Electric Power Systems – An Overview

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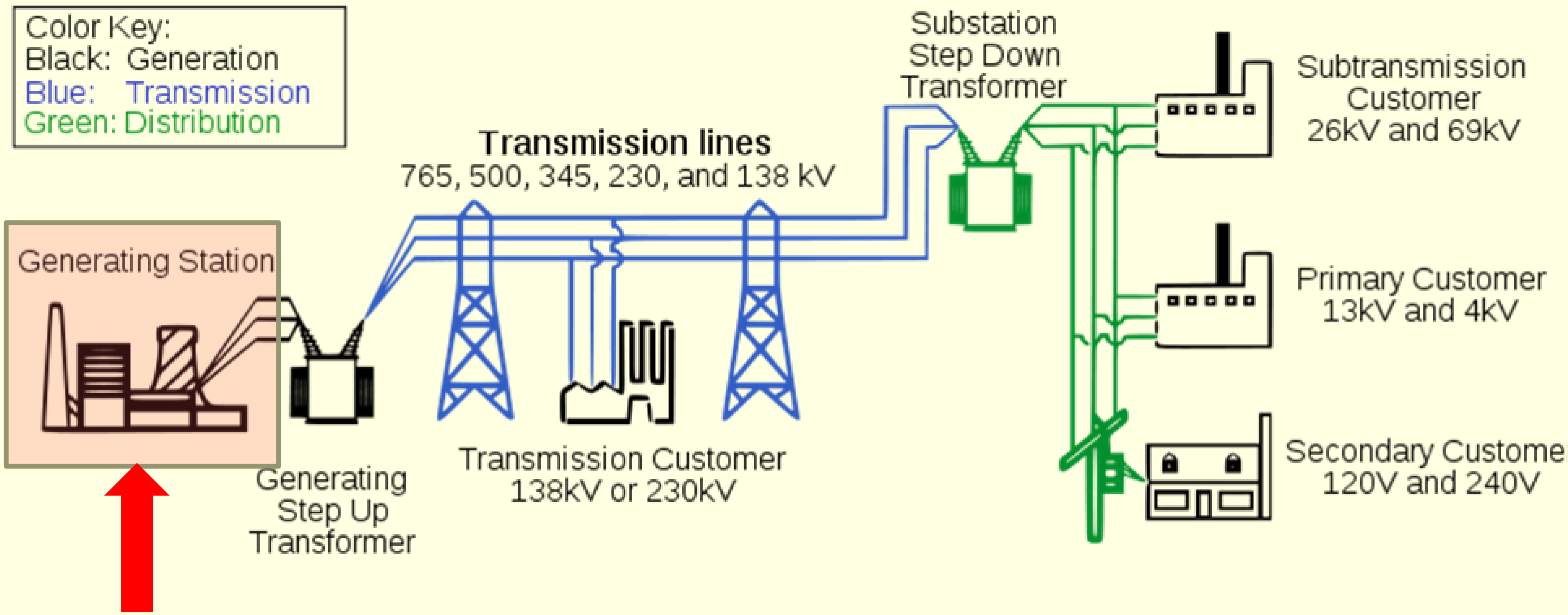
Overview

- Power Generation
  - Conventional power generation
  - Power generation from renewables
- Power transmission
  - Cables and other transmission system equipment
- Power Distribution
  - Distribution system equipment
- Power Utilization
  - Demand curves
- Power System Analysis
  - Power flow, fault currents, economic dispatch.

Basic Conventional Power System Layout



Conventional (non-renewable) primary energy source

US Electricity Generation by Fuel

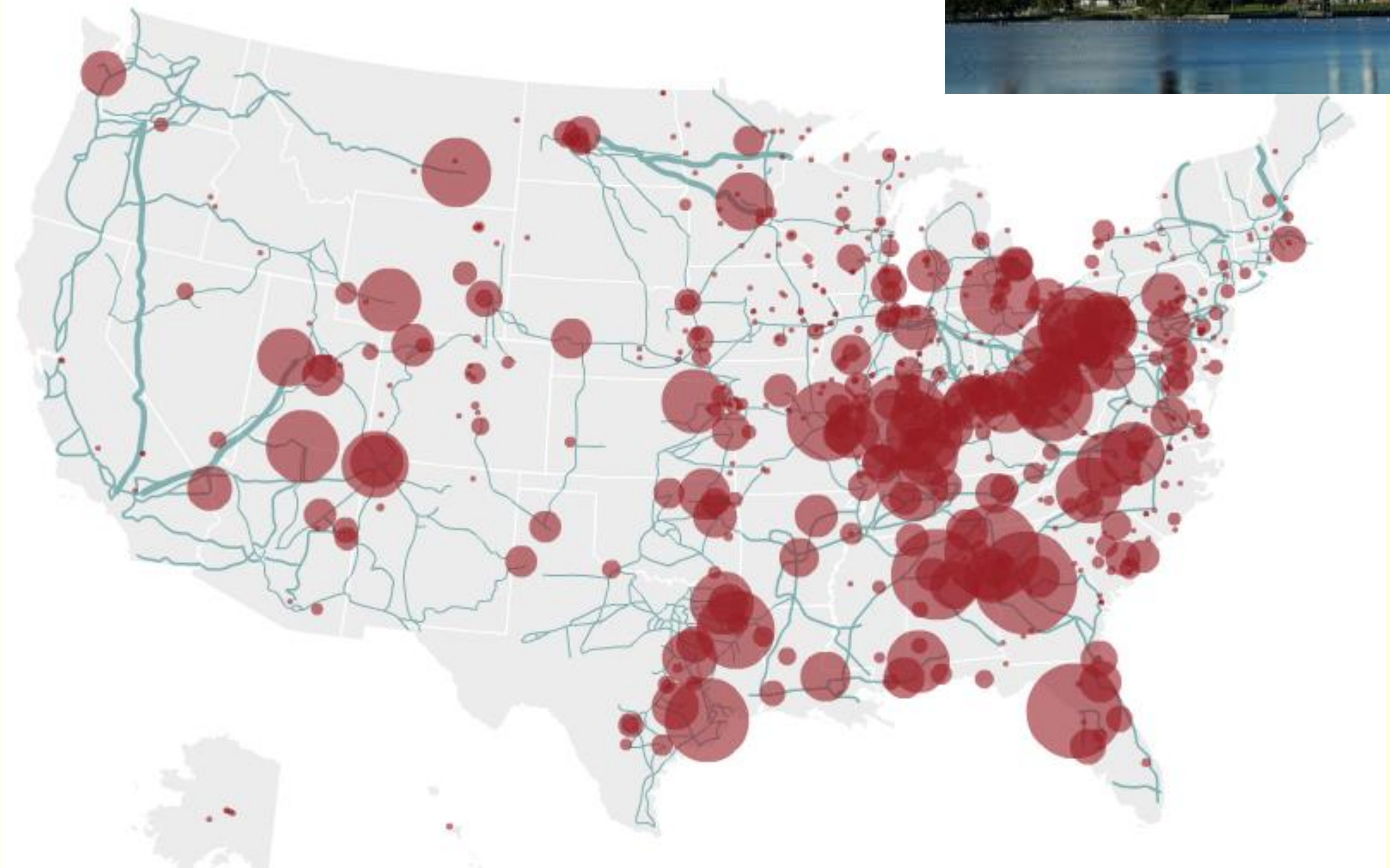
Source: U.S. Energy Information Administration,

Major energy sources and percent share of total U.S. electricity generation in 2014:

- Coal = 39%
- Natural gas = 27%
- Nuclear = 19%
- Hydropower = 6%
- Other renewables = 7%
  - Biomass = 1.7%
  - Geothermal = 0.4%
  - Solar = 0.4%
  - Wind = 4.4%
- Petroleum = 1%
- Other gases < 1%

For latest trend, see http://newsletters.pennnet.com/powerengineeringenl/365650871.html

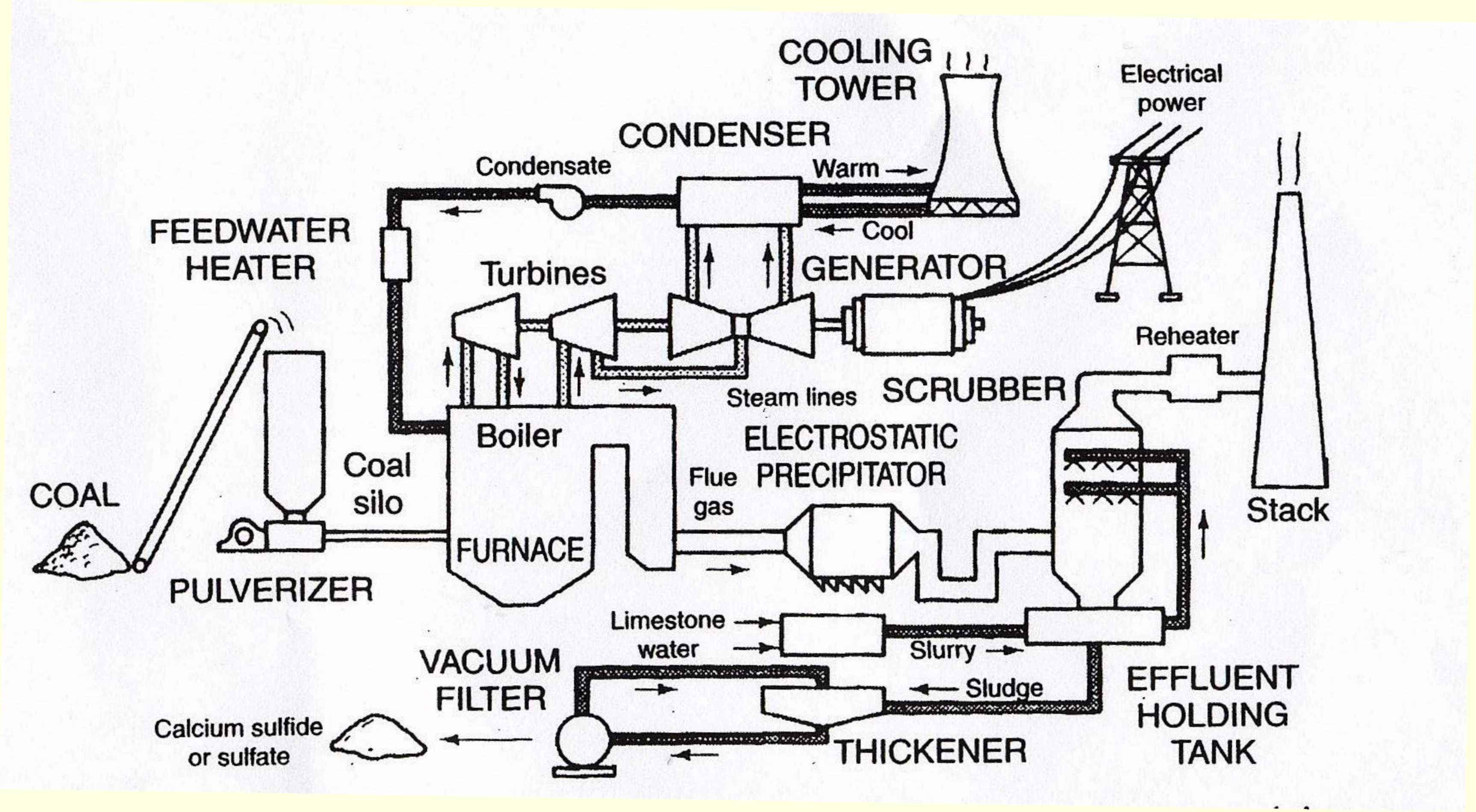
Coal Fired Power Plants:
Number of Generators ≈ 1,450
Total Capacity ≈ 350 GW



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

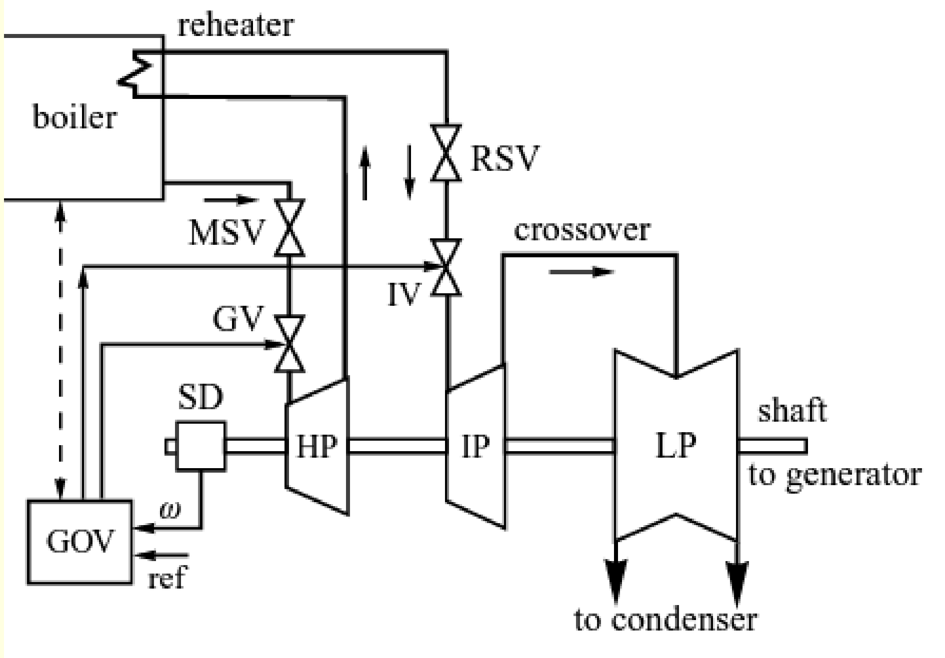
Diagram of a modern coal power plant

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



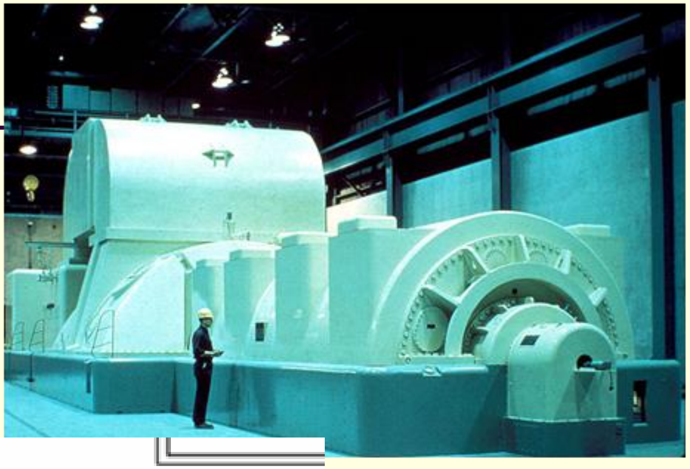
Steam Turbines and their Governors

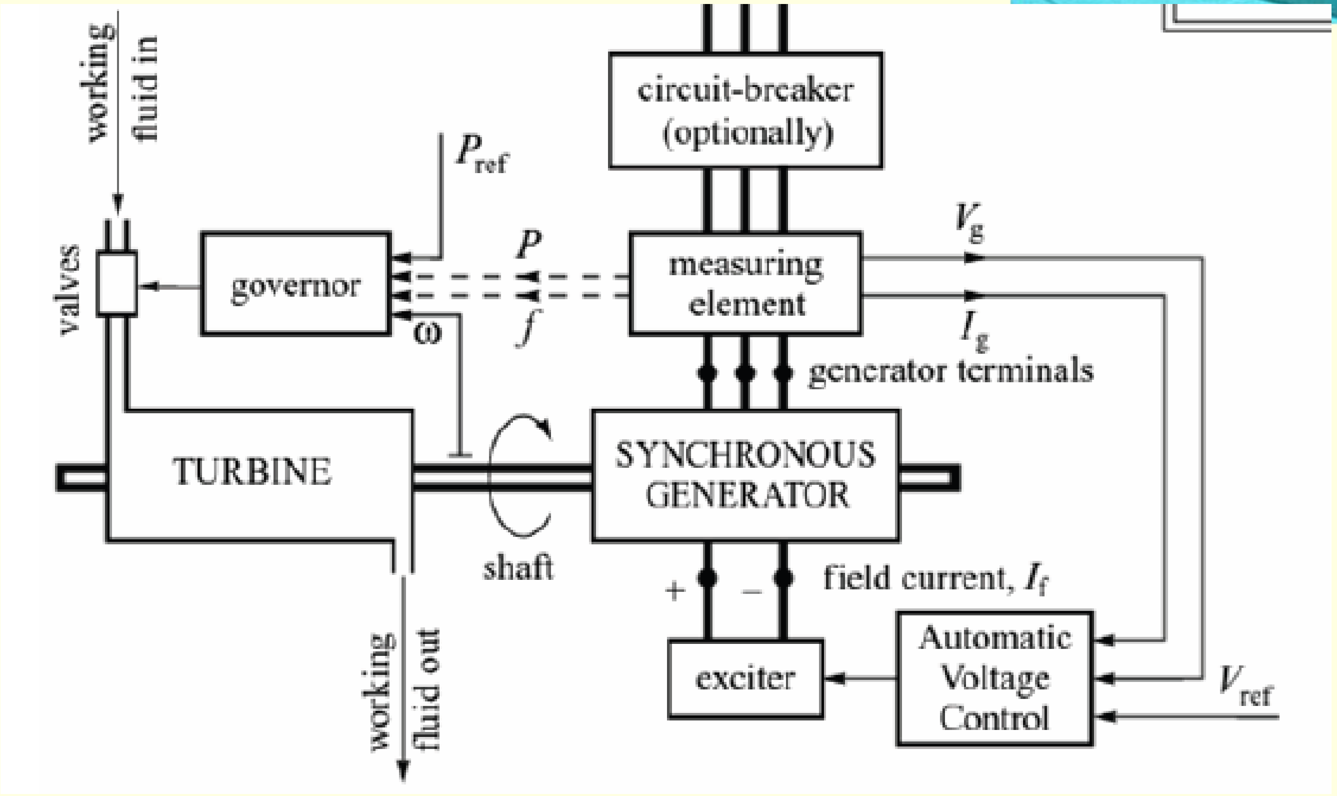
- Steam turbines can have non-reheat, single-reheat or double-reheat.
- The steam flow is controlled by the governor. The main amplifier of the governing system and valve mover is an oil servomotor that is controlled by a pilot valve.
- Main and reheat stop valves are normally fully open - they are used 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

