Electric Power Systems – An Overview

Y. Baghzouz

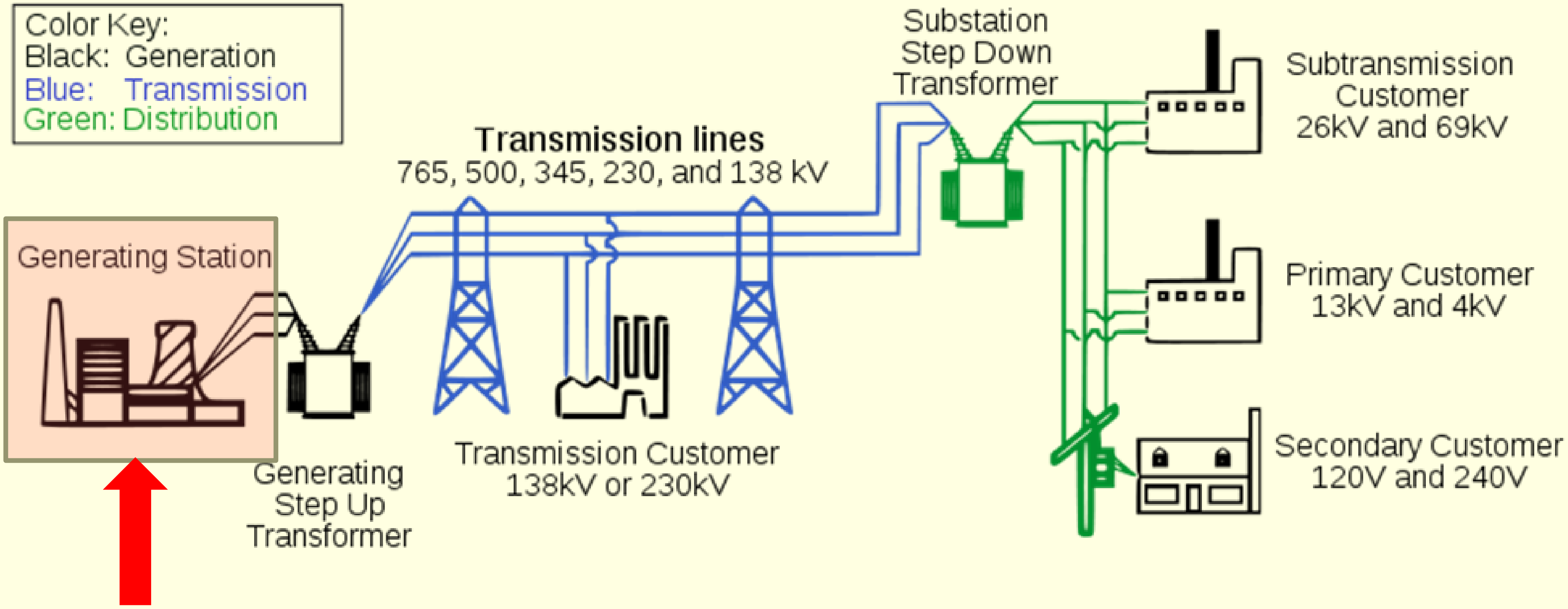
Professor of Electrical Engineering

University of Nevada, Las Vegas

Overview

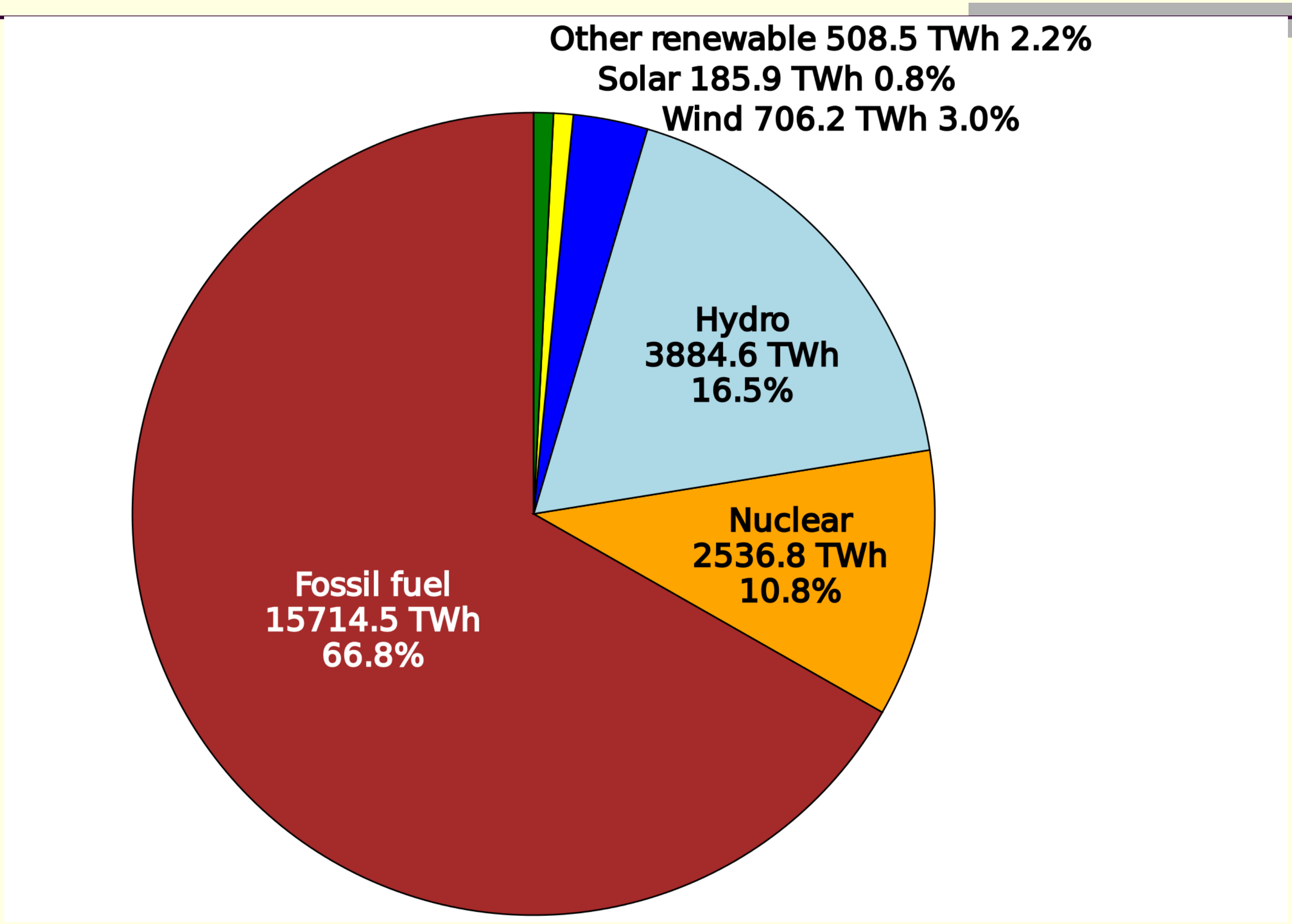
- Power Generation
  - Conventional and renewable power generation
- Power transmission & Distribution
  - Cables and other transmission & distribution system equipment
- Power Utilization
  - Demand curves, load characteristics
- Power System Analysis
  - Power flow, fault currents, economic dispatch.

Basic Power System Layout



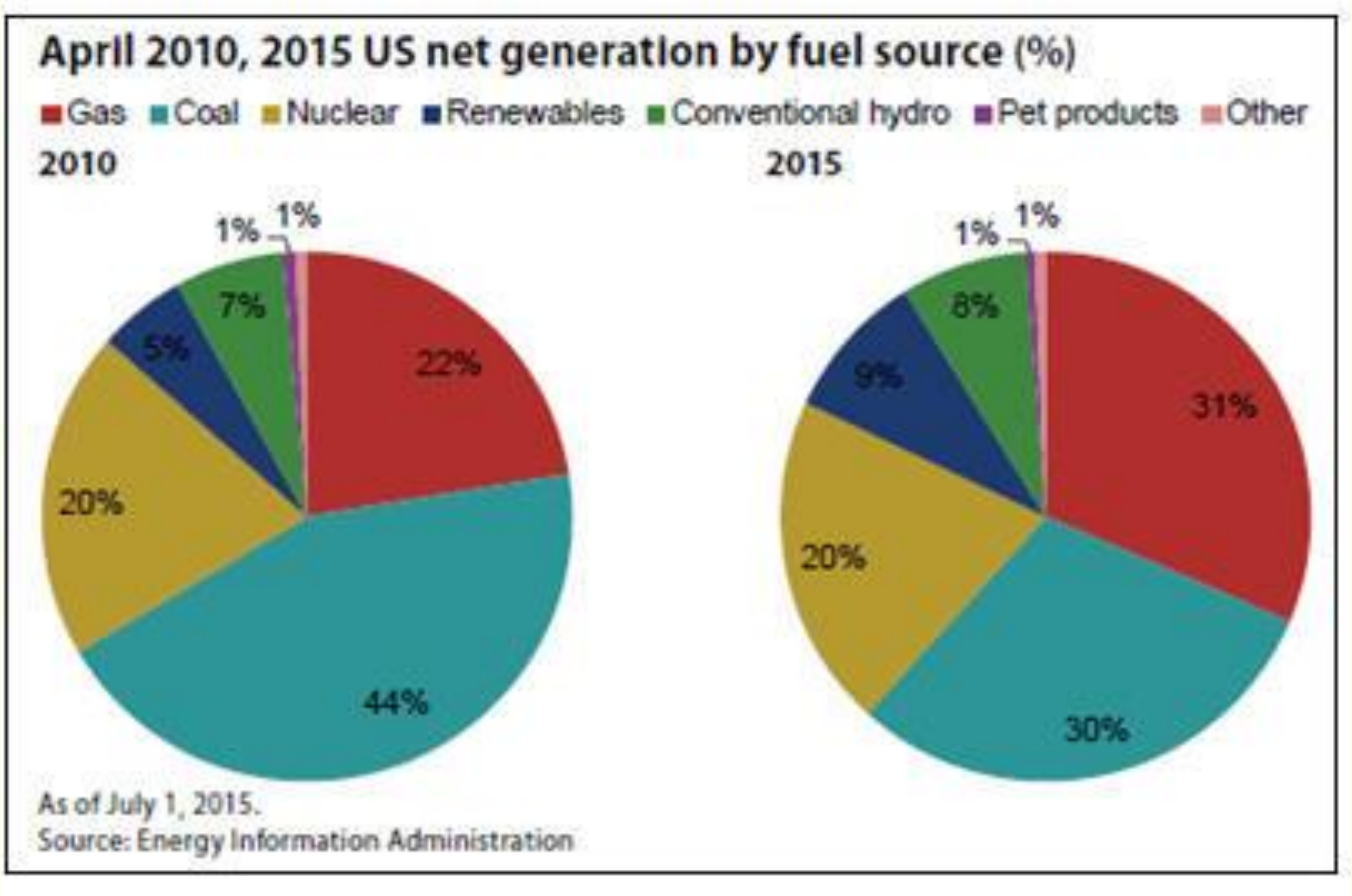
Conventional (non-renewable) primary energy source

World Electricity Generation by Source (2014)

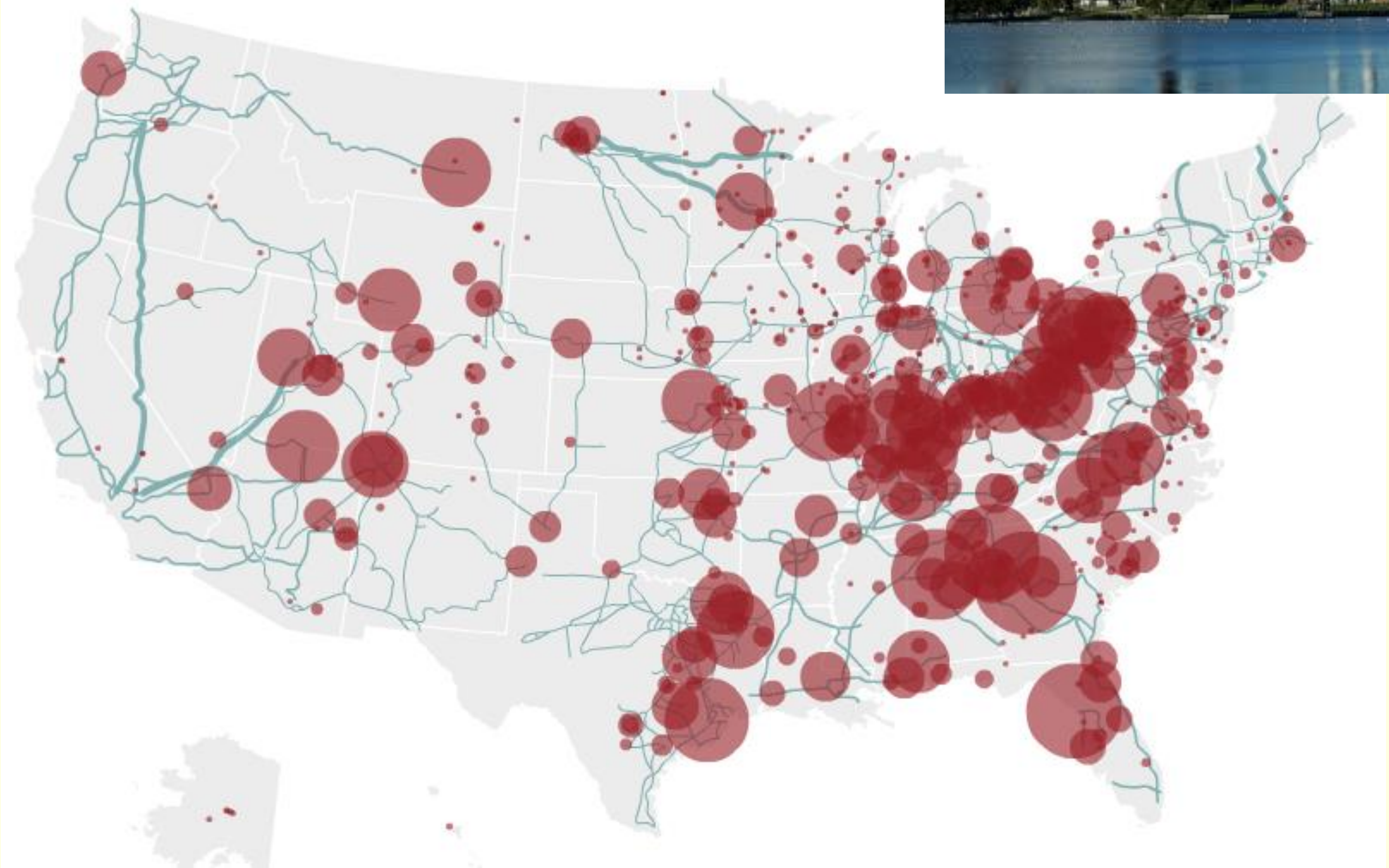


Source: US Energy Information Administration (EIA)

USA Electricity Generation by Source



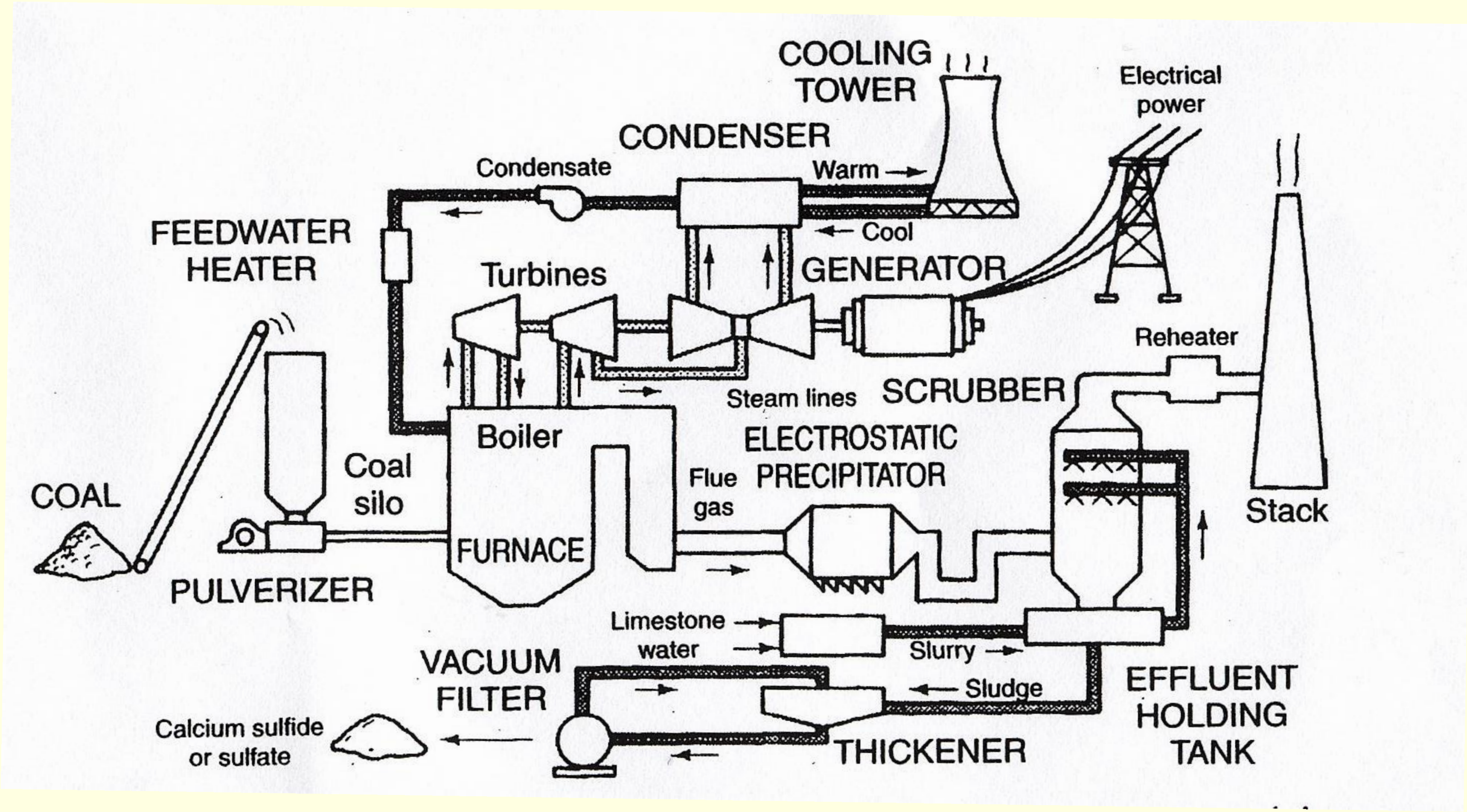
Coal Fired Power Plants:
Number of Generators ≈ 1,450
Total Capacity ≈ 350 GW



(Source: http://www.npr.org)

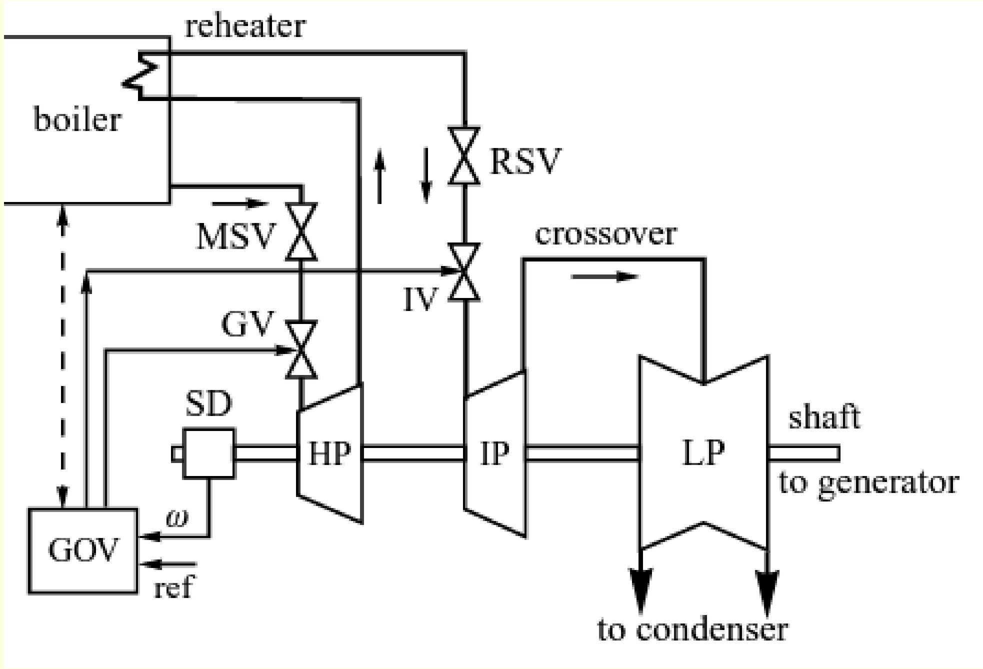
Diagram of a modern coal power plant

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



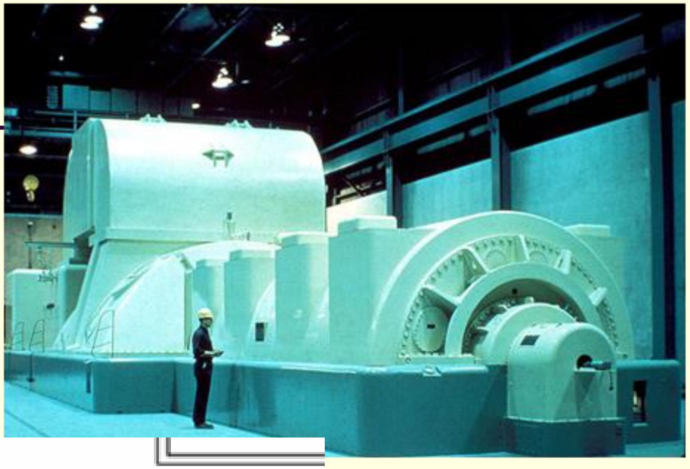
Steam Turbines and their Governors

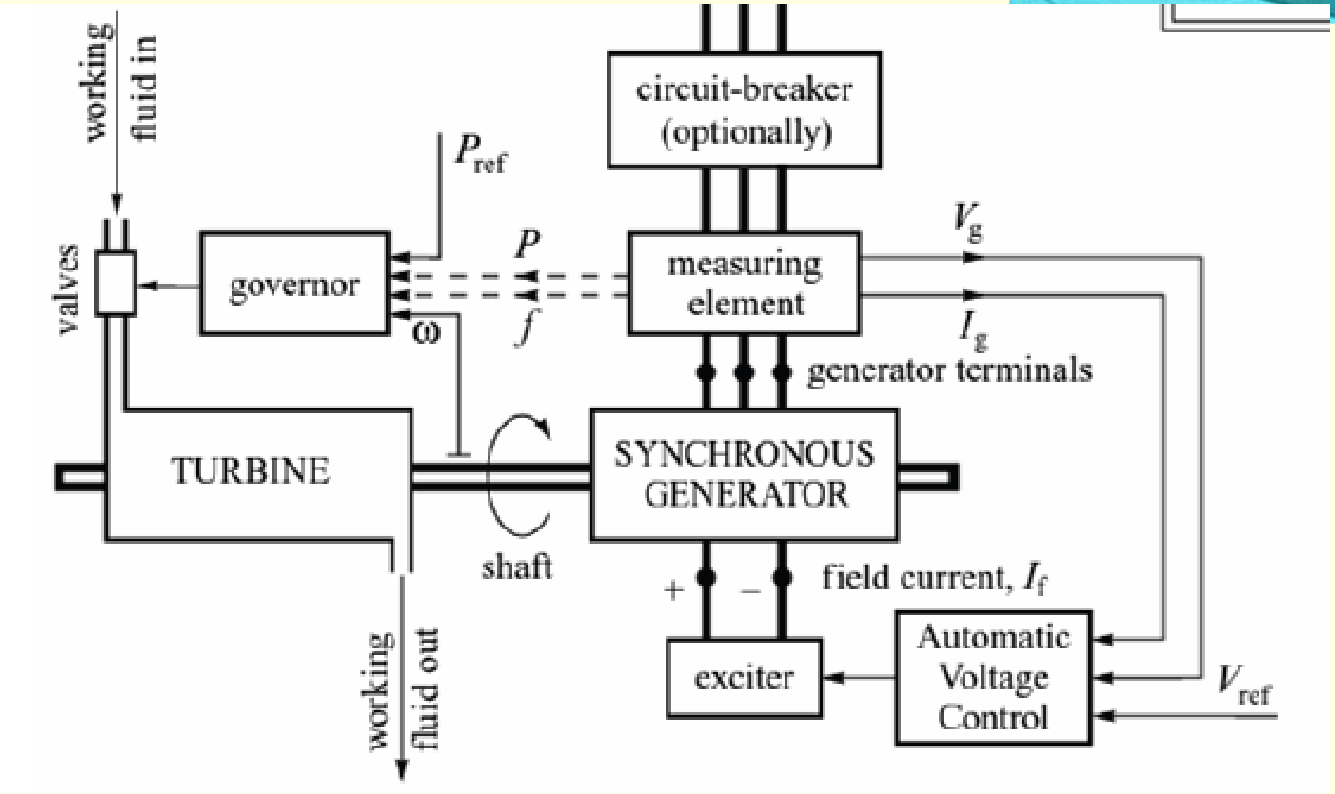
- Steam turbines can have non-reheat, single-reheat or double-reheat.
- The steam flow is controlled by the governor.
- Main and reheat stop valves are normally fully open - they are used only during generator start-up and shut down.



