Electric Power Systems – An Overview

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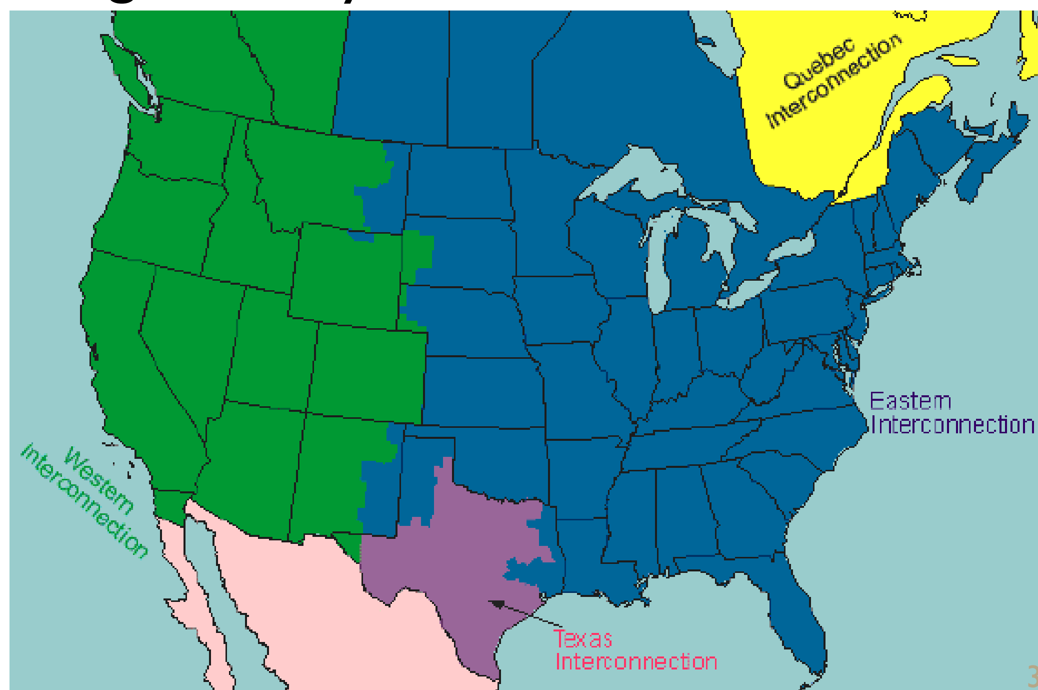
Overview

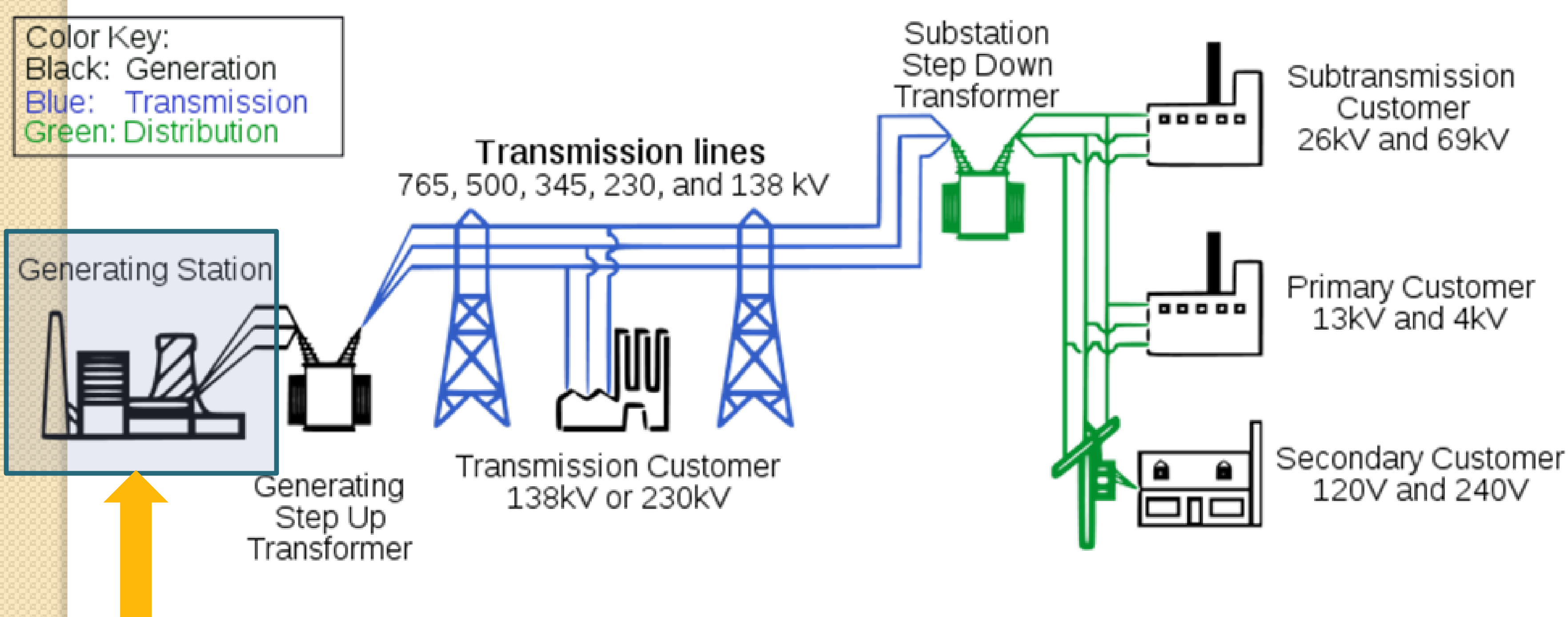
- **Power Generation**
  - Conventional and renewable power generation
- **Power transmission & Distribution**
  - Cables and other transmission & distribution system equipment
- **Power Utilization**
  - Demand curves, load characteristics
- **Power System Analysis**
  - Power flow, fault currents, economic dispatch, unit commitment, state estimation,….

North American Electrical Grid

- Four Islands: Western , Texas, Eastern, Quebec.
- There are over 3,000 electric utilities:
  - Some provide service in multiple states.
  - Over 1,700 non-utility power producers.
  - Utilities are either investor-owned, publicly-owned, or Federal utilities.
  - Electric utilities are regulated by local, State, and Federal authorities.

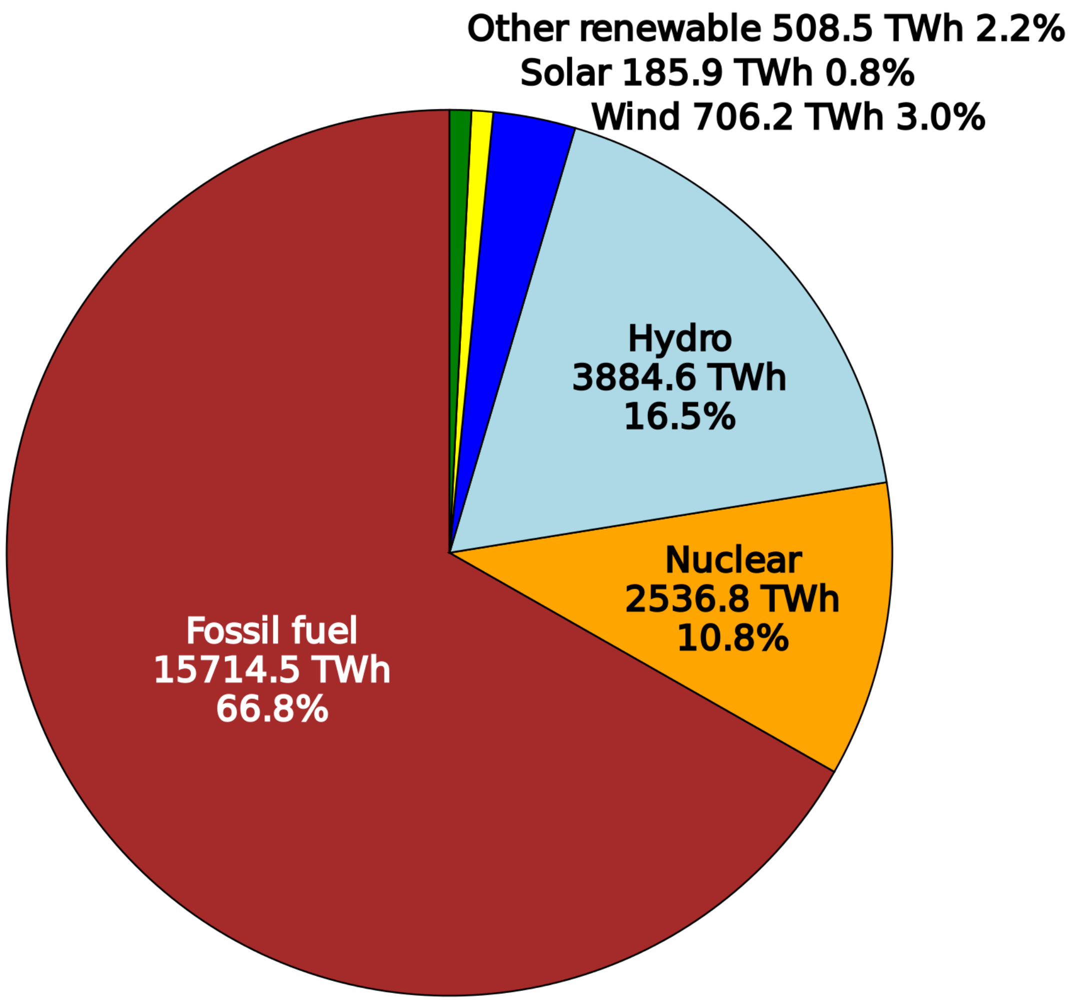


Basic Power System Layout



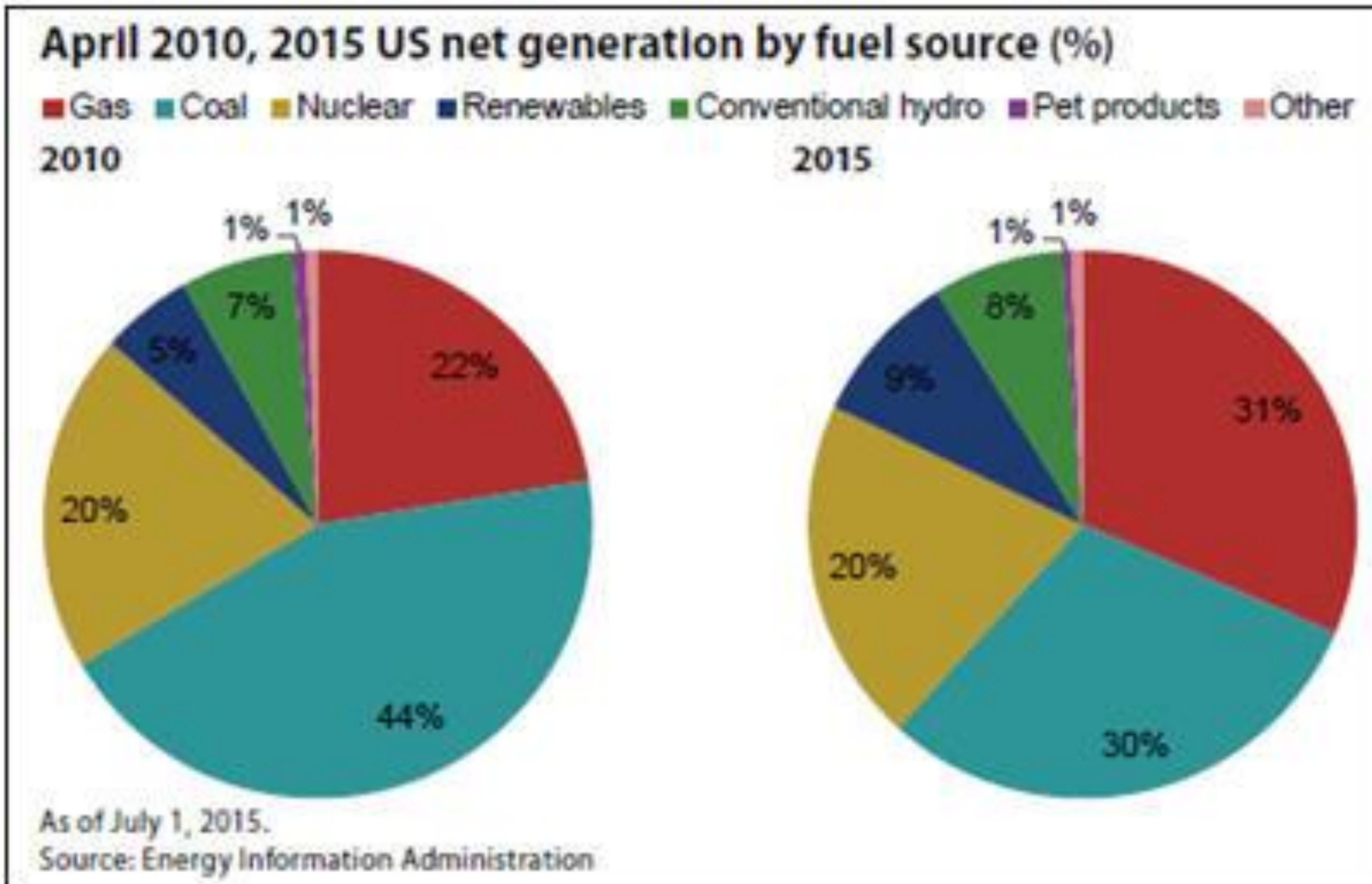
Conventional (non-renewable) primary energy source

World Electricity Generation by Source (2014)

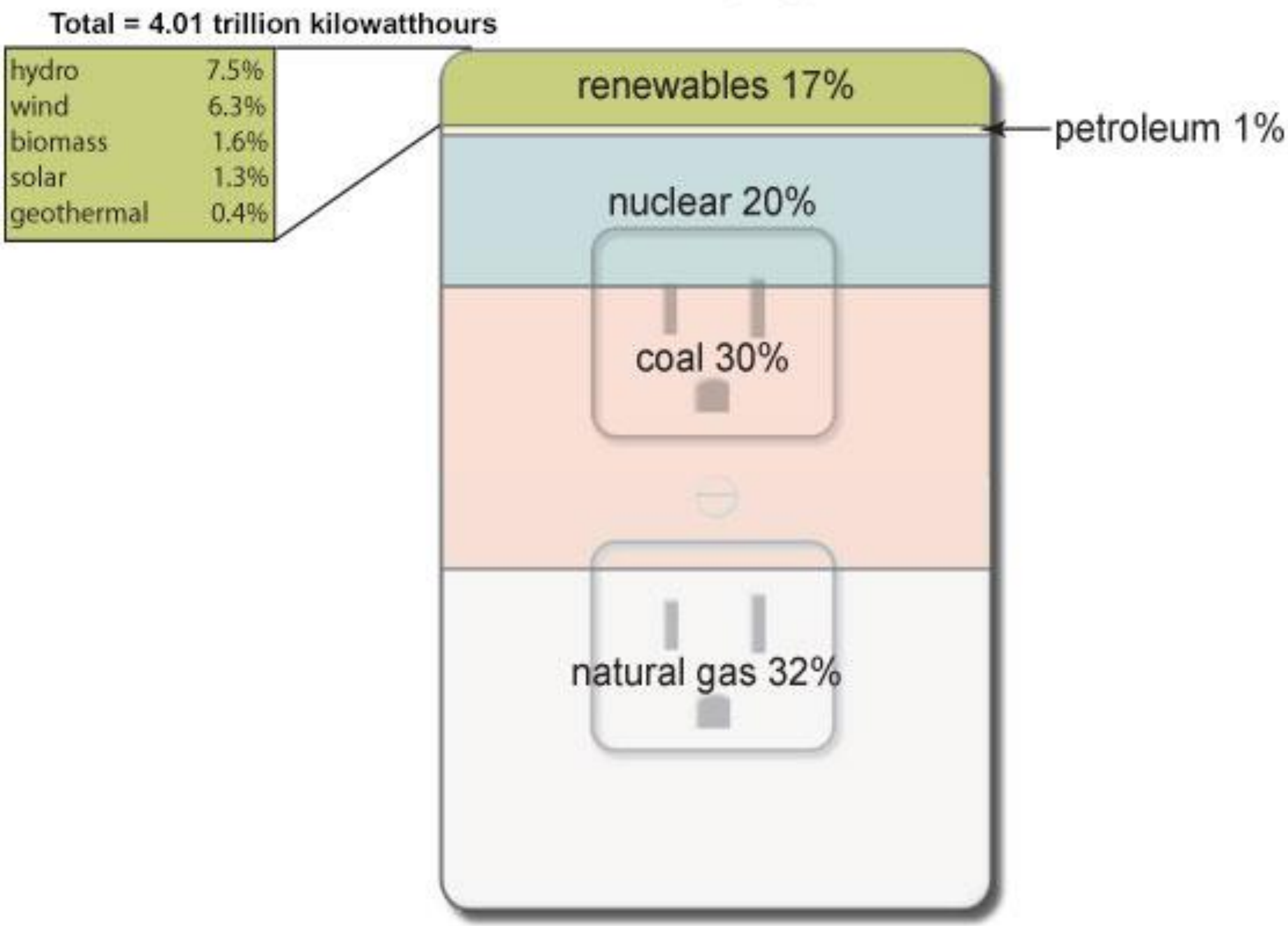


Source: US Energy Information Administration (EIA)

USA Electricity Generation by Source



US Sources of Electricity Generation, 2017

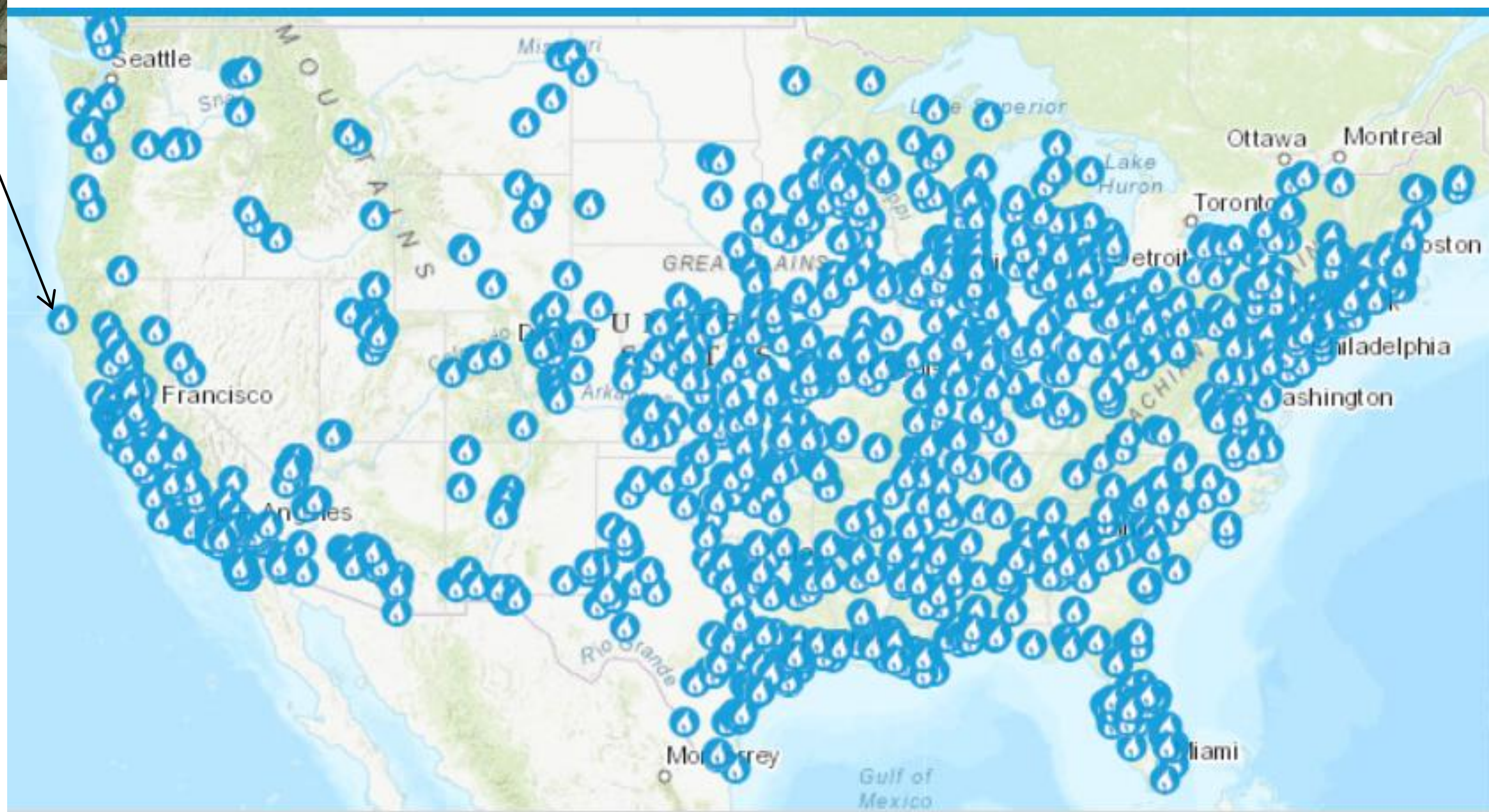


Note: Electricity generation from utility-scale facilities.