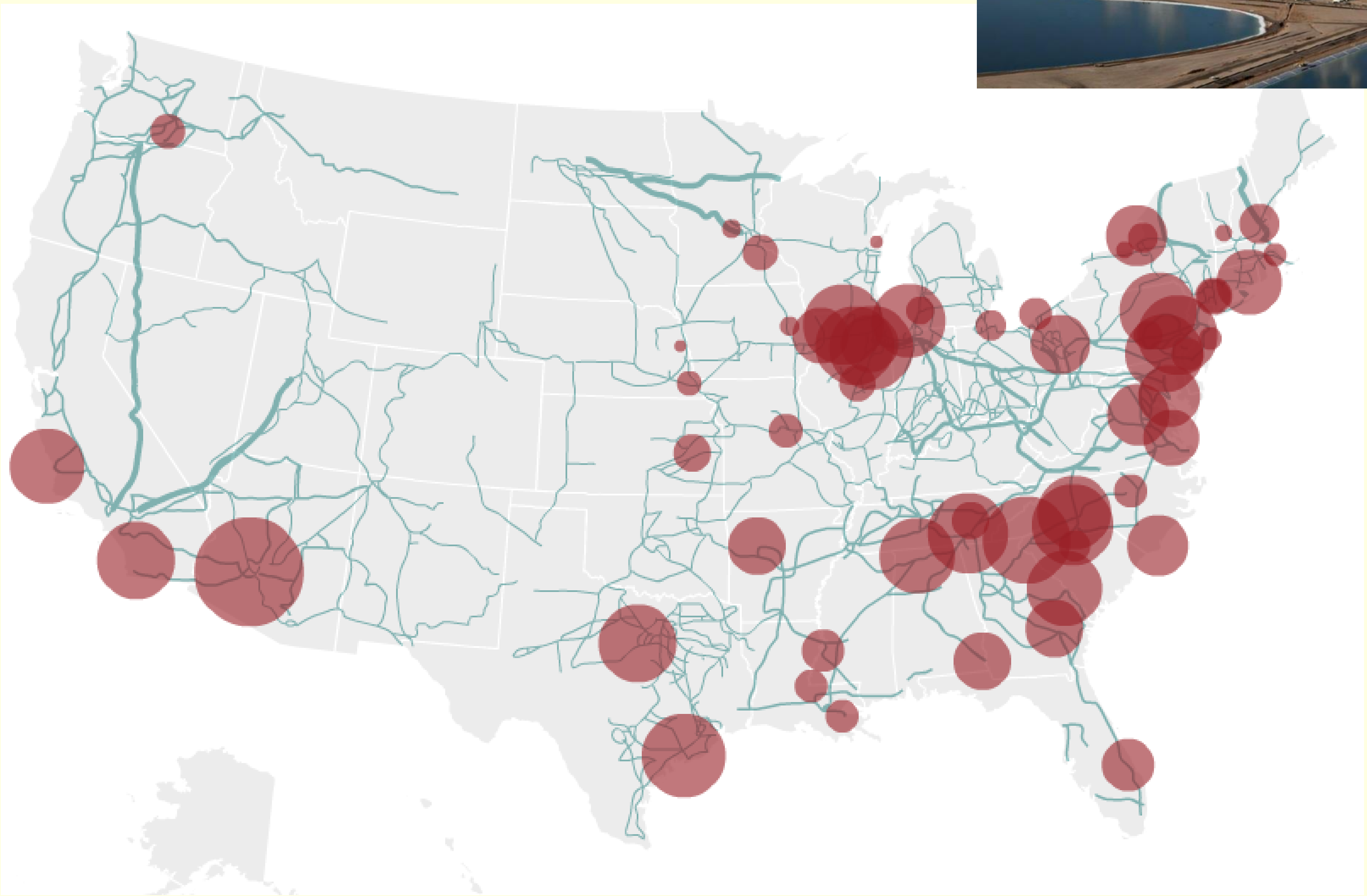
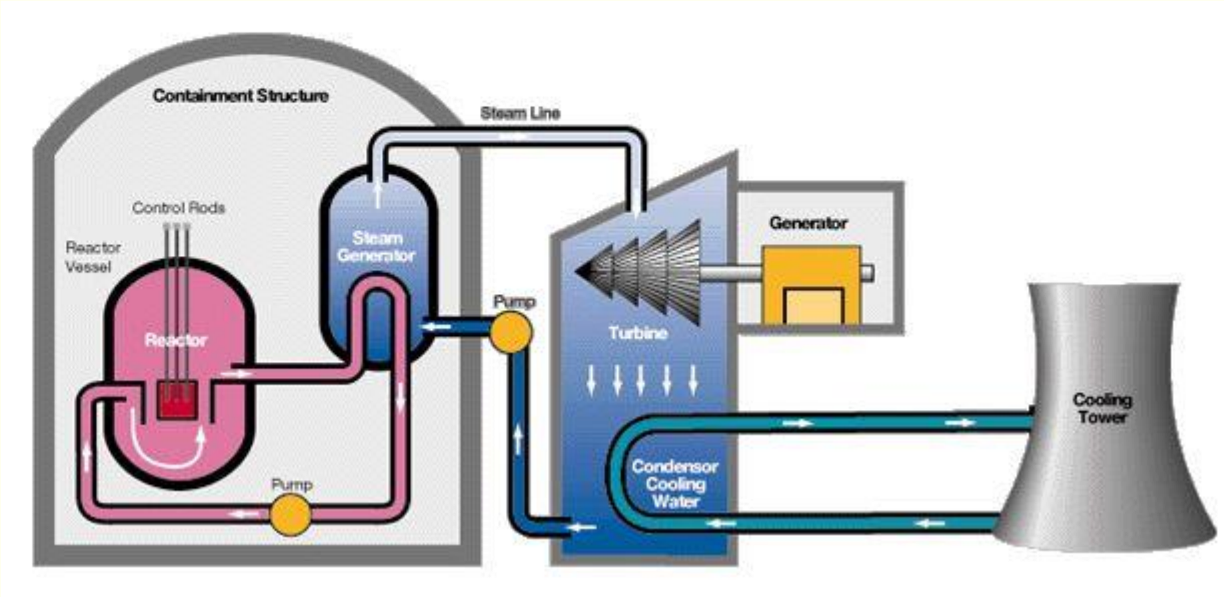
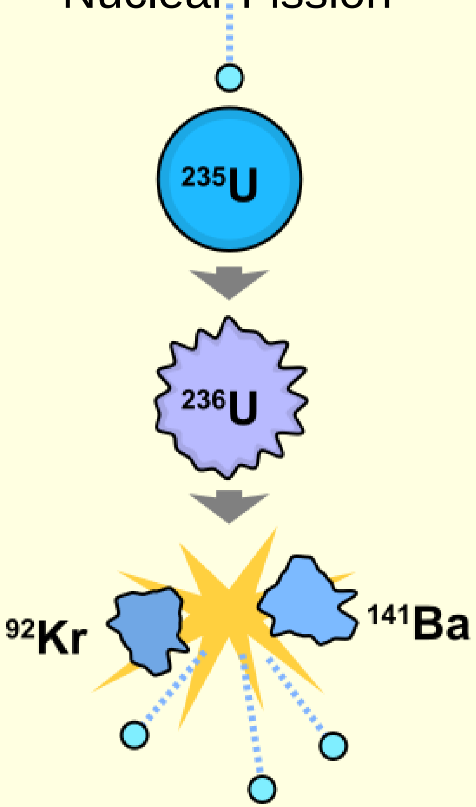


Diagram of a nuclear power plant

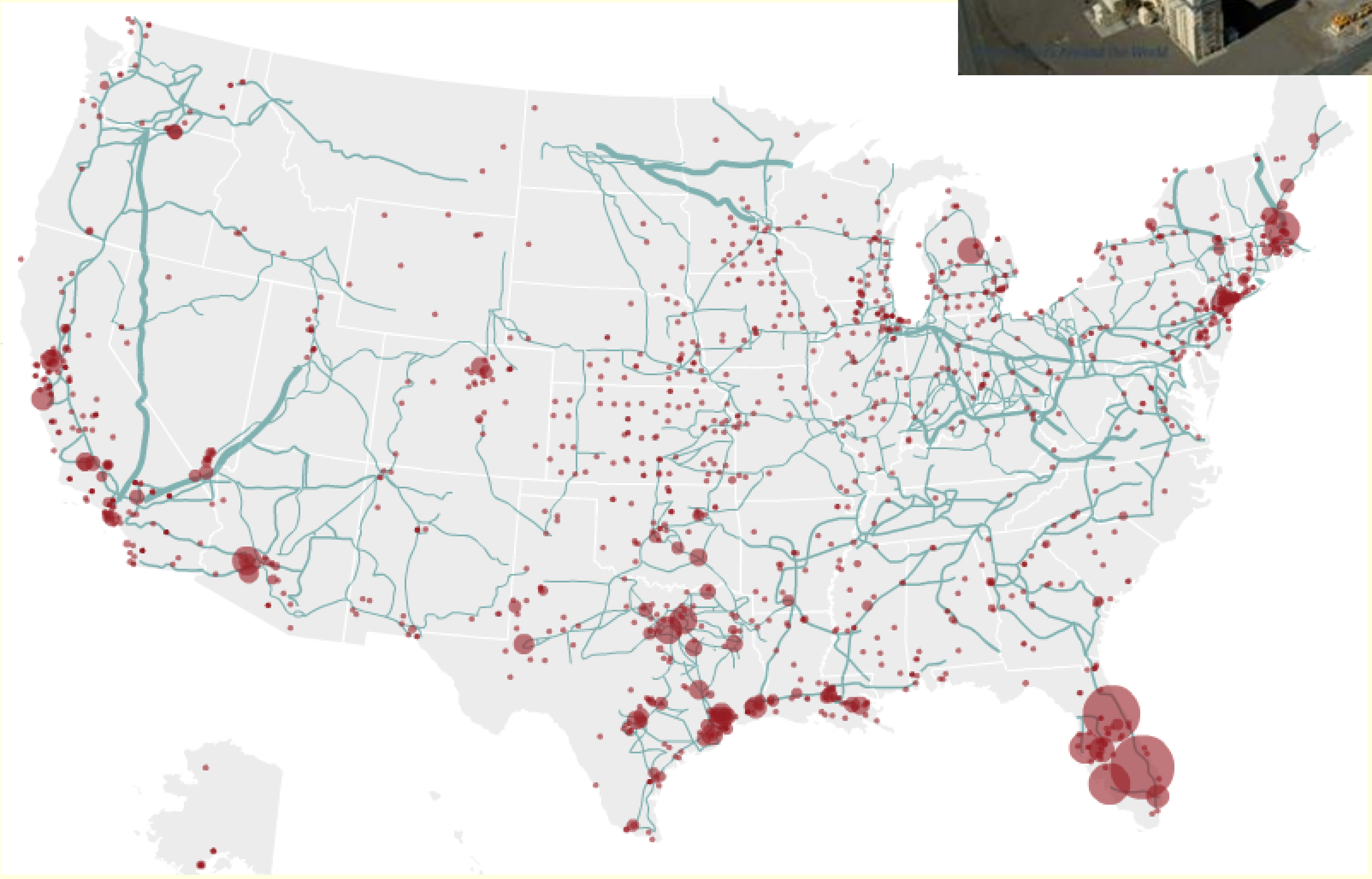
- Types of nuclear reactors:
  - Pressurized Water Reactor (PWR)
  - Boiling Water Reactor (BWR)



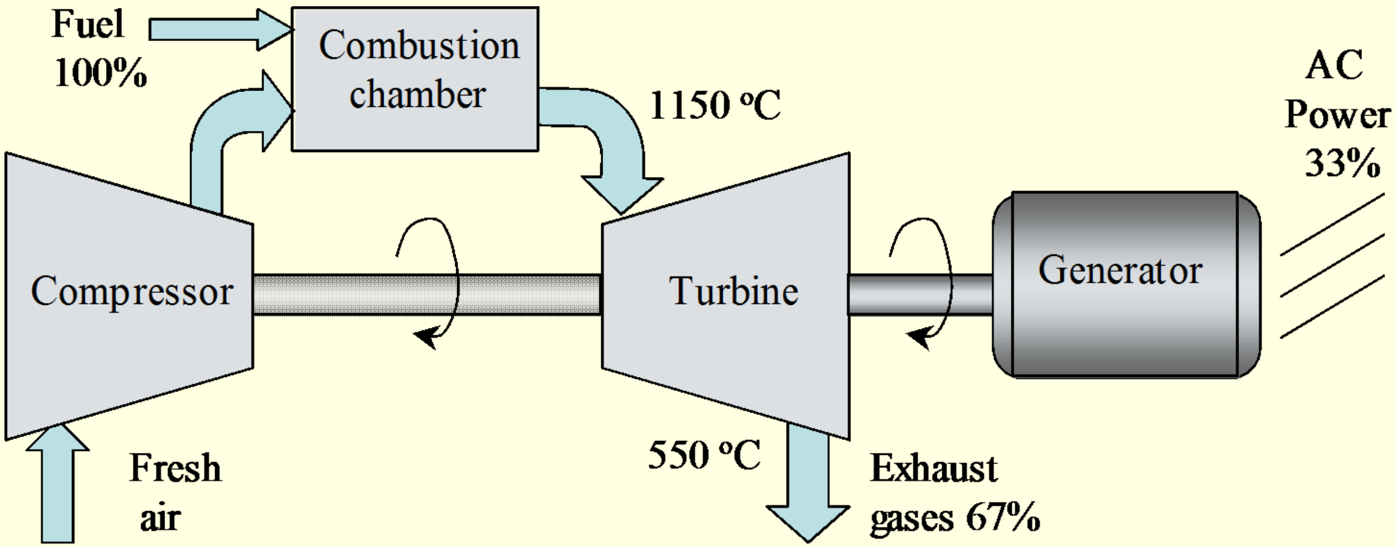
Nuclear Fission



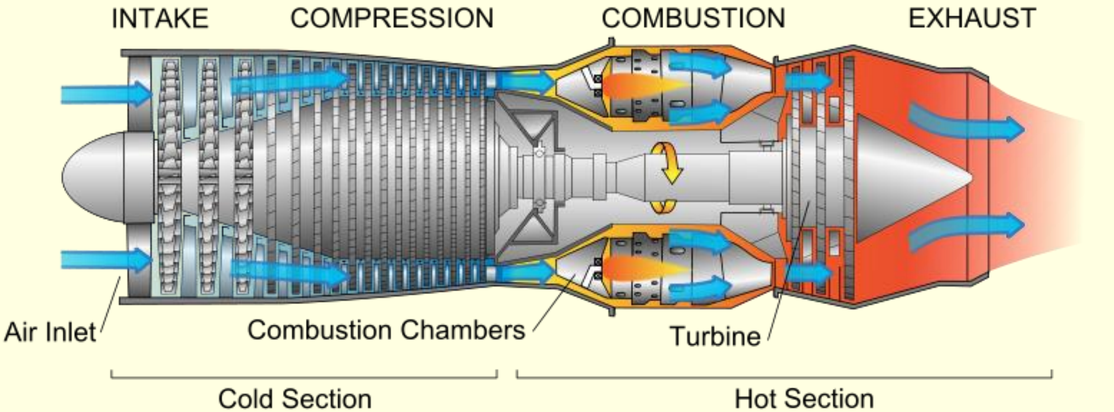
Natural Gas Power Plants: Number of Generators ≈ 5,500 Total Capacity ≈ 450 GW



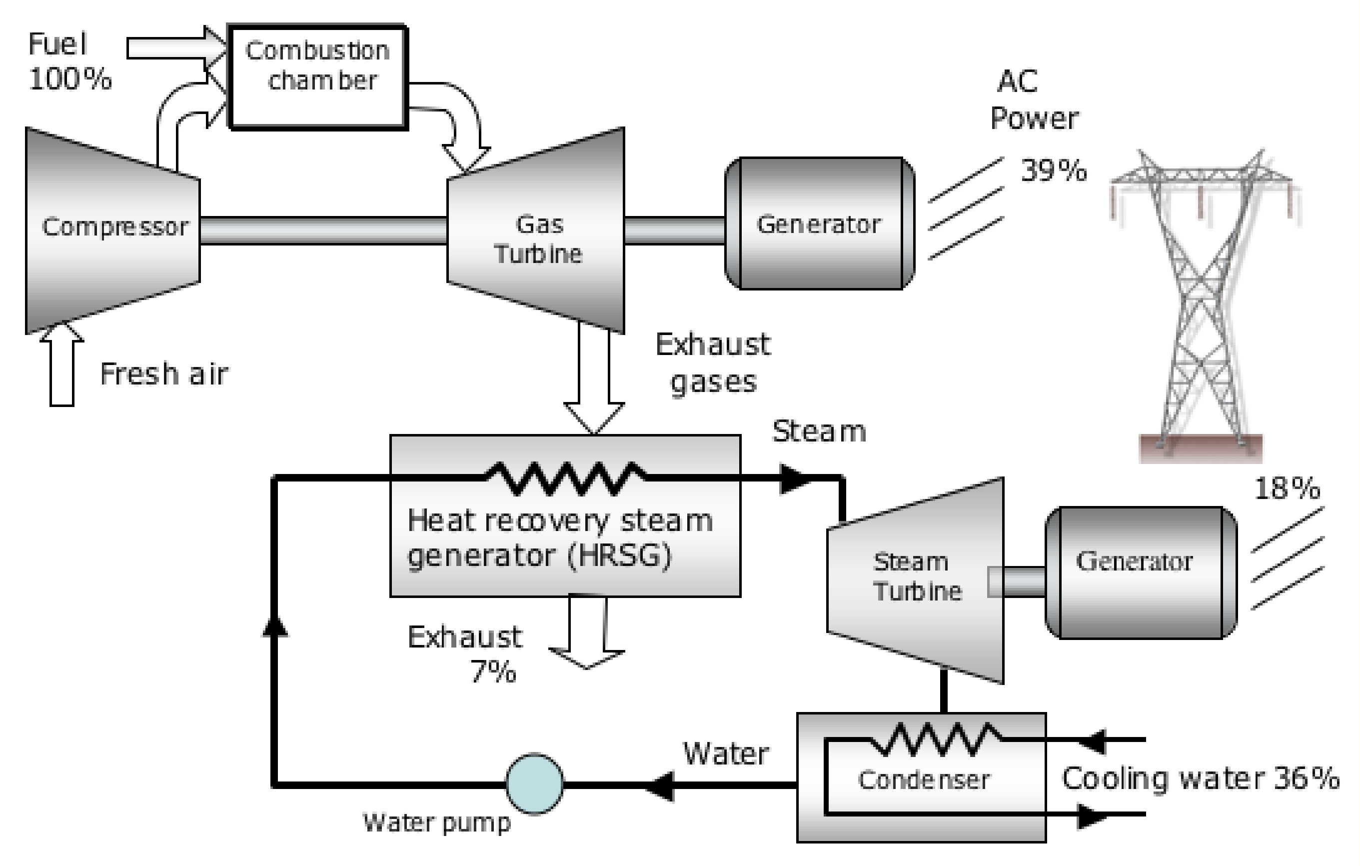
Open cycle gas turbine: Typical efficiency: 30-35%



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.

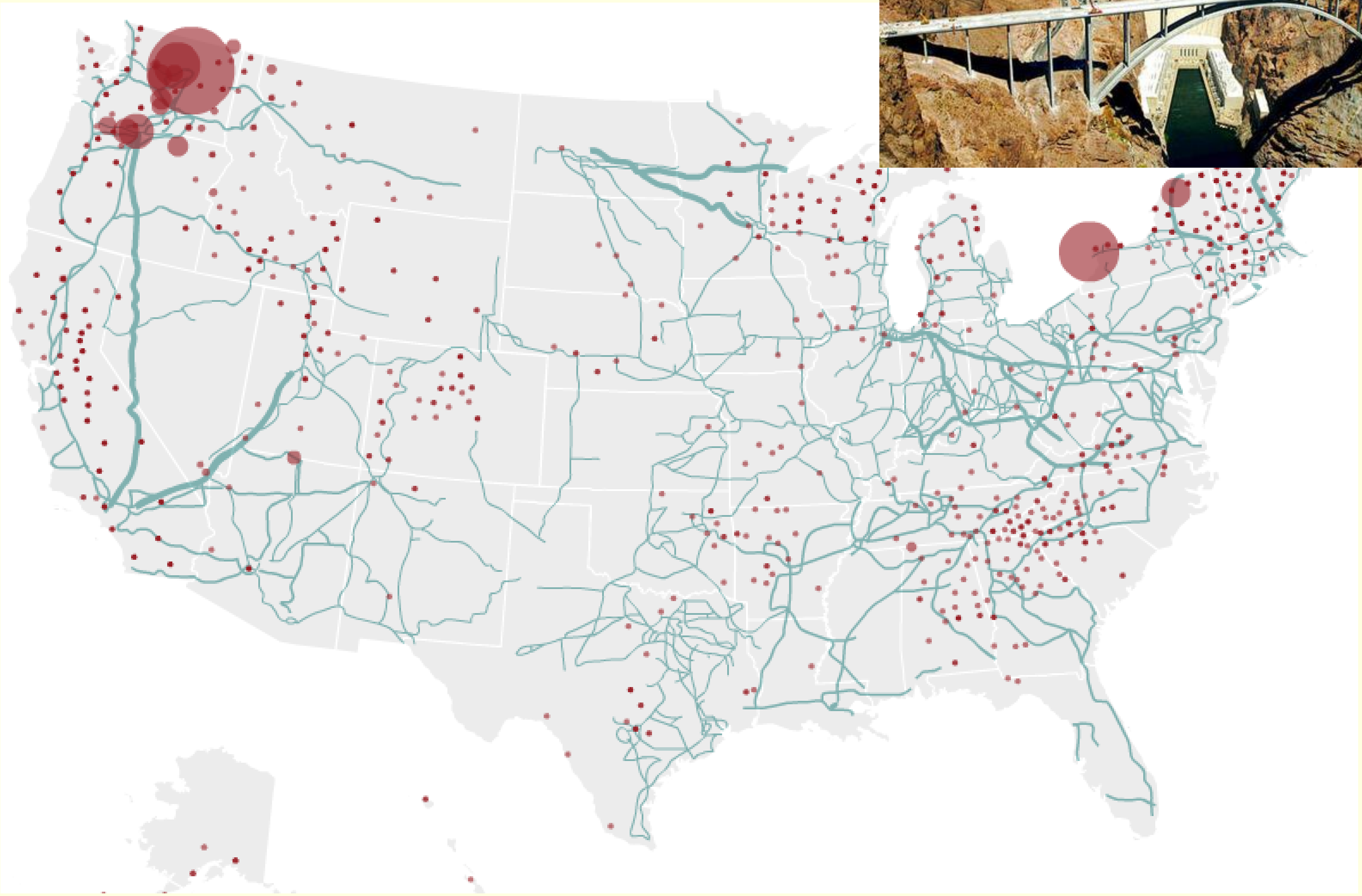


Combined cycle power plant: Typical efficiency: 60-65%



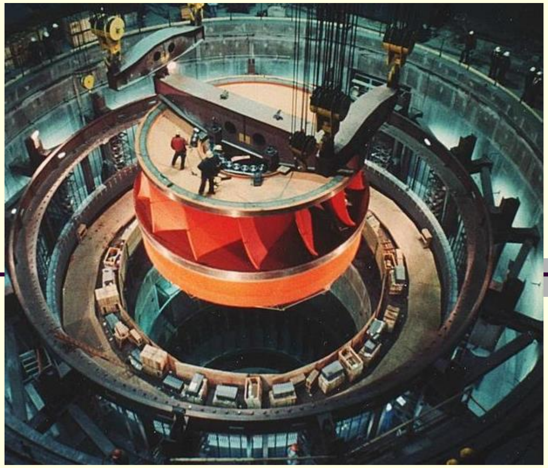
Efficiencies are even higher when the steam is used for district heating or industrial processes.