The electric generator

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





Nuclear Power Plants:
Number of Generators ≈ 100
Total Capacity ≈ 100 GW

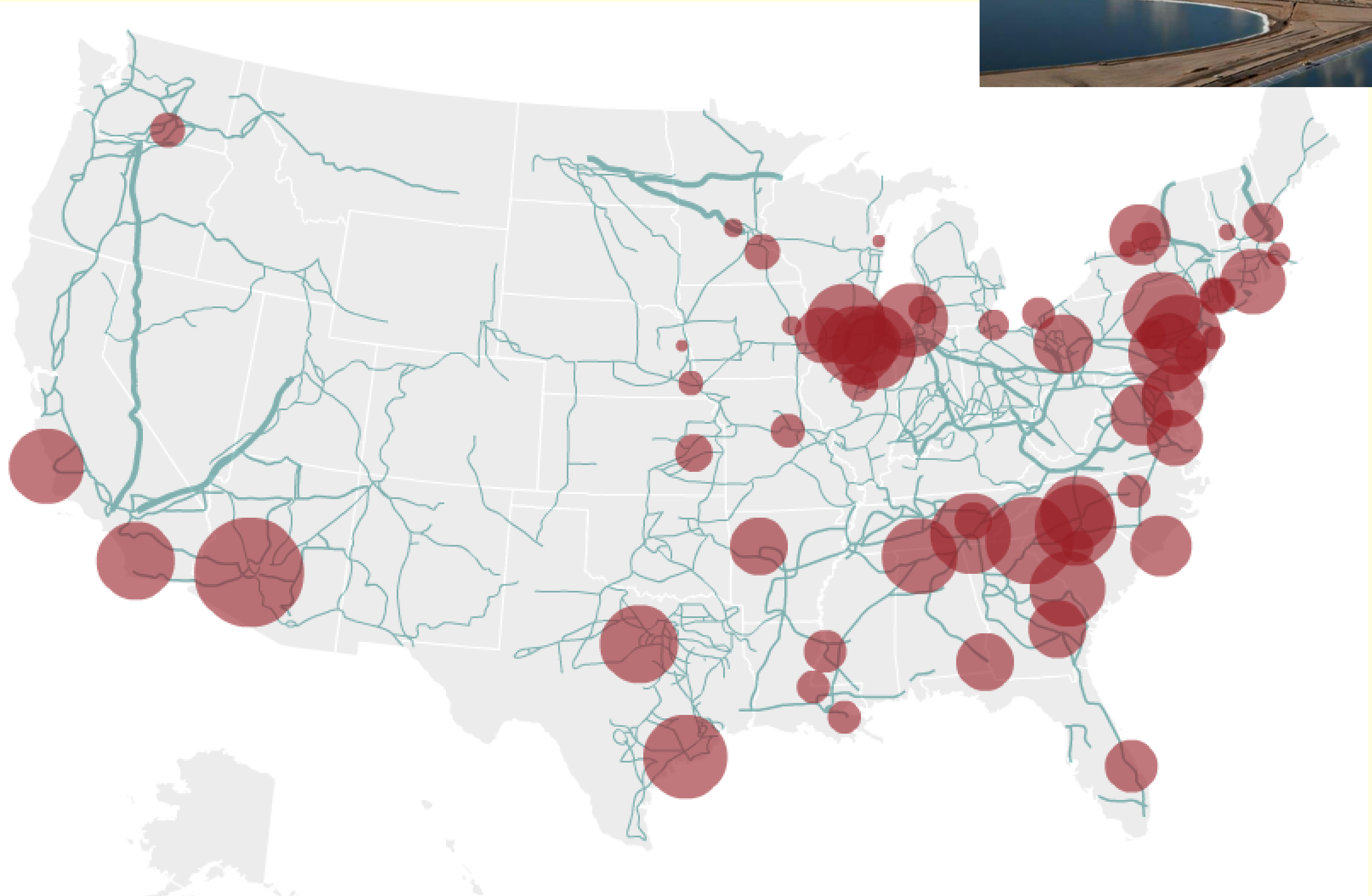
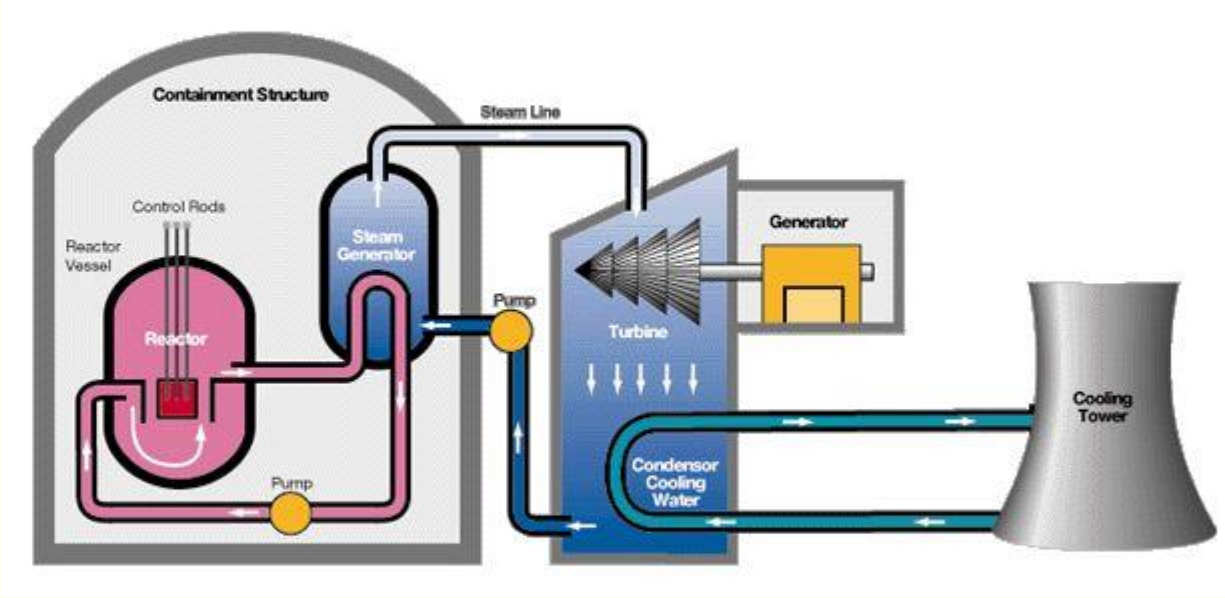
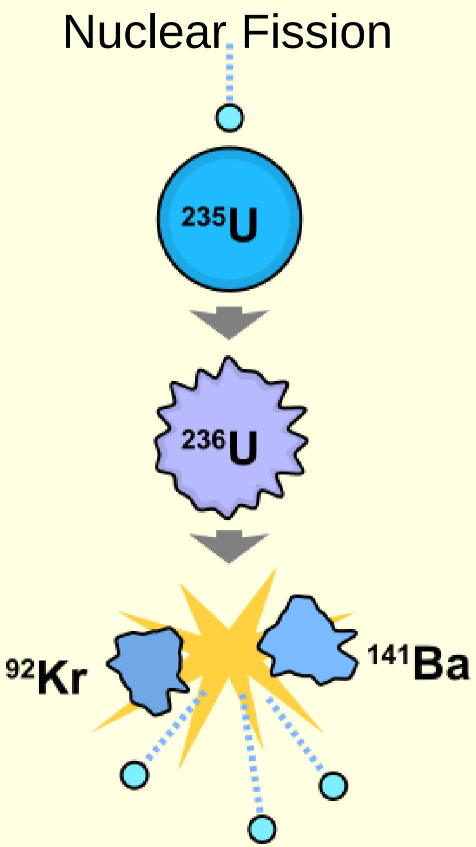


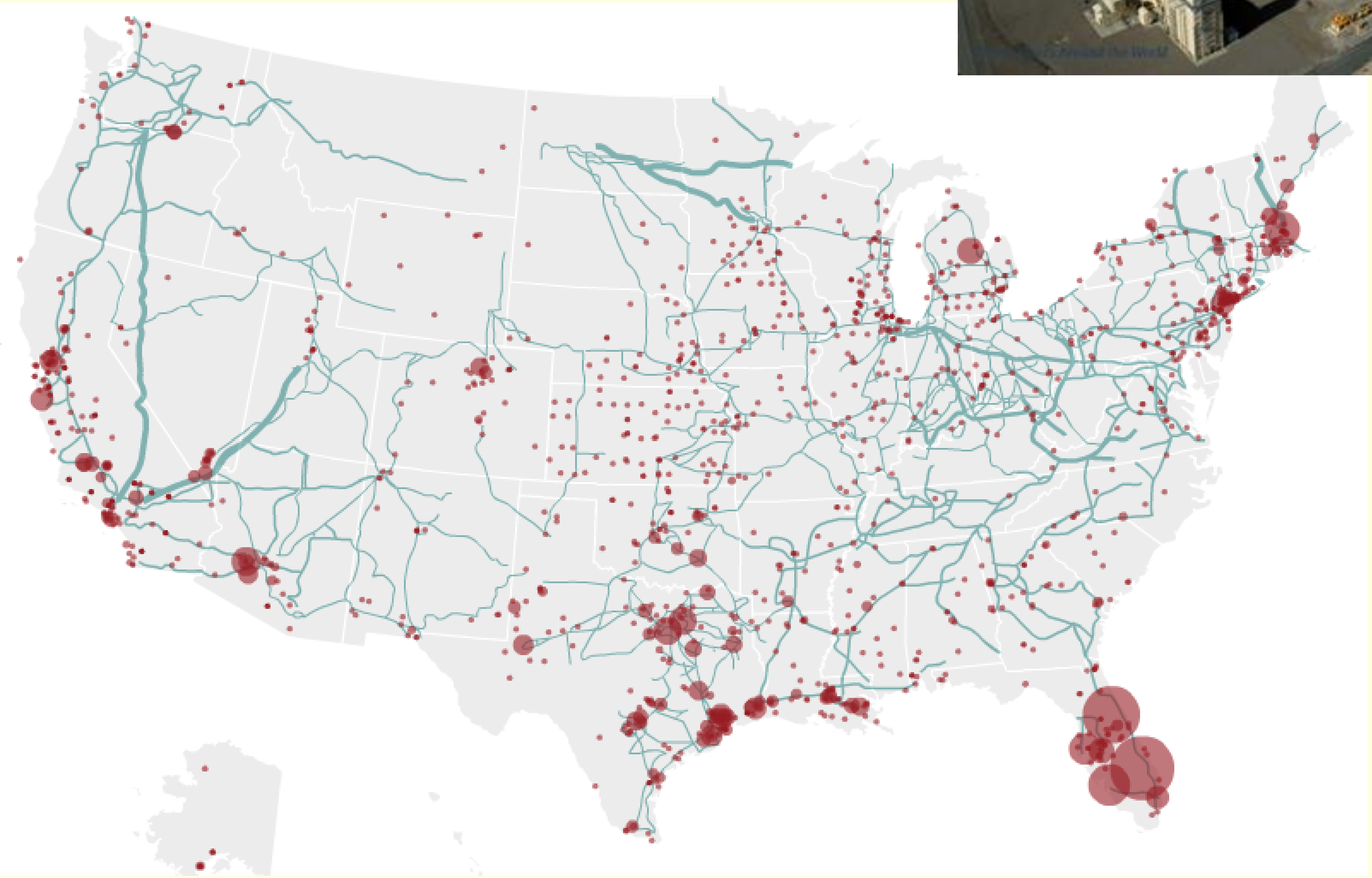
Diagram of a nuclear power plant

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

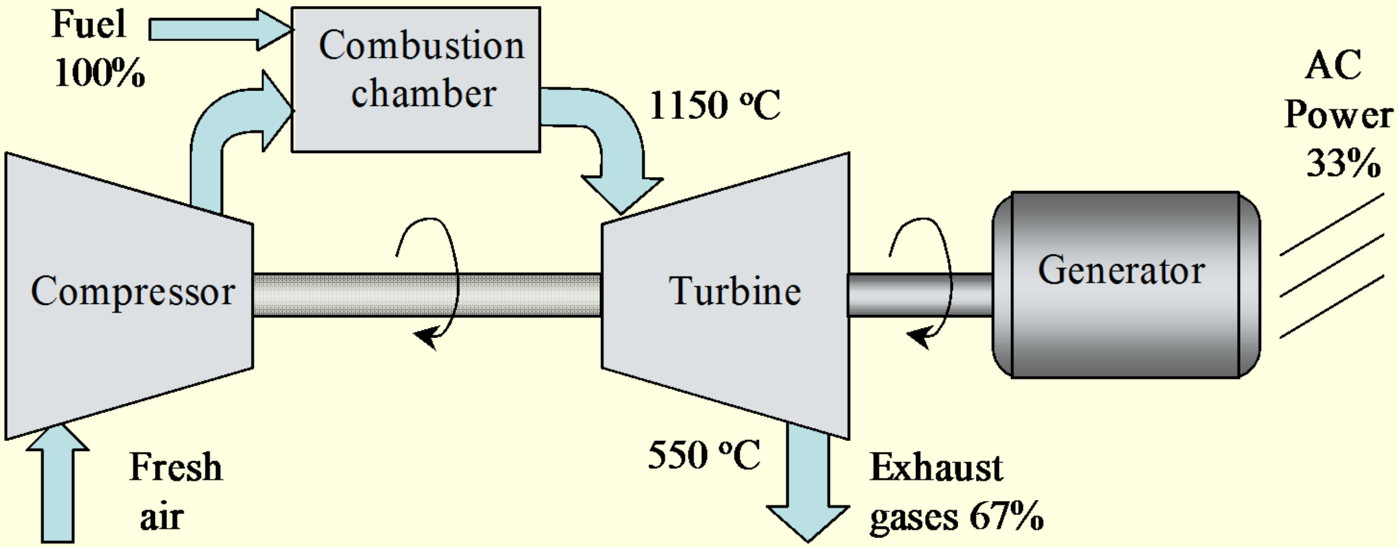




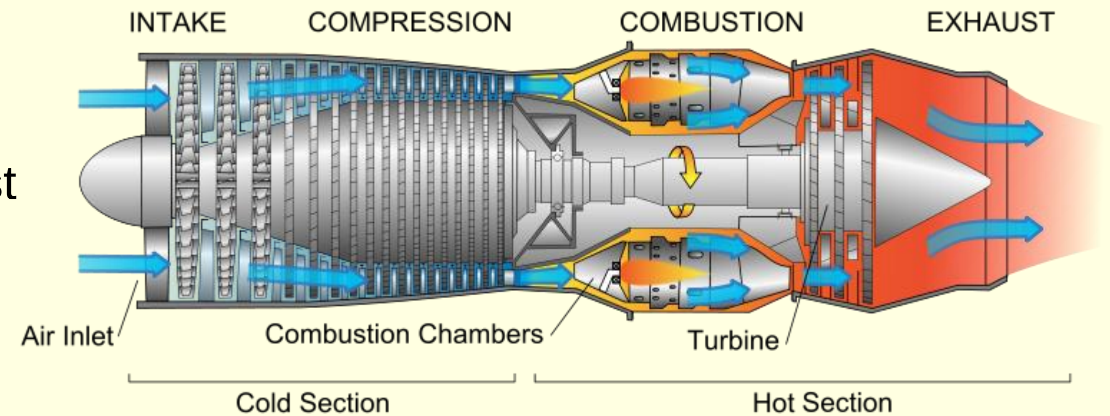
Natural Gas Power Plants:
Number of Generators ≈ 5,500
Total Capacity ≈ 450 GW



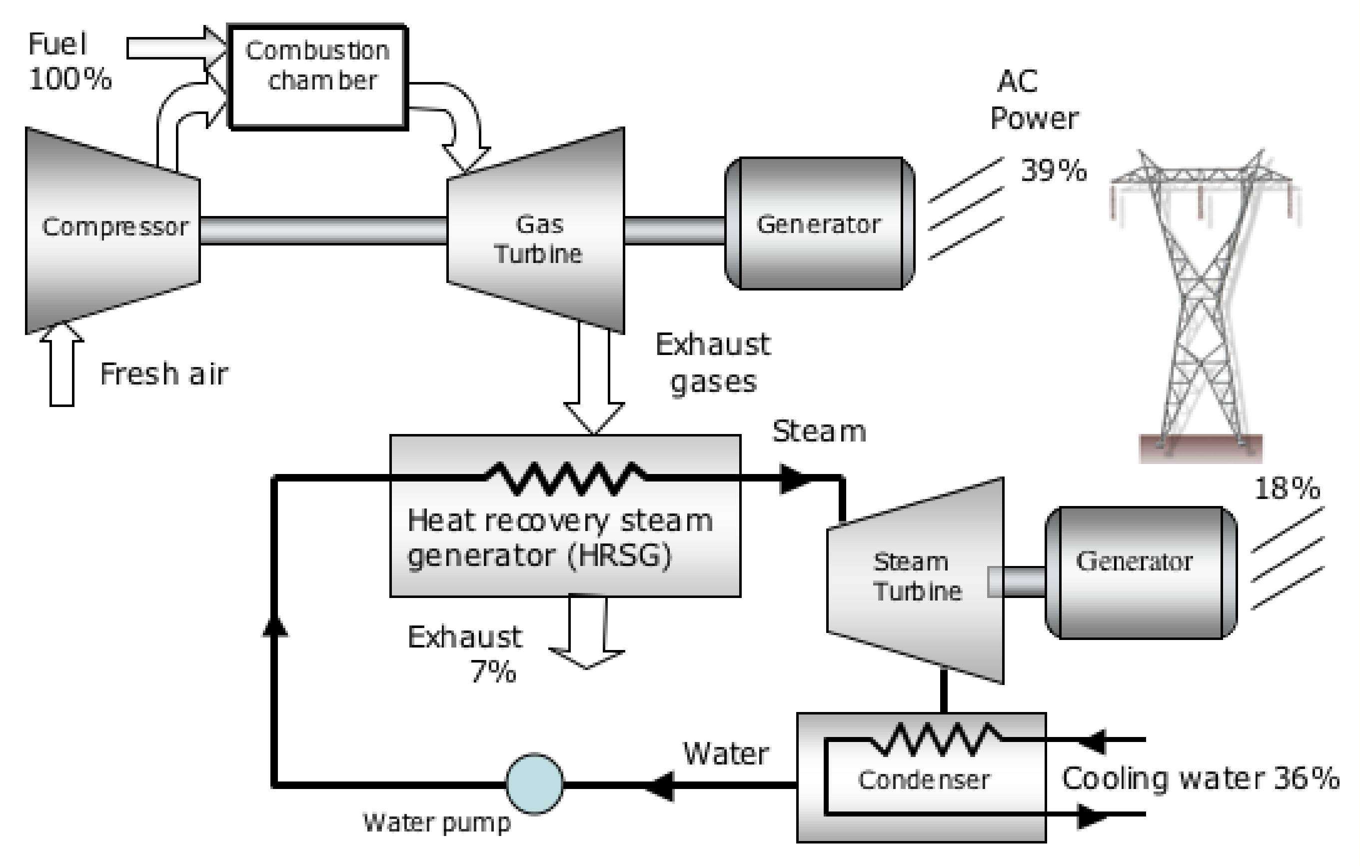
Open cycle gas turbine: Typical efficiency: 30-35%



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.

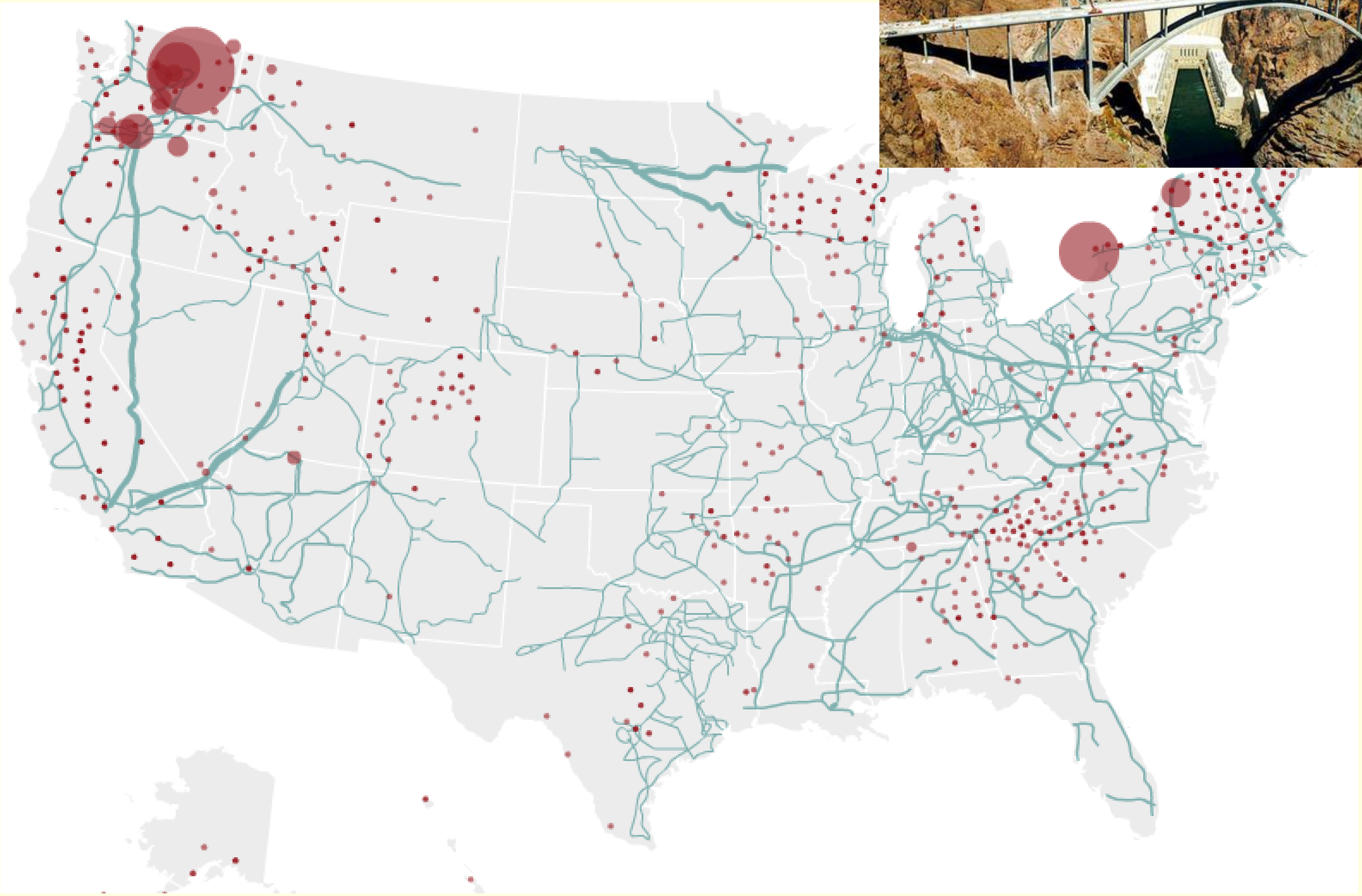


Combined cycle power plant: Typical efficiency: 60-65%



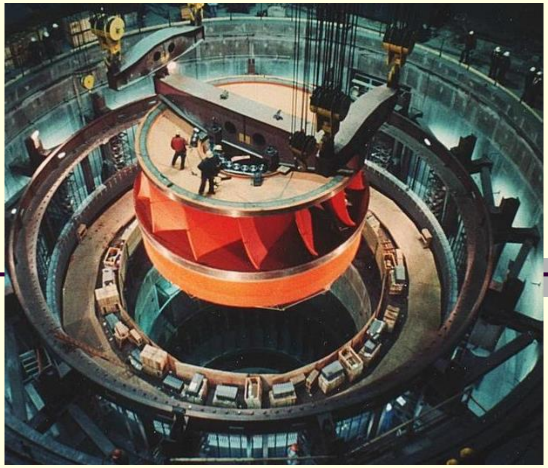
Efficiencies are even higher when the steam is used for district heating or industrial processes.

