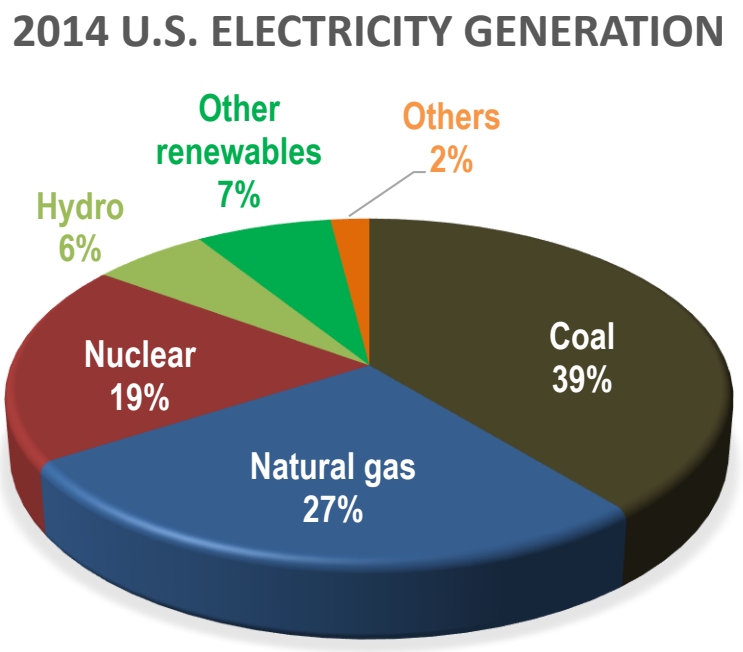
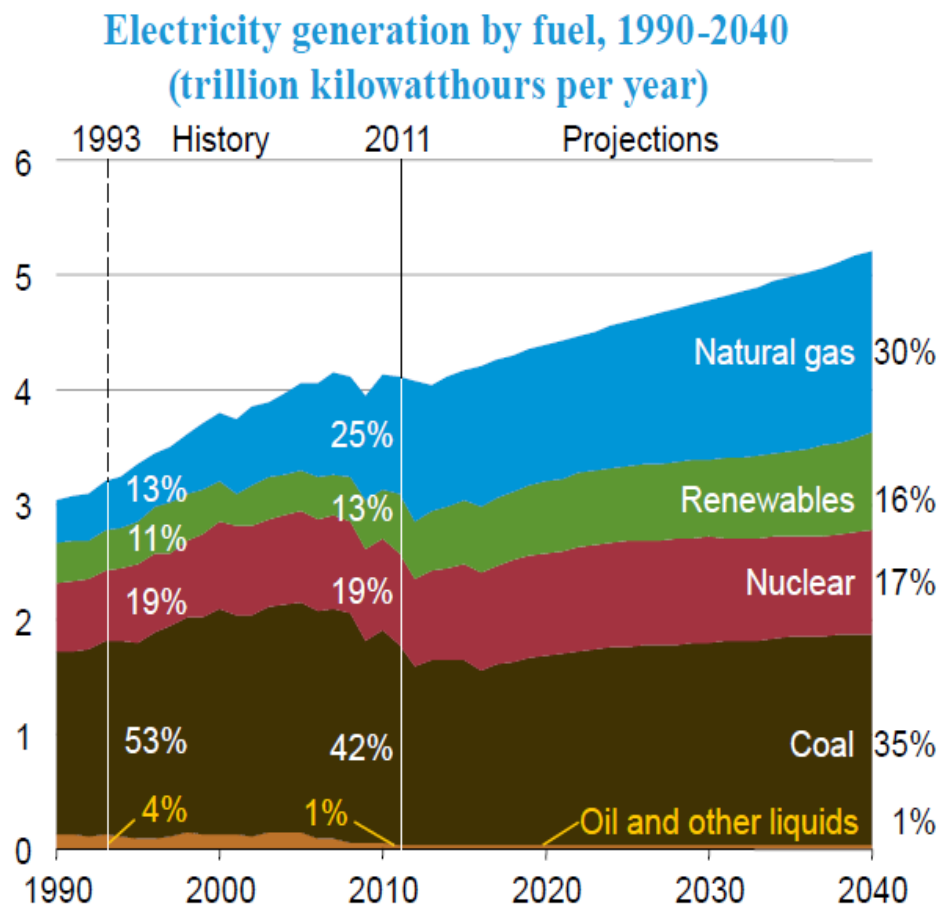
