e·lec·tric·i·ty

ilek'trisitē

Kyle Bradbury
Duke University Energy Initiative

What is electricity?

How do we generate it?

How do we “transport” it?

How do we consume it?

power system facts of life

- Supply and demand must be continuously balanced
- Electrons take the path of least resistance, which is not always the path of greatest convenience
- Forecast demand does not match real demand
- System reliability must be enforced

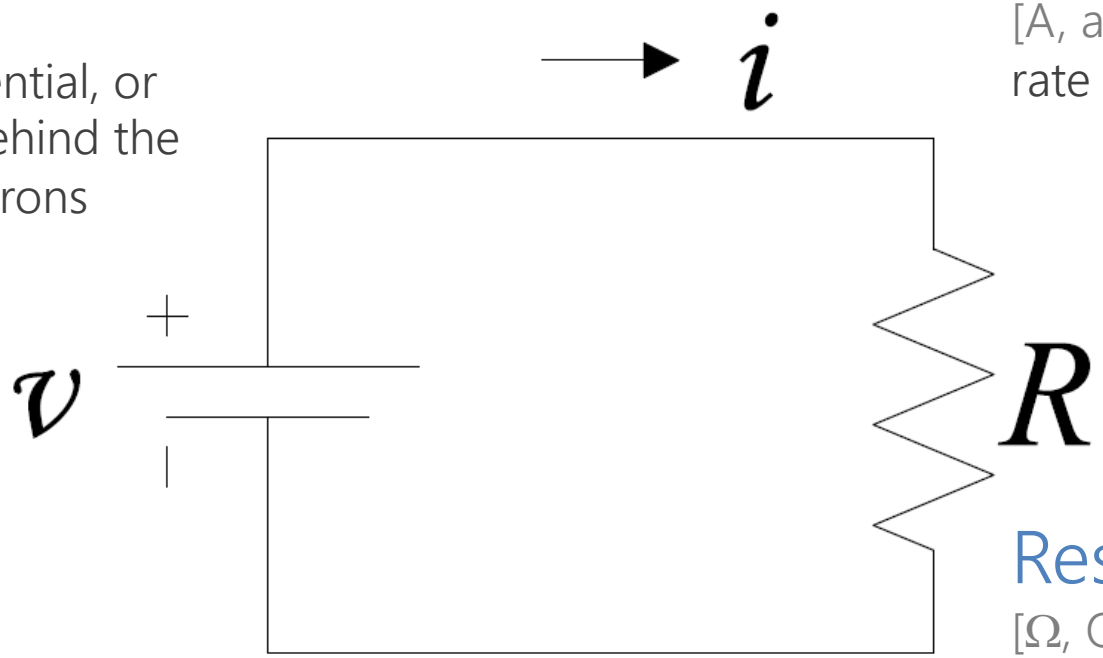
power and energy

Power	Energy
Watt (W)	Watt-hour (Wh)
A 100-W light bulb "on" for 3 hours	
100W	300Wh

important electricity concepts

Voltage
[V, volts]
electric potential, or "pressure"behind the flow of electrons

Current
[A, amperes]
rate of flow of electrons



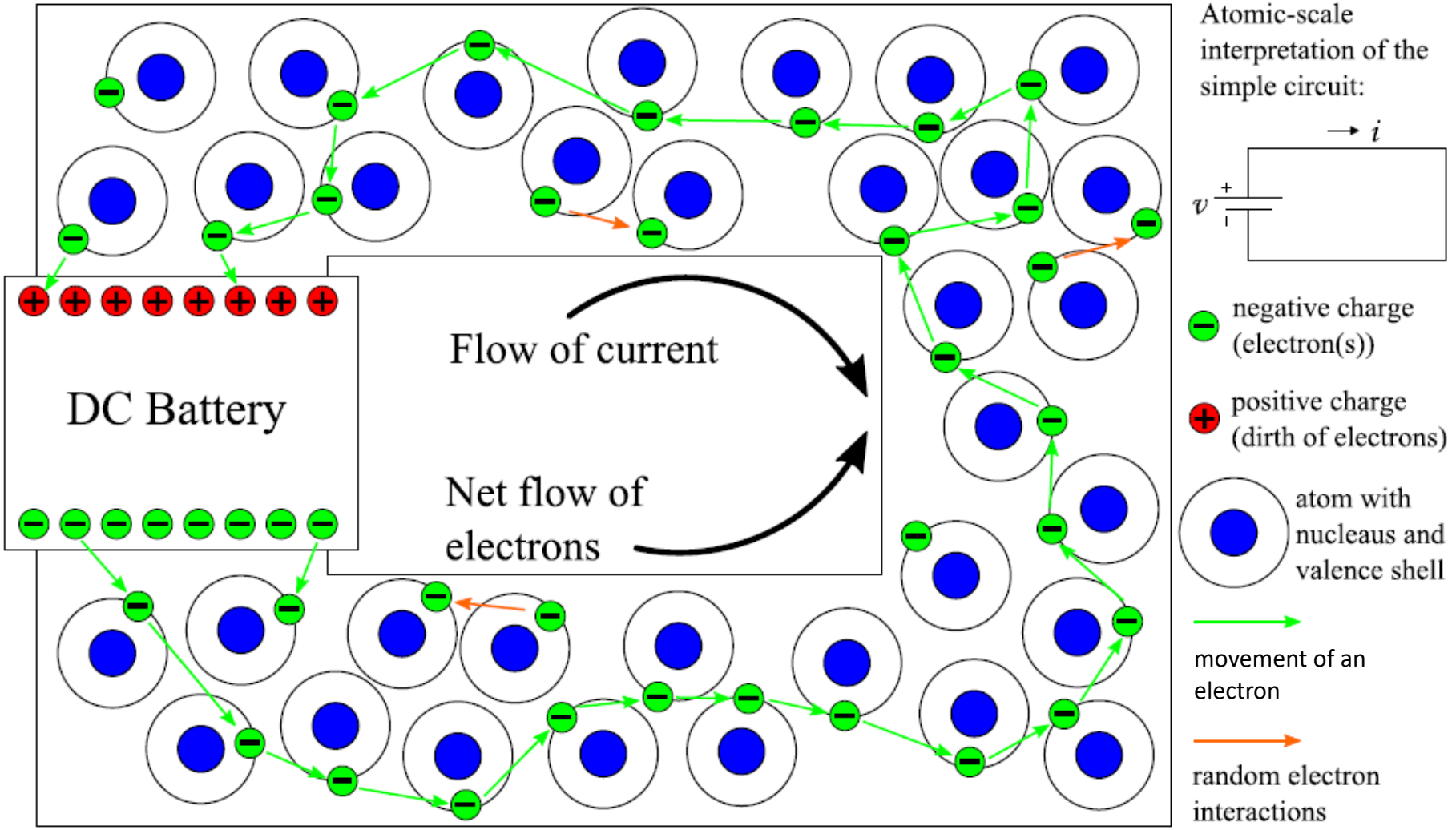
Resistance
[Ω, Ohms]

Proper use of terminology:
Voltage across…
Voltage with respect to…
Current through…

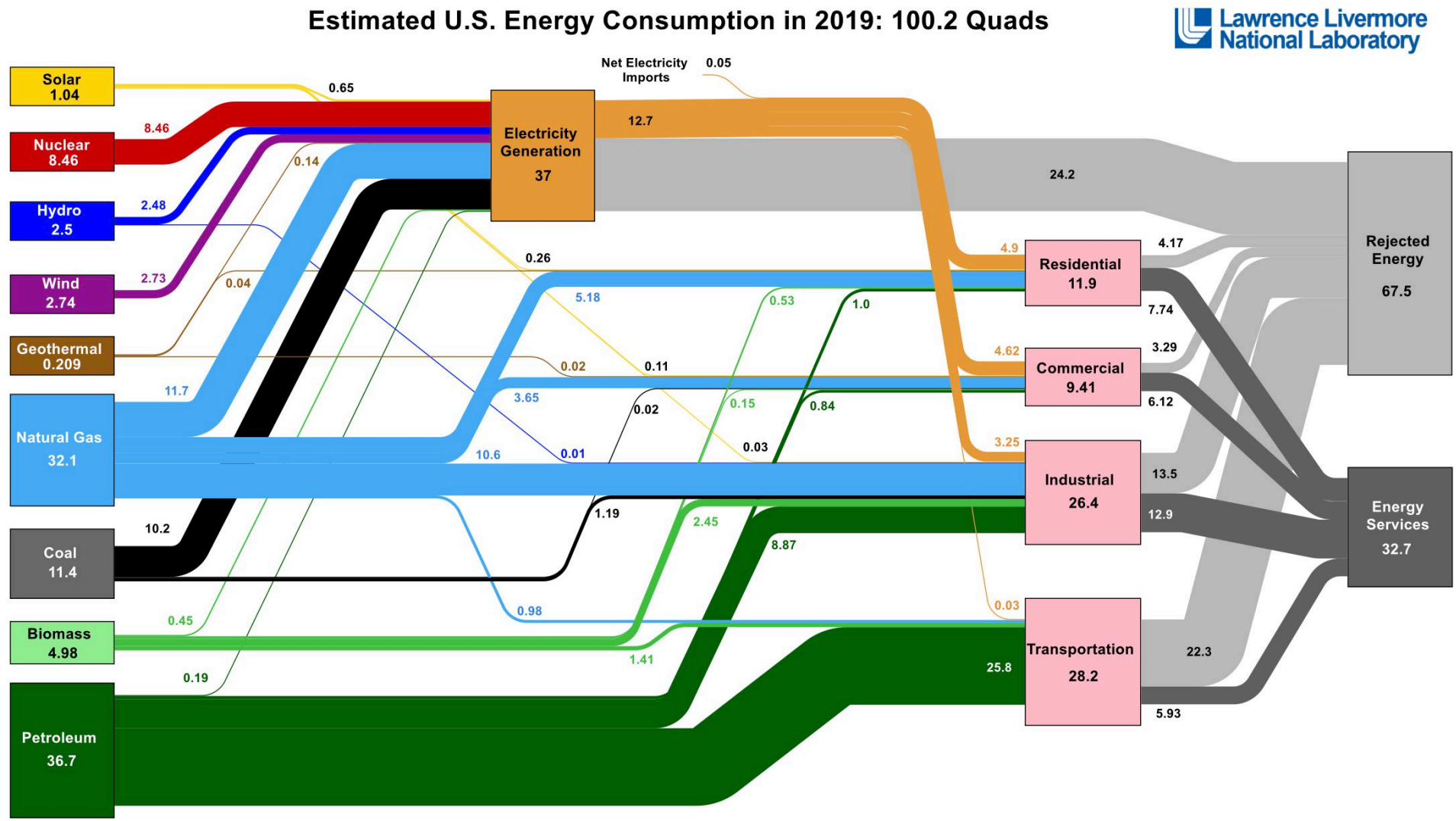
Ohm's Law: $V = IR$

Power [Watts]: $P = VI$

electron "flow"



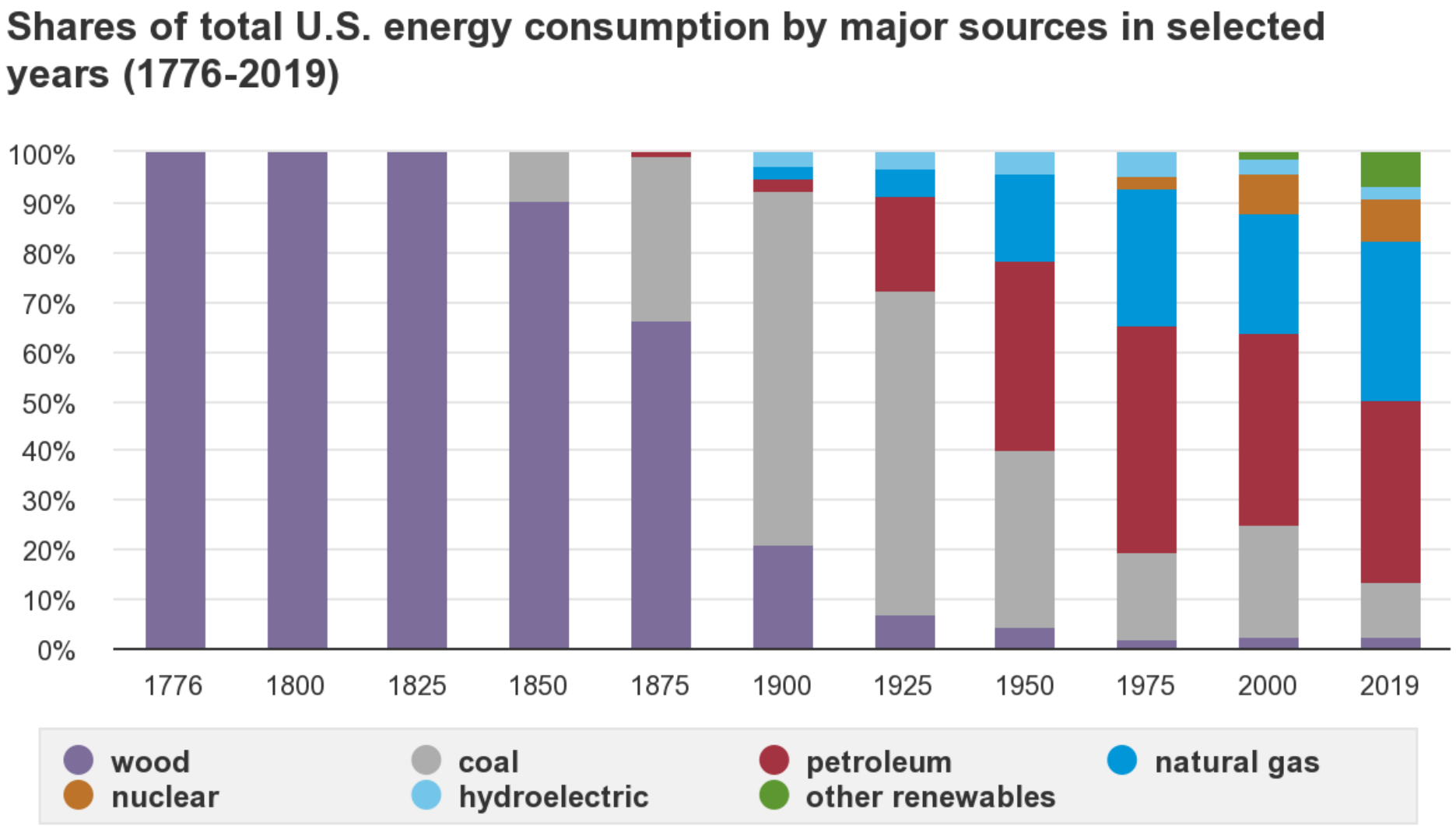
the famous Sankey diagram



[US Energy History Visualization]