Source: U.S. Energy Information Administration, *Electric Power Monthly*, February 2018, preliminary data

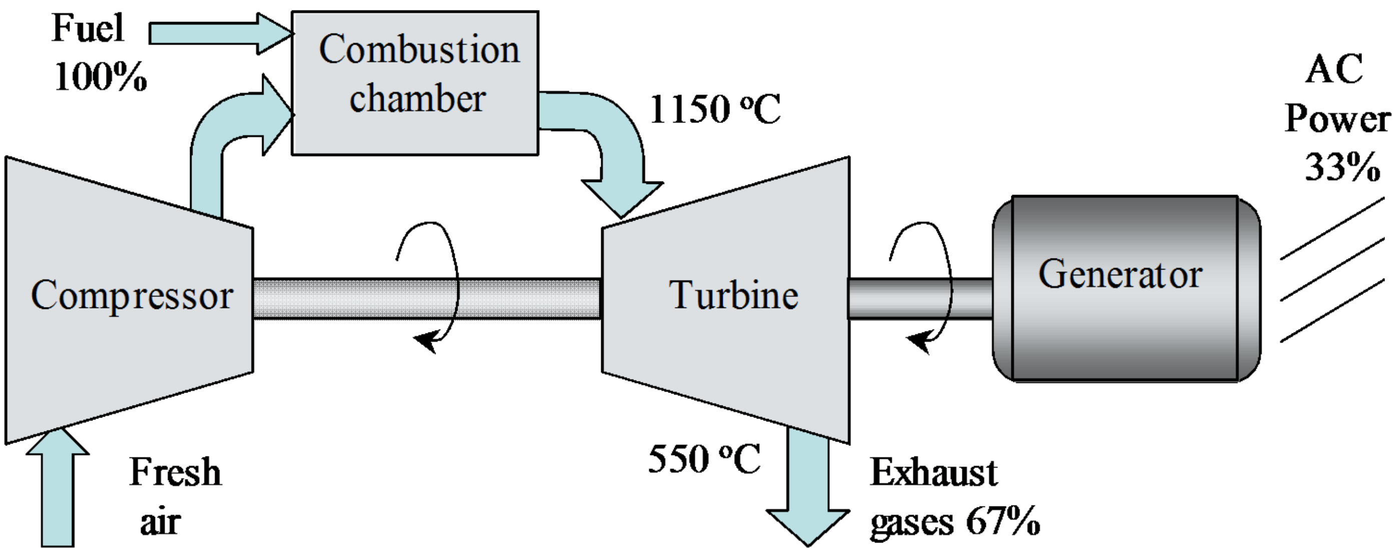
Natural Gas Plants

- Share of Total: 32%
- 8,100 Generators (2016)

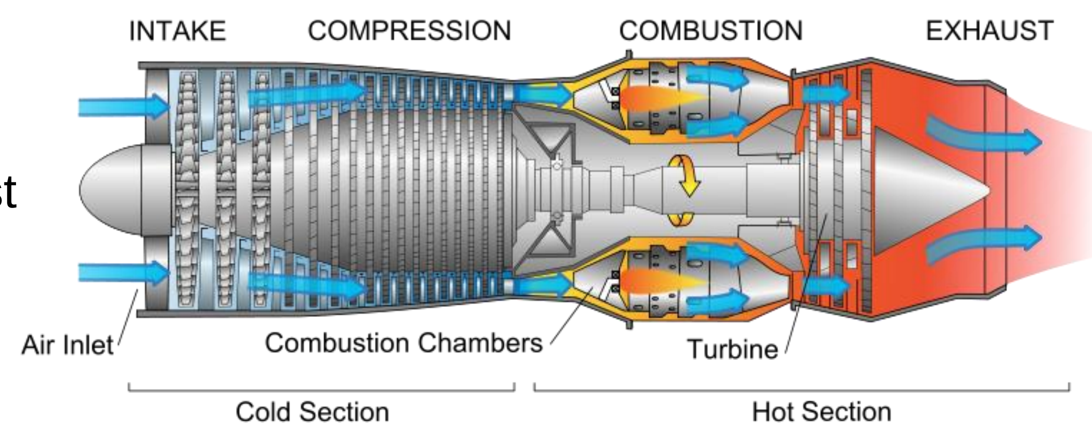


https://www.eia.gov/state/maps.php

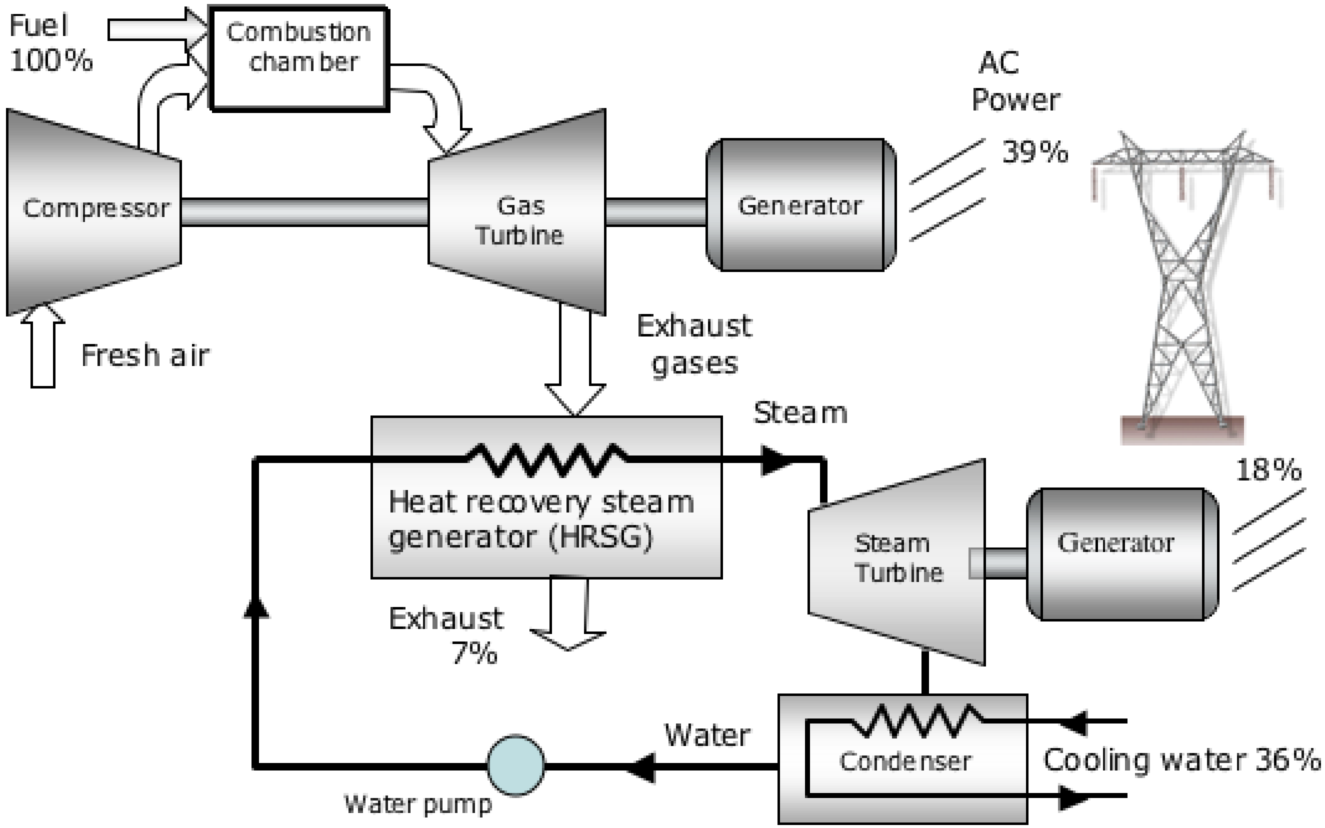
Open cycle gas turbine:
Typical efficiency: 30-35%



Air-breathing jet engines are gas turbines optimized to produce thrust from the exhaust gases. In our case, the system is optimized to produce maximum shaft power.



Combined cycle power plant: Typical efficiency: 60-65%



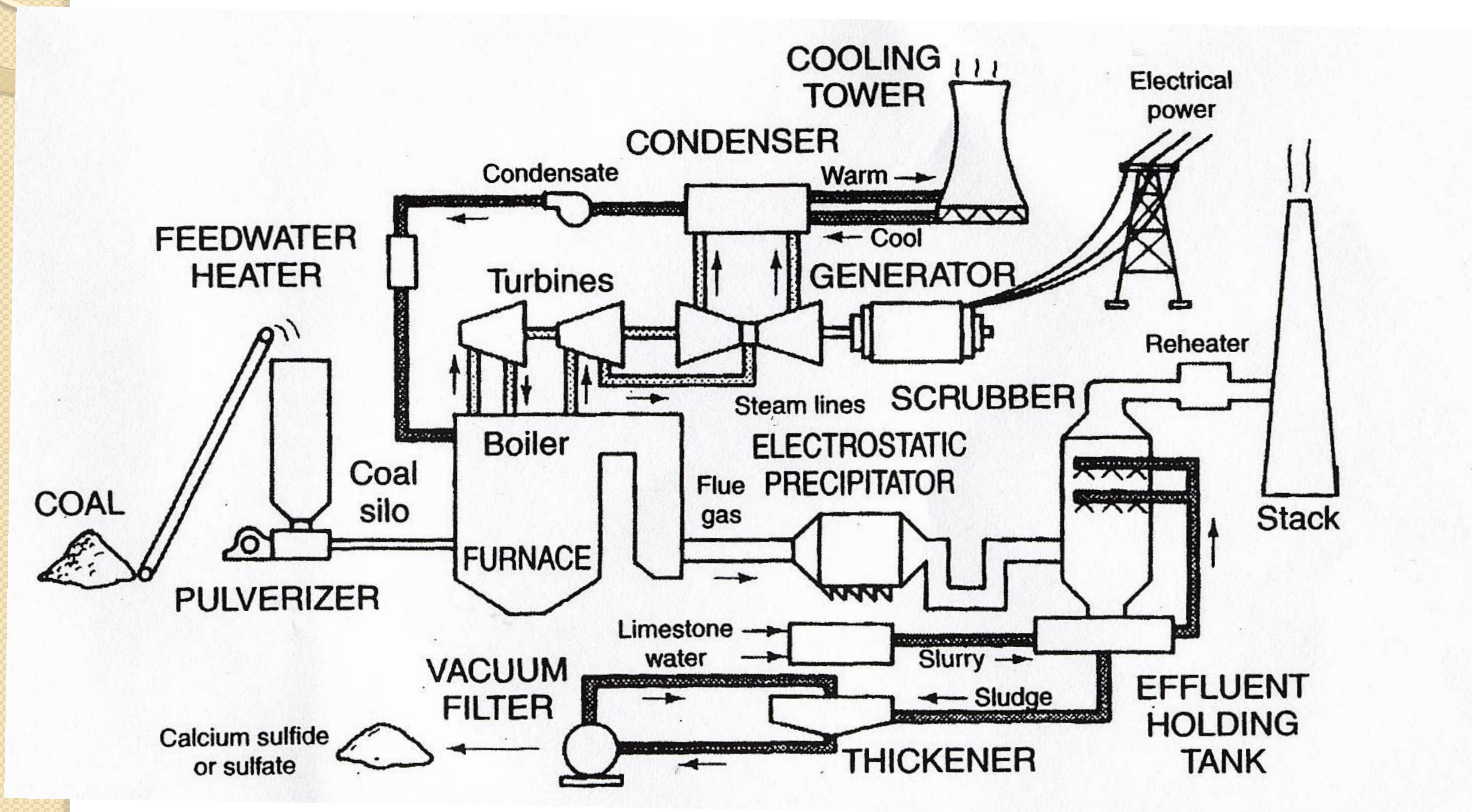
Efficiencies are even higher when the steam is used for district heating or industrial processes.

Coal Plants (shrinking)

- Share of Total: 30%
- 1,300 plants (2012)

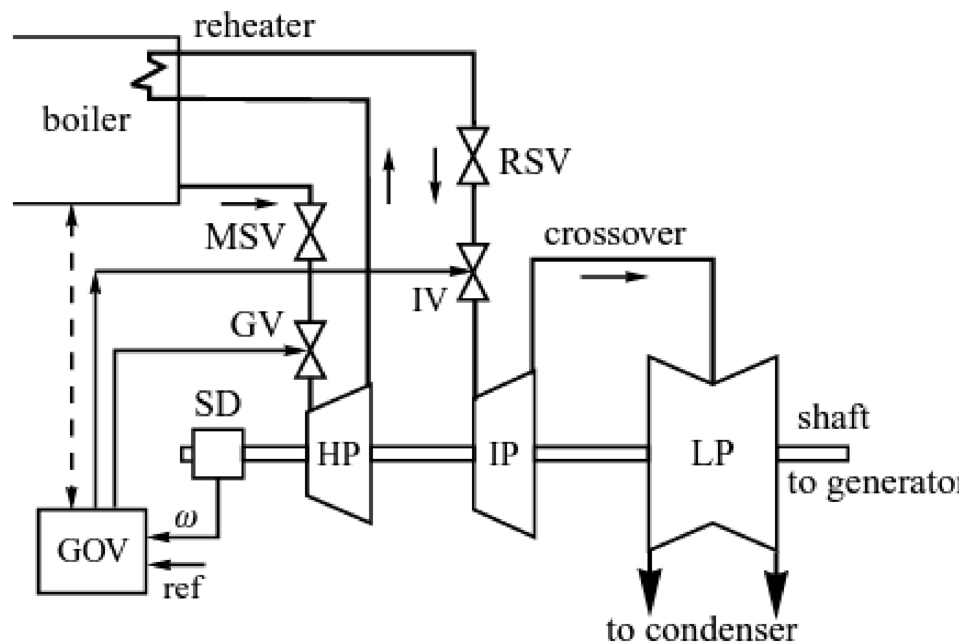
Diagram of a modern coal power plant

(Source: Masters, Renewable and Efficient Electric Power Systems, 2004)



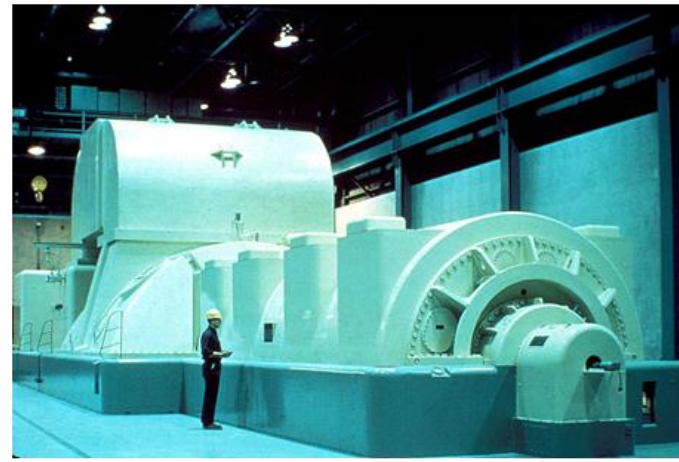
Steam Turbines and their Governors

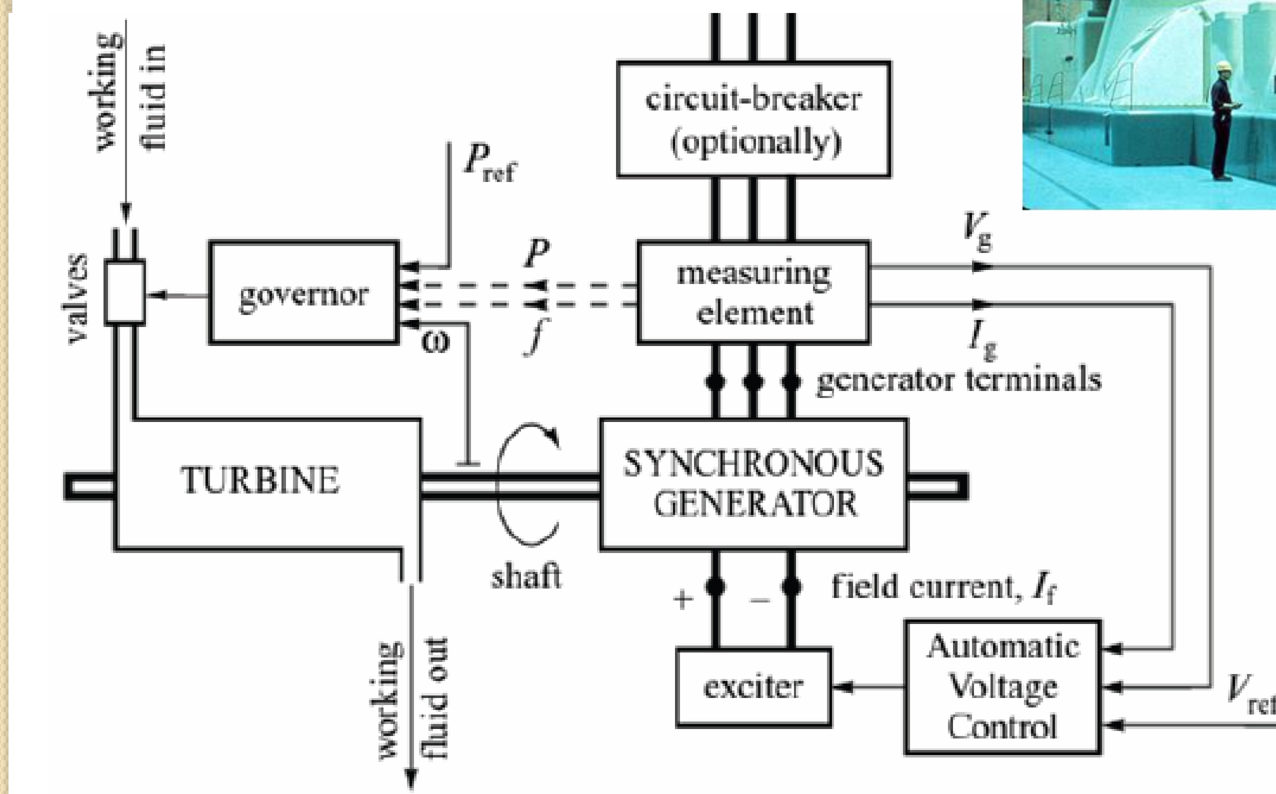
- Steam turbines can have non-reheat, single-reheat or double-reheat.
- The steam flow is controlled by the governor.
- Main and reheat stop valves are normally fully open - they are used only during generator start-up and shut down.



The electric generator

- **Governor** controls turbine torque and power
- **Exciter** controls voltage and reactive power





Nuclear Plants

- Share of Total: 20%
- 61 Plants (2017)

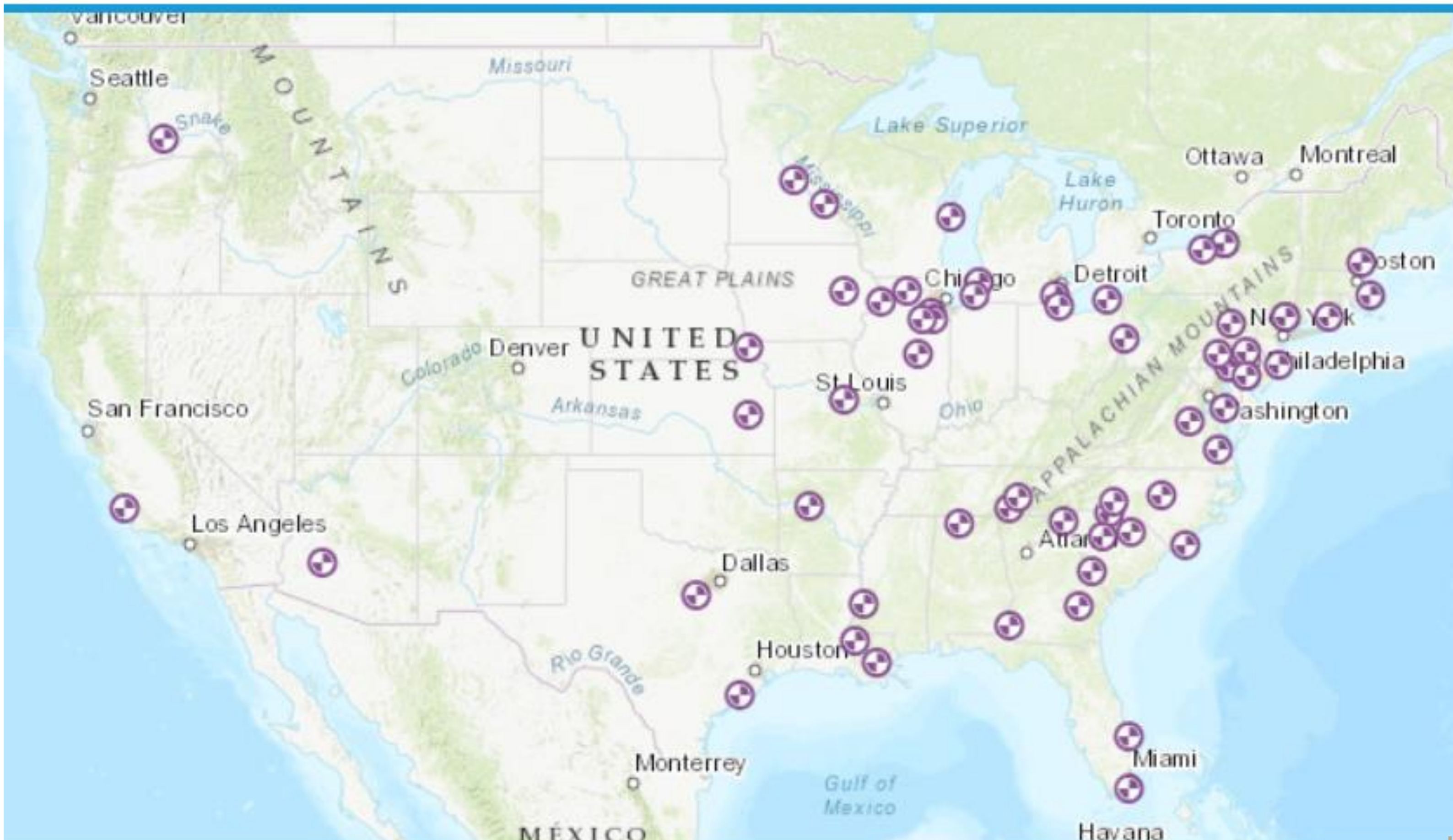
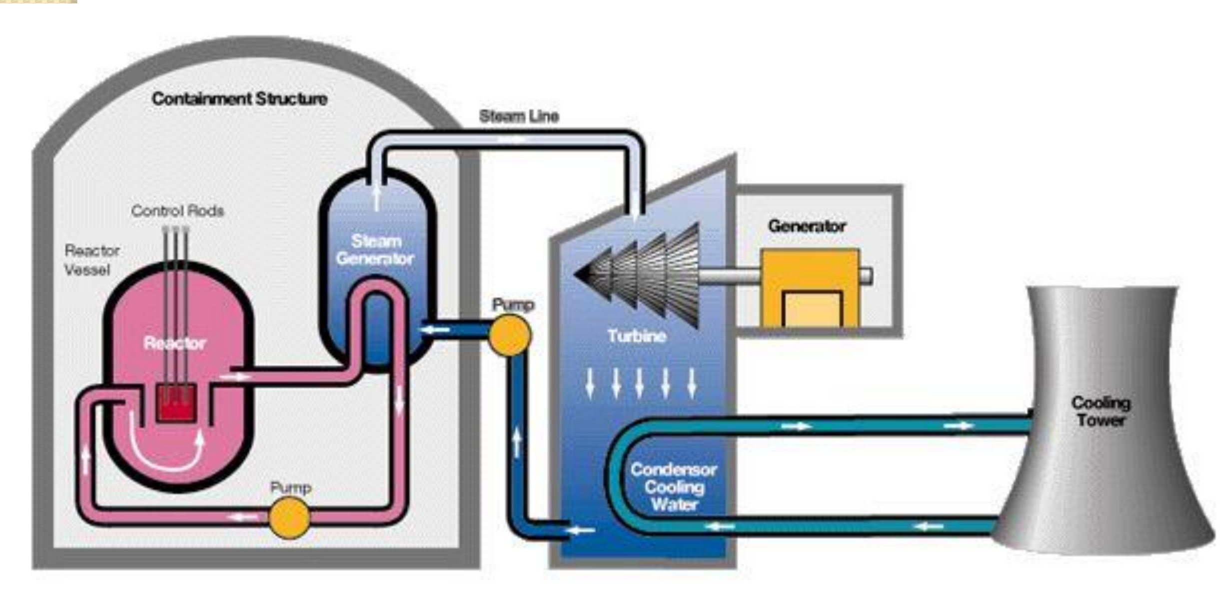
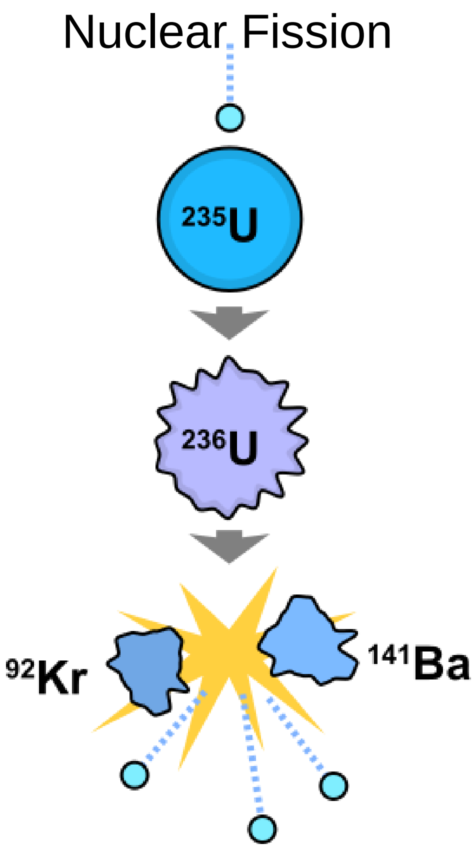


