An Introduction to Transmission Infrastructure

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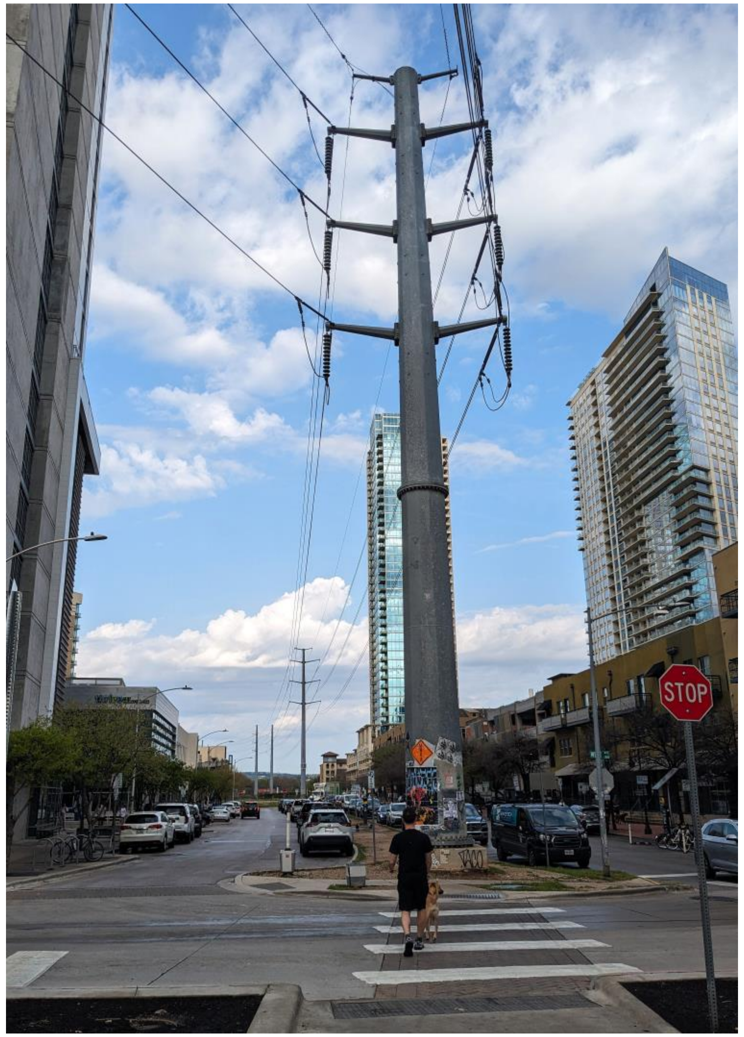
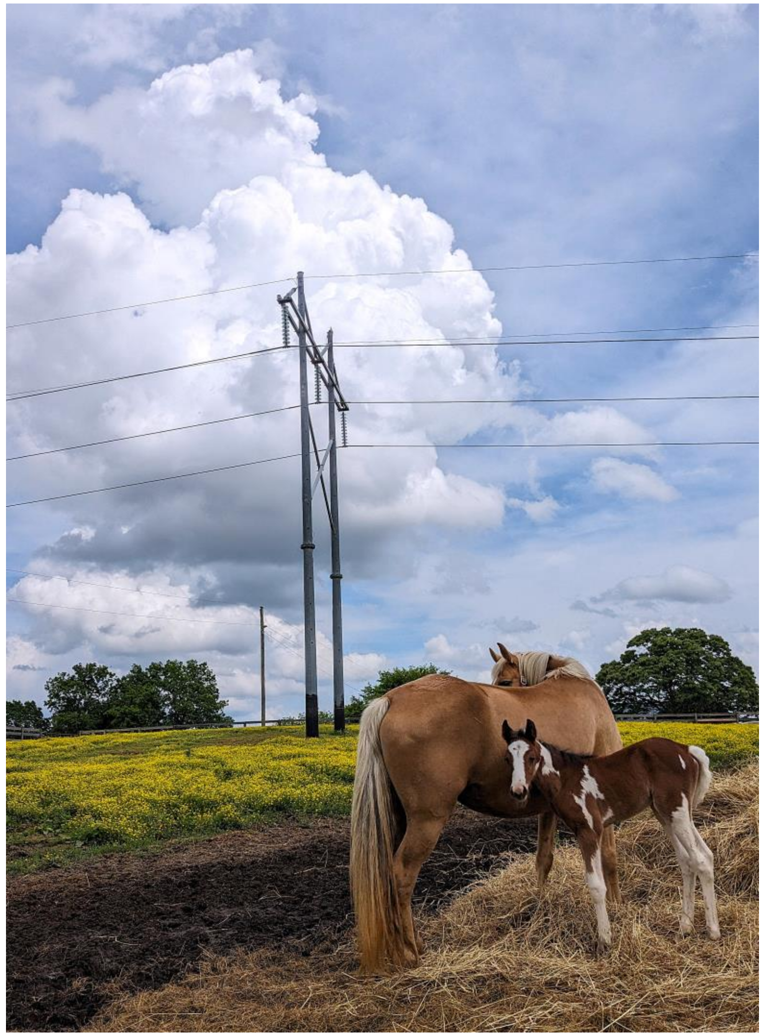
PNNL-SA-211723

Transmission infrastructure plays a critical role in assuring that the nation's electric system provides reliable, adequate, secure, flexible, and economic electricity across the United States.





The **right-of-way**, or buffer area, required to allow a safe margin around transmission infrastructure naturally provides an opportunity for additional uses and benefits—*this requires reframing traditional corridor maintenance practices to provide long-term cost savings and community benefits*.

Image credits: Irena Netik, PNNL (left), Rebecca O'Neil, PNNL (center and right)

Contents

Introduction to Transmission Infrastructure

This presentation describes the fundamentals of electric transmission infrastructure. A basic understanding of transmission components and their functions helps contextualize the role of transmission within the electric grid and the clean energy transition. Siting, safety, and construction considerations provide foundational knowledge of the process required to build out transmission. Upon this foundation, the multifunctionality and additional benefits of transmission corridors are briefly introduced.

This document serves as an introduction to the **Connecting Transmission Corridors (ConCord) Initiative**, *which aims to increase public recognition of existing benefits of electric transmission corridors; provide a broad platform and network that describes and shares credible and useful information about public, community, and environmental benefits from transmission corridors; and expand and extend those benefits into current and future transmission infrastructure design.*

Introduction | The Electric Grid

The **electric grid**, separated into the transmission and distribution system, contains all the infrastructure required to generate and deliver power to electricity consumers. The transmission system transmits power long distances to local substations, which connect to the distribution system that delivers power to local consumers.

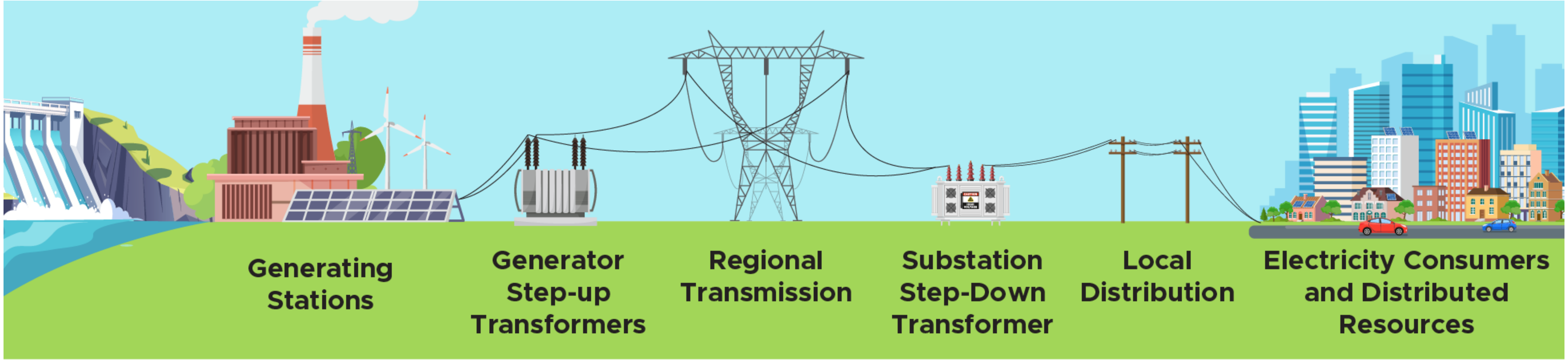


Image credit: Cortland Johnson (PNNL)

Introduction | The Electric Grid

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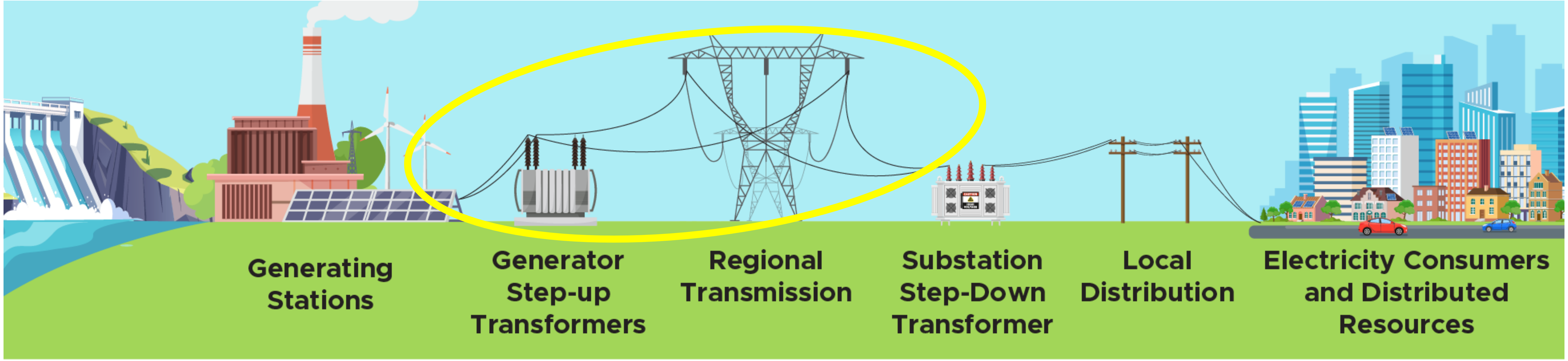

Transmission: The electric infrastructure designed to transfer electricity across long distances between points of supply and points at which it is transformed for delivery to customers or is delivered to other electric grids. Transmission lines tend to operate at high voltages, between 100 – 765 kV (kilovolts). Using high voltages reduces the current along the lines, which mitigates losses due to heat while maintaining the same transfer of power.

Image credit: Cortland Johnson (PNNL)

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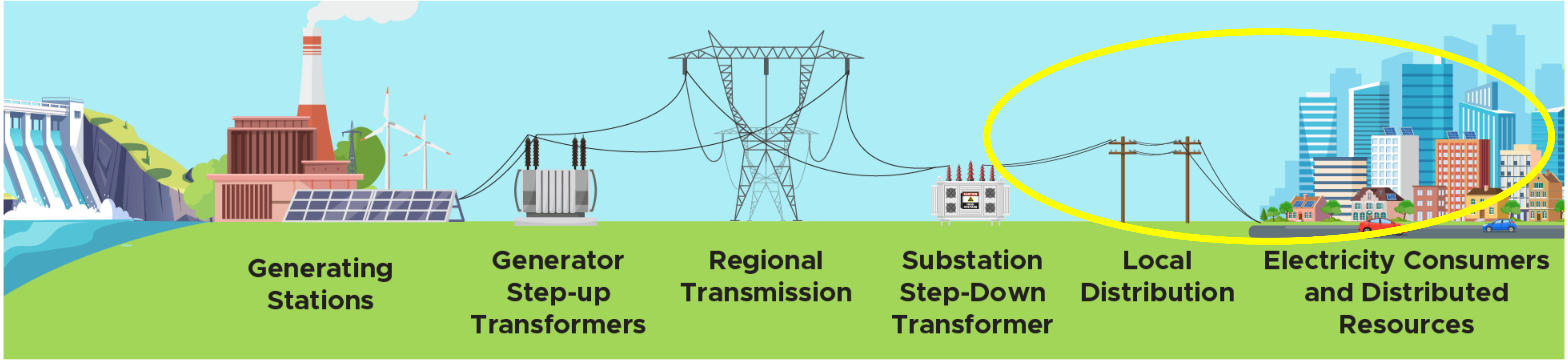

Distribution: The electric infrastructure designed to transfer local electricity to individual end users, located behind a transmission-distribution transformer or distribution substation. Generally considered to be anything from the distribution substation fence to the customer meter. Distribution lines tend to operate at lower voltages, less than 35 kV. Low voltages allow local electricity to be delivered safely to consumers.

Distributed Resources: include rooftop solar, energy storage, and other generators located at the customer's point of electricity consumption.

Image credit: Cortland Johnson (PNNL)

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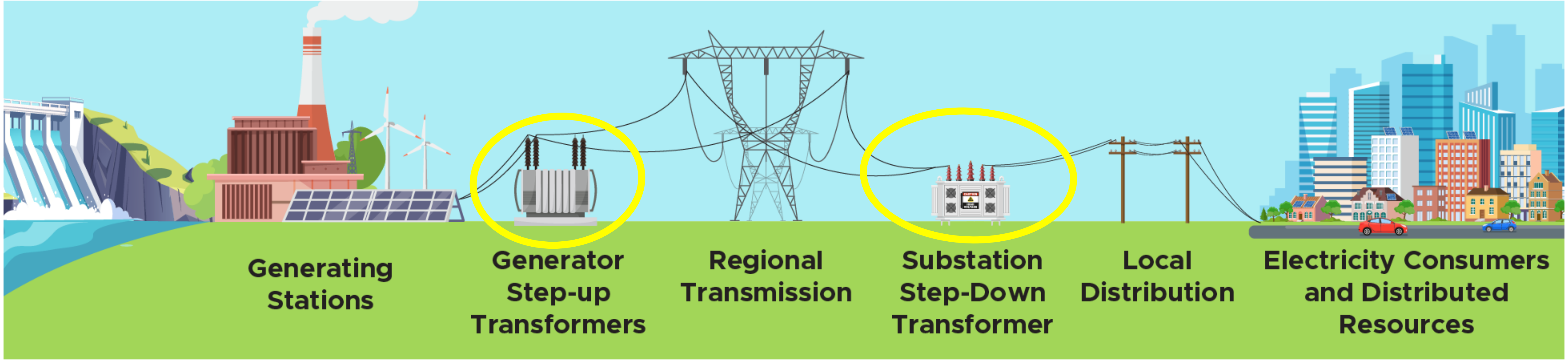

Transformers: Electromagnetic devices that allow the voltage of a transmission or distribution line to be increased (stepped up) or decreased (stepped down) by transferring electrical energy between circuits wound around magnetic cores. Transformers can be used to decrease the transmission line voltages to a safe level for the distribution system.