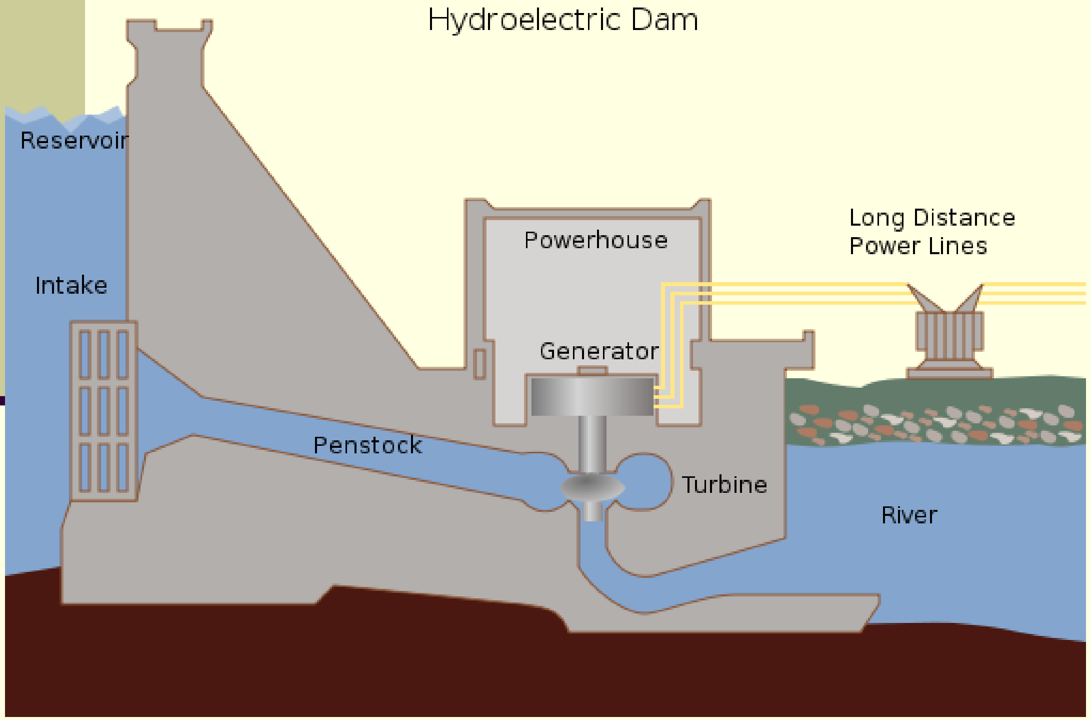
Hydro Power Plants:
Number of Generators ≈ 4,000
Total Capacity ≈ 80 GW

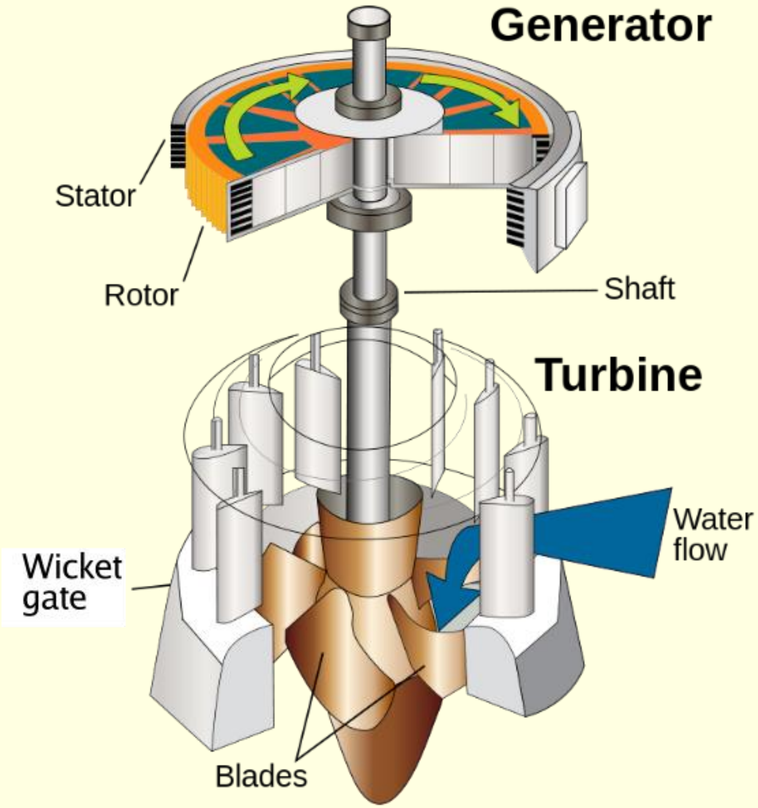


Hydro Power plants

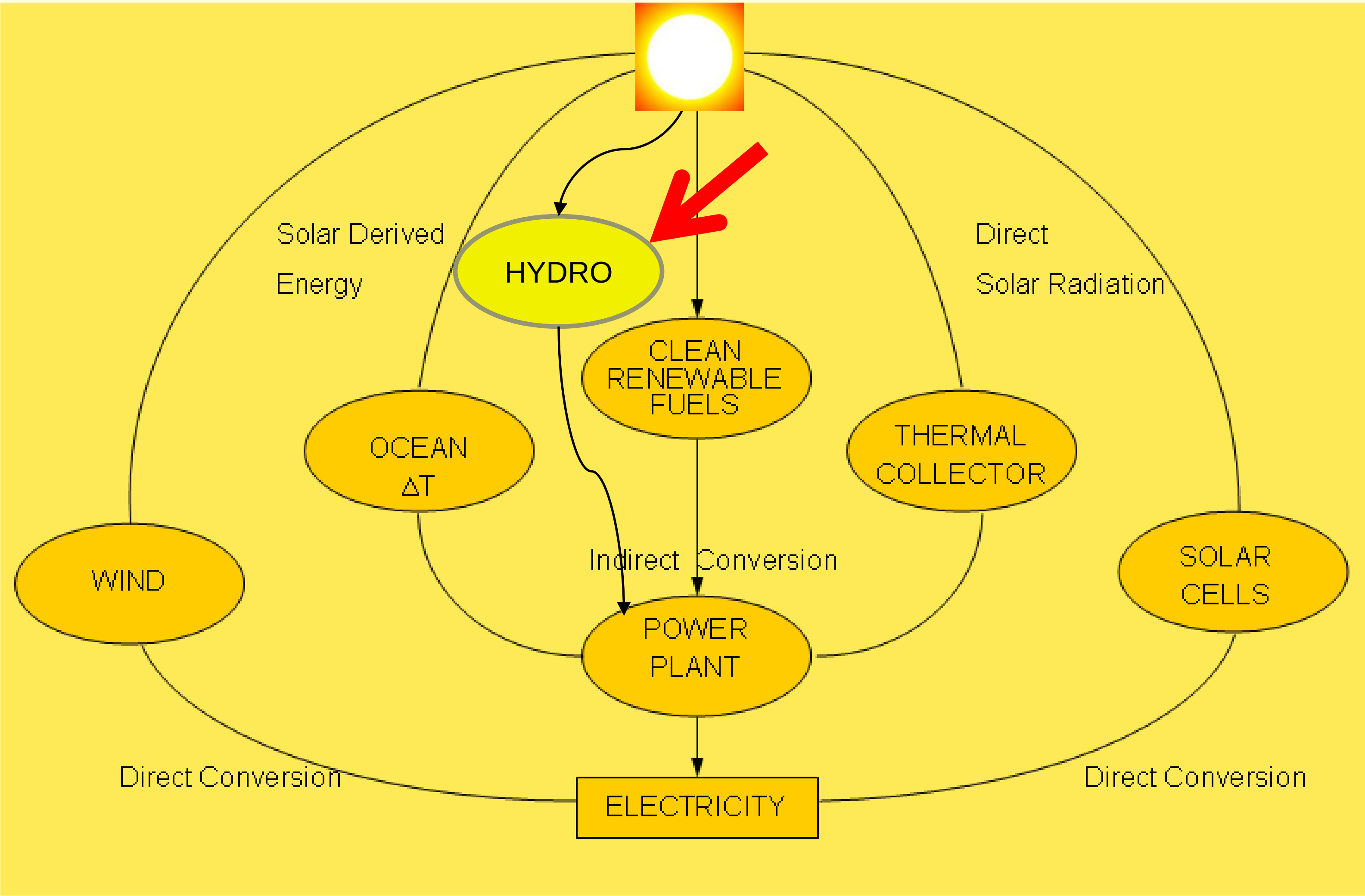
- Low and medium head plants use Francis turbines
- High head plants use Pelton wheel turbines





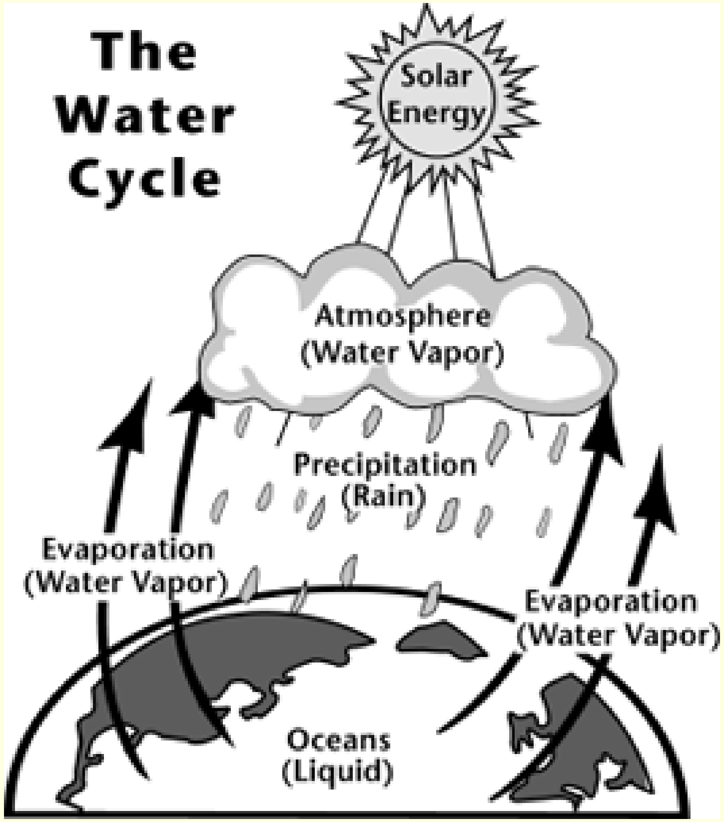


Electricity production from renewables

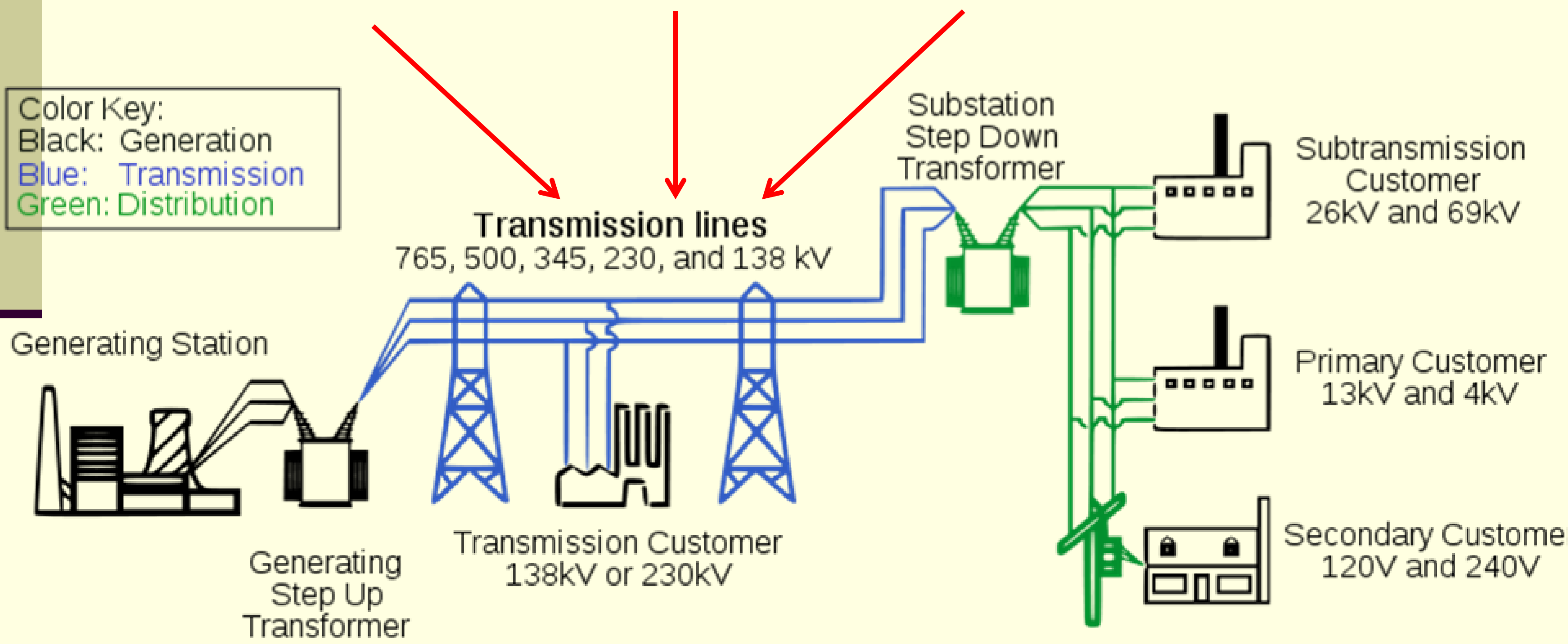


Hydropower is renewable

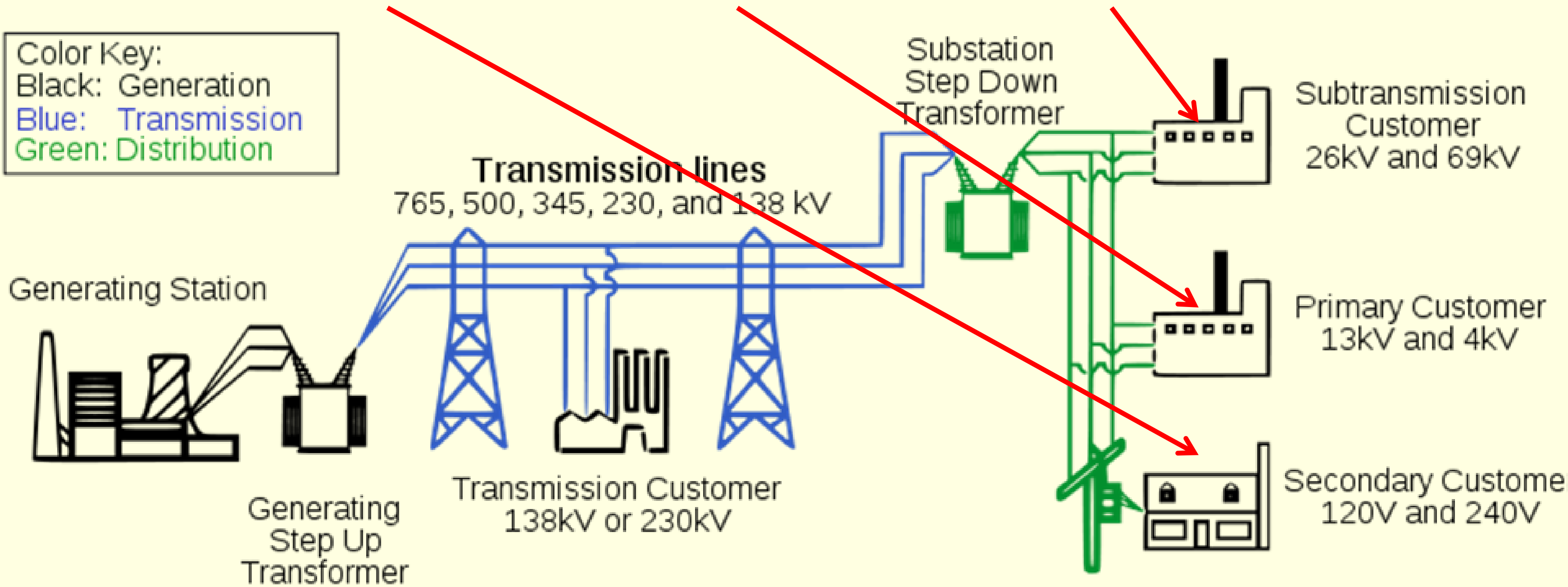
- Hydropower relies on the water cycle. Herein:
  - Solar energy heats water on the surface, causing it to evaporate.
  - This water vapor condenses into clouds and falls back onto the surface as precipitation (rain, snow, etc.).
  - The water flows through rivers back into the oceans, where it can evaporate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



