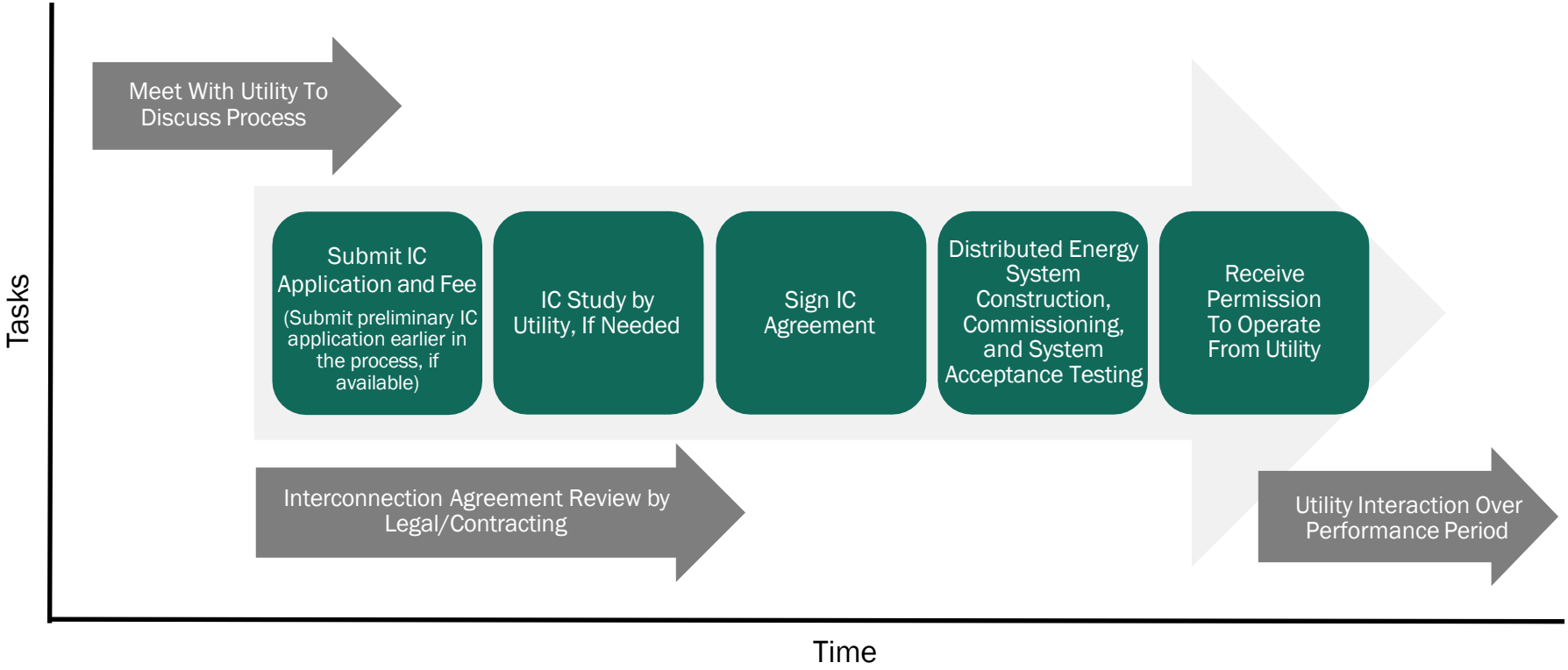
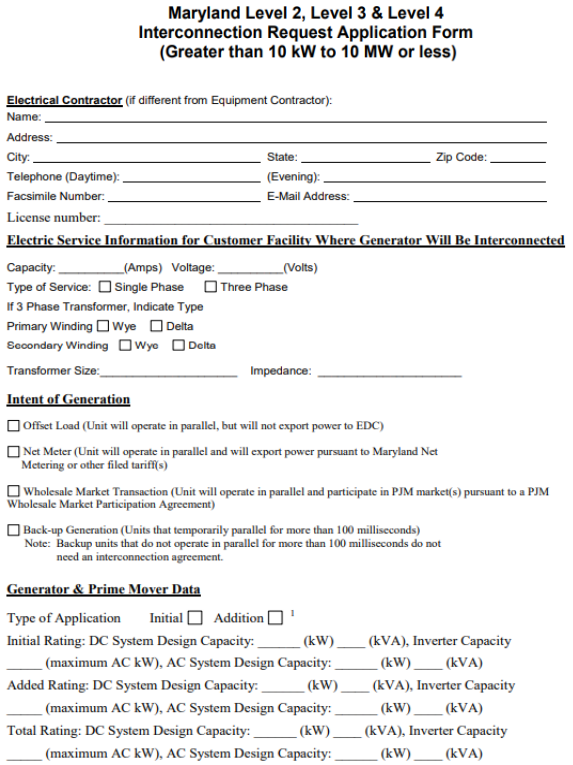