Image credit: Cortland Johnson (PNNL)

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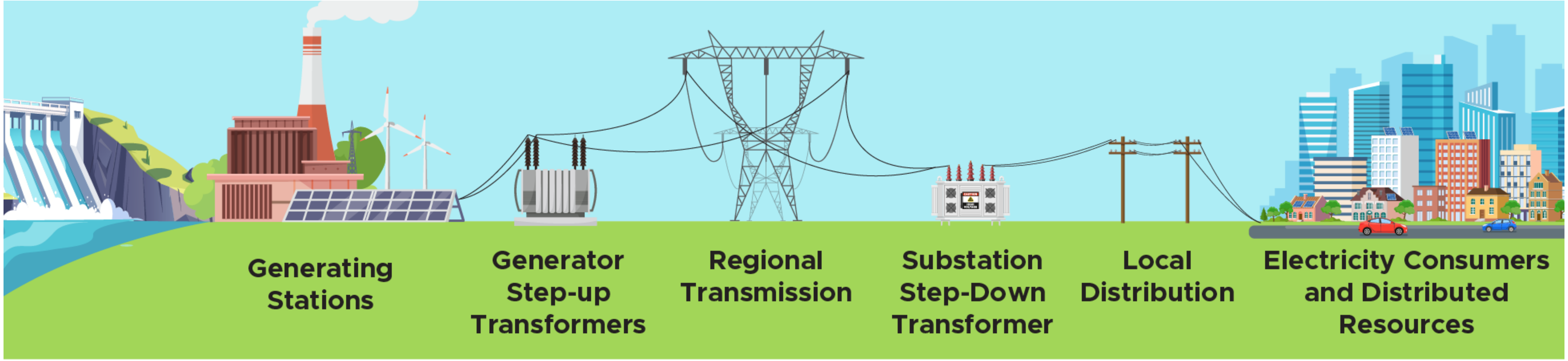
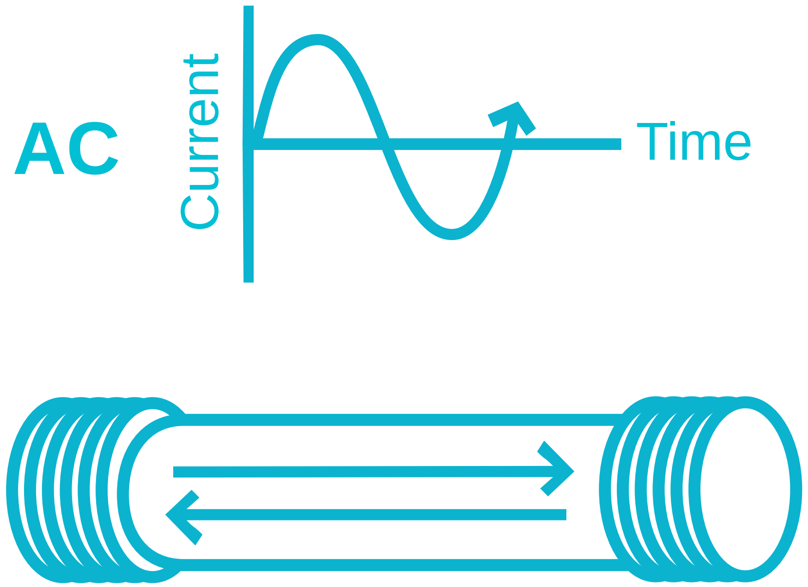


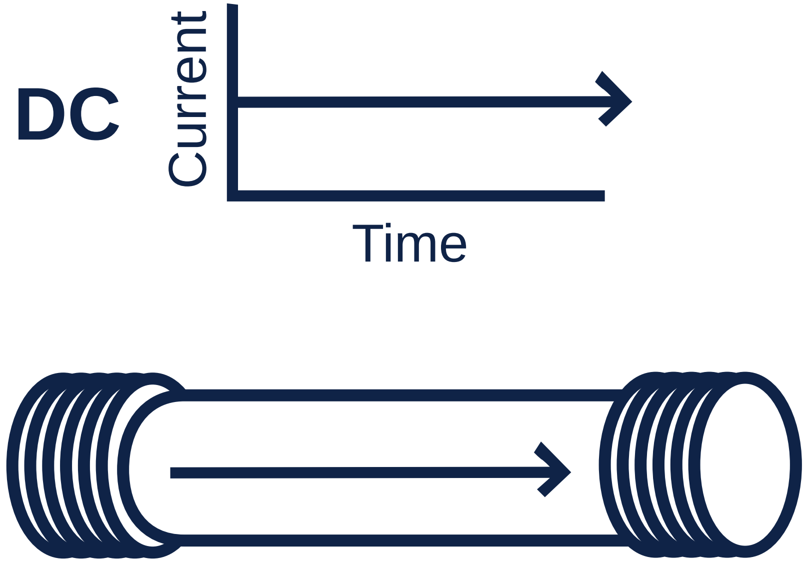
The U.S. electric grid is estimated to have assets worth over $1 trillion, with approximately 590,000 miles of transmission lines, which can be either underground or strung across large towers and poles. The U.S. electric grid has a generation capacity above 1,100 GW, managed by close to 3,500 utility organizations.

Image credit: Cortland Johnson (PNNL)

Introduction | The Electric Grid



If current was like water in a hose, AC would flow both ways and DC would flow one way



Alternating Current vs Direct Current

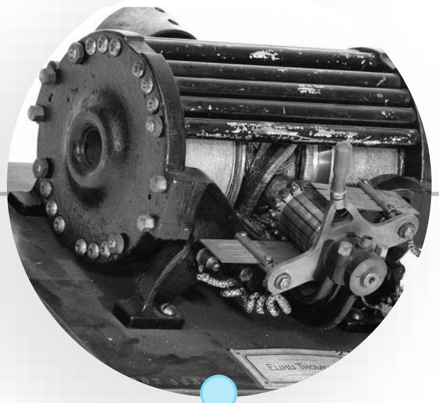
Nearly every transmission line in the U.S. carries alternating current (AC) electricity, which use transformers to step down the voltage of electricity for electricity distribution.

In the early electric grid, direct current (DC) transmission was not possible because it is not compatible with transformers. However, technological advances have since allowed for the integration of DC lines using DC to AC converters and other classes of power systems control devices.

Recently, interest in DC transmission has been growing due to the potential cost and energy savings, as DC lines require fewer conductors than AC and can more efficiently conduct high voltages. However, the DC converters required to enable DC transmission are often prohibitively expensive.

Introduction | The Transmission System

The concept of the electric grid began in the 1880s, with centralized generators providing power locally to a handful of customers. The early grid operated using direct current (DC) at relatively low voltages (100 V). The invention of the transformer allowed newer grids operating with alternating current (AC) to step up or down the voltage being carried along wires.



1885

The electric transformer was invented, **paving the way for the modern transmission system as we know it.** Generators and consumers could now be located much farther apart with little loss of power from the transmission of electricity.

1920s

Standardizing the frequency at which electricity is transmitted to 60 Hz in the 1920s allowed for the interconnection of different electric utilities, creating a diverse and robust electric grid delivering power to most major cities.

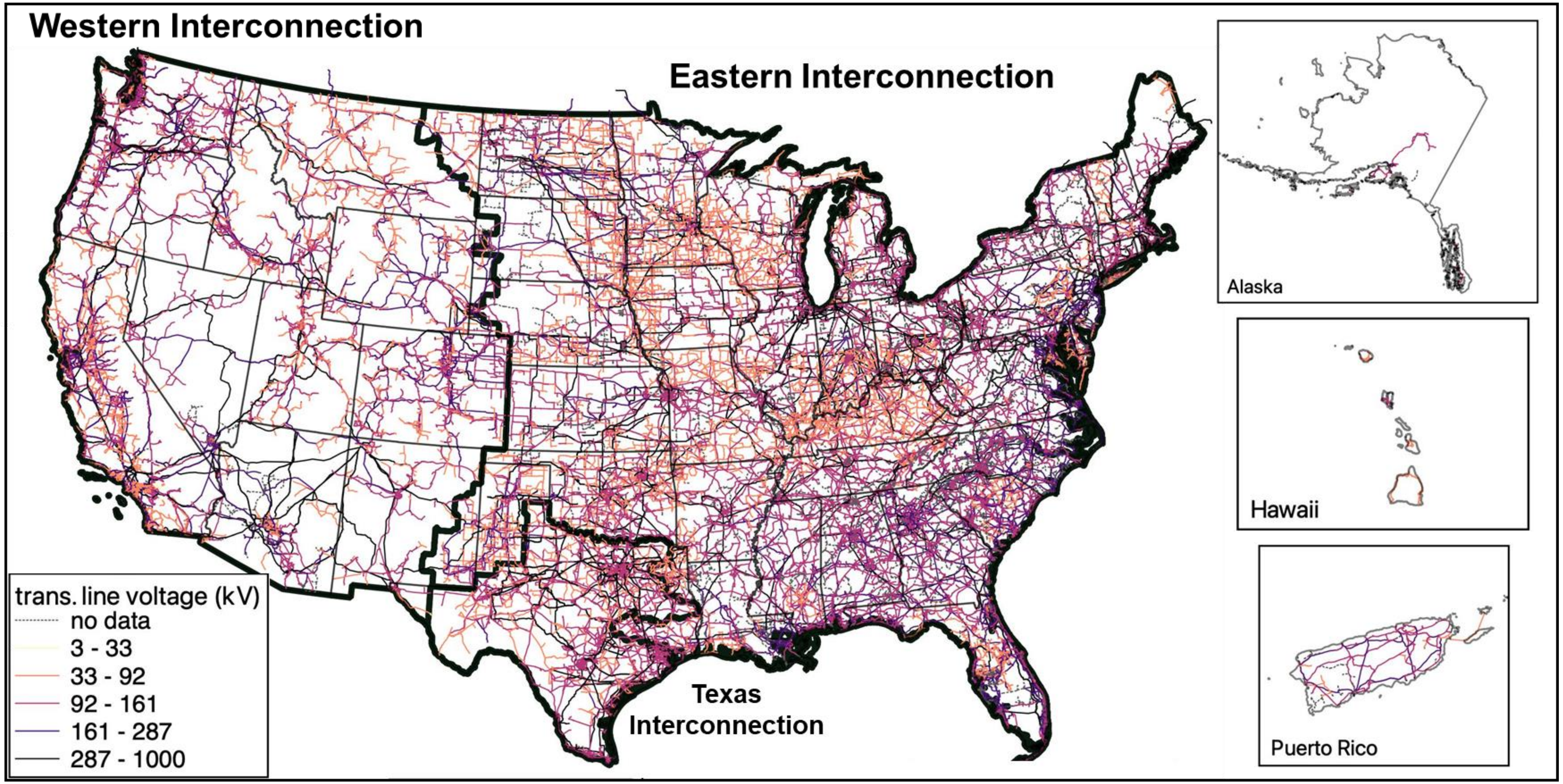
1936

President Franklin D. Roosevelt's New Deal created the **Rural Electrification Administration**, which facilitated the build out of electric infrastructure across the country, specifically to rural areas that did not yet have electricity access. The REA led to the creation of the Electric Cooperative Corporation Act, and within 25 years, the REA had facilitated access to electricity to nearly every rural American.

Image credits: Smithsonian (left), Security Pacific National Bank Collection (center), Library of Congress (right)

Introduction | The Transmission System

There are approximately **590,000 miles of transmission lines** across the United States today.

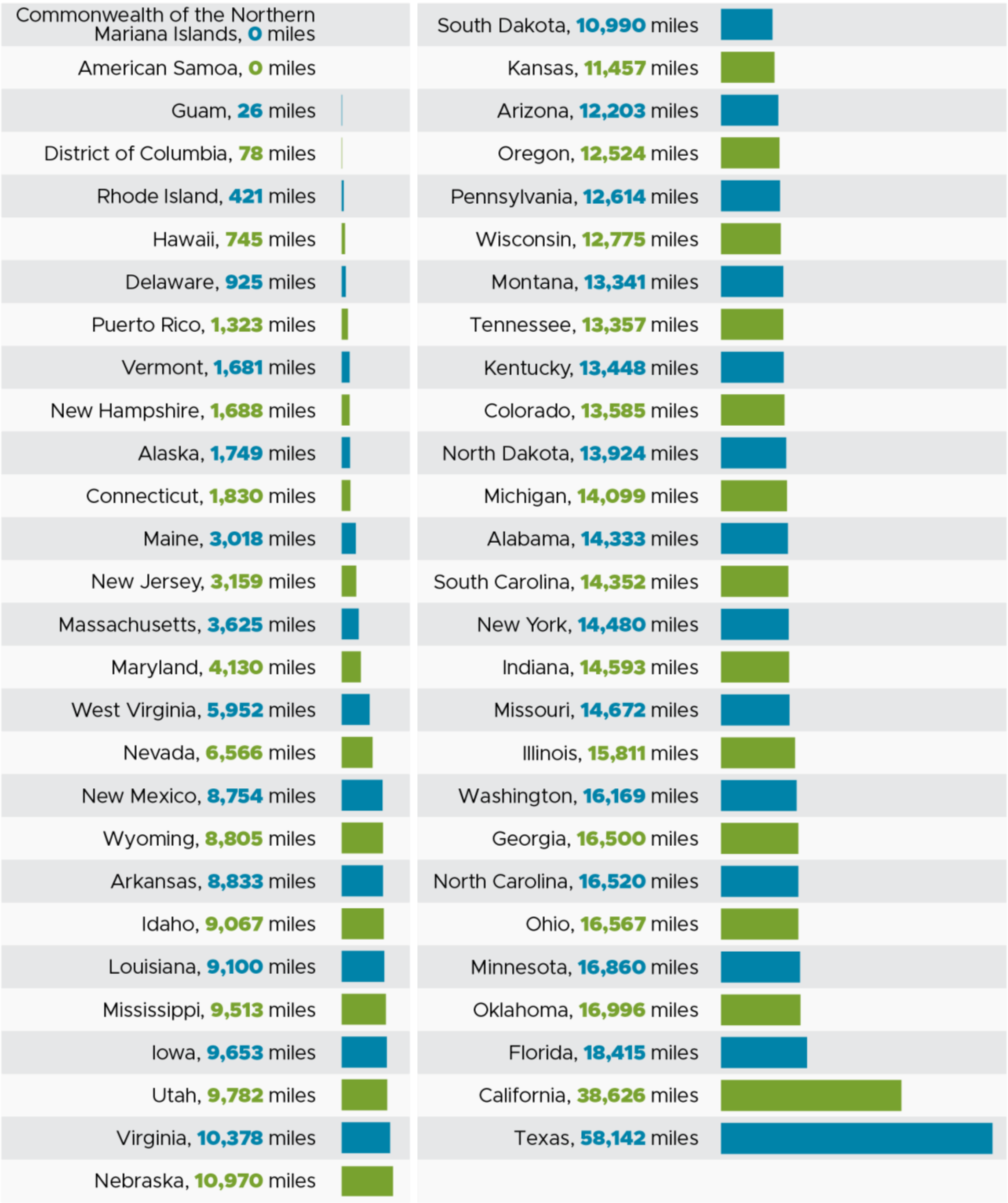


Transmission line map within the Continental U.S., Alaska, Hawaii, and Puerto Rico colored by voltage ranges.