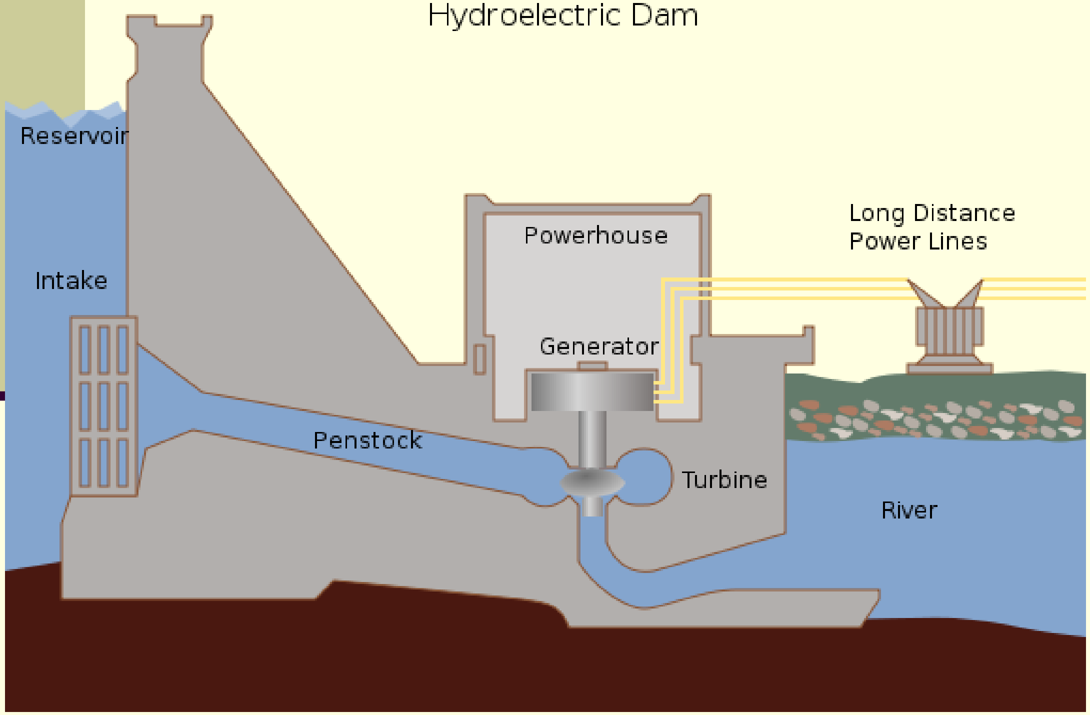
Hydro Power Plants:
Number of Generators ≈ 4,000
Total Capacity ≈ 80 GW

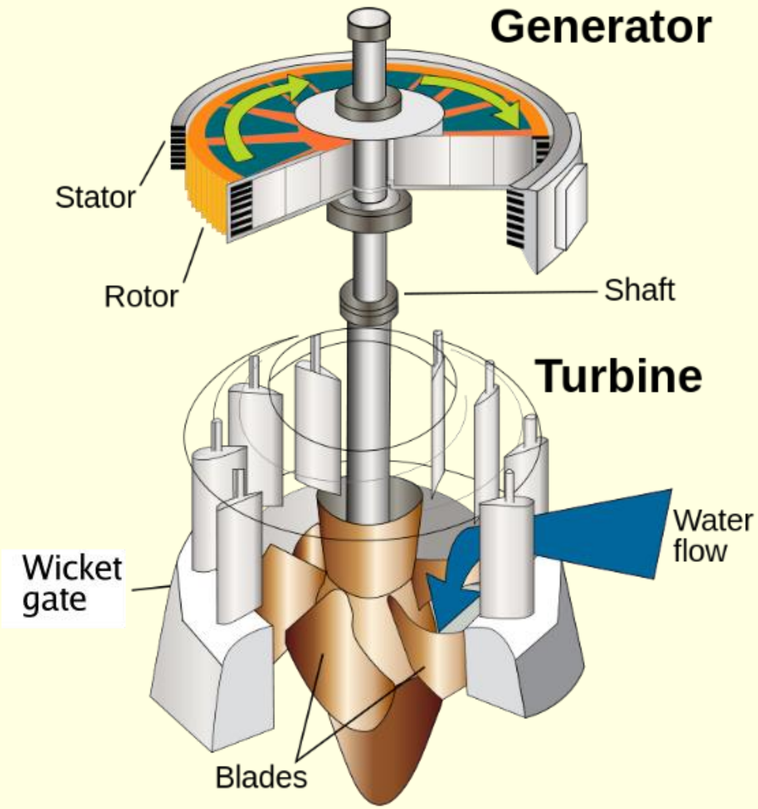


Hydro Power plants

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

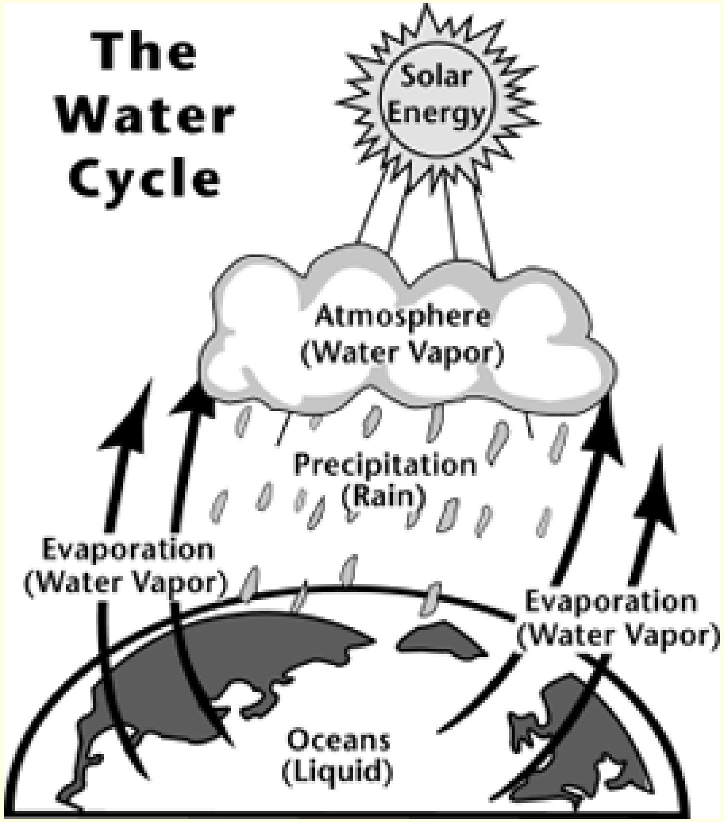




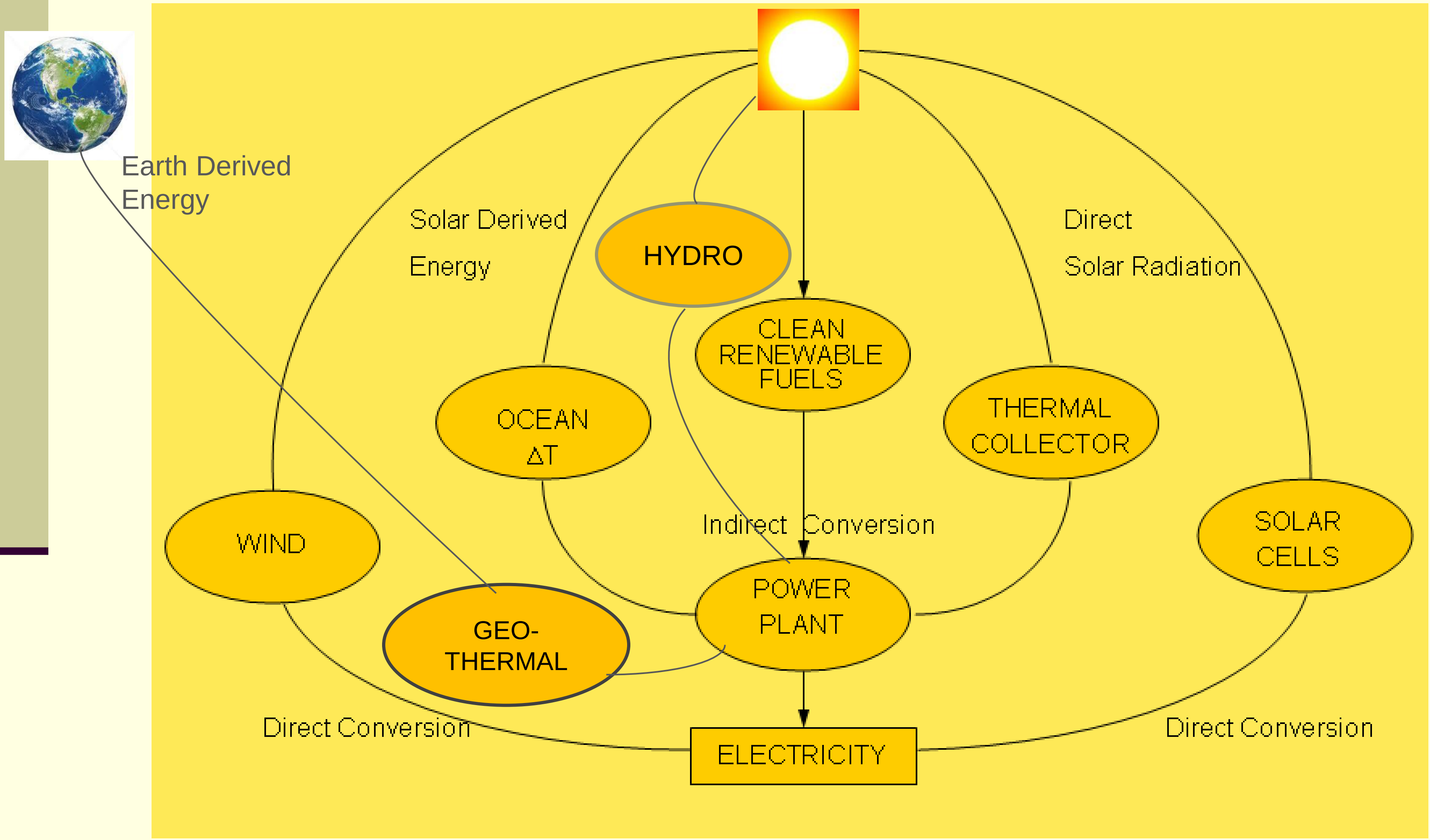


Hydropower is renewable

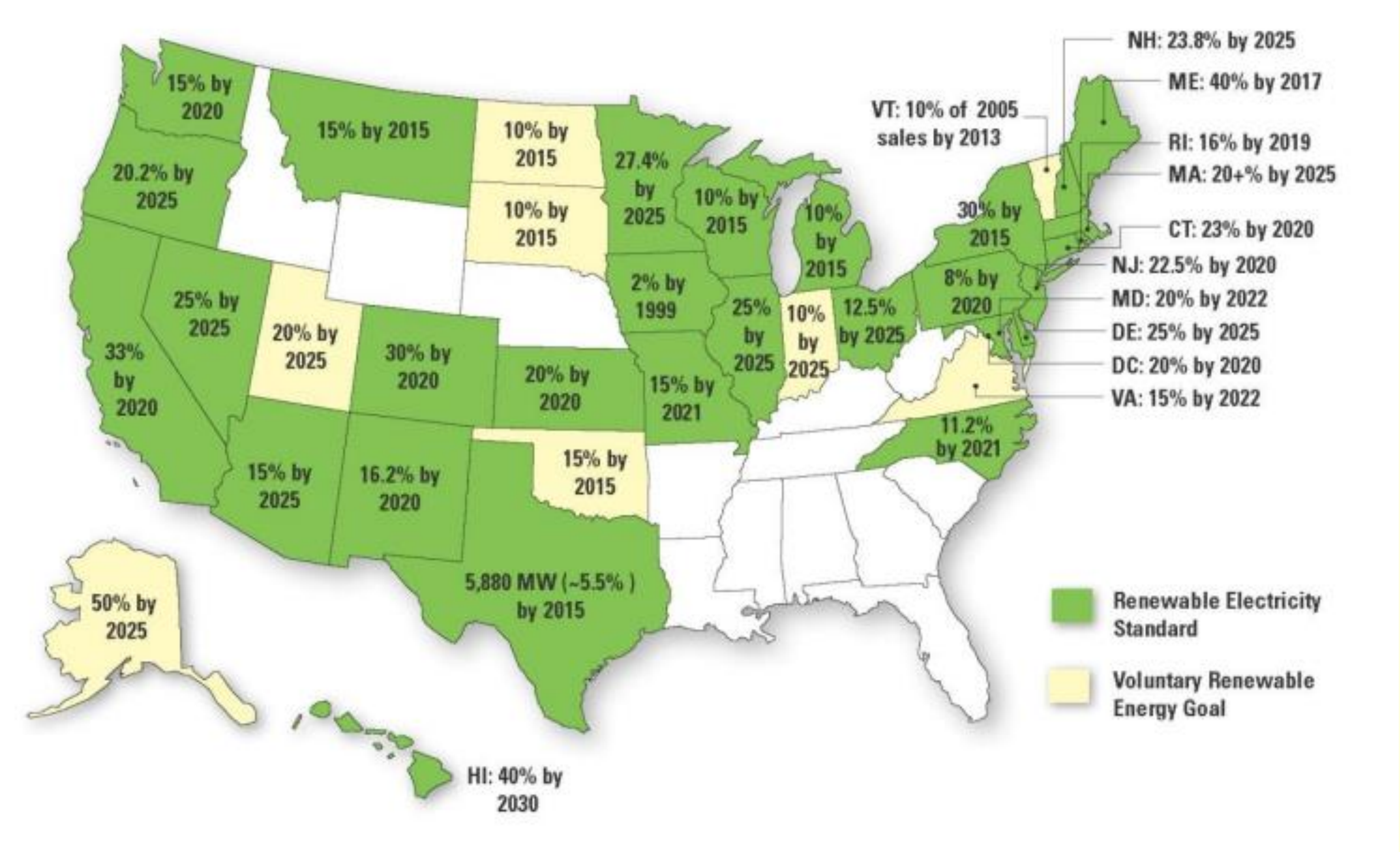
- Hydropower relies on the water cycle. Herein:
  - Solar energy heats water on the surface, causing it to evaporate.
  - This water vapor condenses into clouds and falls back onto the surface as precipitation (rain, snow, etc.).
  - The water flows through rivers back into the oceans, where it can evaporate and begin the cycle over again



Renewable Resources

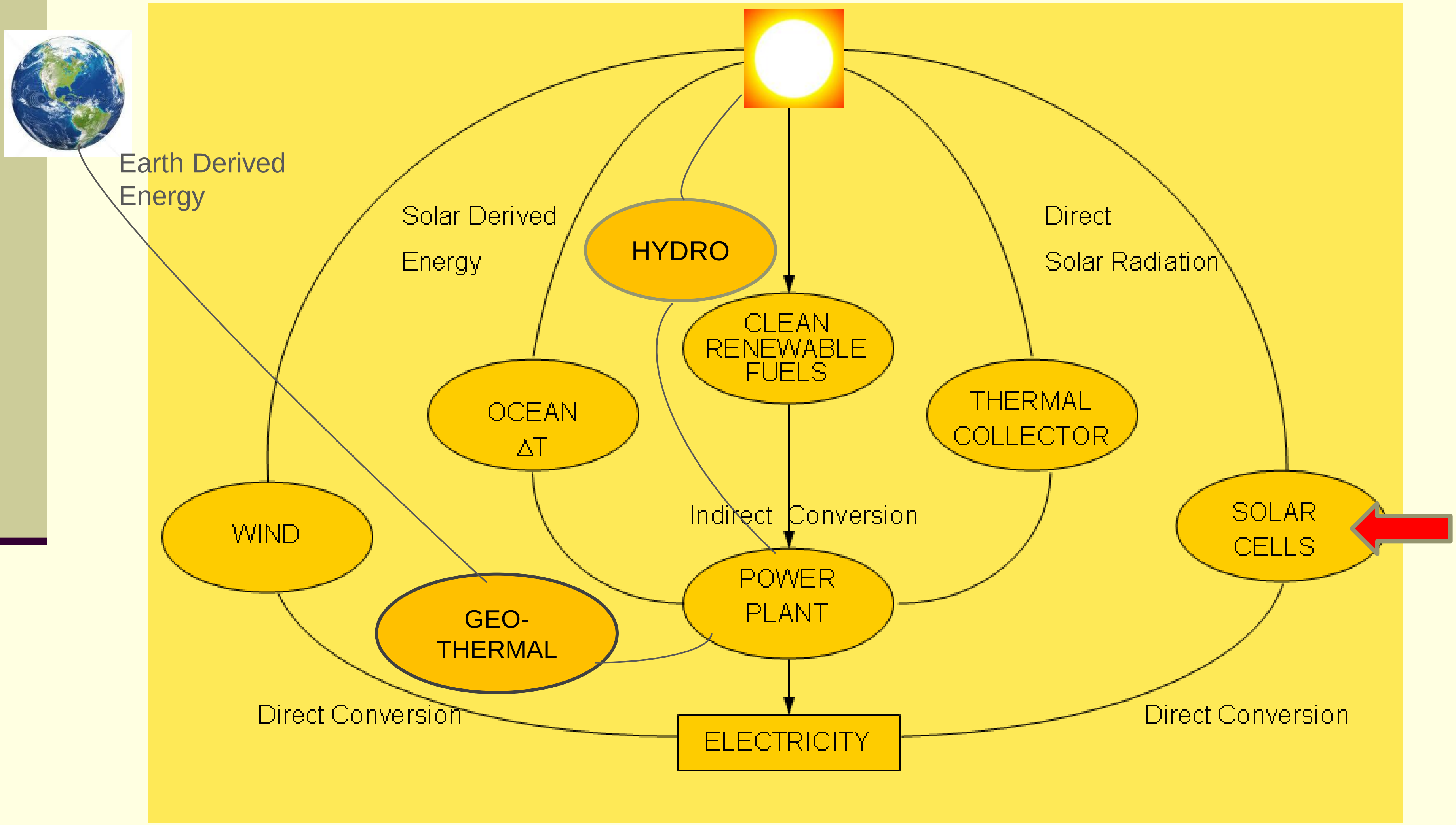


States with Renewable Portfolio Standards



Source: NREL

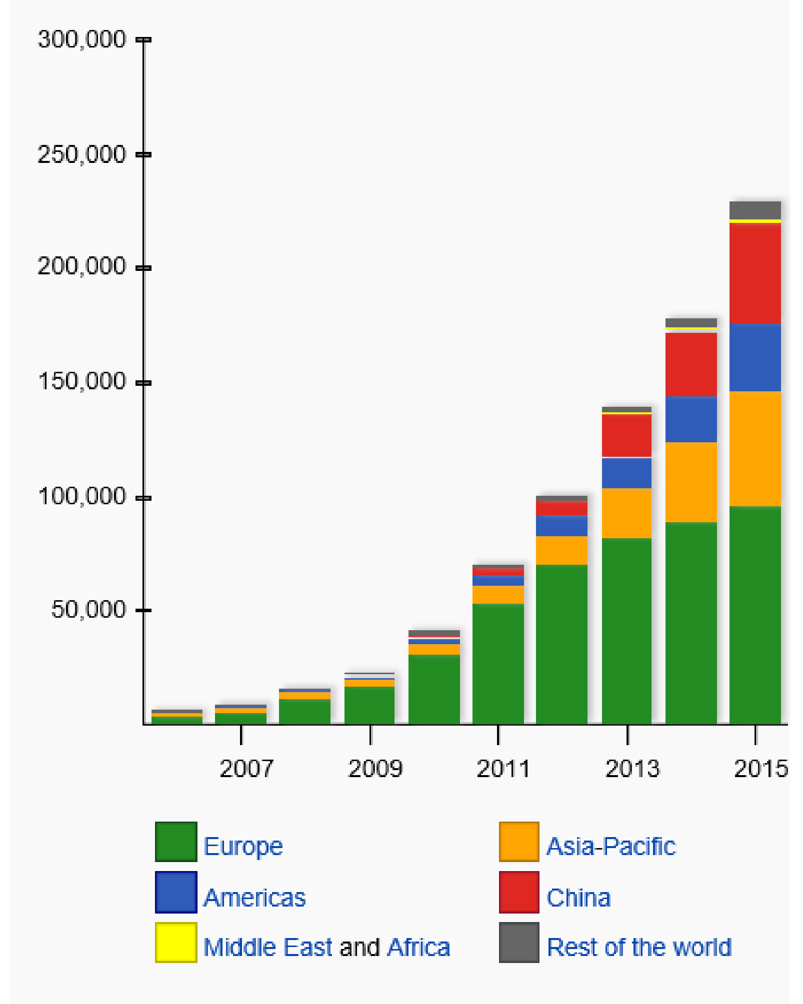
Renewable Resources



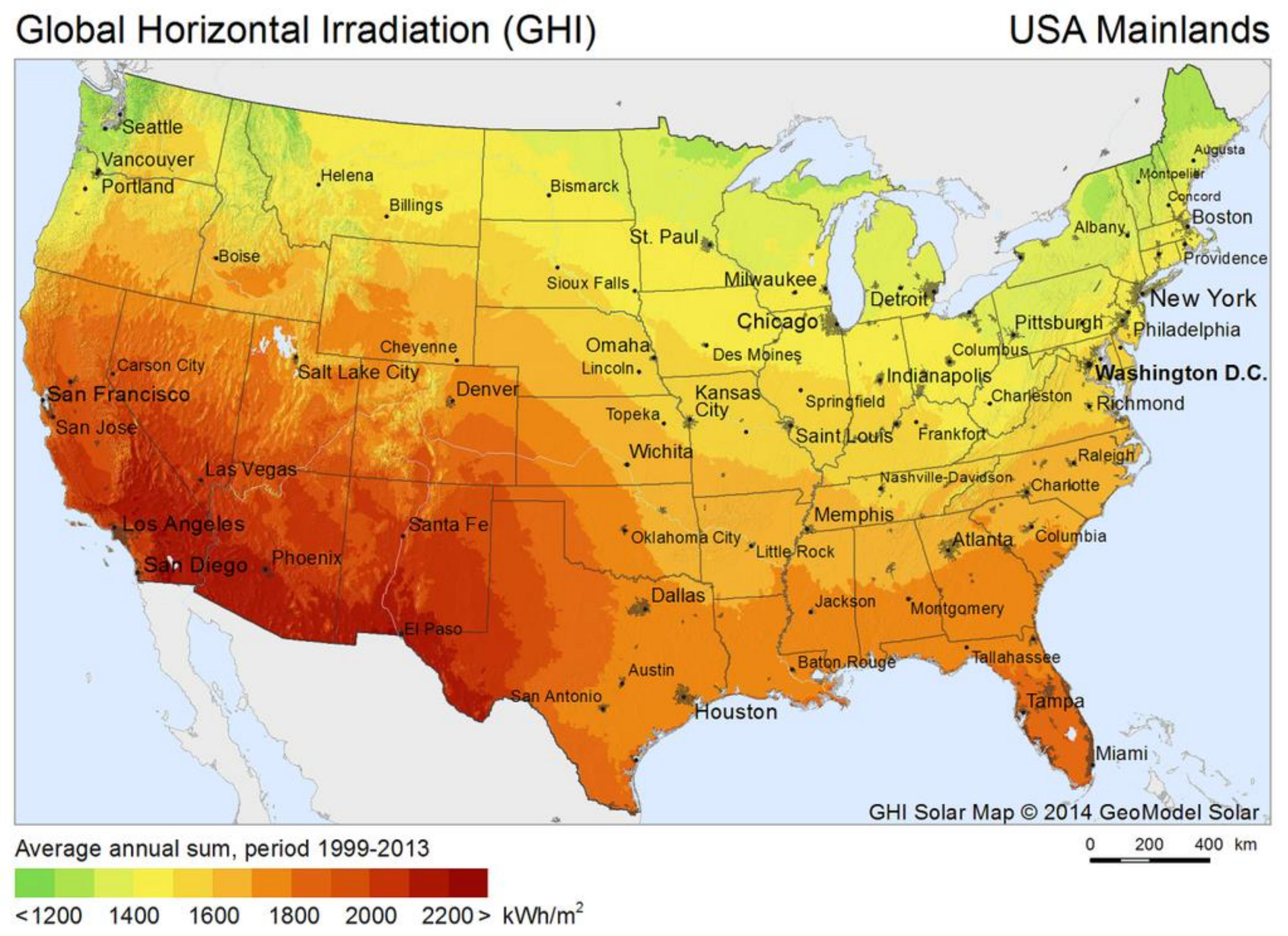
Growth in Solar Photovoltaics

Top PV countries in 2015 (MW)