Image: Shepherd, Gagne, and Shah (2021)

Interconnection Application

- Application requirements depend upon project type and size:
  - Application fees
  - Affected utility account(s)
  - System design
    - Distributed energy project size (kW)
    - Inverter size, if applicable (kW)
    - Equipment details
    - Location
  - Intended use (e.g., non-export, net metering, battery applications).



Maryland Level 2, Level 3 & Level 4
Interconnection Request Application Form
(Greater than 10 kW to 10 MW or less)

Electrical Contractor (if different from Equipment Contractor):
Name: _____
Address: _____
City: _____ State: _____ Zip Code: _____
Telephone (Daytime): _____ (Evening): _____
Facsimile Number: _____ E-Mail Address: _____
License number: _____

Electric Service Information for Customer Facility Where Generator Will Be Interconnected

Capacity: _____(Amps) Voltage: _____(Volts)
Type of Service: ☐ Single Phase ☐ Three Phase
If 3 Phase Transformer, Indicate Type
Primary Winding ☐ Wye ☐ Delta
Secondary Winding ☐ Wye ☐ Delta
Transformer Size:_____ Impedance: _____

Intent of Generation

☐ Offset Load (Unit will operate in parallel, but will not export power to EDC)

☐ Net Meter (Unit will operate in parallel and will export power pursuant to Maryland Net Metering or other filed tariff(s)

☐ Wholesale Market Transaction (Unit will operate in parallel and participate in PJM market(s) pursuant to a PJM Wholesale Market Participation Agreement)

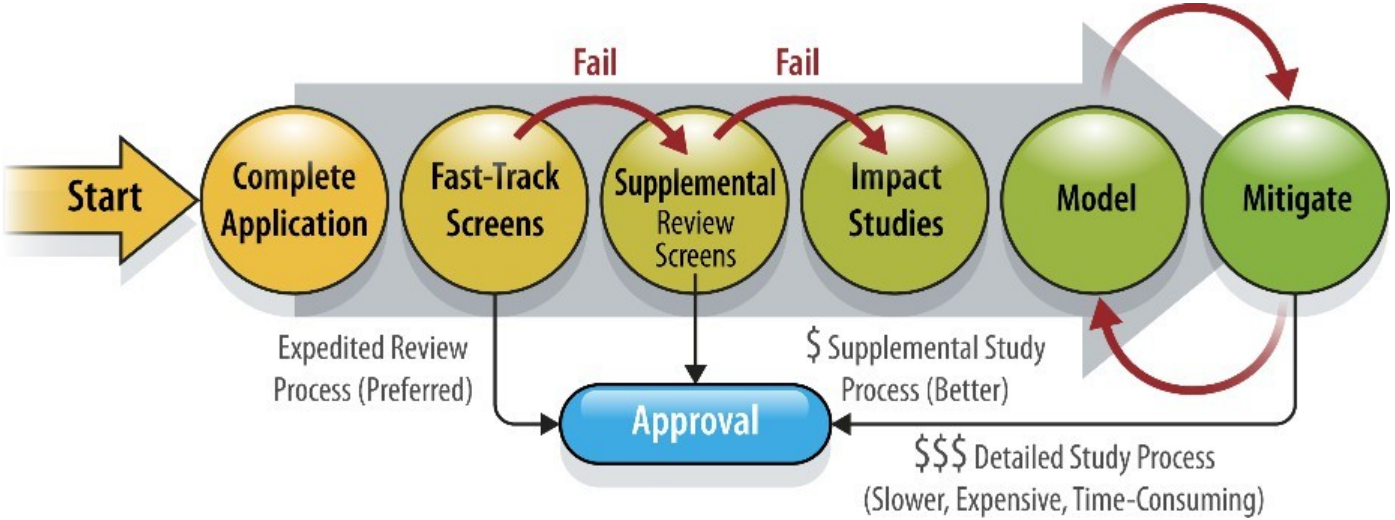
☐ Back-up Generation (Units that temporarily parallel for more than 100 milliseconds)
Note: Backup units that do not operate in parallel for more than 100 milliseconds do not need an interconnection agreement.