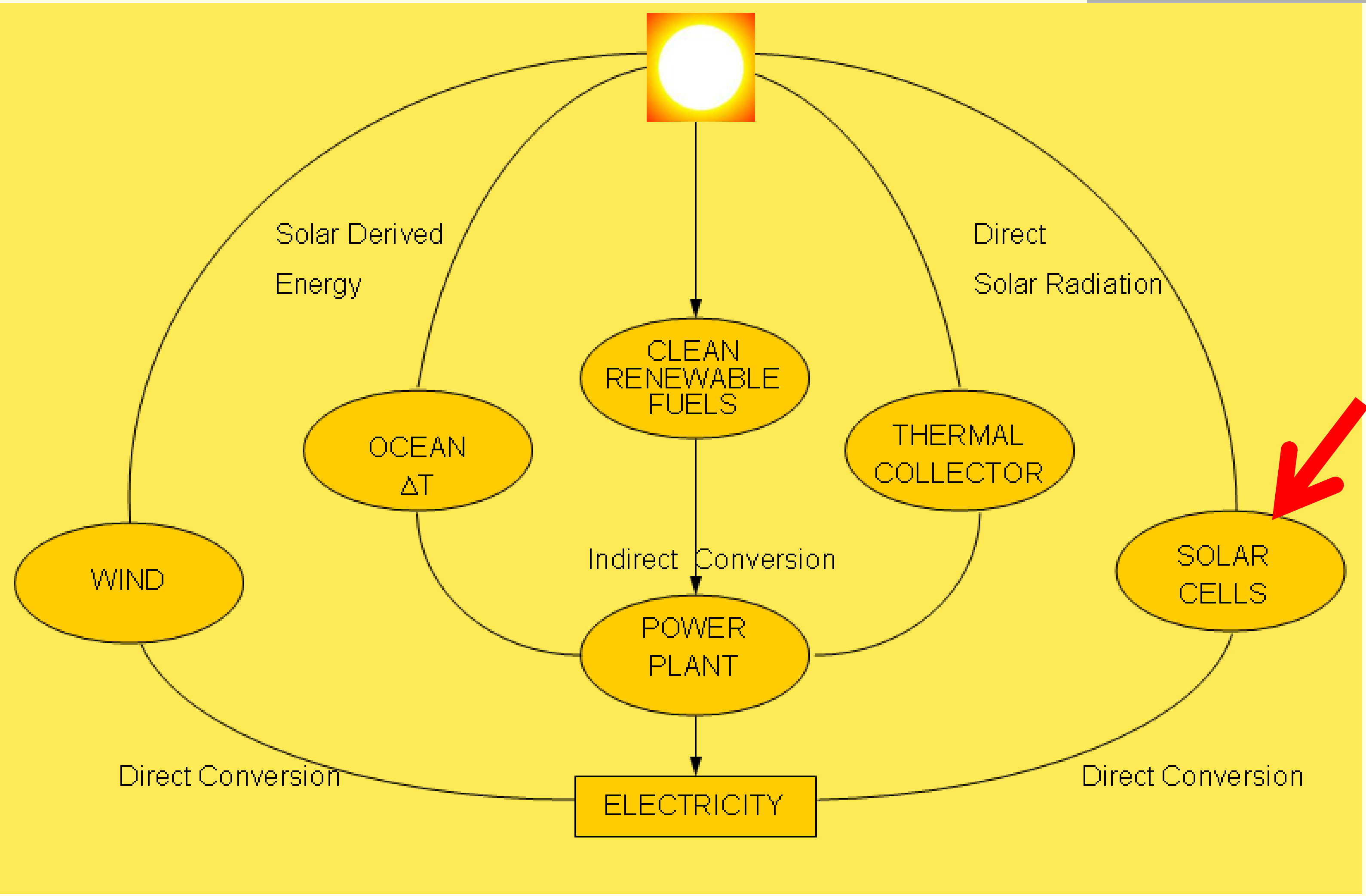
Renewable Power Plants: Large plants are connected to the sub-transmission or transmission system



Renewable Power Plants: Small plants are connected to the distribution system (often on the load side)



Electricity production from renewables: Photovoltaics



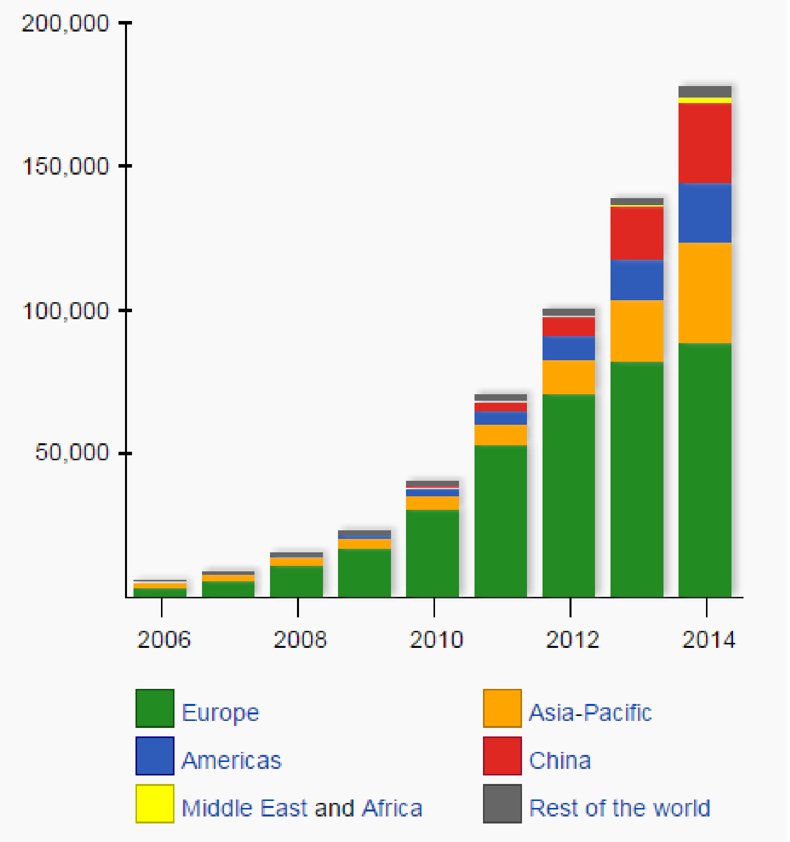
Growth in Solar Photovoltaic

Top 10 PV-Countries of Year 2014 in (MW)

Total Capacity			Added Capacity		
1.	Germany	38,200	1.	China	10,560
2.	China	28,199	2.	Japan	9,700
3.	Japan	23,300	3.	United States	6,201
4.	Italy	18,460	4.	UK	2,273
5.	United States	18,280	5.	Germany	1,900
6.	France	5,660	6.	France	927
7.	Spain	5,358	7.	Australia	910
8.	UK	5,104	8.	South Korea	909
9.	Australia	4,136	9.	South Africa	800
10.	Belgium	3,074	10.	India	616

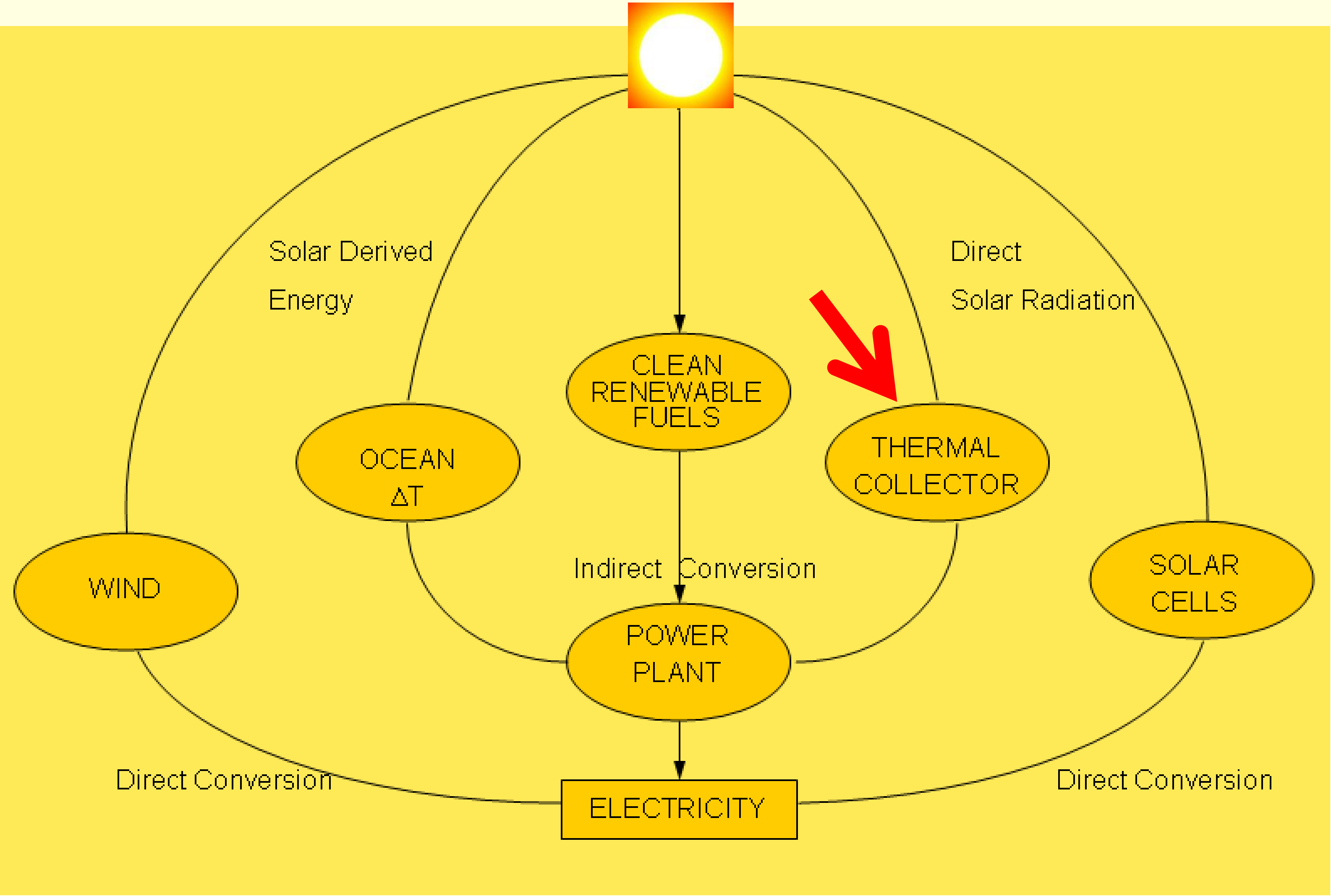
Data: IEA-PVPS *Snapshot of Global PV 1992–2014* report, March 2015[3]:15

Cumulative Capacity in Megawatts [MW_p] Grouped by Region[1][2]:17[3]:15



PV Plants in Nevada:

Electricity production from renewables: concentrating Solar power



Concentrating Solar Power (CSP)

- CSP technologies use mirrors to reflect and concentrate sunlight onto receivers that collect the solar energy and convert it into heat.
- This thermal energy can then be used to produce electricity via a steam turbine or heat engine driving a generator.
- CSP systems are typically classified by how the various systems collect solar energy. The three main systems are
  - The linear system
  - The tower system
  - The dish system.

Concentrating Solar Power

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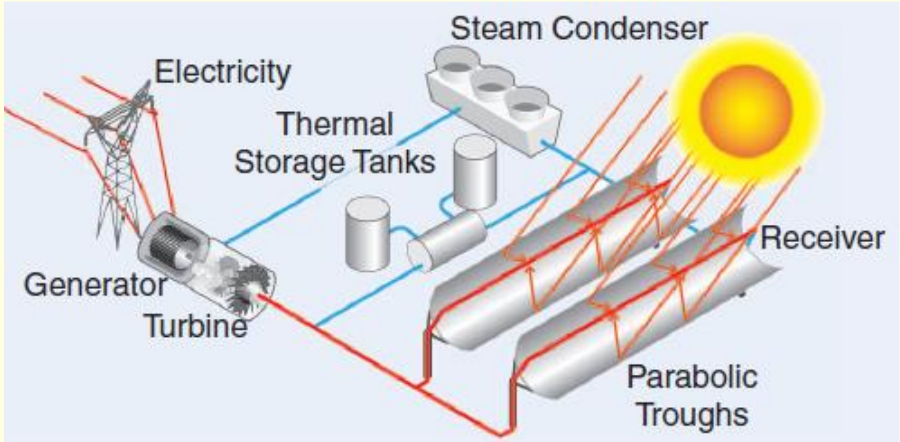
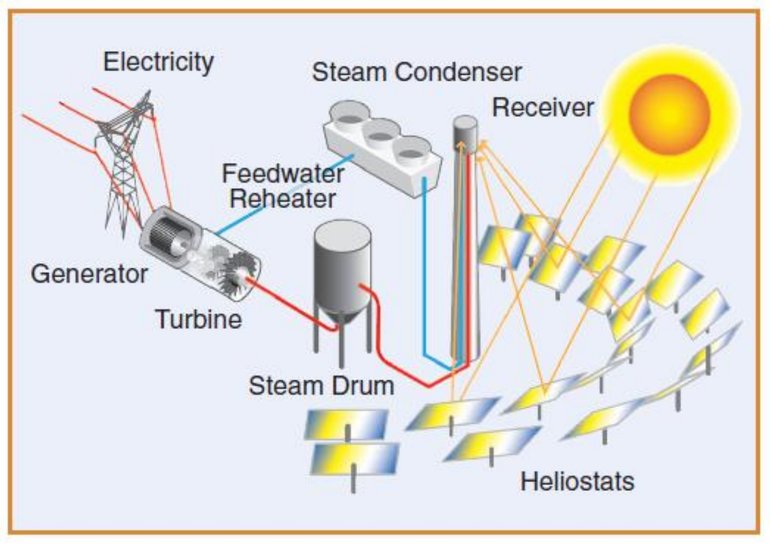
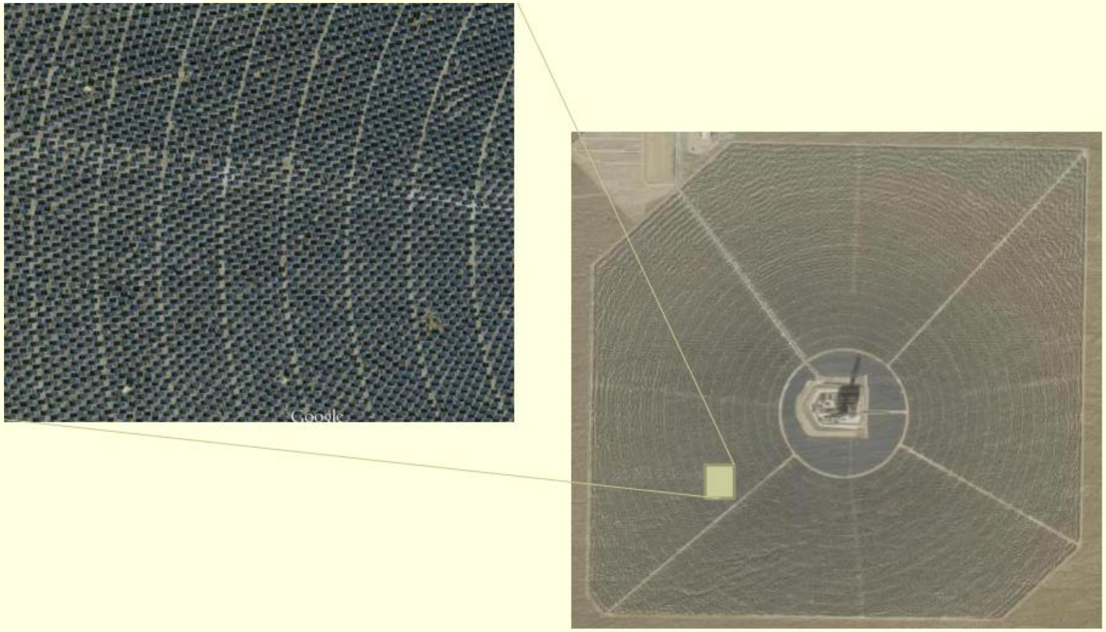
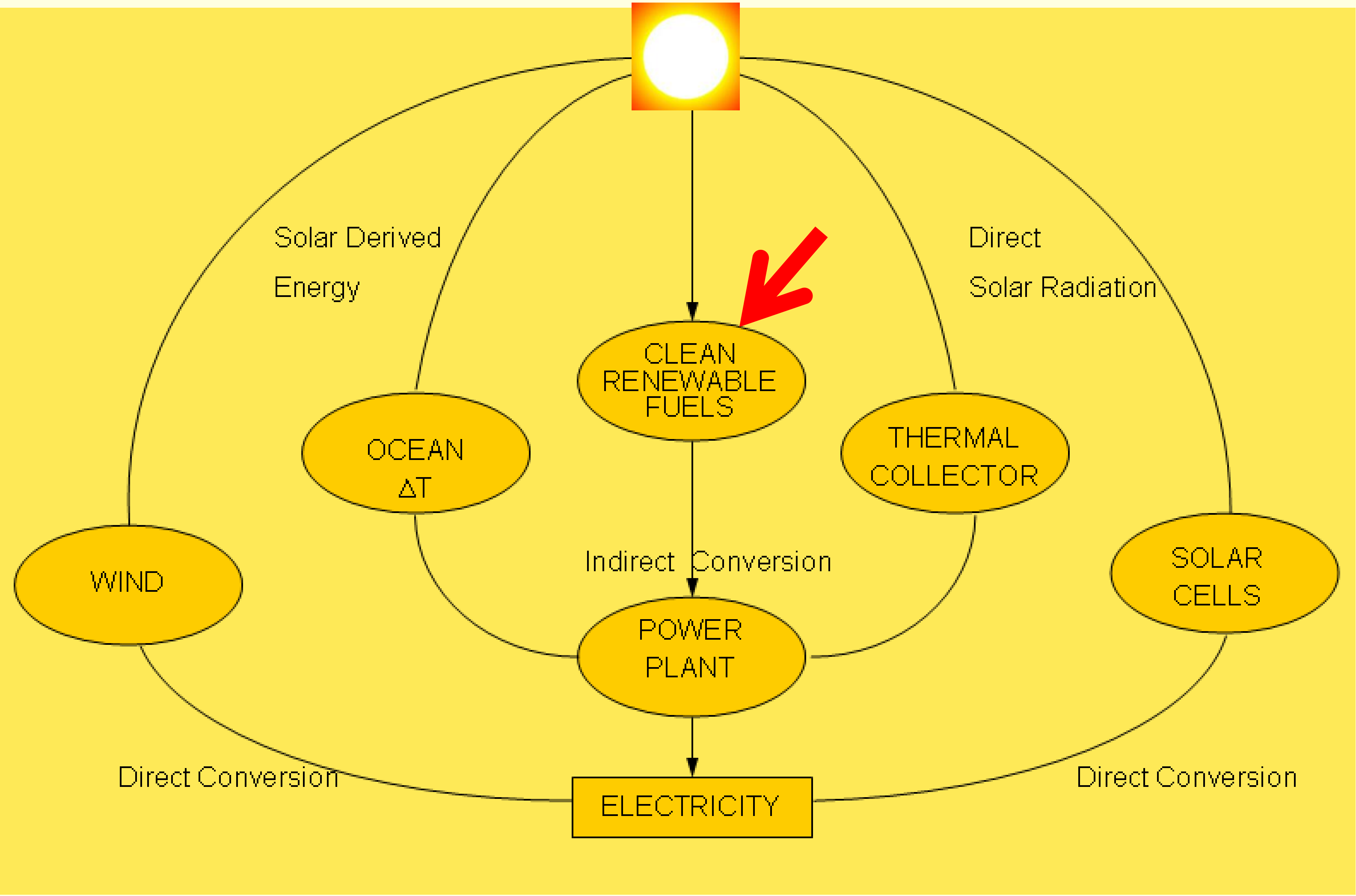