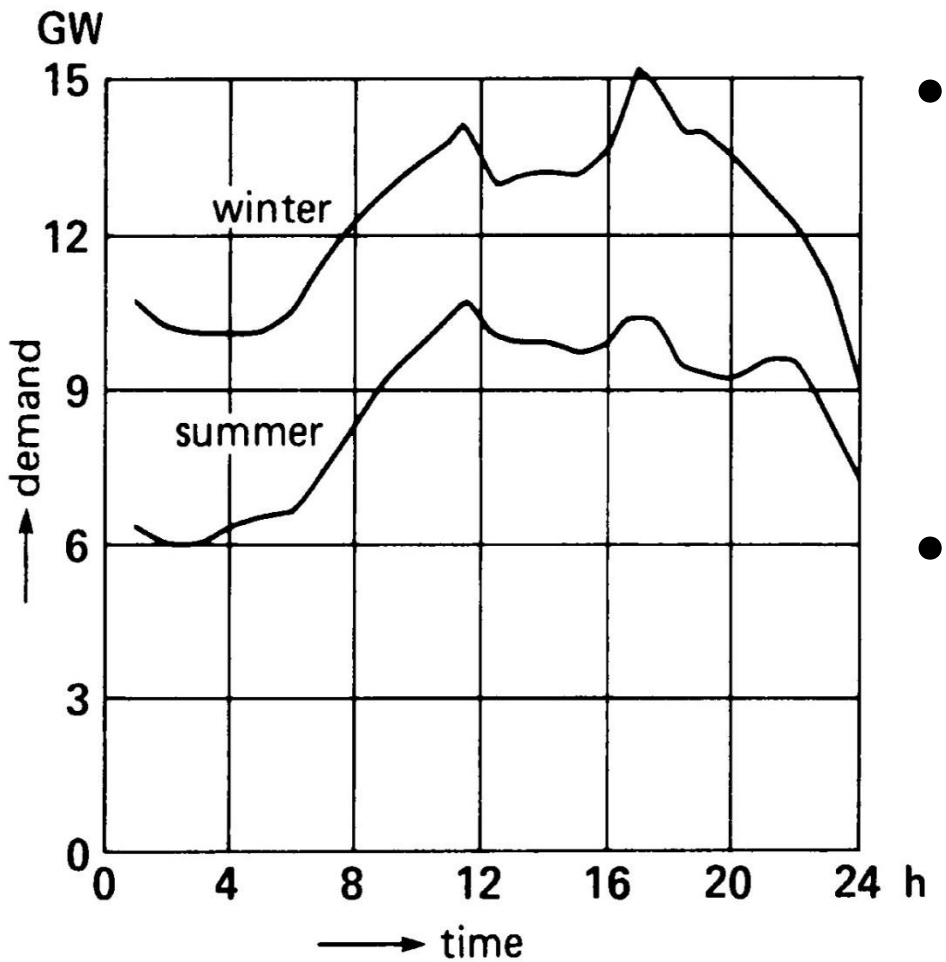
US Energy Resources for Electricity Generation