Generator & Prime Mover Data

Type of Application Initial ☐ Addition ☐ [1]
Initial Rating: DC System Design Capacity: _____ (kW) ____ (kVA), Inverter Capacity
_____ (maximum AC kW), AC System Design Capacity: _____ (kW) ____ (kVA)
Added Rating: DC System Design Capacity: _____ (kW) ____ (kVA), Inverter Capacity
_____ (maximum AC kW), AC System Design Capacity: _____ (kW) ____ (kVA)
Total Rating: DC System Design Capacity: _____ (kW) ____ (kVA), Inverter Capacity
_____ (maximum AC kW), AC System Design Capacity: _____ (kW) ____ (kVA)

Interconnection Study Process

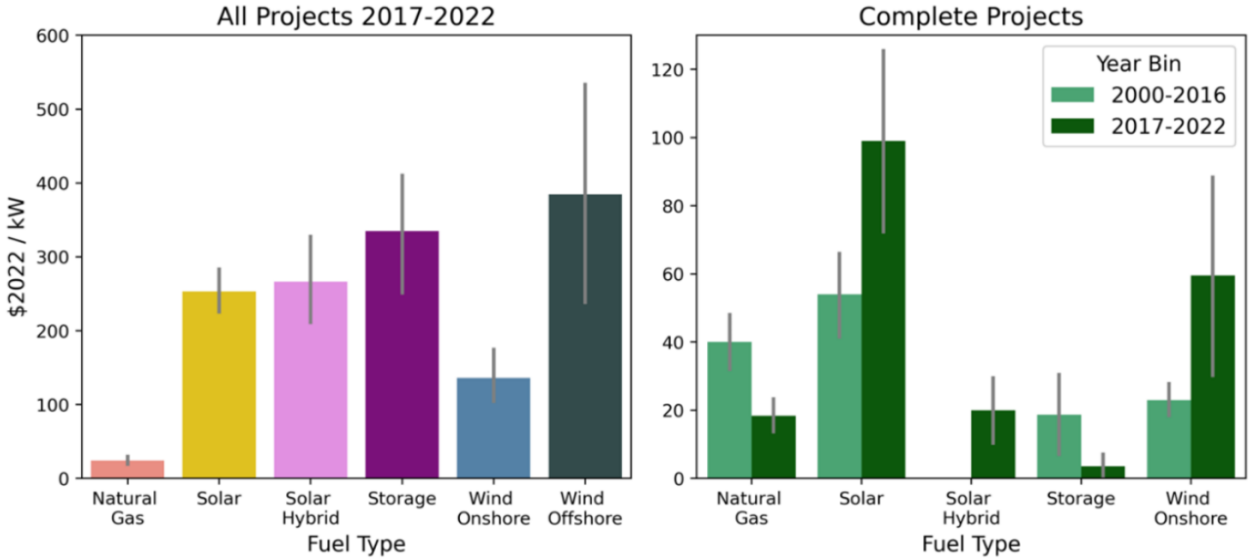
- Additional interconnection studies may be required for larger systems or in certain constrained areas
- Fees, timelines, and queue vary by project size, technology type, utility jurisdiction, and point of interconnection.