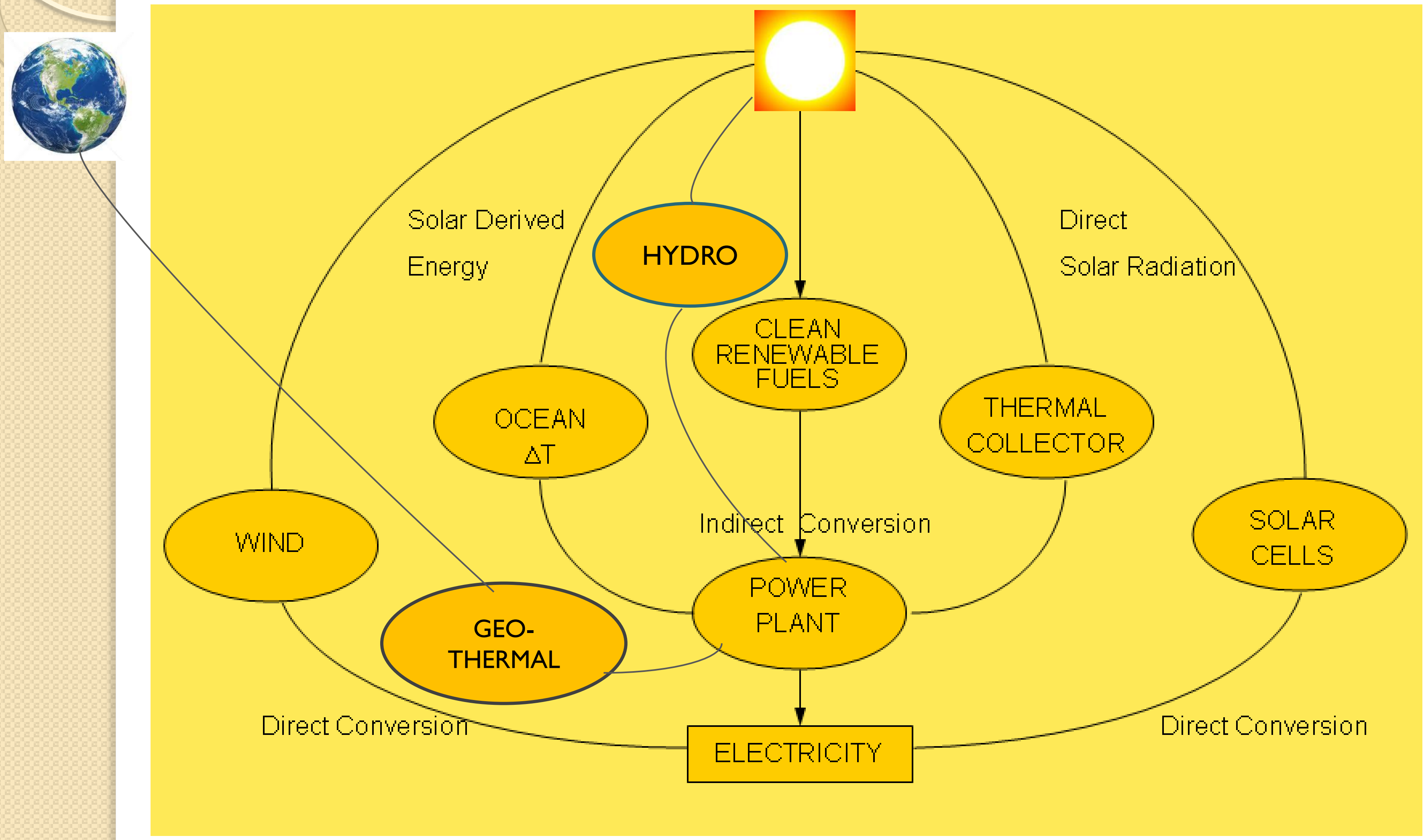
Diagram of a nuclear power plant

- Types of nuclear reactors:
  - Pressurized Water Reactor (PWR)
  - Boiling Water Reactor (BWR)

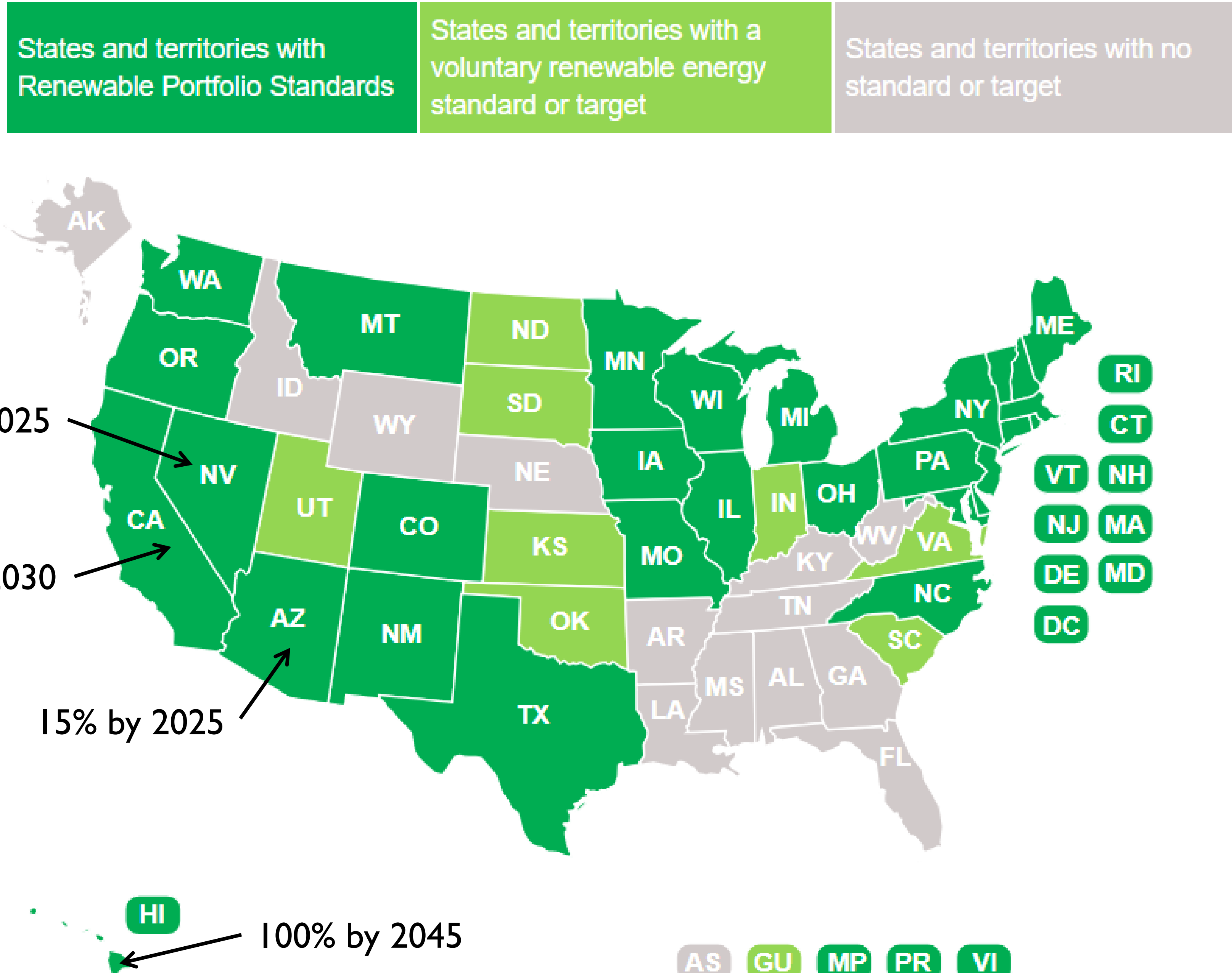




Renewable Resources

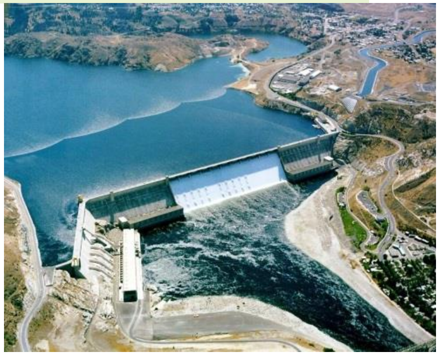


States with RPS

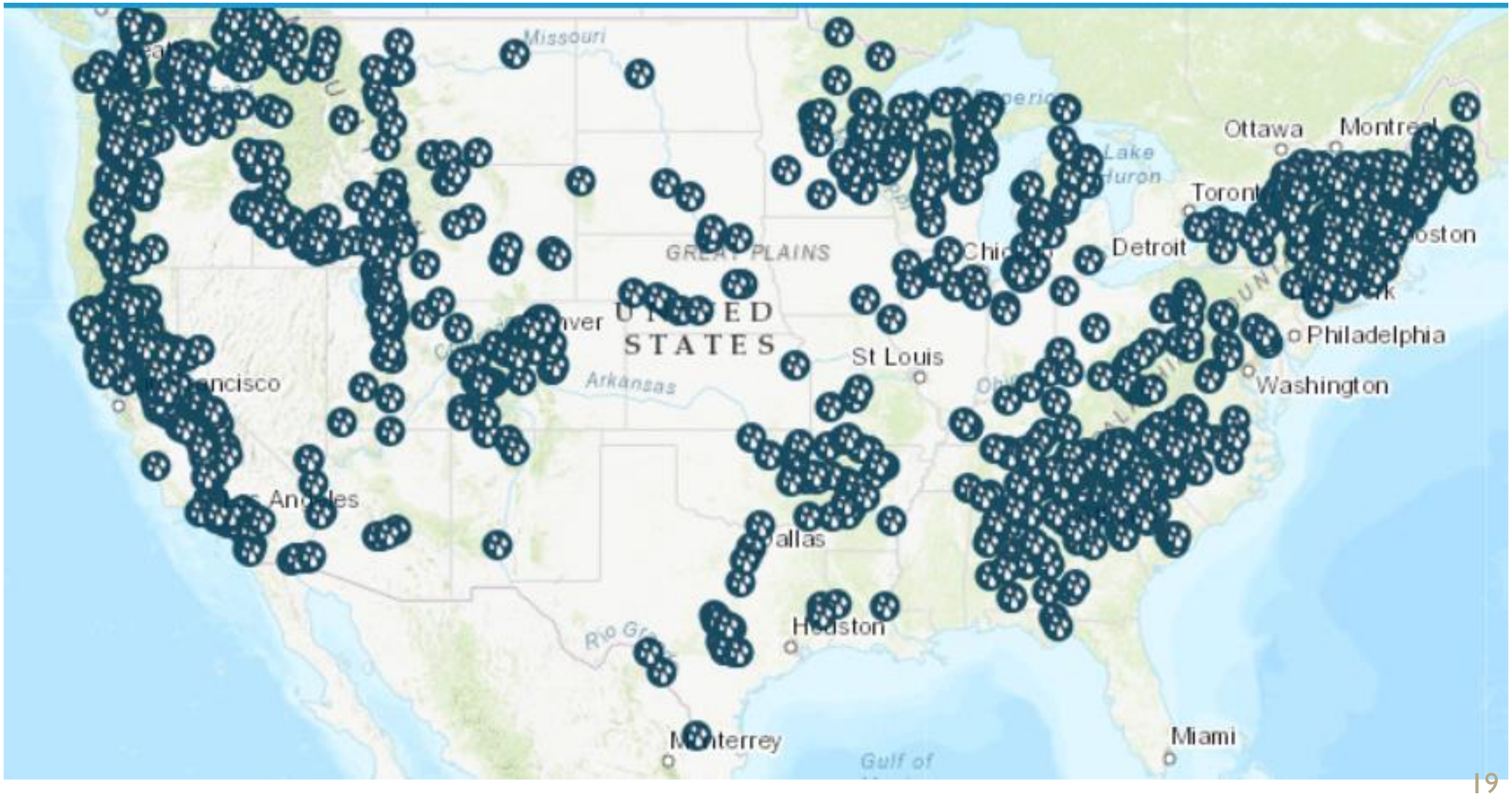


Hydro Plants

Grand Coulee
6,800 MW

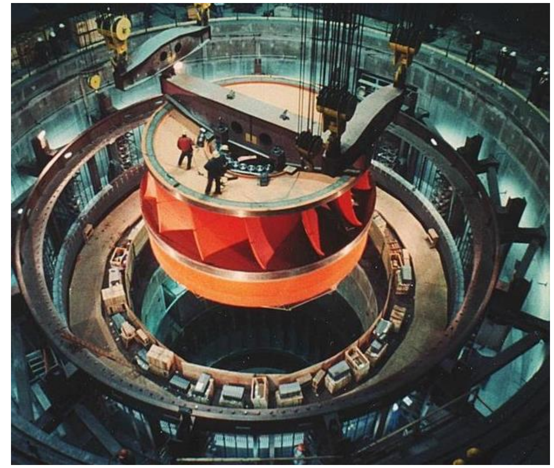


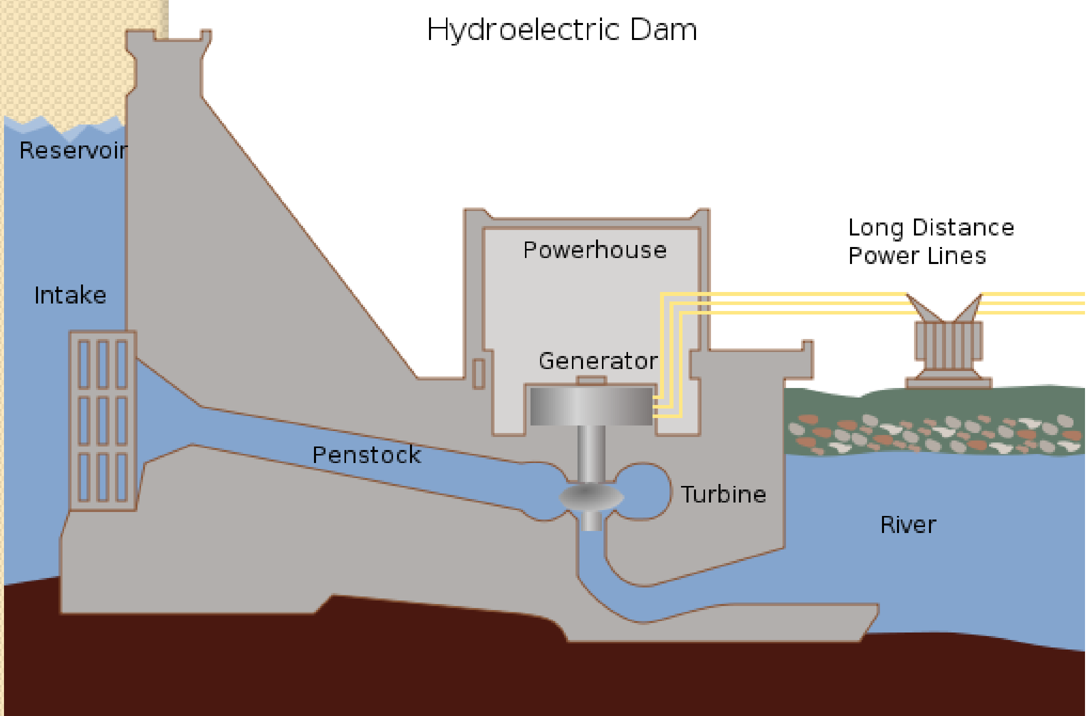
- Share of Total: 7.5%
- 50 Large plants (>100 MW)

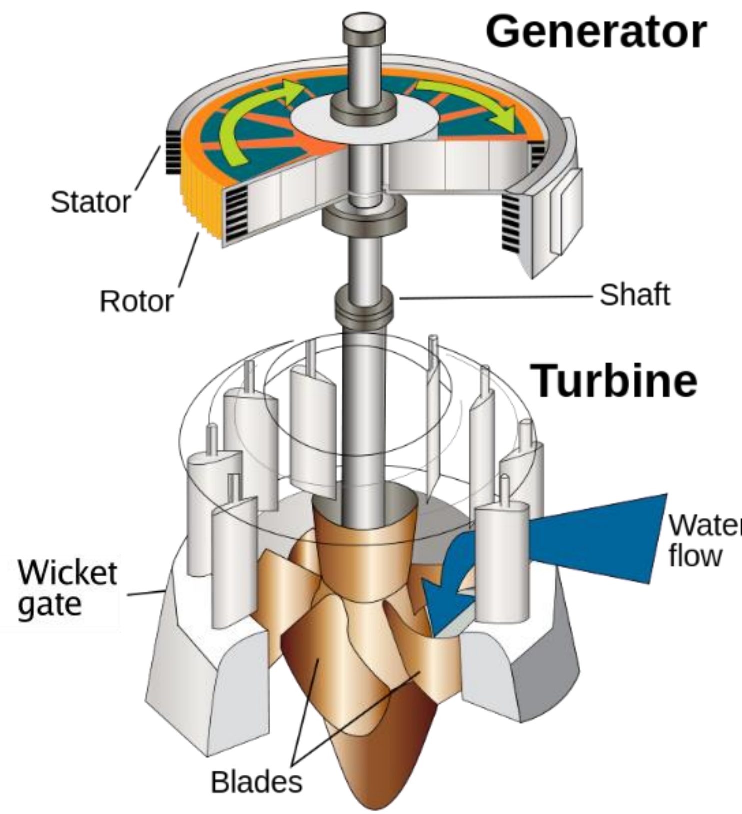


Hydro power plants

- Low and medium head plants use Francis turbines
- High head plants use Pelton wheel turbines

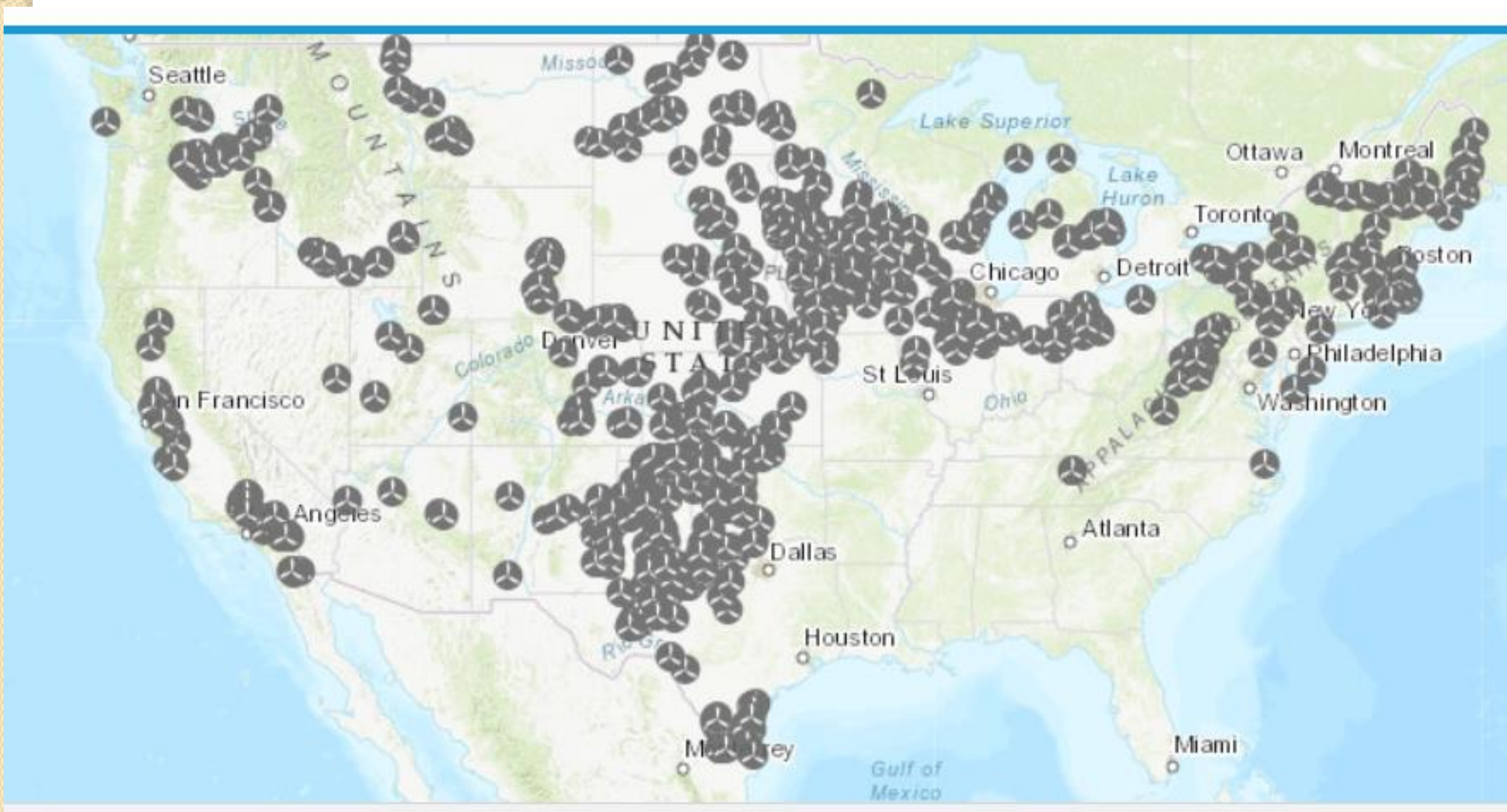






Wind Plants

- Share of Total: 6.5%
- Over 50,000 wind turbines (2017)