Image credit: Created by Pacific Northwest National Laboratory (PNNL) using open-source geographic information system (GIS) software QGIS. Data from public Homeland Infrastructure Foundation-Level Data (HIFLD) from the Geospatial Management Office (GMO) of the Department of Homeland Security.

Introduction | The Transmission System

Miles of Transmission Per State



The figure on the left breaks down the total miles of transmission lines by state, territory, Washington D.C., and American Samoa. This represents over 94,000 individual lines and a total length that would stretch from New York City to Los Angeles 240 times over. The amount of transmission a state needs is correlated to its size and population density, with less densely populated and smaller areas requiring less transmission to carry power across their physical footprint.

The table below summarizes the total miles of transmission line across the U.S. and the range of voltages they carry.

The U.S. Transmission System Line Miles by Voltage

Voltage (kV)	AC Transmission Lines (mi)	DC Transmission Lines (mi)
0 – 100	125,558	-
101 – 200	230,222	52
201 – 300	88,952	-
301 – 400	65,458	436
401 – 500	28,986	240
701 - 800	2,411	-
1000	-	844
Total	**541,559**	**1,573**

Transmission Infrastructure

Transmission infrastructure varies across the U.S. and other countries according to its structure, size, voltage, and electrical components.

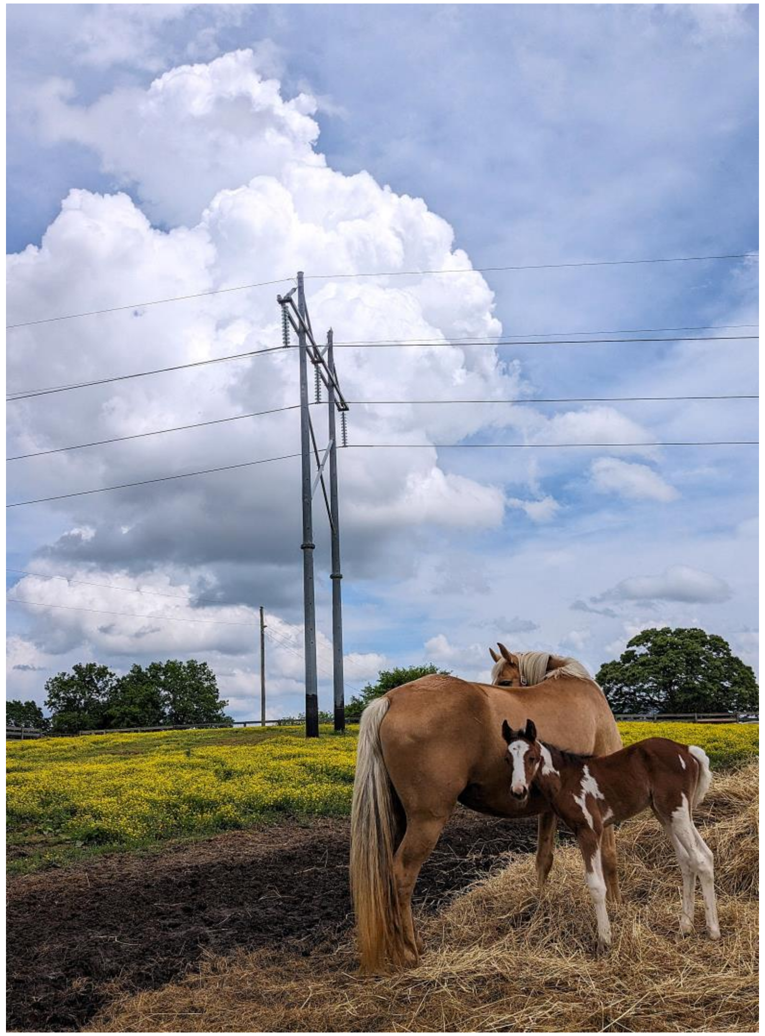


Image credits: Irena Netik, PNNL (left), Rebecca O'Neil, PNNL (center and right)

Transmission Towers and Transmission Line Ratings

A transmission tower's transmission line voltage rating defines the line's maximum allowable power flow; **the higher the rating, the more power it can safely carry**. Transmission towers are designed to keep high-voltage lines adequately separated from one another and their physical surroundings.

The voltage on the lines determines the tower height, line spacing, and insulator length required to safely transmit power along the lines.

Transmission towers must also be built to withstand the physical stress from weather events and any other environmental conditions.

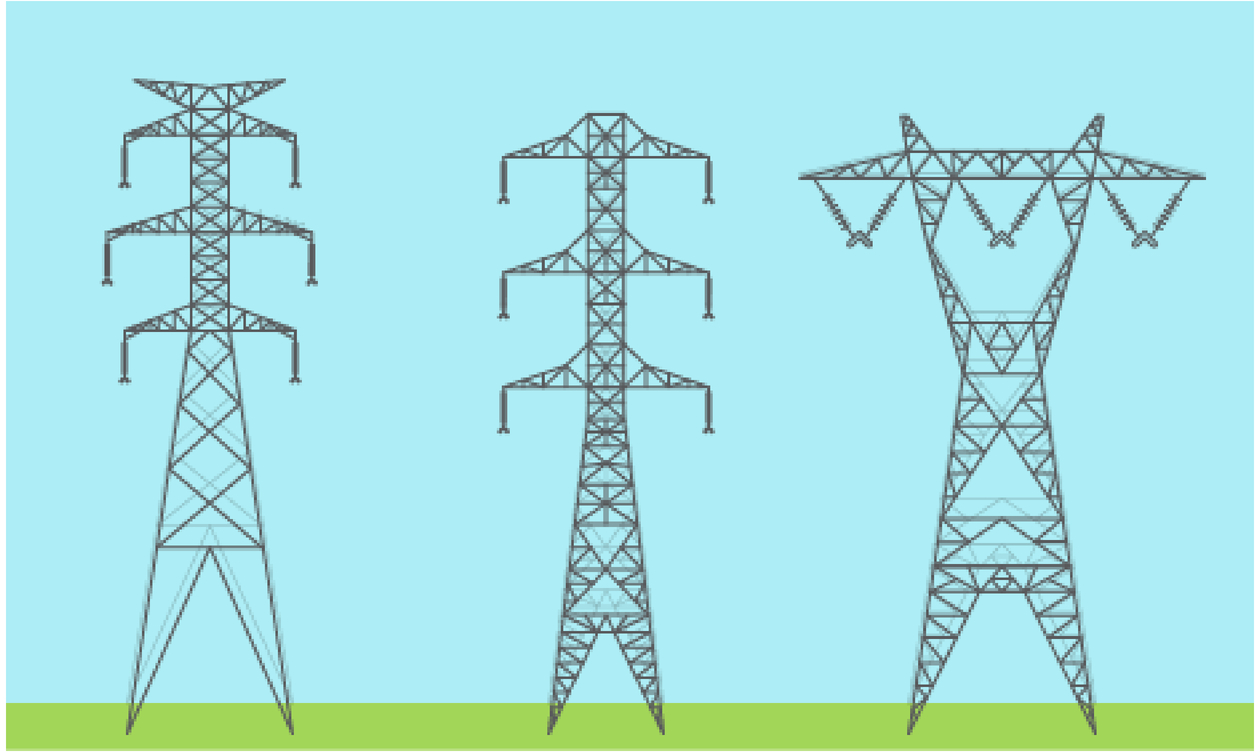
Transmission towers are typically between 50 and 180 feet (ft) tall.

Image credit: Andrea Starr (PNNL)

Transmission Towers and Transmission Line Ratings

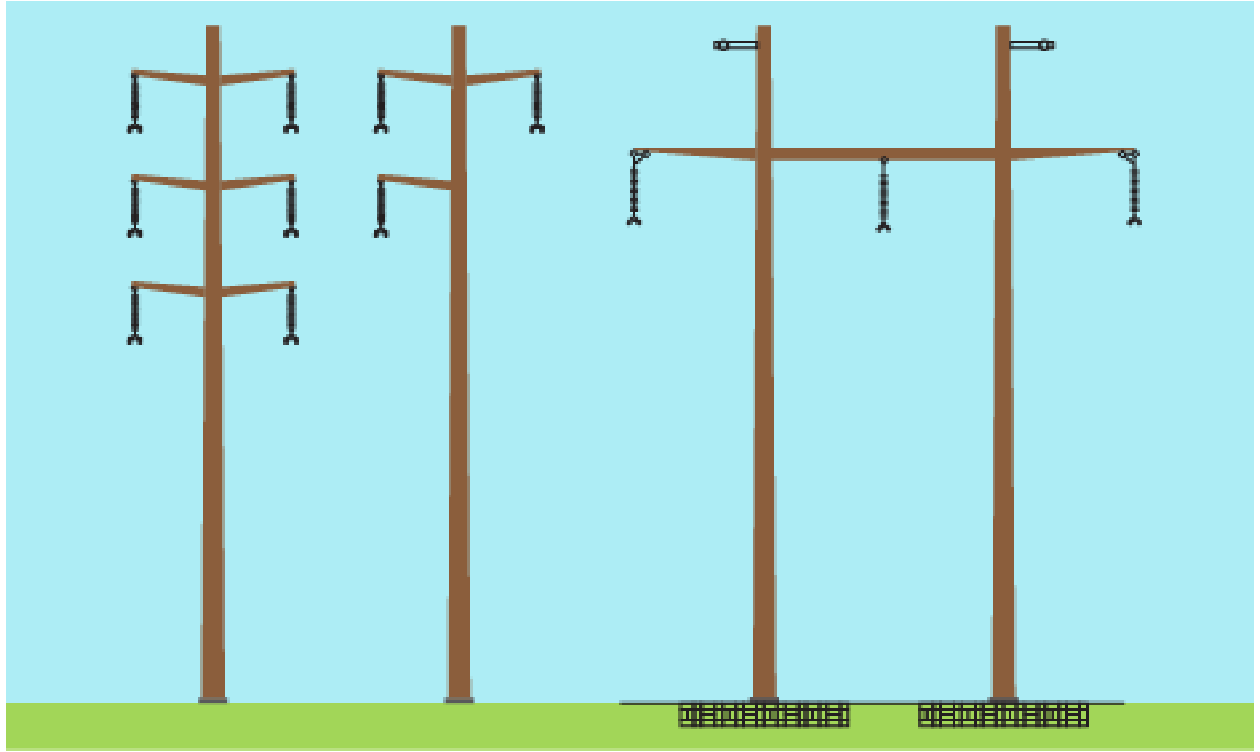
There are two main types of transmission tower design: **lattice steel towers** and **tubular steel poles**. Either can be **single-** or **double-circuit** type, meaning they have either one or two rows of current-carrying conducting wires, which corresponds to whether the lines are stacked horizontally (single) or vertically (double).

Lattice Steel Towers



220 kV Double-Circuit 110 – 200 ft | 500 kV Double-Circuit 150 – 215 ft | 500 kV Single-Circuit 80 – 200 ft

Tubular Steel Poles*



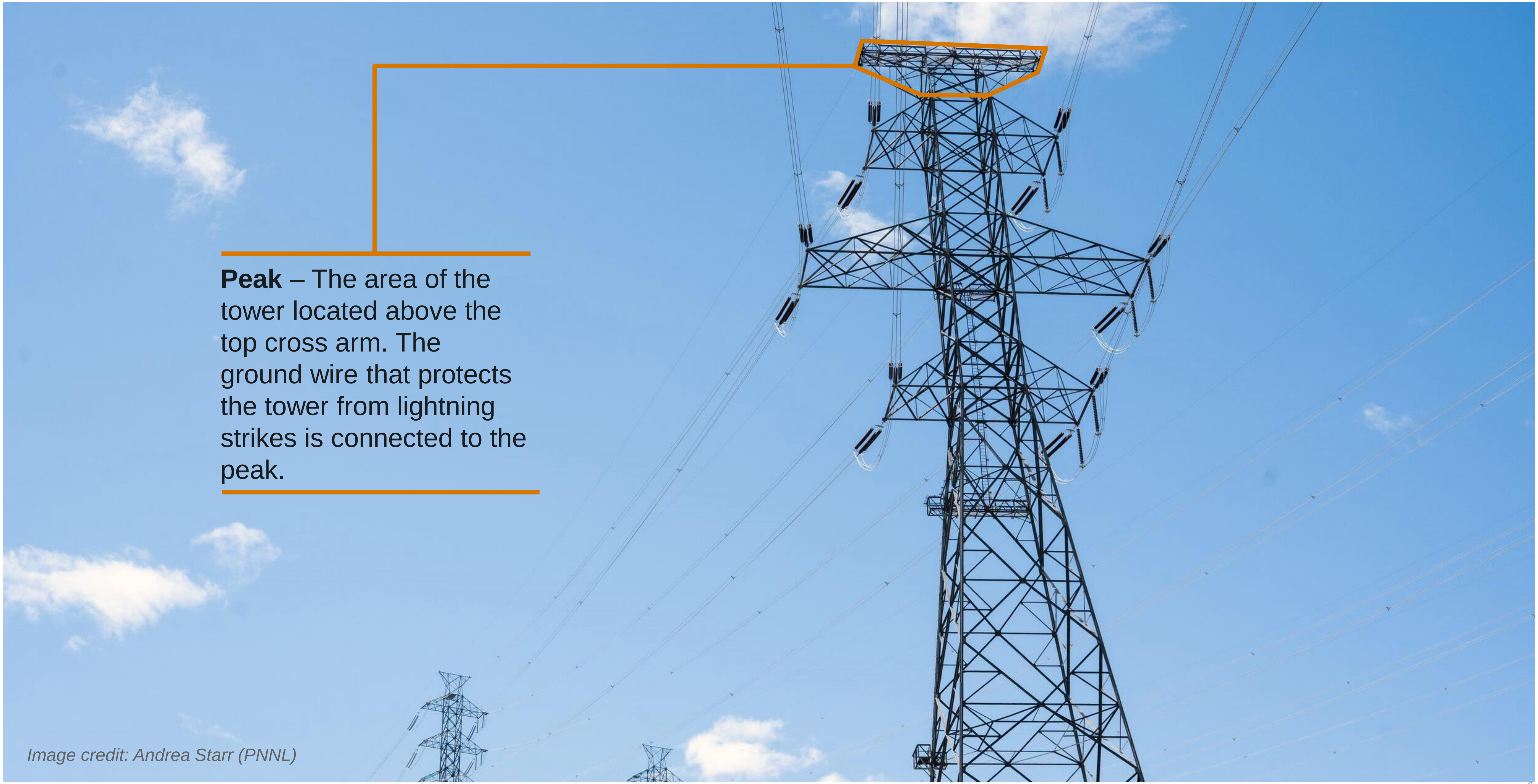
220 kV Double- Single-Circuit 70 – 200 ft | 220 kV Single-Circuit H-Frame 50 – 200 ft

For safety, the **minimum height between the ground and the lowest conductor on a transmission tower is determined by the voltage it carries**; double-circuit towers therefore stand taller than single-circuit towers for the same voltage.

