MSCE in Energy Infrastructure

Brief on Electricity Infrastructure

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Introduction

From the EIA:
"The origin of the electricity that consumers purchase varies. Some electric utilities generate all the electricity they sell using just the power plants they own. Other utilities purchase electricity from other utilities, power marketers, and independent power producers or from a wholesale market organized by a regional transmission reliability organization."

"The retail structure of the electricity industry varies from region to region. The company selling you power may be:"

- A not-for-profit municipal electric utility such as Seattle City Light,
- An electric cooperative owned by its members (public utility districts can fall into this category),
- A private, for-profit electric utility owned by stockholders (often called an investor-owned utility) such as Puget Sound Energy.

"In some states, electric utility customers can purchase electricity through a power marketer, and the electricity is delivered by a local distribution utility. A few federally owned power authorities—including the Bonneville Power Administration and the Tennessee Valley Authority, among others—also generate, buy, sell, and distribute power. Local electric utilities operate the distribution system that connects consumers with the grid regardless of the source of the electricity."

"Power plants generate the electricity that is delivered to customers through transmission and distribution power lines …. higher voltage electricity is more efficient and less expensive for long-distance electricity transmission. Lower voltage electricity is safer for use in homes and businesses. Transformers at substations increase (step up) or reduce (step down) voltages to adjust to the different stages of the journey from the power plant on long-distance transmission lines to distribution lines that carry electricity to homes and businesses."

"At the beginning of the 20th century, more than 4,000 electric utilities operated in isolation from each other. As the demand for electricity grew, especially after World War II, utilities began to connect their transmission systems. These connections allowed utilities to share the economic benefits of building large and often jointly owned power plants to serve their combined electricity demand at the lowest possible cost. Interconnection also reduced the amount of extra generating capacity that each utility had to hold to ensure reliable service during times of high and peak demand."

Electricity generation is typically reported as kilowatt hours (kWh) or megawatt hours (MWh). The US has a generation capacity of about 1.1 million MW and 4.1 billion MWh annually. A wide range of components make the electricity system function so that the generation can accommodate load…and slightly exceed it.

We will briefly examine a broad view of electricity infrastructure by (1) components associated with the overall electrical system, (2) the type and extent of generation, and (3) transmission + pipeline resources.

Components of Electricity Infrastructure

There are thousands of components that constitute electricity infrastructure ranging from small to massive. This includes the electricity grid which is overviewed in another **Brief** titled **"The Grid**." These components or elements can include:

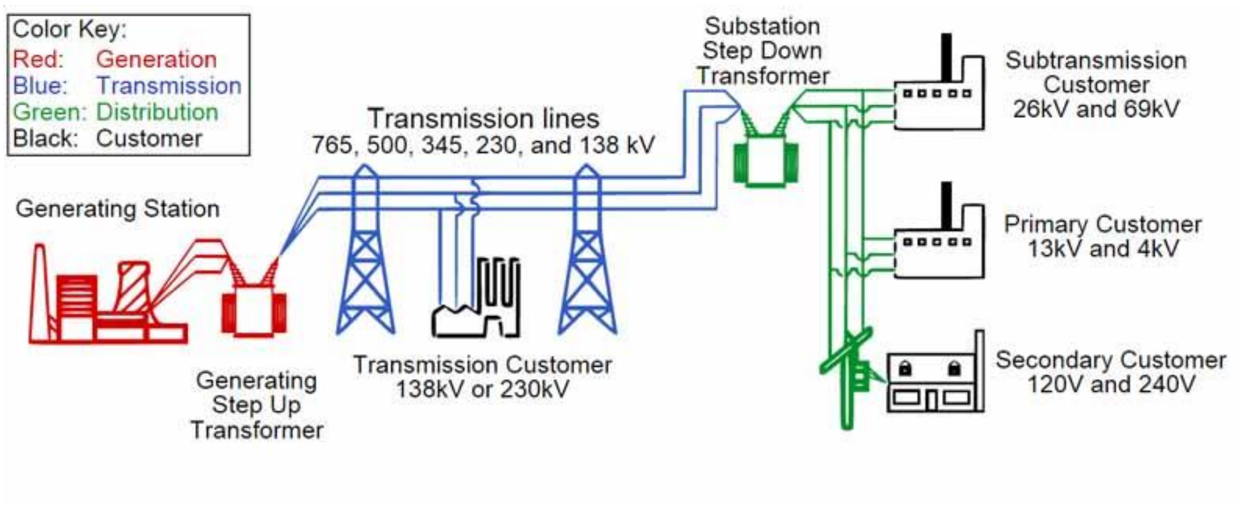
- Power plants ranging from coal-fired to geothermal.
- Transmission and distribution and their components such as:
    - Substations
    - Conductor cabling
    - Transformers
    - Circuit breakers
    - And far more….