US Wind Resource Map

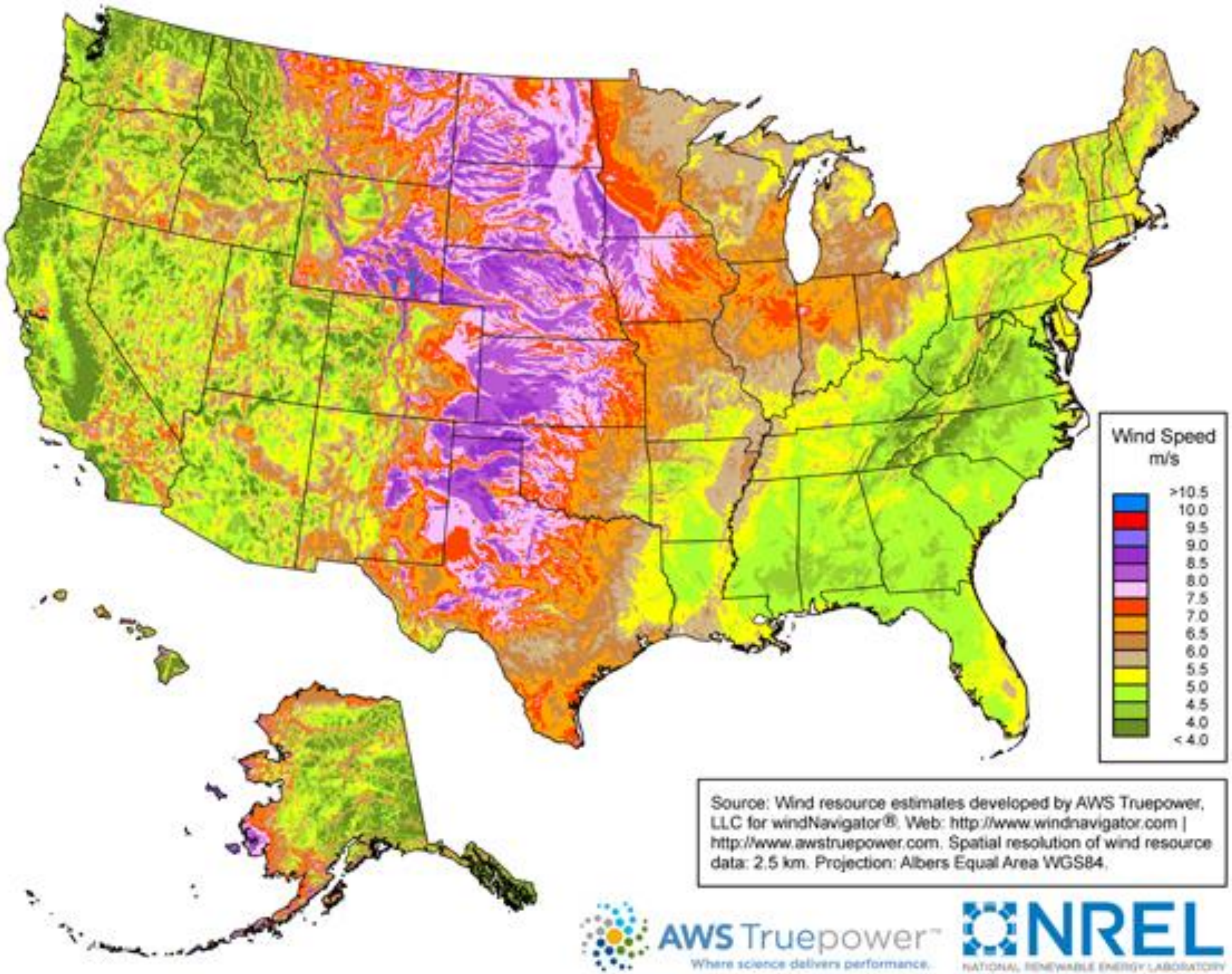
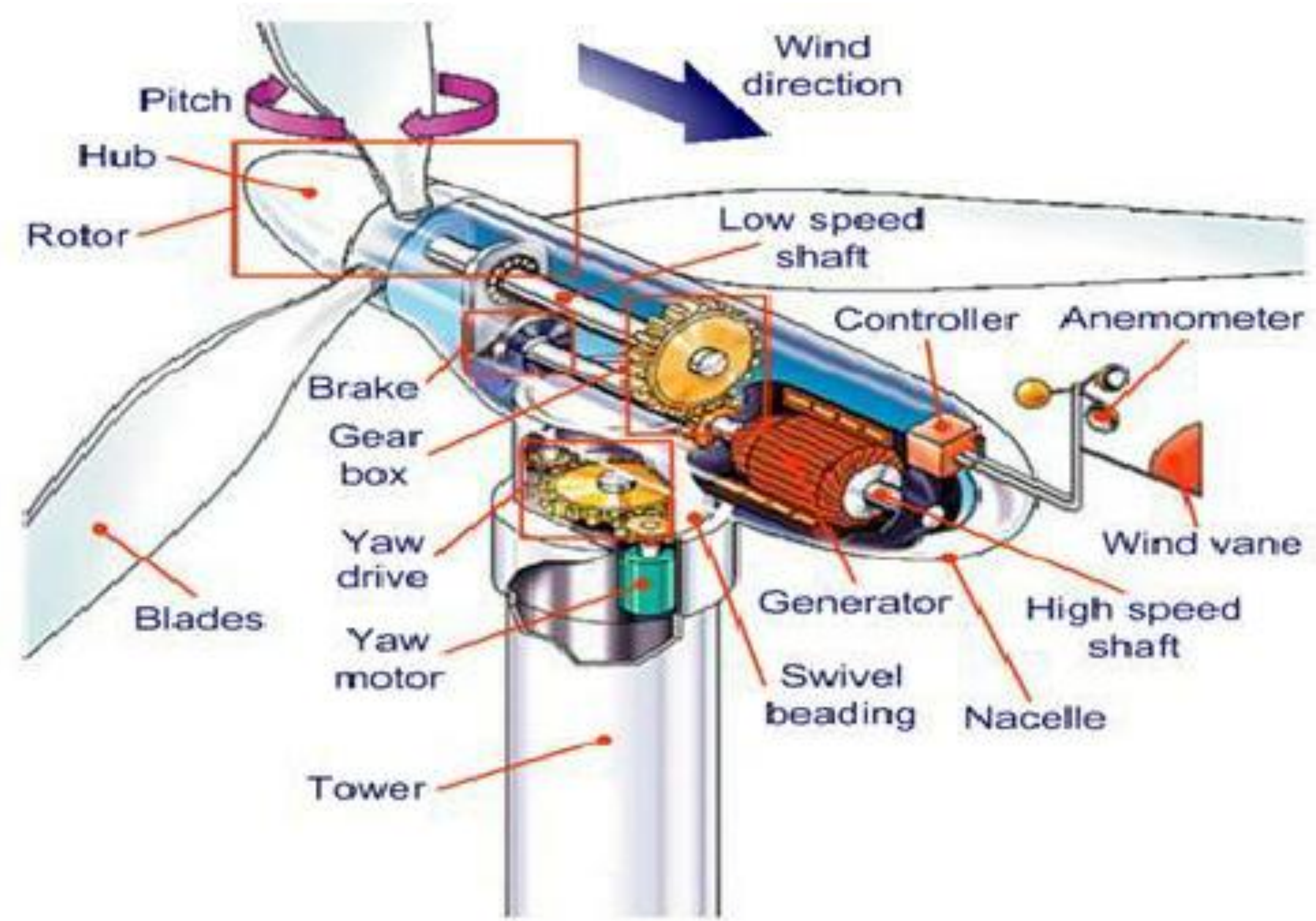
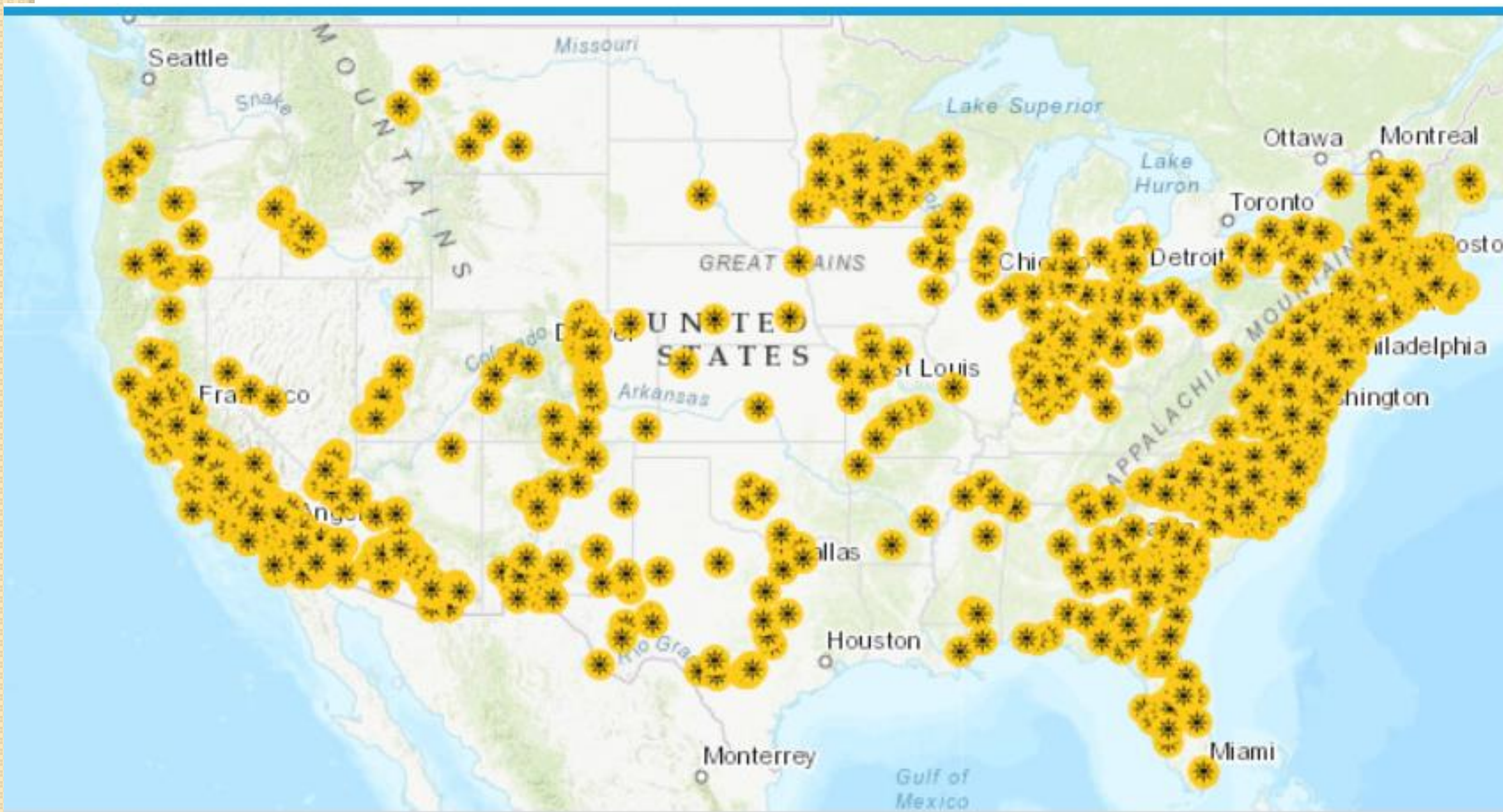


Diagram of a wind turbine generator

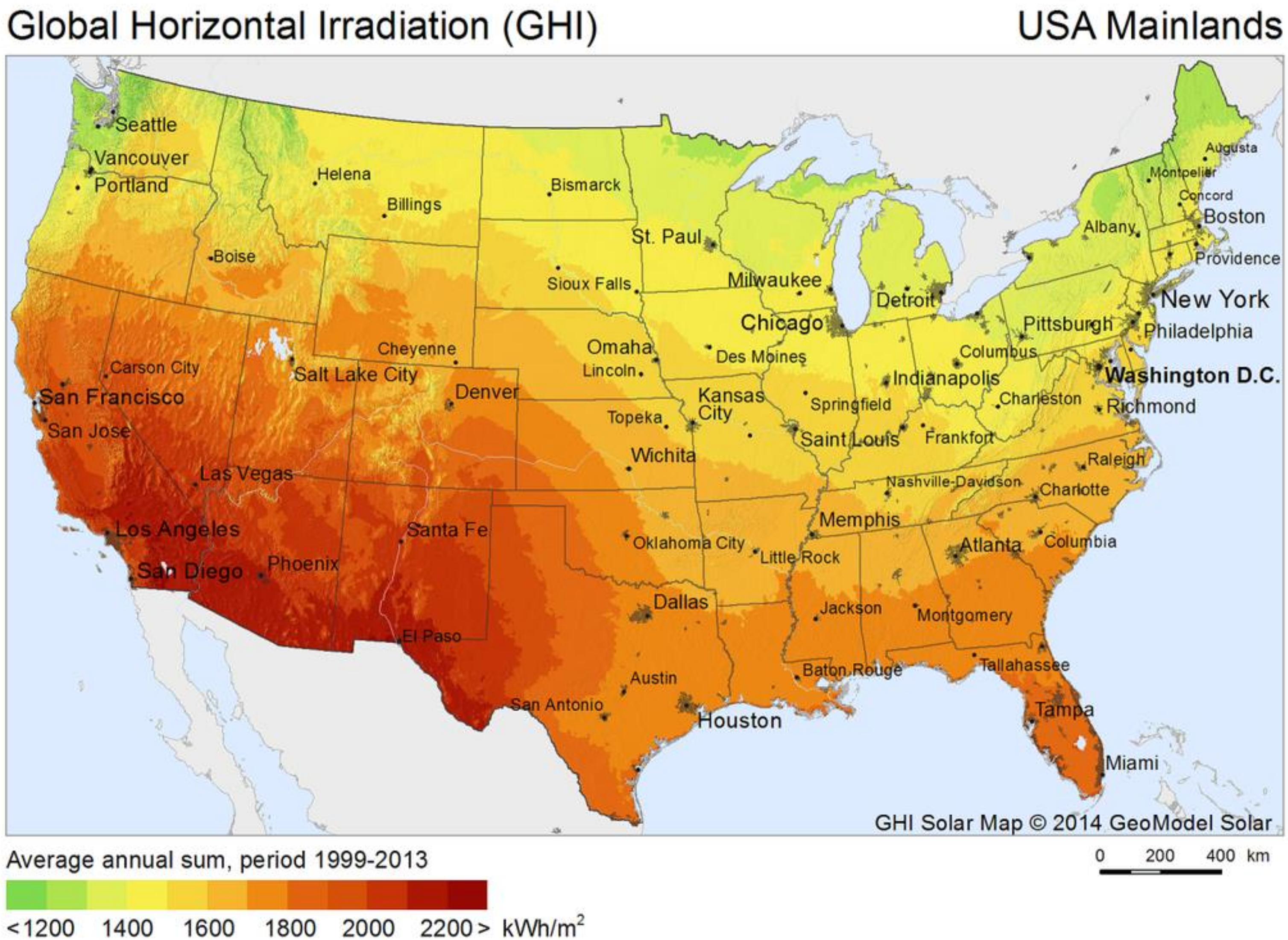


Solar Plants

- Share of Total: 2%

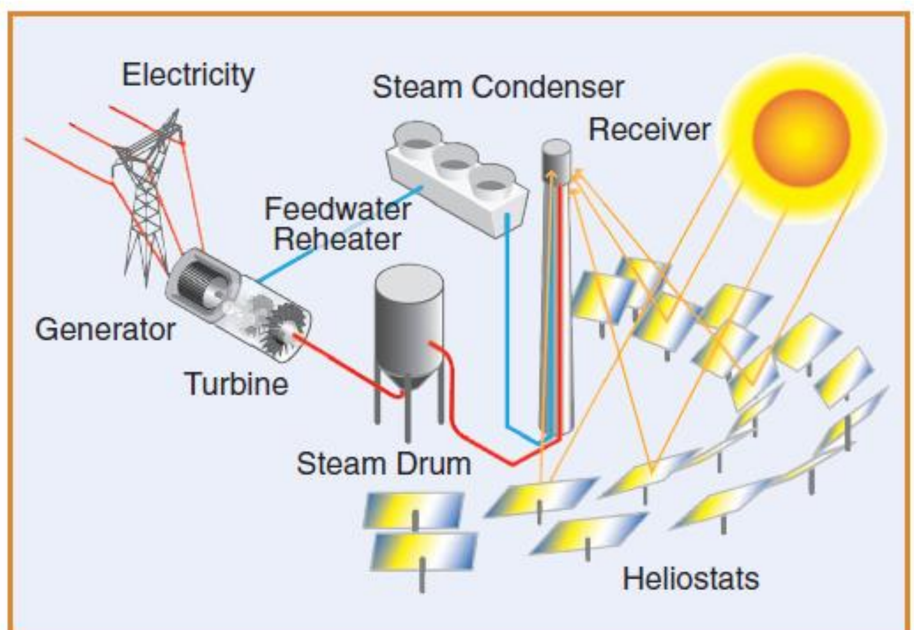


Solar Resource



Power Tower CSP Systems

- Sun-tracking mirrors (heliostats) focus sunlight onto a receiver at the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which in turn is used by turbine generator to produce electricity.
- Some power towers use water/steam as the heat transfer fluid. Other advanced designs are experimenting with molten nitrate salt because of its superior heat-transfer capabilities.

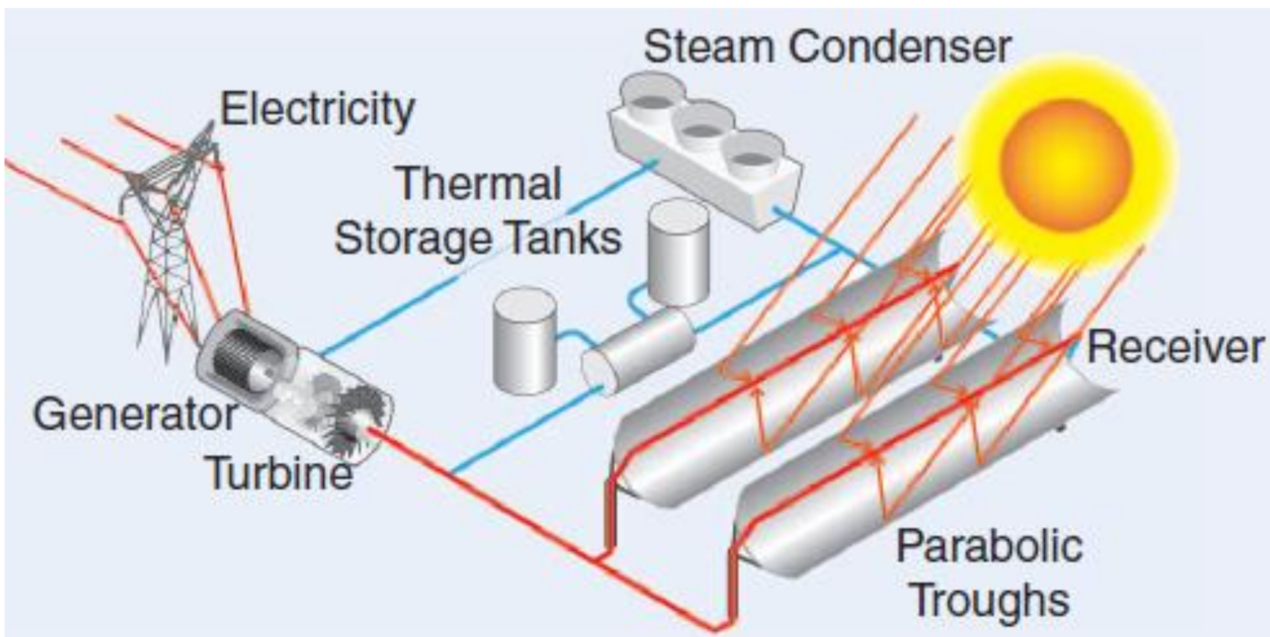


World's Largest - Ivanpah Solar, CA: 400 MW

Power Tower CSP in Nevada: Tonopah – 110 MW

Linear CSP Systems

- Linear CSP collectors capture the sun's energy with large mirrors that reflect and focus the sunlight onto a linear receiver tube.
- The receiver contains a fluid that is heated by the sunlight and then used to create steam that spins a turbine driving a generator to produce electricity.



Linear CSP Plant, Belridge, CA – 850 MW

Linear CSP in Nevada: NV Solar I (65 MW)

Linear CSP in Arizona: Gila Bend (280 MW)

Drought Issue!

Average annual precipitation in desert southwest : 10 cm!

Dry Cooling
For CSP

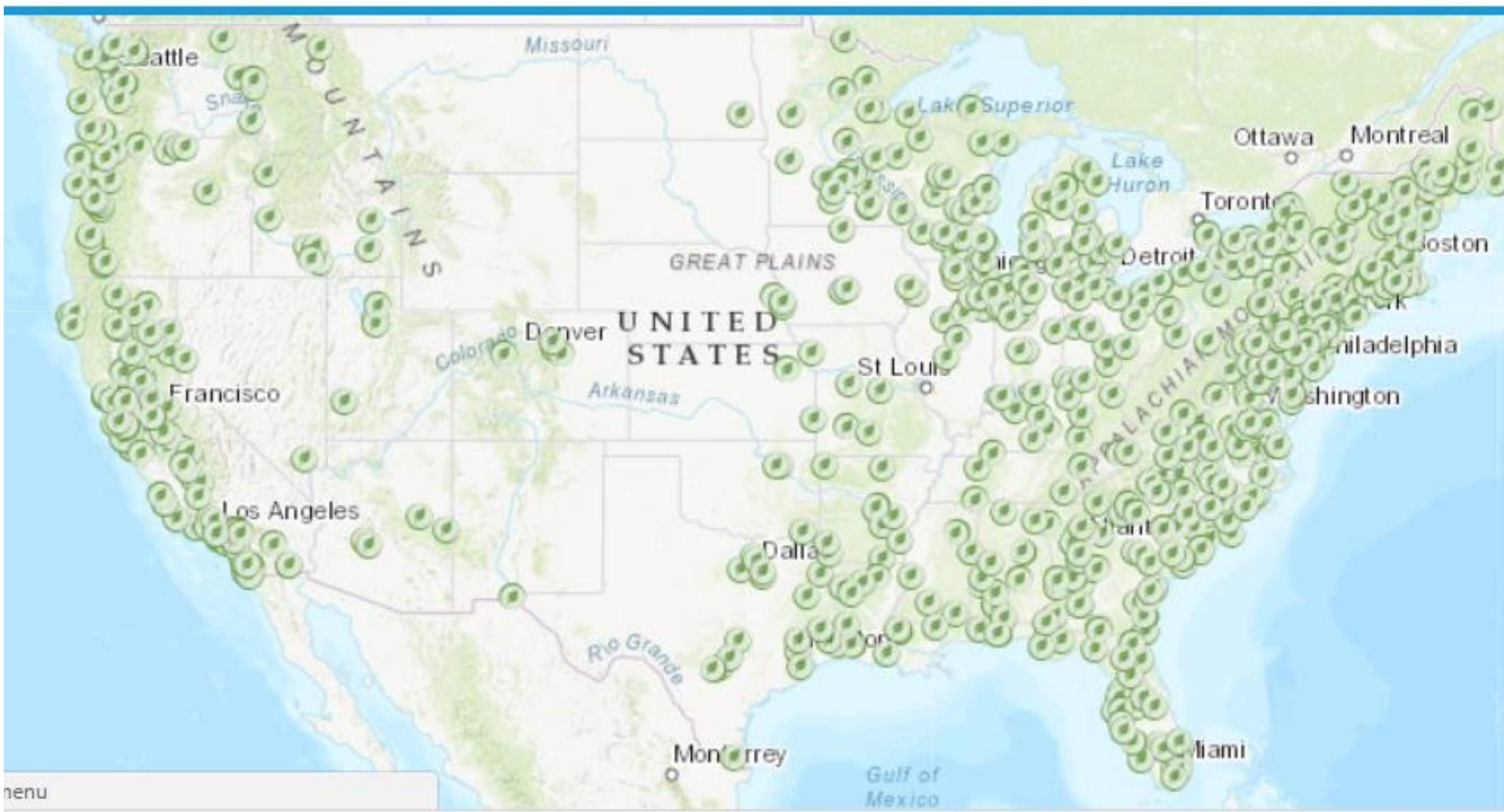
Largest PV Systems in CA – several over 500 MW