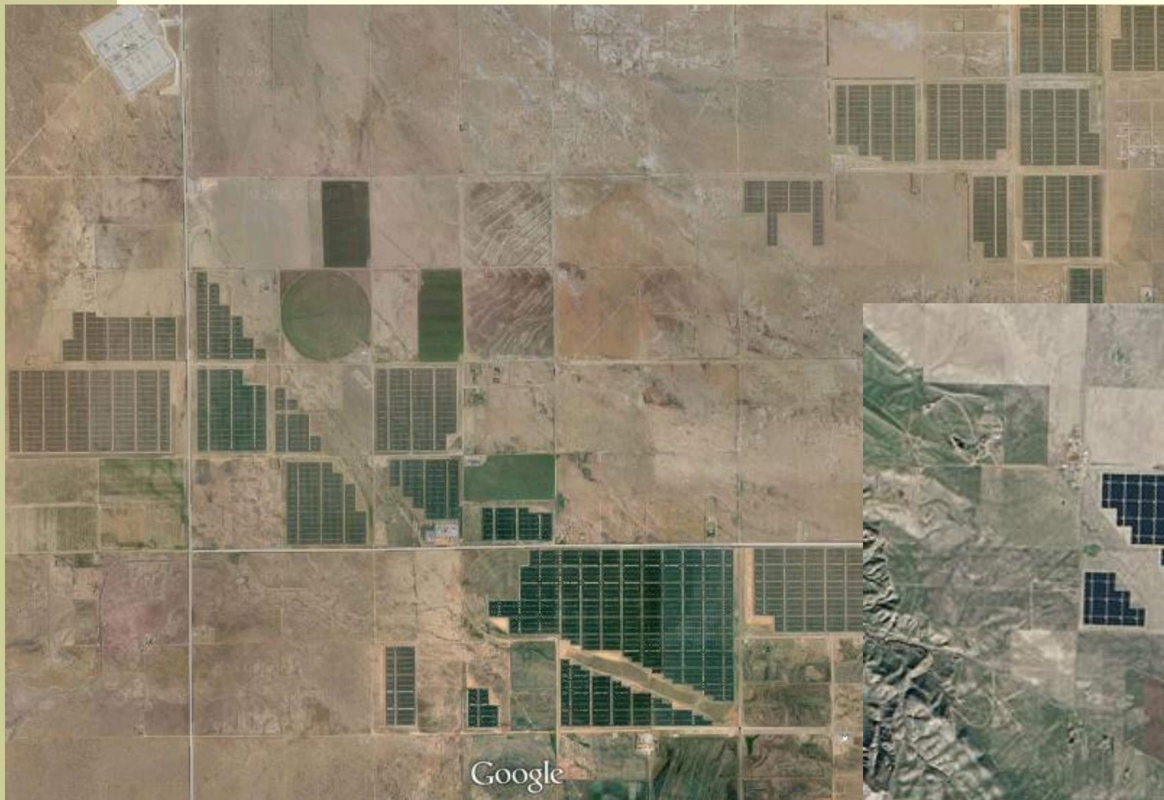
Rank	Country	Total capacity	Date
1.	China	43,060	2015
2.	Germany	39,640	2015
3.	Japan	33,300	2015
4.	United States	27,320	2015
5.	Italy	18,920	2015
6.	UK	9,080	2015
7.	France	6,550	2015
8.	India	5,170	2015
9.	Spain	4,832	2015
10.	Australia	4,100	2015
11.	Belgium	3,200	2015
12.	South Korea	3,200	2015
13.	Greece	2,600	2015
14.	Canada	2,240	2015
15.	Czech Republic	2,070	2015

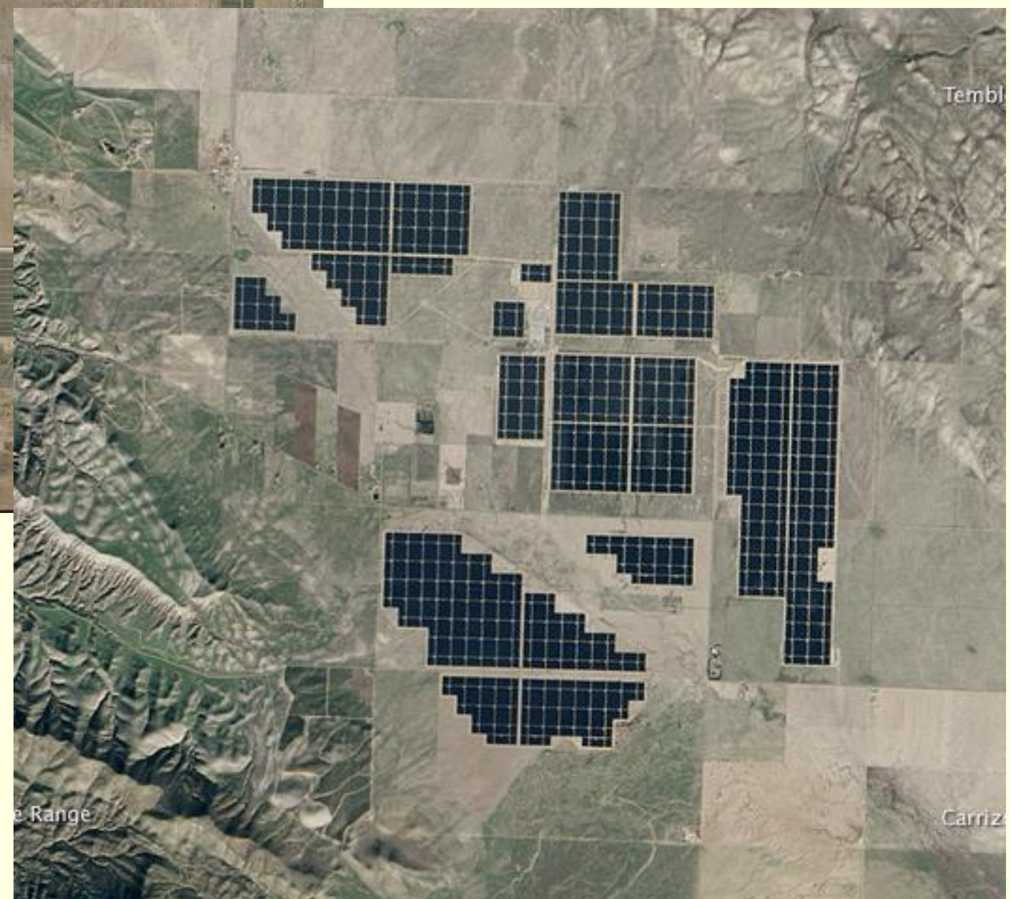


Solar Resource (available worldwide)

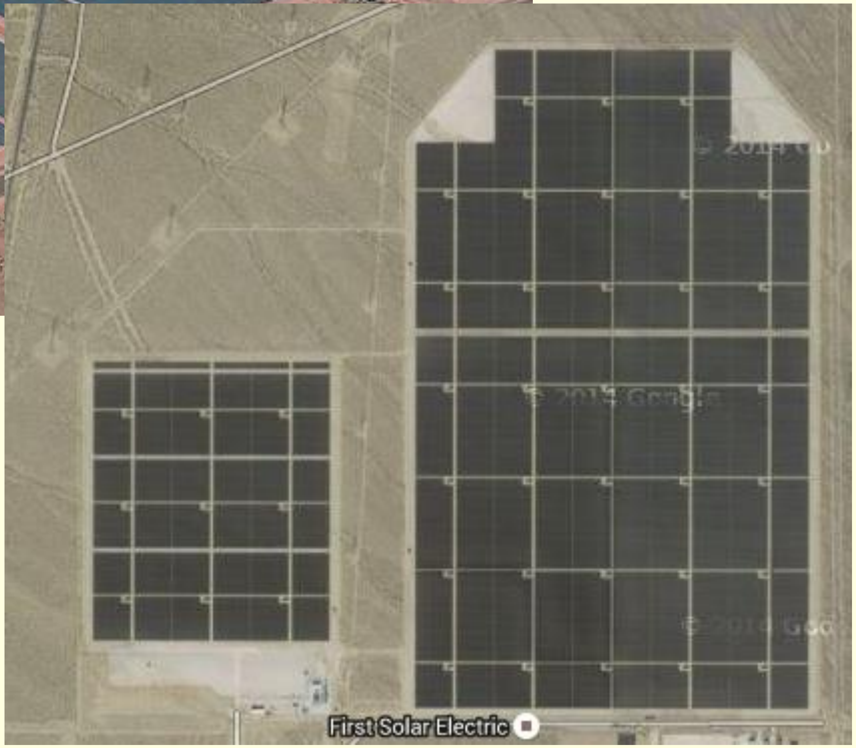


Largest PV Systems in CA – over 500 MW





Large Solar PV plants in Nevada



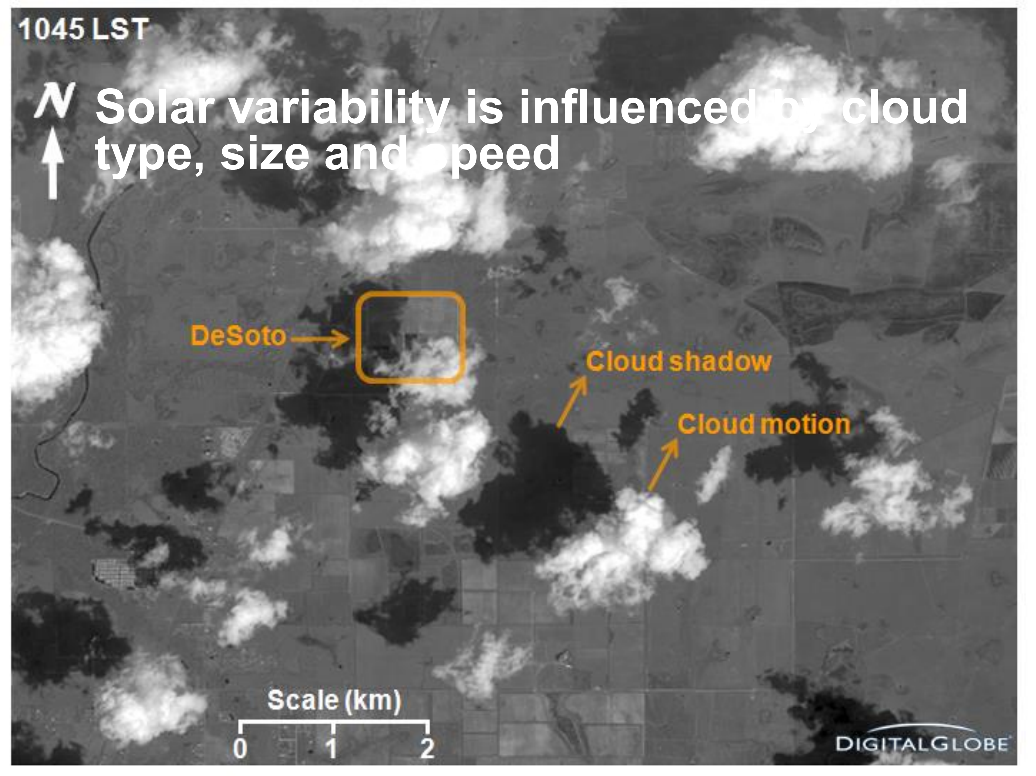
Mid-Size and small PV Plants in Nevada

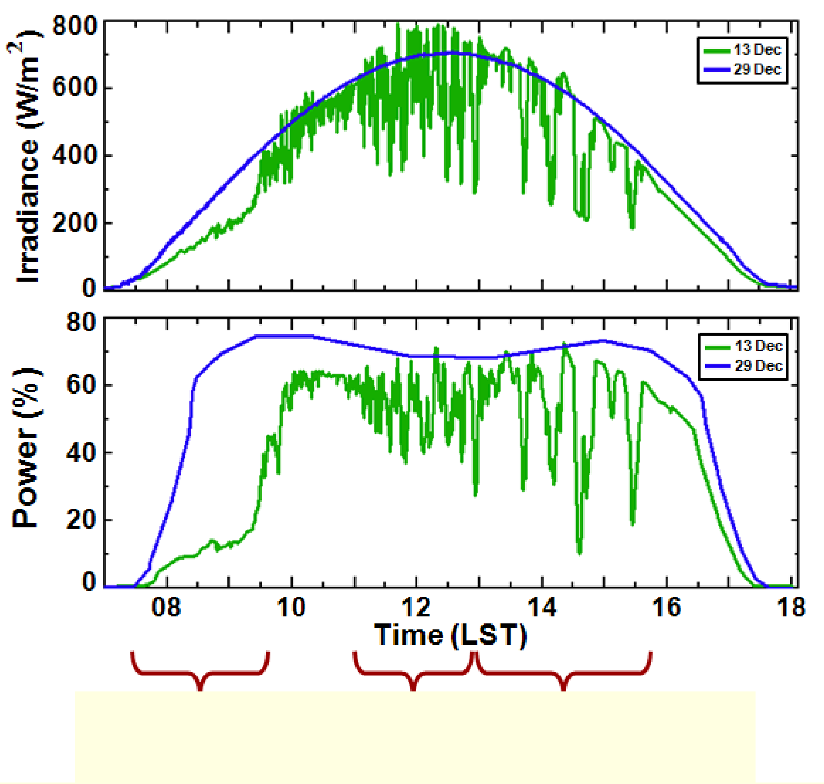
- 50 MW (Prim)
- 30 MW (1-axis tracking @ NAFB)
- Numerous distributed PV systems (few kW – 500 kW)





Solar power variability is influenced by the weather (clouds, wind speed, …)

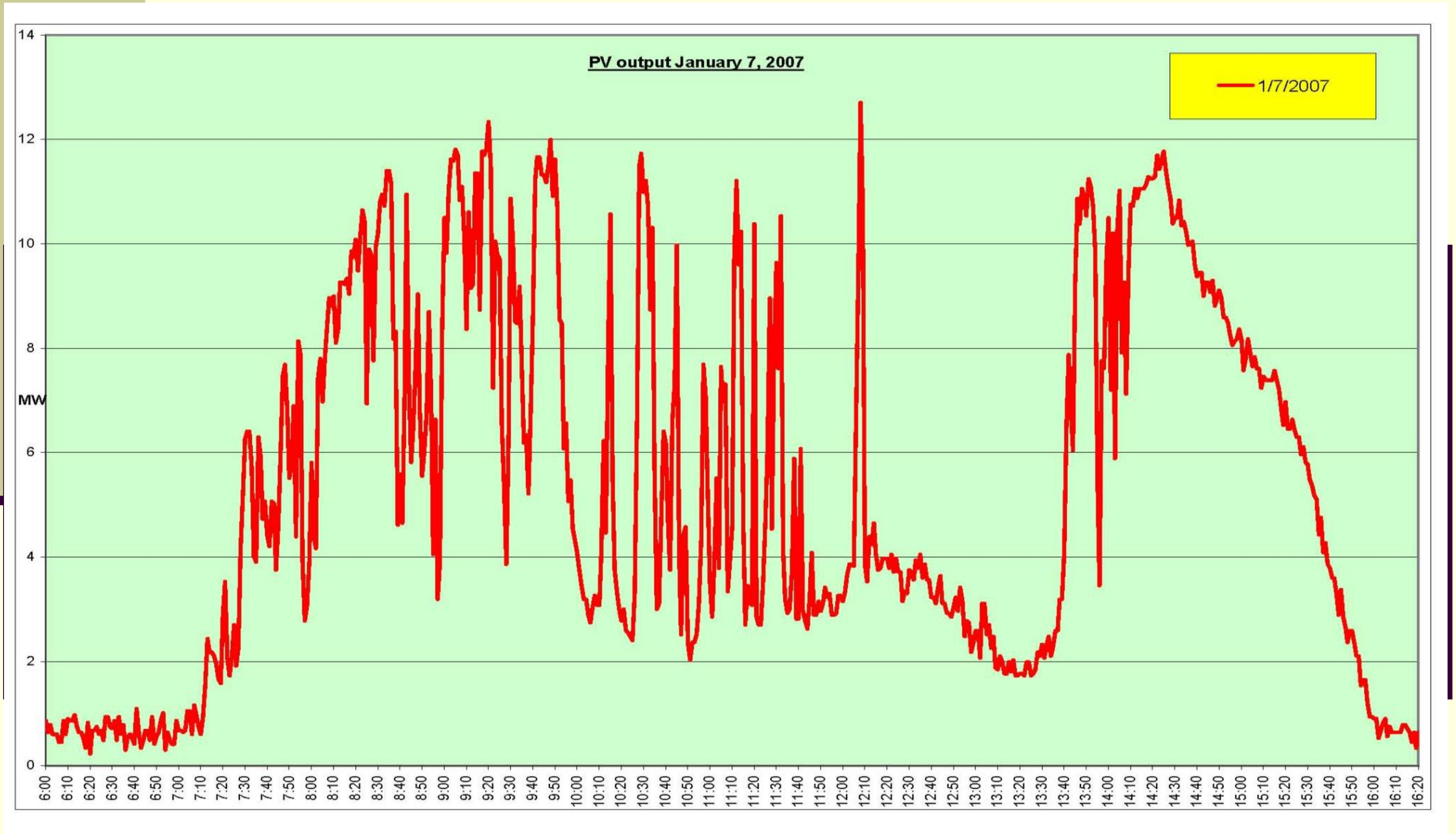




Example of clouds over the DeSoto PV Site (Central Florida)
System Type: Single-Axis Tracking
System Rating: 25 MW

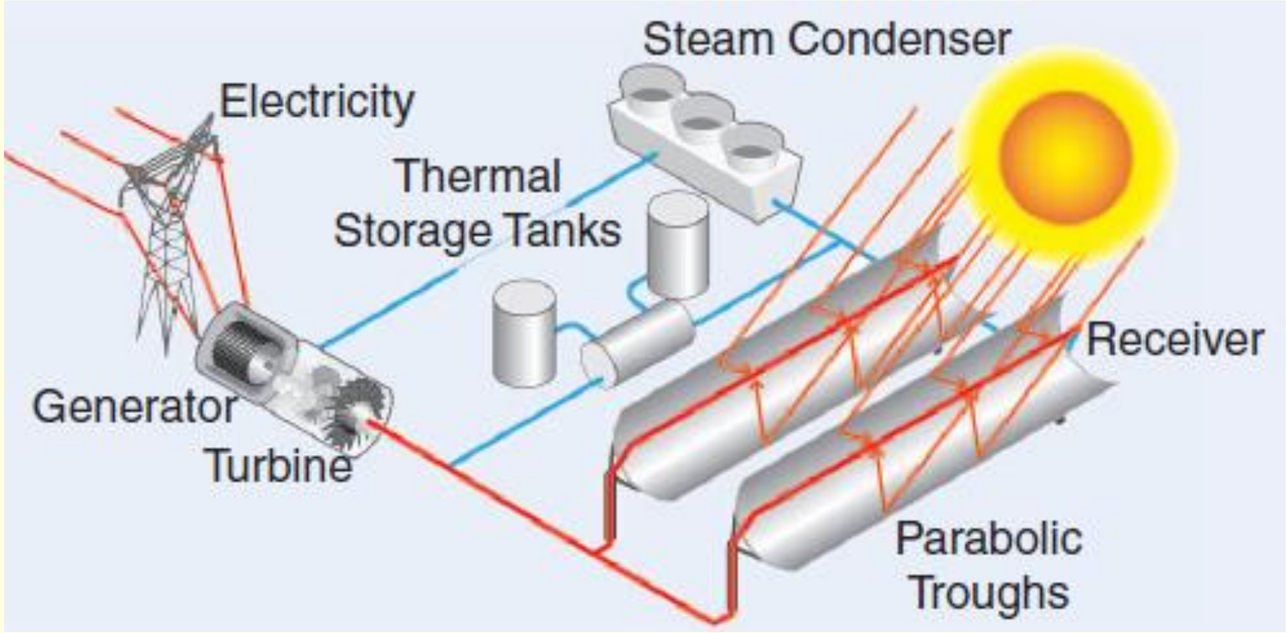
PV Power variability of local 15 MW plant

Due to lack of inertia, PV power can change rapidly under cloudy skies, many times per day!