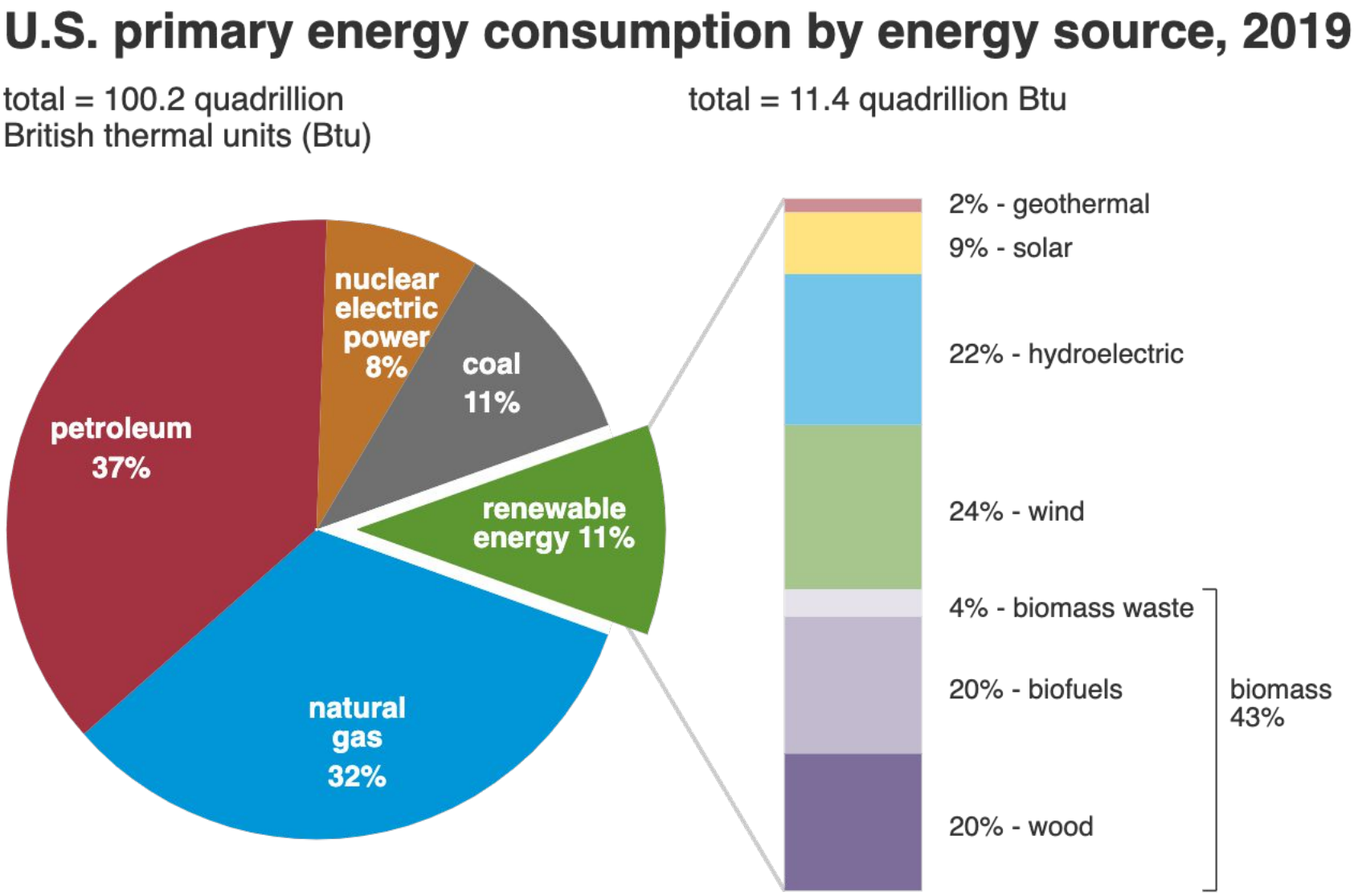
image from: https://flowcharts.llnl.gov/

energy generation in the U.S. over time

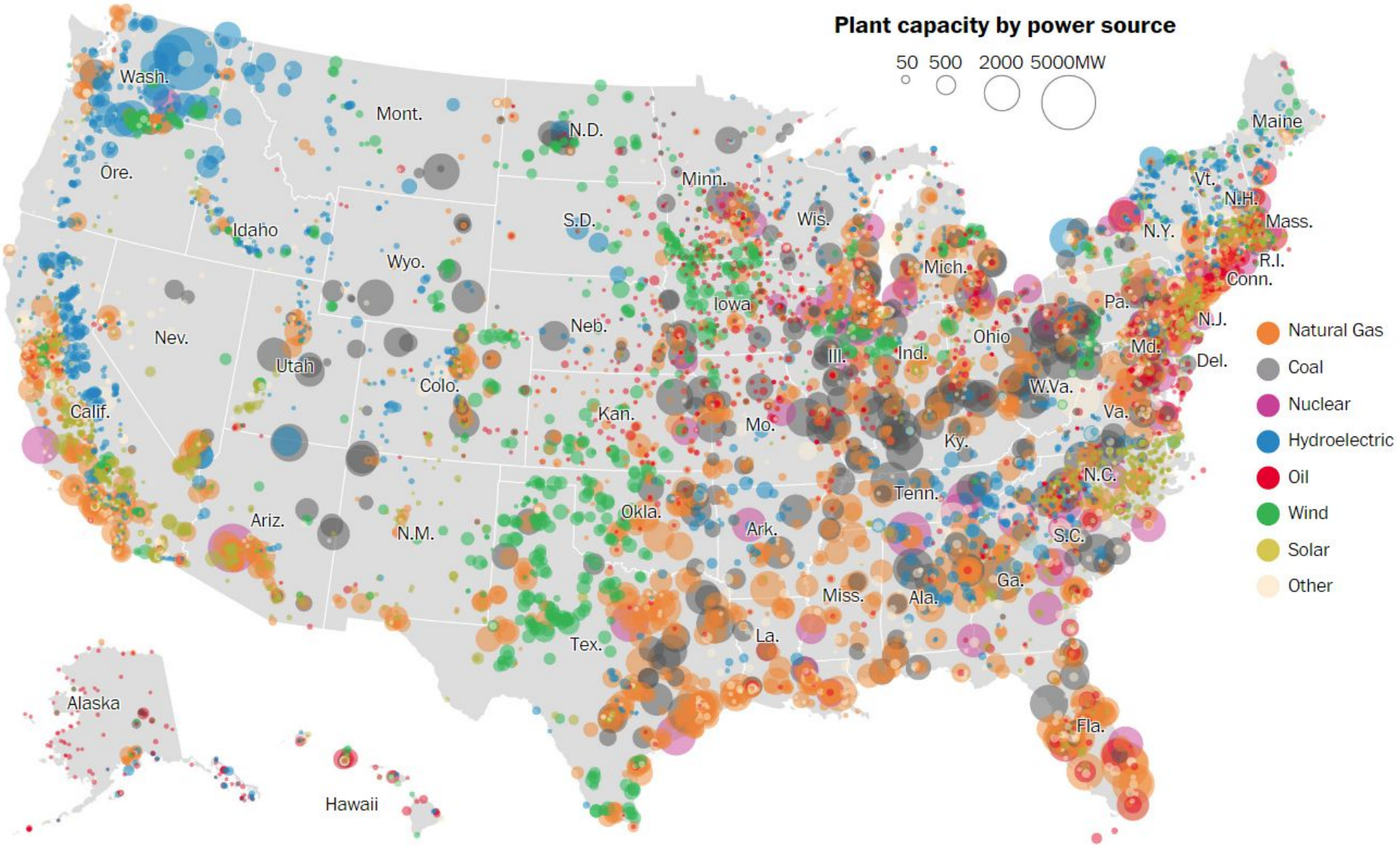


Note: Wood includes wood and wood waste; other renewables includes biofuels, geothermal, solar, and wind.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Appendix D.1, and Tables 1.1 and 10.1, April 2020, preliminary data for 2019

U.S. energy consumption in 2019



Note: Sum of components may not equal 100% because of independent rounding.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2020, preliminary data



[Interactive map of the U.S.]

[Map of the World]

Image Source: Washington Post

electric power systems

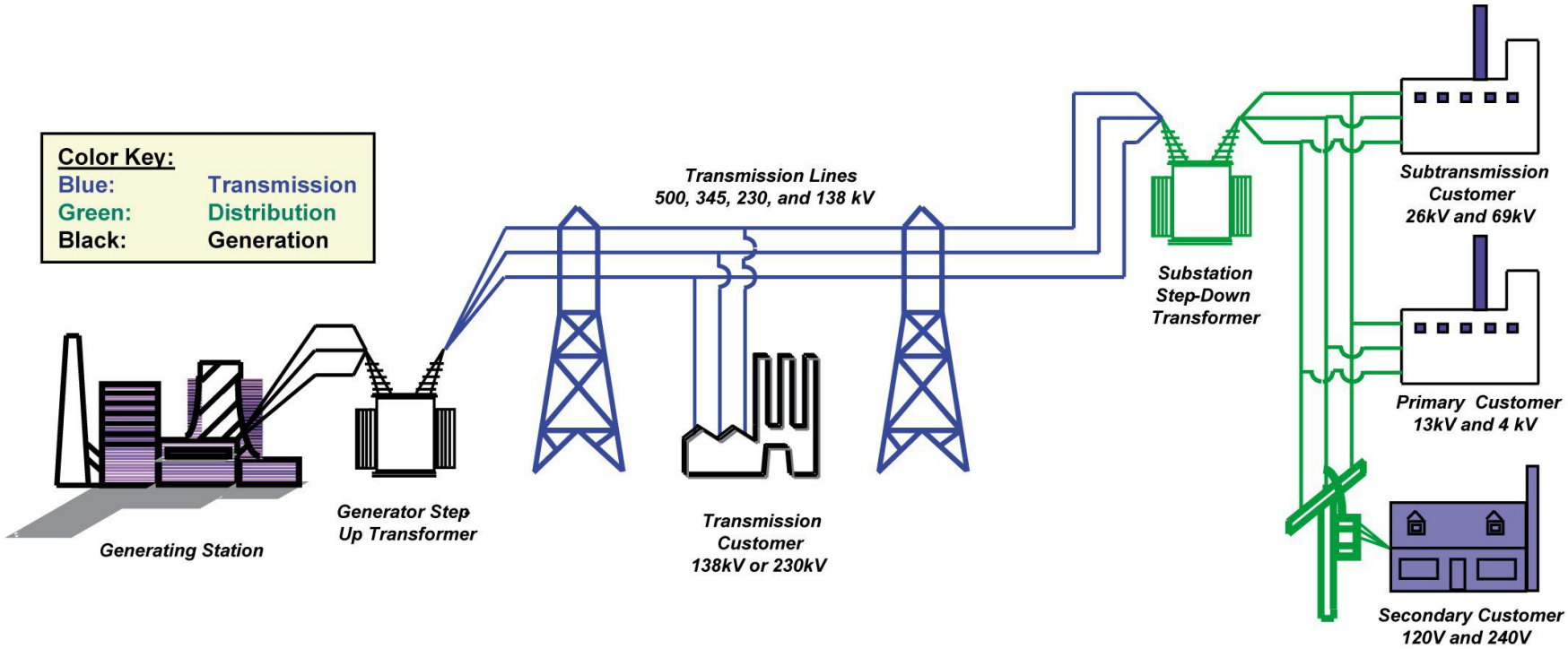


image from http://www2.econ.iastate.edu/

electric power systems

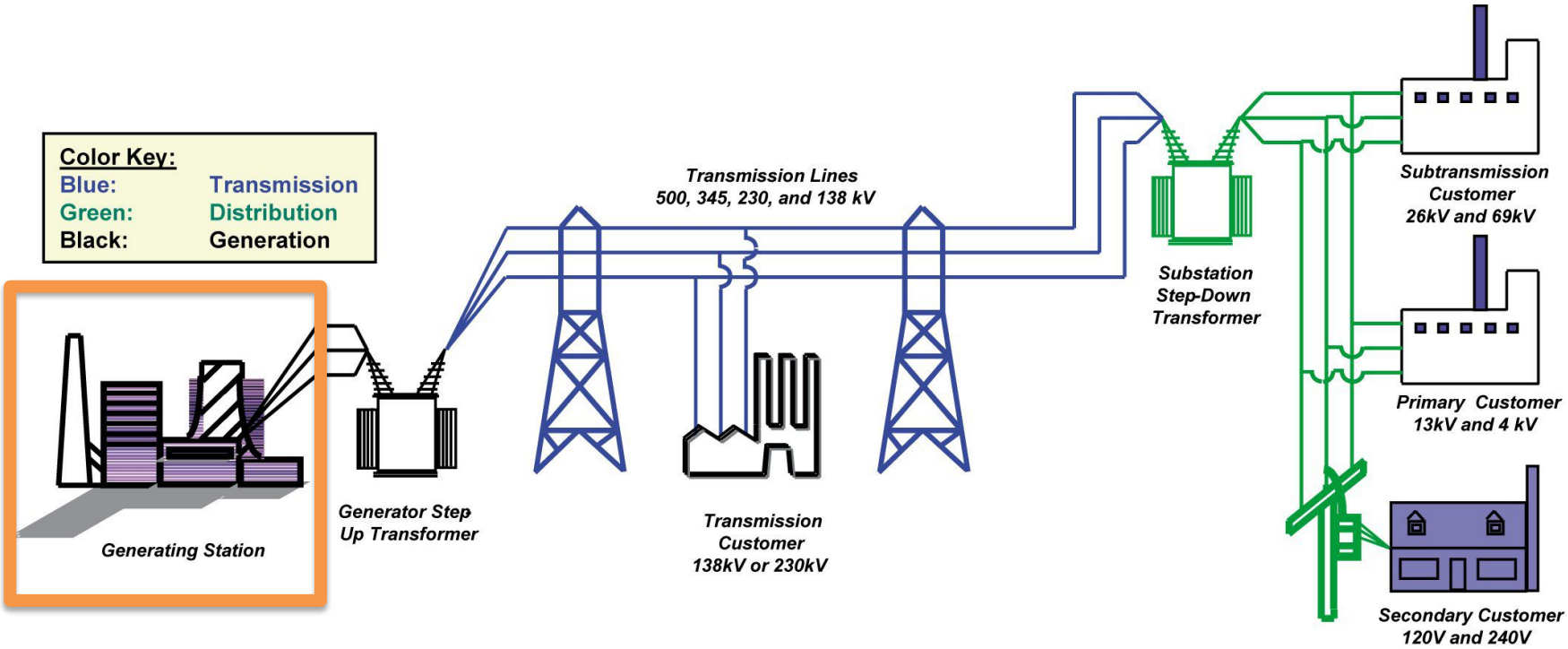


image from http://www2.econ.iastate.edu/

thermal power station

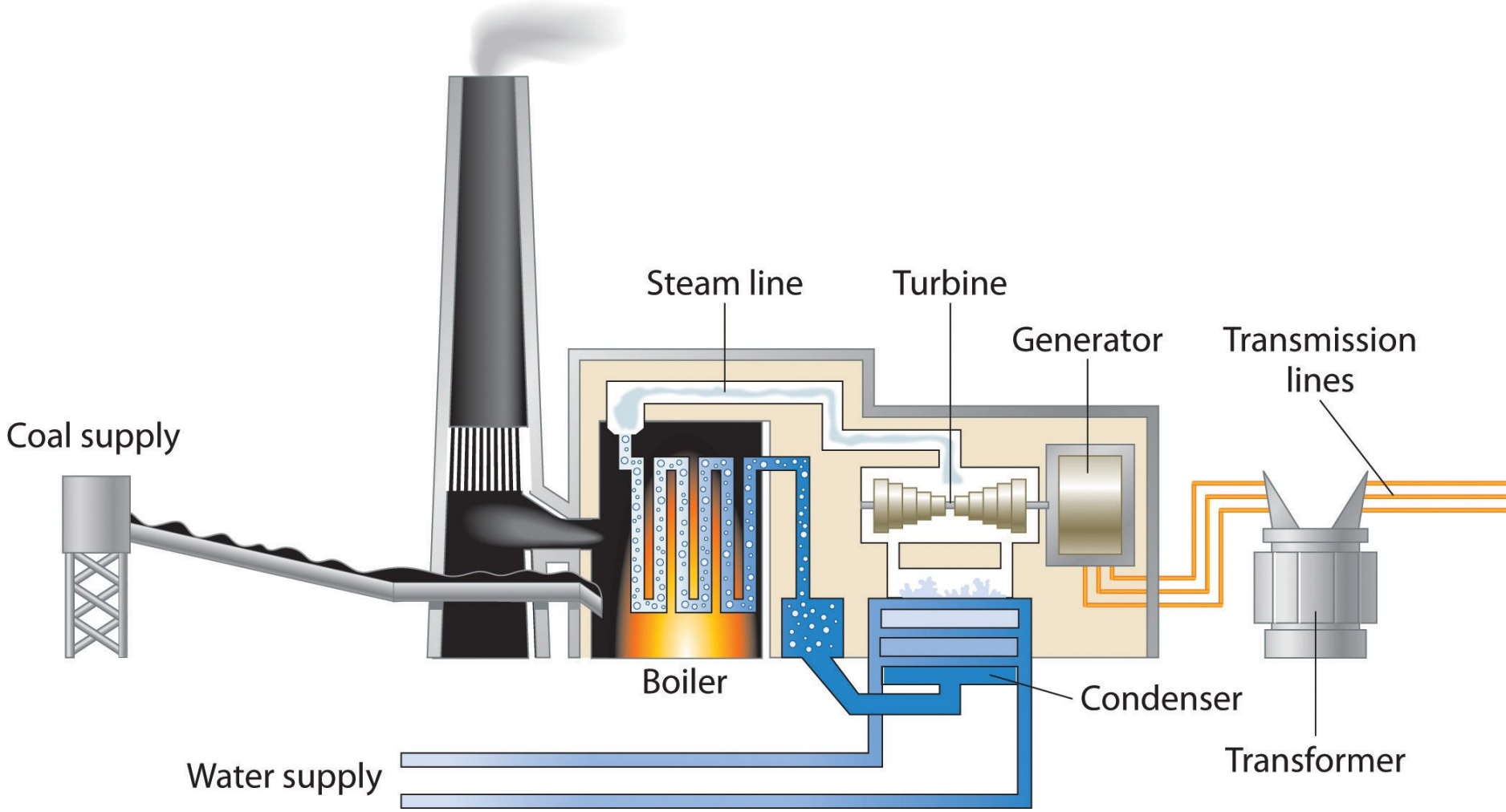


Image from General Chemistry: Principles, Patterns, and Applications, v. 1.0 (2 Volume Set) by Bruce Averill and Patricia Eldredge