Power tower CSP

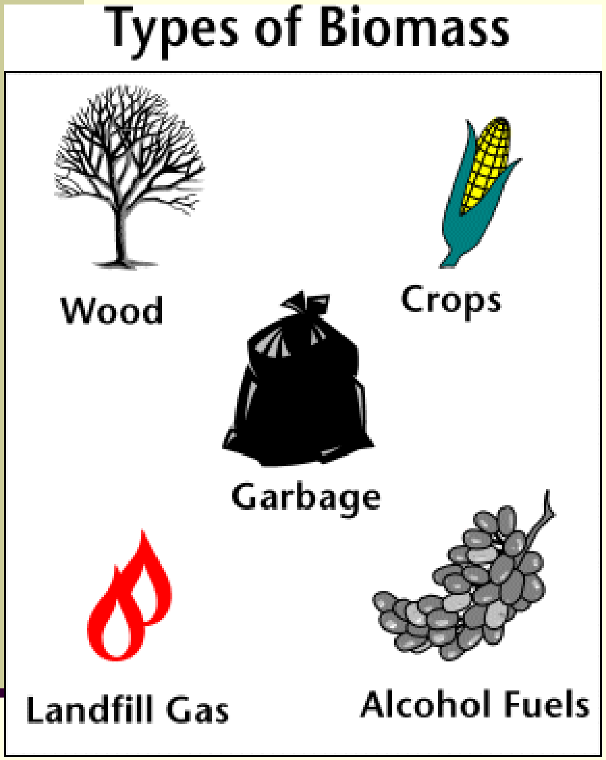


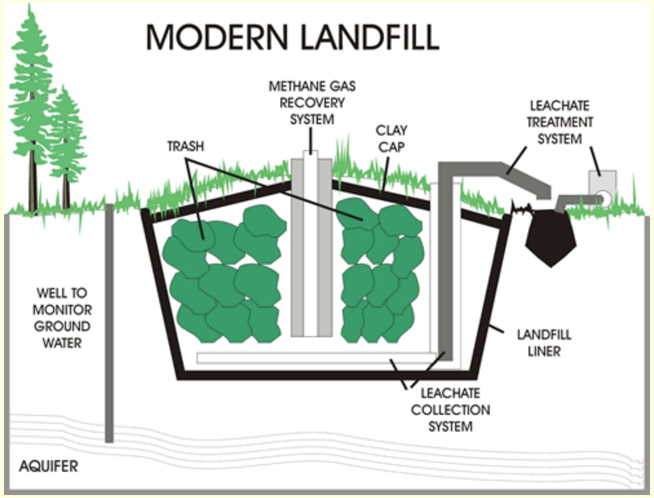


Electricity production from renewables: Biomass



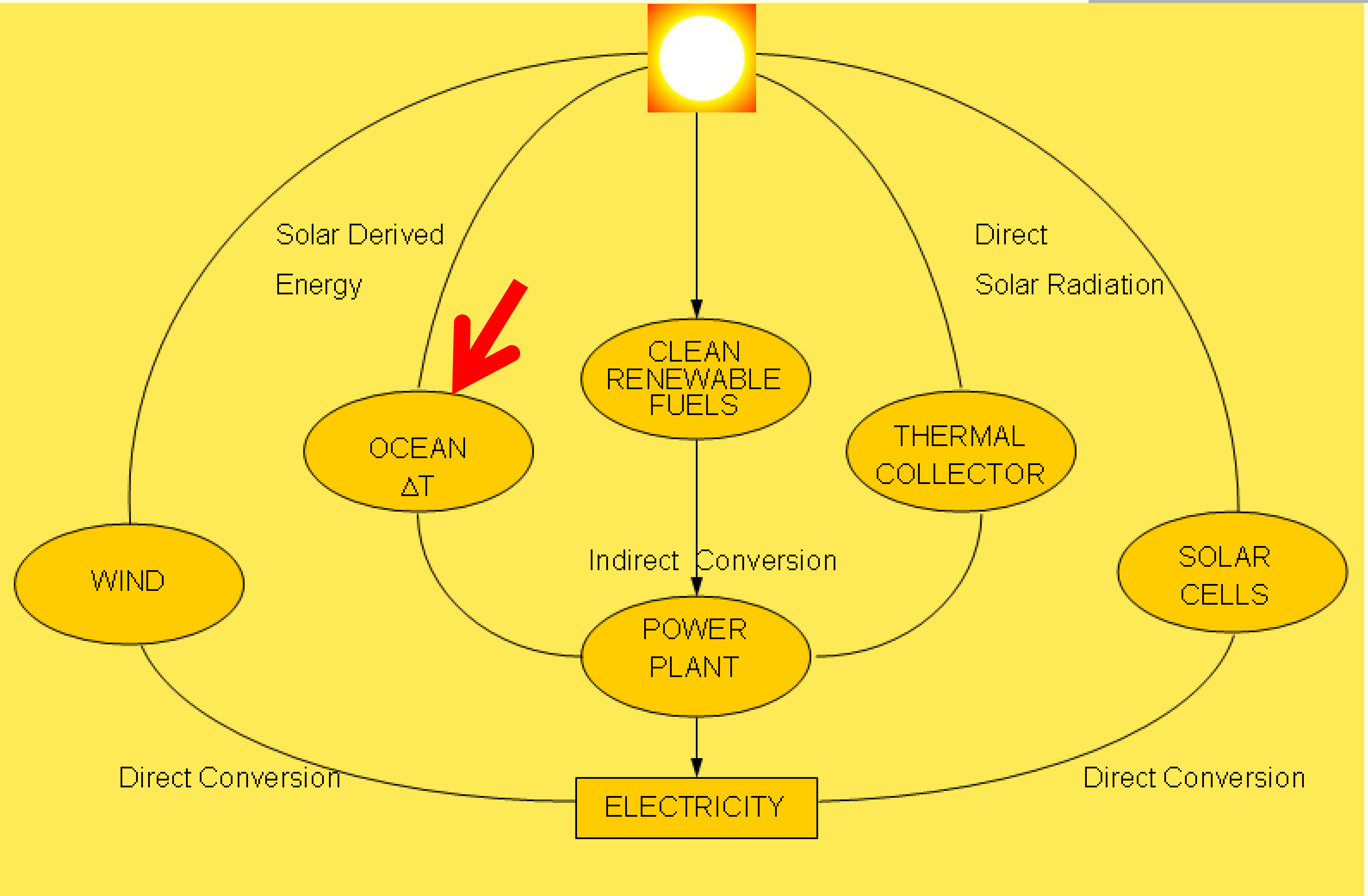
Biomass Energy





Landfill Energy near Las Vegas, NV (12 MW)

Electricity production from renewables: Ocean power

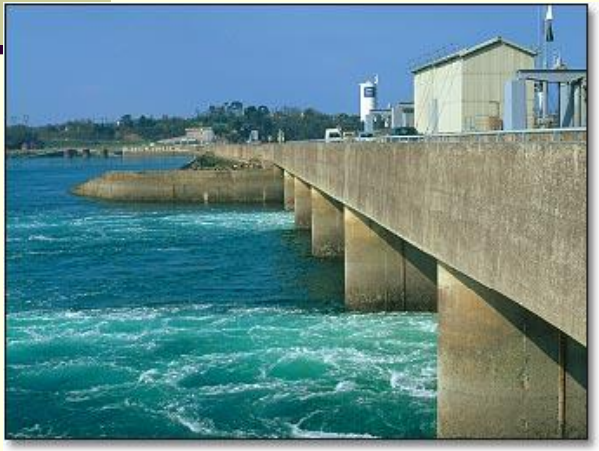


Capturing Ocean Power

Attenuator

Point Absorber

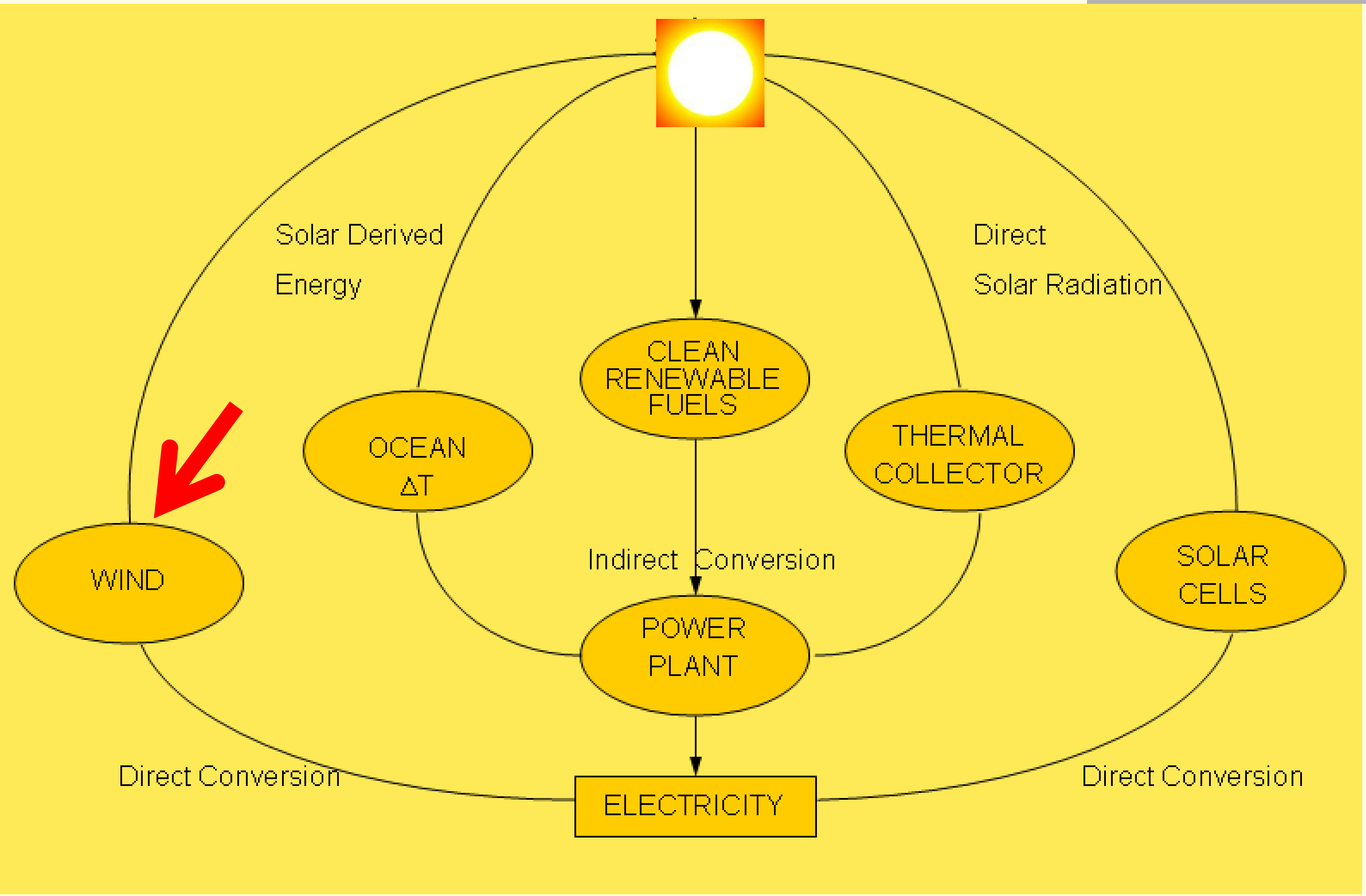
Tidal Power



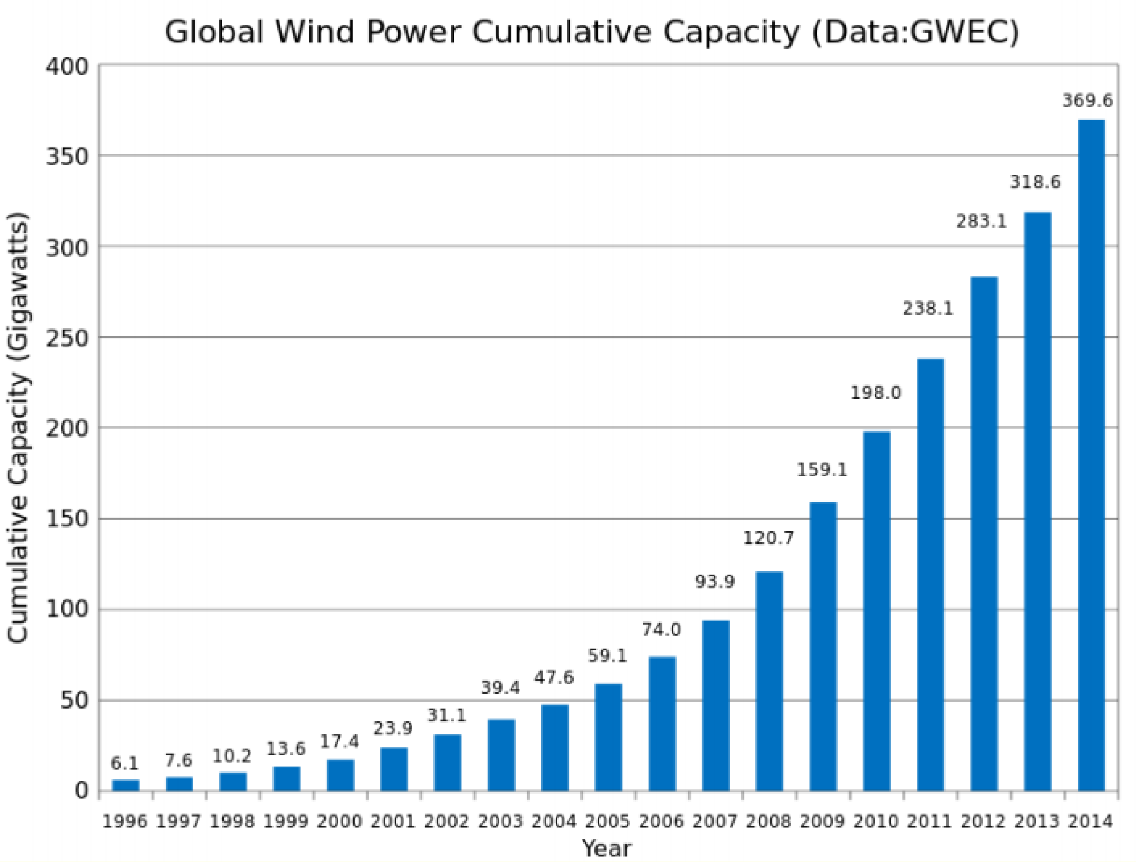
Oscillating Water Column

Ocean Current

Electricity production from renewables: Wind



Wind Power



Global Wind Power Cumulative Capacity (Data:GWEC)
Cumulative Capacity (Gigawatts)
Year
0
50
100
150
200
250
300
350
400
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014
6.1
7.6
10.2
13.6
17.4
23.9
31.1
39.4
47.6
59.1
74.0
93.9
120.7
159.1
198.0
238.1
283.1
318.6
369.6

Installed Wind Capacity by Country (MW)

Top 10 windpower countries of 2014

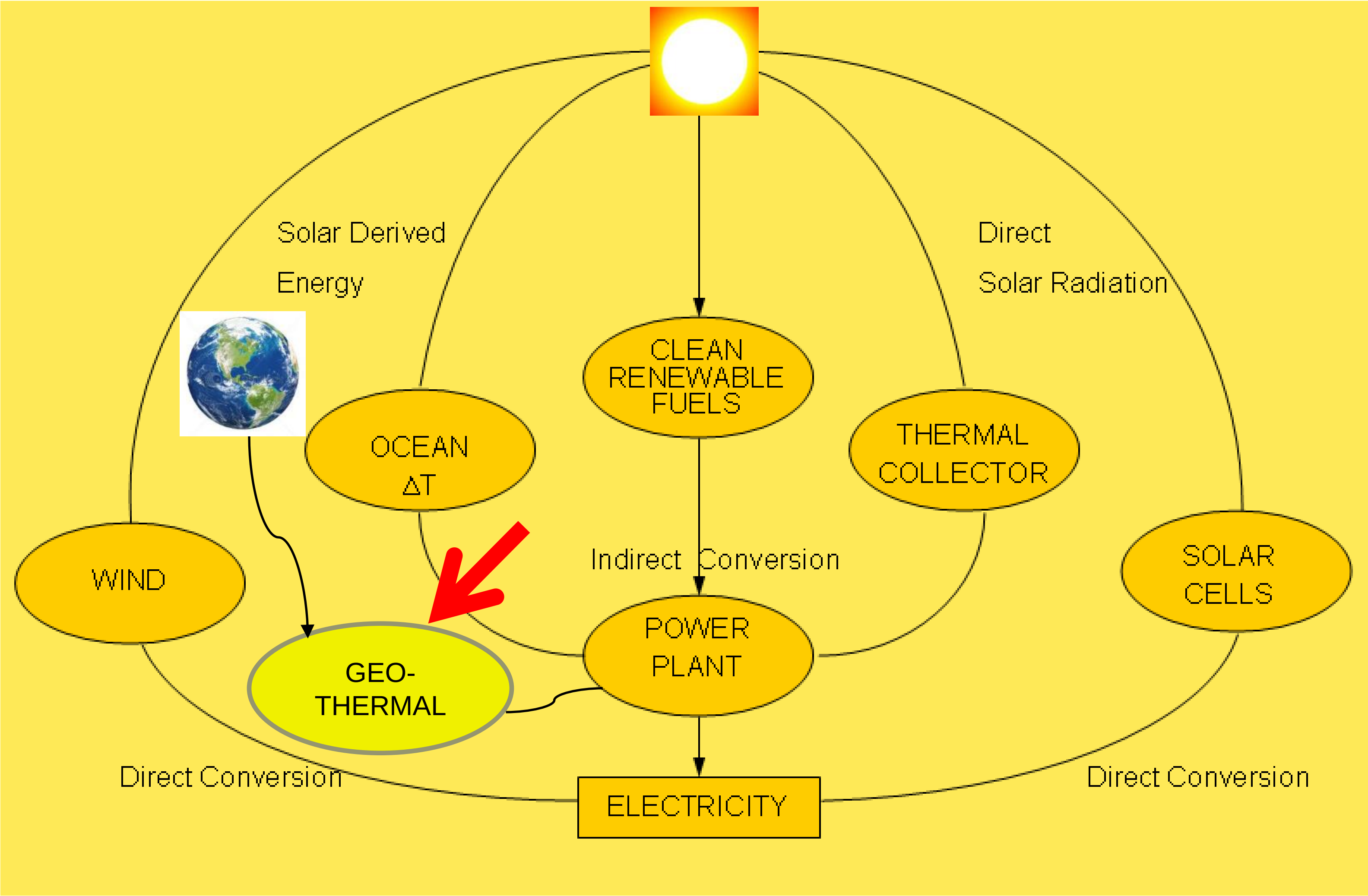
Country	Capacity (MW)	% of Total
China	114,763	31.0
United States	65,879	17.8
Germany	39,165	10.6
Spain	22,987	6.2
India	22,465	6.1
United Kingdom	12,440	3.4
Canada	9,694	2.6
France	9,285	2.5
Italy	8,663	2.3
Brazil	5,939	1.6
(rest of world)	58,275	15.8
World total	**369,553**	**100%**

Denmark has broken another record of wind energy in 2015, having generated an astonishing 42% of its power from windmills, the highest share ever produced by any country.