Linear CSP Systems

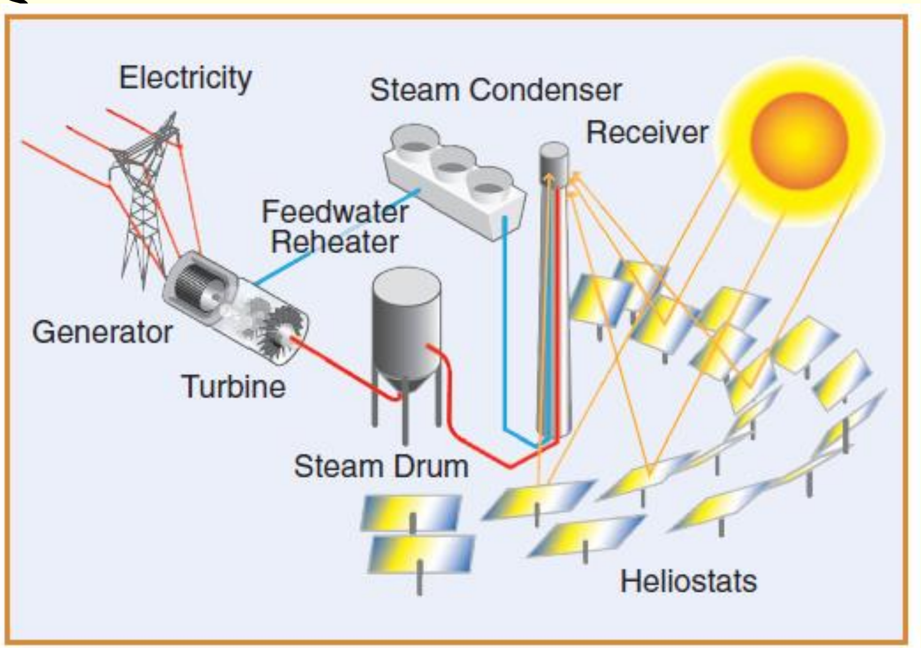
- Linear CSP collectors capture the sun's energy with large mirrors that reflect and focus the sunlight onto a linear receiver tube.
- The receiver contains a fluid that is heated by the sunlight and then used to create steam that spins a turbine driving a generator to produce electricity.



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

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.

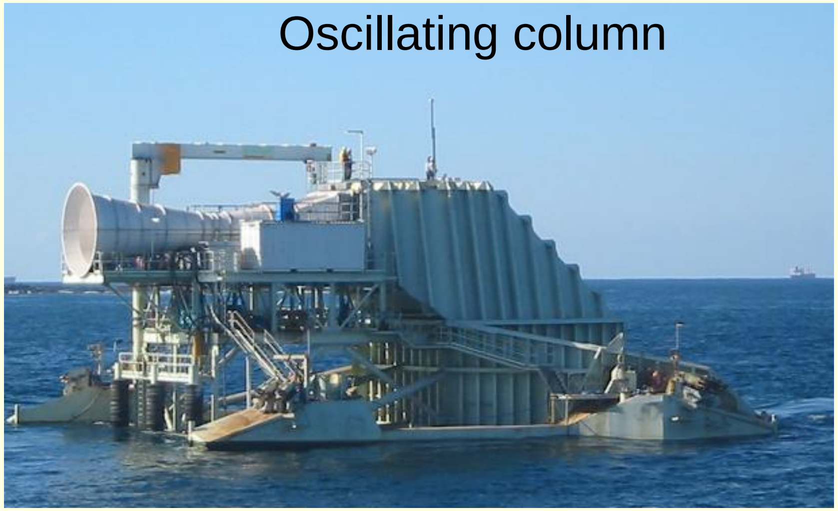


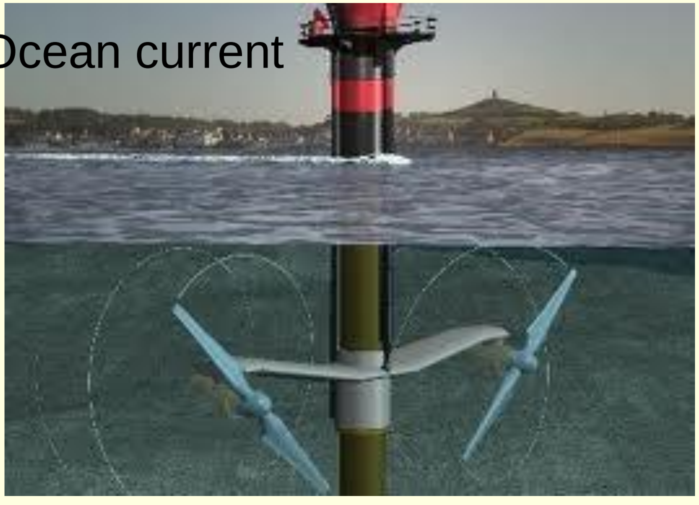
Power Tower CSP in Nevada: Tonopah – 110 MW

World's largest - Ivanpah Solar, CA: 350 MW

Ocean Power

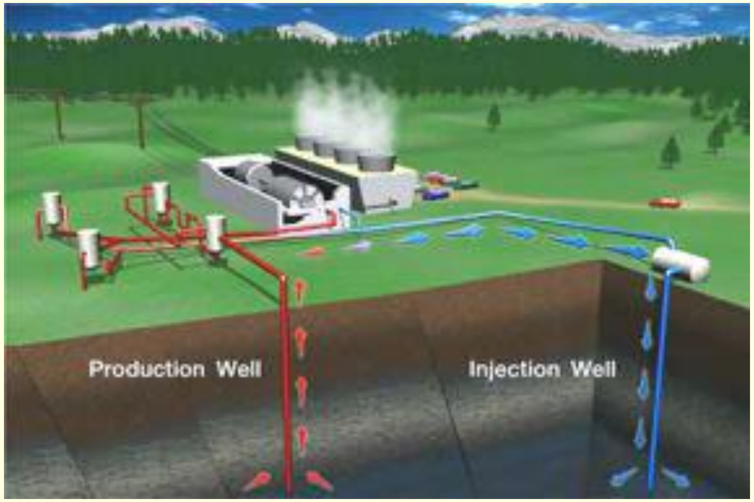
- Energy can be extracted from the power of the waves, from the tide, or from ocean currents – limited success.

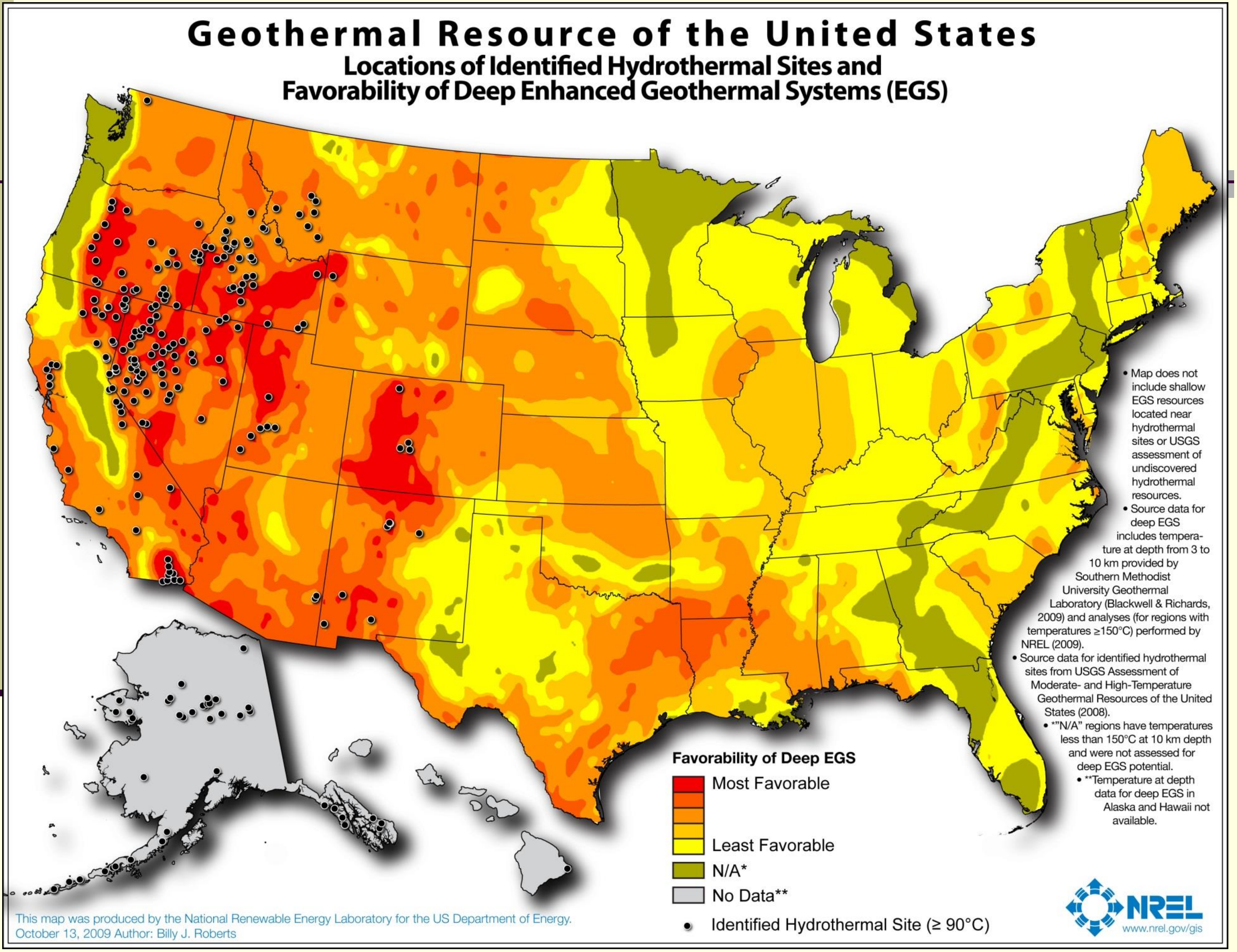




Geothermal

- **Dry steam plants** use steam piped directly from a geothermal reservoir to turn the generator turbines
- **Flash steam plants** take high-pressure hot water from deep inside the earth and convert it to steam to drive the generator turbines. When the steam cools, it condenses to water and is injected back into the ground to be used over and over again.





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

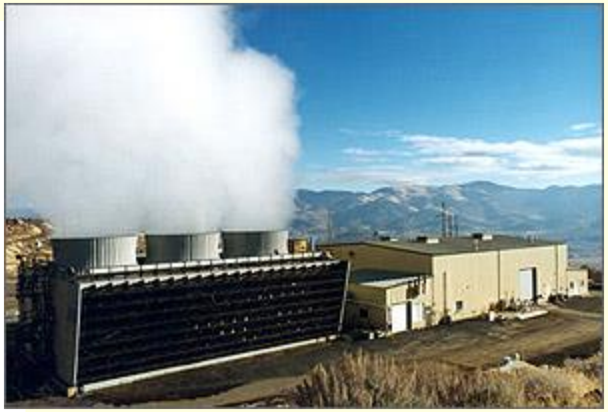
NV Geothermal Current Capacity: 385 MW

- Geothermal power is controllable

GEOTHERMAL

1. **Beowawe Power** 17.7 MW
2. **Brady Geothermal Project** 24.0 MW
3. **Clayton Valley 1** ● 53.5 MW
4. **Desert Peak Geothermal Project #2** 25.0 MW
5. **Dixie Meadows** ● 51.0 MW
6. **Faulkner 1** 49.5 MW
7. **Galena 2** 13.0 MW
8. **Galena 3** 26.5 MW
9. **Homestretch** 2.1 MW
10. **Jersey Valley Geothermal Project** 22.5 MW
11. **McGinness Hills** 48.0 MW
12. **Richard Burdette Generation Facility** 26.0 MW
13. **Salt Wells** 23.6 MW
14. **San Emidio** 11.8 MW
15. **Soda Lake I** 3.6 MW
16. **Soda Lake II** 19.5 MW
17. **Steamboat Hills** 14.6 MW
18. **Steamboat IA** 2.0 MW
19. **Steamboat II** 13.4 MW
20. **Steamboat III** 13.4 MW
21. **Stillwater 2** 47.2 MW (Photovoltaic Addition 22.0 MW)
22. **Tuscarora (aka Hot Sulfur Springs 2)** 32.0 MW

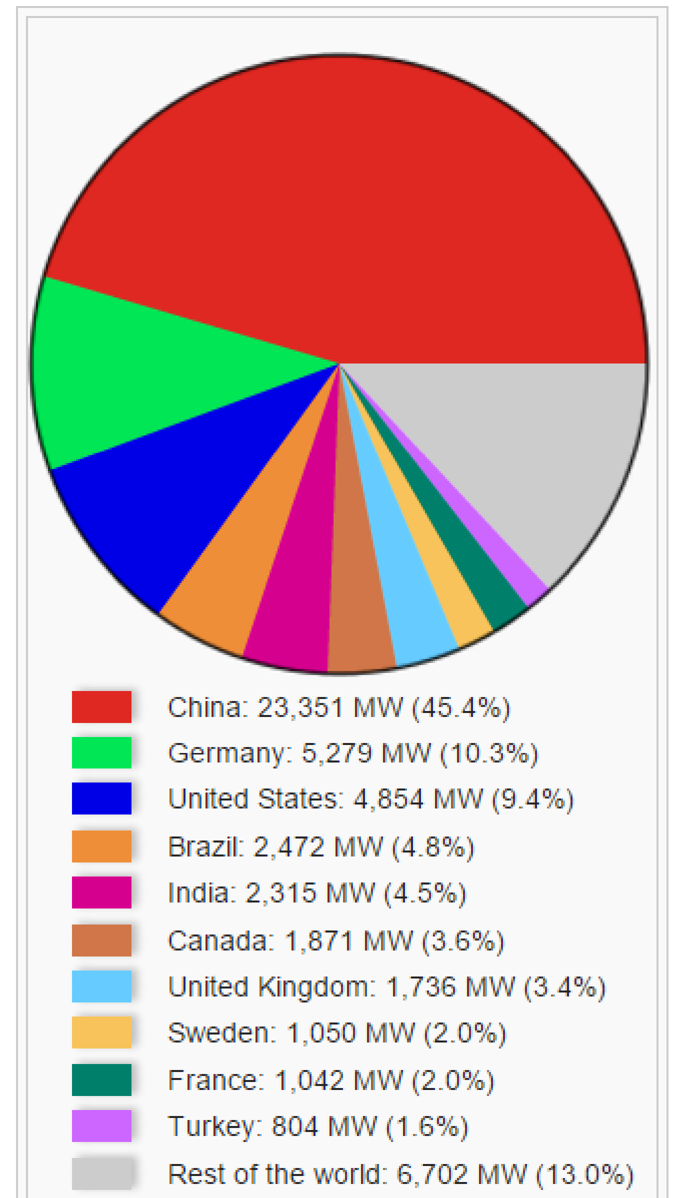
● In development or in construction

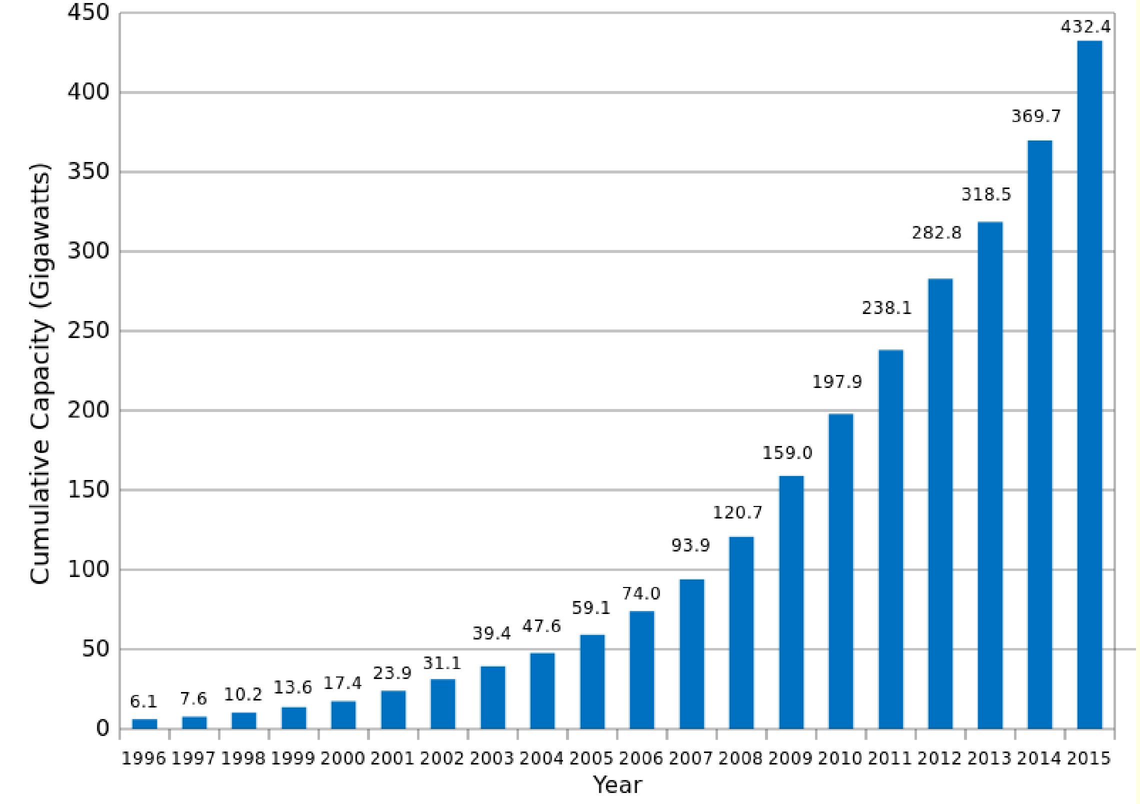


Source: NV Energy Website

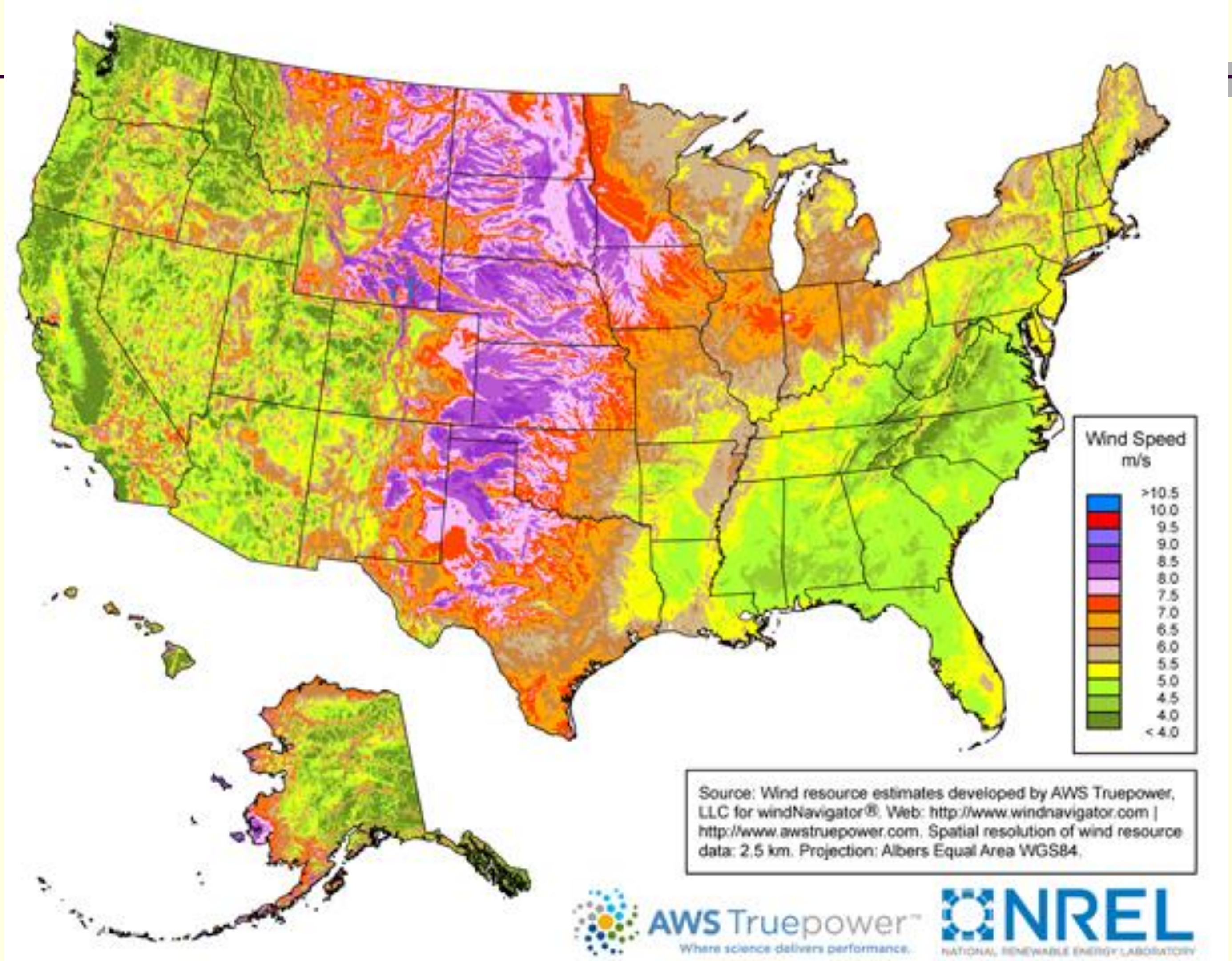
Wind Power … inland and offshore

Global wind power cumulative capacity (2015)





US Wind Resource Map



Largest wind power generators (7-8 MW)

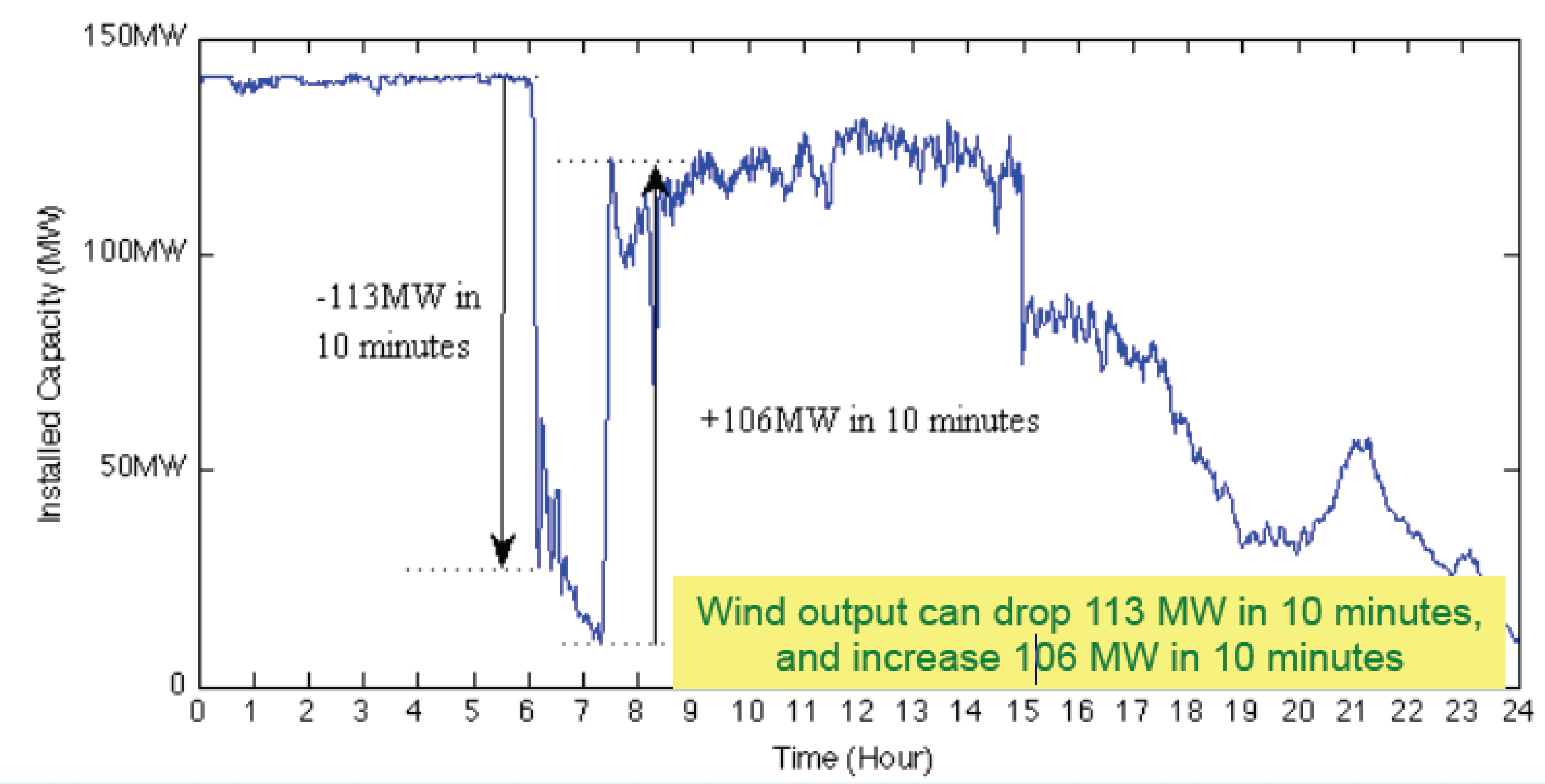
- Manufacturers:
  - Enercon,
  - Mitsubishi,
  - Samsung,
  - Vestas

California wind farm: Tihachapi - 4,500 MW

Wind Power in Nevada:
Spring Valley (Pine County): 150 MW

Variability and Uncertainty of Wind Power

Like solar resources, wind power can be highly variable due to sudden changes in wind speed, and uncertain as timing of this variable generation is less predictable.