**Note that the pole design requires a significantly larger foundation than the lattice tower to ensure structural stability. This can impact siting decisions.*

Image credit: Cortland Johnson (PNNL)

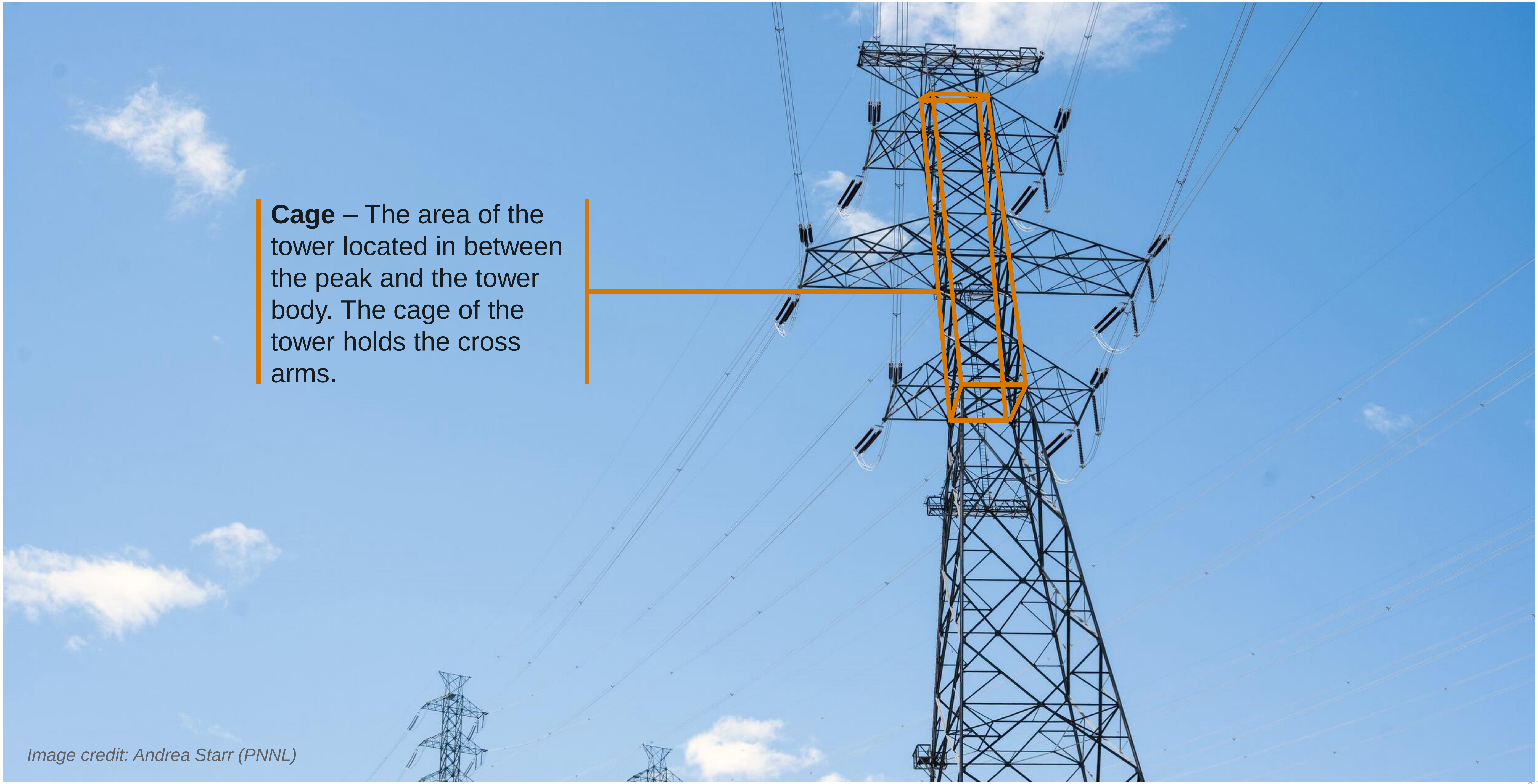
Transmission Infrastructure Components



Peak – The area of the tower located above the top cross arm. The ground wire that protects the tower from lightning strikes is connected to the peak.

Image credit: Andrea Starr (PNNL)

Transmission Infrastructure Components



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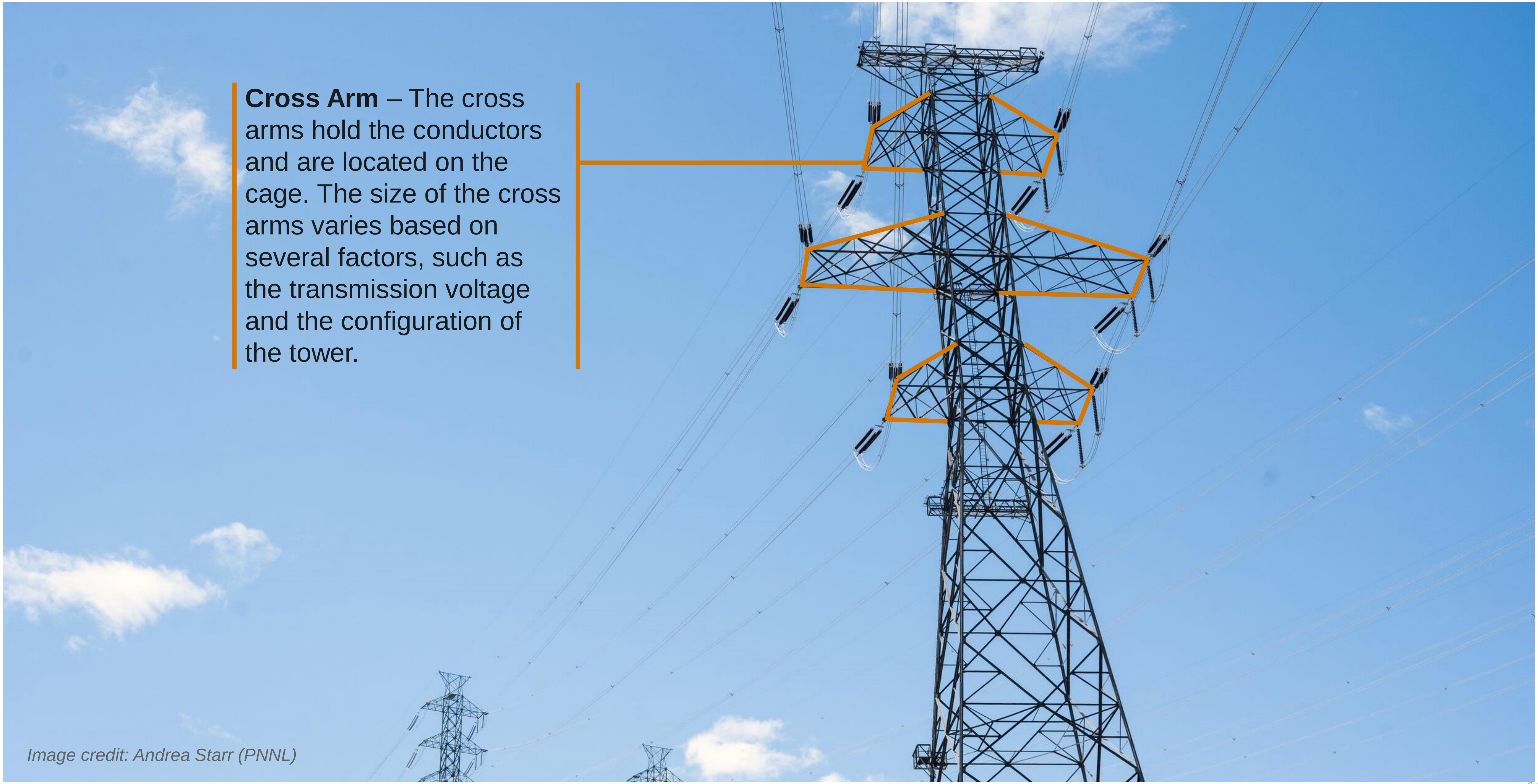
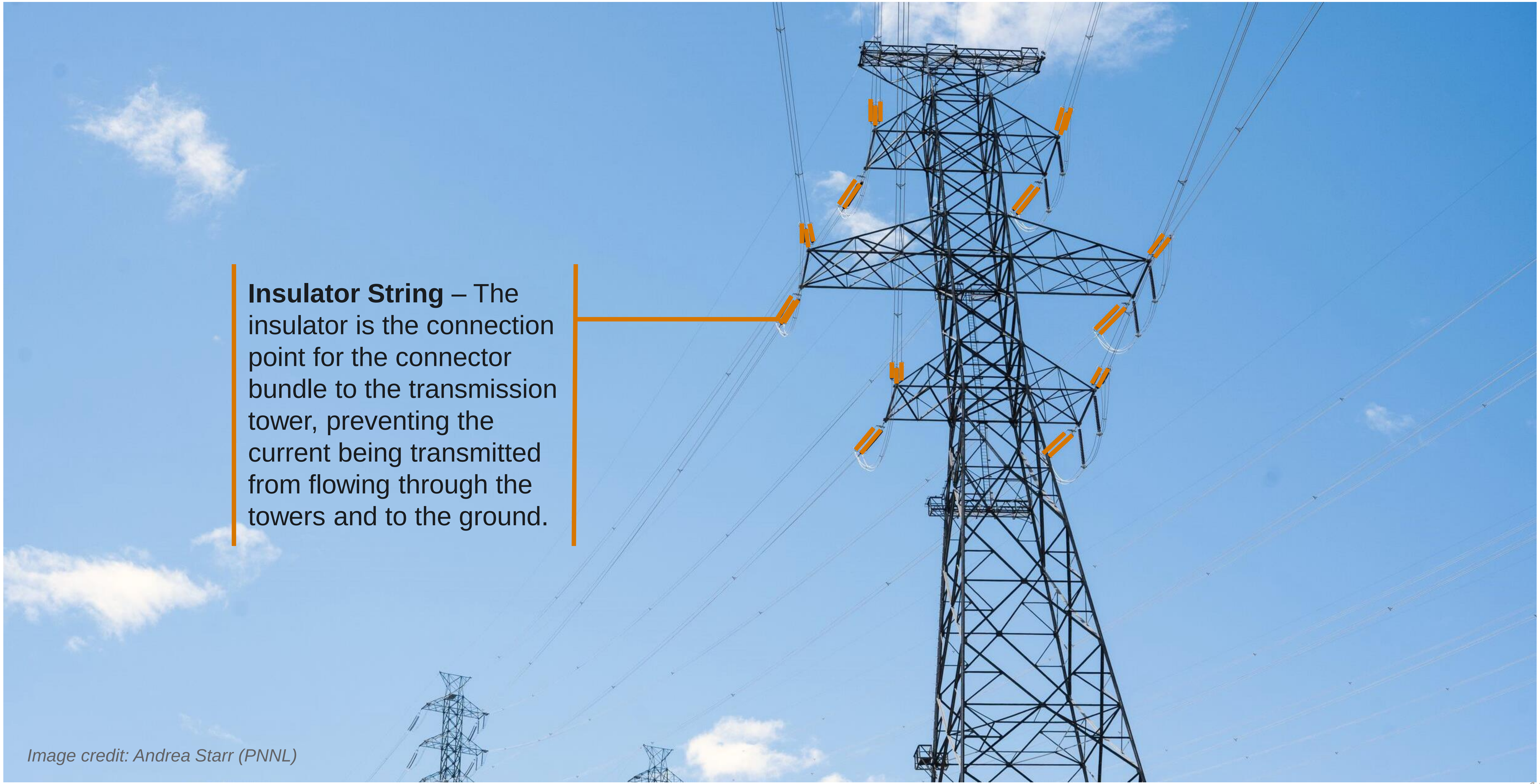


Cross Arm – The cross arms hold the conductors and are located on the cage. The size of the cross arms varies based on several factors, such as the transmission voltage and the configuration of the tower.

Image credit: Andrea Starr (PNNL)

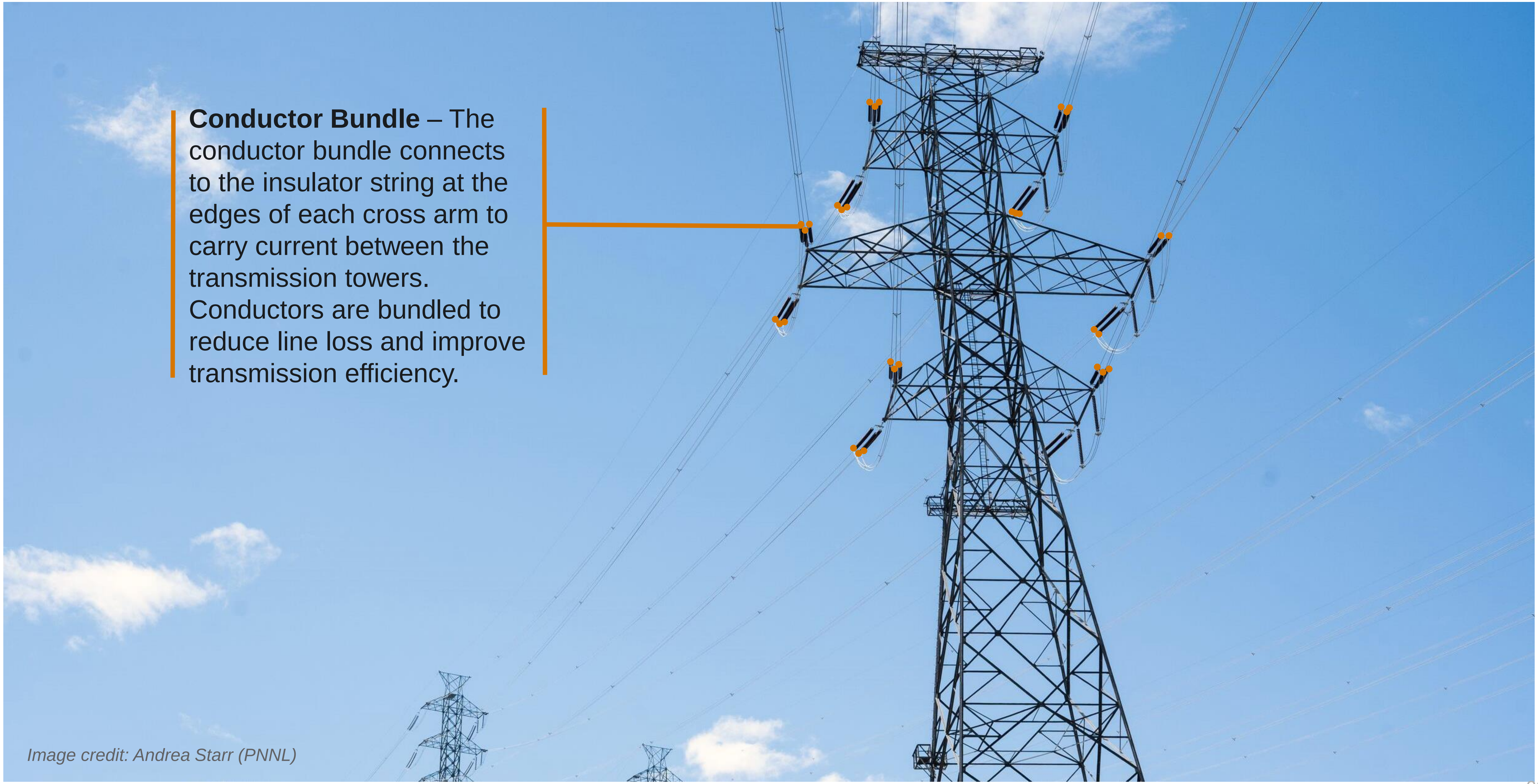
Transmission Infrastructure Components



Insulator String – The insulator is the connection point for the connector bundle to the transmission tower, preventing the current being transmitted from flowing through the towers and to the ground.