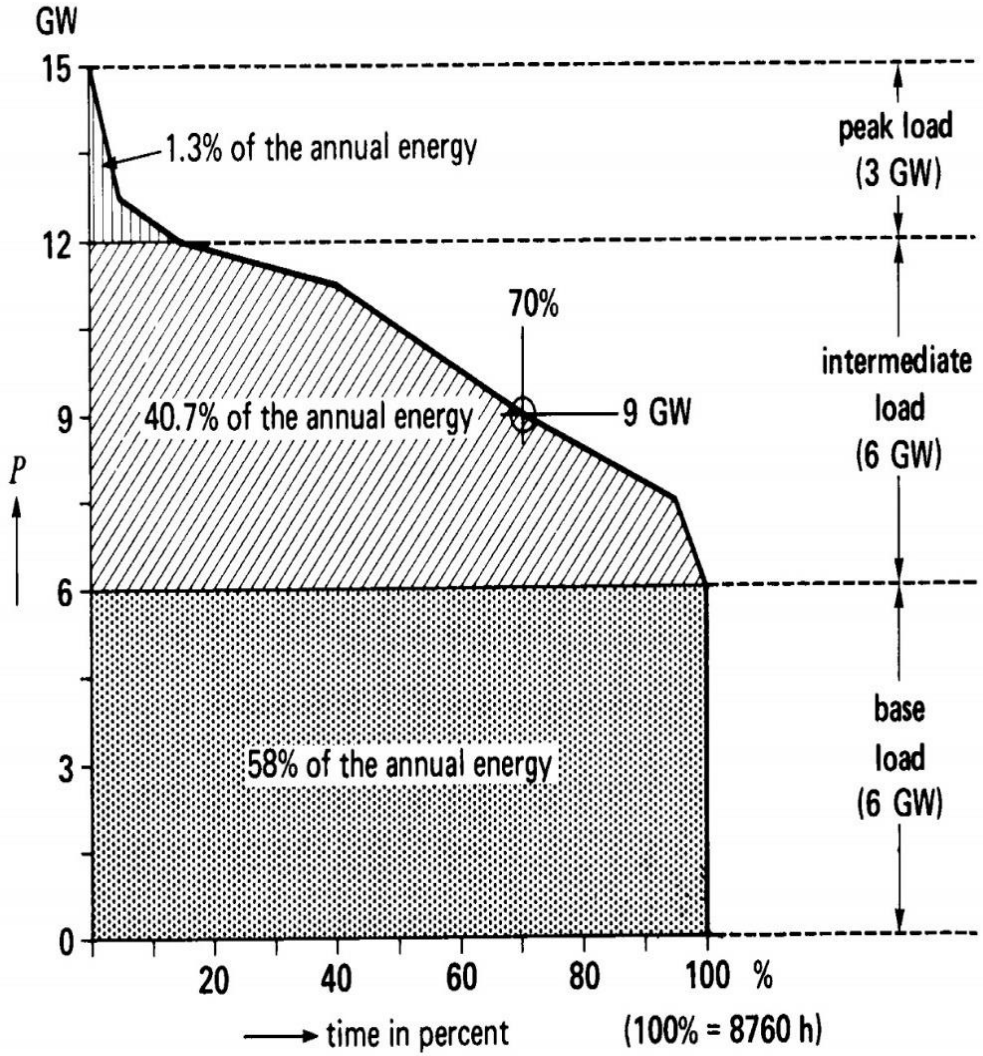
From www.wikipedia.org and www.eia.gov

Demand of an Electric Power System



- System load level:
  - Base (min.) load: 6GW.
  - Peak (max.) load: 15GW.
  - Intermediate loads: in between
- Observations:
  - Daily demands of two seasons have similar patterns. Why?
  - Geographic location?