Turbine Deck at Diablo Canyon Power Station

1,100 MW Generator

image from: http://depletedcranium.com

turbines

Low Pressure Turbine

High Pressure Turbine

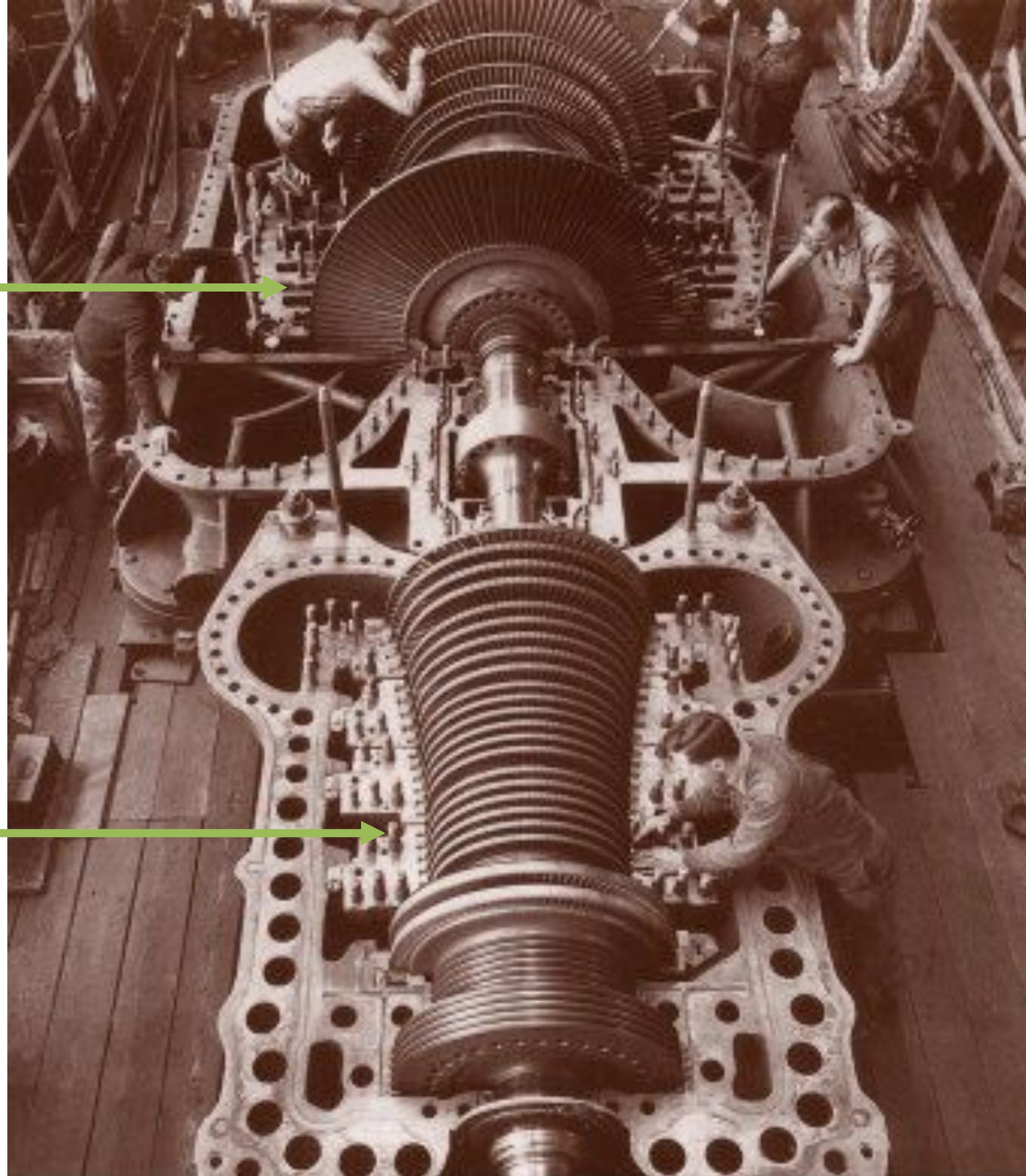


Photo from http://www.allposters.com

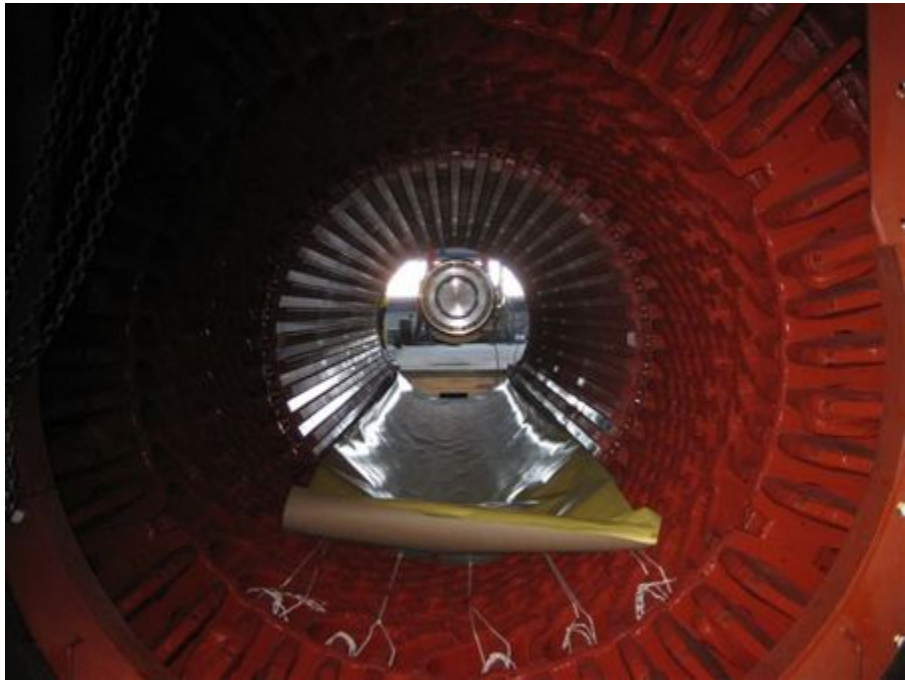
low pressure turbine

Image: "Turbine Philippsburg-1" by Christine und David Schmitt from Vienna, Austria, Austria - Flickr photo page "Dampfturbine"

generator

ROTOR

this is the "magnet" that spins (*weighs 61 tons*)



STATOR

stationary component that contains wound wire for the power to flow through

Images from http://basinelectric.wordpress.com/2009/08/14/generator-coming-together-at-dry-fork-station/

this is a synchronous machine

spins at 3600 rpm, 60 cycles per second (Hz)

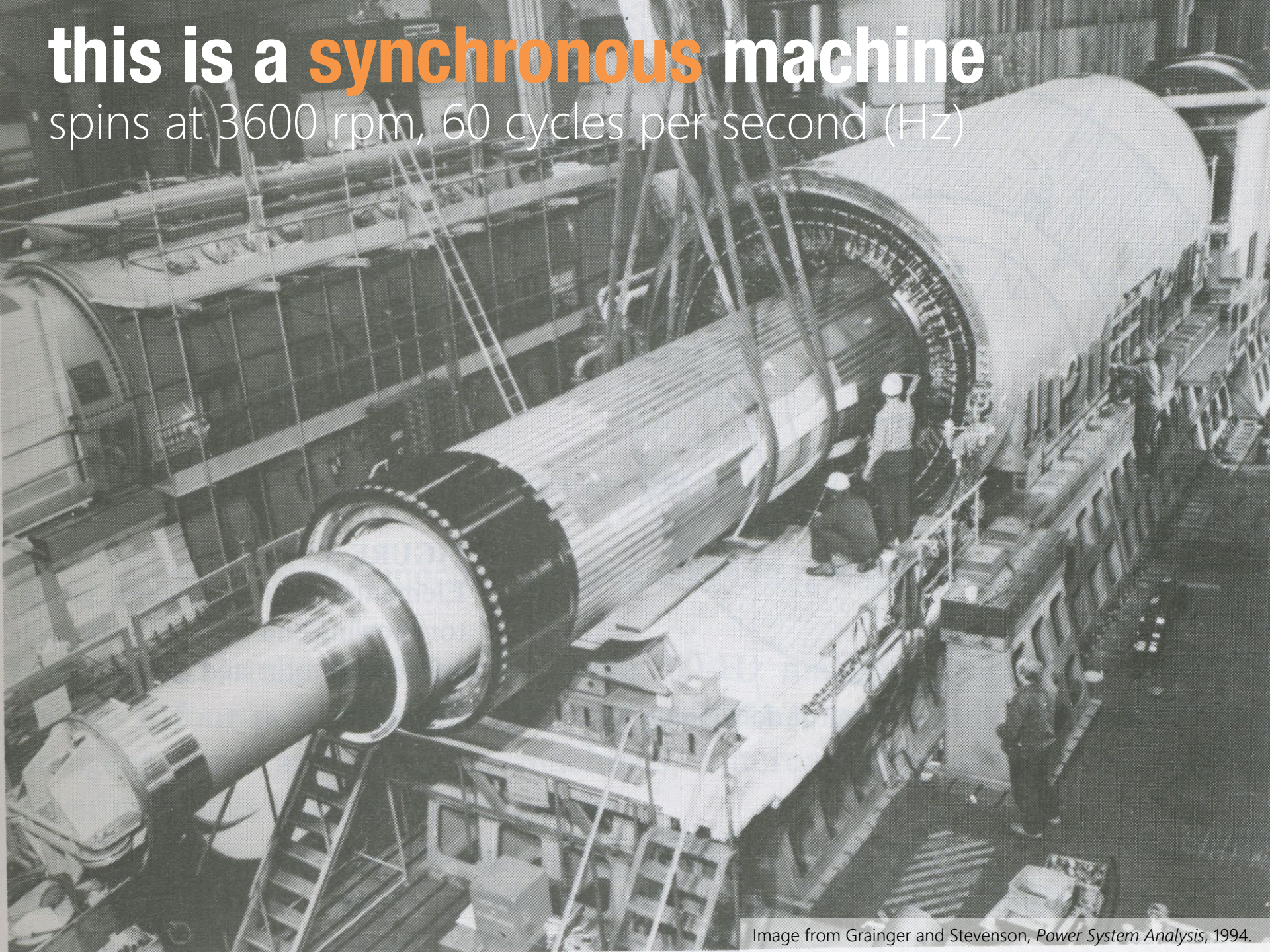
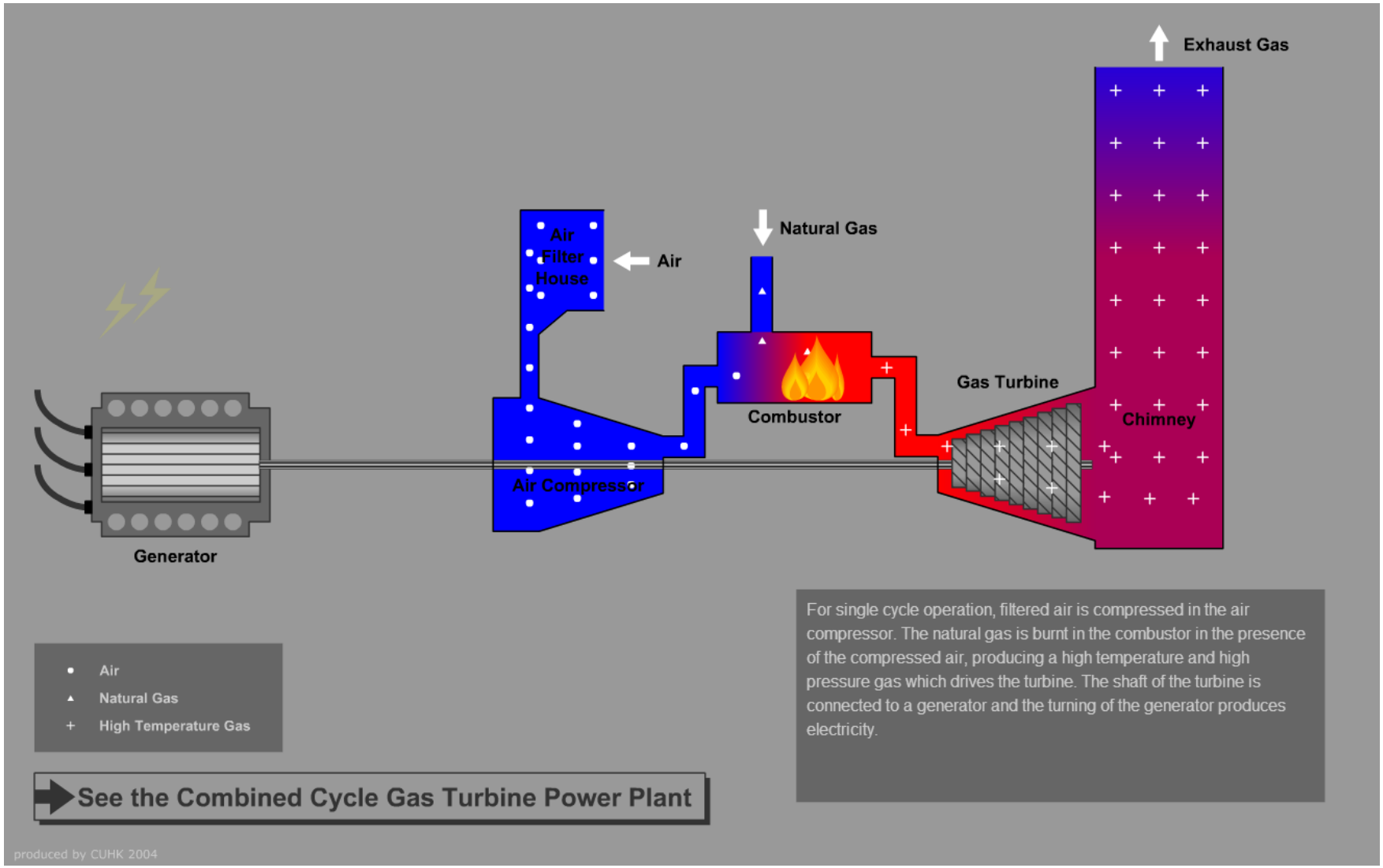


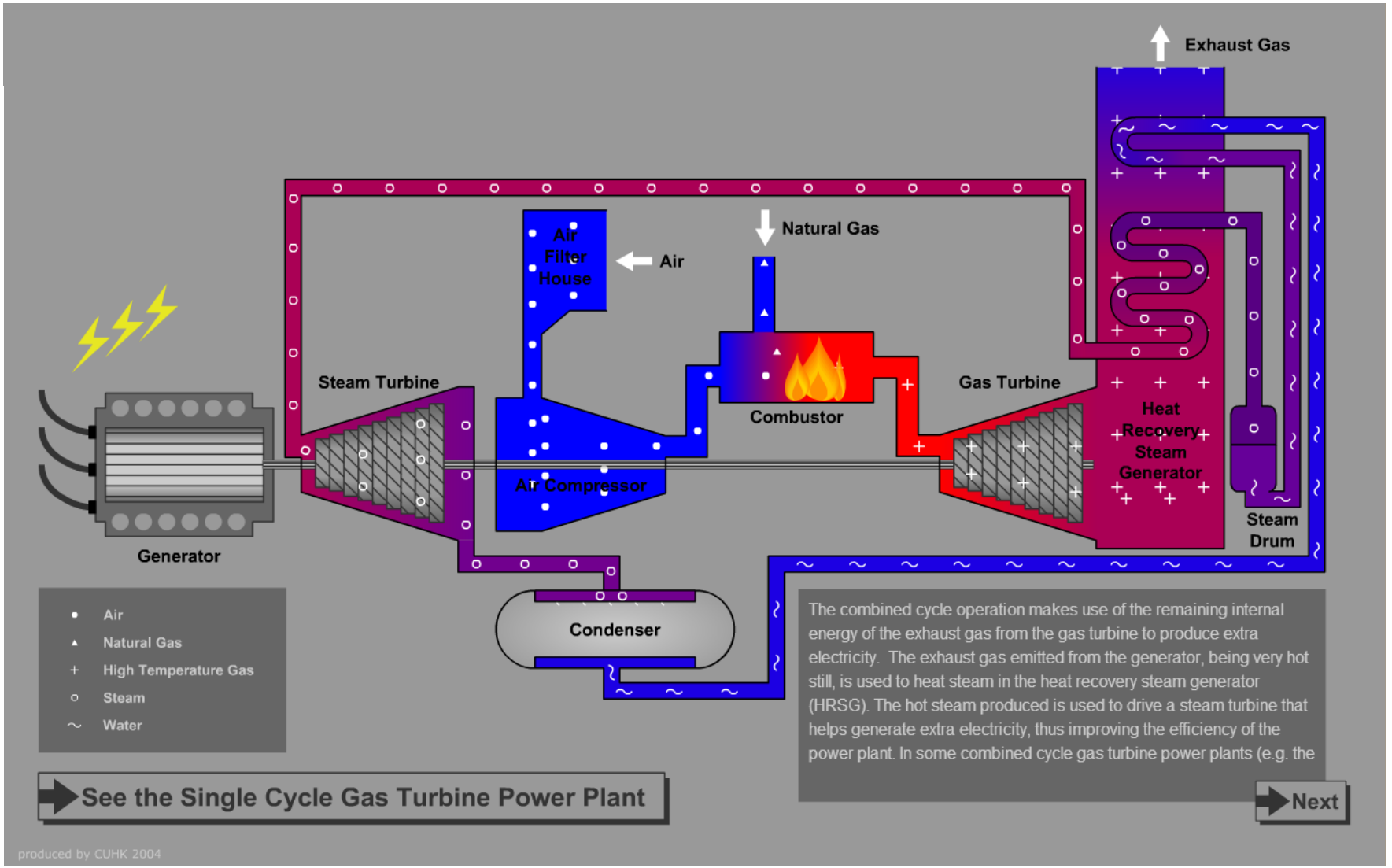
Image from Grainger and Stevenson, *Power System Analysis*, 1994.