Image credit: Andrea Starr (PNNL)

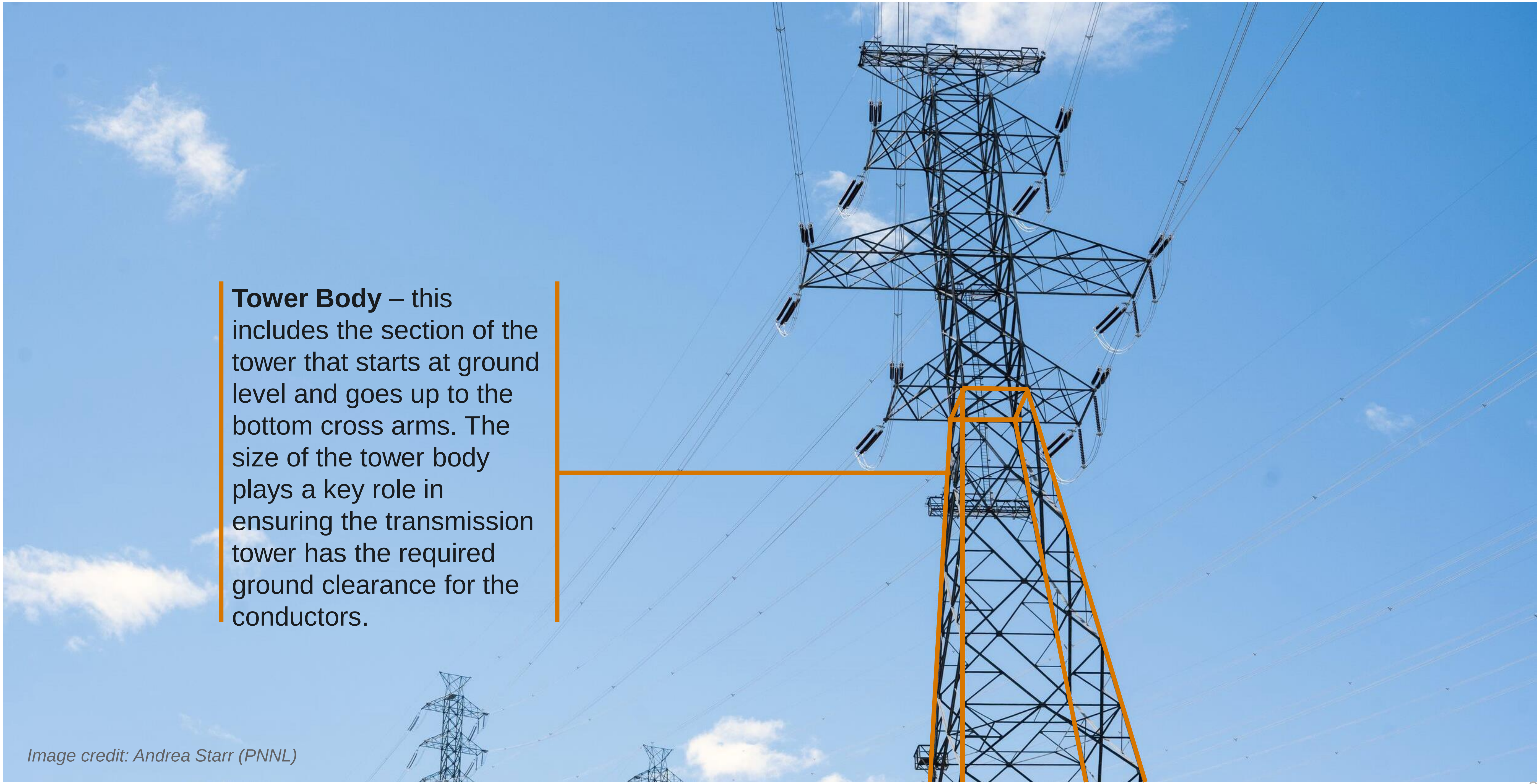
Transmission Infrastructure Components



Conductor Bundle – The conductor bundle connects to the insulator string at the edges of each cross arm to carry current between the transmission towers. Conductors are bundled to reduce line loss and improve transmission efficiency.

Image credit: Andrea Starr (PNNL)

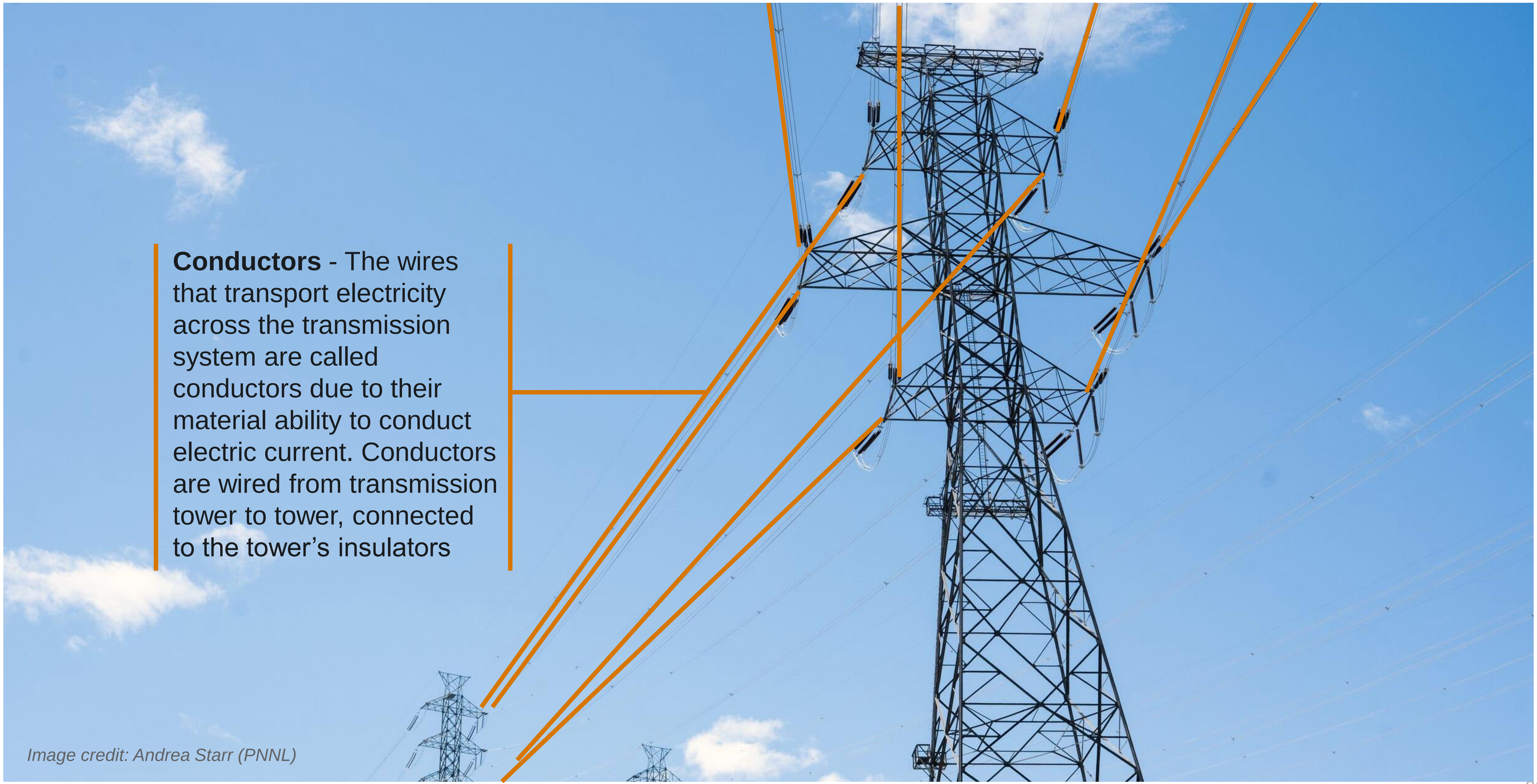
Transmission Infrastructure Components



Tower Body – this includes the section of the tower that starts at ground level and goes up to the bottom cross arms. The size of the tower body plays a key role in ensuring the transmission tower has the required ground clearance for the conductors.

Image credit: Andrea Starr (PNNL)

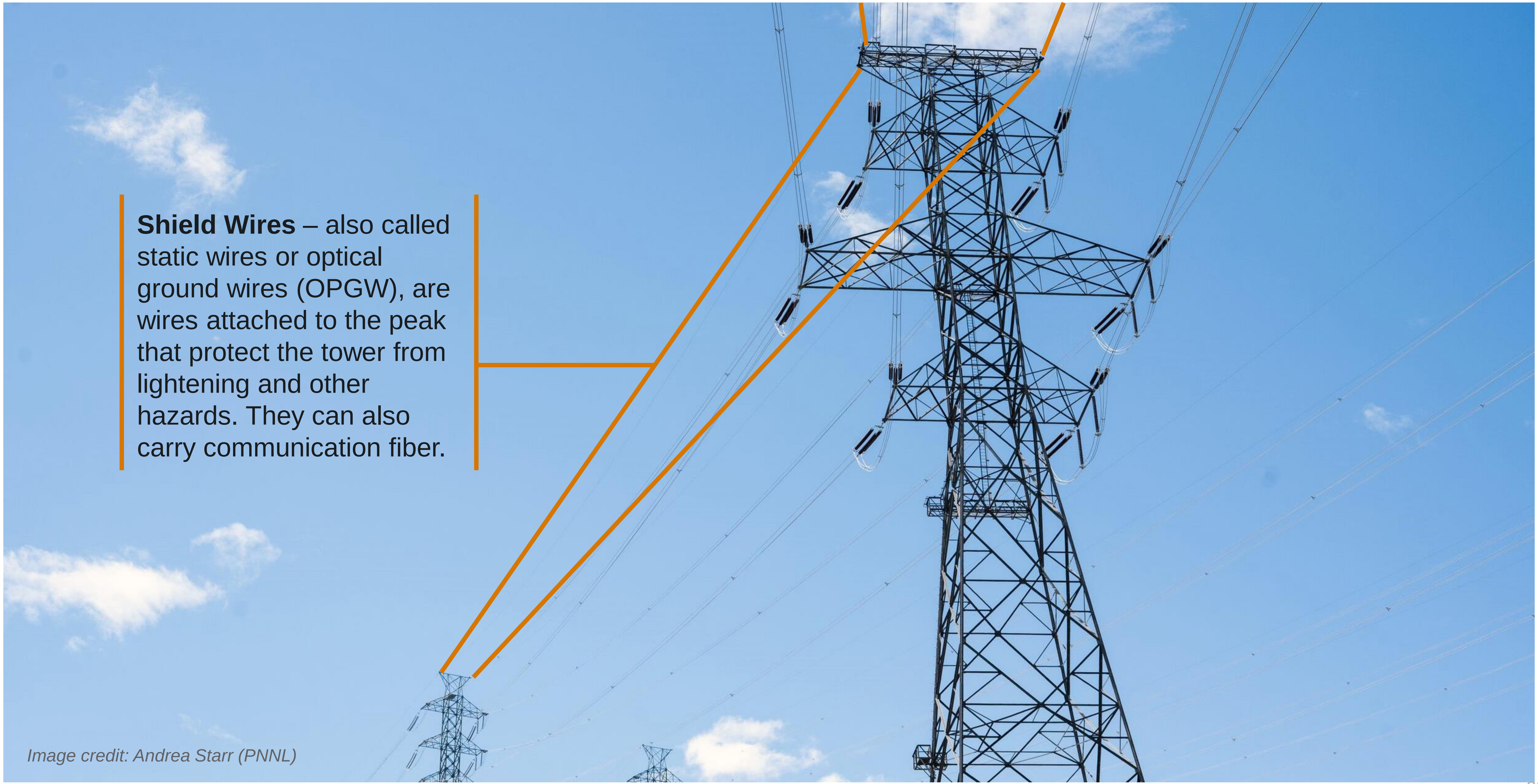
Transmission Infrastructure Components



Conductors - The wires that transport electricity across the transmission system are called conductors due to their material ability to conduct electric current. Conductors are wired from transmission tower to tower, connected to the tower's insulators

Image credit: Andrea Starr (PNNL)

Transmission Infrastructure Components

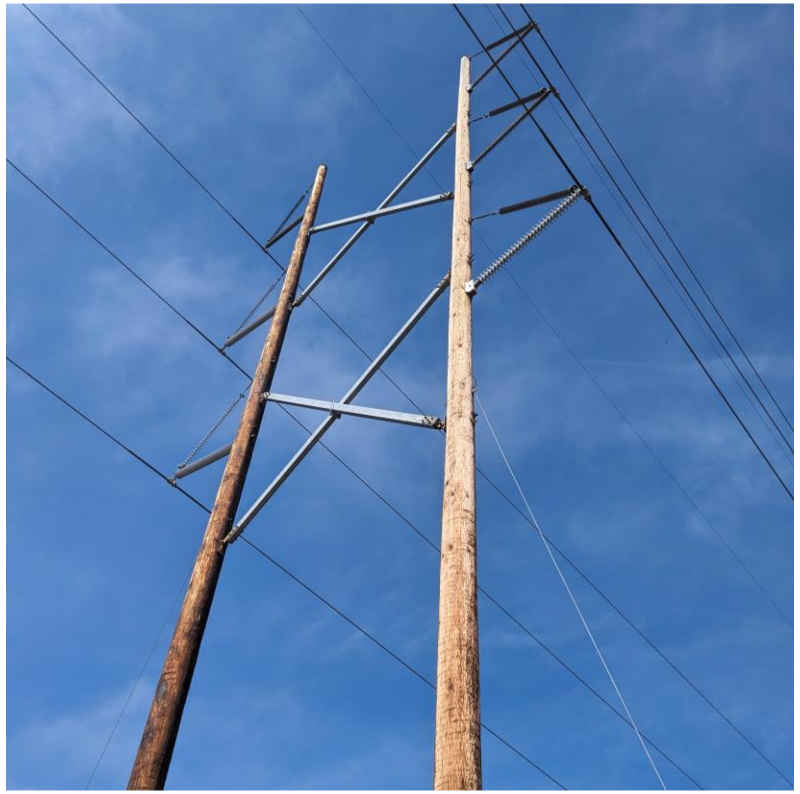


Shield Wires – also called static wires or optical ground wires (OPGW), are wires attached to the peak that protect the tower from lightening and other hazards. They can also carry communication fiber.