Large Solar PV plants in Nevada

Large Solar PV plants in Arizona

Biomass Plants

- Share of Total: 1.5%



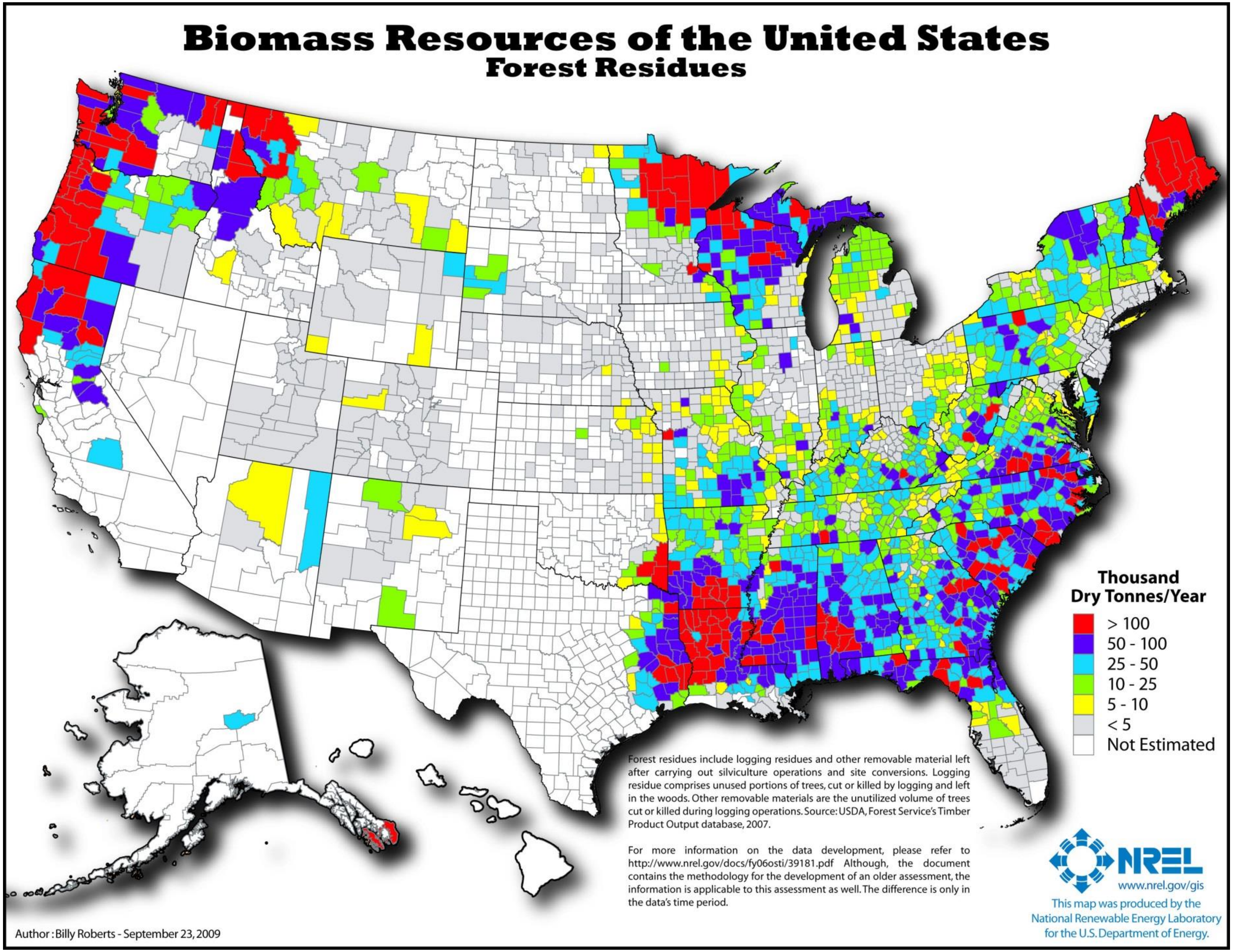
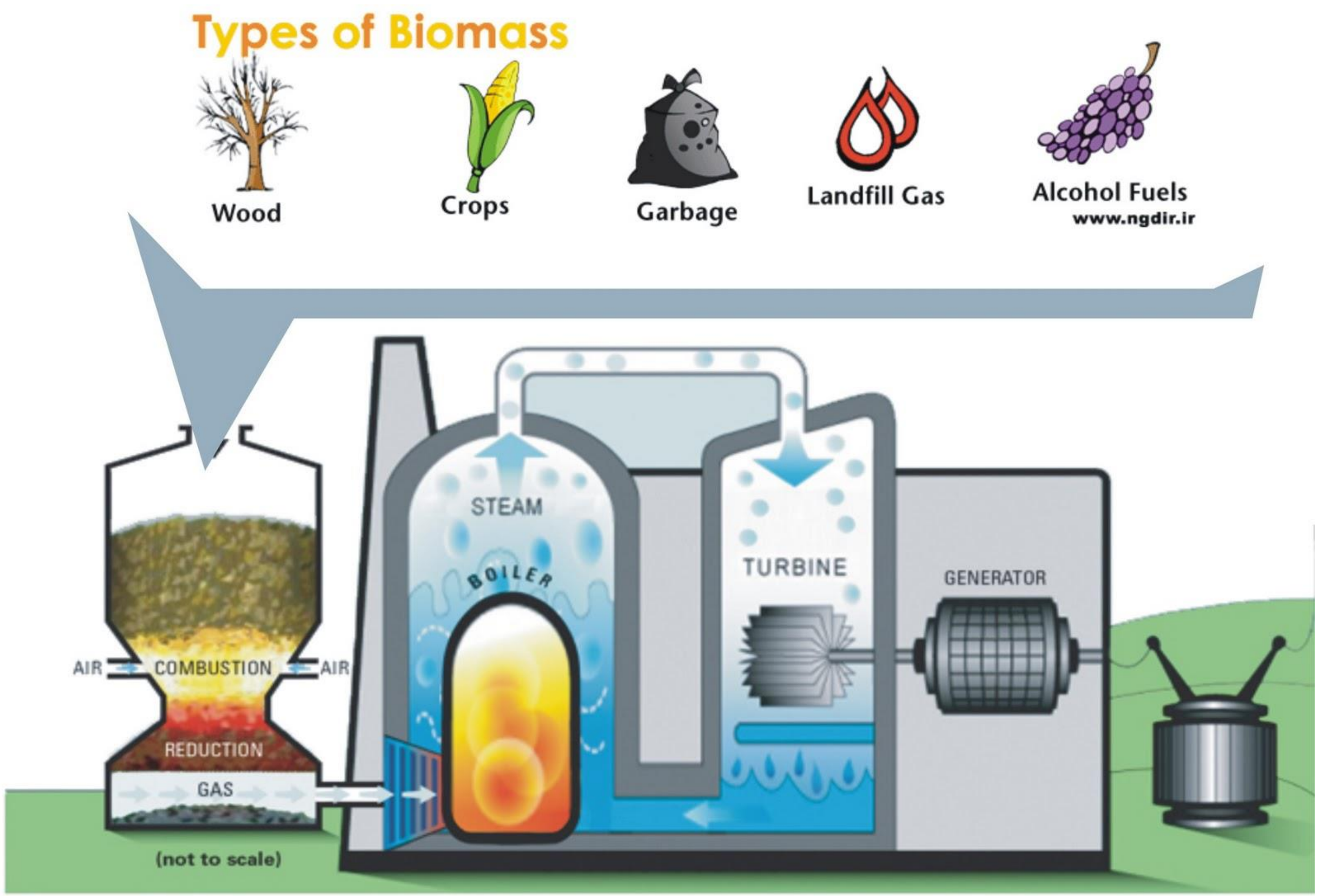

Biomass Resources of the United States
Forest Residues
Thousand
Dry Tonnes/Year
> 100
50 - 100
25 - 50
10 - 25
5 - 10
< 5
Not Estimated
Forest residues include logging residues and other removable material left after carrying out silviculture operations and site conversions. Logging residue comprises unused portions of trees, cut or killed by logging and left in the woods. Other removable materials are the unutilized volume of trees cut or killed during logging operations. Source: USDA, Forest Service's Timber Product Output database, 2007.
For more information on the data development, please refer to http://www.nrel.gov/docs/fy06osti/39181.pdf Although, the document contains the methodology for the development of an older assessment, the information is applicable to this assessment as well. The difference is only in the data's time period.
www.nrel.gov/gis
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.
Author: Billy Roberts - September 23, 2009

Diagram of a biomass power plant



Geothermal Plants

- Share of Total: 0.5%

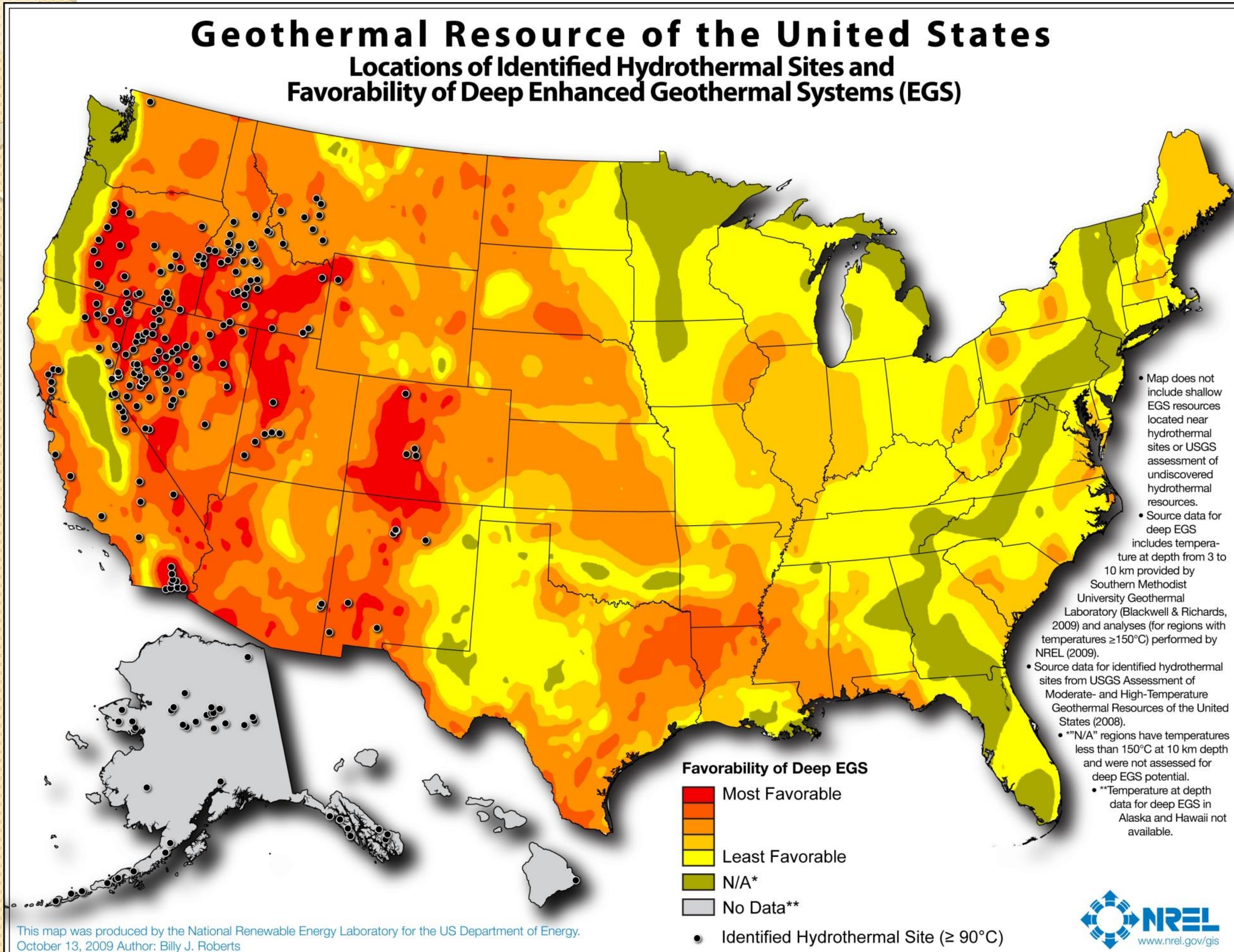
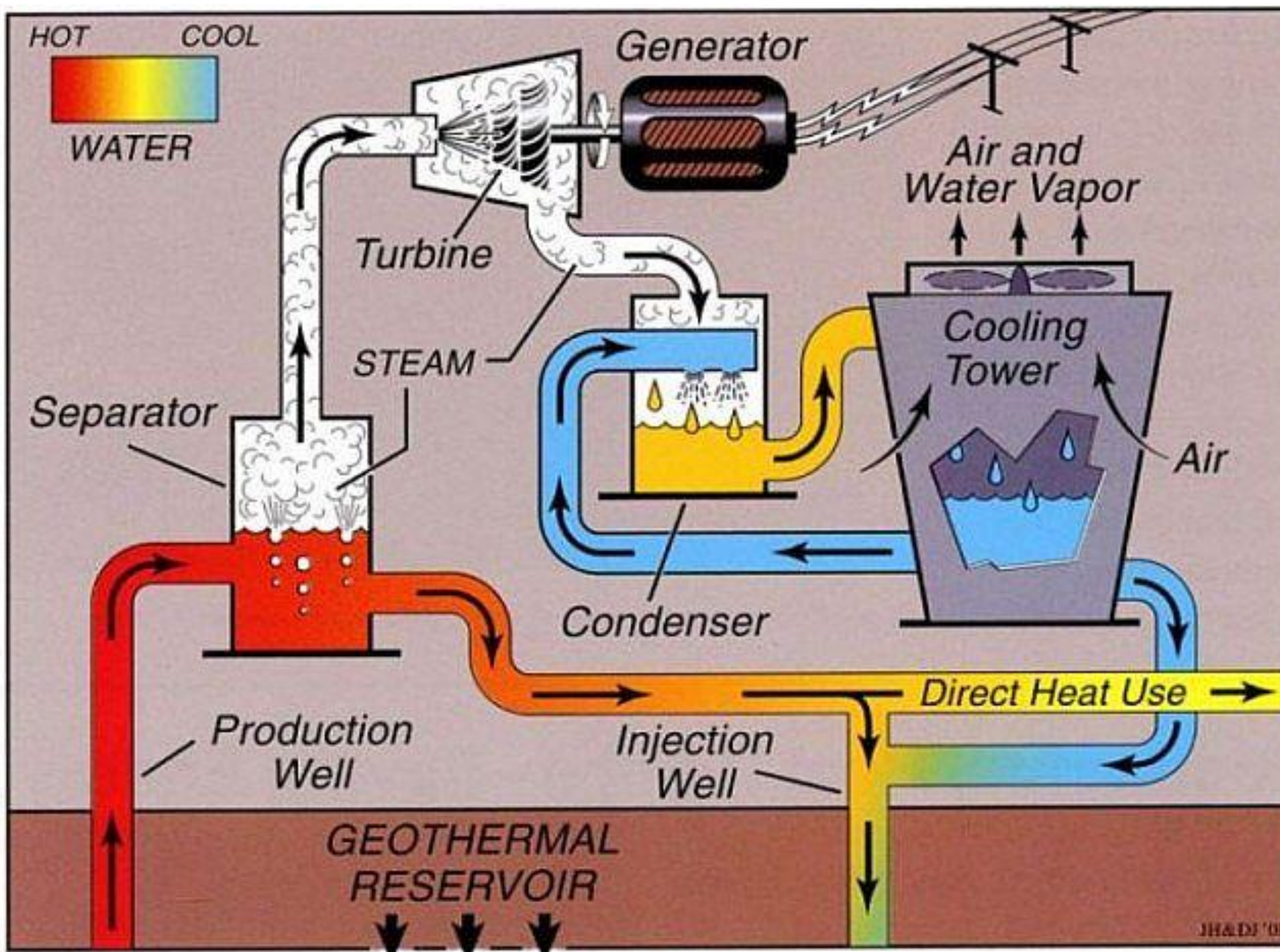
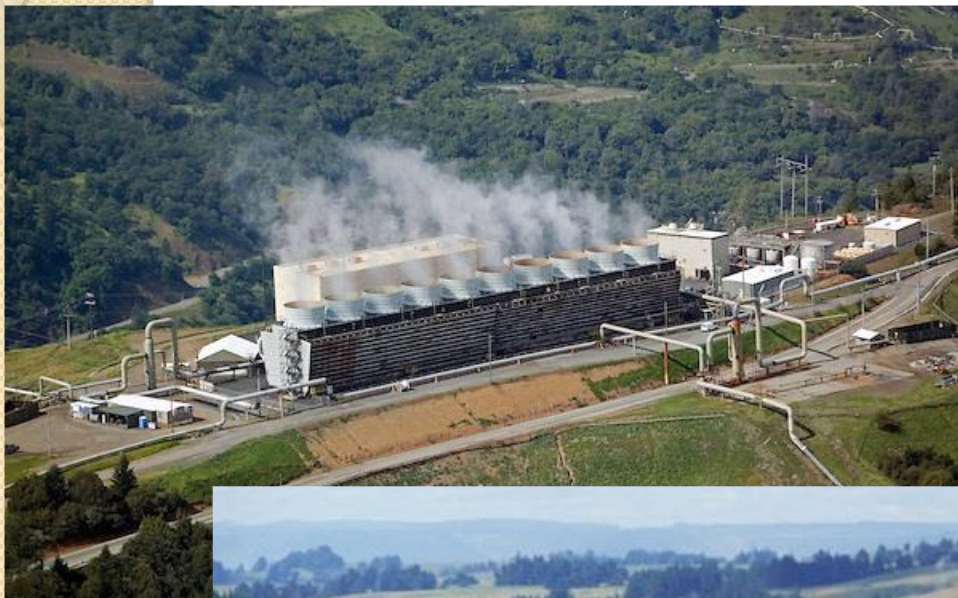

Geothermal Resource of the United States
Locations of Identified Hydrothermal Sites and
Favorability of Deep Enhanced Geothermal Systems (EGS)
• Map does not include shallow EGS resources located near hydrothermal sites or USGS assessment of undiscovered hydrothermal resources.
• Source data for deep EGS includes temperature at depth from 3 to 10 km provided by Southern Methodist University Geothermal Laboratory (Blackwell & Richards, 2009) and analyses (for regions with temperatures ≥150°C) performed by NREL (2009).
• Source data for identified hydrothermal sites from USGS Assessment of Moderate- and High-Temperature Geothermal Resources of the United States (2008).
• *"N/A" regions have temperatures less than 150°C at 10 km depth and were not assessed for deep EGS potential.
• **Temperature at depth data for deep EGS in Alaska and Hawaii not available.
Favorability of Deep EGS
Most Favorable
Least Favorable
N/A*
No Data**
Identified Hydrothermal Site (≥ 90°C)
This map was produced by the National Renewable Energy Laboratory for the US Department of Energy.
October 13, 2009 Author: Billy J. Roberts
NREL
www.nrel.gov/gis

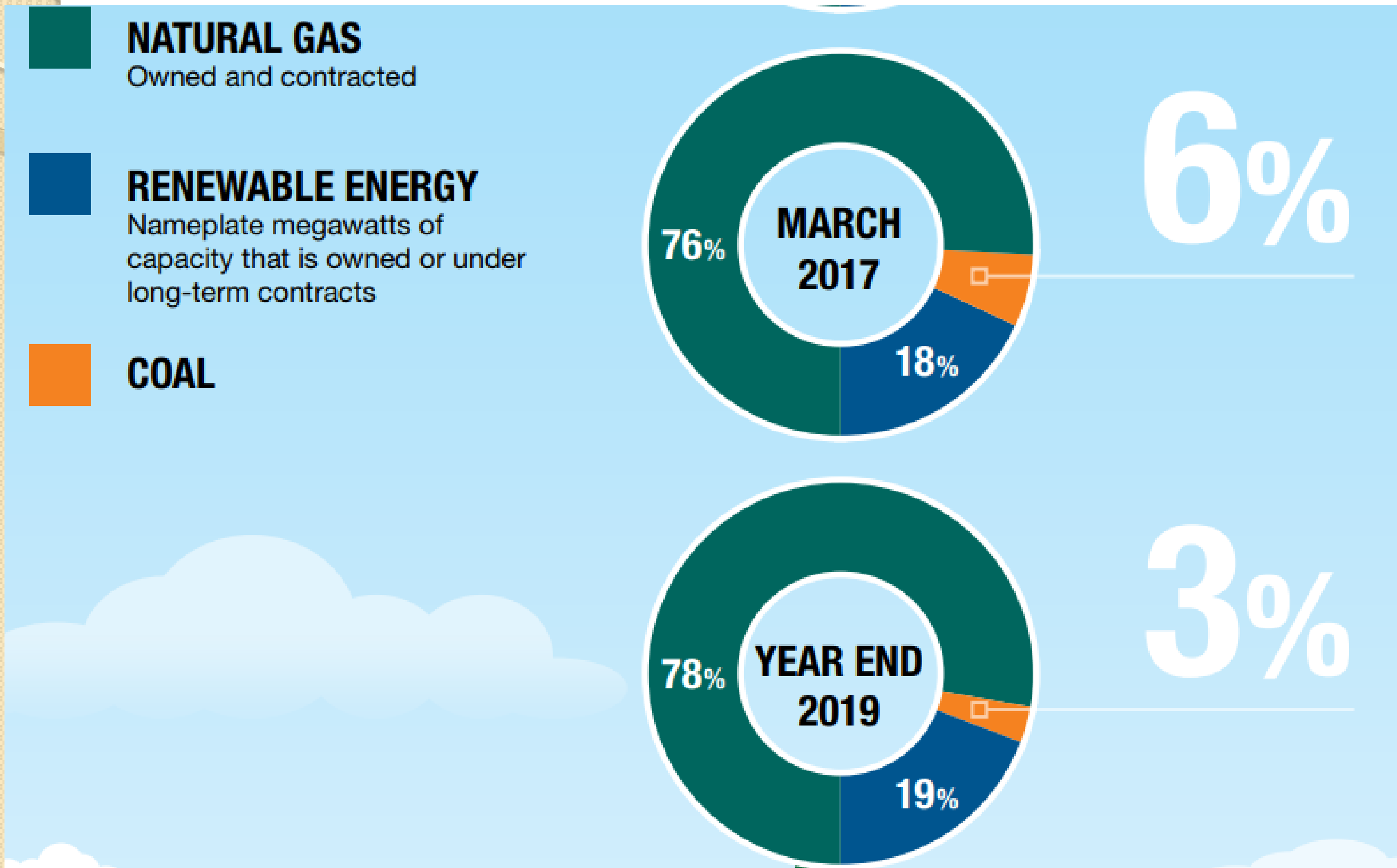
Diagram of a flash steam geothermal power plant



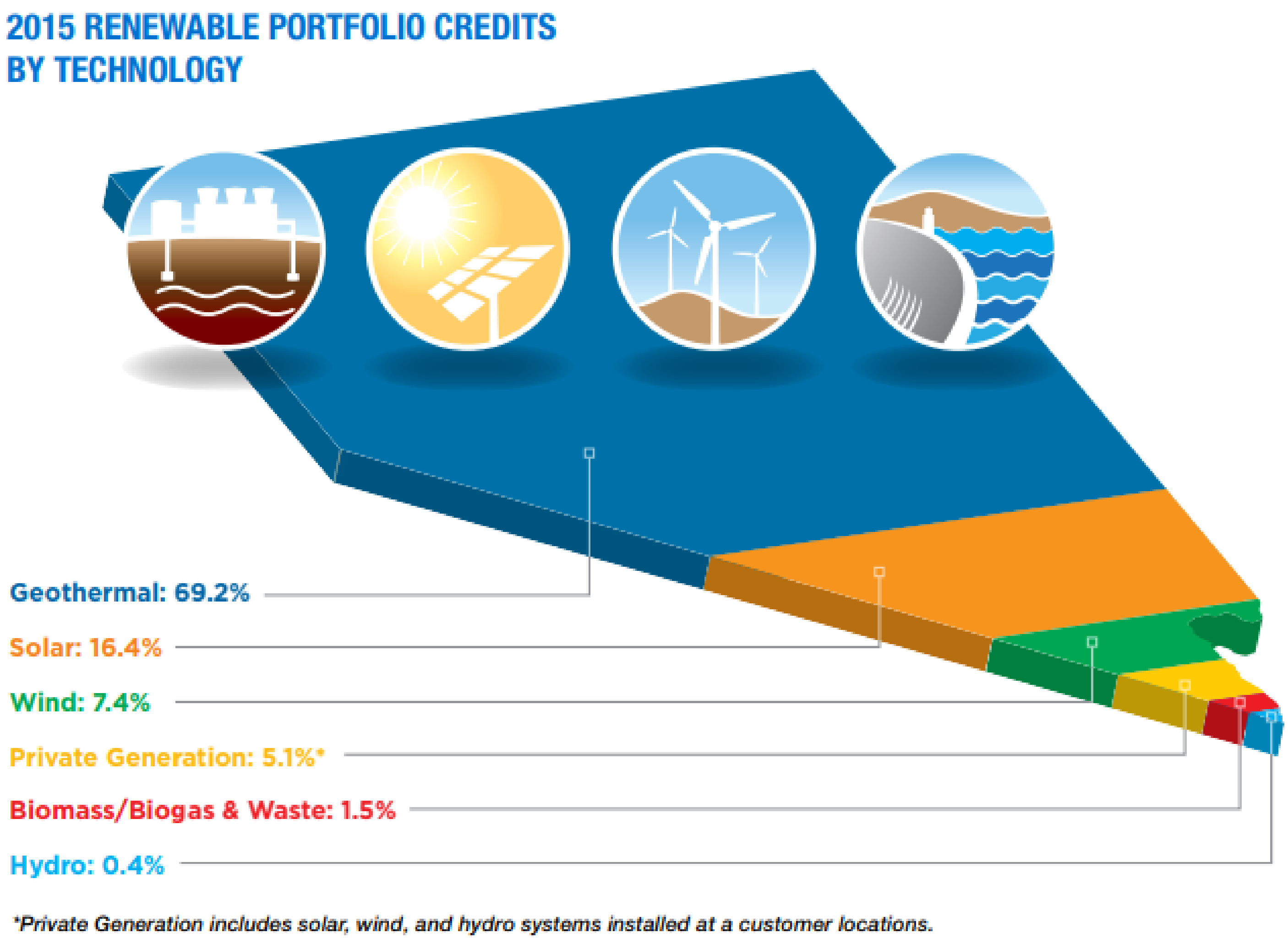
Geothermal plants in NV & CA



Nevada Power Generation by Source



Nevada Renewables



List of Nevada Renewable Plants

Geothermal: 550 MW
Solar: 1000 MW
Solar rooftops: 250 MW
Hydro: 250 MW
Wind: 150 MW
Other: 20 MW