single cycle gas turbine



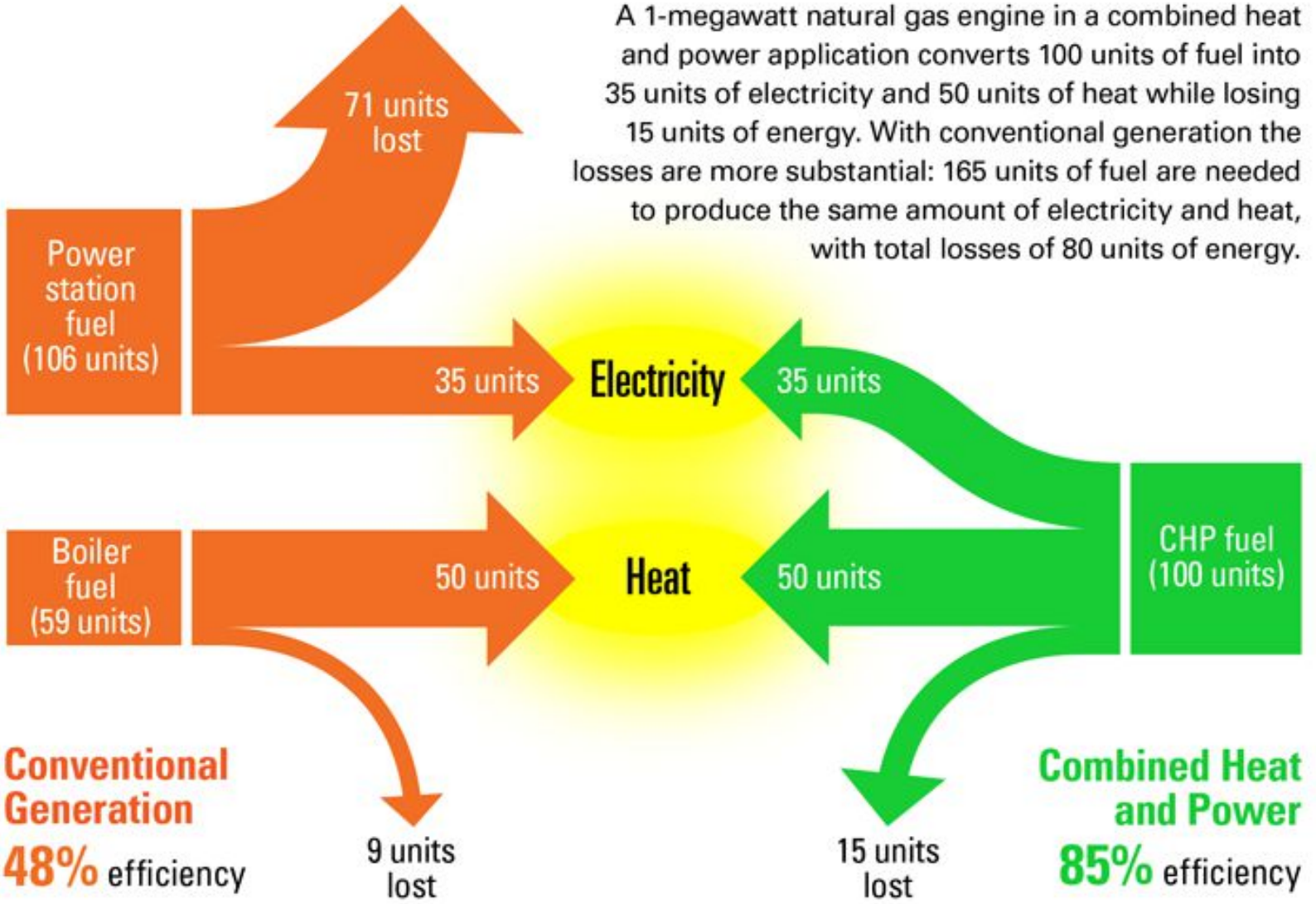
http://www.hk-phy.org/energy/power/elect_phy/flash/powerplant_e.html

combined cycle gas turbine



http://www.hk-phy.org/energy/power/elect_phy/flash/powerplant_e.html

combined heat and power



Source: U.S. Department of Energy Northeast CHP Technical Assistance Partnership

hydroelectric plant

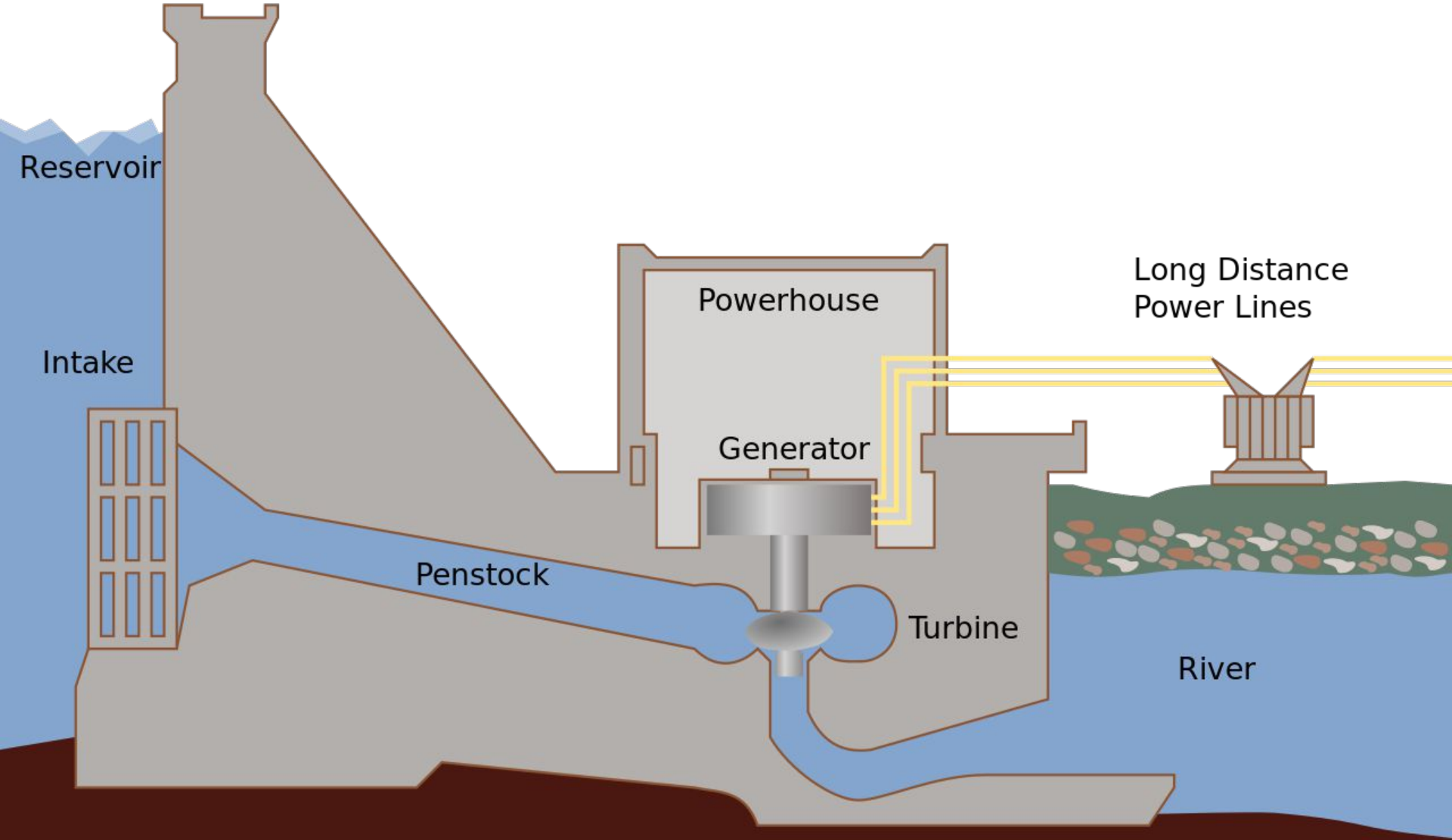
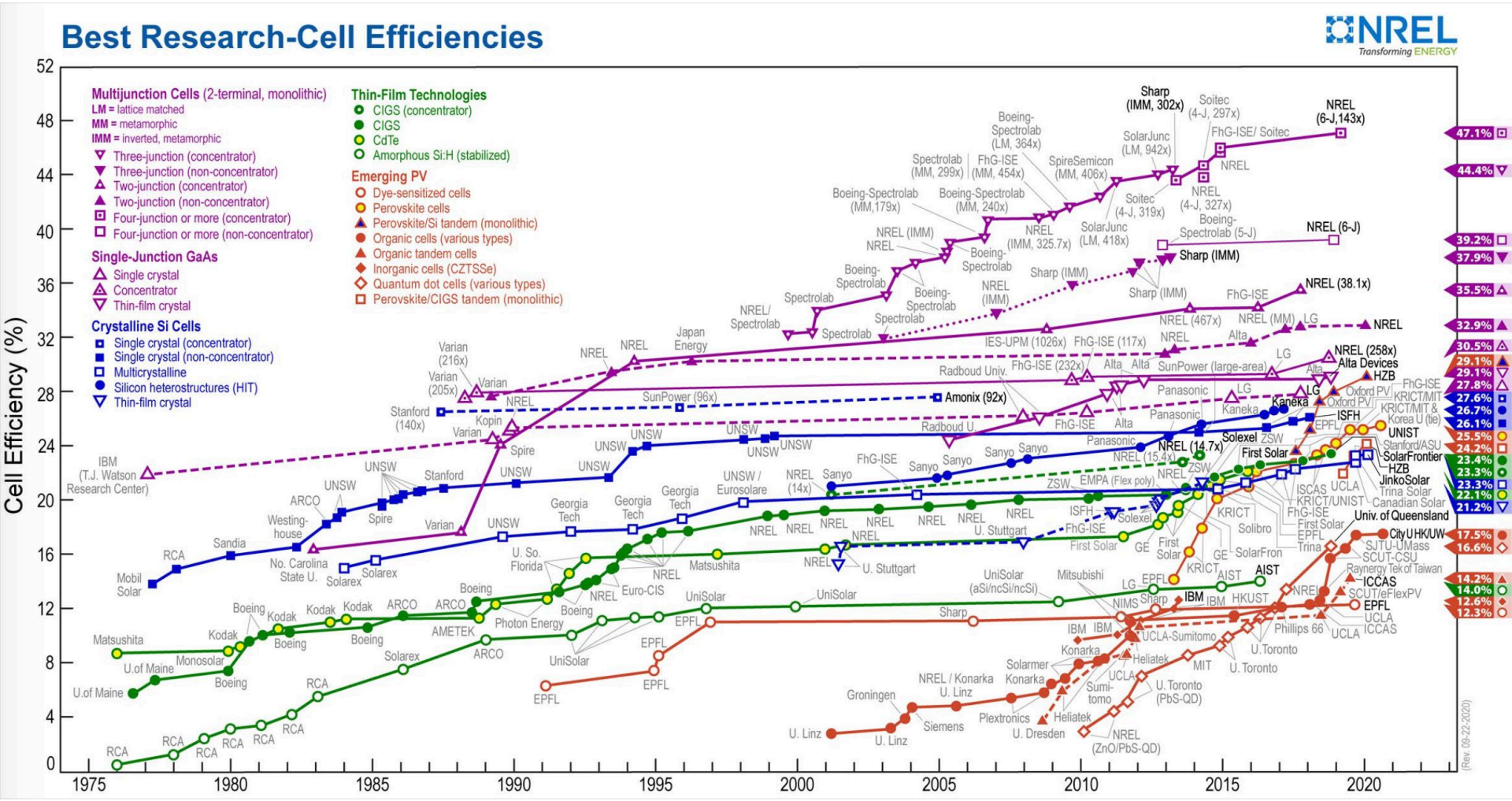
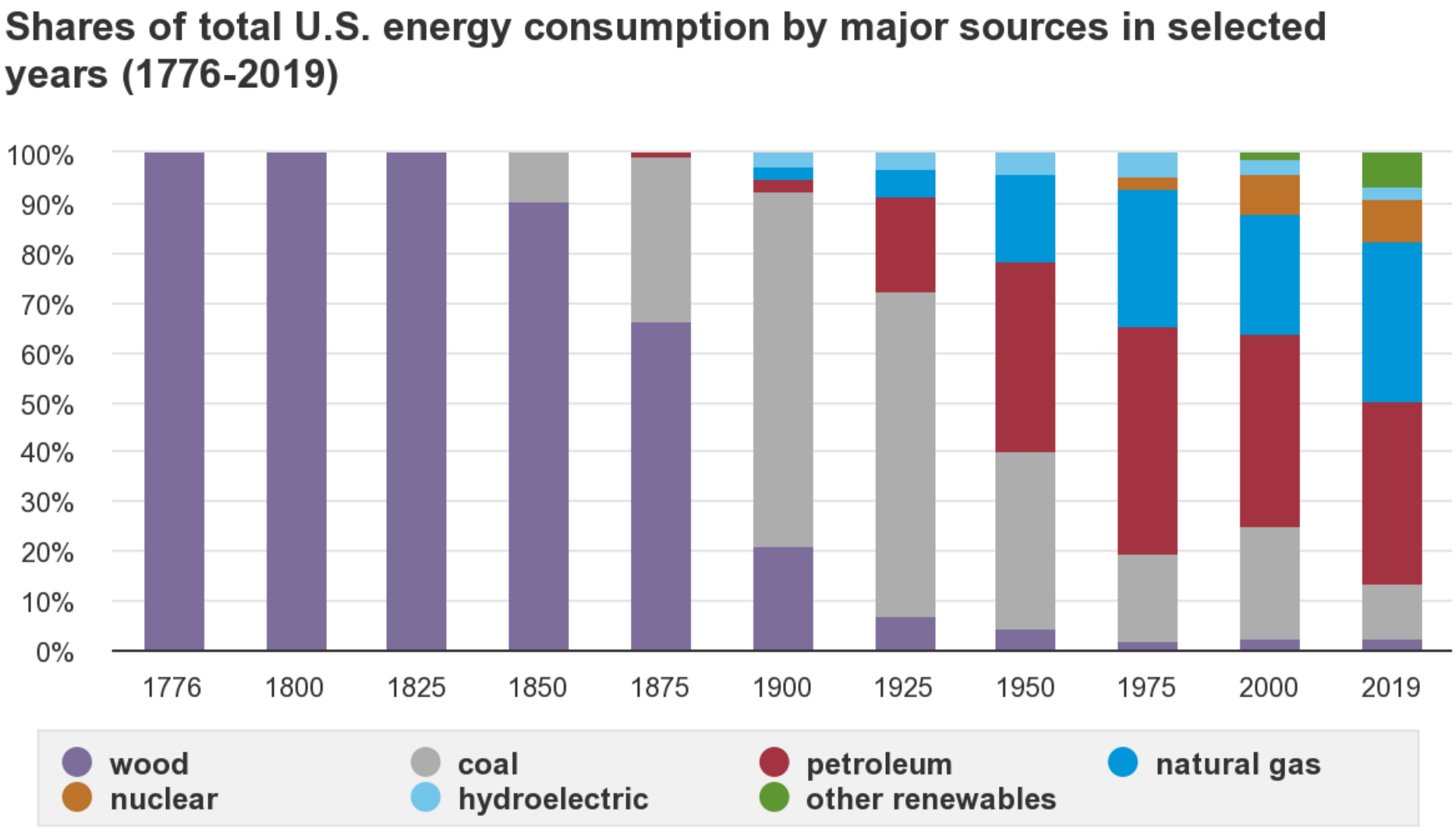


Image: "Hydroelectric dam" by Tomia - Own work. http://en.wikipedia.org/wiki/Hydroelectricity#mediaviewer/File:Hydroelectric_dam.svg

solar cell efficiency



energy consumption in the U.S.