Load Duration Curve



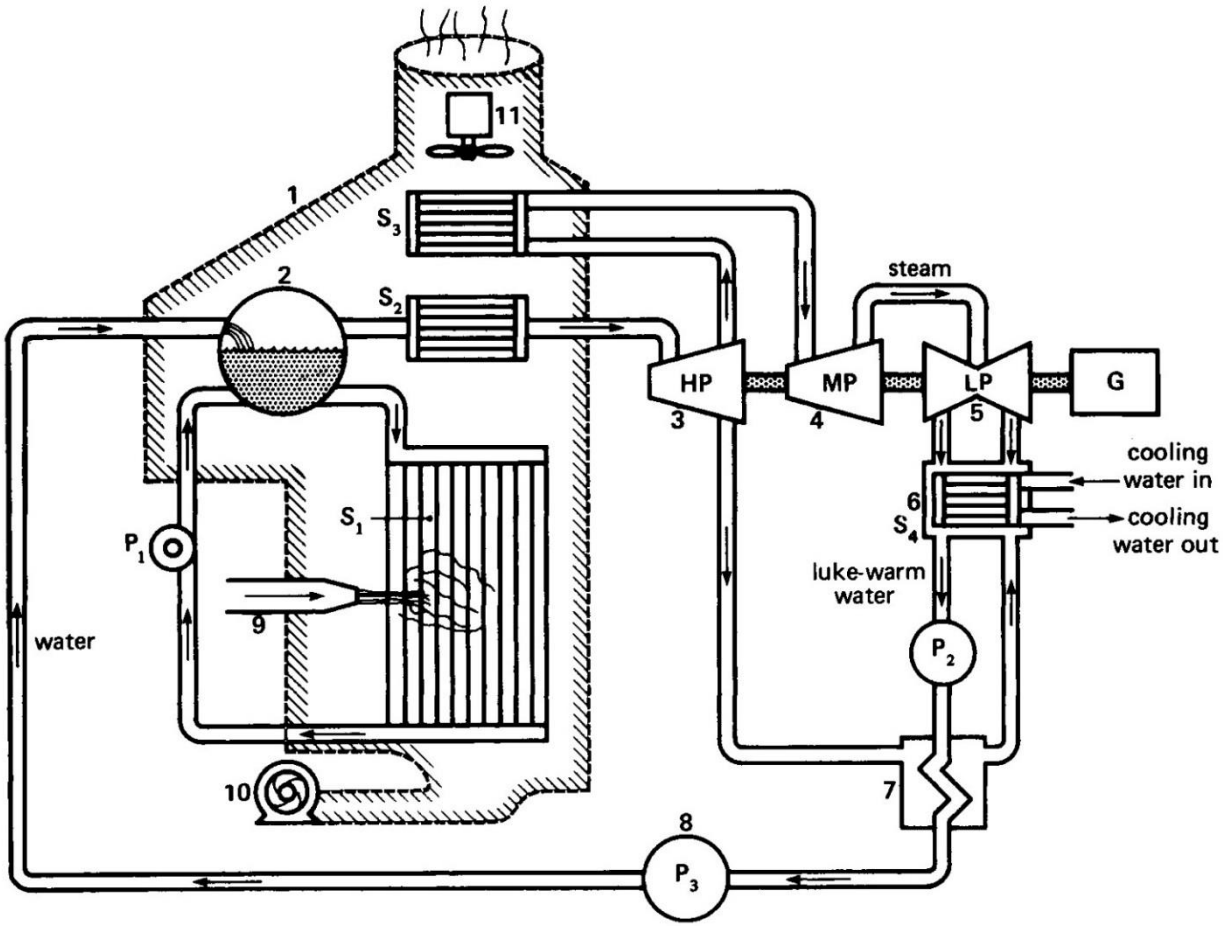
- Peak-generation plants:
  - Gas turbine plants & pumped-storage hydropower plants
- Intermediate-power plants:
  - Quickly responding to changes in demand
  - Hydropower & some fossil plants
- Base-power plants:
  - 100% power output at all times
  - Nuclear & coal-fired power plants