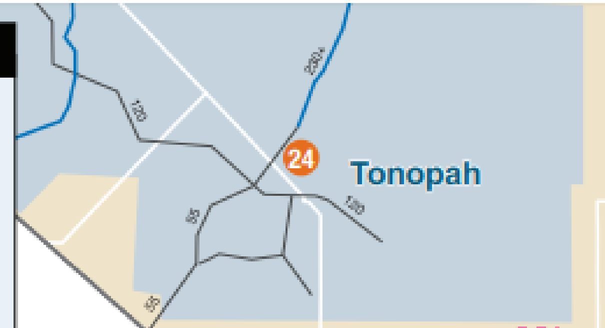
Total: 2.22 GW
Peak Load: 7.3 GW

RENEWABLE ENERGY PROJECTS

NAMEPLATE MEGAWATTS AC

	Project	MW
	GEOTHERMAL	
1	Beowawe Power	17.7
2	Brady	24.0
3	Burdette	26.0
4	Desert Peak 2	25.0
5	Galena 2	13.0
6	Galena 3	26.5
7	Homestretch	5.6
8	Jersey Valley	22.5
9	McGinness Hills	96.0
10	NGP Blue Mountain	49.5
11	Salt Wells	23.6
12	Soda Lake 1	3.6
13	Soda Lake 2	19.5
14	Steamboat 1A**	2.0
15	Steamboat 2	13.4
16	Steamboat 3	13.4
17	Stillwater Geothermal	47.2
18	Tuscarora	32.0
19	USG San Emidio	11.8
	SOLAR	
20	ACE Searchlight Solar	17.5
21	Apex Nevada Solar	20.0
22	Boulder Solar I	100.0
23	Boulder Solar II	50.0
24	Crescent Dunes Solar	110.0
25	Fort Churchill Solar Array	19.5
26	Mountain View Solar	20.0
27	Nellis 1 (Solar Star)**	13.2
28	Nellis Solar Array 2	15.0
29	Nevada Solar One	69.0
30	Silver State Solar North	52.0
31	Spectrum Nevada Solar	30.0
32	Stillwater Solar PV	22.0
33	SunPower (Las Vegas Valley Water District)**	3.0
34	Switch Station 1	100.0
35	Switch Station 2	79.0
36	Techren Solar 1*	100.0
37	Techren Solar 2*	200.0
38	Techren Solar 3*	25.0
39	Techren Solar 4*	25.0
40	Turquoise Solar*	50.0

* Pending regulatory approval, in development or under construction.
** Portfolio credits only



RENEWABLE ENERGY PROJECTS

NAMEPLATE MEGAWATTS AC

	Project	MW
	HYDRO	
41	Fleish (TMWA)	2.4
42	Frank Hooper	0.8
43	Hoover Dam (Excluded from Renewable Portfolio Standard)	237.6
44	New Lahontan (TCID)	4.0
45	Verdi (TWMA)	2.4
46	Washoe (TWMA)	2.5
	WIND	
47	Spring Valley Wind	151.8
	BIOMASS / METHANE / OTHER	
48	Apex Landfill Renewable Energy	12.0
49	Goodsprings Energy Recovery Station	7.5
50	Lockwood Renewable Energy Facility	3.2
51	Truckee Meadows Water Reclamation Facility**	0.8

RENEWABLEGENERATIONS PROJECTS (Statewide)

Total Incentivized Private Rooftop Solar, etc. 201.1

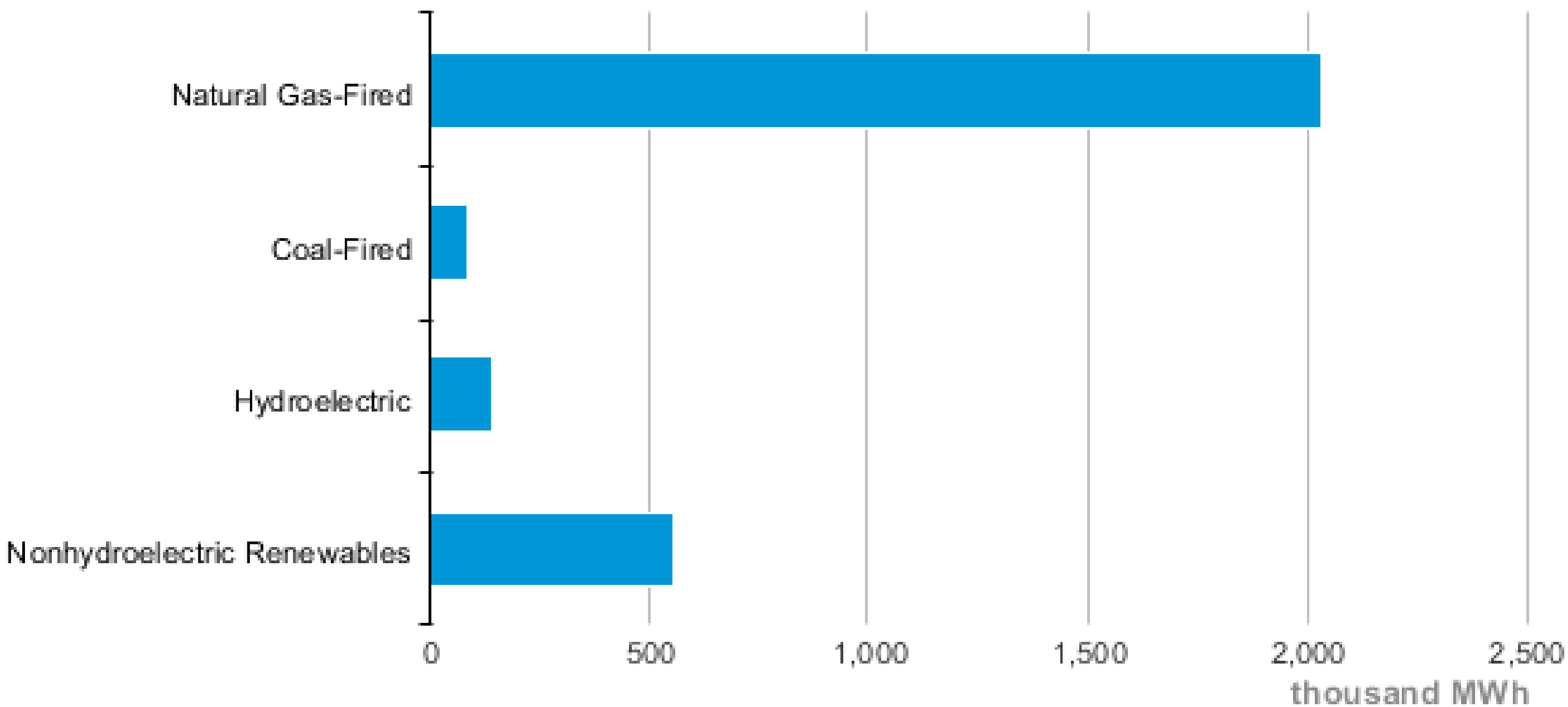
Total NV Energy Clean Energy Resources (MW)........2,218.6

ENERGY EFFICIENCY

Peak Demand Reduction
Statewide .... 519 Megawatts

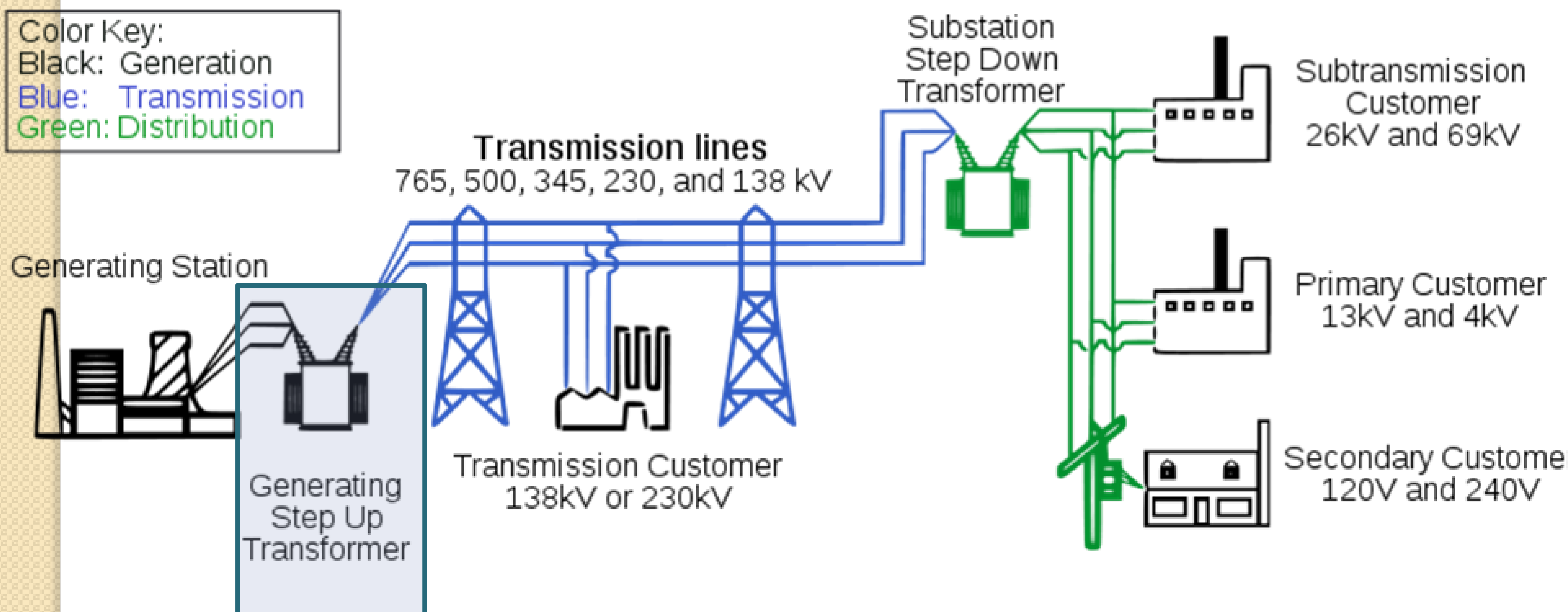
Calculated for Years 2005 through 2017

Nevada Net Electricity Generation by Source, Jan. 2018



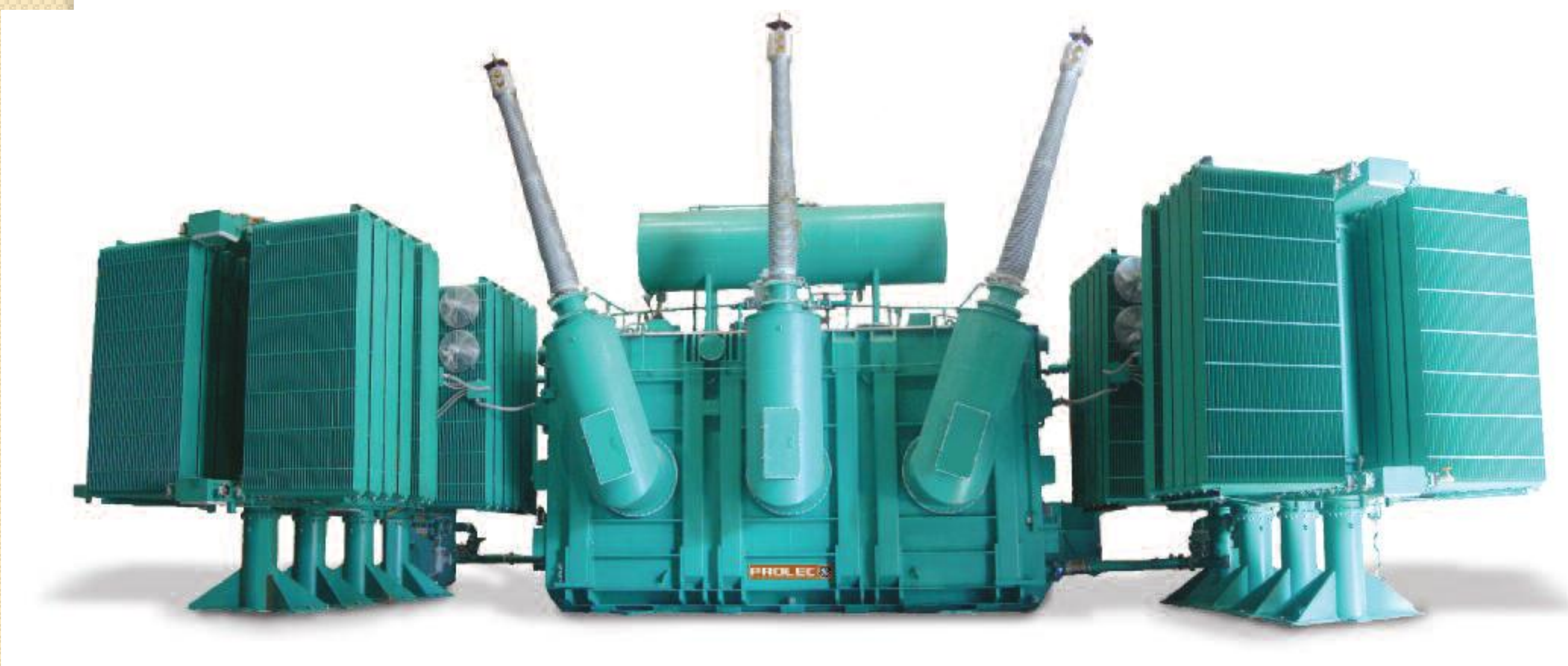
Source: Energy Information Administration, Electric Power Monthly

Basic Conventional Power System Layout

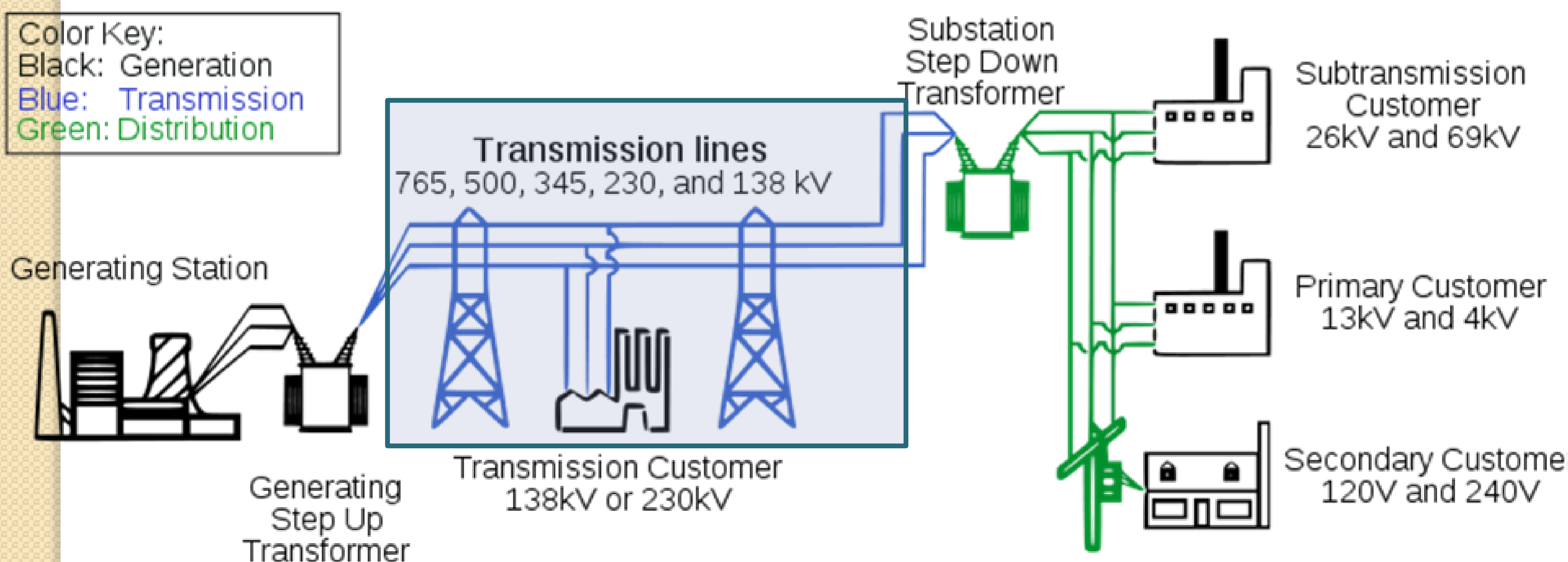


Step-up (Station) transformers:

- Size up to 1000 MVA
- generator voltage up to 25 kV
- Transmission voltage up to 765 kV
- Forced Air and Forced Oil Cooling.

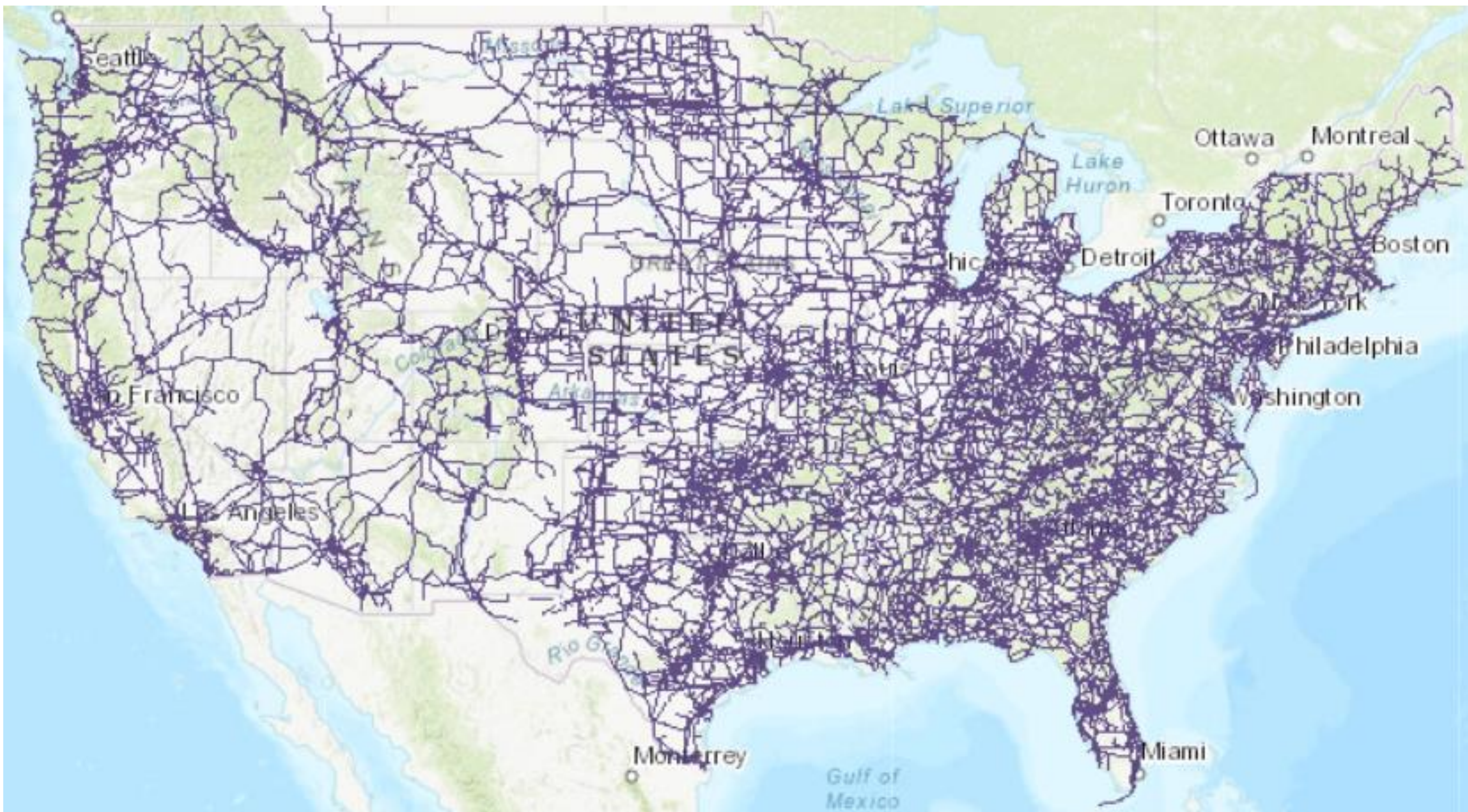


Basic Conventional Power System Layout



Electric Transmission Lines

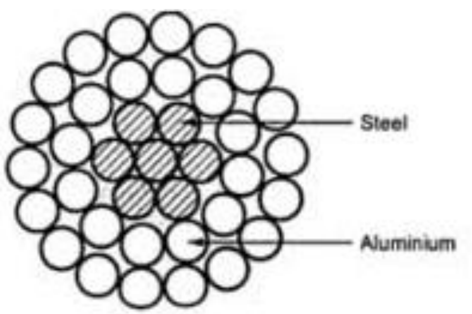
- Voltages: 115 kV, 138 kV, 161 kV, 230 kV, 345kV, 500kV, 765kV
- Over 180,000 miles of high-voltage lines, connecting to about 7,300 power plants.



https://www.eia.gov/state/maps.php

High Voltage Power Lines (overhead)

- Common voltages in north America: 138, 230, 345, 500, 765 kV
- Bundled conductors are used in extra-high voltage lines
- Stranded instead of solid conductors are used.