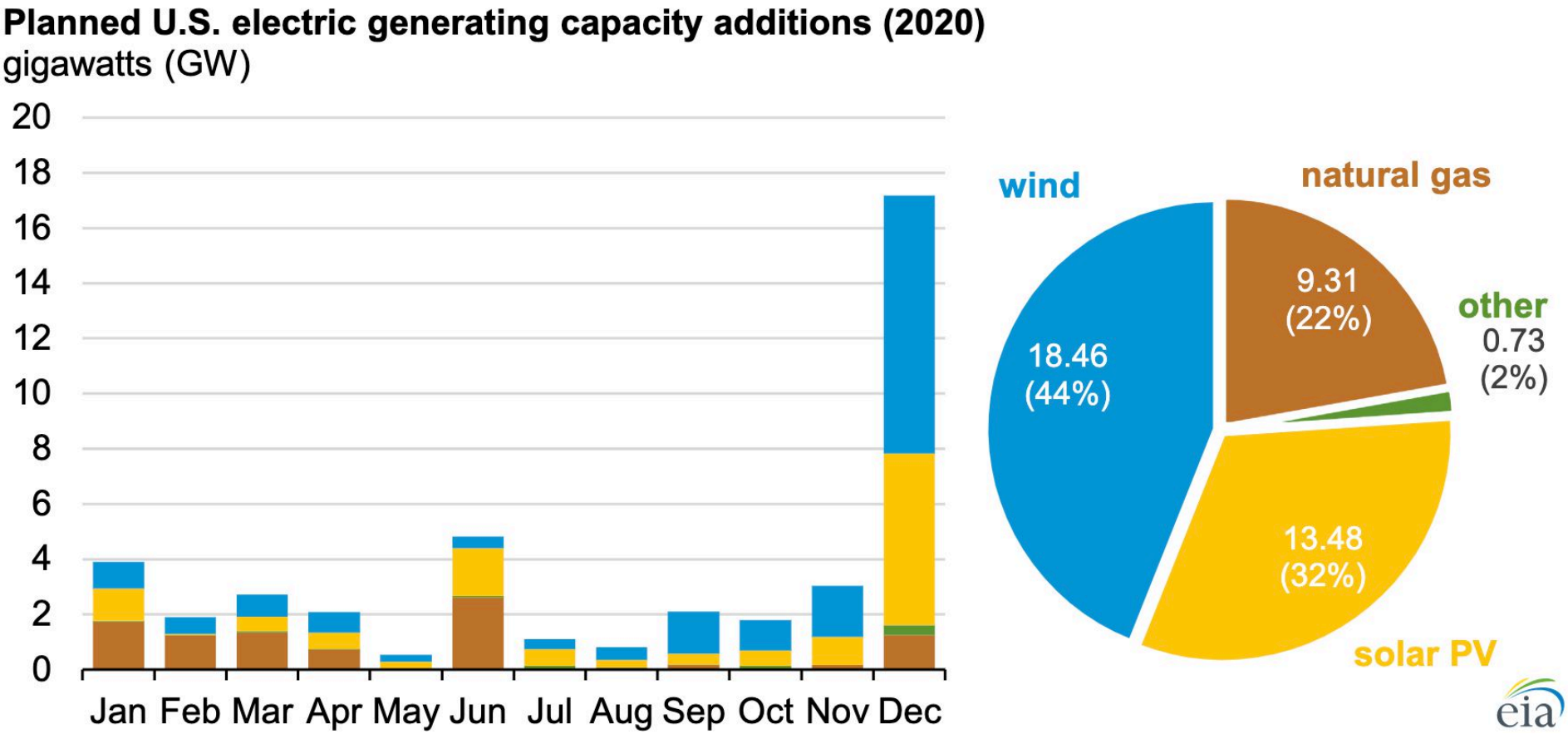


Note: Wood includes wood and wood waste; other renewables includes biofuels, geothermal, solar, and wind.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Appendix D.1, and Tables 1.1 and 10.1, April 2020, preliminary data for 2019

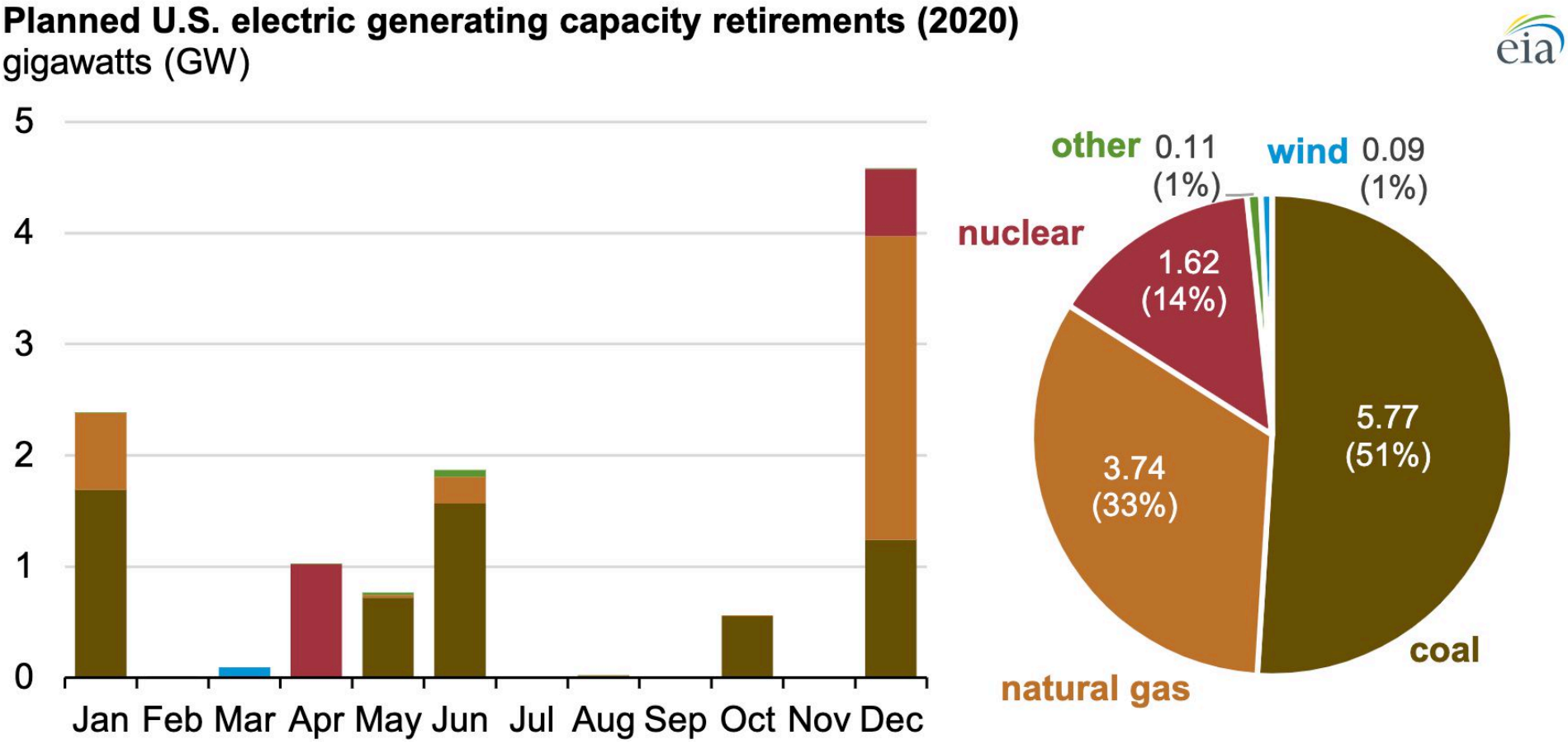
eia

https://www.eia.gov/energy_in_brief/

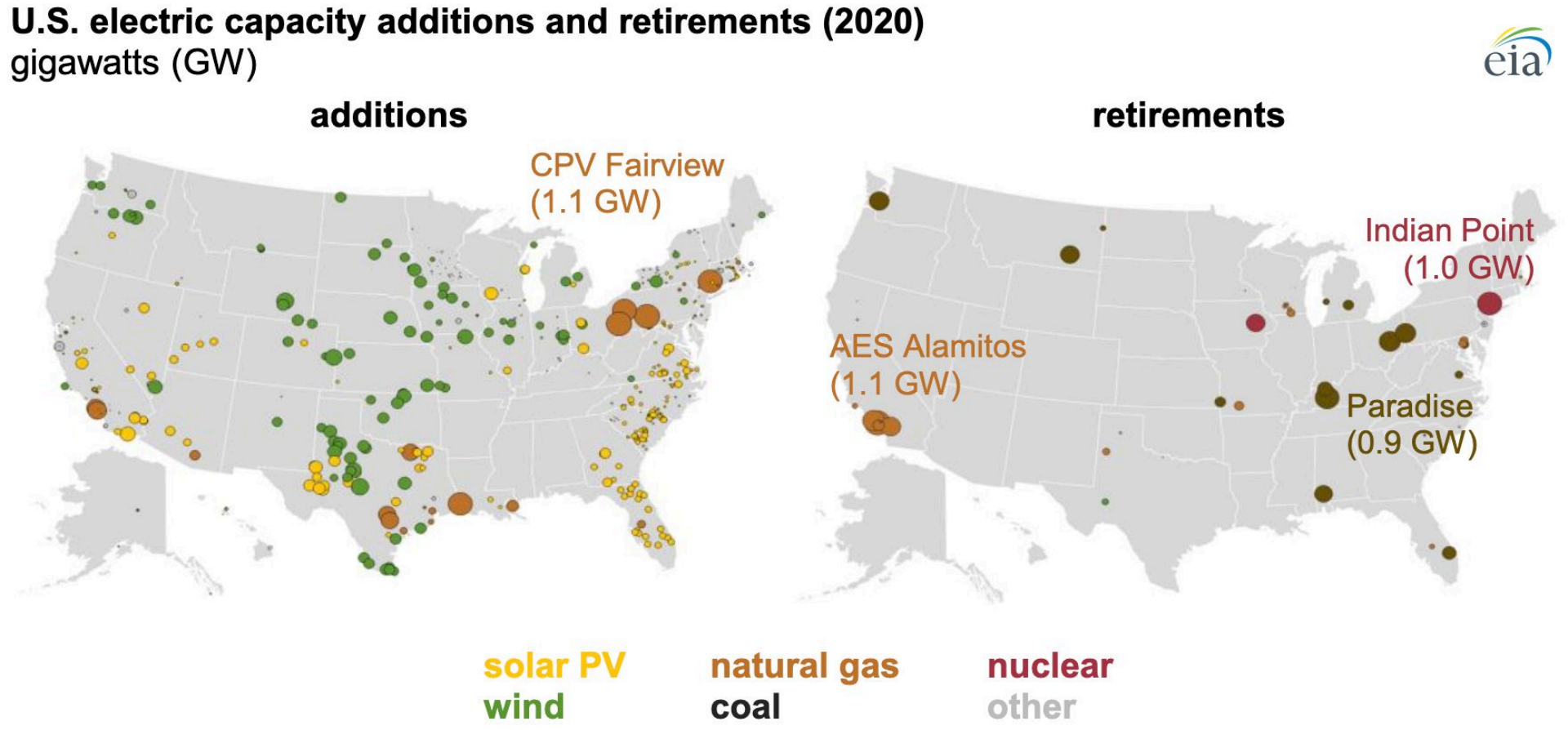
planned additions



planned retirements



locations of changes in power plants



Mechanical Systems

PUMPED HYDRO

Compressed Air Energy Storage

Flywheel

Electrical Systems

Capacitor

SUPERCAPACITO R

Superconducting Magnetic Energy Storage

Thermal Systems

ICE Storage

Molten Salt

Chemical Systems

LEAD ACID

LITHIUM-ION

Sodium Sulfur

Zinc Bromine

Nickel Cadmium

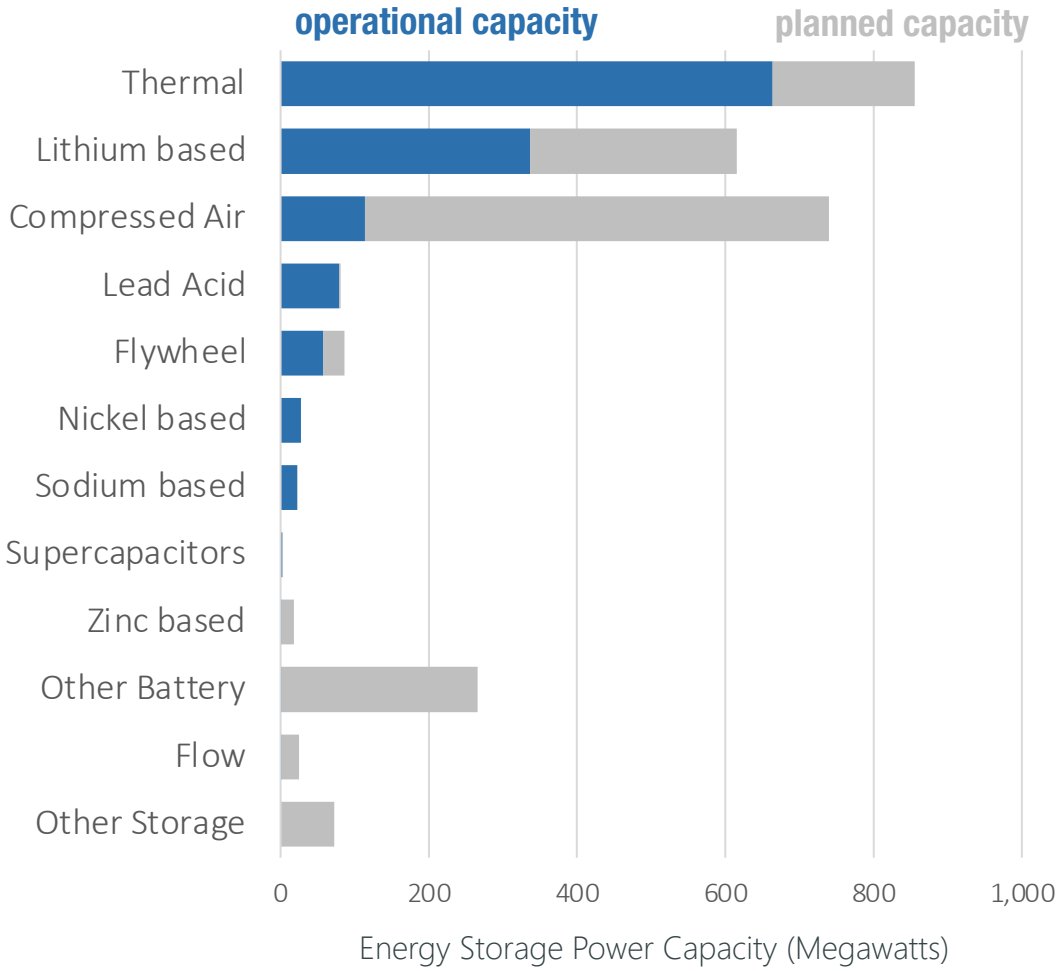
FLOW **BATTERIES**

Kyle Bradbury, Duke University Energy Initiative

energy storage

excluding pumped hydroelectric energy storage

Top 20 states shown



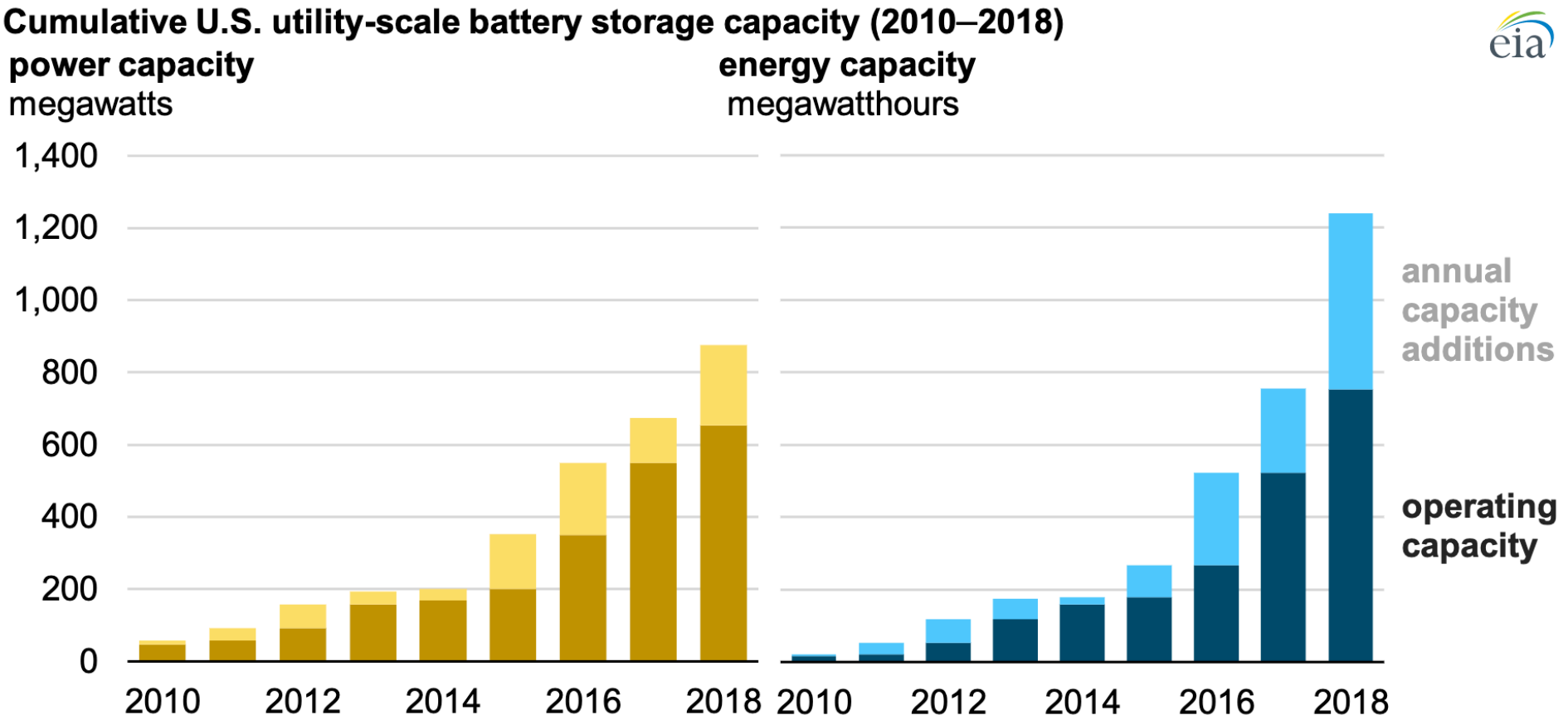
thermal storage is dominated by large molten salt storage facilities in the southwest. Ice-based storage is increasing

a small number of large compressed air energy storage facilities have been announced in CA and TX