Note: A site distribution system study may also be required.

Image: Shepherd, Gagne, and Shah (2021)

Interconnection Upgrades Cost



PJM Interconnection Costs by Fuel Type (left) and Over Time for Complete Projects (right) (bars: means, gray lines: standard error)

Graph: DOE, 2023

- For larger distributed energy systems, upgrades to the utility's system may be required to mitigate impacts.
- The costs of interconnection studies and resulting system upgrades are typically paid by the party requesting interconnection.

Interconnection Agreement Overview

- A signed interconnection agreement (ICA) with your utility is typically required to connect distributed energy projects
- ICAs may have problematic terms/conditions
- Negotiations may be necessary and can be lengthy.

Image: Shepherd, Gagne, and Shah (2021)

Interconnection Agreement: Questions To Ask Utility

- **Which party will sign the ICA?**
  - Agency or private owner for privately owned projects
  - Is a tri-party agreement needed?
- **Does the utility have a template ICA?**
  - Is there a government-specific ICA template?
  - Government-specific ICA templates can ease the process, if available; however, solutions do not always translate.
- **Can the ICA be modified and, if so, what PUC and/or other approvals are required?**

Project Inspection and Acceptance

- How can you ensure that your project is designed and installed as intended?
  - Inspection and commissioning ensure that the system is complete and performs as expected.
    - Safely put the system into operation
    - Often required by utility and/or for warranty
    - Ensure complete and accurate documents
- What are system acceptance testing requirements?
  - Recommend 30 continuous days of operation at estimated energy production levels, with 100% system availability
  - Reference IEC 62446 for PV commissioning standards
  - Reference EPRI's Energy Storage Commissioning Guide 2016
  - Meet all utility requirements

Photo: Shepherd, Gagne, and Shah (2021)

Interconnection Best Practices

- Notify your utility of planned distributed energy projects early in the planning process
- Check your utility's website for information on their interconnection process.
- Ask if the utility offers:
  - A simplified interconnection process for smaller systems
  - An application checklist summarizing all requirements
  - A point of contact to answer questions about the process
  - Hosting capacity maps or other utility system information

Interconnection Process Best Practices

- Carefully review the utility's documentation requirements. Submitting incorrect documentation can prolong the process.
- Ensure close communication between organization, contractor, and utility
- Clarify roles and responsibilities among the parties
- Request written responses from your utility
- Identify points of non-agreement early and address them.
- Understand your utility's interconnection process, including:
  - Published policies, regulations and orders
  - If a pre-application report is available to obtain early-stage feedback on interconnection limitations
  - Application requirements (equipment details, one-line diagrams, inverter specifications)
  - Specific requirements if batteries/microgrid included

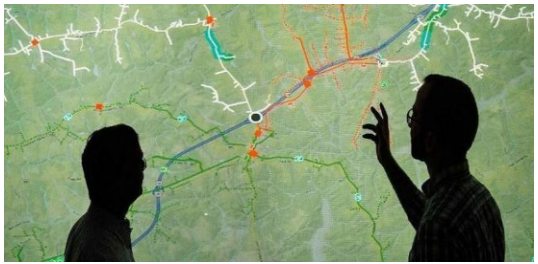


Image: Shepherd, Gagne, and Shah (2021)

Reliability

Metrics that indicate declining performance (*2020, NERC observation*):

- Count and severity of energy emergency alerts are increasing.
- Planning reserve margin continues to not meet expected thresholds in some areas.
- Instances of transmission-related events resulting in loss of load increased in number and severity from 2018.
- Element unavailability for AC circuits and transformers show an increase due to operational outages.[1]
- Reliability operating limit exceedances in the Eastern Interconnection increased in number and duration.