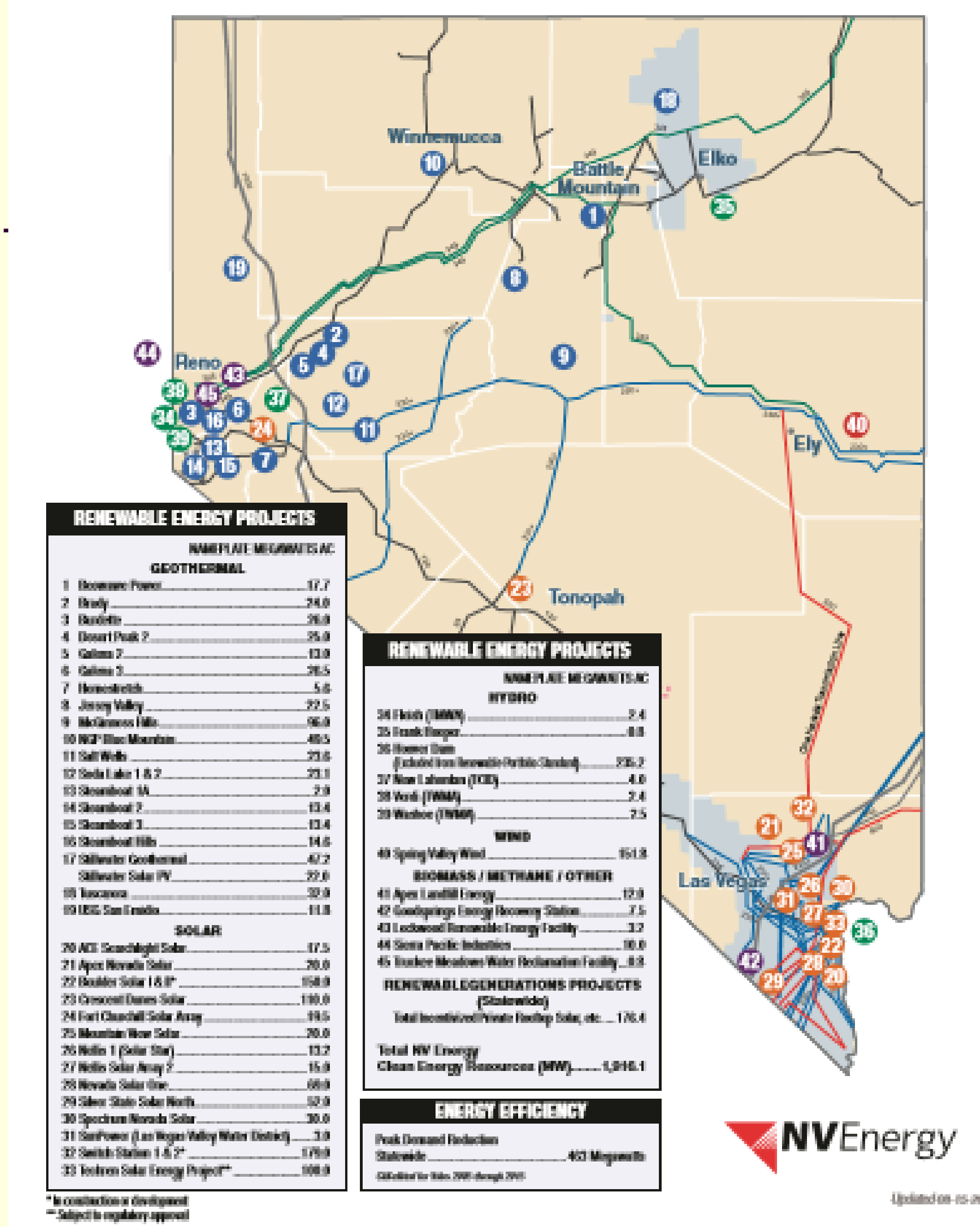


Source: NREL

Renewable Plants in Nevada

Geothermal: 550 MW
Solar: 750 MW (large)
Solar rooftops: 250 MW
Hydro: 250 MW
Other: 30 MW

Total: 1.83 GW
Peak Load: 7.3 GW

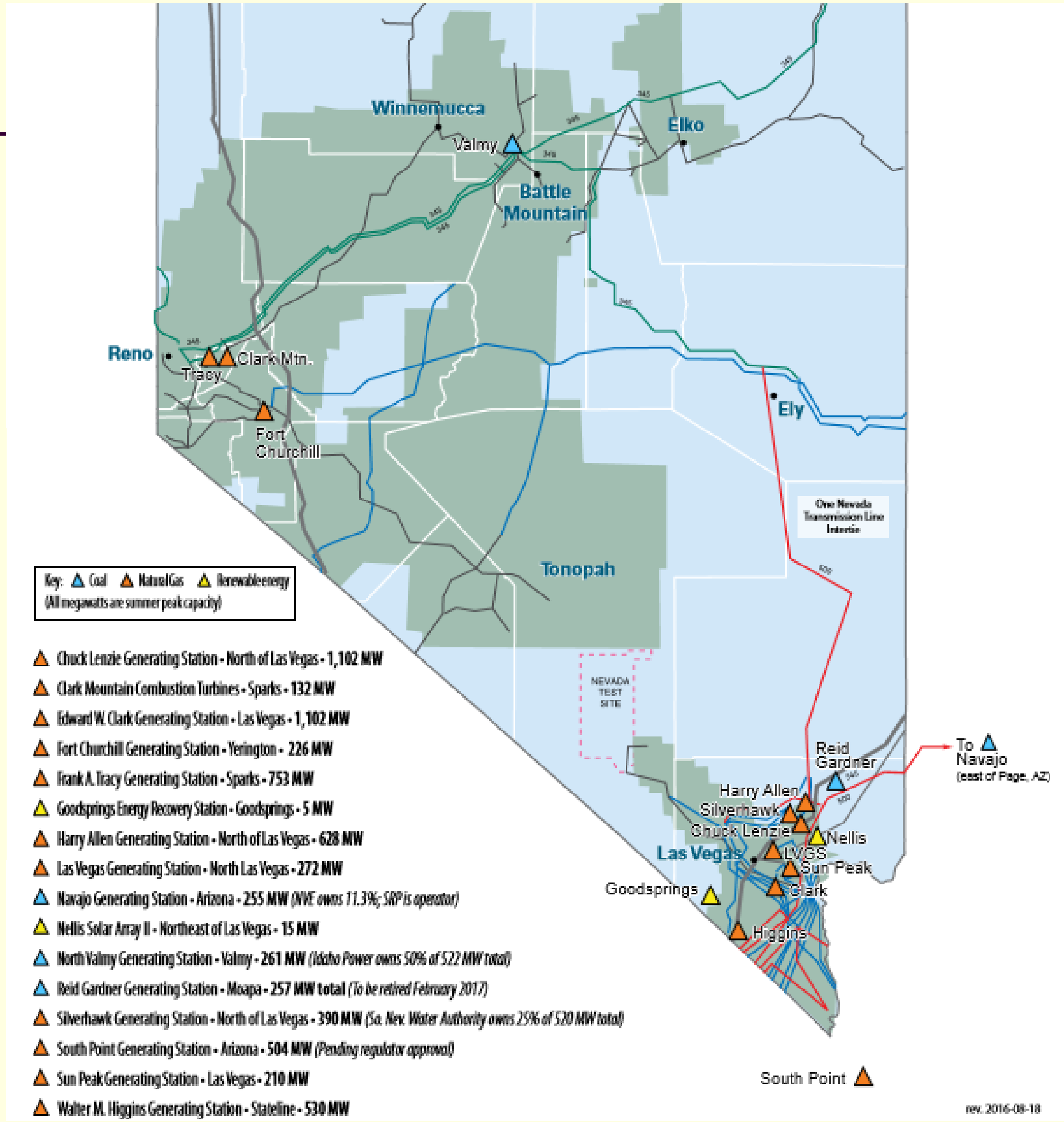


Source: NV Energy website

Nevada fossil fuel power plants

Natural Gas: 5.8 GW
Coal: 0.5 GW

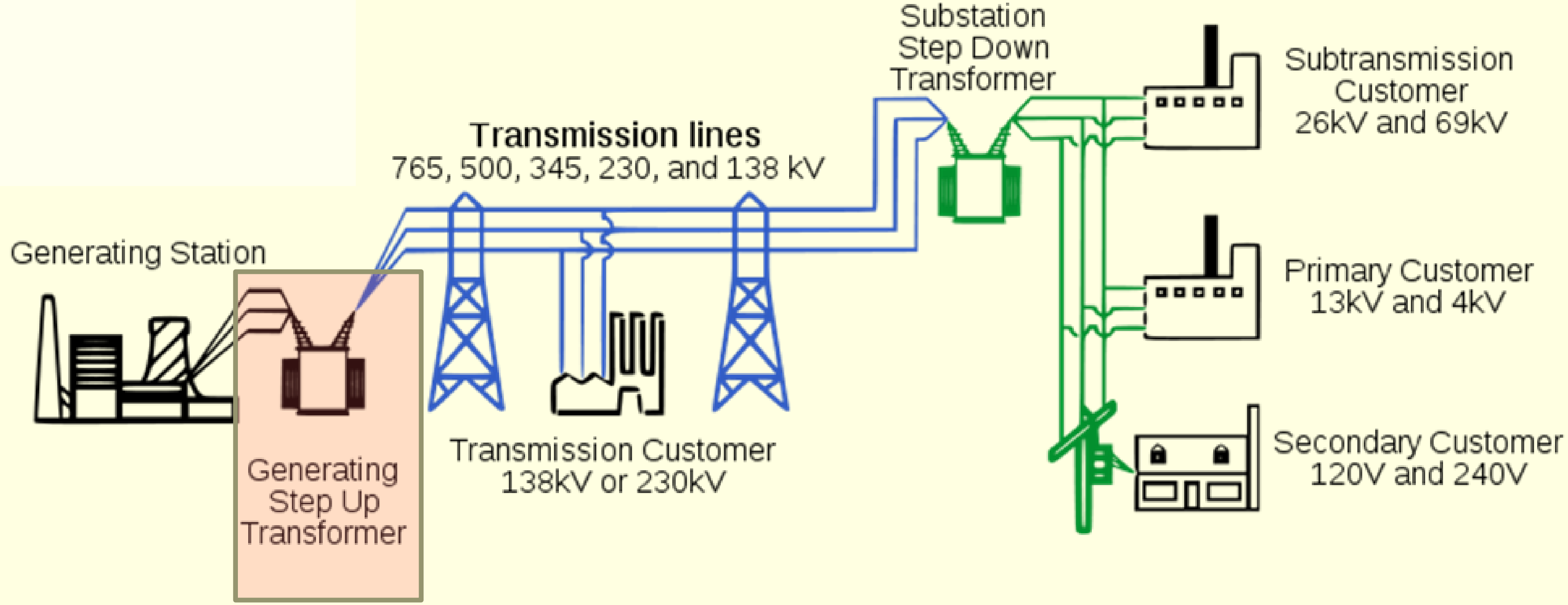
Total Capacity: 6.5 GW
Peak Load: 7.3 GW



US Map of Various Sources of Power Generation

- http://www.eia.gov/state/maps.cfm

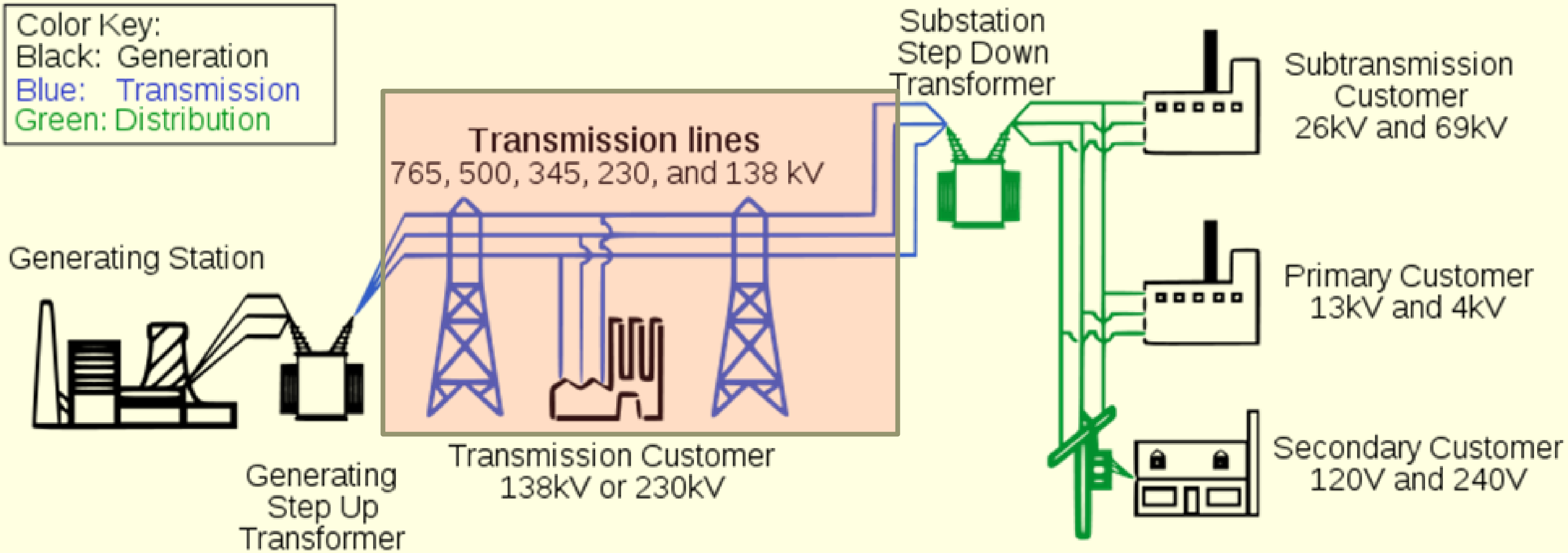
Basic Conventional Power System Layout



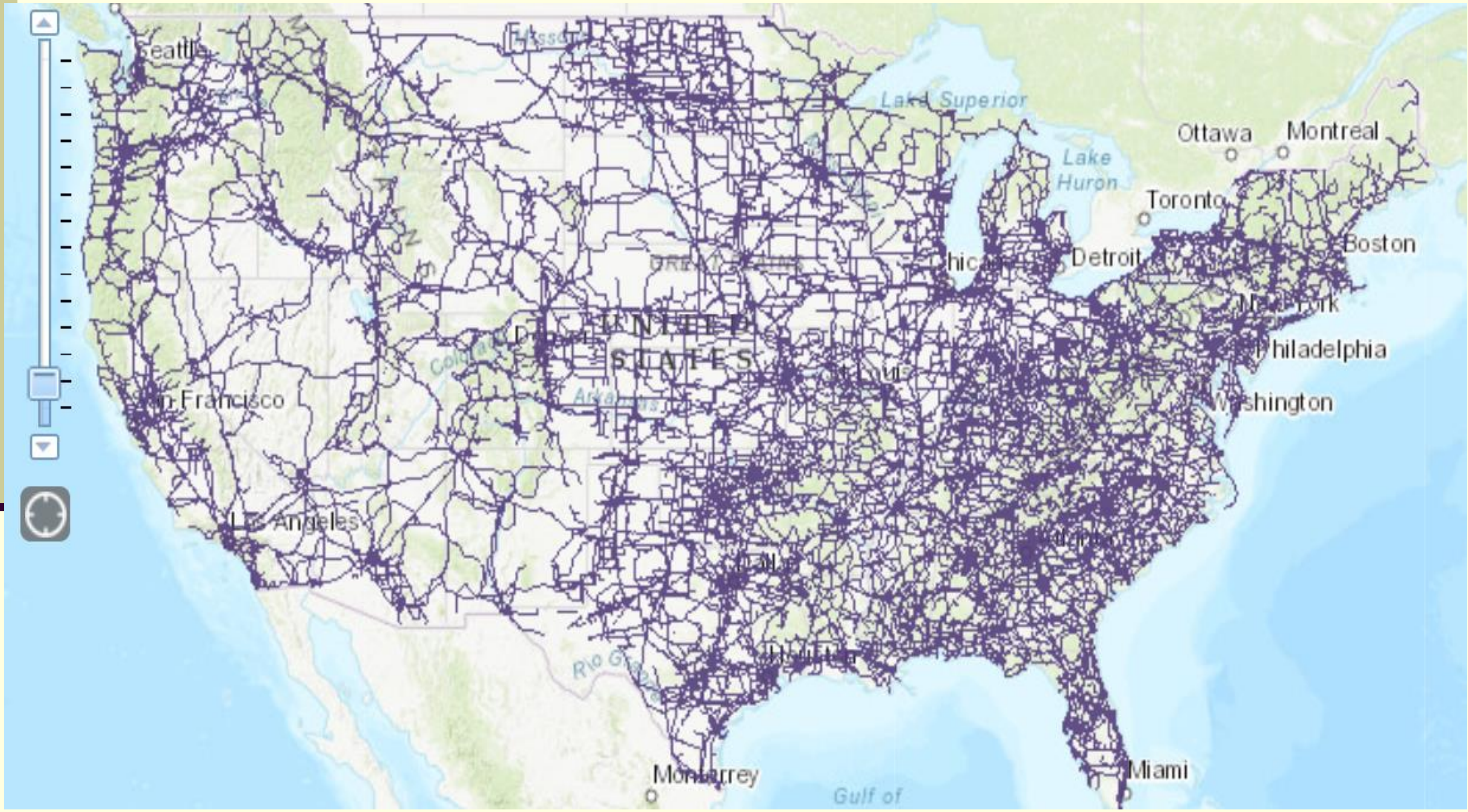
Step-up (Station) transformers:

- 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

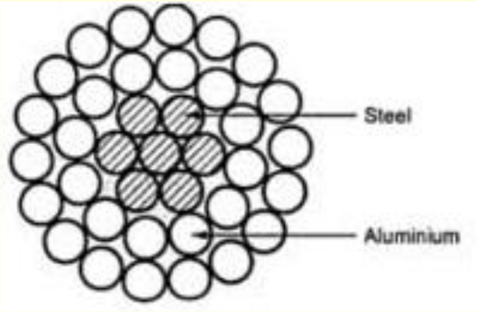


US Power Transmission Grid (138 kV and Higher)



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.



Tree Trimming underneath power lines

Before

After

Construction of “One Nevada” Power Line

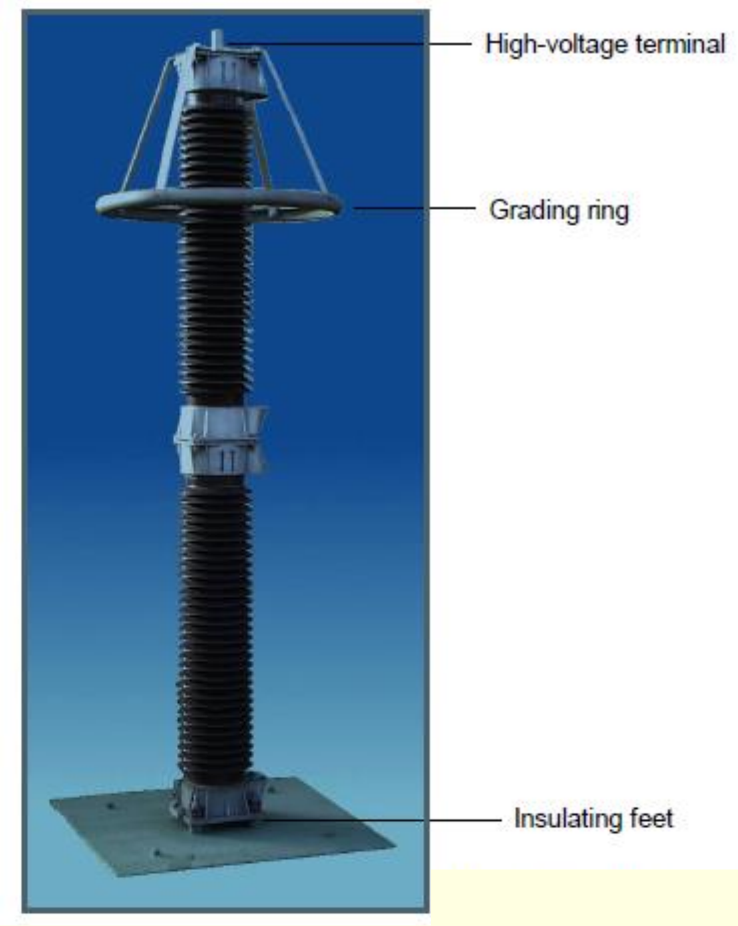
- http://www.myrgroup.com/electrical-construction-projects/one-nevada-500kv-transmission-line-on-line-project-southwest-intertie-project-swip/

High Voltage Power Cables (underground)

- Cable lines are designed to be placed underground in urban areas or under water. The conductors are insulated from one another and surrounded by protective sheath.
- Cable lines are more expensive and harder to maintain. They also have a large capacitance – not suitable for long distance.