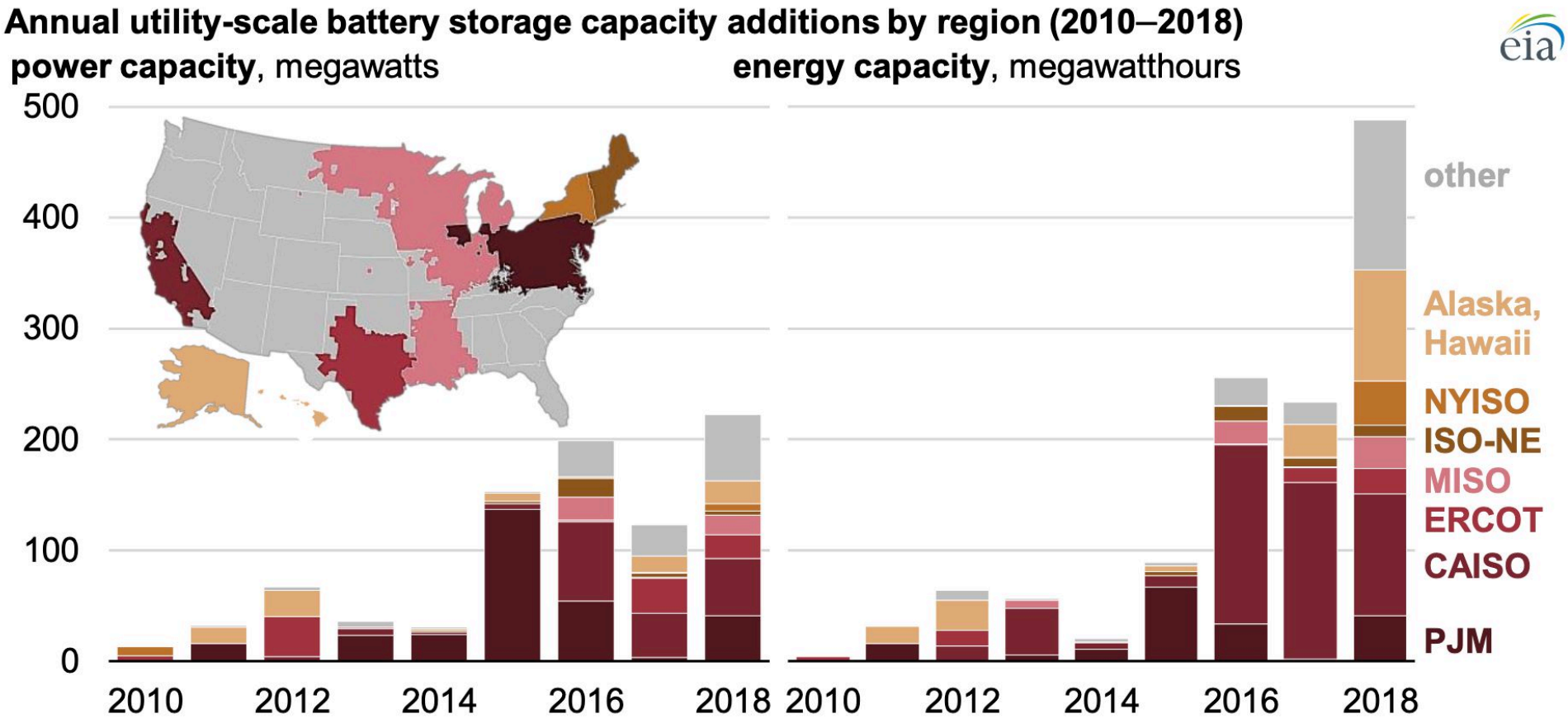
Kyle Bradbury, Duke University Energy Initiative

Data from DOE Global Energy Storage Database

energy storage

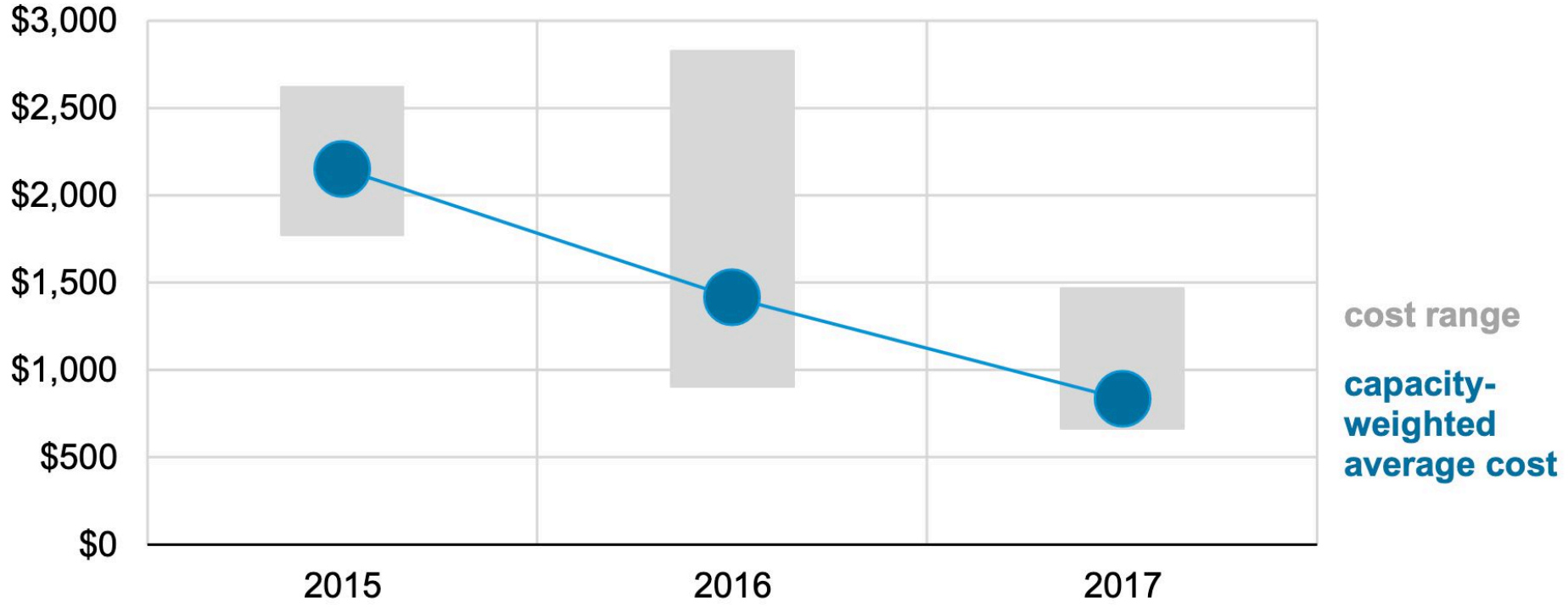


Energy storage



Energy storage

Total installed cost of utility-scale battery systems by year (2015–2017)
energy capacity cost
dollars per kilowatthour



electric power systems

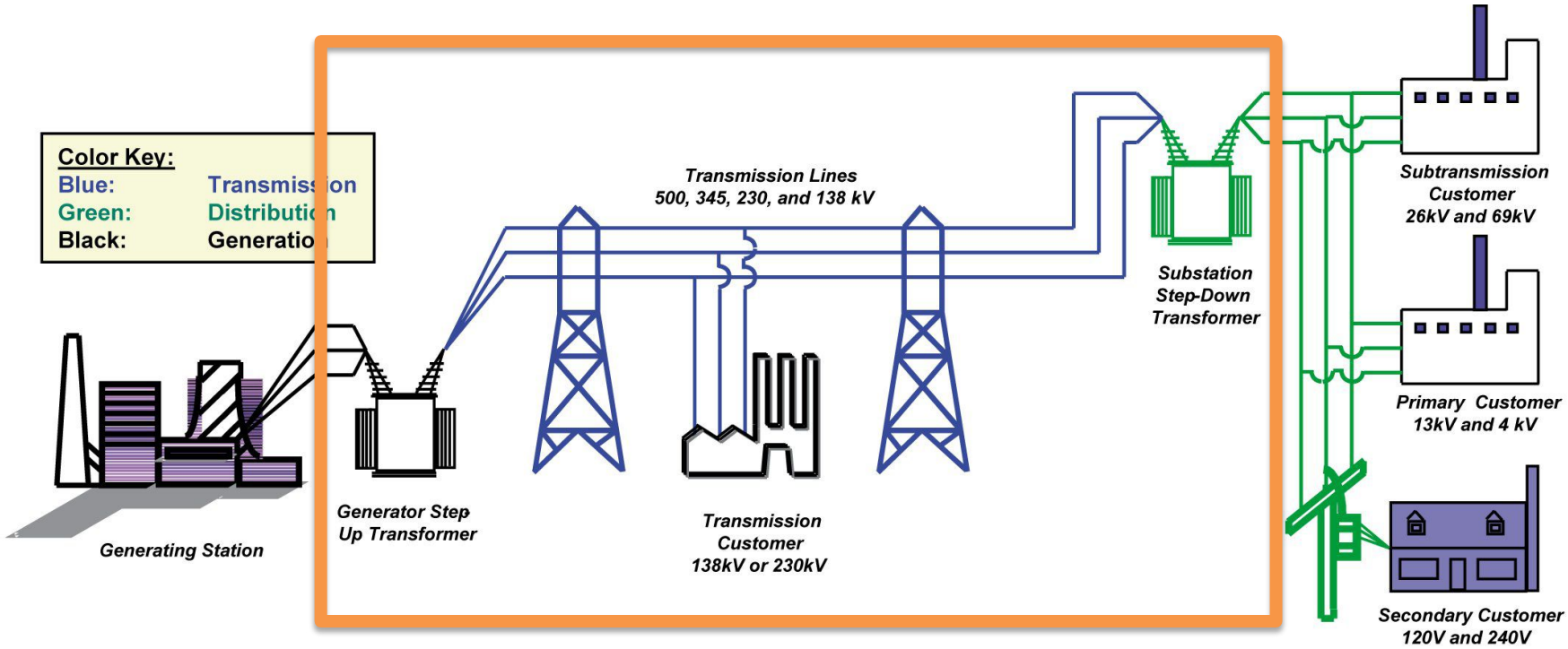


image from http://www2.econ.iastate.edu/

why high voltage transmission?

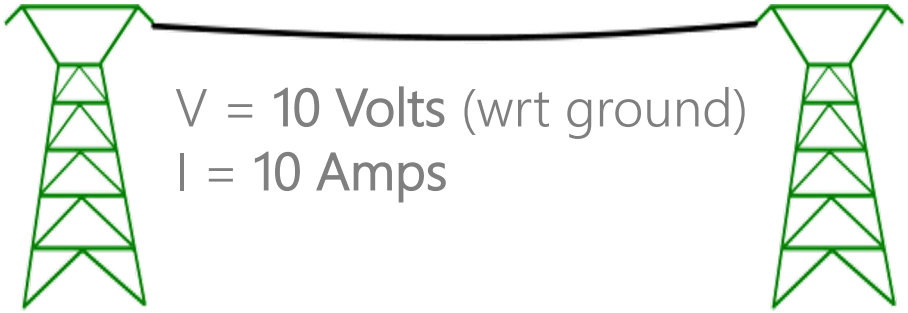
Ohm's Law: $V = IR$

Power (Watts): $P = VI$

Resistive power losses: $P_L = I^2R$

Power loss is proportional to the square of the current

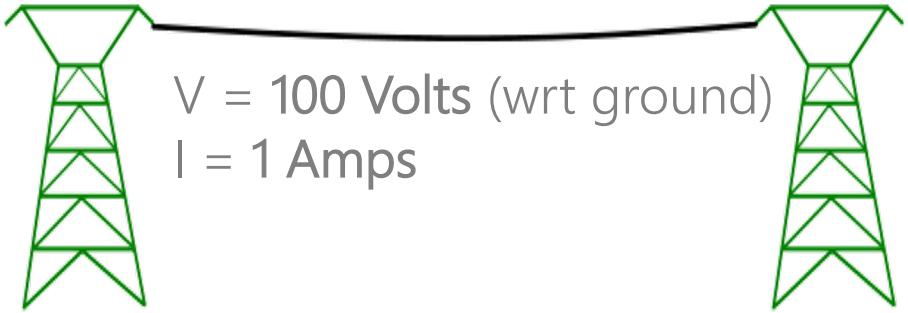
Scenario 1:



V = **10 Volts** (wrt ground)
I = **10 Amps**

$P_L = I^2R = (100)(0.1)$
$= 10$ Watts

Scenario 2:



V = **100 Volts** (wrt ground)
I = **1 Amps**

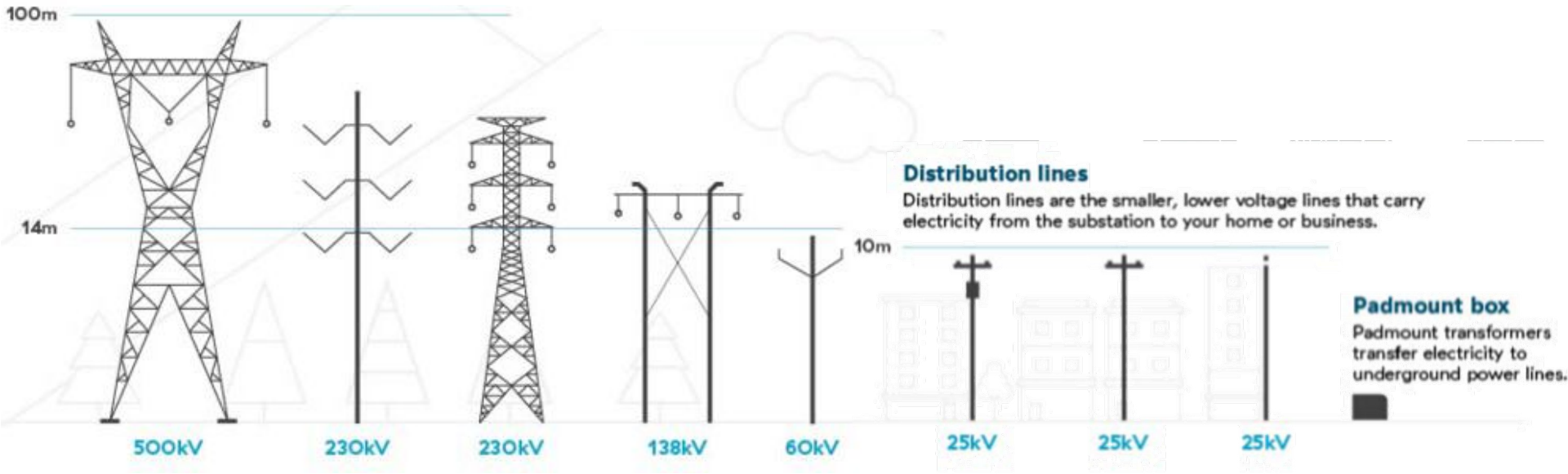
$P_L = I^2R = (1)(0.1)$
$= 0.1$ Watts

R = 0.1 Ohms (same line resistance)
P = VI = 100 Watts (same power transfer)