Power Generations

Principal Components of a Thermal Power Plant

- Generation of electricity by releasing of heat energy

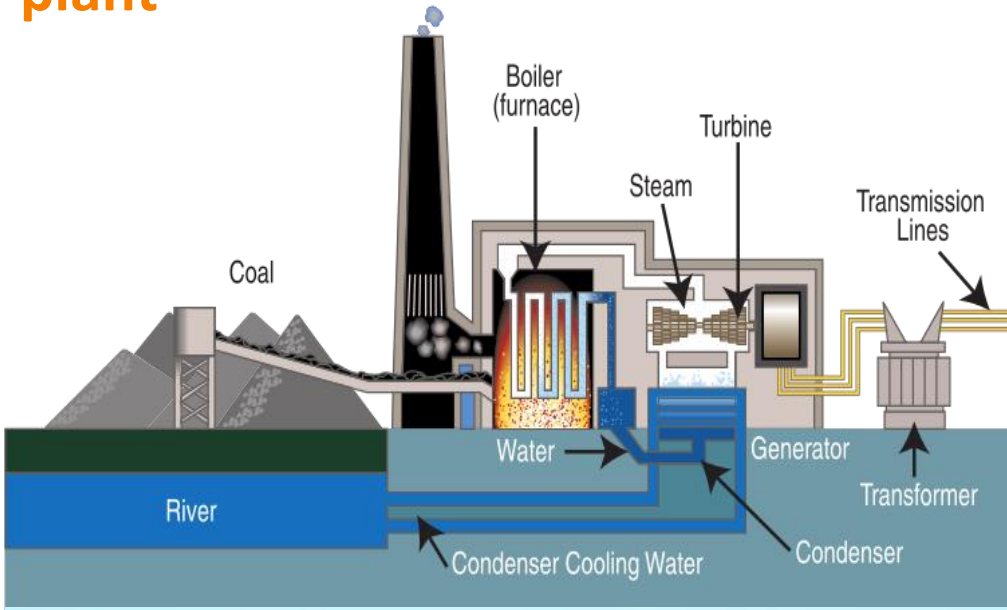
$$\eta_{overall}=(1-T_{out}/T_{in})\times \eta_{others} \sim (1-293K/823K)\times 70\% = 0.644\times 70\% = 45\%$$



G – Generator
1 – Boiler
2 – Drum
3 – High Pressure turbine
4 – Medium-Pressure turbine
5 – Low-Pressure turbine
6 – Condenser
7 – Reheater
8 – Feedwater pump
9 – Burners (coal, gas, nuclear, …)
10 – Forced-draft fan
11 – Induced fan
P – Pump
S – Water tubes