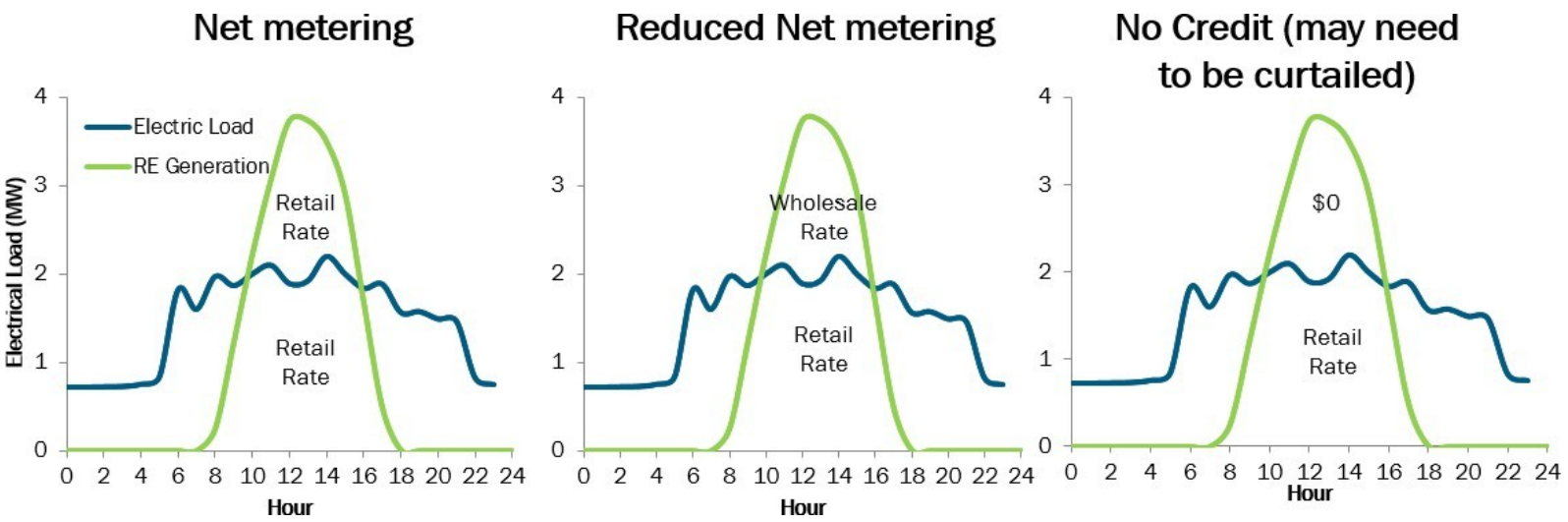
NERC, "2020 State of Reliability | An Assessment of 2019 Bulk Power System Performance," July 2020.

[1] Operational Outage: A nonautomatic outage for the purpose of avoiding an emergency (i.e., risk to human life, damage to equipment, damage to property) or to maintain the system within operational limits and that cannot be deferred. Includes nonautomatic outages that result from manual switching errors.

Net Metering

Net metering is a billing arrangement in which the utility credits a customer for excess electricity from an onsite distributed energy project that is fed into the utility grid.

What is your site load compared to estimated distributed energy project generation?



Graphs: Shepherd, Gagne, and Shah (2021)

Net Metering: Questions to Ask Your Utility

- Does utility offer net metering or other similar policies?
- Will net metering requirements be included in the ICA or as a separate agreement?
- What is the maximum allowable project type/size?
  - How is project size measured (DC or AC; based on inverter size)?
- What are the metering requirements and who will pay for the meter?
- What is the value of exported electricity? How is net excess generation treated?
  - At the end of the month/year
- Who owns the project?

Thank You

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