Note: In practice, high voltage is > 35kV

Image from focusnews.co

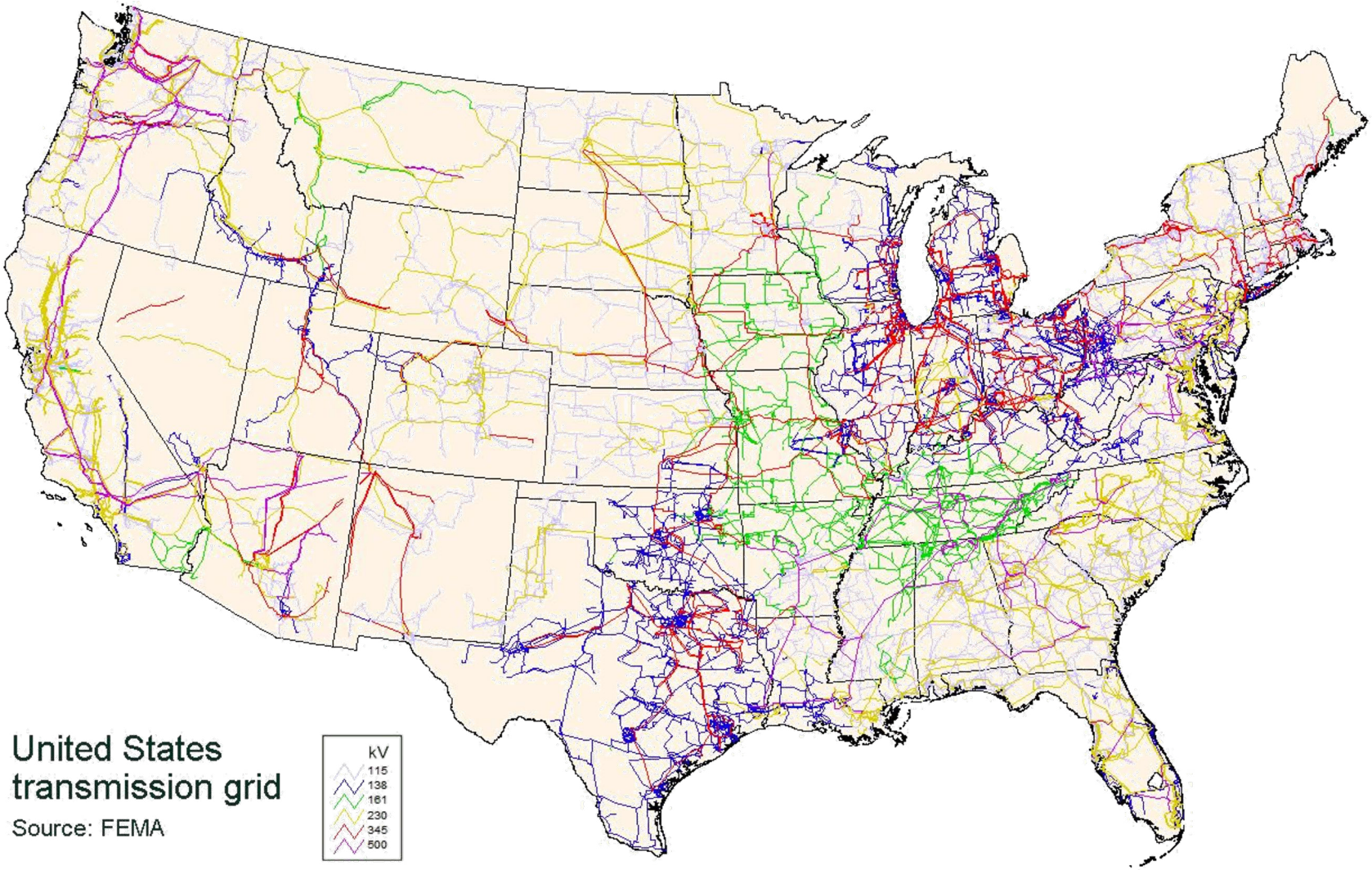
transmission and distribution



transmission | subtransmission | distribution

Image from Dominion Energy

transmission



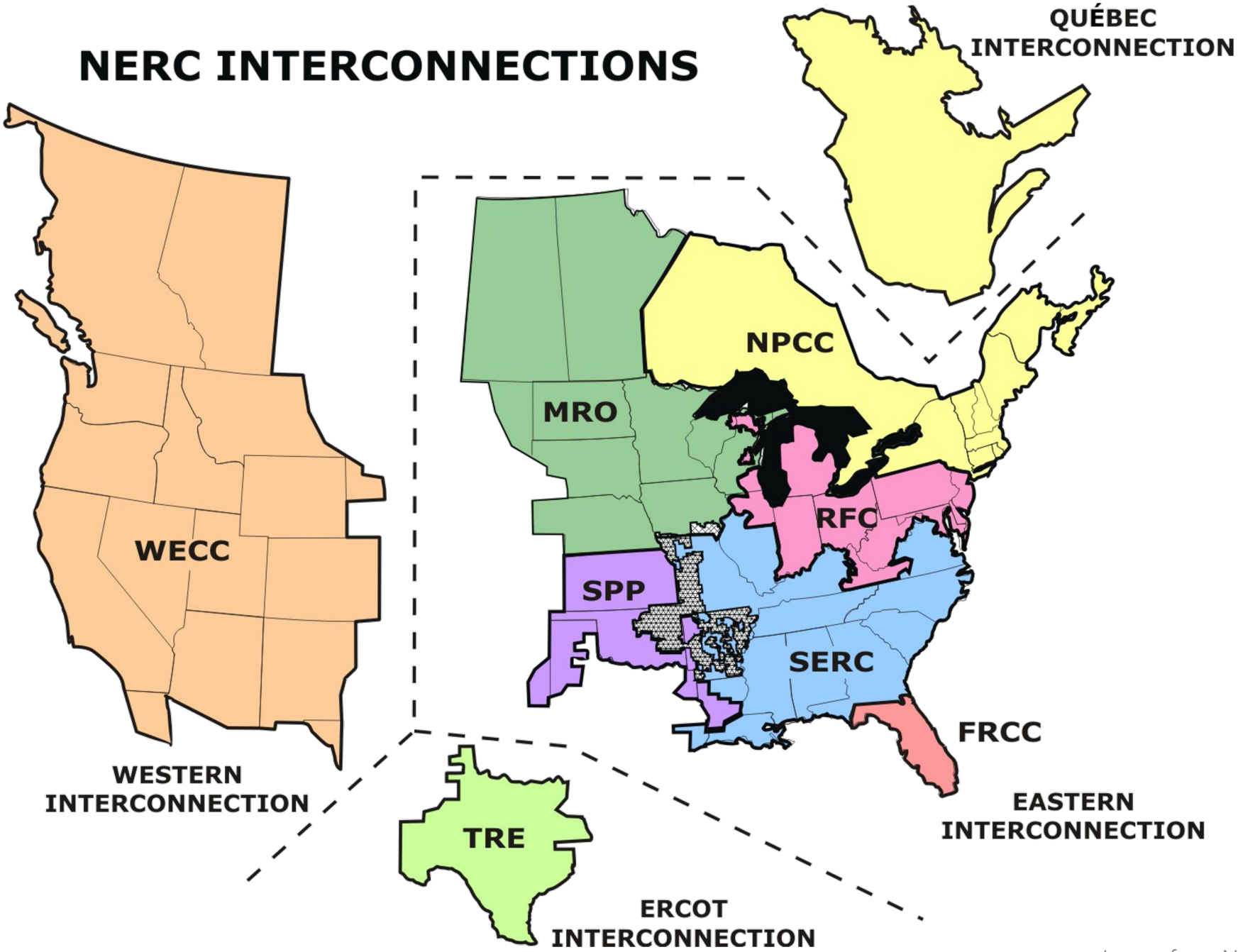


Image from NERC

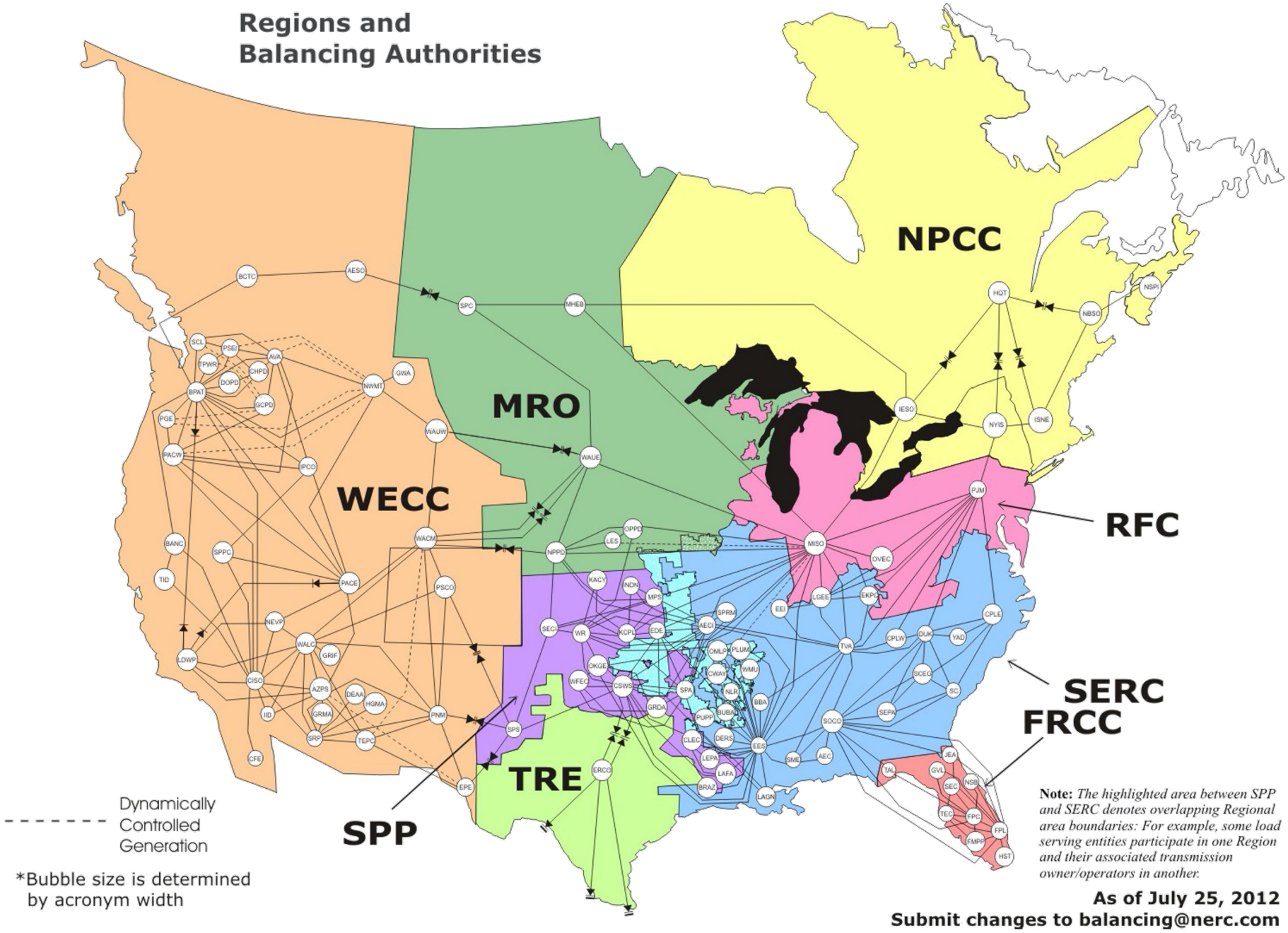


Image from NERC

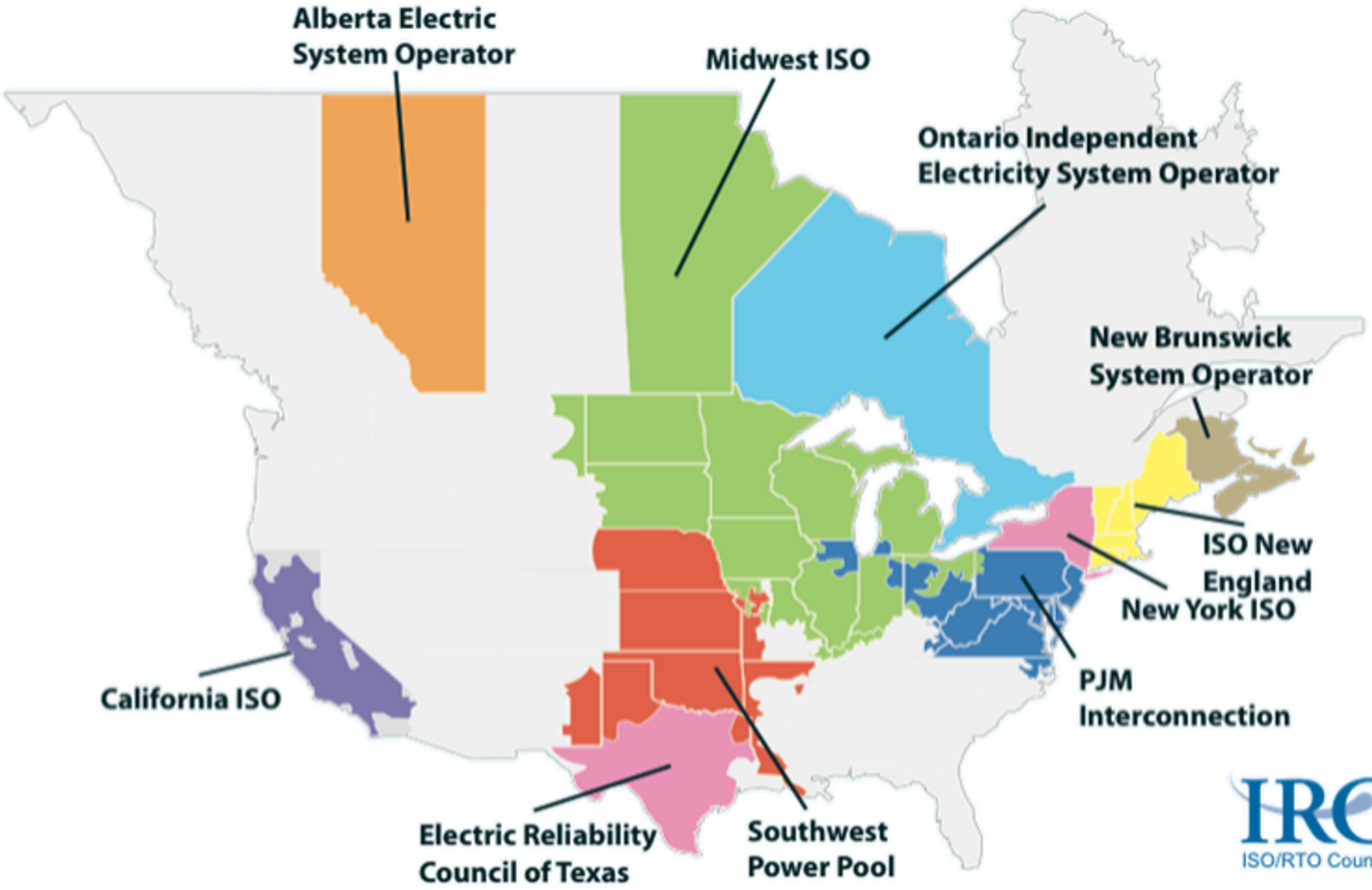


image from http://www.opuc.texas.gov/ERCOT.html

generator outage

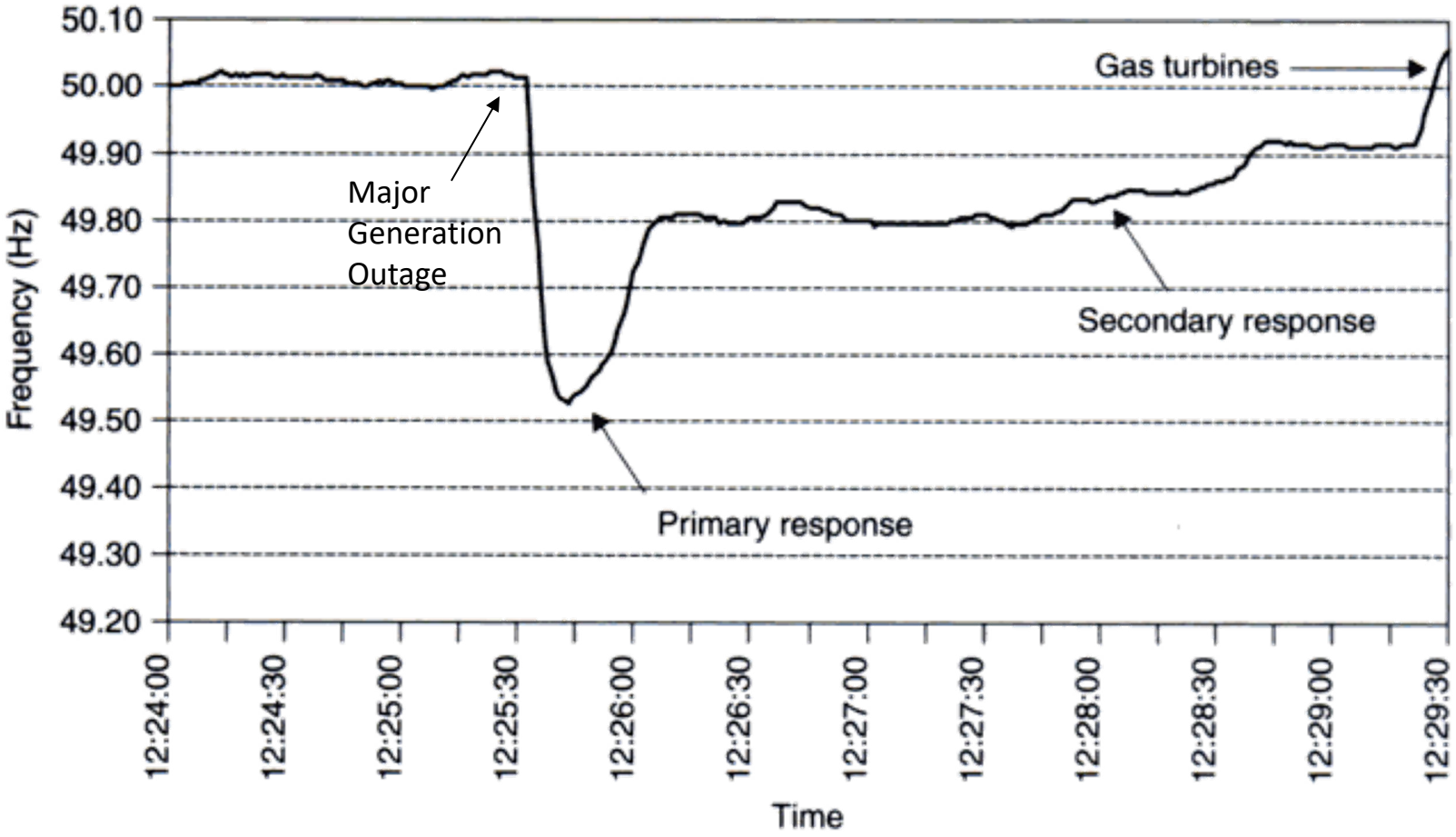


Image from Kirschen and Strbac, Power System Economics, 2005

electric power systems

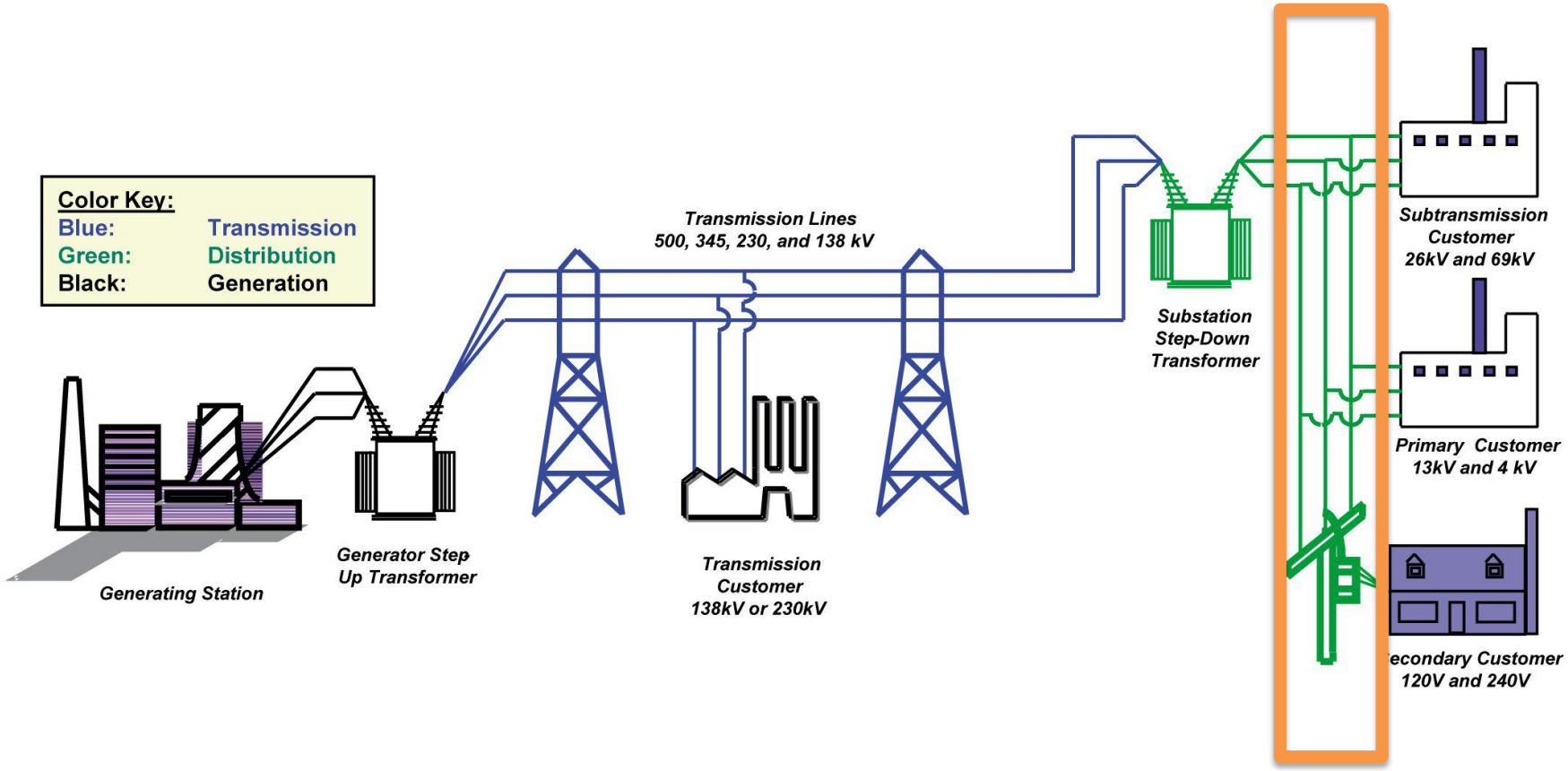