Although the variety of infrastructure can include access roads (such as for wind or solar farms), buildings, mining, and far more. These are often referred to as 'balance of plant" … namely the infrastructure which is not directly involved in electricity generation.

Next, we will examine, briefly, an example of an electricity generation to end user pathway. This will involve a small hydroelectric project followed by a broader view of the complete electrical delivery system.

A limited but visual example of electricity infrastructure is shown via a small hydroelectric generator (8 kW) in the Pacific Northwest (one generator is shown although there are multiple generators associated with the hydroelectric project). It starts with a dam creating a reservoir with water from the reservoir driving a turbine which runs the generator then to transformers and a high voltage transmission line then a substation to reduce voltage for the distribution system which provides direct service to customers. This is only one type of linked electricity infrastructure.

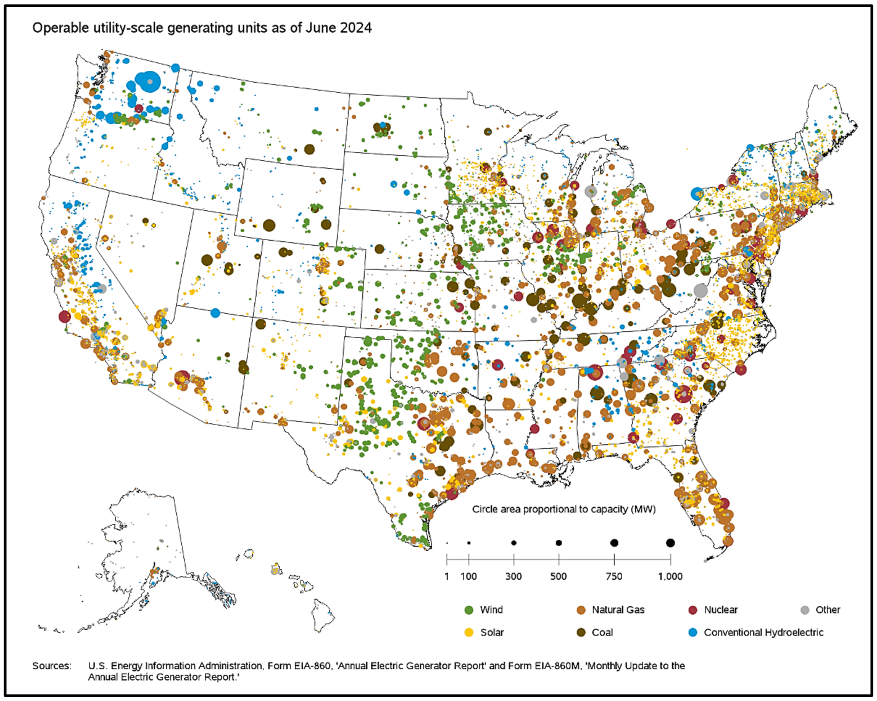
Another way of viewing electrical infrastructure is a line drawing as shown below.



From left to right, the drawing illustrates the generation source (earlier that was the hydroelectric turbine/generation combination) as red. The transformer steps up the voltage for transmission (blue). The step-down transformer reduces the voltage to different levels for different customers vis the distribution systems (green).