Source: http://www.energymarketprice.com/

Wind Power in Nevada:
Spring Valley Wind (Pine County): 152 MW

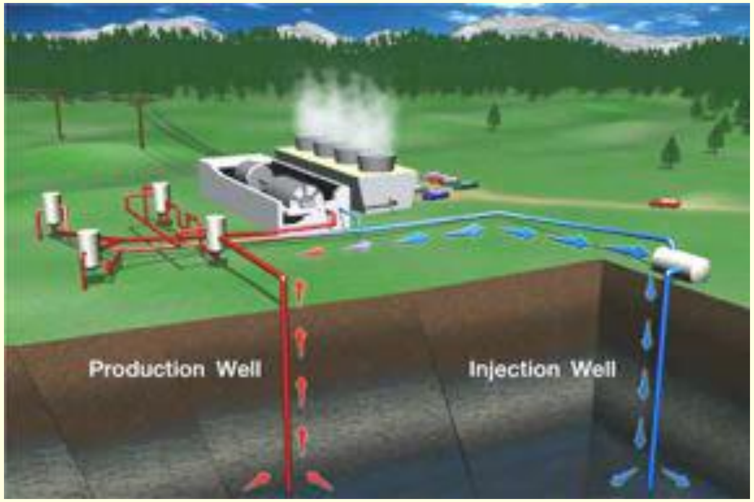
Electricity production from renewables: geothermal

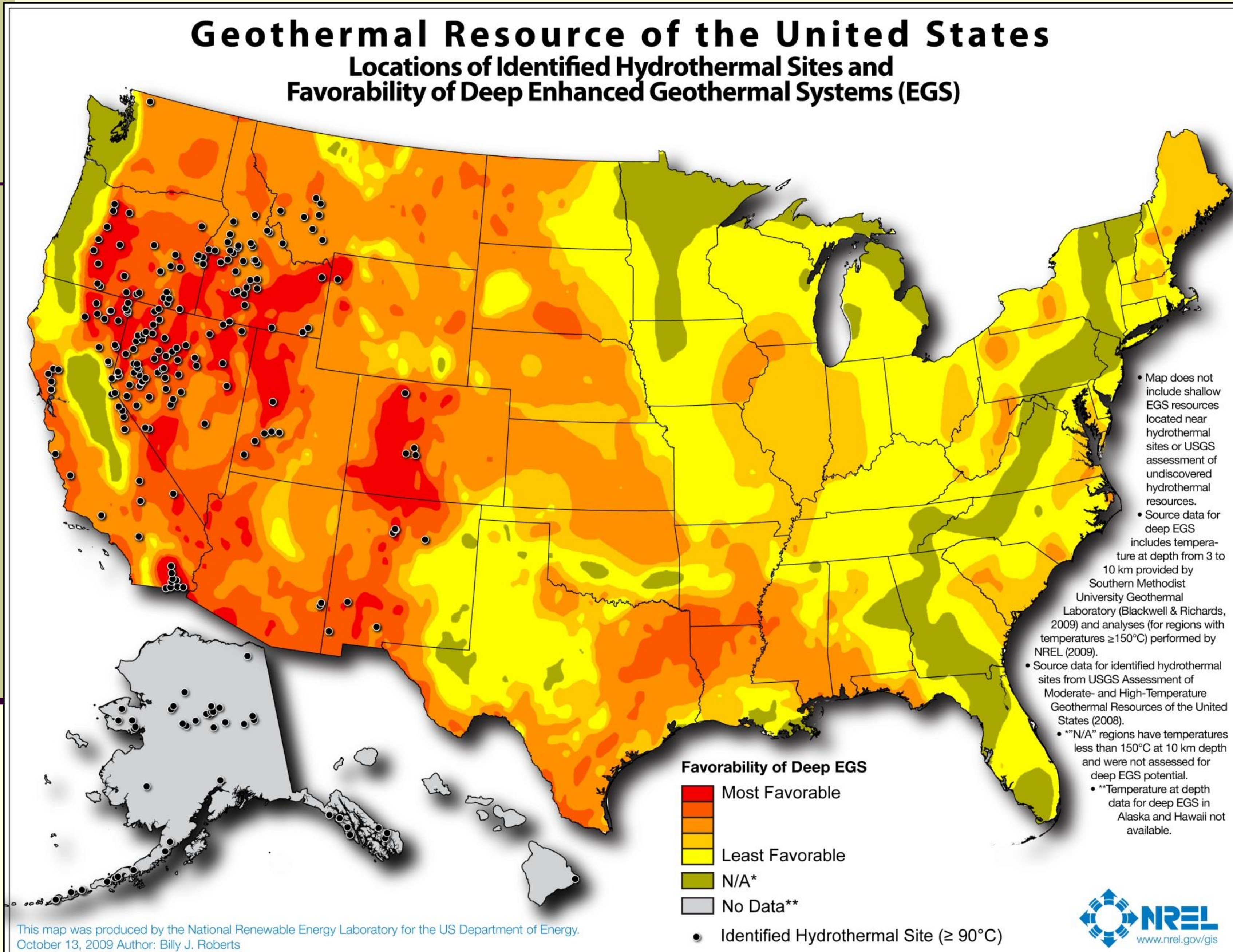


Geothermal

- **Dry steam plants** use steam piped directly from a geothermal reservoir to turn the generator turbines. The first geothermal power plant was built in 1904 in Tuscany, Italy.

- **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.



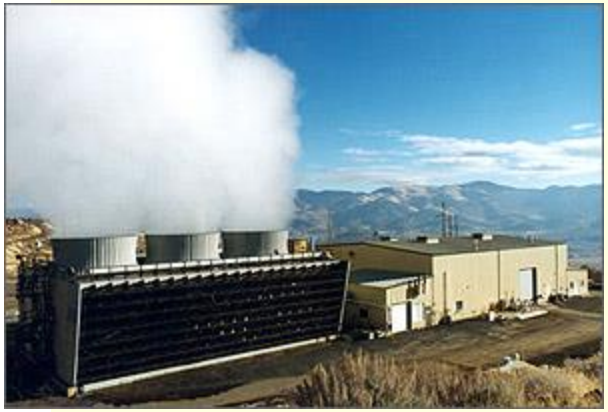

Geothermal Resource of the United States
Locations of Identified Hydrothermal Sites and
Favorability of Deep Enhanced Geothermal Systems (EGS)
• Map does not include shallow EGS resources located near hydrothermal sites or USGS assessment of undiscovered hydrothermal resources.
• Source data for deep 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

Geothermal in Nevada:
Current Capacity: 385 MW
(+ 150 MW in construction or development stage).

GEOTHERMAL

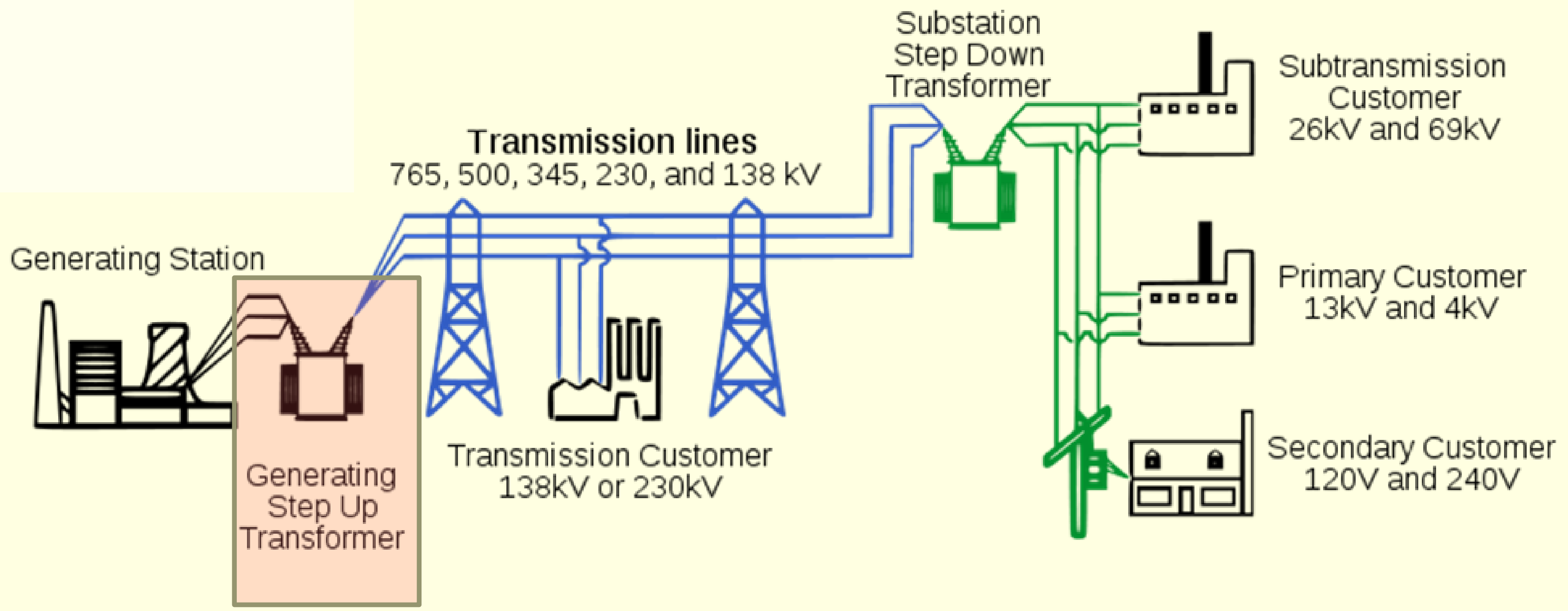
1. Beowawe Power 17.7 MW
2. Brady Geothermal Project 24.0 MW
3. Clayton Valley 1 ● 53.5 MW
4. Desert Peak Geothermal Project #2 25.0 MW
5. Dixie Meadows ● 51.0 MW
6. Faulkner 1 49.5 MW
7. Galena 2 13.0 MW
8. Galena 3 26.5 MW
9. Homestretch 2.1 MW
10. Jersey Valley Geothermal Project 22.5 MW
11. McGinness 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

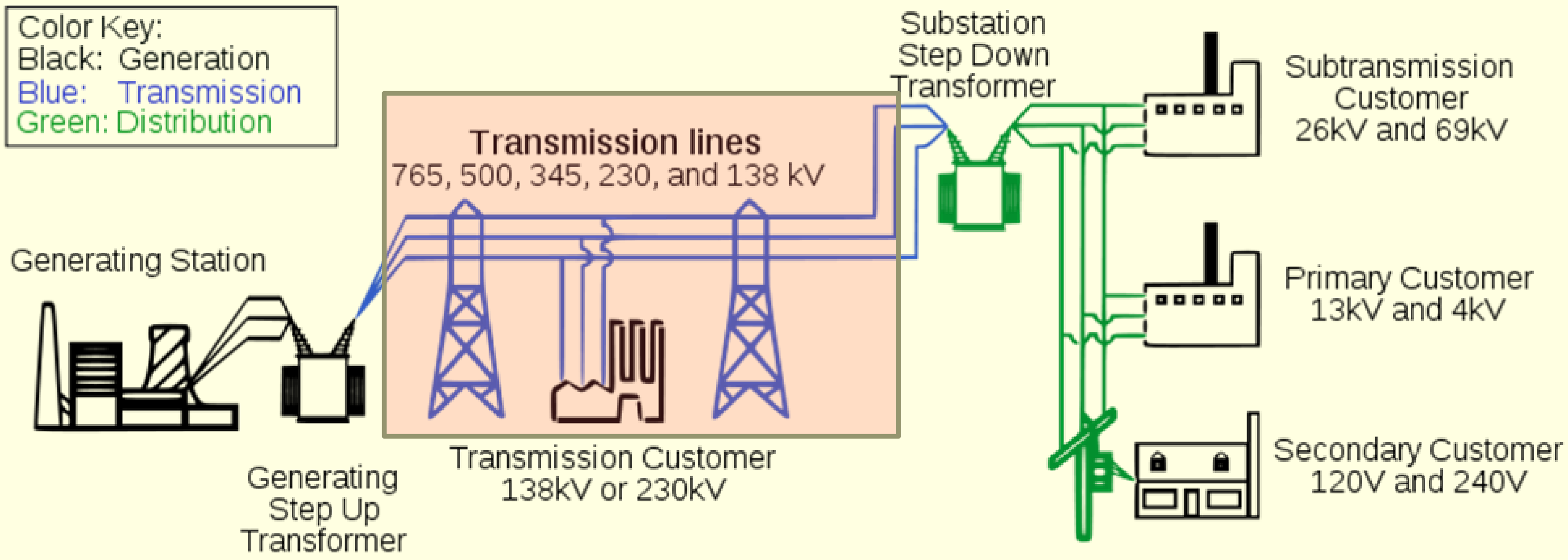
Basic Conventional Power System Layout



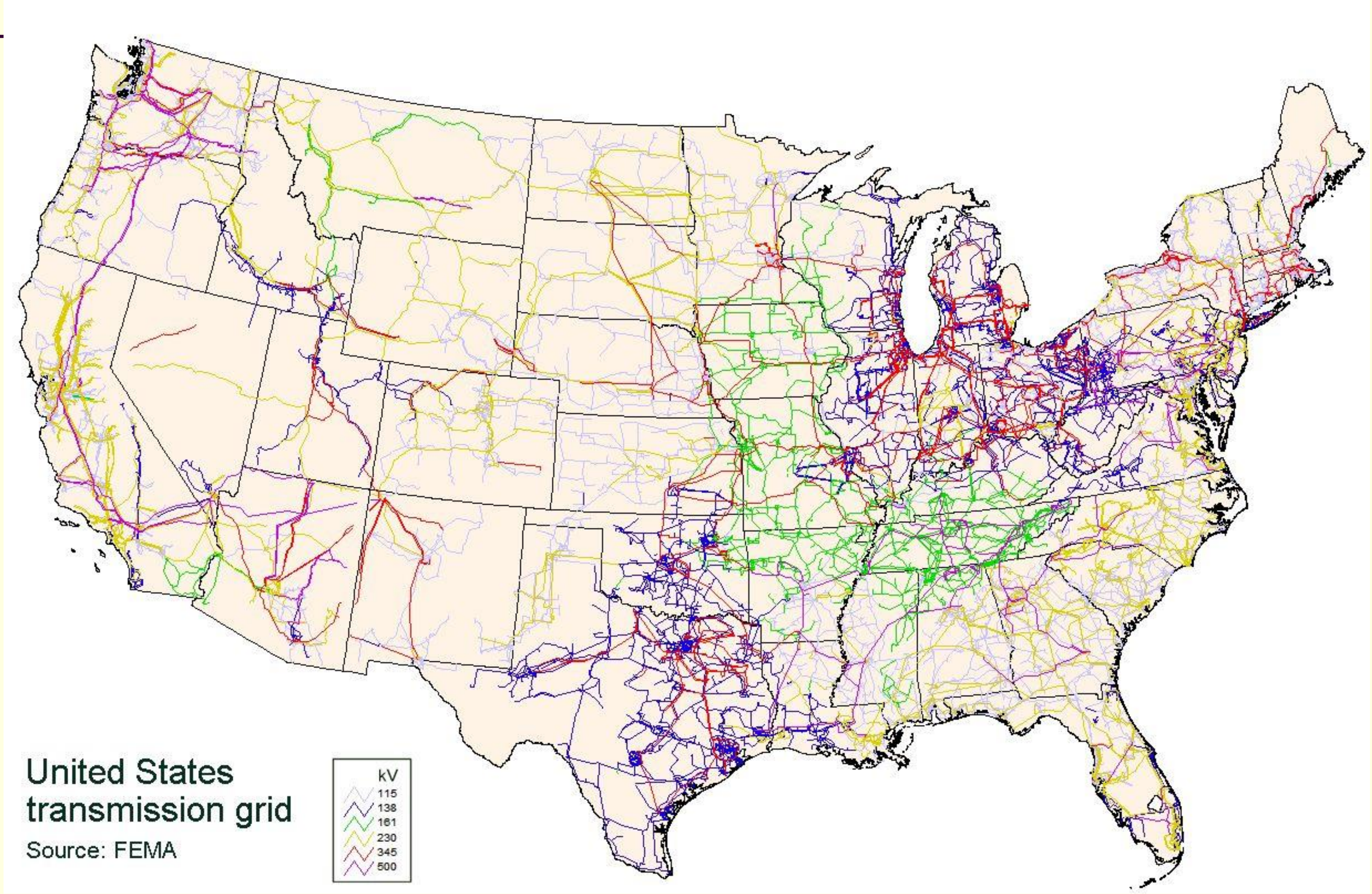
Step-up (Station) transformers:

- Size 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

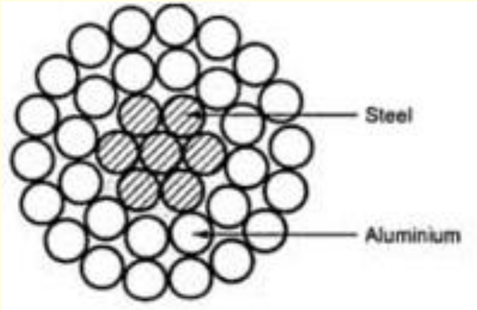


US Power Transmission Grid



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.



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.

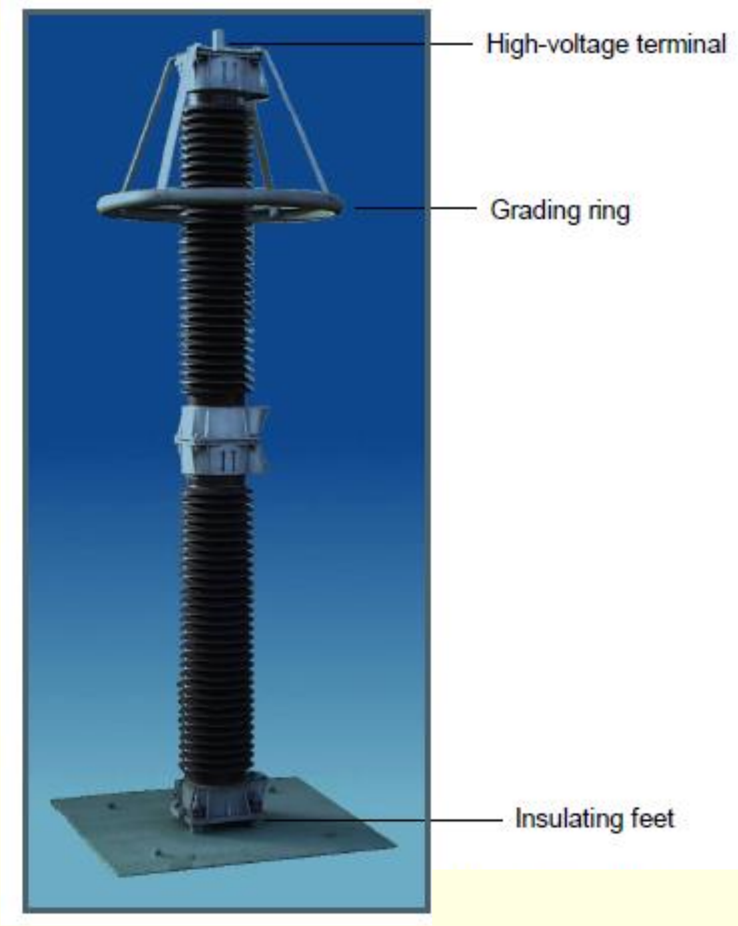
Tree Trimming underneath power lines

Before

After

Transmission System Protection

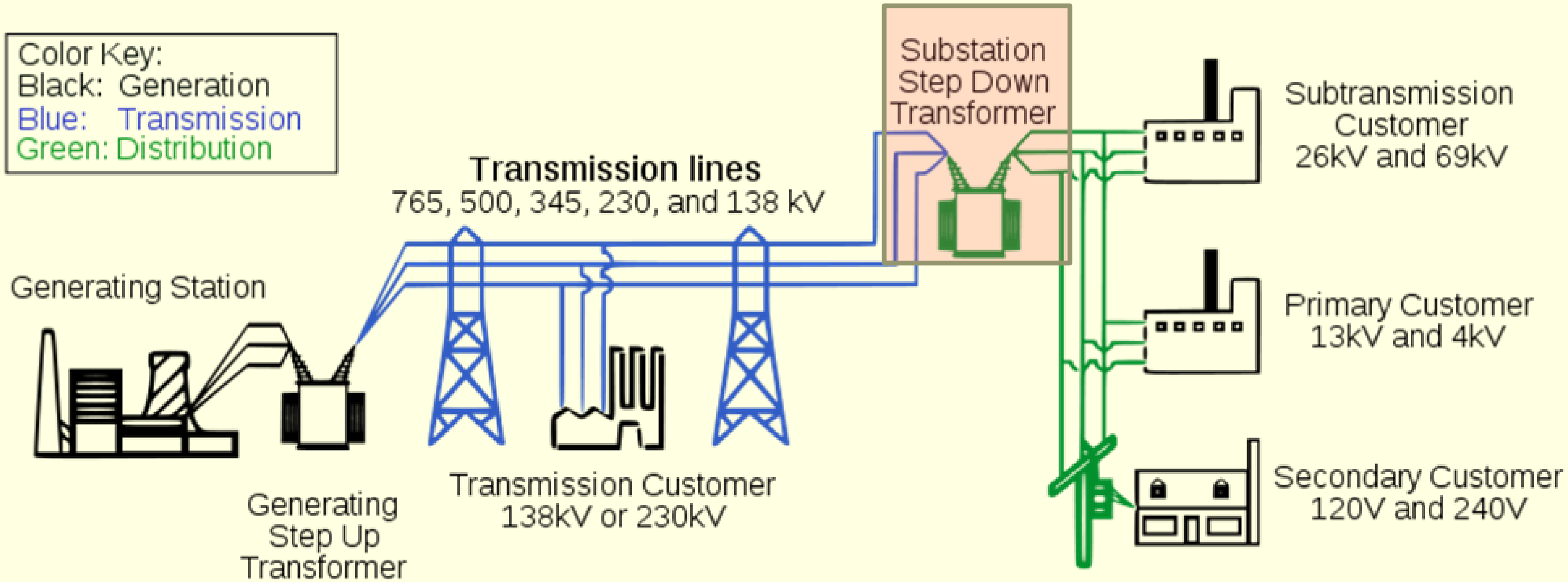
- Protective equipment needs to protect the system from over-voltages (surge arrestors) and over-currents (circuit breakers).