image from http://www2.econ.iastate.edu/

electric power systems

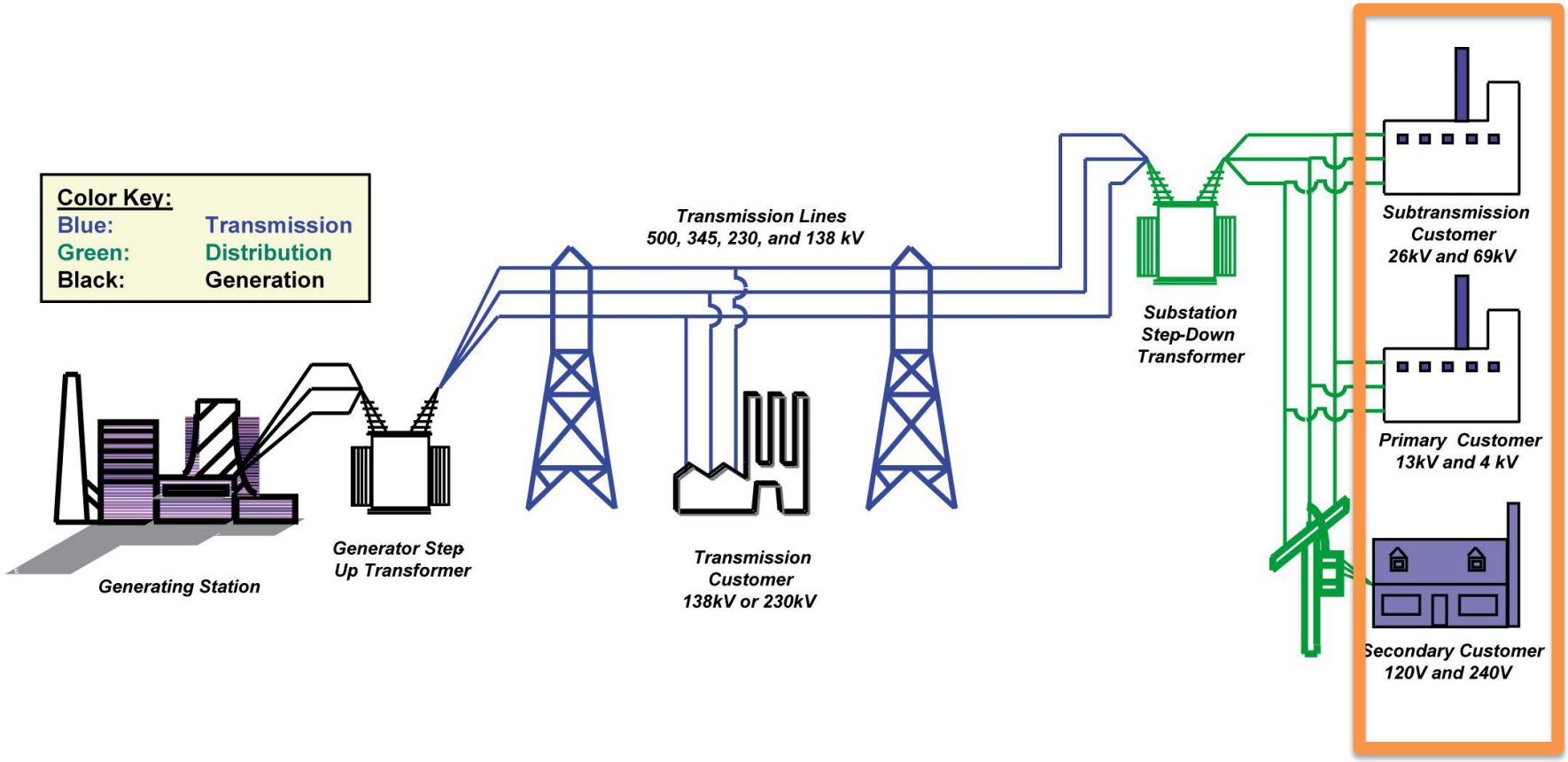
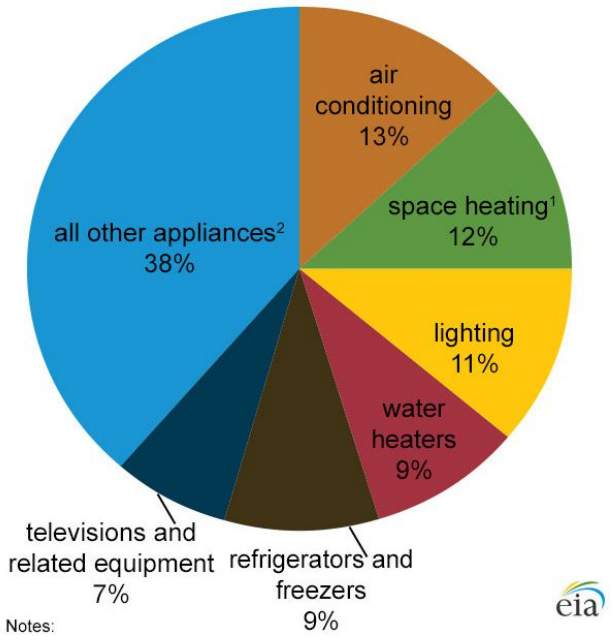


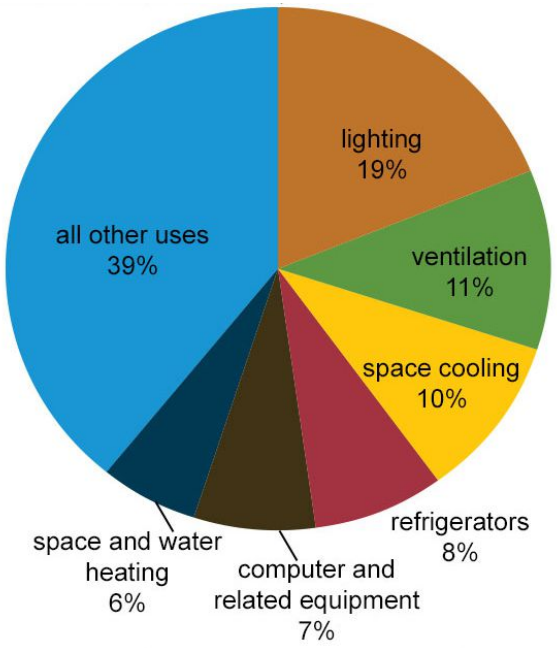
image from http://www2.econ.iastate.edu/

electricity end use

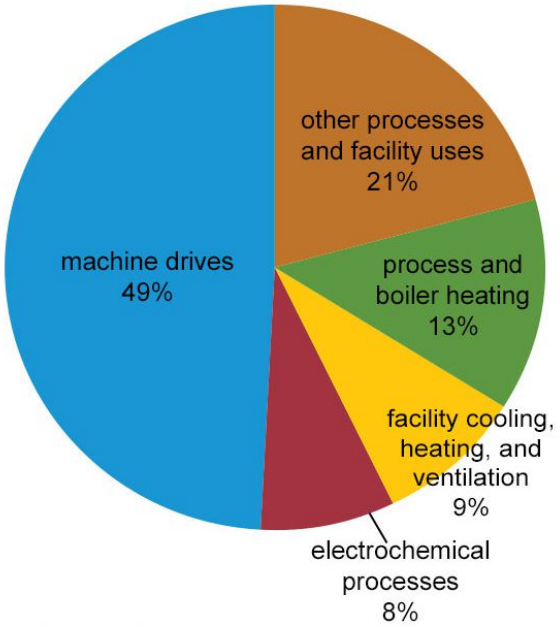
residential



commercial



industrial



https://www.eia.gov/energyexplained/index.cfm?page=electricity_use

Open Electrical Energy Markets

- Bilateral Trading
- Power Pool:

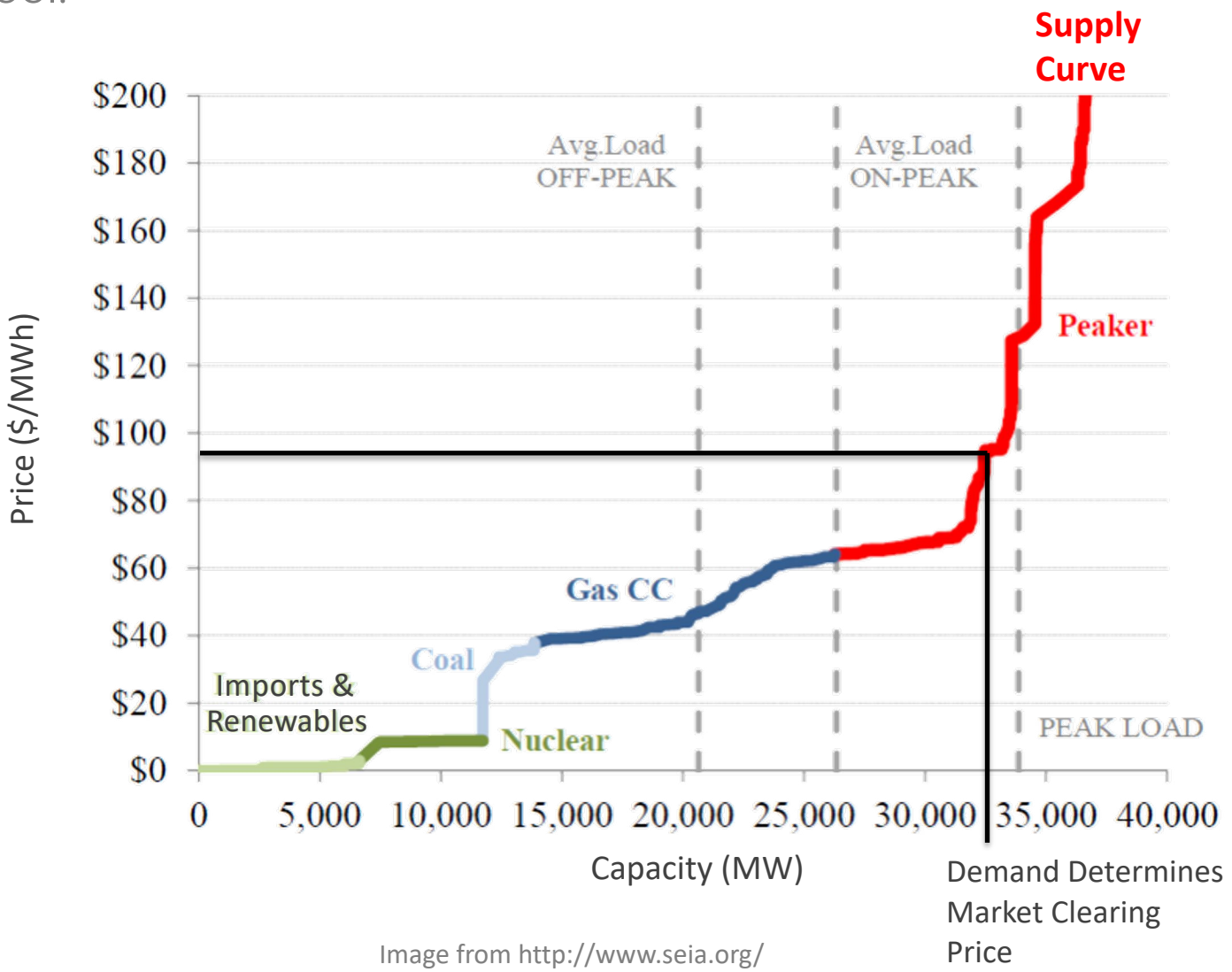


Image from http://www.seia.org/

throughout space there is energy... it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature.

Nikola Tesla, 1892