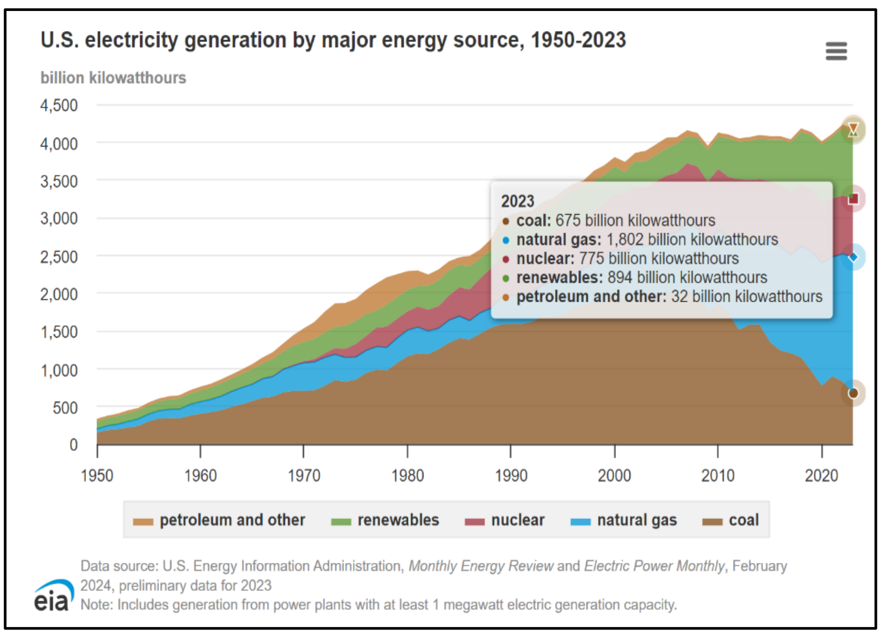
Generation

Electricity generation requires power plants, and the EIA figure below helps to visualize the location and extent of these plants [EIA-860M, June 2024]. Most power plants are categorized by fuel type and the six primary ones are: (1) natural gas, (2) nuclear, (3) coal-fired, (4) wind, (5) solar, and (6) hydroelectric; although, geothermal energy, which is now only 0.4% of US electrical capacity, is expected to grow over the next several years. The number and distribution of these plants are illustrated in the following figure which are based on generation capacities (MW).



The types of plants range from hydroelectric (most of which are in the Western US) to wind and solar. The one type of plant slowly decreasing in number are coal-fired plants. The green dots are wind projects which are concentrated mostly in the Mid-Western states and Texas.

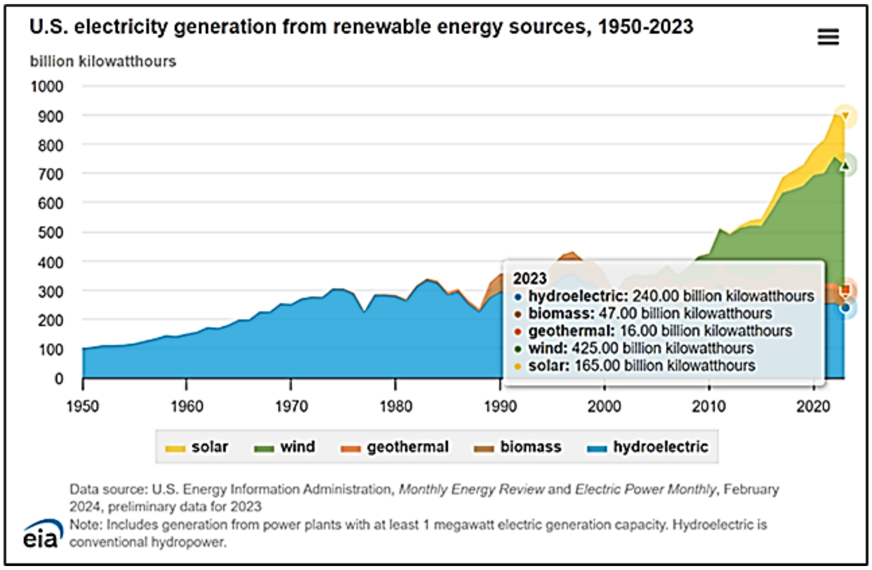
The figure also shows generation capacity in MW. The smallest are less than 1 MW (1,000 kW) and the largest over 1,000 MW (1,000,000 kW).