Coal-fired steam turbine power plant

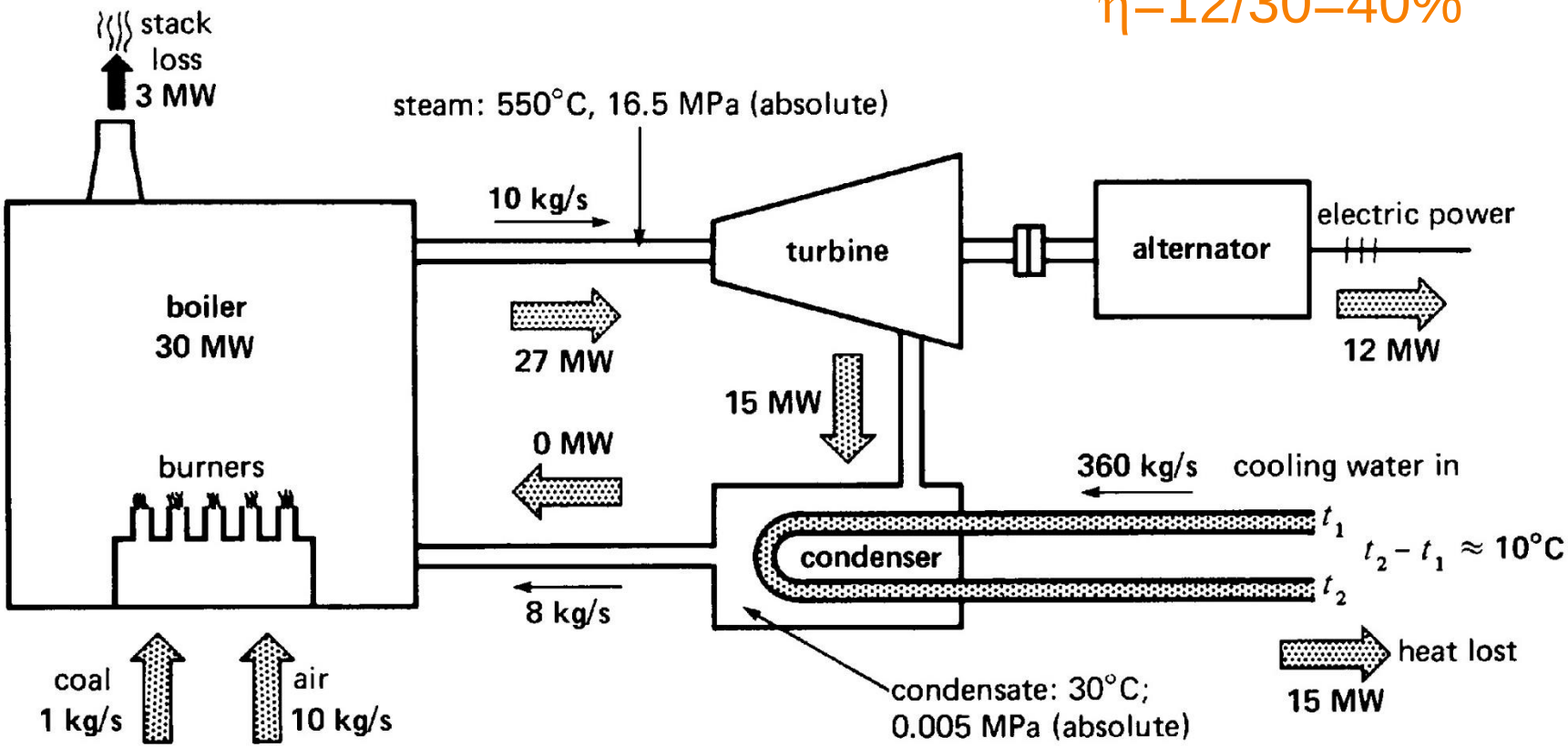
- Generation of electricity
  1. Boiler burns pulverized coal to produce high P&T steam
  2. Turbines (HP-MP-LP) convert heat of flowing steam to mechanical energy spinning a generator
  3. Generator converts mechanical energy to electric energy
- Concerns:
  - Low efficiency: $\eta<45\%$
  - Takes several hours to start up
  - Environmental concerns (major emitters of CO_2)



A coal plant in Rochester, Minnesota (source: wikipedia.org)

Efficiency of a Coal-fired Power Plant

η=12/30=40%



Gas turbine power plant

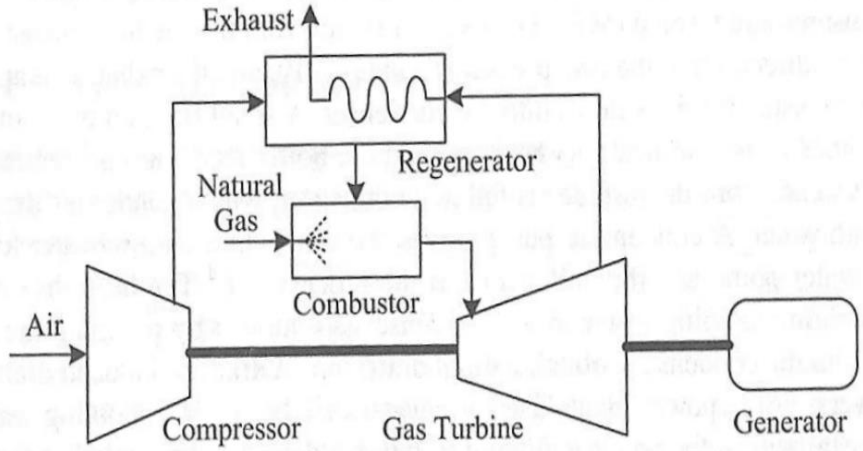


FIGURE 1.3
Schematic diagram of a simple gas turbine power plant.