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



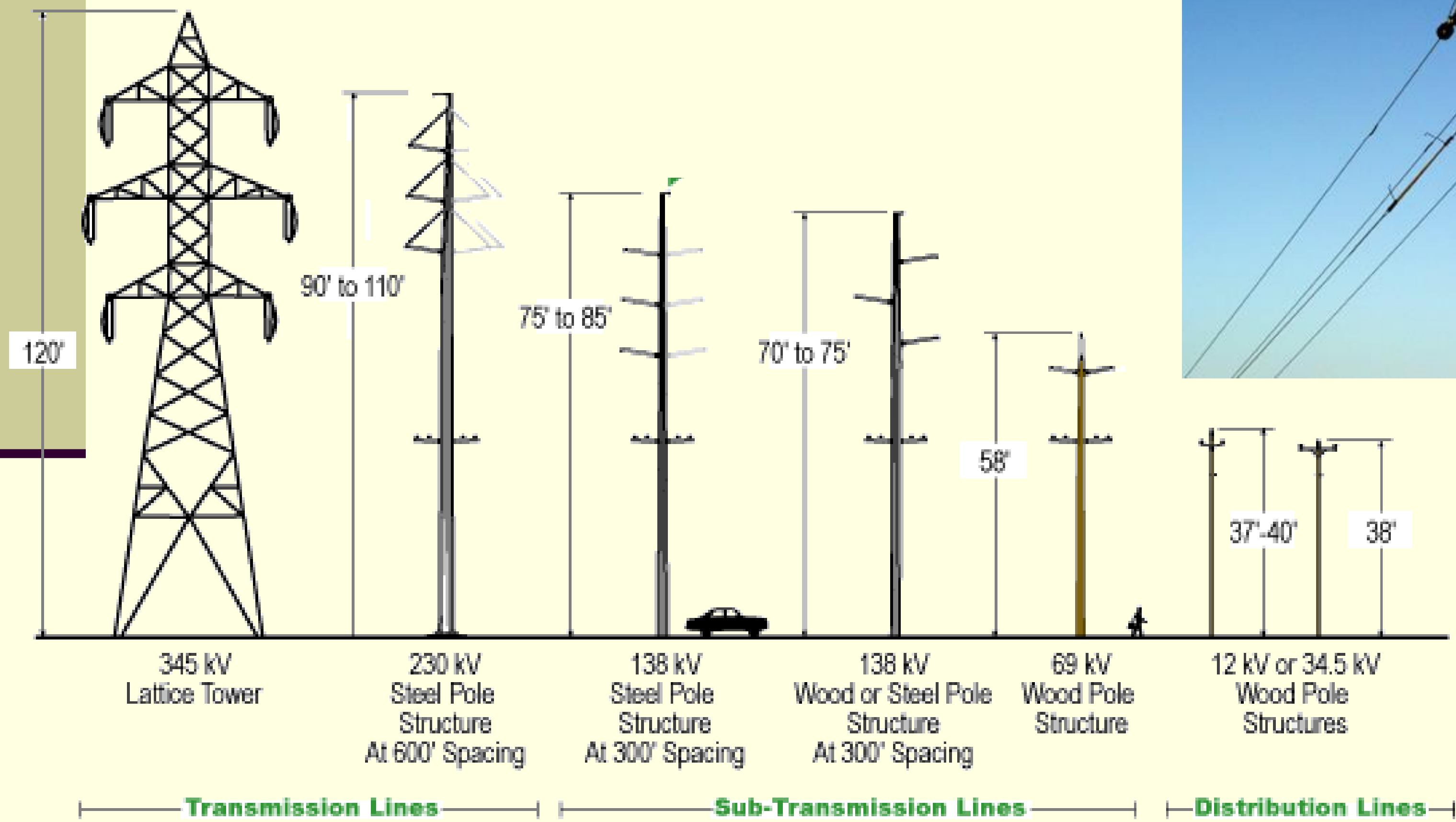
Substation Transformers

- 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.

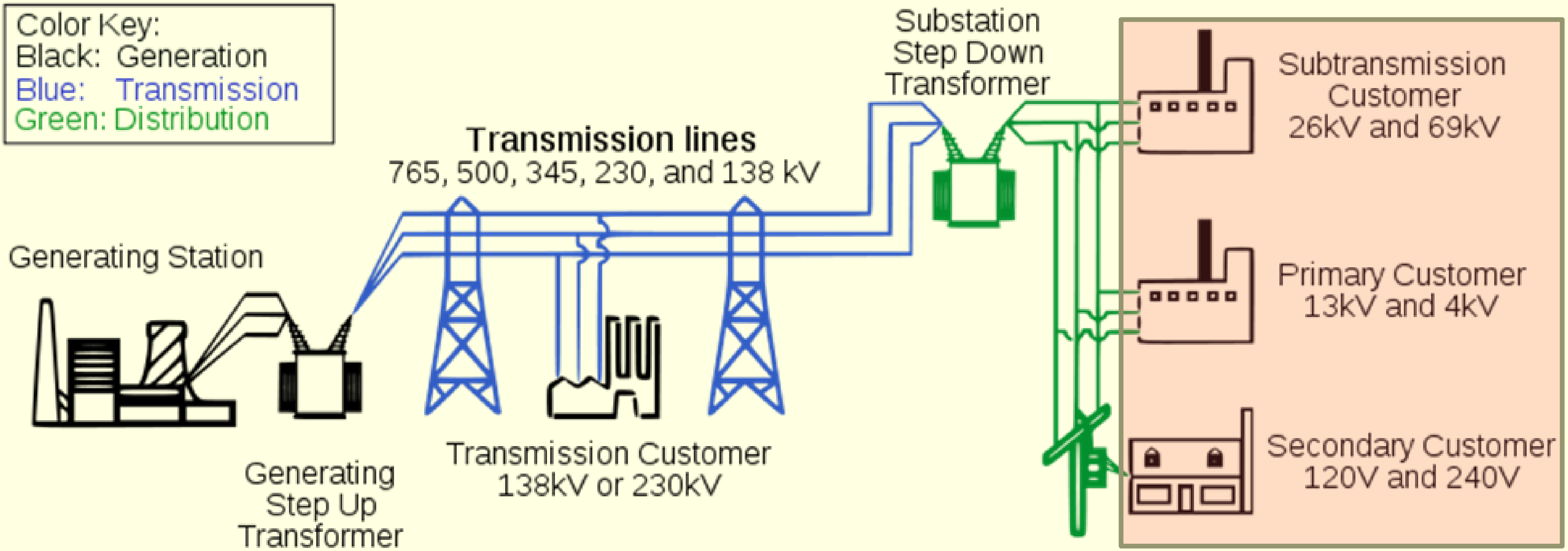
Overhead Transformer Bank & Service

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



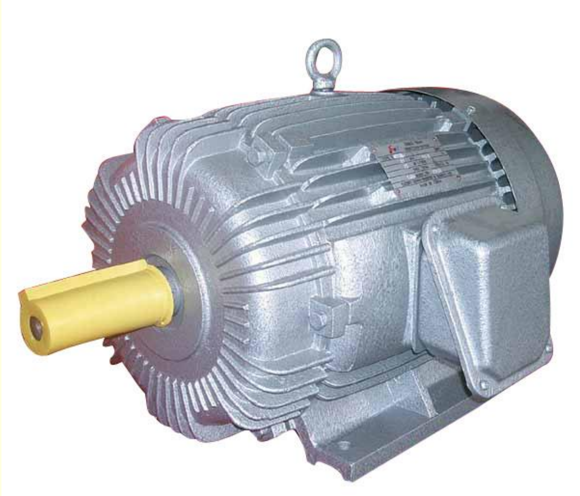
Electrical Power Utilization (electric load)

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





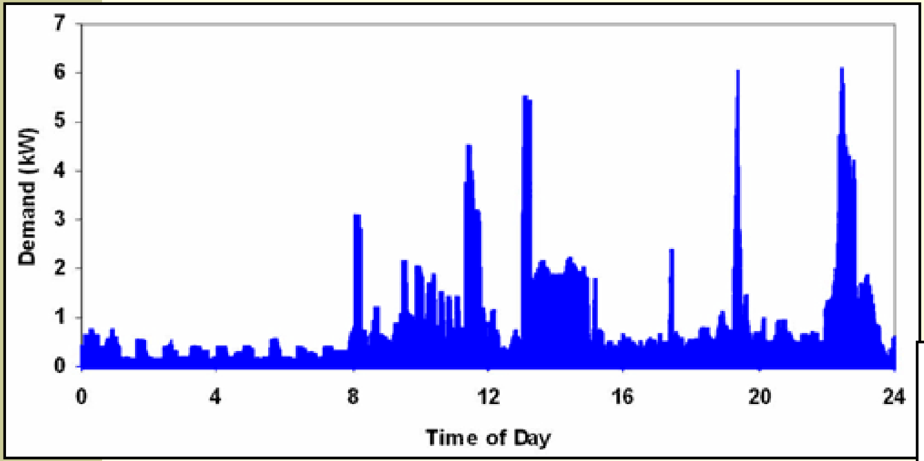


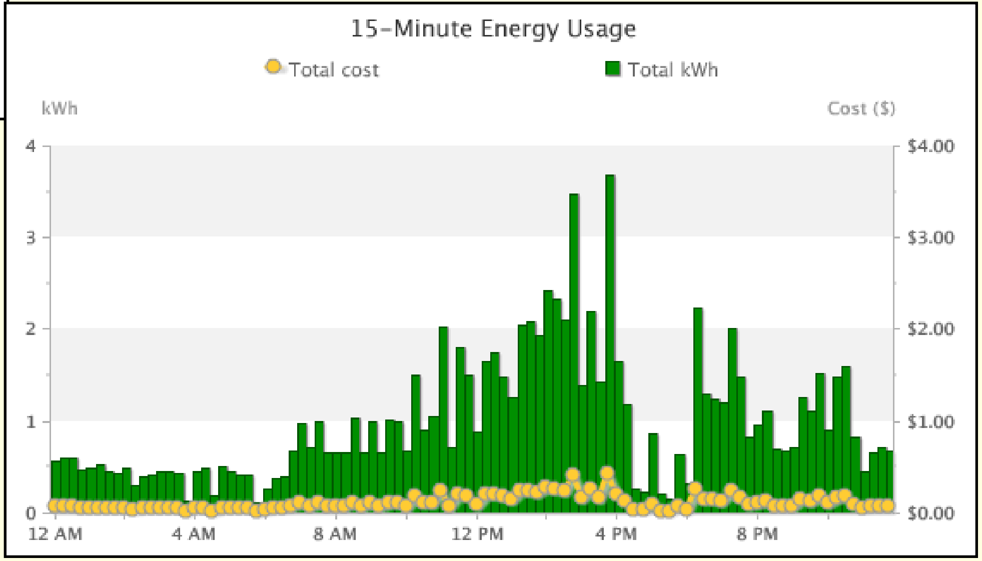



2/3 –3/4 of electricity is consumed by motors

Demand

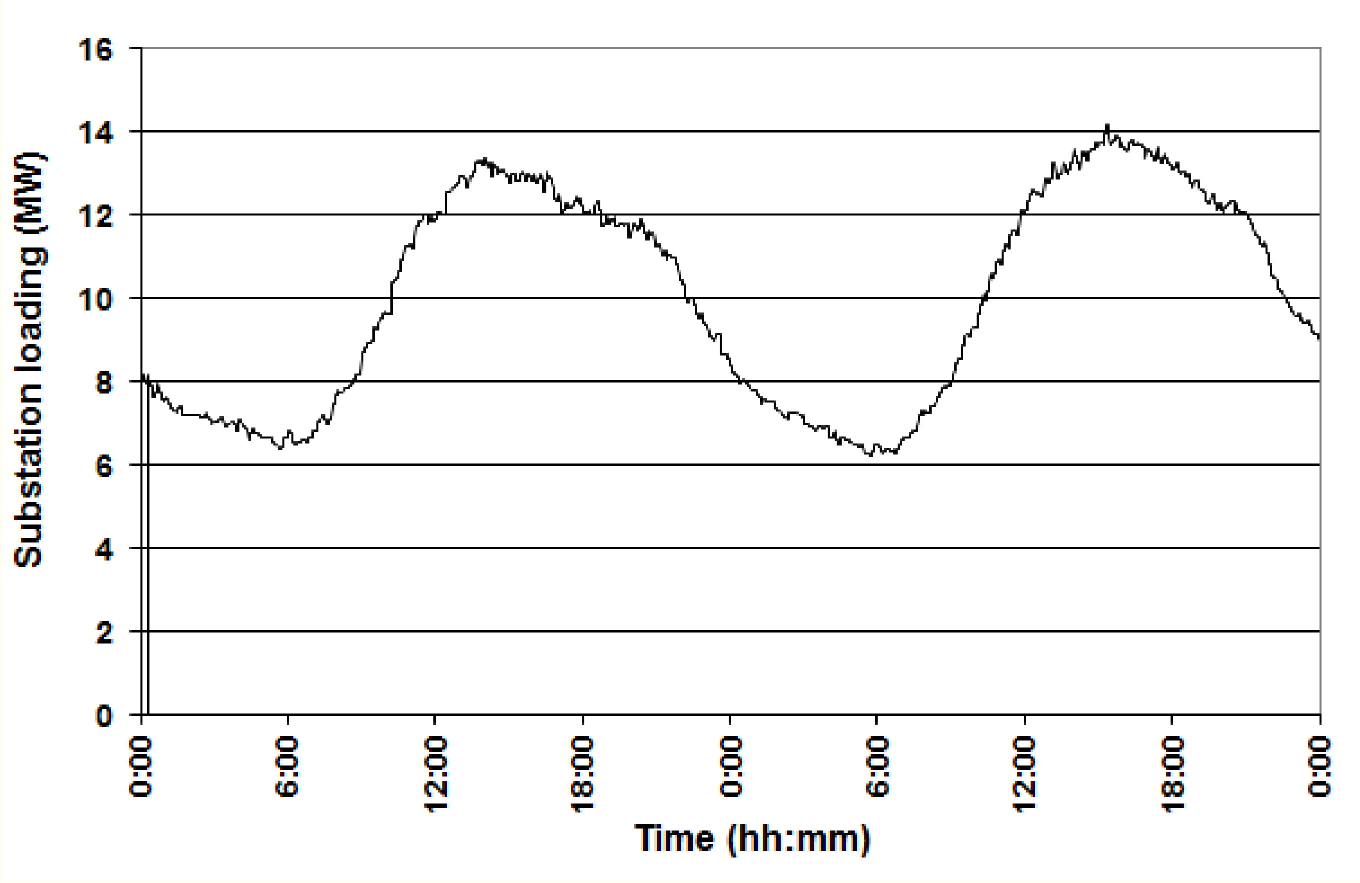
- Changes in demand of individual customers is fast and frequent due to load switching.



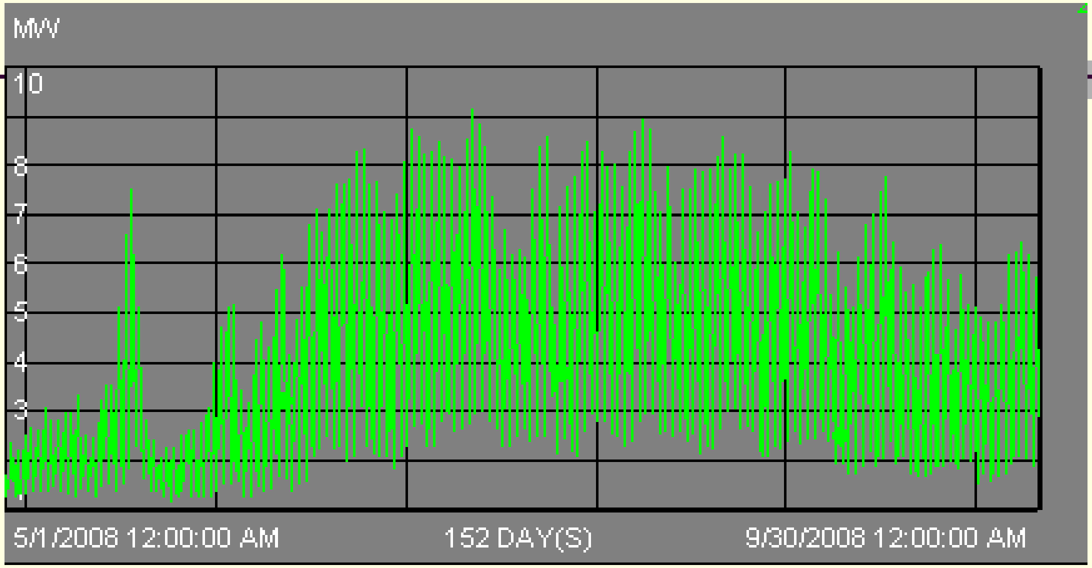


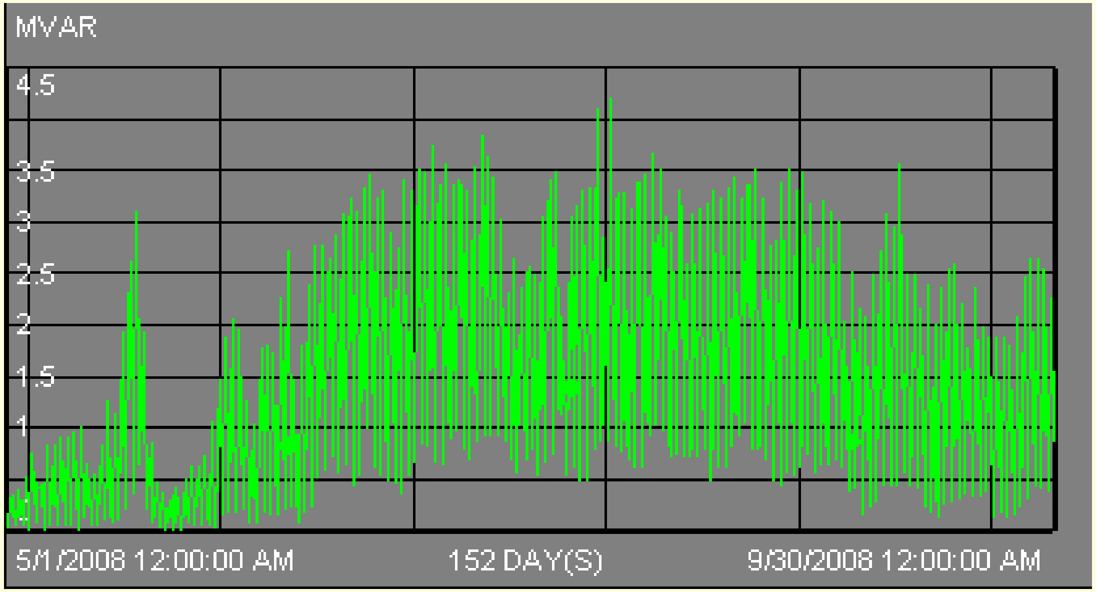
Substation Load: 48 hours

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



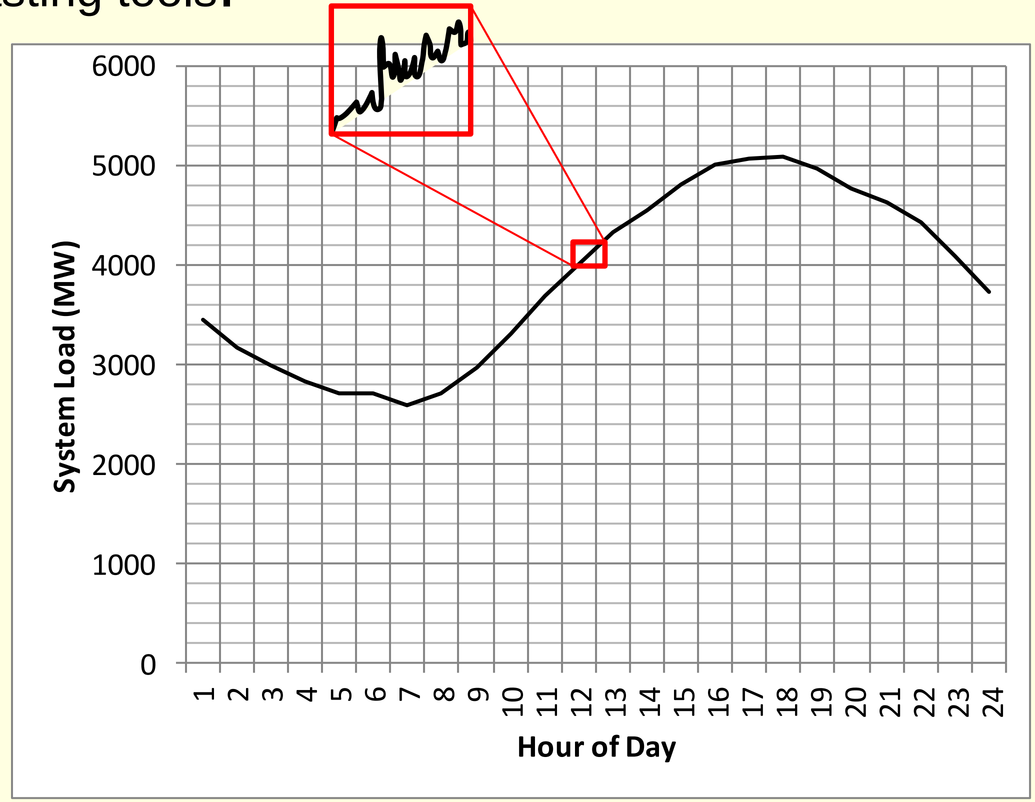
MW and MVAR loading on a feeder – 4 months