Next, electrical generation sorted by energy source ("fuel") is shown below in terms of billions of kW per year.

For 2023, the generation is shown for coal, natural gas, nuclear, renewables (solar, wind, hydroelectric) and petroleum. The data only includes plants with a capacity ≥ 1 MW.

Two major trends are noted: (1) coal-fired plants and associated generation have undergone a major decline, and (2) renewable and natural gas generation has significantly increased. Capacity factors, not directly shown, are important since fossil fuel plants generally have high-capacity factors (> 80%) and are described as providing **base load**. Renewable generation capacity factors range between 25% to 50% and are **intermittent**. Thus, energy storage becomes more important for renewables.



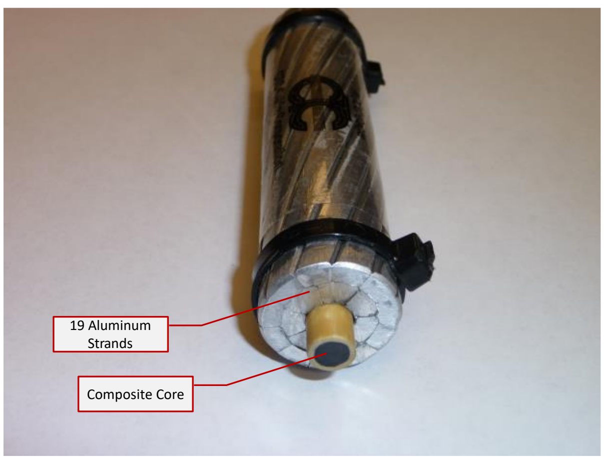
The data in this figure focuses on renewable generation…namely solar, wind, geothermal, biomass, and hydroelectric.

Renewables represent about 22% of US generation and coal-fired plants have decreased to 16%. Wind is the single largest renewable at 10% of US generation. Renewable energy plants are the most rapidly growing source of electricity plants.

All generation from renewable sources, except for geothermal, have modest to low-capacity factors…which can be enhanced with energy storage systems.