Image credit: Andrea Starr (PNNL)

Transmission Infrastructure Components

Materials



Steel is the most common material for transmission towers due to its high strength. However, **wooden** and **reinforced concrete** transmission towers are also used, but are more common in distribution towers and utility poles. **Fiber-reinforced composite** materials are gaining traction due to their high strength, light weight, good insulation, and resistance to corrosion.

Image credits: Andrea Starr, PNNL (left), Rebecca O'Neil, PNNL (center), Unsplash (right)

Transmission Infrastructure Components

Conductor Materials

Transmission lines are comprised of a system of conductors which can be made from many different conducting materials, with trade-offs between conductivity and material strength.

- **Copper**: high conductivity, low strength. Used historically, but mechanical strength is the limiting factor.
- **Aluminum**: reduced conductivity (60% that of copper), but much lighter and therefore improved conductivity-to-weight ratio (twice that of copper). Aluminum is also less expensive than copper.
- **Aluminum/Steel**: steel is a poor conductor, but very strong. Steel cores are surrounded by aluminum strands for high strength and conductivity. ACSR, or aluminum conductor steel reinforced conductors have aluminum surrounding steel strands at the core. ACSS, or aluminum conductor steel supported conductors, are similar to ACSR conductors, but can carry higher currents at higher temperatures. ACSS wires can be either trapezoidal wire type (TW) or annealed wire type (AW).
- **Aluminum/Ceramic**: ceramic fibers within a matrix of aluminum allow for even greater strength and less weight. ACCR, or aluminum conductor composite reinforced, also provide increased resistance to heat degradation. ACCC, or aluminum conductor composite core utilizes carbon fiber to deliver high strength at light weight.

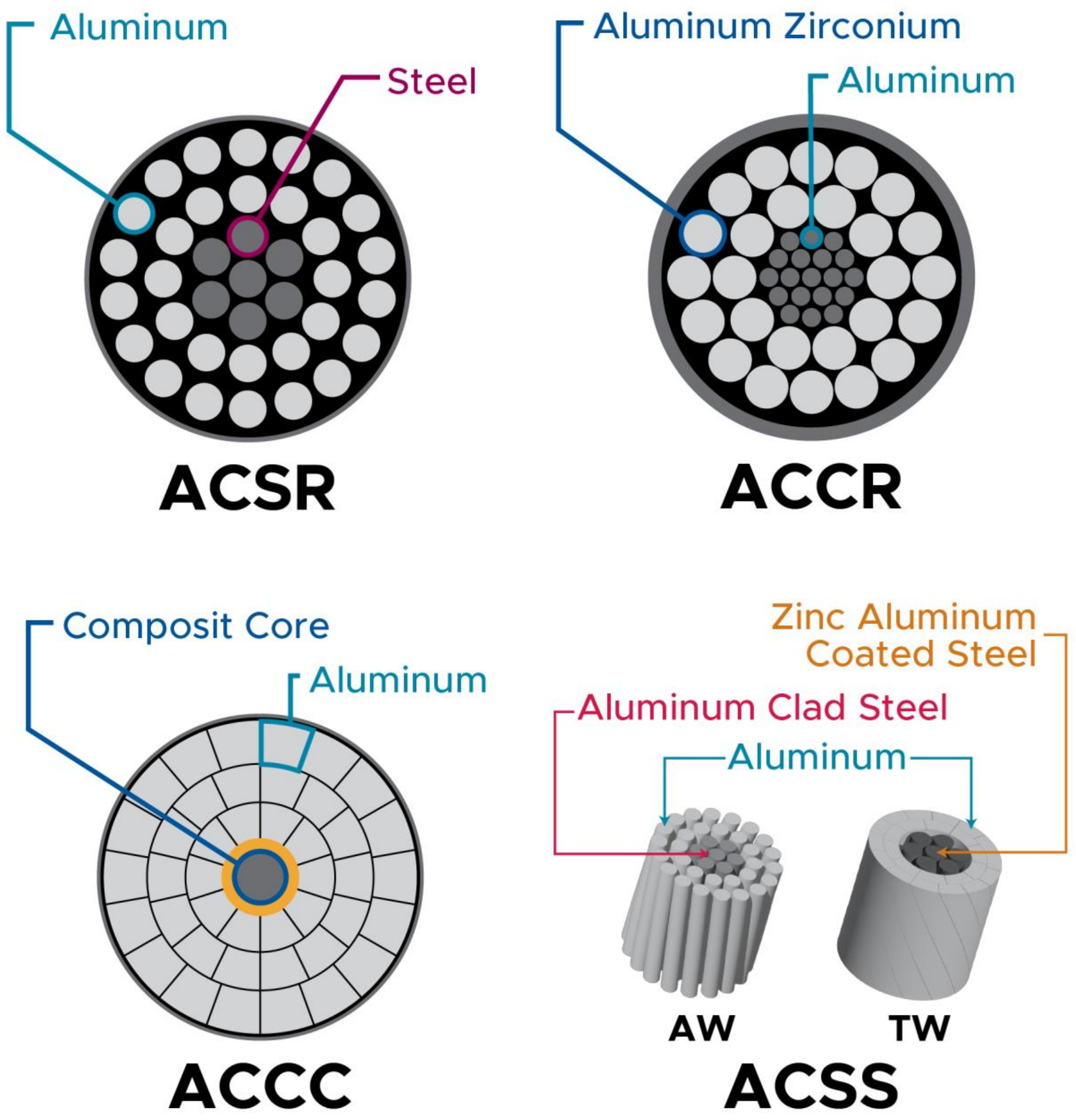
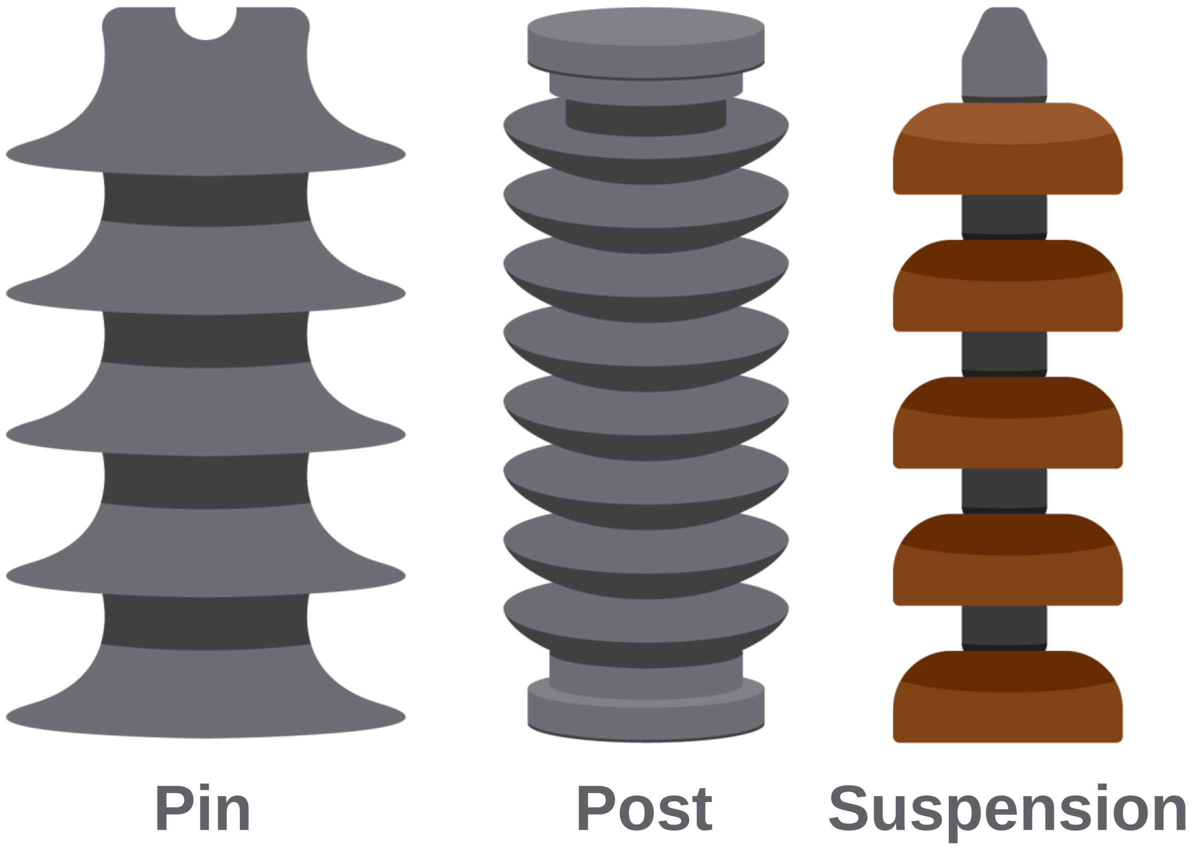


Image credit: Cortland Johnson (PNNL)

Transmission Infrastructure Components



Insulators

Insulators are mounted to the cross-arms and connect the conductor to the tower. The insulator is necessary to prevent current from flowing from the conductor to the Earth though the tower. The insulators also provide mechanical support and separation distance for the conductor. There are three types, all of which are designed to prevent leakage or shortage even when exposed to rain or other debris:

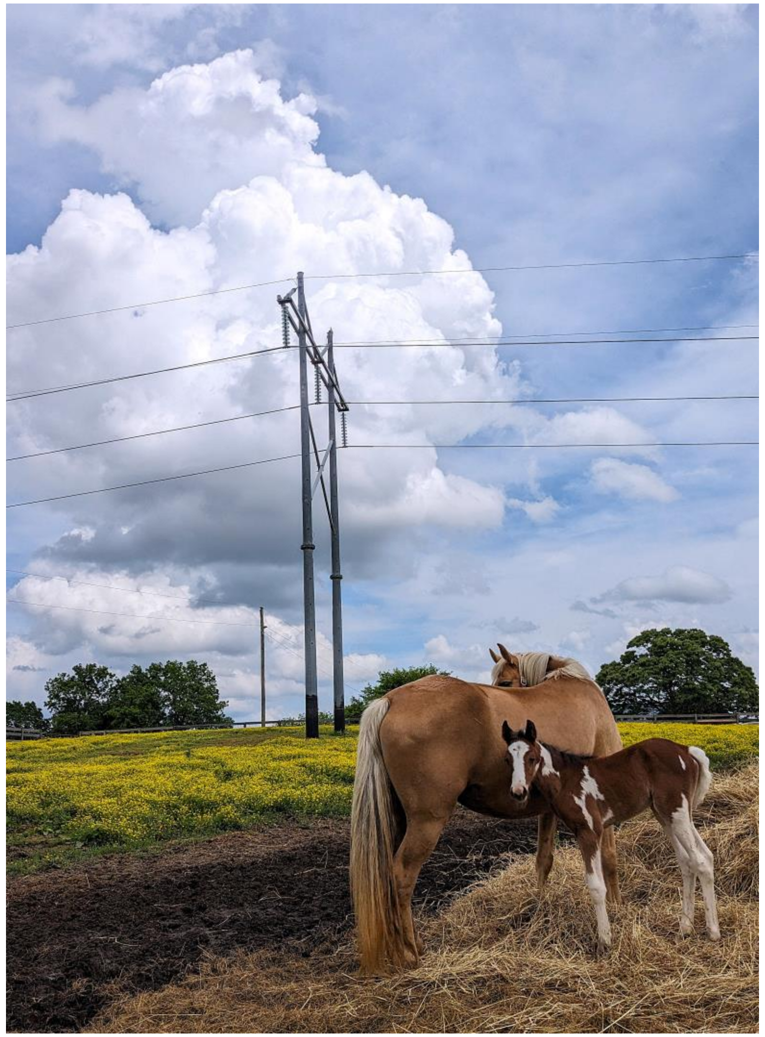
- **Pin**: A soft metal thimble separates the porcelain (insulating material) and the hard metal pin so there is no direct contact. Generally used for voltages up to 33 kV.
- **Post:** Similar to a pin-type insulator but has a metal base and a metal cap to allow for more than one unit to be mounted in series. The insulating material is shaped in the form of cones that fit inside one another. Used for supporting bus bars and disconnecting switches in the substations.
- **Suspension:** Used for lines above 33 kV as pin-type insulators are expensive for higher voltages. Has a disc-shaped insulating material with a metal cap on top and a metal pin on the bottom. Also known as disc or string insulators.

Historically, porcelain and glass have been the most common materials for insulators due to their low cost, high strength, and flexible maintenance. Newer polymer or composite insulators provide increased material strength and durability at lighter weights and reduced costs.

Image credit: Cortland Johnson (PNNL)

Siting and Safety | Transmission Corridors

Transmission infrastructure is designed to transport high-voltage electricity across large, often remote distances, with little margin for failure. This requires strict siting and safety standards.



Transmission corridors are strips of land designated for certain uses, such as by telecommunication, electric and gas utilities, or for transportation highways and railways.

Image credits: Irena Netik, PNNL (left), Rebecca O’Neil, PNNL (center and right)

Siting and Safety | Transmission Corridors

Transmission Corridors can include either above- or below-ground lines.

The width of a transmission corridor depends on the type of tower design, voltage on the lines, and the surrounding landscape. Corridors are designed to be as wide as necessary to safely isolate the high-voltage transmission lines from nearby structures, vegetation, and activity. These siting and safety regulations vary by county and state.

Image credits: Pixabay (left), Shutterstock (right)

Oversight | Transmission Siting and Permitting

Who oversees the siting and planning of transmission infrastructure?