Transmission System Protection

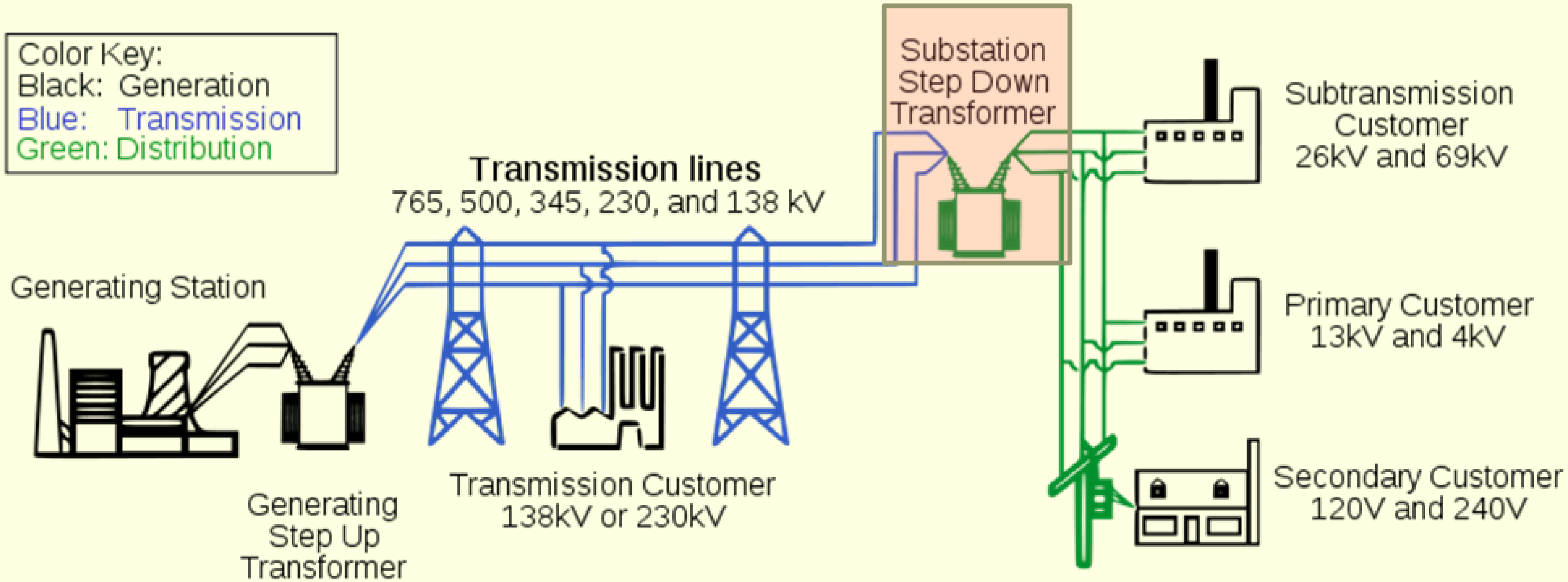
- Protective equipment needs to protect the system from over-voltages (surge arrestors) and over-currents (circuit breakers).



Long line series and shunt compensation

- **Shunt reactors** are used to compensate the line shunt capacitance under light load or no load.
- **Series capacitors** are often used to compensate the line inductive reactance in order to transfer more power.

Basic Conventional Power System Layout



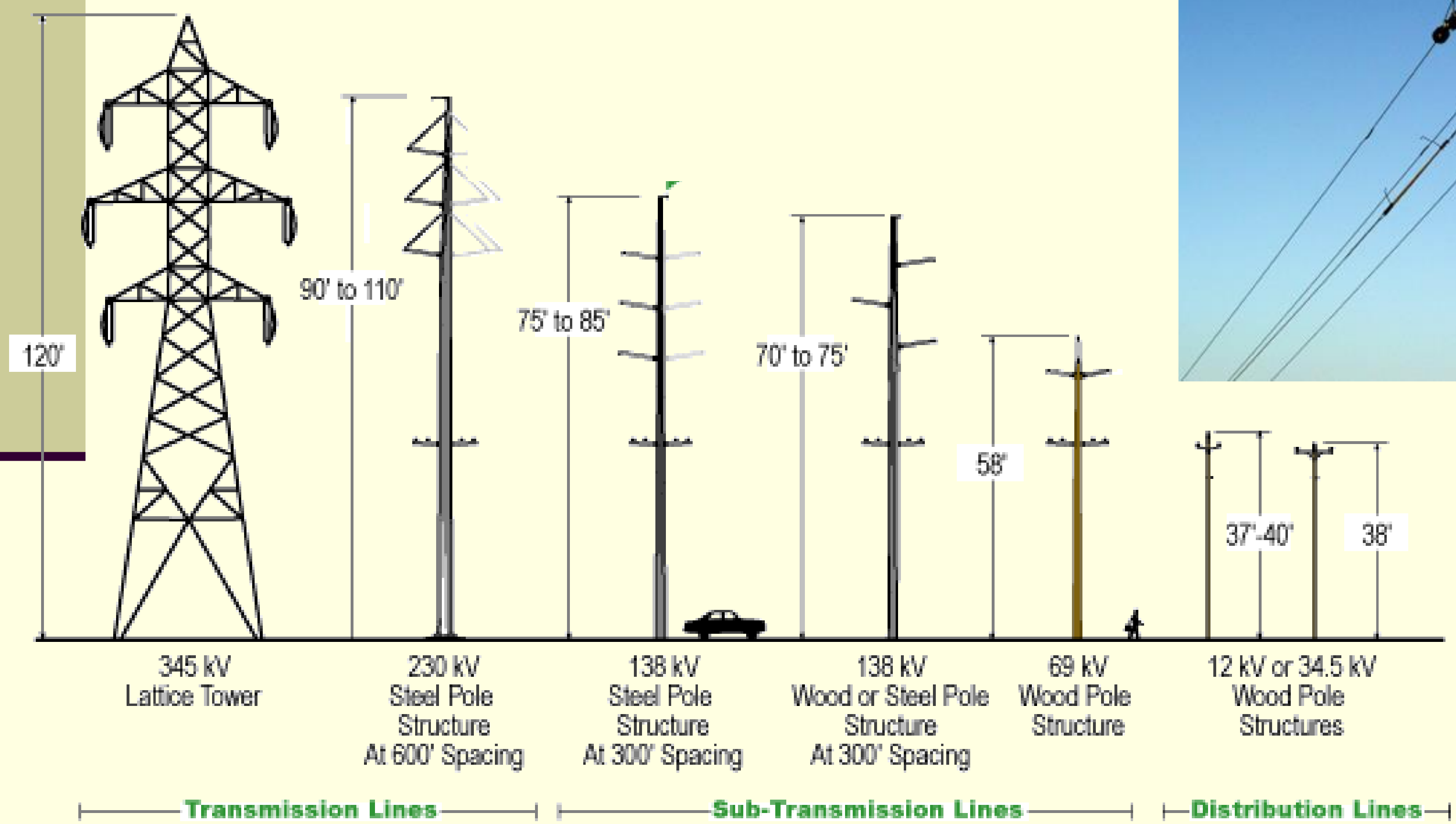
Substation Transformers

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

Distribution Substation Layout

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.

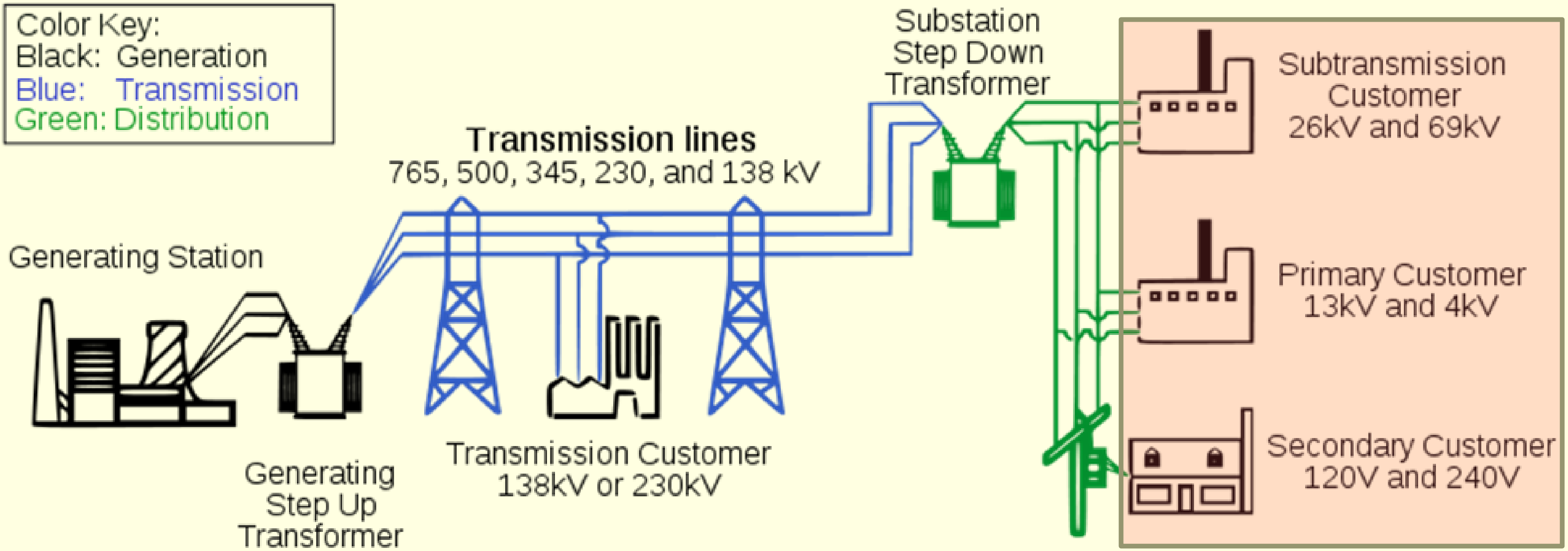
Overhead Transformer Bank & Service

Padmount Transformer for Underground System

Switched Capacitors

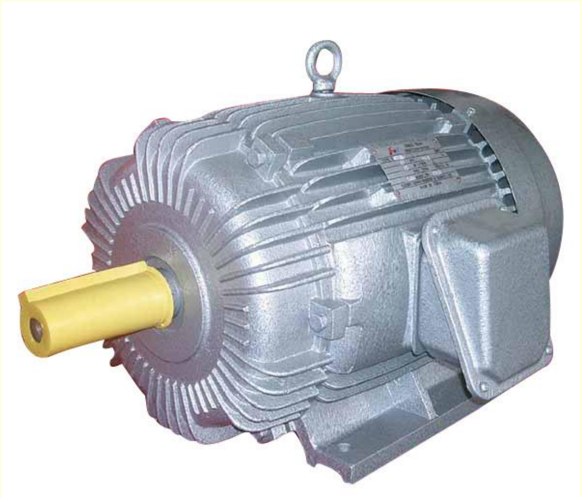
- Typical Sizes: 300, 600, 900, 1200, 1800 kvar
- Changes the voltage approx 2% each step
- Control
  - Quantity: time, temperature, voltage, current, or kvar
    - » Whatever can be best correlated to load
  - Time delay: typically 30 sec or more

Basic Conventional Power System Layout



Electrical Power Utilization (electric load)

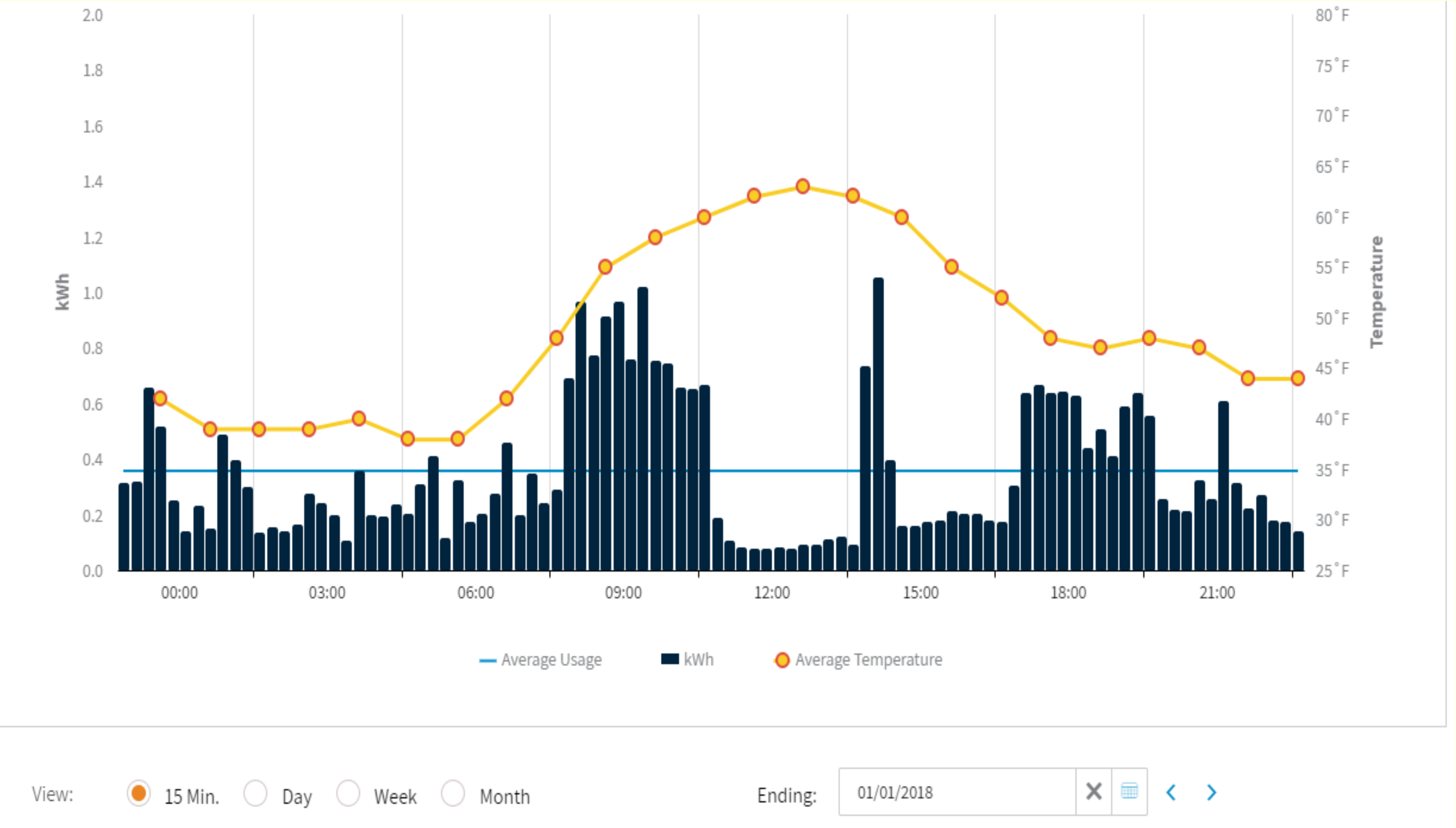
- **Utilization voltage: 120V, 208V*, 240V, 277V, 480V*, 600V***



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

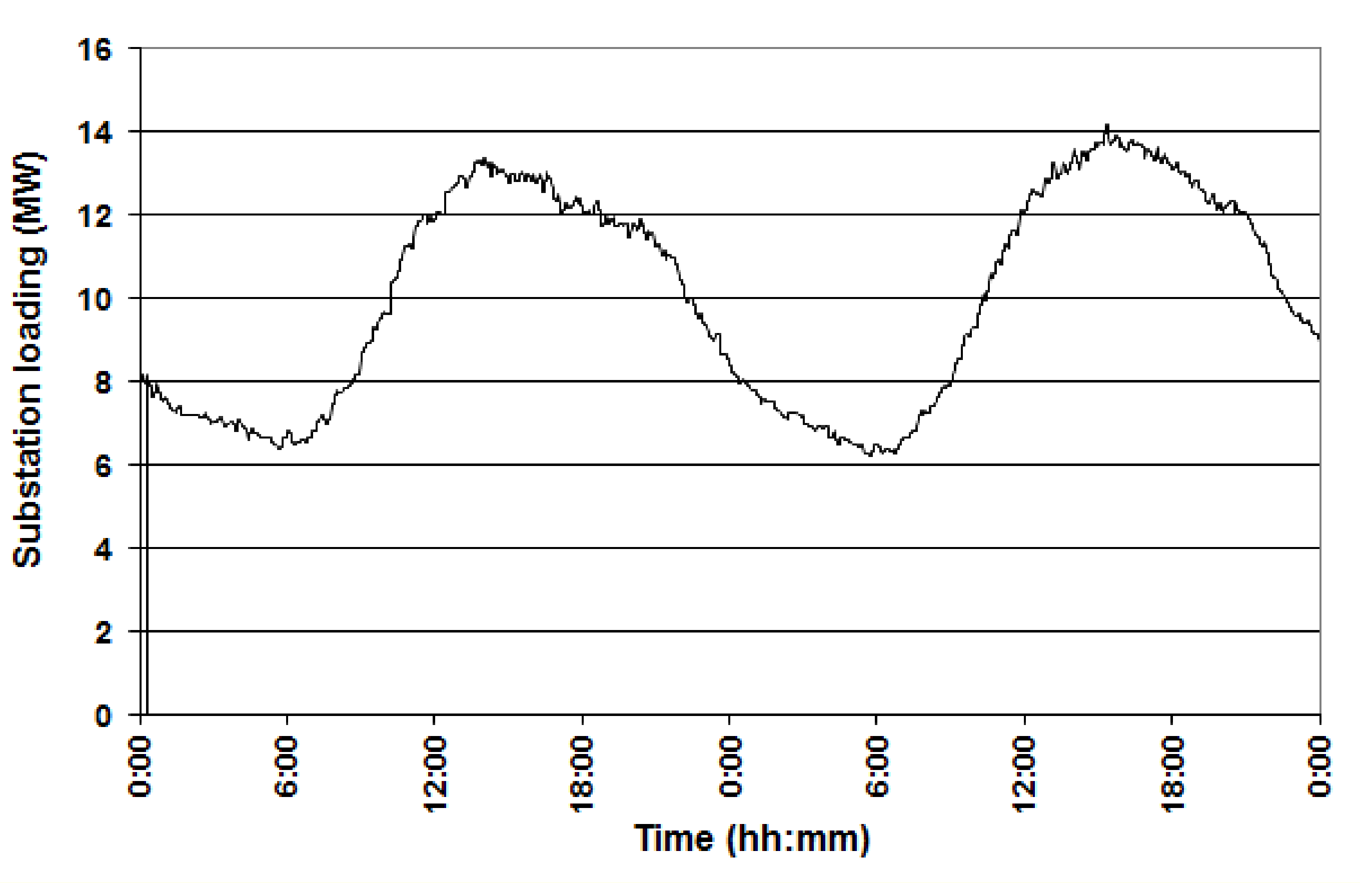
Power Demand

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

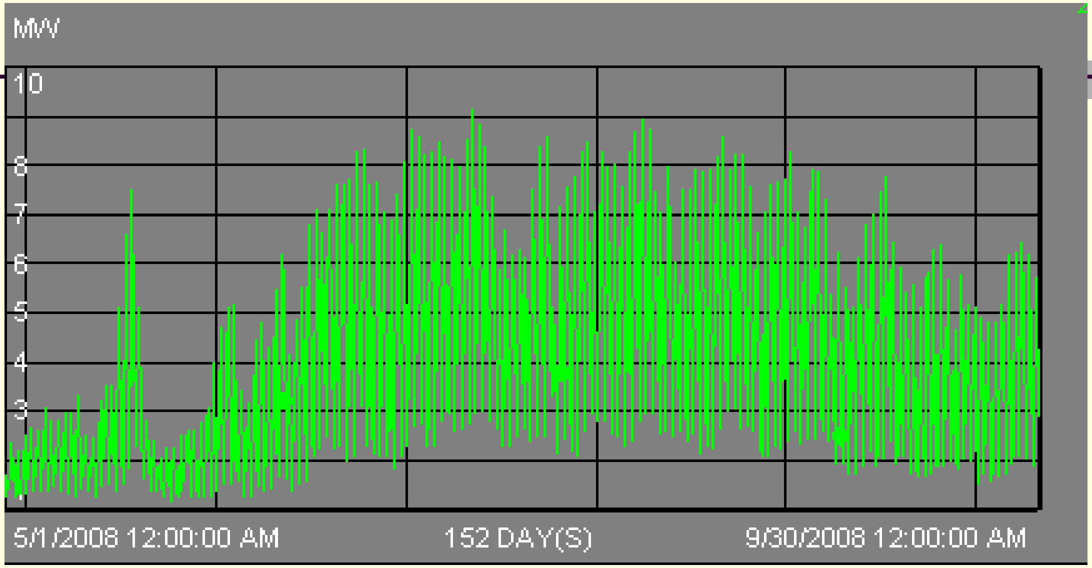


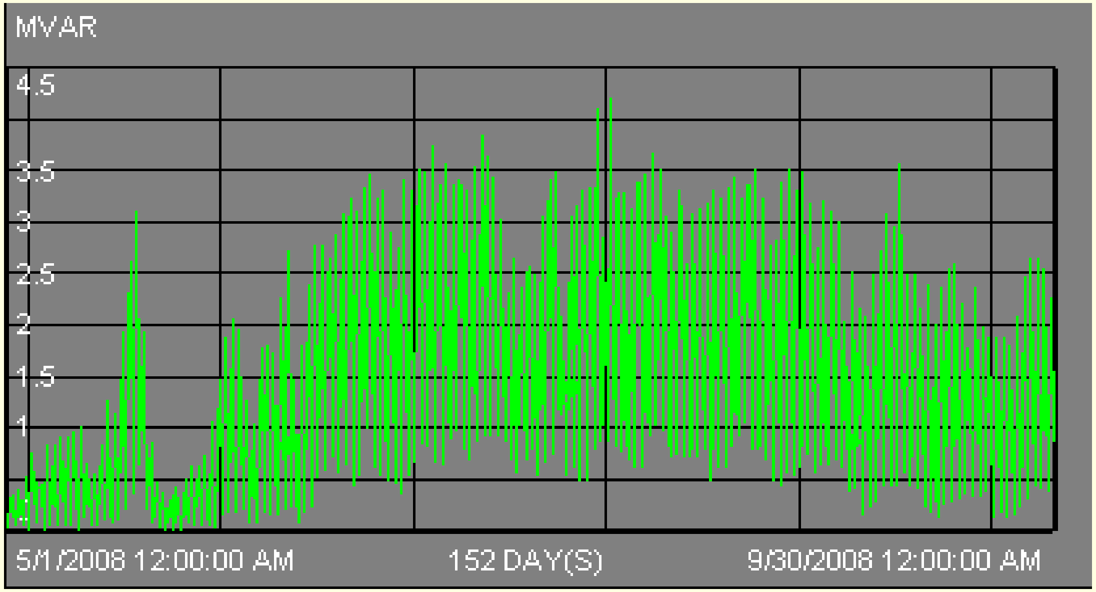
Substation Load: 48 hours

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



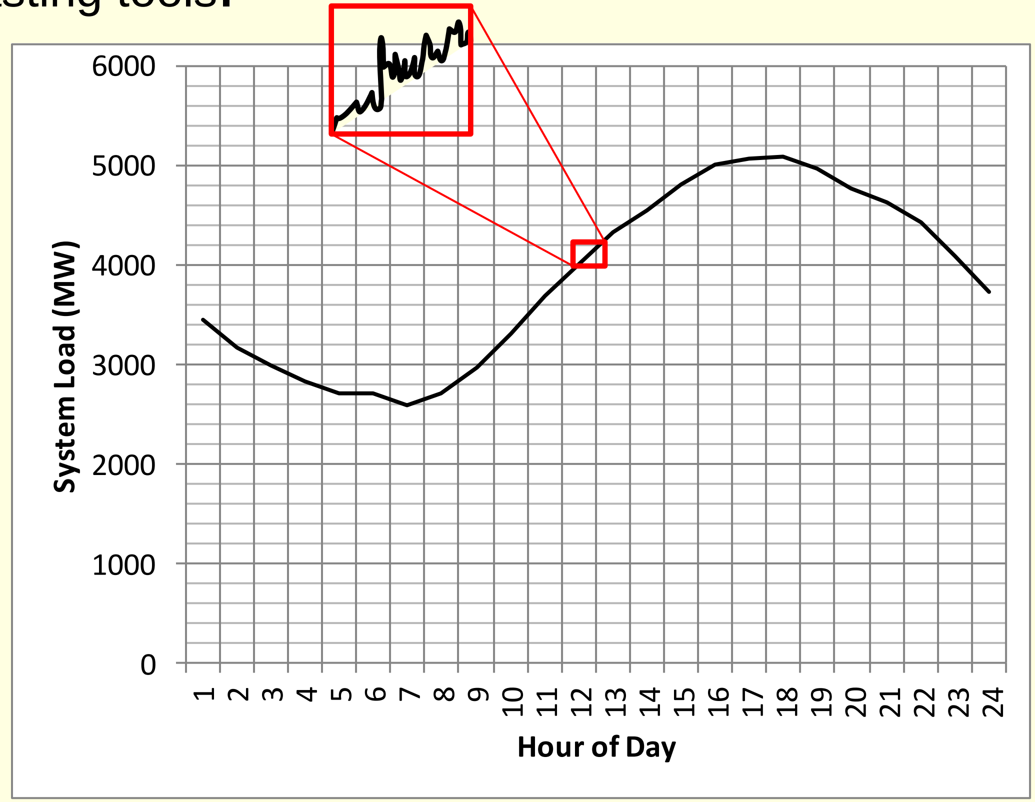
MW and MVAR loading on a distribution feeder over 4 month period