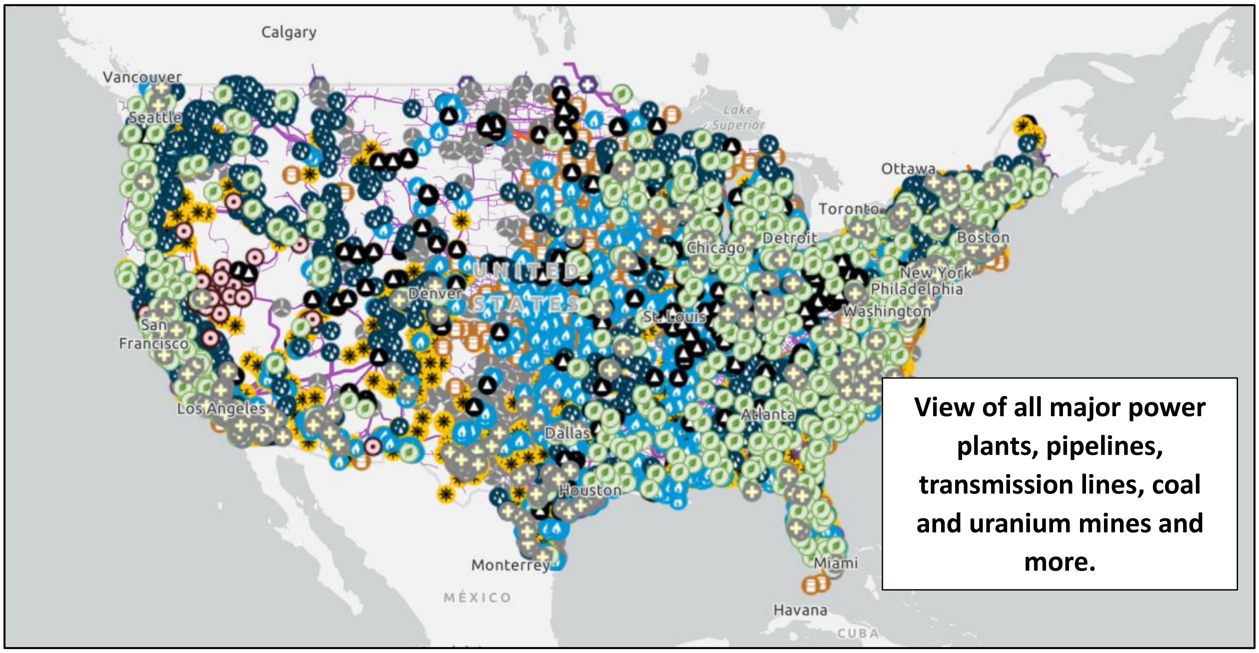
Transmission

Transmission is the backbone of electricity infrastructure. Conductors for transmission lines are typically aluminum wrapped around a steel or composite core to support the line between towers. The aluminum is high purity (> 99%) which maximizes the ability to conduct electricity.

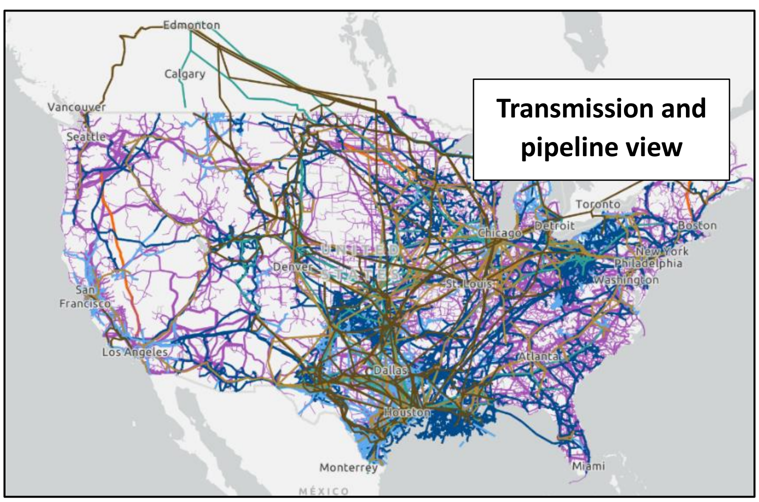


To provide further insight into transmission, we will examine an important resource, the "US Energy Atlas." The figure below is a busy graphic showing the major energy infrastructure in the US. The Atlas is granular in viewing transmission lines and includes categories for:

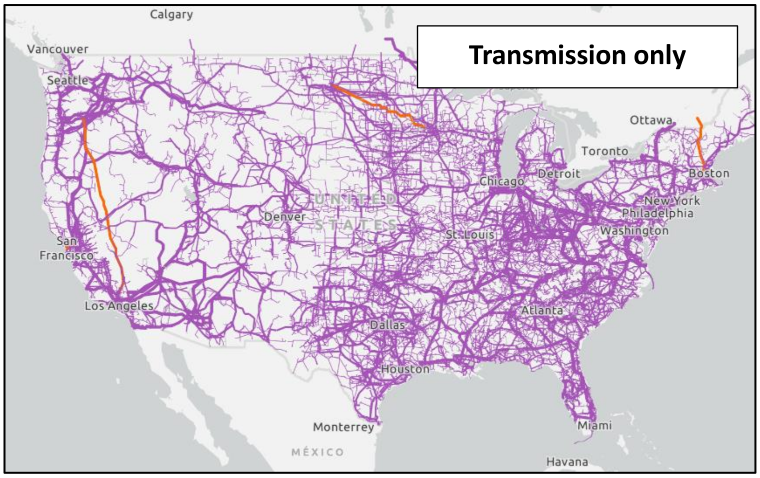
- Alternating Current
  - < 100 kV
  - 100 to 161 kV
  - 220 to 287 kV
  - 345 kV
  - ≥ 735 kV
- Direct Current