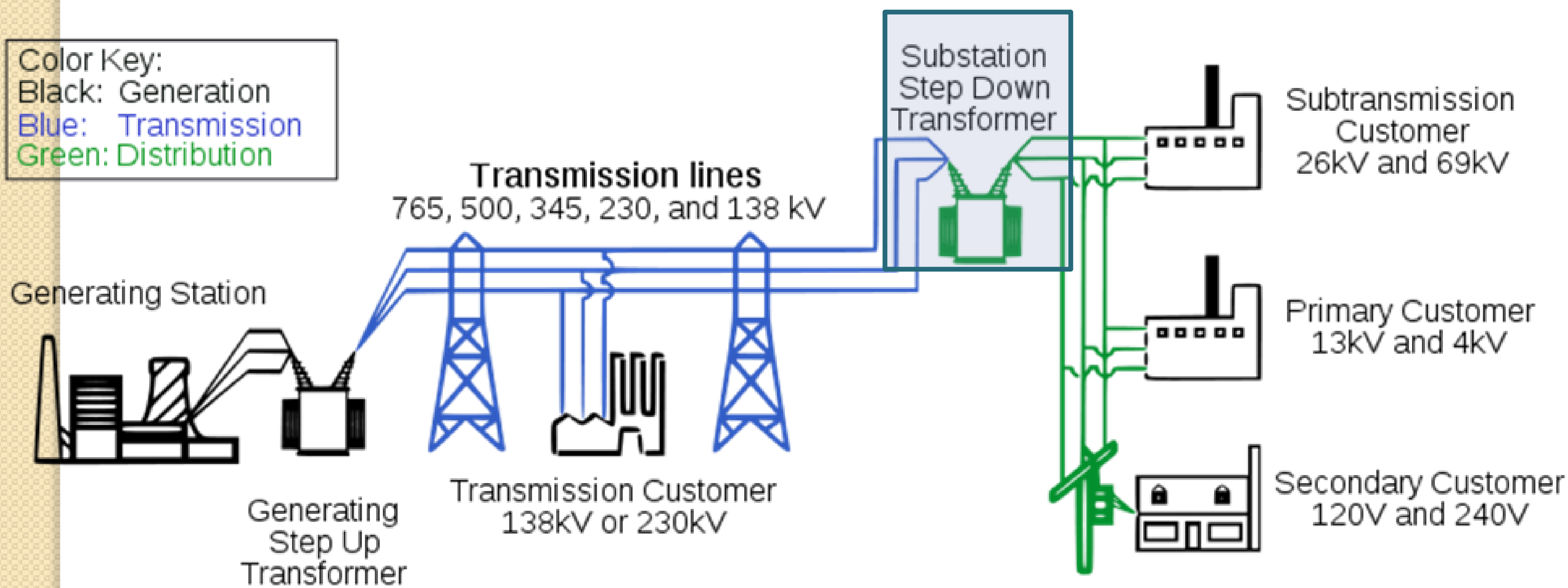
Construction of "One Nevada" Power Line

- http://www.myrgroup.com/electrical-construction-projects/one-nevada-500kv-transmission-line-on-line-project-southwest-intertie-project-swip/

11,000 kV Line in China

- https://www.youtube.com/watch?v=SpVR3pySq-U
- https://www.youtube.com/watch?v=WiHzvkB2jdk

Basic Conventional Power System Layout



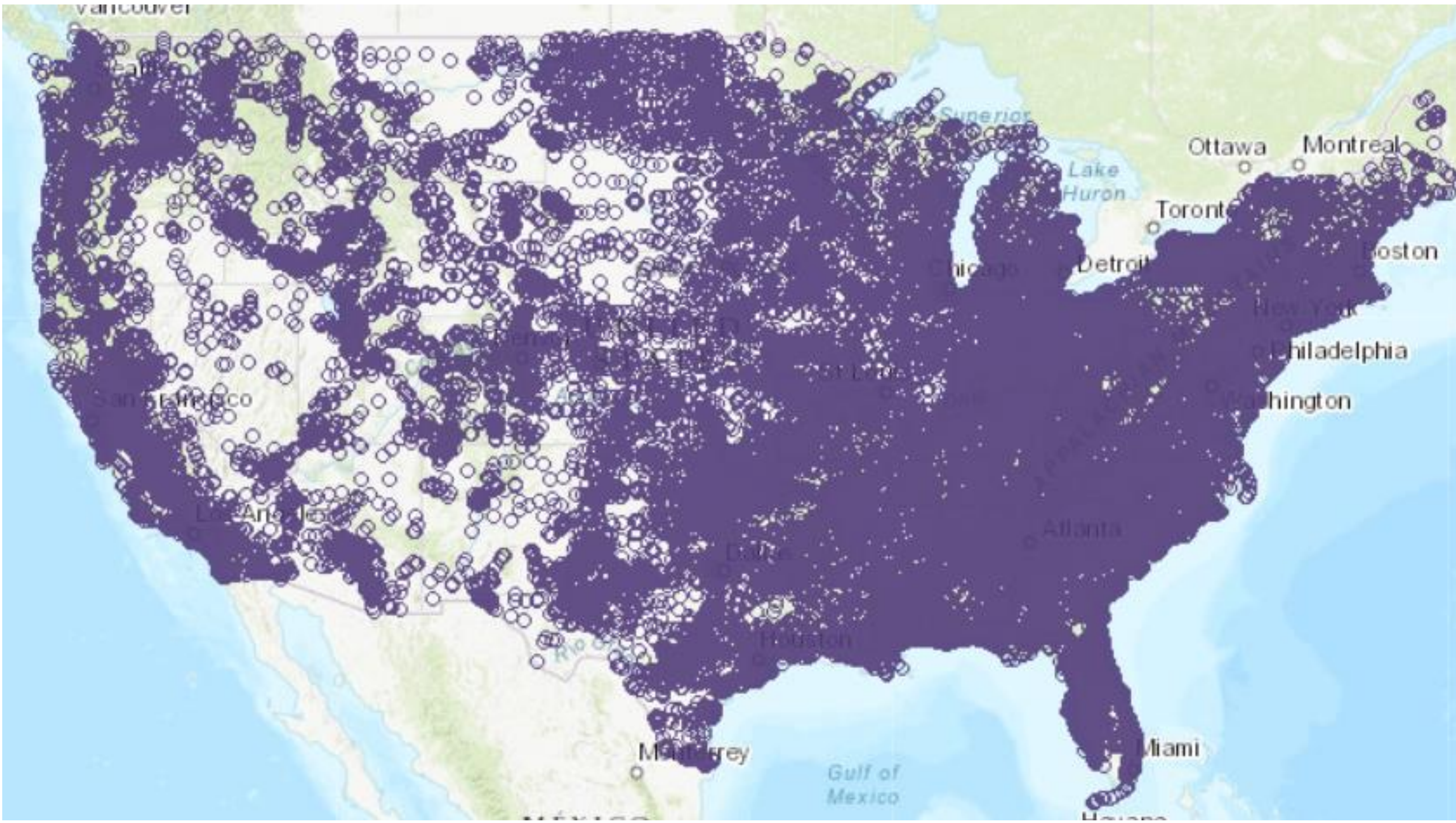
Substation Transformers

- Typical size; 20 MVA
- Primary voltage down to 69 kV
- Secondary voltage down to 4.16kV

Distribution Substation Layout

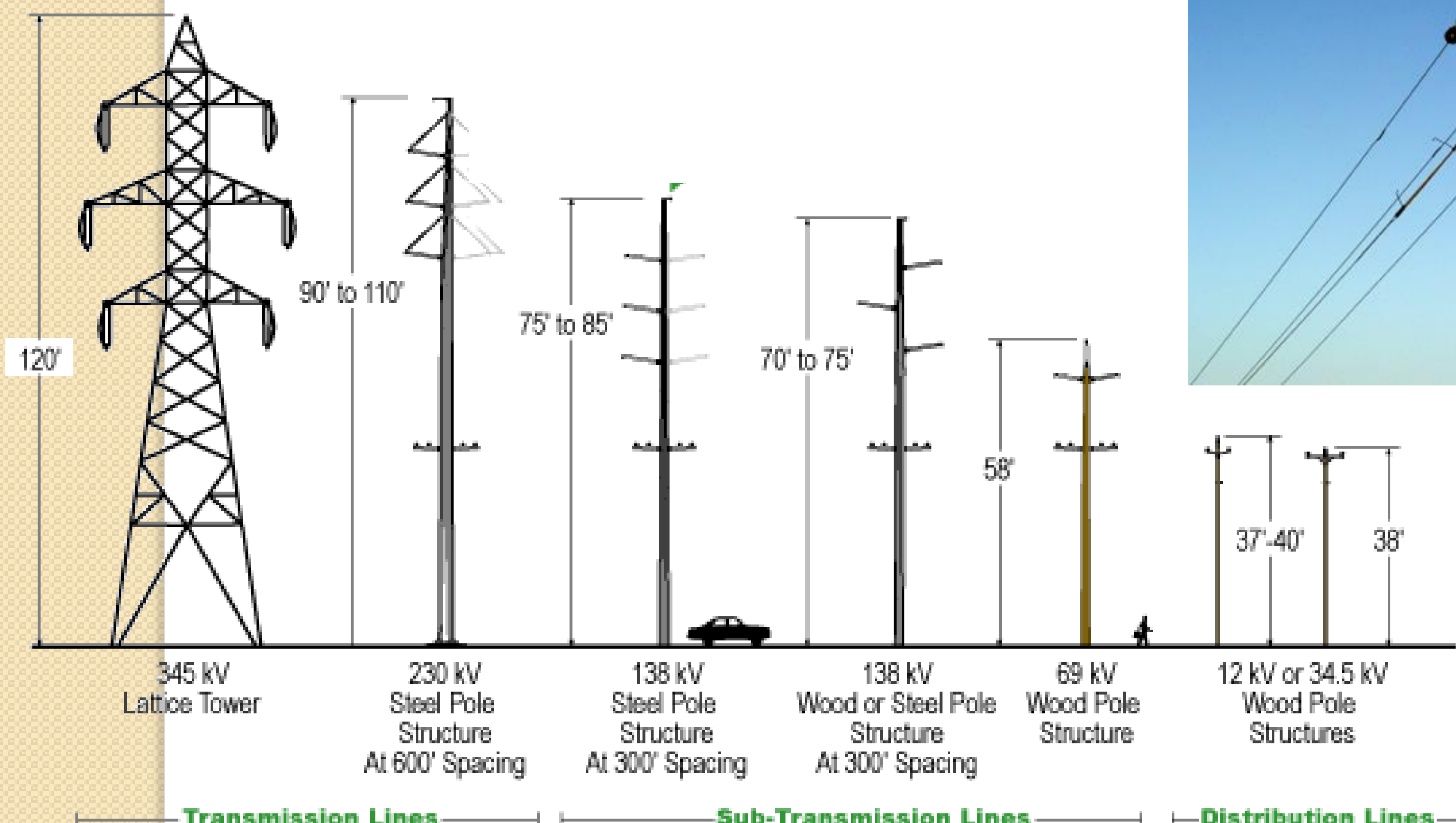
Electric Substations

- Over 55,000 Substations



Power distribution lines
(placed underground in new urban areas)

- Primary Distribution voltages: 4.16, 12.47, 13.2, 13.8, 25, 34.5 kV



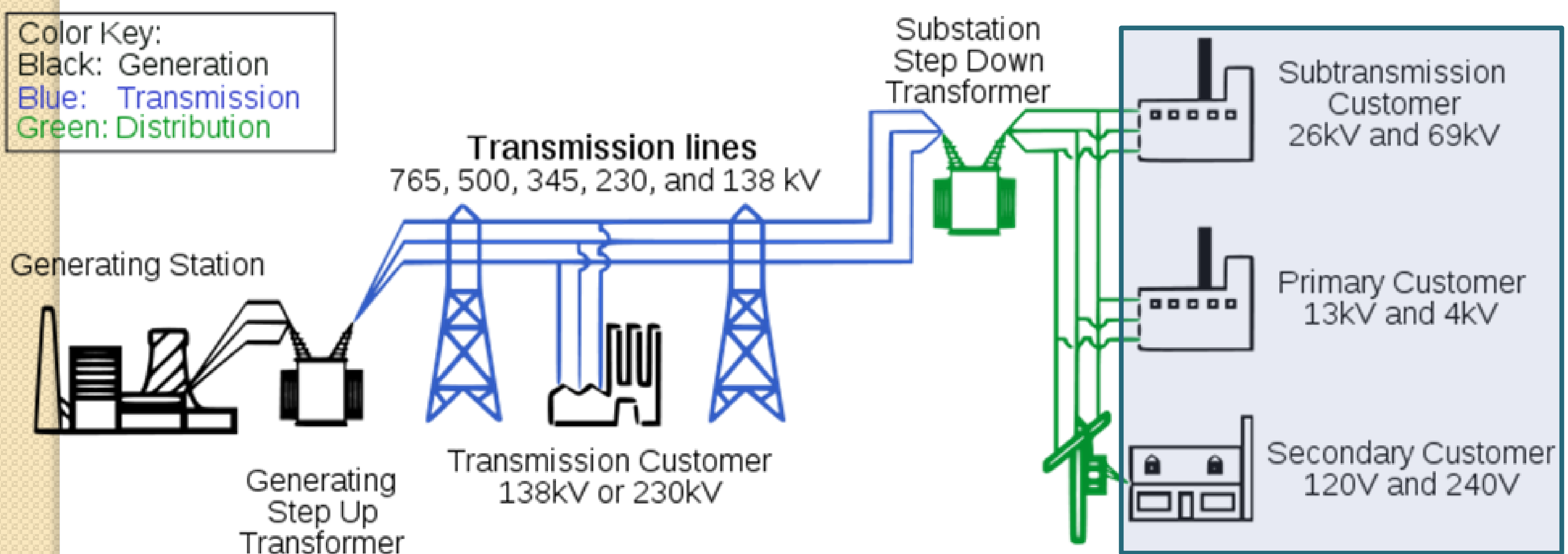
Power distribution transformers

- The distribution circuits may be overhead or underground. This will depend on the load density and the physical conditions of the particular area to be served.

Overhead Transformer Bank & Service

Padmount Transformer for Underground System

Basic Conventional Power System Layout



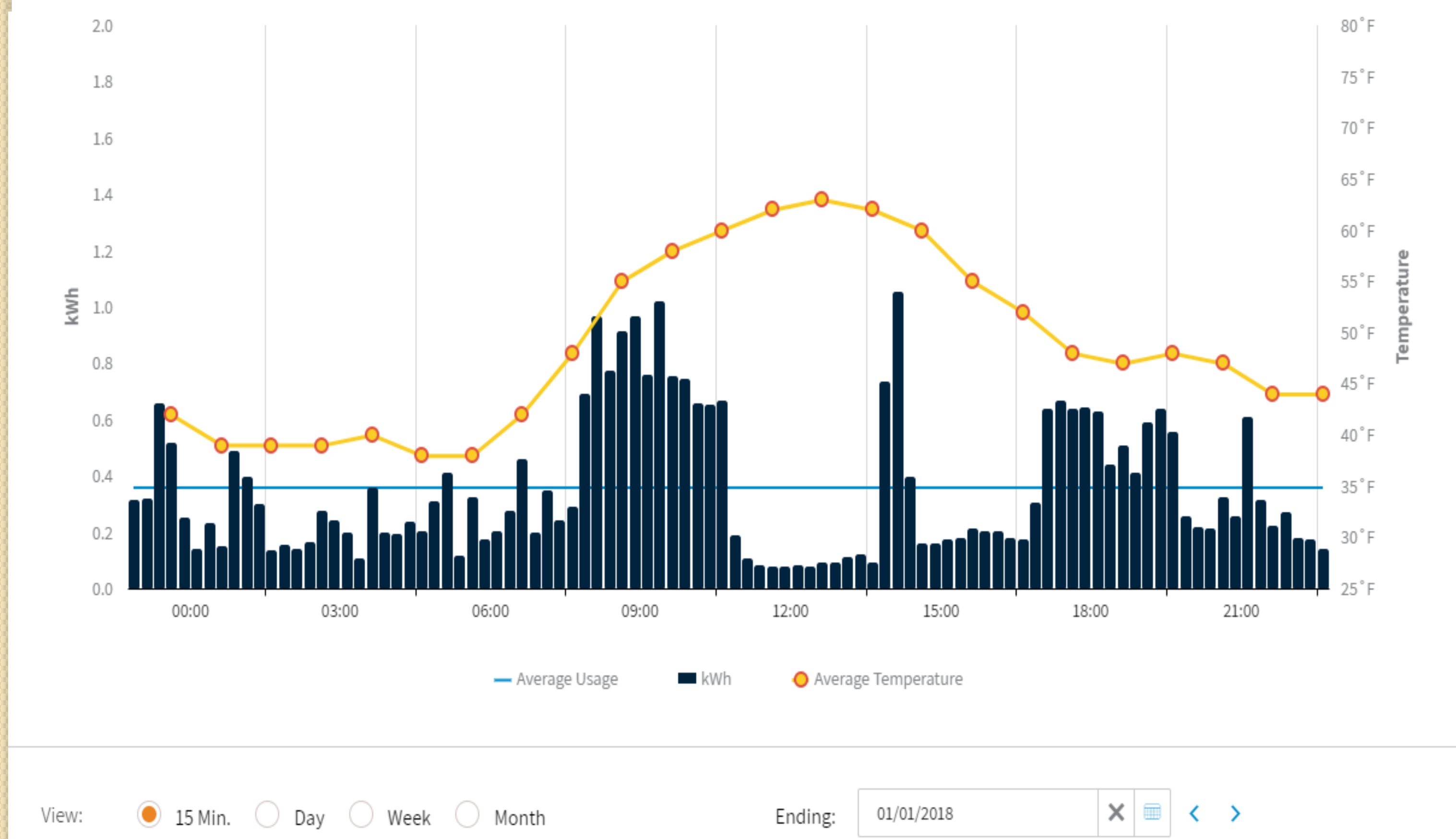
Electrical Power Utilization (electric load)

- Utilization voltage: 120V, 208V*, 240V, 277V, 480V*, 600V*

2/3 to 3/4 of electricity is consumed by motors

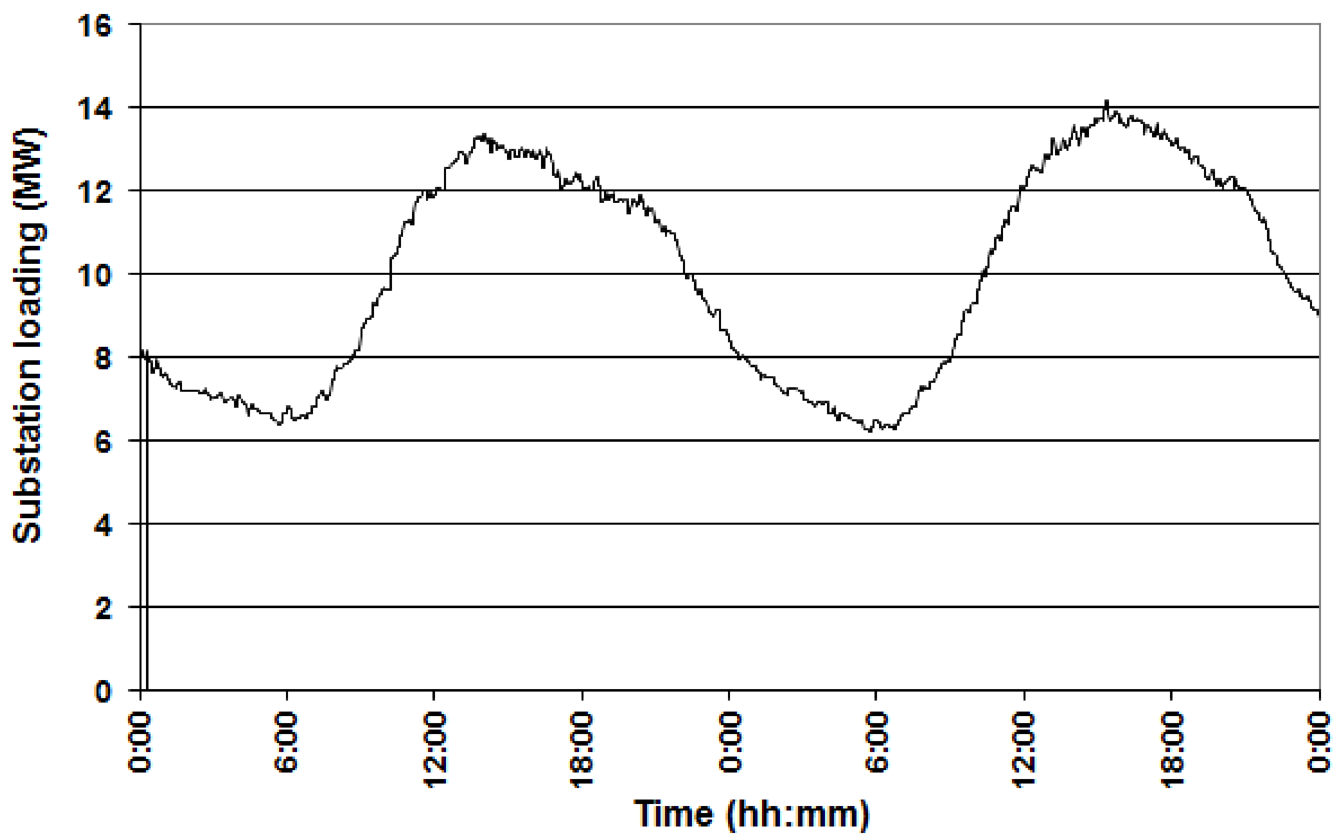
Power Demand

- Changes in demand of individual customers is fast and frequent due to load switching.

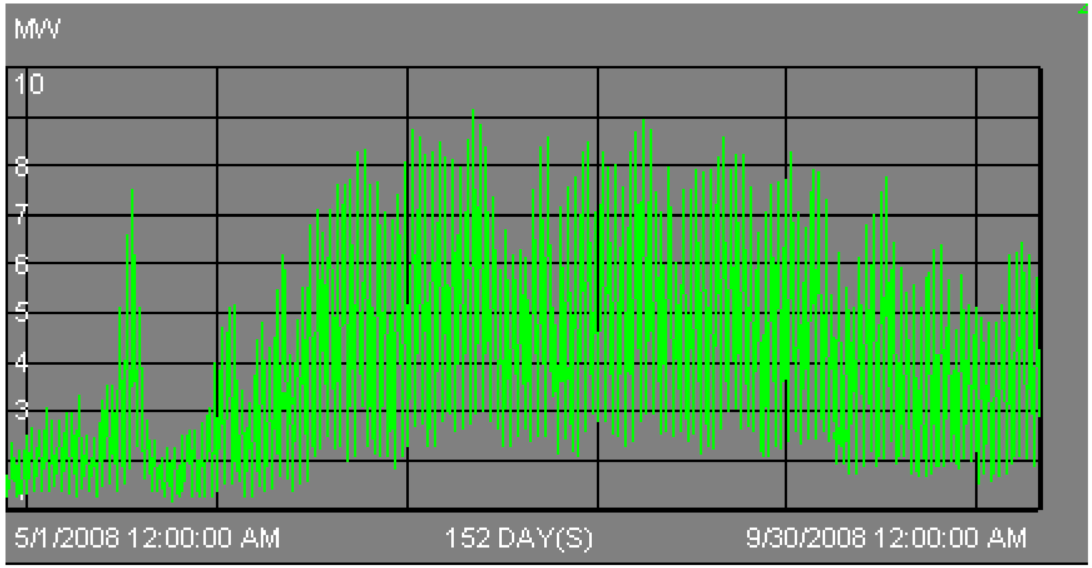


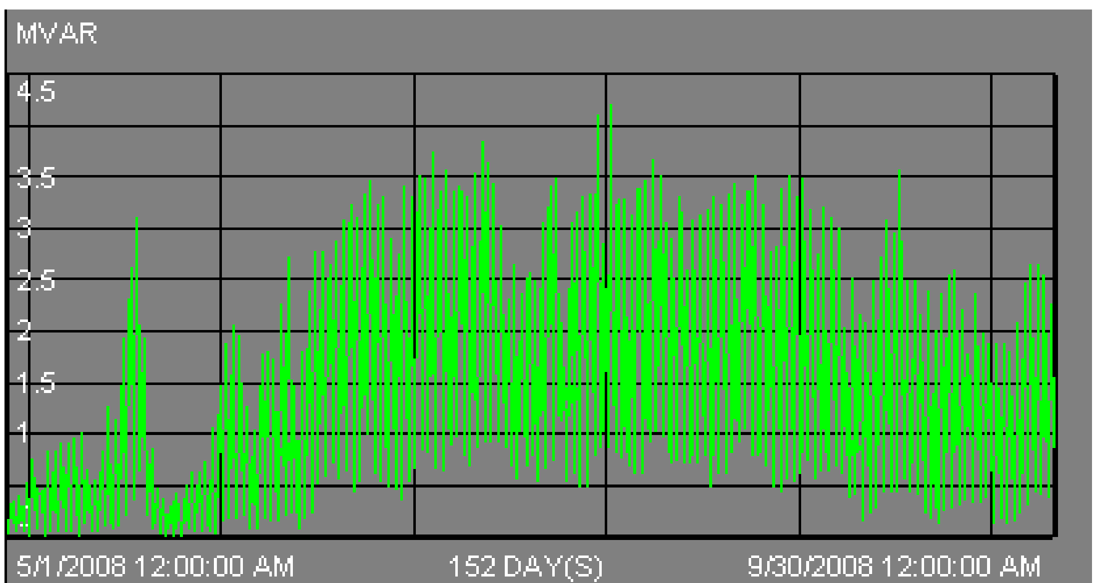
Substation load demand: 48 hours

- The aggregated demand at the substation is smoother, and total load fluctuations are usually small.