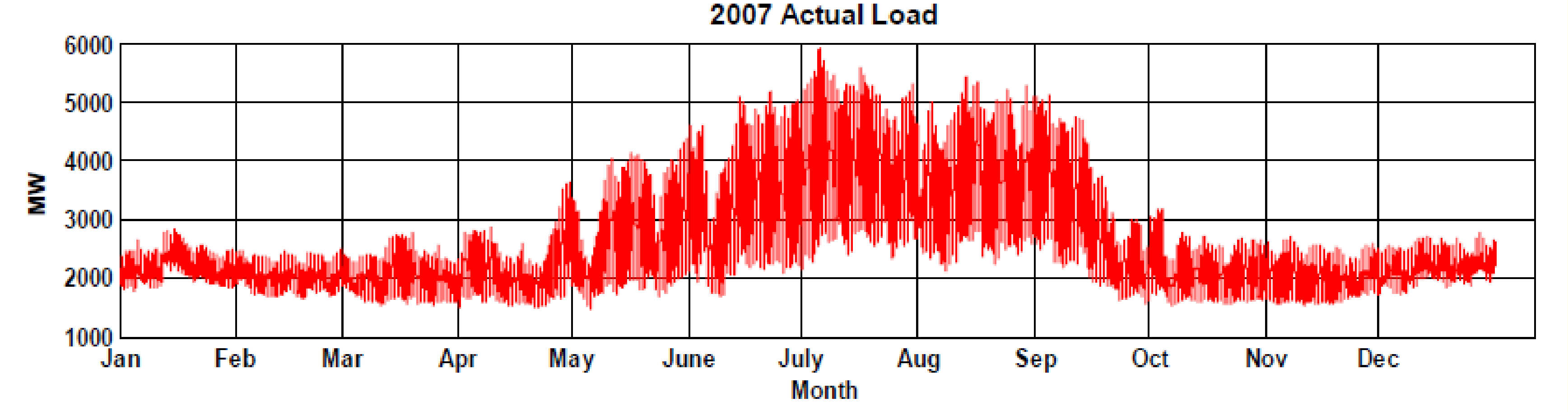
System load: 24-hours

- 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

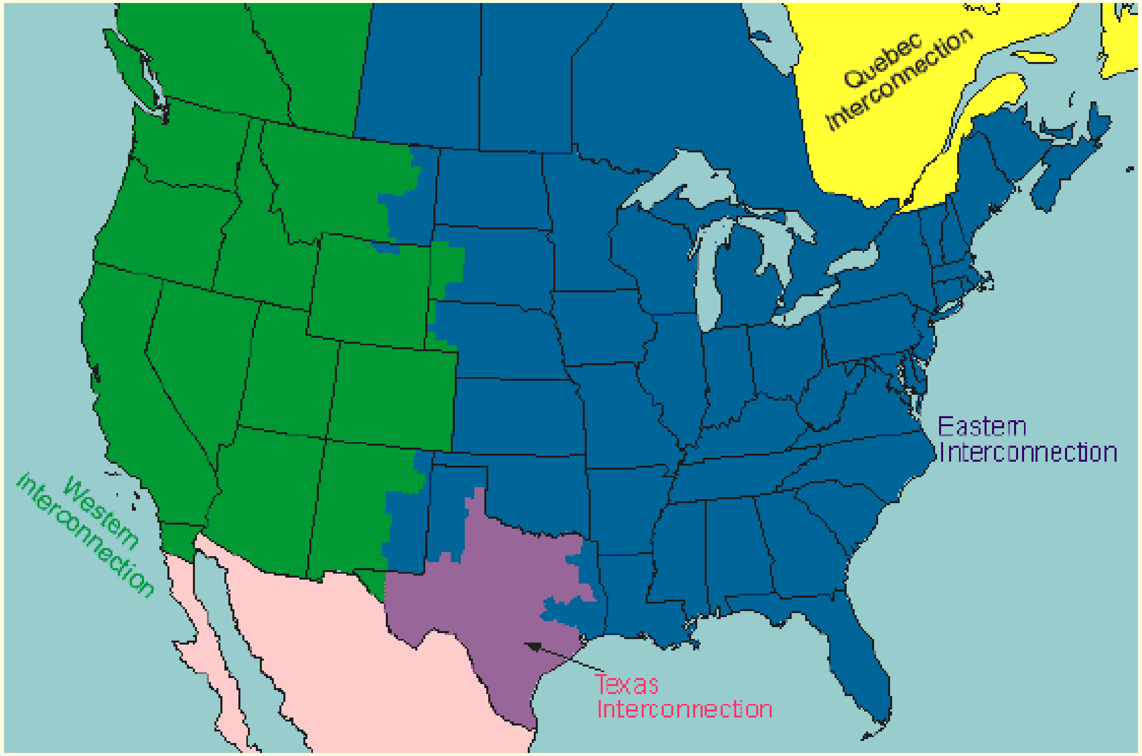
The local load is dominated by winter and summer patterns, with May and October as shoulder months.



North American Electrical Interconnections

The power system of North America is divided into four major Interconnections which can be thought of as independent islands.

- **Western** – Generally everything west of the Rockies.
- **Texas** - Also known as Electric Reliability Council of Texas (ERCOT).
- **Eastern** – Generally everything east of the Rockies except Texas and Quebec.
- **Quebec**.

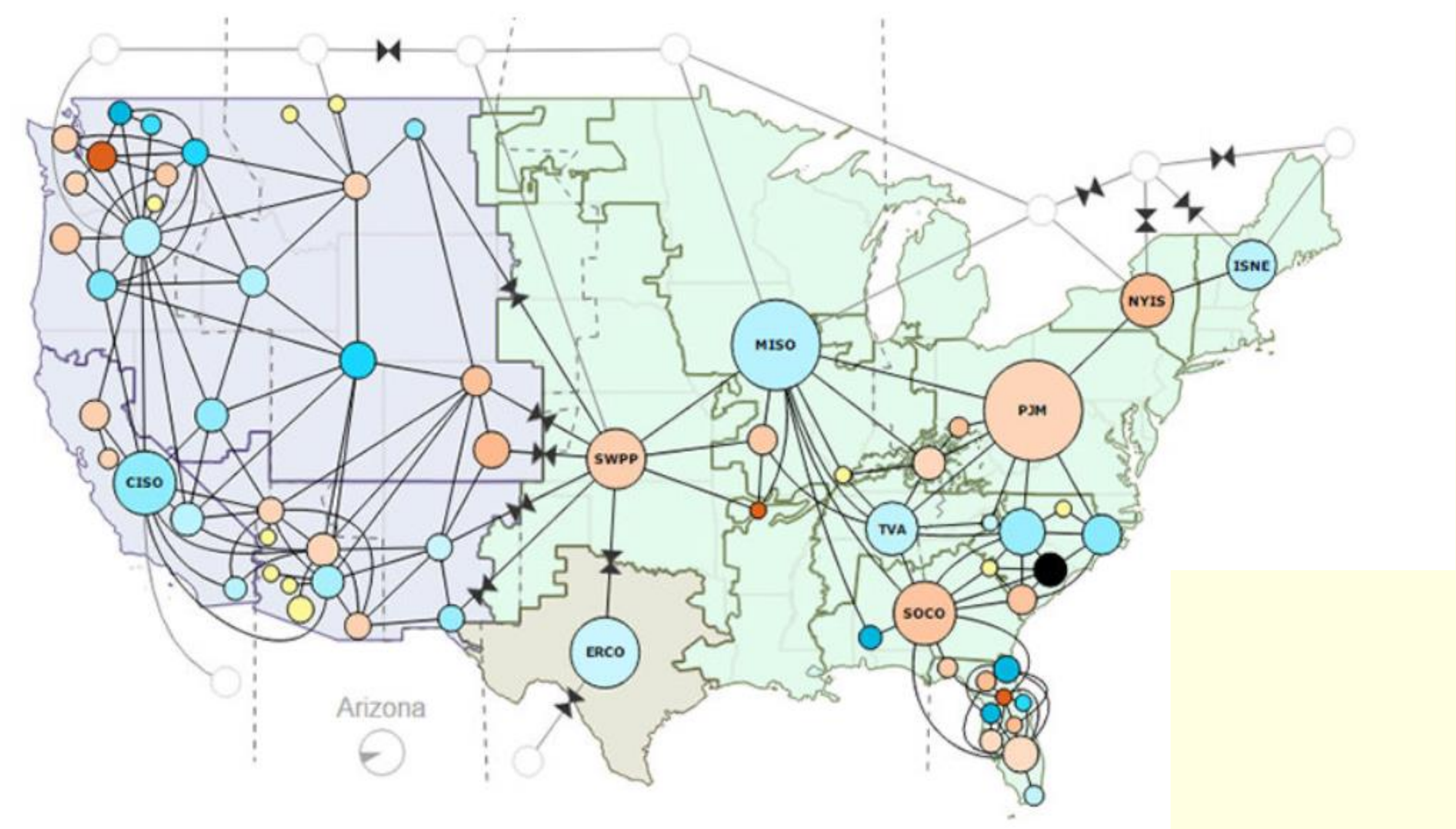


Interconnection Ties

- Electricity does not flow freely between interconnections.
- Interconnections are tied through AC-DC-AC links which act like valves (with limited power transfer capability).
- The ties prevent electrical disturbances in one interconnection from spreading into other interconnections.

Balancing Authorities (BA)

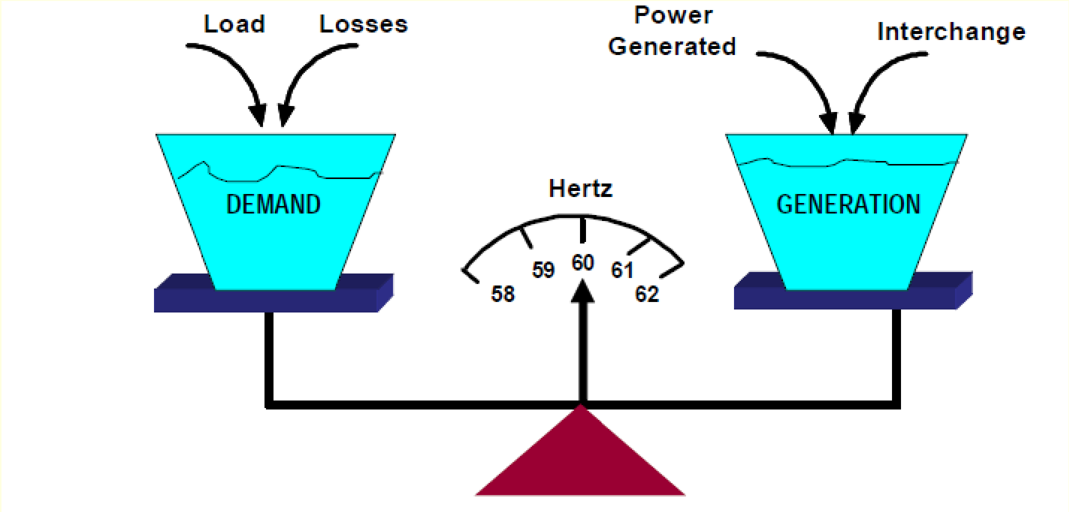
- No single entity is responsible for the real-time operation of a given interconnection. Instead, over 70 balancing authorities are responsible for maintaining operating conditions under mandatory reliability standards

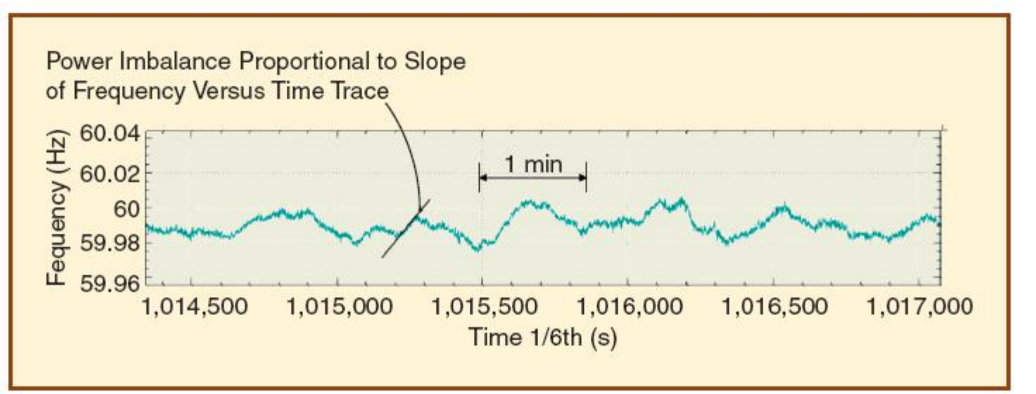


Generation-load balance

- As electricity itself cannot presently be stored on a large scale, changes in customer demand are met by controlling conventional generation, using stored fuels.

- Frequency is maintained as long as there is a balance between resources and customer demand (plus losses). An imbalance causes a frequency deviation.





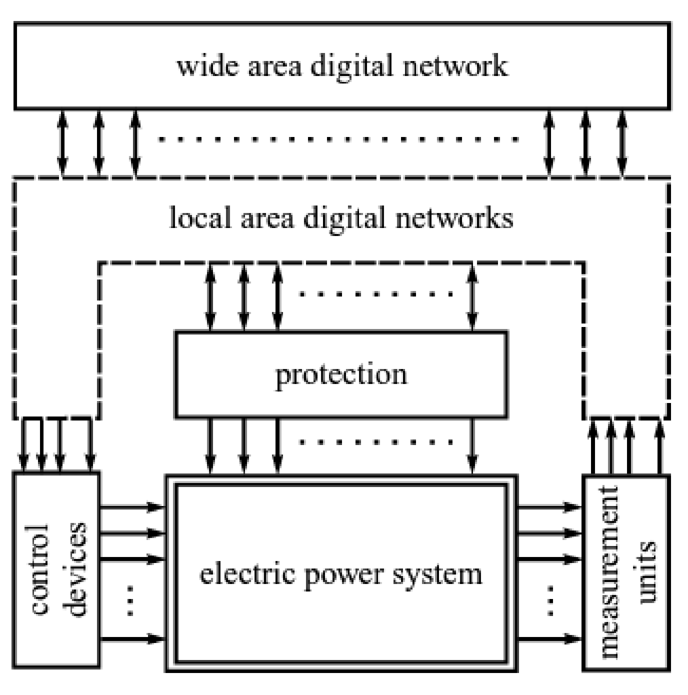
Power Transfer among BAs

- Electricity flows freely within an interconnection.
- A transfer of electricity from one BA system to another is not directed along a certain transmission path. Instead, the electricity travels along all interconnecting paths based on the laws of physics.
- A planned transfer of power between BAs doesn’t happen through a system of opening and closing valves or lines.
- Transfers happen when BAs coordinate a controlled imbalance in their systems between supply and demand.
  - Example: BA #1 increases the output of its generators by 200 MW, and BA #2 decreases the output of its generators by the same amount at the same time. This results in 200 MW electricity flow between the two systems.

Regional Updated Demand Curves

- http://www.eia.gov/beta/realtime_grid/#/summary/demand?end=20170115&start=20161215&regions=01

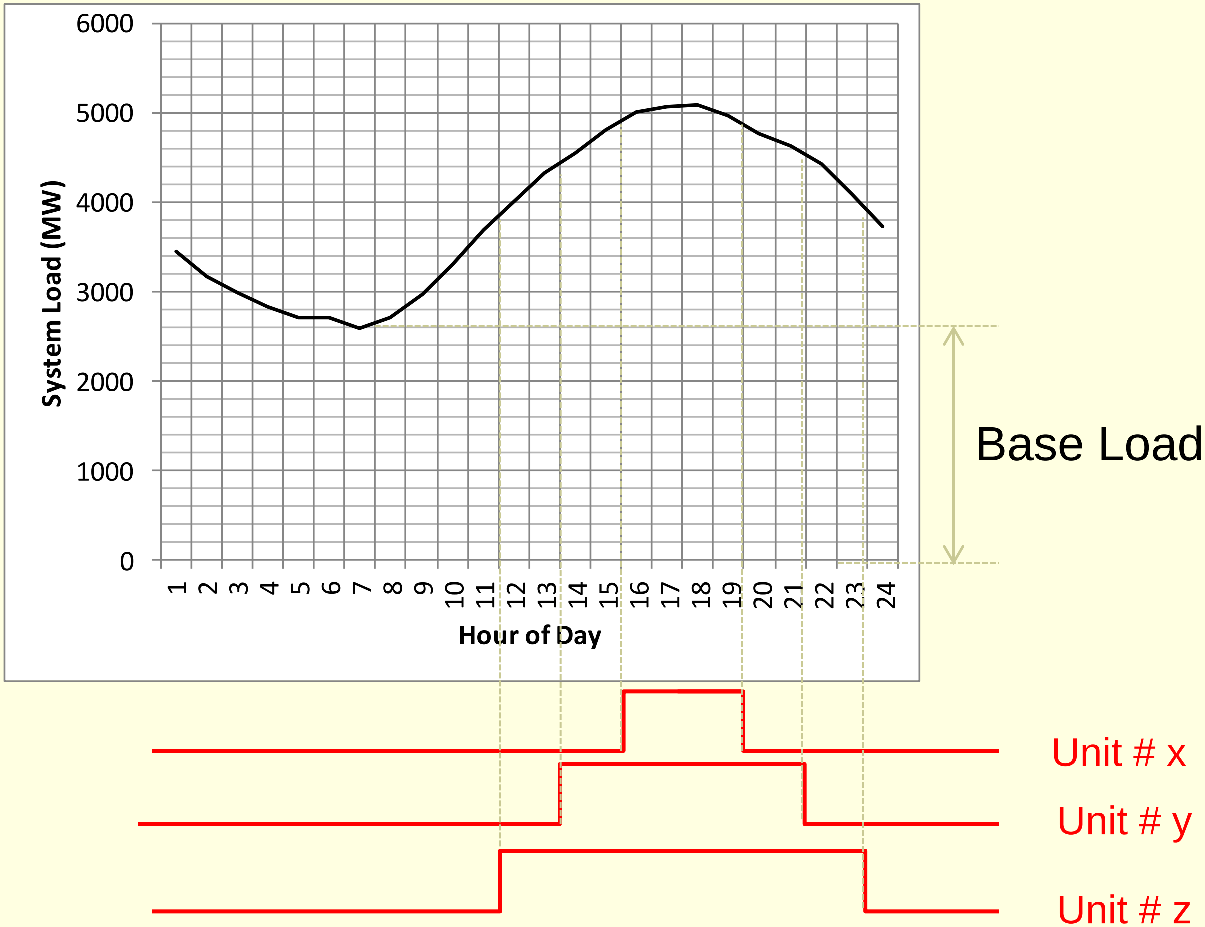
System monitoring. Analysis, Operation and Control



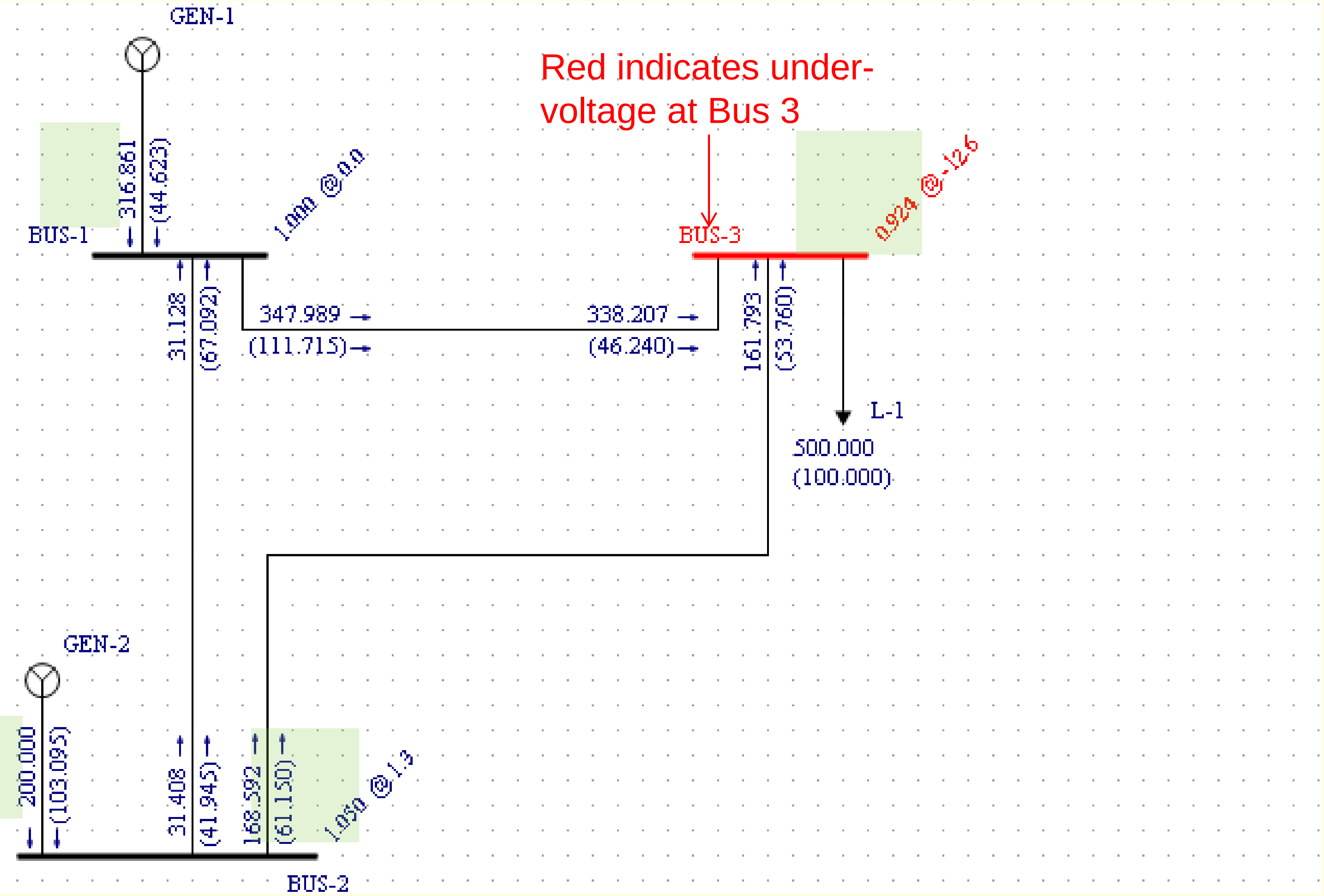
Electric system disturbances occur too quickly to rely on human intervention to detect losses and to manually bring on new generating capacity.
System operators do not *operate* electric systems. Their job is to maintain conditions that allow an electric system to automatically maintain the balance of supply and demand by providing adequate electricity supply to meet demand and to respond to outages.

Generator Scheduling (Economic Dispatch)

- Given a power system with *n* generators, and a load forecast, determine the optimal schedule of each generator while recognizing generating unit limits and output capability.



Power Flow Analysis



Inclement weather and animals are major contributors of power outages.

END!