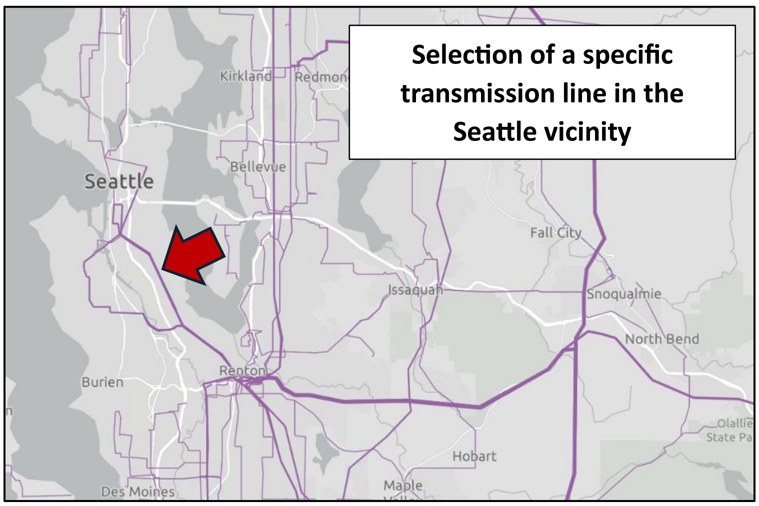
The next figure is an overview of US major transmission and pipelines. We will examine a subset of this data—transmission lines.



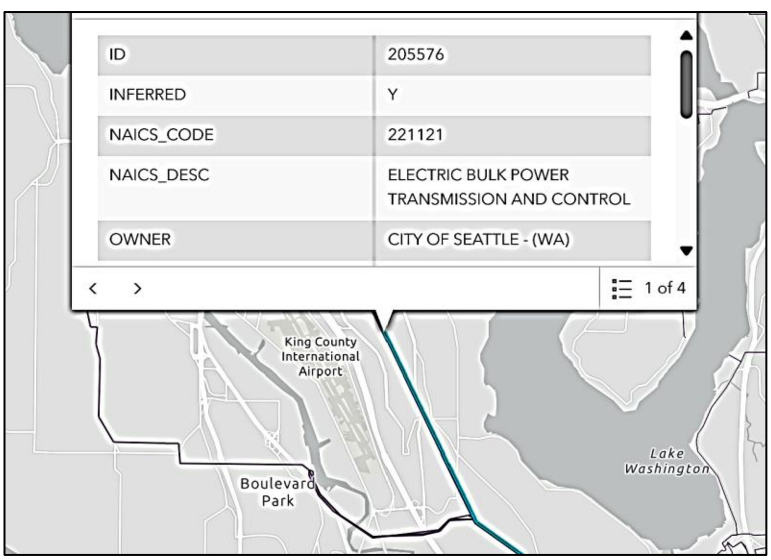
The significance of the EIA database is that you can focus on a specific location. The purple lines are transmission lines and the blue and brown lines pipelines. In the following examples, we will select the Seattle area for additional detail.



This view from the Atlas excludes all other data except transmission lines.