FERC: The Federal Energy Regulatory Commission

- Regulates interstate transmission of electricity and oversees regional transmission planning.
- FERC Order 1920 (2024): advanced a new framework for identifying benefits and assigning beneficiaries in support of more accurate evaluation and cost allocation of transmission infrastructure. This order encourages "right-sizing" the scale of transmission and emphasizes upgrades and other improvements to existing routes and lines.

State and Local Jurisdictions (structure and approach varies)

- Independent Siting Committees and Boards
- State Energy Office
- Environmental Regulatory Authority
- State Utility Regulatory Commission

Jurisdiction can depend on:

- Line Length
- Power Rating
- State/County Boundaries Crossed

Siting and Safety | Transmission Siting and Permitting

What is required for permitting of transmission infrastructure?

- **Easement**: a legal agreement that allows one party to utilize the land of another for a particular purpose, such as transmission of electricity.

Transmission easements allow the landowner to continue to use the ROW for activities such as ranching, farming, and wildlife preservation.

Image credit: Irena Netik (PNNL)

- Grants the utility the right to build and maintain transmission lines from the landowner.
  - Landowners are compensated for granting the easement, usually with a one-time payment based on market value.
  - Landowners still have use of their land, so long as it does not interfere with the operation, maintenance, or safety of the transmission line.
  - Process varies by state and local regulations.
- **Right of Way (ROW)**: the physical land agreed upon in the easement.

Siting and Safety | Transmission Safety and ROW

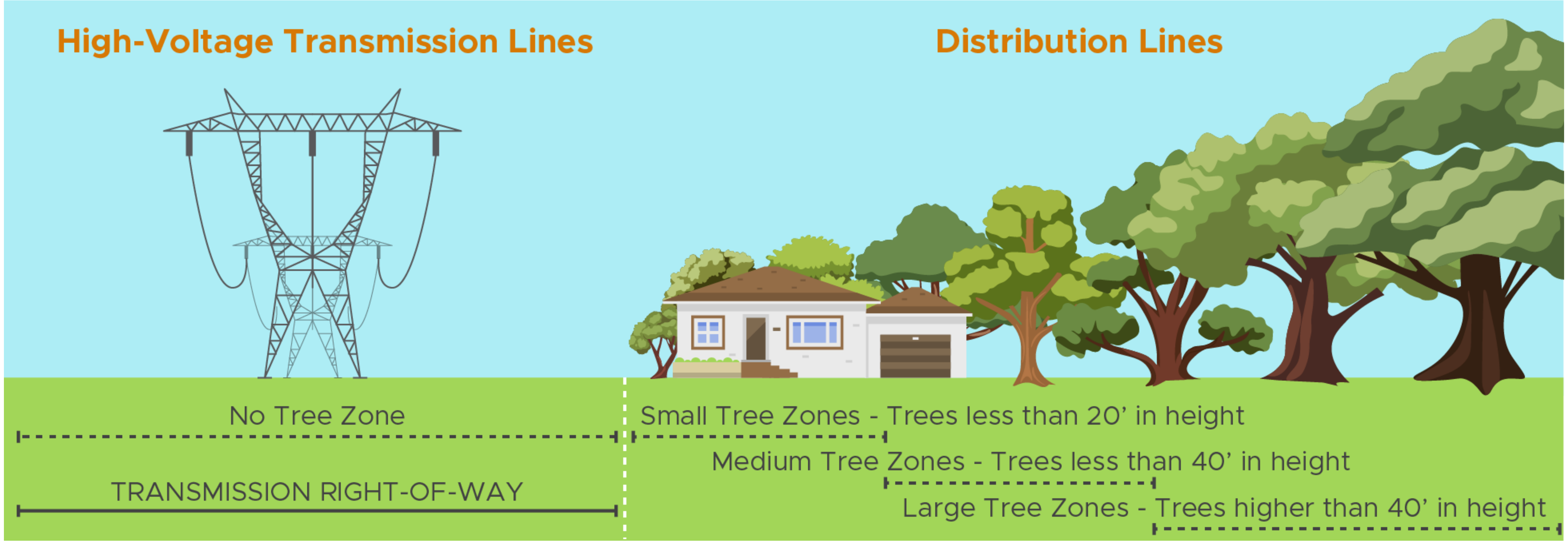
The **North American Electric Reliability Corporation** (NERC) provides the minimum safe vegetation clearance distances between transmission towers and adjacent vegetation, by voltage and depending on elevation.

These minimum safe distances are required to provide adequate safety margins between the transmission lines and the surrounding infrastructure and vegetation.

Voltage (kV)	Minimum Vegetation Clearance Distance (ft) [sea level up to 500 ft]
69 – 72	1.1
88 – 100	1.5
115 – 121	1.9
138 – 145	2.3
161 – 169	2.7
230 – 242	4.0
287 – 302	5.2
345 – 362	4.3
500 – 550	7.0
765 – 800	11.6

Siting and Safety | Transmission Safety and ROW

The **American National Standards Institute** (ANSI) requires minimum clearance distance between transmission lines and adjacent vegetation, depending on the voltage on the lines and the species of tree and its growth characteristics.



Traditional vegetation management strategies include mechanically clearing tree and brush, pruning branches, and applying selective herbicides to control tall-growing species.

Image credit: Cortland Johnson (PNNL)

Siting and Safety | Transmission Safety and ROW

Image credit: Unsplash

Integrated Vegetation Management (IVM): an innovative strategy to maintain safe clearance between transmission and vegetation while promoting the ecological benefits of local, low-growing vegetation, mitigating the need for costly and labor-intensive mechanical clearing.

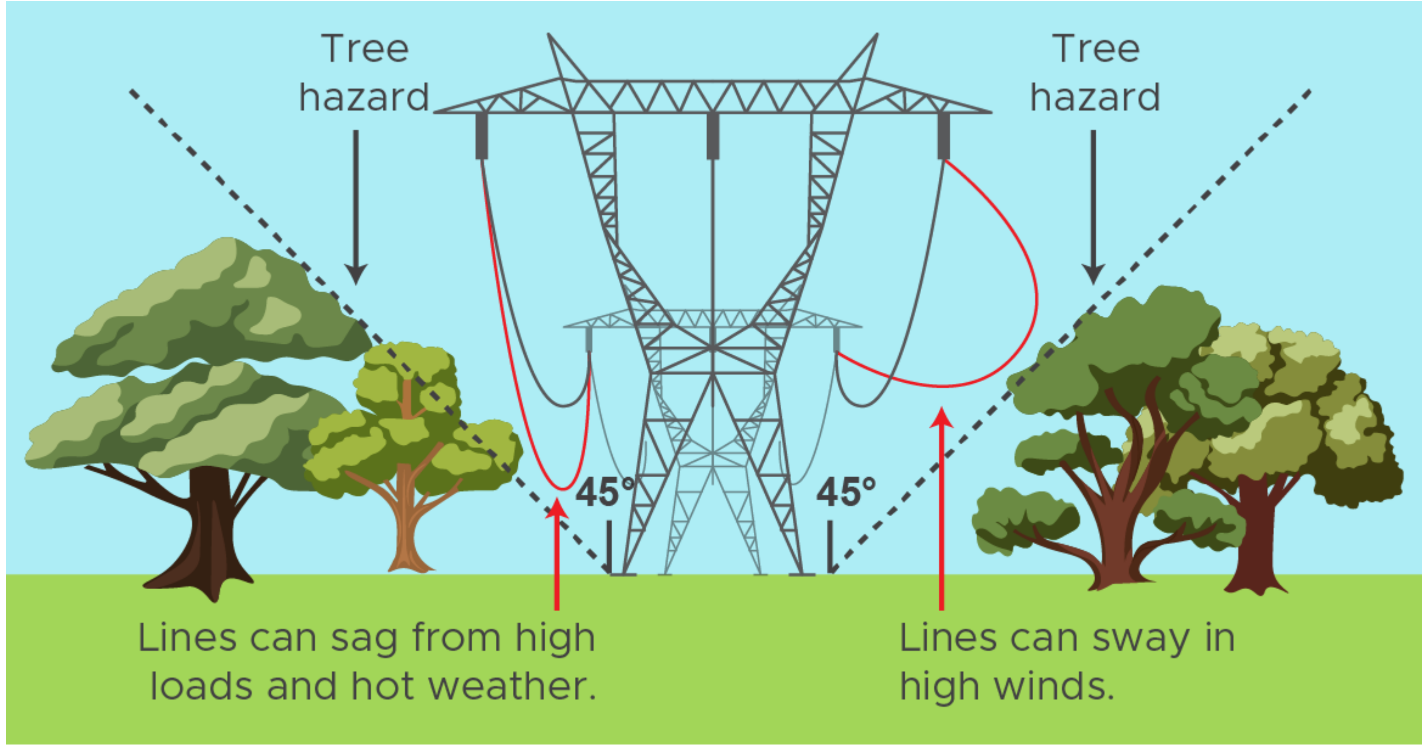
- See the Right-of-Way Stewardship Council's technical standards for best practices in IVM
- ANSI A300 codifies requirements for third party accreditation

Siting and Safety | Transmission Safety and ROW

Transmission lines are designed to sag slightly to avoid too much tension, but extreme outdoor temperatures and heat from high loads can cause transmission lines to sag as the metal expands.

High winds can also cause transmission lines to sway, which is why transmission line ROWs extend beyond the physical footprint of the tower.

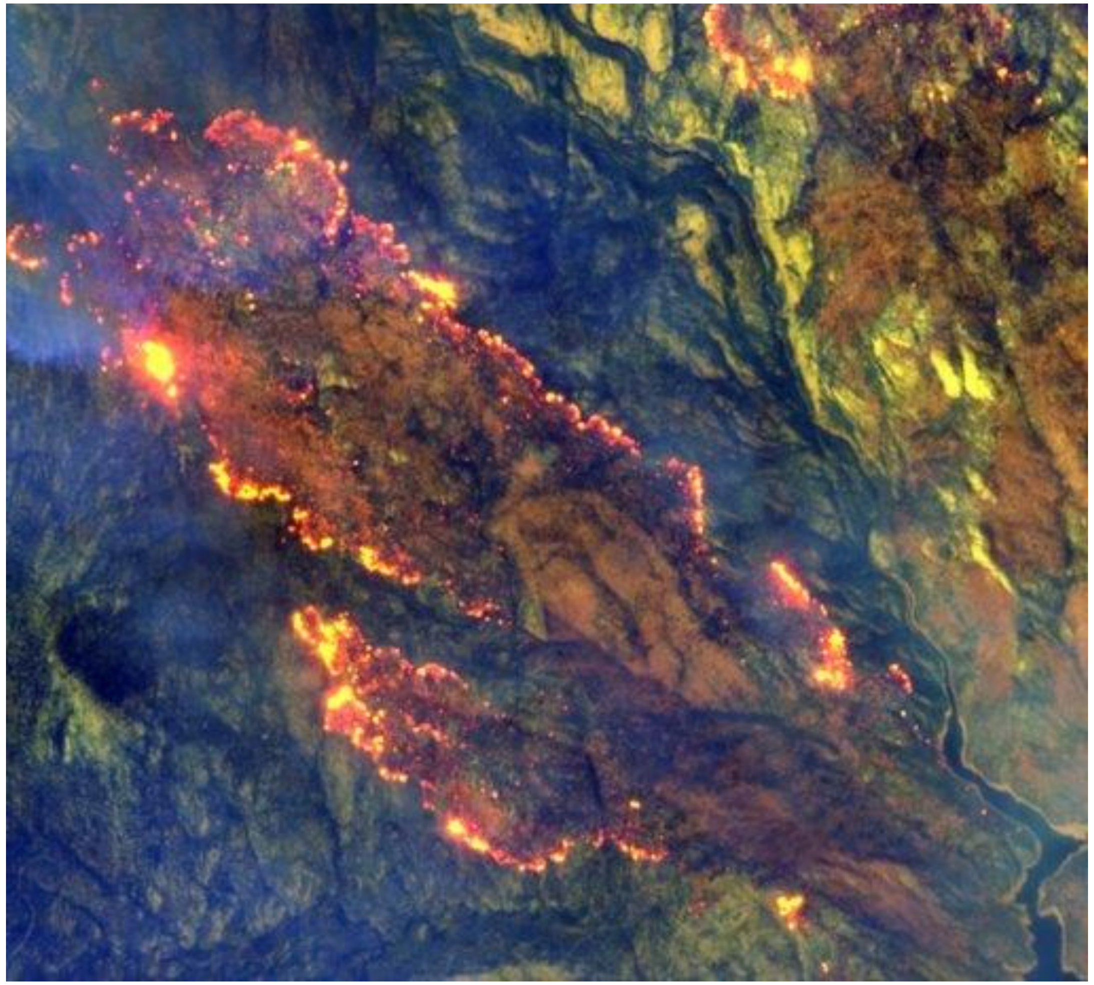
Transmission line sag can be estimated via physical calculations or directly monitored using cameras, laser scanners, and GPS to ensure safe transmission operation.



Line materials, the distance between towers, and the load on the lines can all impact the severity of transmission line sag.

Image credit: Cortland Johnson (PNNL)

Siting and Safety | Transmission Safety and ROW



High-resolution satellite imagery allows research teams to actively monitor events.

Image credit: Andre Coleman (PNNL)

Wildfires not only subject transmission infrastructure to the threat of burning, but also extreme temperatures above 2,000 °F. At such high temperatures, metal warps and loses mechanical strength.

Structural Hardening Measures can improve mechanical stability. Pole wraps of fire-protecting material such as wire or fiberglass mesh are designed to swell when exposed to heat to preserve structural integrity.

DOE’s **Grid Resilience Innovation Partnership** (GRIP) Program provides large-scale investments in grid reliability and resilience in partnership with utilities. Approximately ¼ of the first round of funding was directed toward wildfire mitigation strategies such as fire-resistant poles, covered power lines, undergrounding, sensors and monitoring, and vegetation management.