- Also called combustion turbine and operates like a jet engine
- $\eta \rightarrow 46\%$
- Start quickly in minutes (used for peak load)
- Usually used in a combined-cycle or co-generation power plant to utilize the heat left with exhaust.

Combined-cycle power plant

- Higher overall efficiency (η>60%)

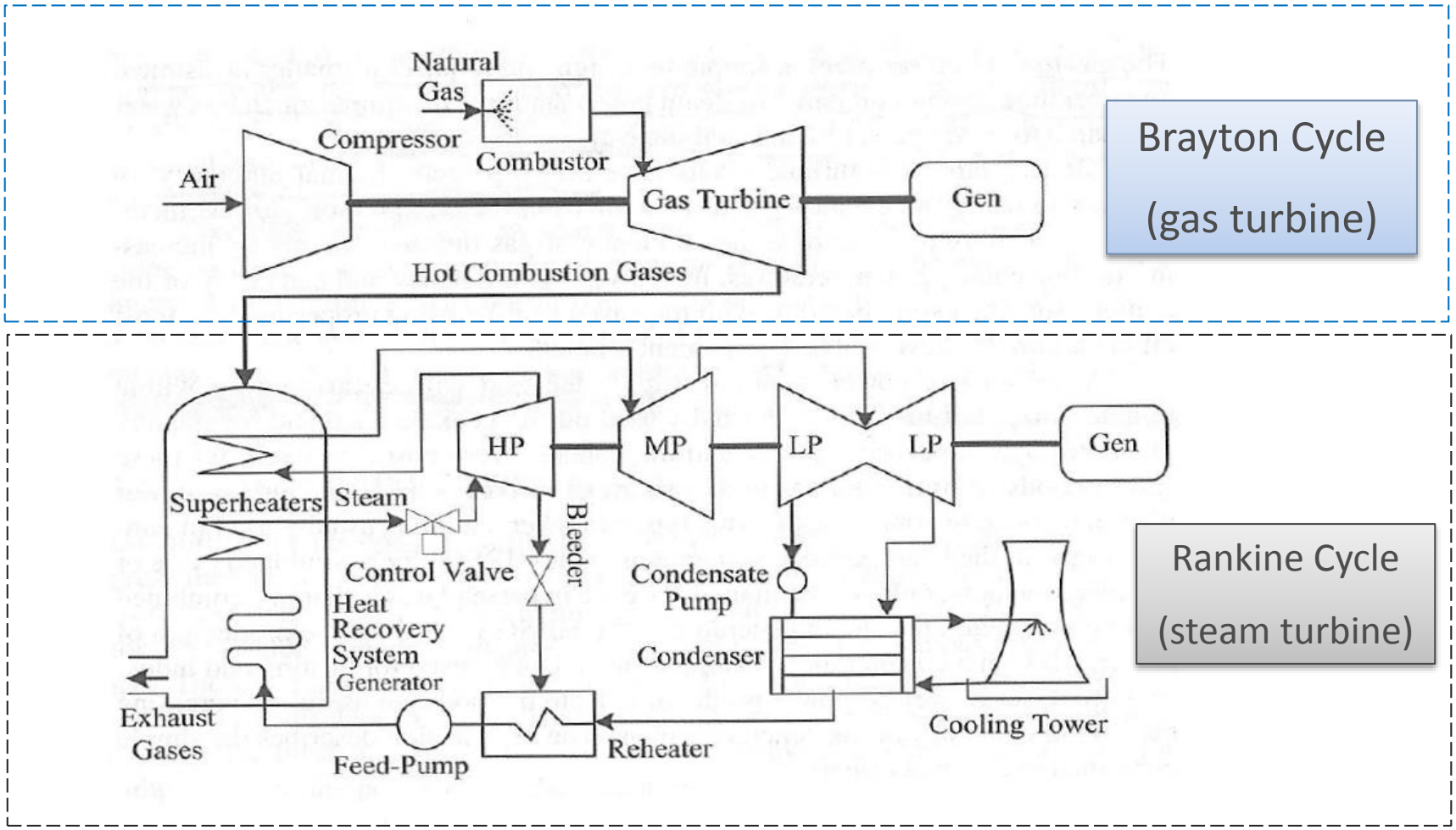


FIGURE 1.4
Schematic of a combined-cycle power plant.

Nuclear Power Plant