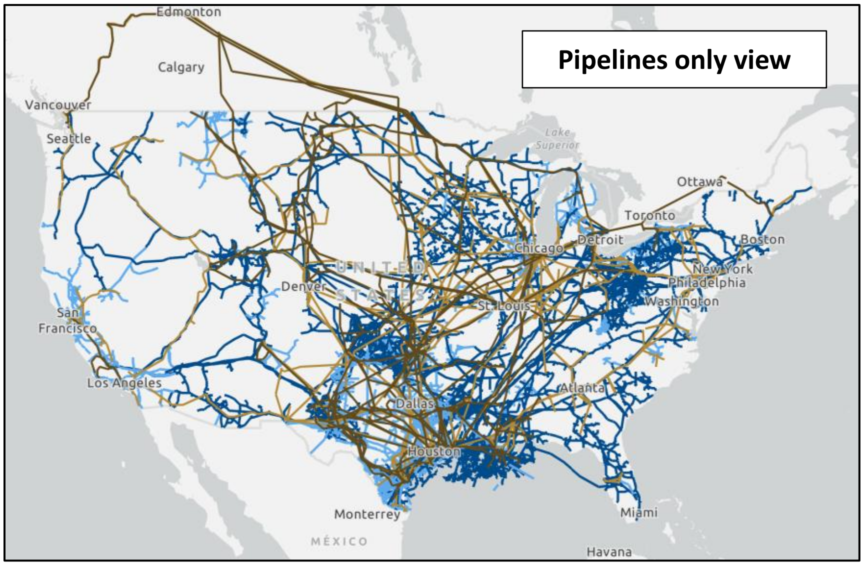


Pick a transmission line of interest and click to open relevant information. The arrow shows a line we chose to examine.

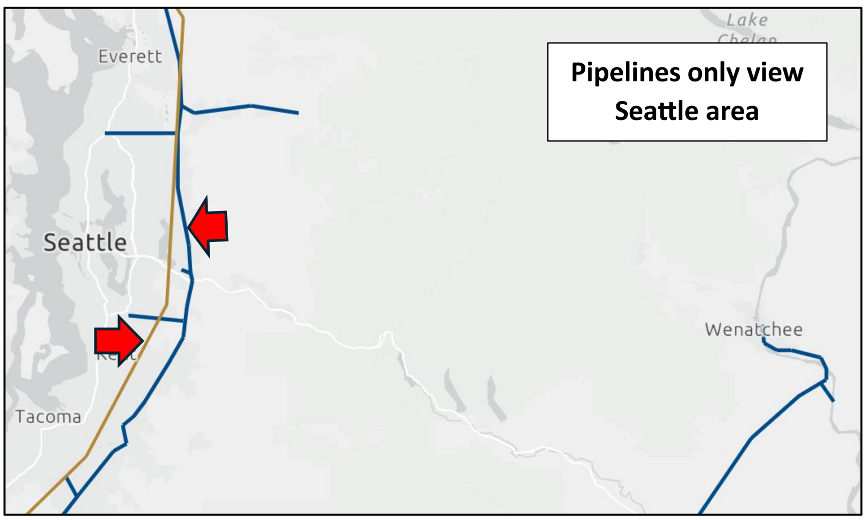


Clicking on the line reveals some of the following:

- Owner: City of Seattle
- Classification: Electric Bulk Power Transmission
- The substations where the line starts and ends
- Type: AC, overhead
- Voltage: 230 kV (which is a major transmission line for SCL)



This view from the Atlas excludes all other data except major energy pipelines.



Zooming in on the Seattle area again, we see two major pipelines. After clicking each of the two choices, the **brown colored line** is a **Petroleum Product** Pipeline owned by Enbridge. The **blue line** is a **Natural Gas Interstate** pipeline owned by Northwest Pipeline.

Summary

This limited introduction illustrated basic terms and a few stats on electrical generation including renewable energy. The focus was on the helpful EIA **US Energy Atlas**.

Useful Websites

- EIA, "Electricity Explained," https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php
- EIA, "US Energy Atlas," https://atlas.eia.gov/
- UW MSCE Energy Infrastructure, https://www.energy-infrastructure.uw.edu/