Siting and Safety | Transmission Line Construction

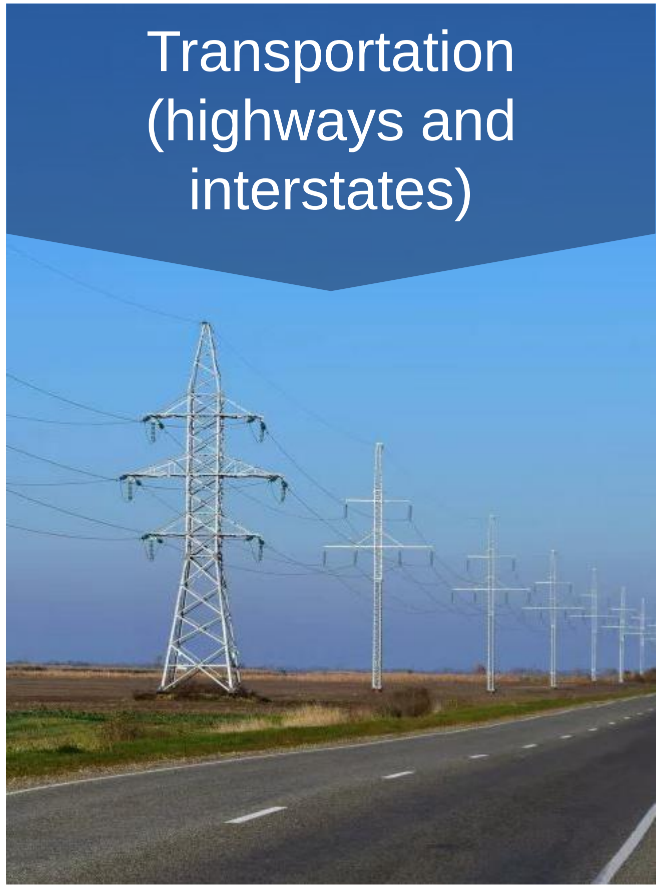
The timing and specifics of the transmission line construction process generally proceed through the following steps.

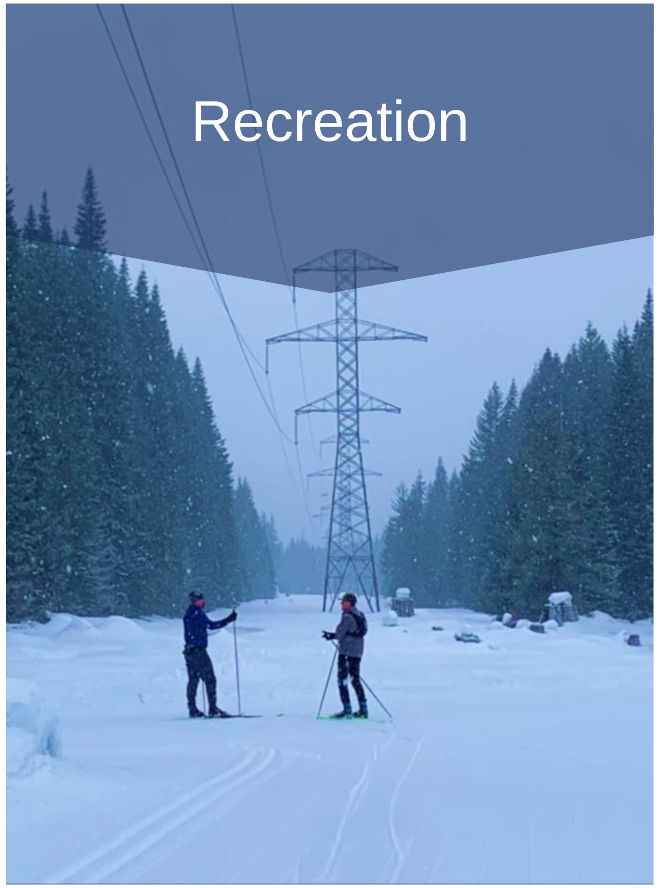
1. **Soil surveys and property staking**—Field surveys conducted to determine mechanical properties of soil. ROW agents request access to the property and coordinate between soil boring contractor and property owner. Final pole locations are determined and staked in the field with tree clearing limits, ROW boundaries, and property features. For example, 345 kV lines typically require 150-ft wide easements.
2. **Construction access and tree clearing**—Construction access routes to ROWs are typically 25–30 ft wide to accommodate the drill rig, concrete trucks, and crane delivery to the site. Tree clearing and vegetation removal occurs, and often matting is put down to prevent compaction of wet or soft soil.
3. **Mobilizing equipment and delivering material**—Including a crane, drill rig, concrete truck, boom trucks, trailers, structures, steel casing, and rebar cages.
4. **Foundation construction**—Can be either drilled pier or direct embed foundations. Drilled pier foundations are 6–9 ft in diameter and 20–40 ft deep. Reinforced steel and anchor bolts are placed in the drilled hole and the concrete is poured. Direct embed foundations are 3–5 ft in diameter and 15–30 ft deep. The pole base is placed in the drilled hole and backfilled with rock, soil, or concrete.
5. **Installing the structure**—Poles are assembled at the foundation site and set in place with cranes or other equipment.
6. **Stringing conductor**—Conductors are pulled from one structure to the next through a pulley system temporarily placed on the structures. Once pulled through, the conductor is attached to the insulators, after which the pulleys are removed. Bird diverters, spacers, and galloping devices are also installed.
7. **Land restoration**—Once completed, the ROW is cleaned and restored. Tile and fences are repaired, rut removal, decompaction, tilling, seeding, and wetland restoration are all possible restoration activities.

Multifunctionality of Transmission Corridors

Building new transmission can be a lengthy process that requires participation from numerous stakeholders, from permitting and approvals boards to local communities. One way to engage communities in the siting of transmission corridors is to communicate the multiple possible uses for those corridors beyond the transmission of electricity.

Opportunities for transmission corridor multifunctionality include:





This list is not meant to be exhaustive. For example, transmission corridors are often sited alongside or adjacent to agricultural land uses.

Image credits: Irena Netik and Rebecca O'Neil (PNNL)

Habitat Conservation & Wildfire Mitigation

The space in a corridor required to maintain safe transmission operations can be managed not just to avoid interaction with vegetation, but to promote habitat conservation and an opportunity to improve the local ecosystem. The following organizations provide guidance, best practices, and accreditation in IVM practices:

- Rights-of-Way as Habitat Working Group
- Wildlife Habitat Council
- Million Pollinator Garden Challenge

Utilities have begun to incorporate principles of environmental stewardship into transmission corridor planning and maintenance, the results of which can have a positive impact on local wildlife, especially for climate-vulnerable pollinators.

- Reduces long-term maintenance costs
- Promotes desirable, stable, and low-growing plant communities
- Reduces wildlife habitat fragmentation
- Promotes geographic diversity
- Promotes wildfire mitigation by controlling brush and other ladder fuels that accelerate fires

Multifunctionality of Transmission Corridors | Recreation

Hiking and bike trails are commonly located under transmission lines.

Transmission corridors can also be co-located with recreation, such as trails or parks. Electric utilities have begun to partner with trail managing agencies, governments, and communities to build safe and accessible multi-use areas by building transmission along existing trails, building trails along transmission corridors, or to develop the two in coordination from the onset.

Regulations can support such combined land use. For example, a Colorado law requires notification for potential trails along powerlines when applying for transmission development and allows contracts with public and private entities for recreational trails.

Image credit: Chris Henderson (PNNL)

Multifunctionality of Transmission Corridors | Wealth-Building

Transmission corridors also represent an economic opportunity for local communities to grow their wealth in cooperation with transmission developers. This is a nascent co-benefit which could take the form of:

- Lease payments
- Direct and indirect ownership
- Other forms of transfers like profit sharing

Expanding opportunities for communities to participate in and receive direct financial benefits from ROWs could play an important role in the acceptance of transmission development and have follow-on effects by promoting economic development for local communities.

Image credit: Southern California Edison

The Morongo Band of Mission Indians were the first Tribal entity to be approved as a participating transmission owner through partnership with the electric utility.

Common Questions about Transmission Infrastructure

What do transmission lines do?

Transmission lines transport electricity across large distances, connecting remote generators and local electric distribution grids. Transporting electricity across such large distances requires the electricity to be stepped up to a very high voltage to reduce losses. For this reason, transmission towers must be larger, creating greater space between the lines and the ground for safety.

Common Questions about Transmission Infrastructure

What do transmission lines sound like?

While transmission lines typically make very little noise, transporting electricity through conducting wire creates an electric field around the transmission line. If this field becomes strong enough and there is sufficient moisture in the air, an electric discharge can ionize the surrounding air, which can sound like a humming or crackling noise.

Common Questions about Transmission Infrastructure

Can you park a car or truck under a transmission line?

The National Electric Safety Code establishes the required clearance height of transmission lines based on the voltage they carry. This height factors in line sagging due to heavy loading, high winds, ice, and high heat. These design considerations ensure the safety of those nearby or beneath transmission lines. However, there is a possibility that the electric field around the transmission lines can induce a voltage on the metal frame of a vehicle if parked on a nonconductive surface like dry rock, especially in humid weather. If this happens, you can receive an electric shock when you touch the vehicle; this is referred to as a nuisance shock, which is comparable in sensation to household static electricity. However, the rubber tires of the vehicle are usually enough to prevent an induced voltage.

Common Questions about Transmission Infrastructure

Can you climb a transmission tower?

First, it is illegal to climb transmission towers in many states. Second, it is highly dangerous, as these towers are designed to separate the high-voltage electricity they transport from you and the surrounding infrastructure. Workers that must climb towers to perform maintenance do so with an abundance of both climbing and electrical training and use appropriate safety gear. In all circumstances, **it is critical to conform with all safety signage posted on transmission towers.**

Common Questions about Transmission Infrastructure

Who owns transmission lines?

Transmission infrastructure is most commonly owned by the electric utilities that deliver electricity within that region. Transmission lines can also be owned by developers who charge load-serving entities to use their lines. A third option, transmission infrastructure can be owned by independent transmission companies that connect more than one utility service territory.

Common Questions about Transmission Infrastructure

How big are transmission towers?

Transmission towers range in height from roughly 50 ft to 200 ft tall. The difference in height depends on the voltage of the electricity being transported and the design of the tower to ensure a minimum safe distance between the wires and the ground.

Glossary

Adequacy: the ability of the electric system to supply the electrical demand and energy requirements of customers, at all times, taking into account both scheduled and unscheduled outages of power lines and plants.

Alternating Current (AC): electric current with frequency that varies, or alternates, between high and low frequencies as time passes. The U.S. electric grid operates primarily using AC current as its voltage can be changed by passing through electric transformers.

Cage: the area of the transmission tower that is located in between the peak and the tower body. The cage of the transmission tower holds the cross arms.

Circuit: a complete path for electric current to flow. A circuit contains a current source, conductors, and a load.

Conductor: the current-carrying wires that transfer, or conduct, the flow of electricity.

Cross arm: hold the transmission conductor and are located on the cage. The size of the cross arms varies based on several factors, such as the transmission voltage and the configuration of the tower.

Direct Current (DC): electric current with frequency that remains constant in time.

Distribution: the portion of an electric grid that delivers electric energy from the substation to the customer.

Easement: a legal agreement that outlines the agreement between a utility and a landowner in which the utility acquires the rights to utilize the owner’s land to build and maintain a transmission line.

Electrification: the process of converting or replacing systems that rely on non-electric fuel sources, such as natural gas or fuel oil, to electrically powered systems.

Glossary

Electric Demand/Load: the rate of electricity consumption. Electric demand tends to refer more generally to electric consumption, whereas electric load is often specific to one device. The terms are often used interchangeably.

Energy: the amount of electricity being measured, in watt-hours (Wh). Utility bills typically report energy consumption in kWh, or kilowatt hours, which are 1000 Wh.

Flexibility: allows power requirements to be met by a diverse set of generation sources, located most appropriately based on generator requirements.

Frequency: the rate of change of alternating current, measured in Hertz (Hz), which is $^1/_s$. The frequency at which the U.S. electric grid transmits electricity is 60 Hz, standardized to protect electrical equipment throughout the grid.

Generation: the conversion of energy into electricity. Different generators convert different types of energy, such as turbines that can convert kinetic energy (motion) into electricity by rotating a magnet surrounded by copper coils to induce an electric current, or photovoltaic generators (photovoltaic panels), that convert the energy from photons of light striking solar cells into electricity by way of the photovoltaic effect.

Insulator: devices made of poorly conducting, or electrically insulating material that connect transmission conductors to transmission towers to keep the electric current passing through the conductors from discharging through the tower.

Integrated Vegetation Management (IVM): a strategy for managing the vegetation surrounding transmission infrastructure that integrates both safety and reliability goals with habitat preservation, wildfire mitigation, and environmental stewardship.

Interconnection: the legal agreement governing the physical connection of a generation resource to the electric grid. An interconnection agreement is required before energizing a system capable of exporting electricity onto the grid and details the system requirements and export limits of the connecting resource.

Peak: the area of the tower located above the top cross arm. The ground wire that protects the tower from lightning strikes is connected to the peak.

Glossary

Pin-type insulator: has a pin that is secured to the cross arm of the tower. A soft metal thimble separates the porcelain (insulating material) and the hard metal pin so there isn’t any direct contact. Generally used for voltages up to 33 kV.

Post-type insulator: similar to a pin type insulator but has a metal base and a metal cap to allow for more than one unit to be mounted in series. The insulating material is shaped in the form of cones that fit inside one another. Used for supporting bus bars and disconnecting switches in the substations.

Power: a measure of the change in energy over time, in watts (W). Large generators or collections of generators might measure their power output in megawatts (MW) or gigawatts (GW), which are 10^6 W and 10^9 W, respectively.

Reliability: the ability to withstand grid disturbances such as instability, uncontrolled or unscheduled events, cascading failures, or loss of system components. Transmission connects users to a diverse set of power plants, with a certain degree of built-in redundancy to ensure uninterrupted electricity service.

Right-of-way: a type of easement granted to a utility or transmission owner that grants the right to use and access the land directly below a transmission line according to the terms of the easement.

Sag: high current load, temperatures, or wind can cause transmission lines to droop down lower than they would under “normal” operating conditions. Transmission lines are designed to sag to accommodate such circumstances while still remaining a safe distance from nearby vegetation or structures.

Security: the ability of the electric grid to withstand sudden disturbances, such as electric short circuits or unanticipated loss of system facilities.

Substation: substations connect the transmission system to the distribution system and contain a series of transformers and electrical protection equipment designed to step down the high-voltage electricity delivered by the transmission system to safer, lower voltages to be distributed to end use customers.

Glossary

Suspension-type insulator: used for lines above 33 kV due to how expensive pin insulators are at higher voltages. Has a disc-shaped insulating material with a metal cap on top and a metal pin on the bottom. Also known as disc or string insulators.

Tower Body: this includes the section of the tower that starts at ground level and goes up to the bottom cross arms. The size of the tower body plays a key role in ensuring the transmission tower has the required ground clearance for the conductors.

Transformer: an electric device that allows the voltage of alternating current to be stepped up or down to higher or lower voltages. Stepping up to higher voltages allows transmission of electricity over greater distances with reduced electrical losses. Stepping down to lower voltages allows safe distribution of electricity to customers.

Transmission: an interconnected group of lines and associated equipment for the movement or transfer of electric energy between points of supply and points at which it is transformed for delivery to customers or is delivered to other electric grids.

Transmission Corridor: strips of land designated for certain uses, such as by telecommunication, electric, and gas utilities, or for transportation highways and railways.

Voltage: the force that pushes electric current through a conductor, measured in volts. High-voltage transmission lines tend to be on the order of kV, or 1000s of volts.

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