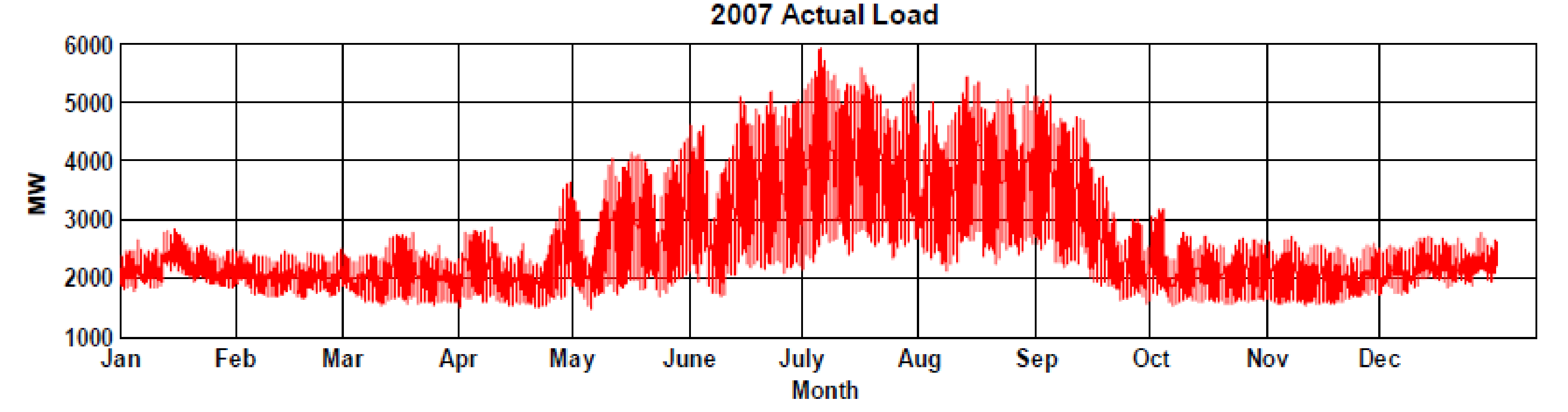
System load: 24-hours

- 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

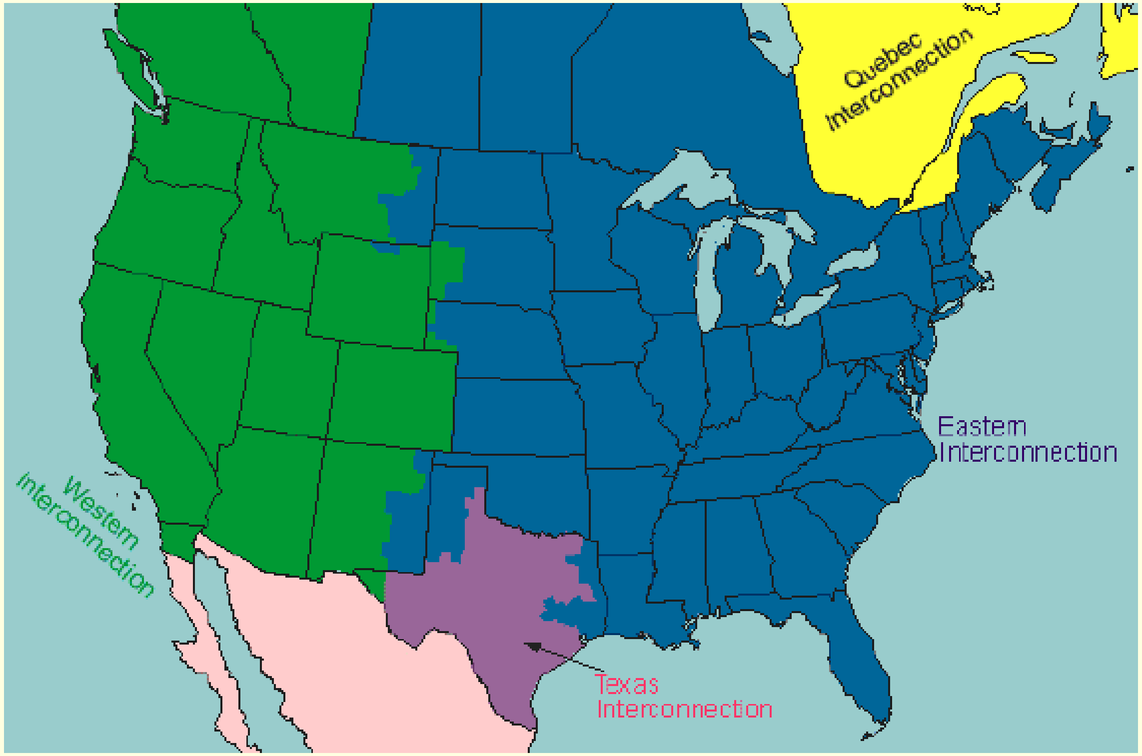
The local load is dominated by winter and summer patterns, with May and October as shoulder months.



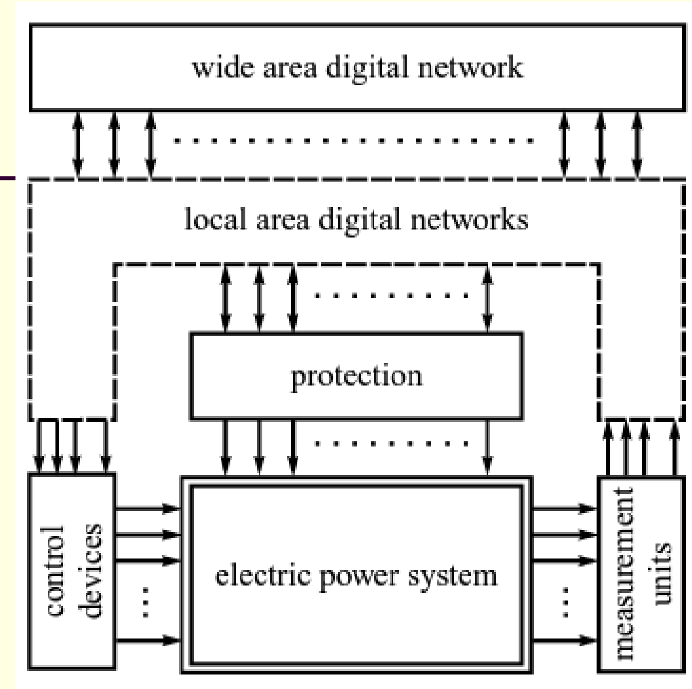
North American Electrical Interconnections

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**.



System monitoring. Analysis, Operation and Control



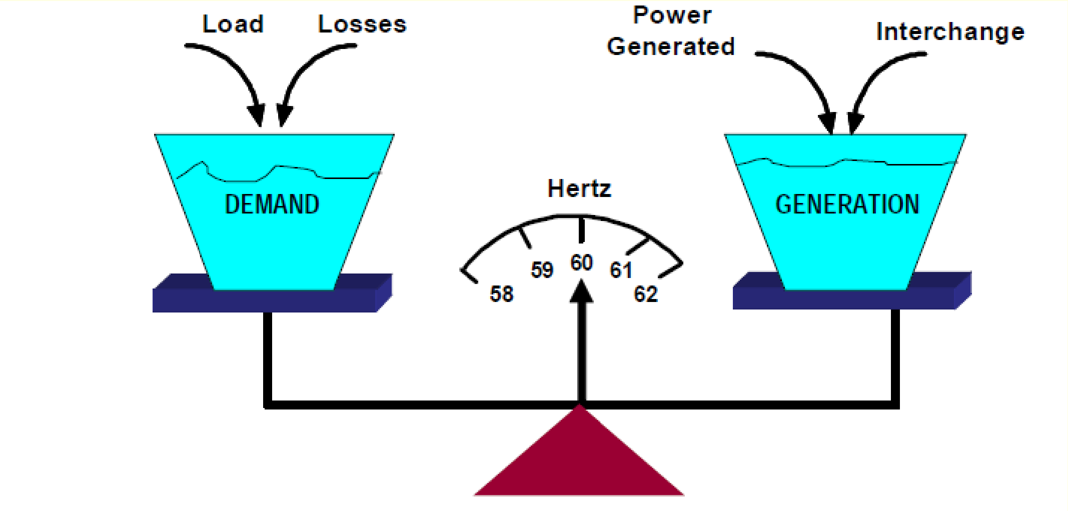
Important Studies:

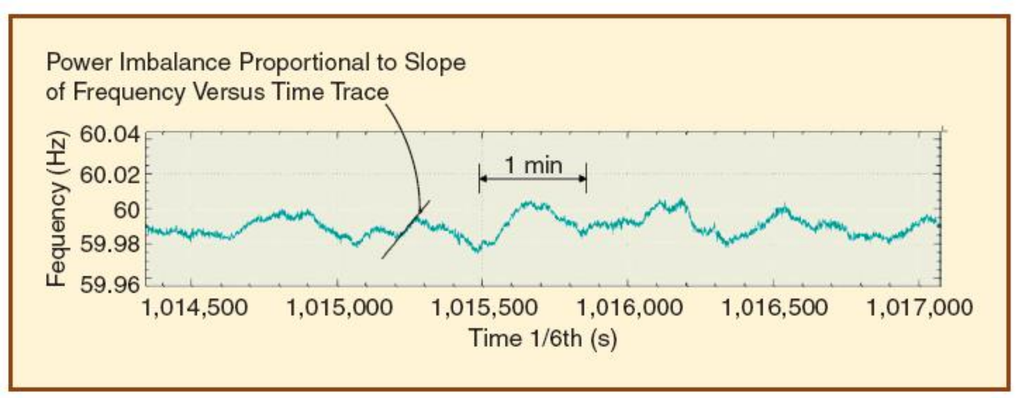
- Economic generation scheduling and unit commitment
- Power flow analysis
- Short-circuit analysis
- System stability and dynamic analysis
- Load forecasting
- System planning
- Etc …

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.

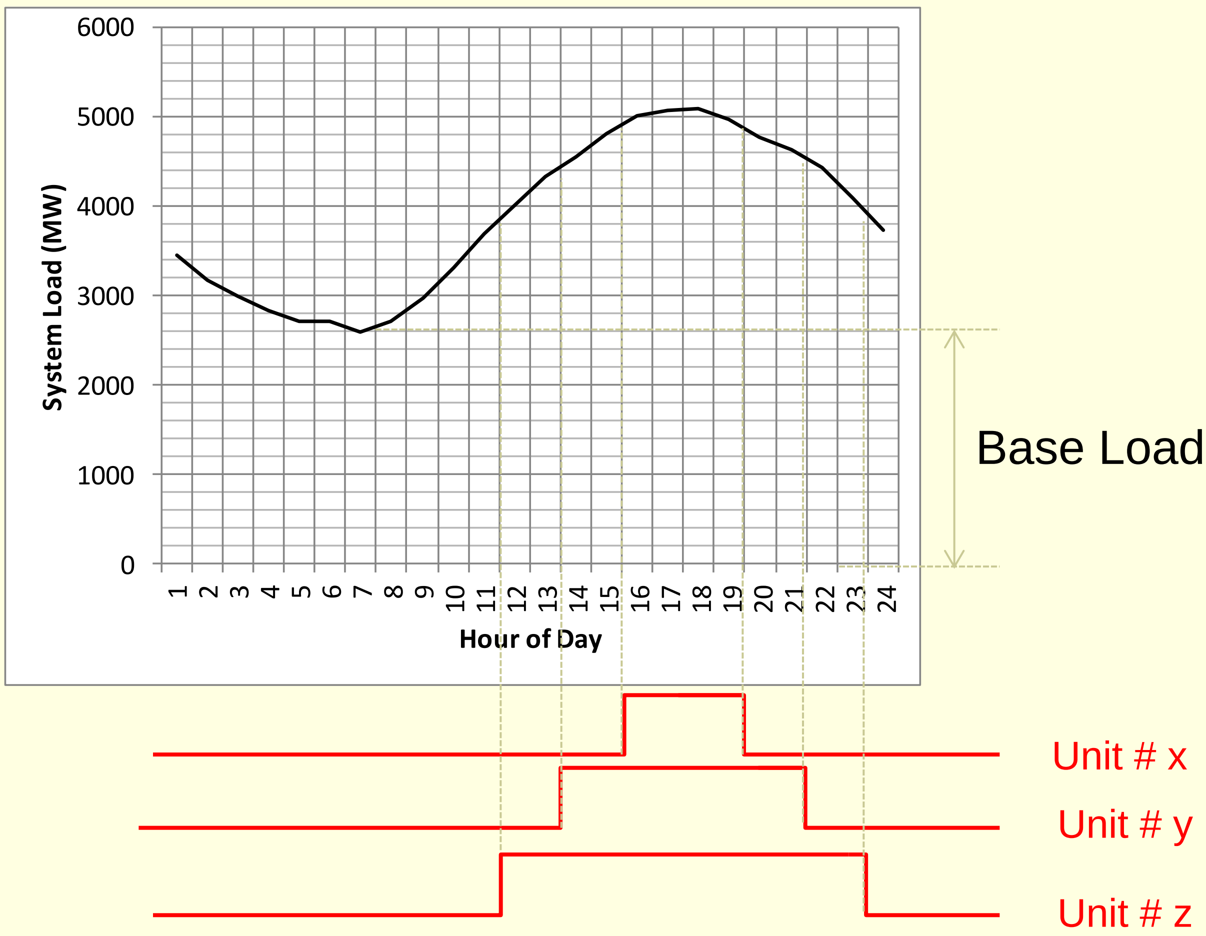
- Frequency is maintained as long as there is a balance between resources and customer demand (plus losses). An imbalance causes a frequency deviation.





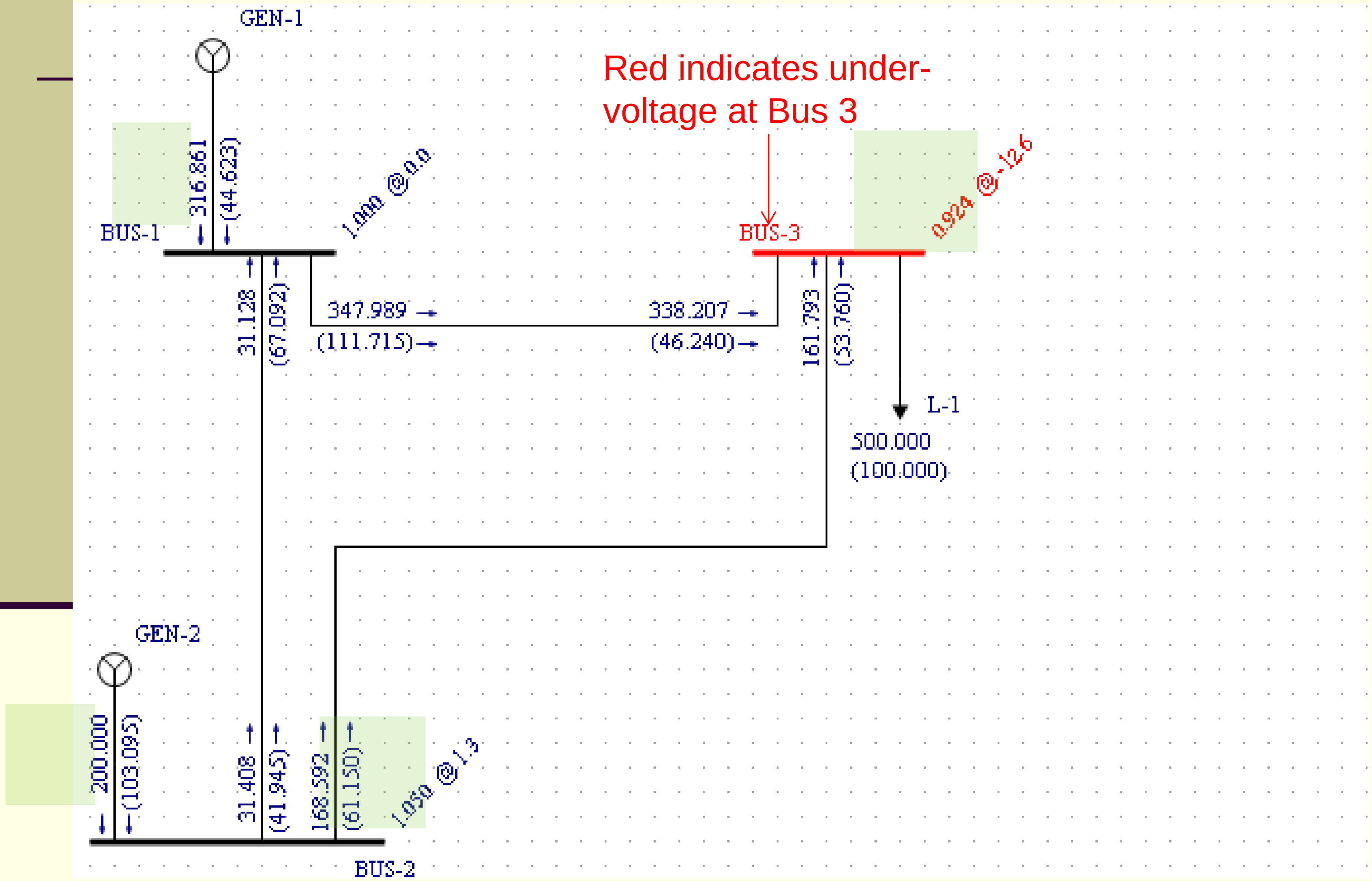
Generator Scheduling (economic Dispatch)

- 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

Red indicates under-voltage at Bus 3



END!