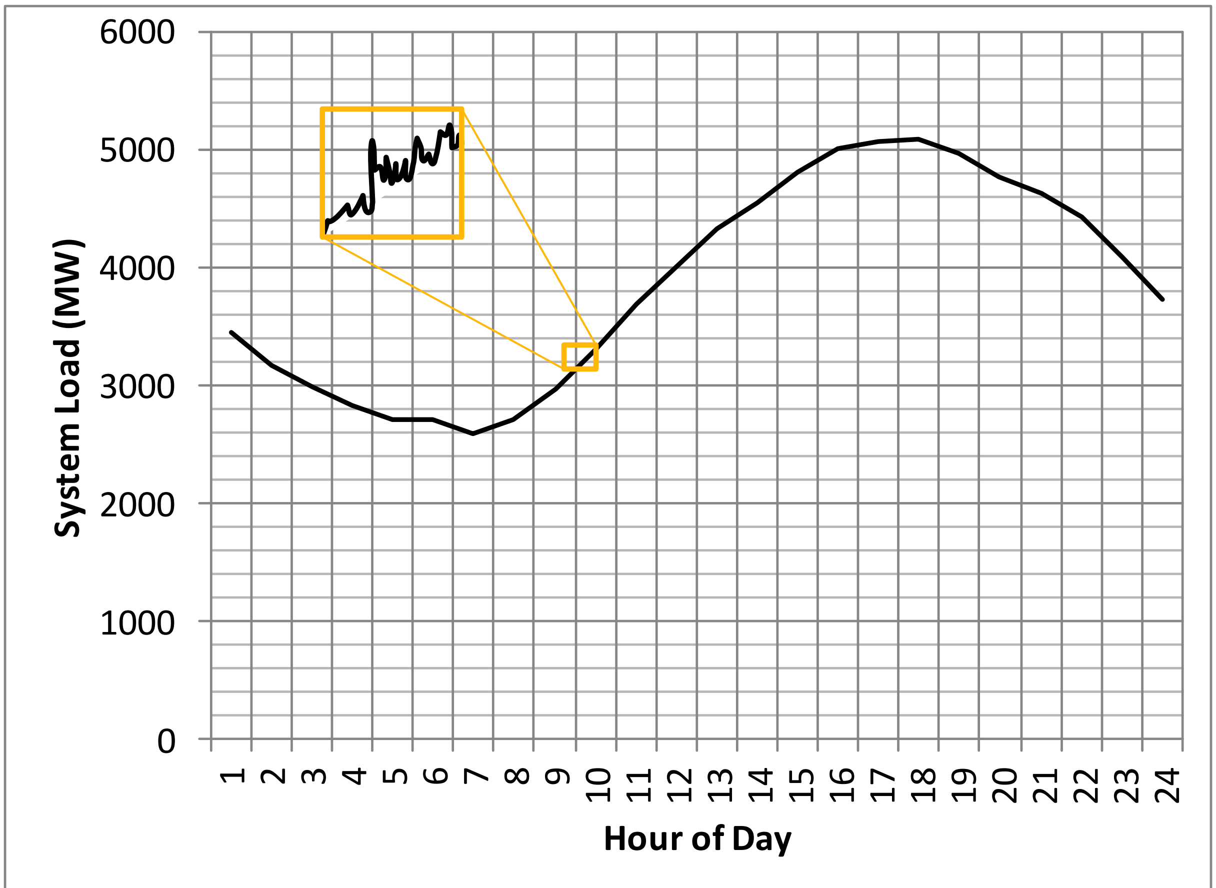
MW and MVAR loading on a distribution feeder over 4 month period





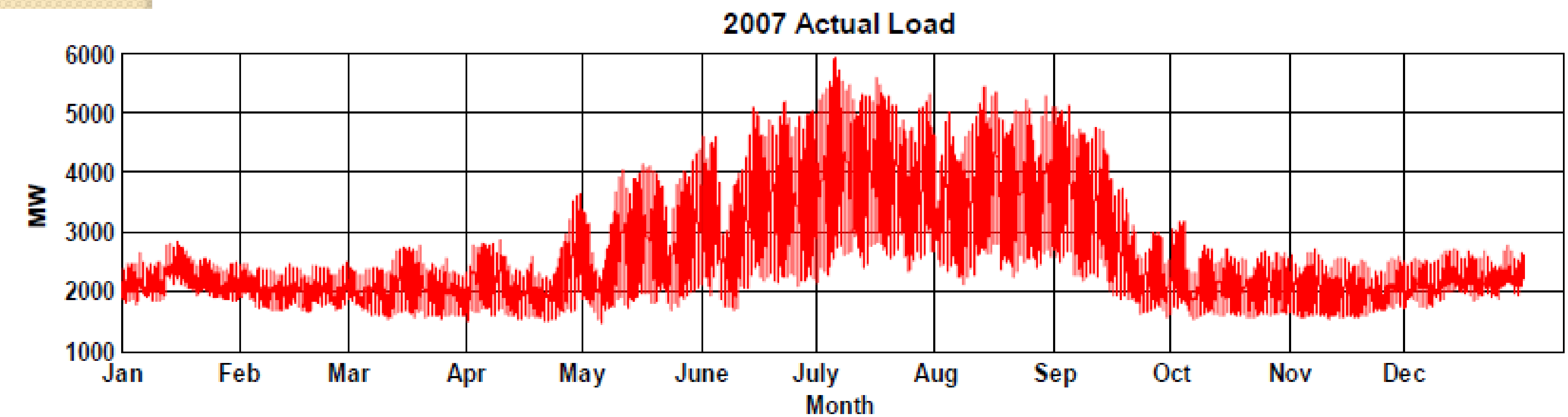
System load: 24-hours

- The aggregated demand on the system is even smoother, and total load fluctuations are very small. The overall daily profile of load can be predicted reasonably well using forecasting tools.

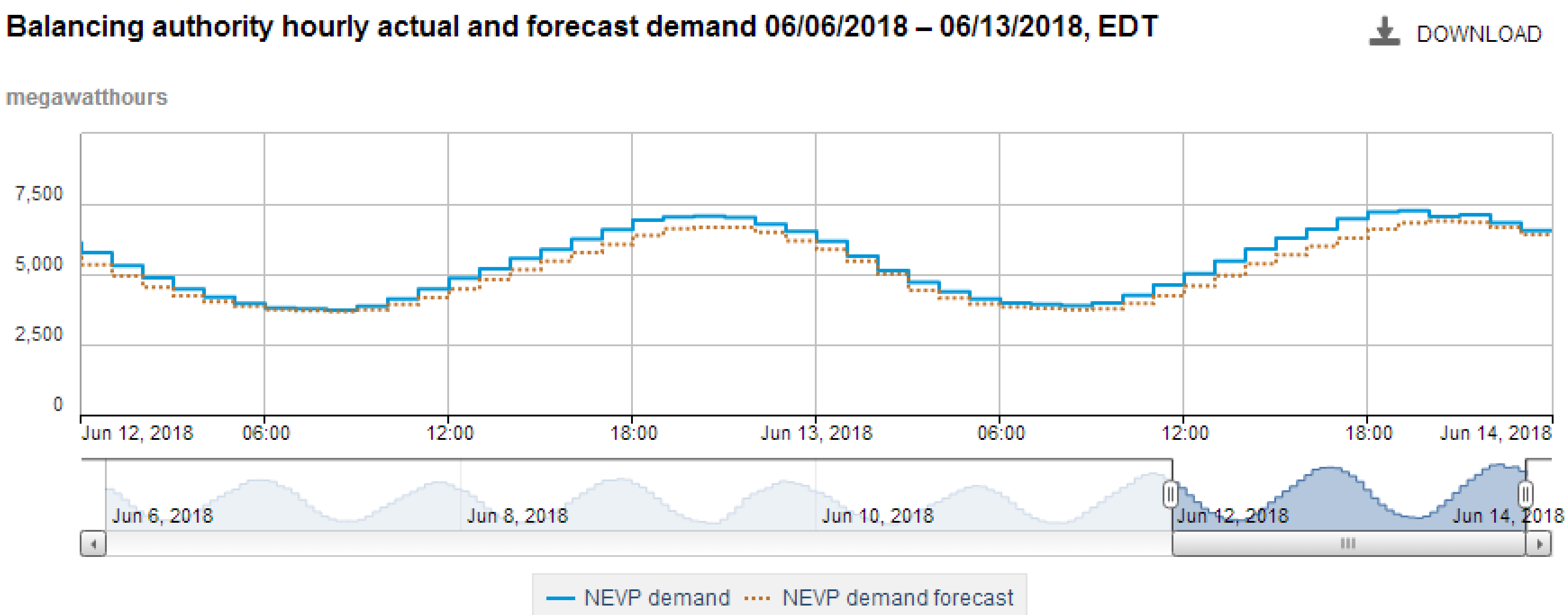


Seasonal Load Patterns

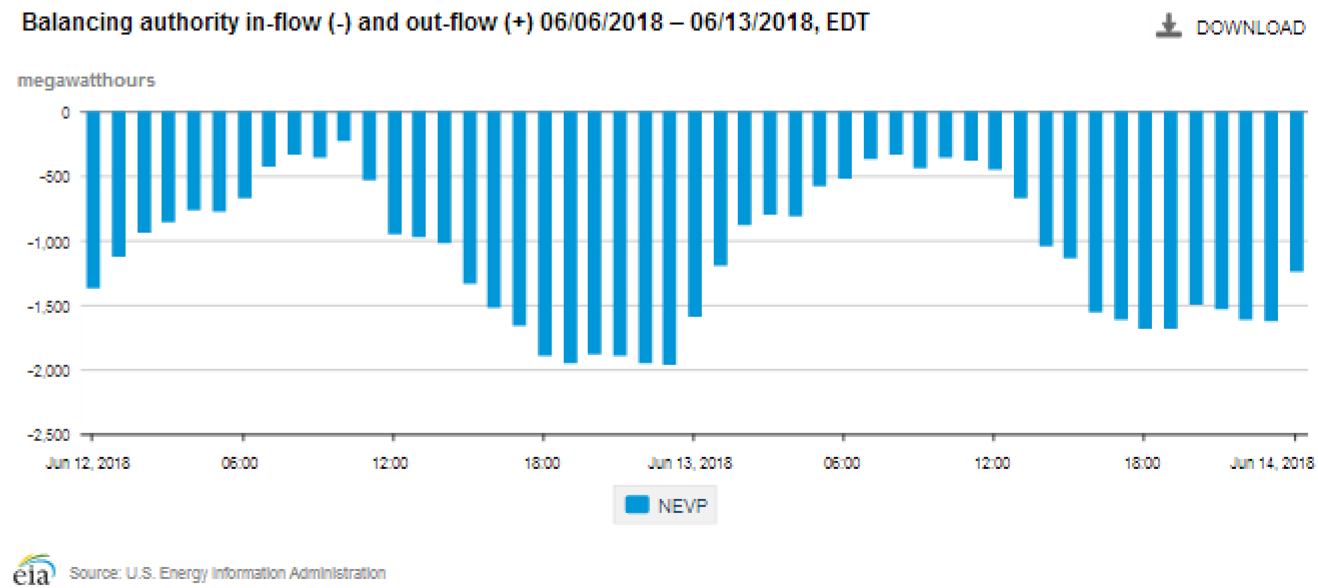
The local (southern Nevada) load is dominated by winter and summer patterns, with May and October as shoulder months.



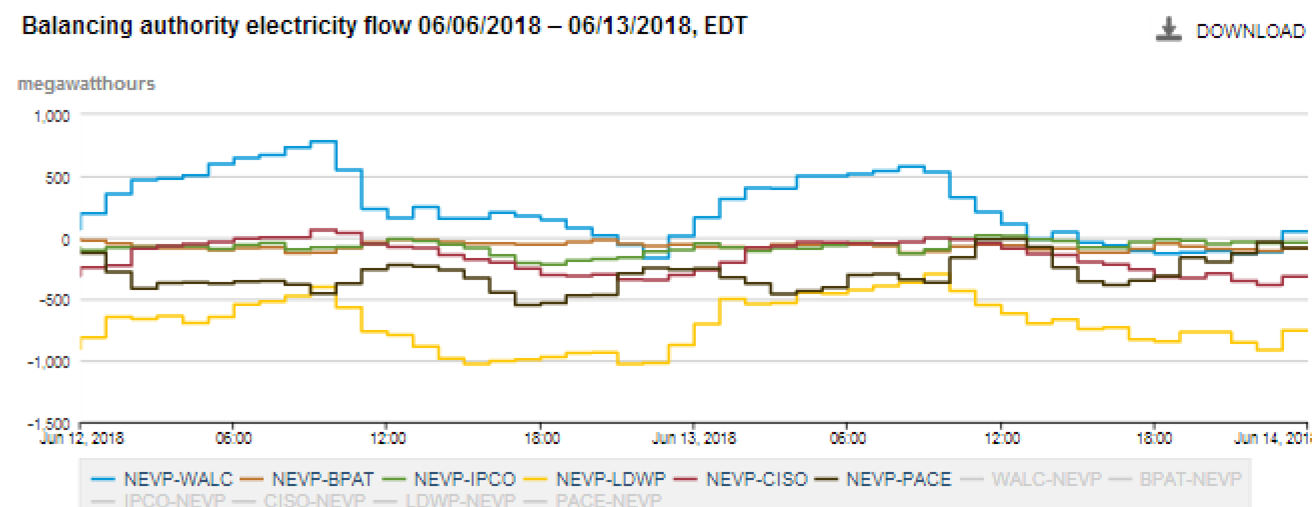
Nevada typical demand curve: June 12-14



Nevada Power Interchange



Balancing authority Interchange *(BA-to-BA interchange data available up to two days prior to current day.)*

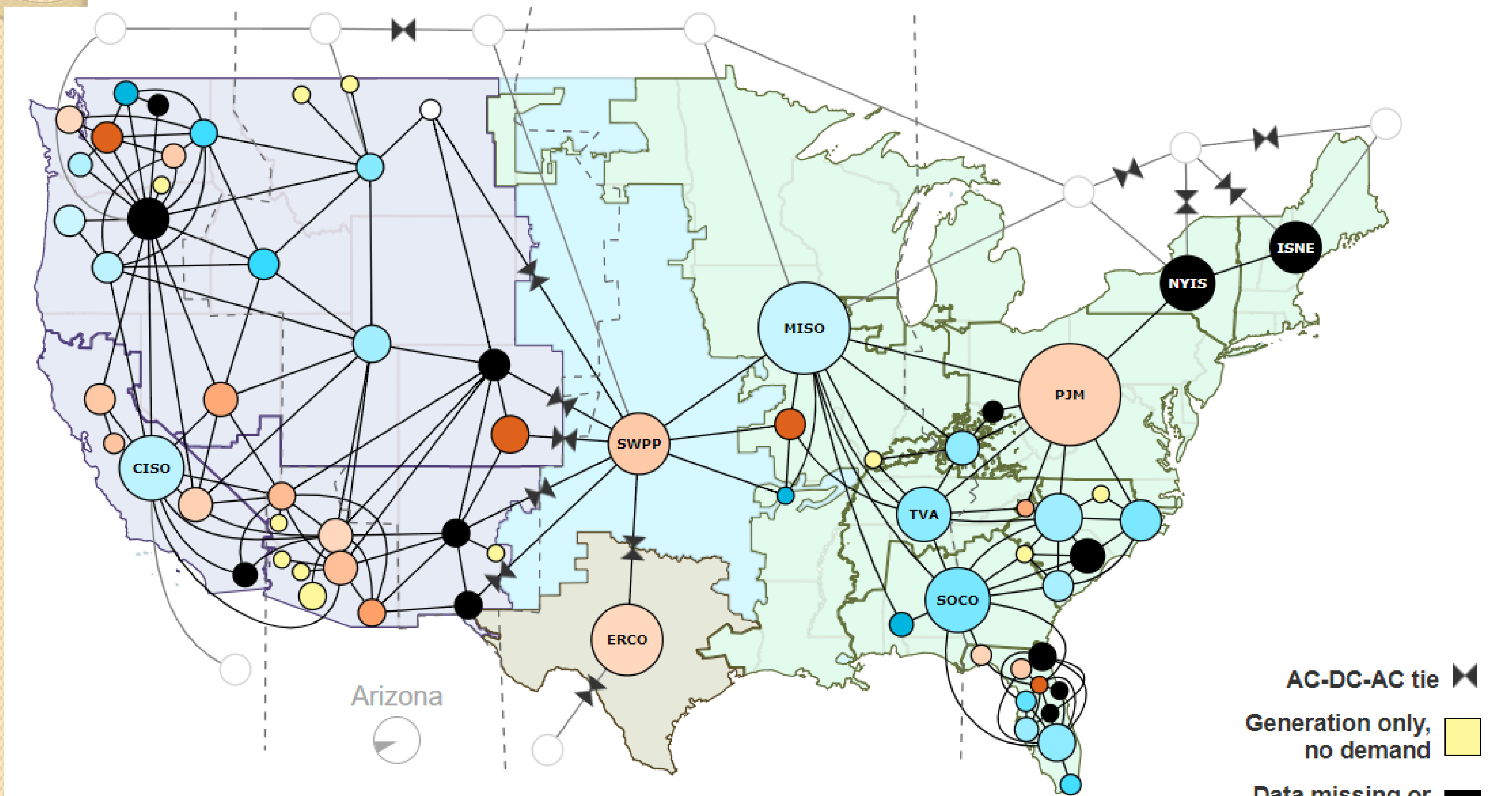


Typical US Demand Curve

Peak demand in 2017: 770 GW

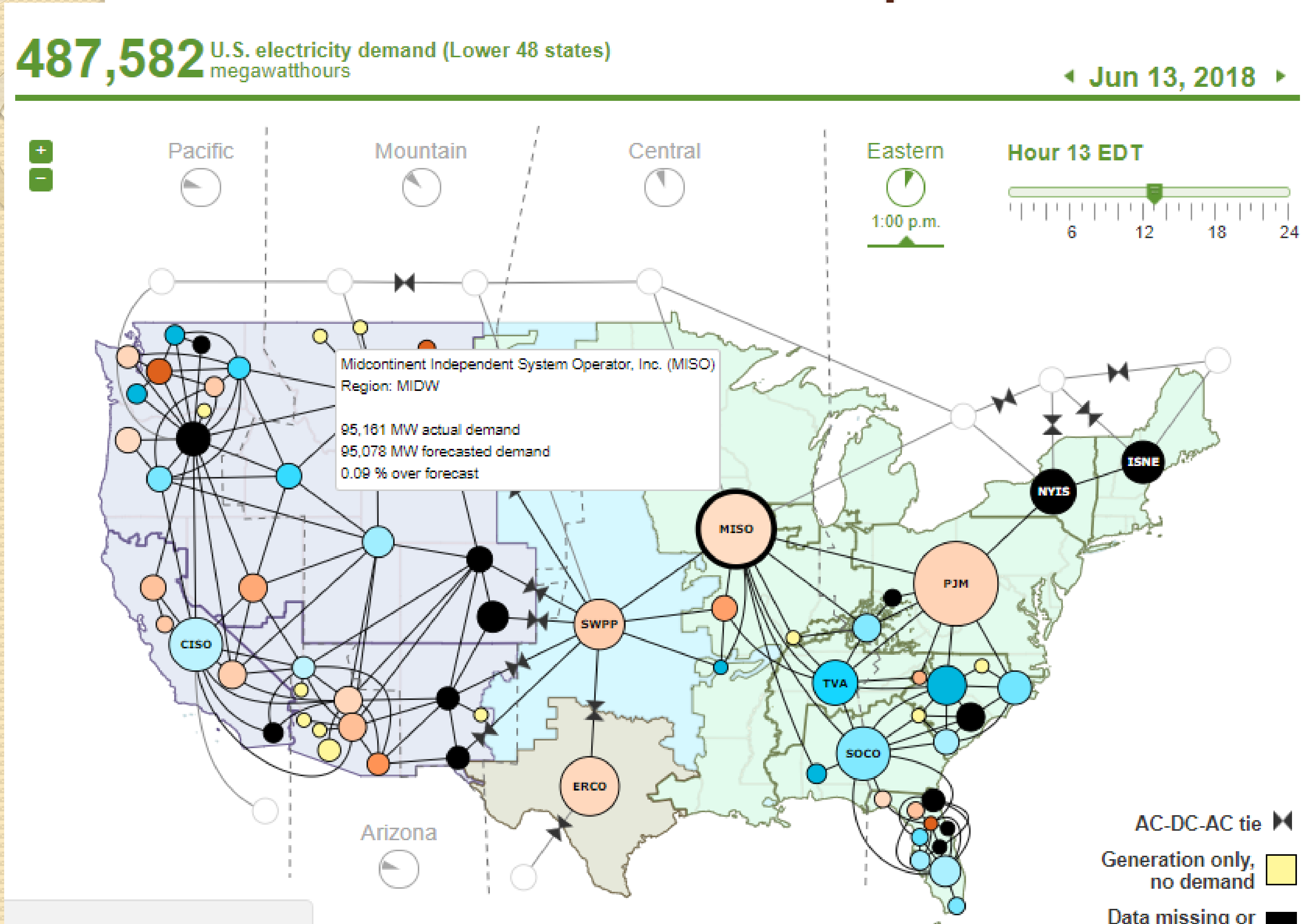
North American Balancing Authorities

- The actual operation of the interconnections is handled by over 100 Balancing Authorities (BA's). The BA's dispatch generators in order to meet their individual needs.



https://www.eia.gov/realtime_grid/?src=data#/status?end=20180613T12

Status Map


487,582 U.S. electricity demand (Lower 48 states)
megawatthours
Jun 13, 2018
Pacific
Mountain
Central
Eastern
1:00 p.m.
Hour 13 EDT
6
12
18
24
Midcontinent Independent System Operator, Inc. (MISO)
Region: MIDW
95,161 MW actual demand
95,078 MW forecasted demand
0.09 % over forecast
MISO
PJM
NYIS
ISNE
SWPP
CISO
TVA
SOCO
ERCO
Arizona
AC-DC-AC tie
Generation only, no demand
Data missing or