- Steam power plant except that the boiler is replaced by a nuclear reactor, e.g. BWR (boiling-water reactor) and PWR (pressurized-water reactor)
- $\eta \approx 30\%$
- Take days to start up once shut down

(Source: Wikipedia.org)

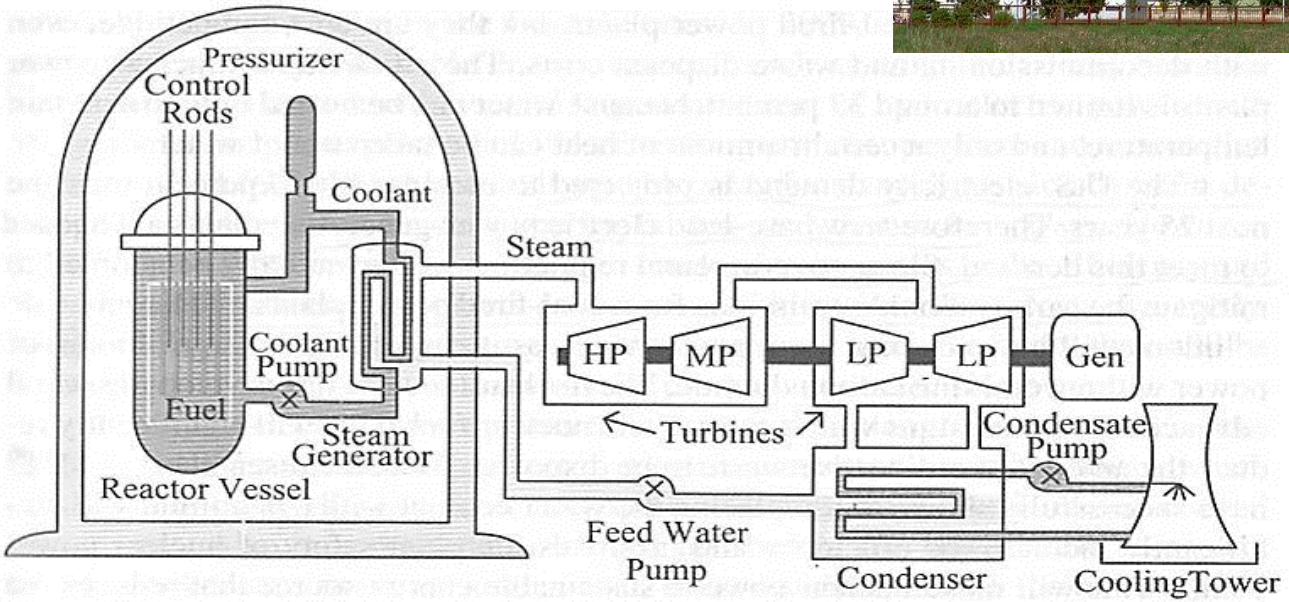


FIGURE 1.5
Schematic diagram of a pressurized water reactor.

Hydropower Plant

- *Generated electric power:*

$$P_W = E_P / t = V \rho g h / t = q \rho g h$$

$$P_o = \eta P_W = \eta q \rho g h = 9.81 q h \eta \quad \text{(kW)}$$

η - overall efficiency (~90%)

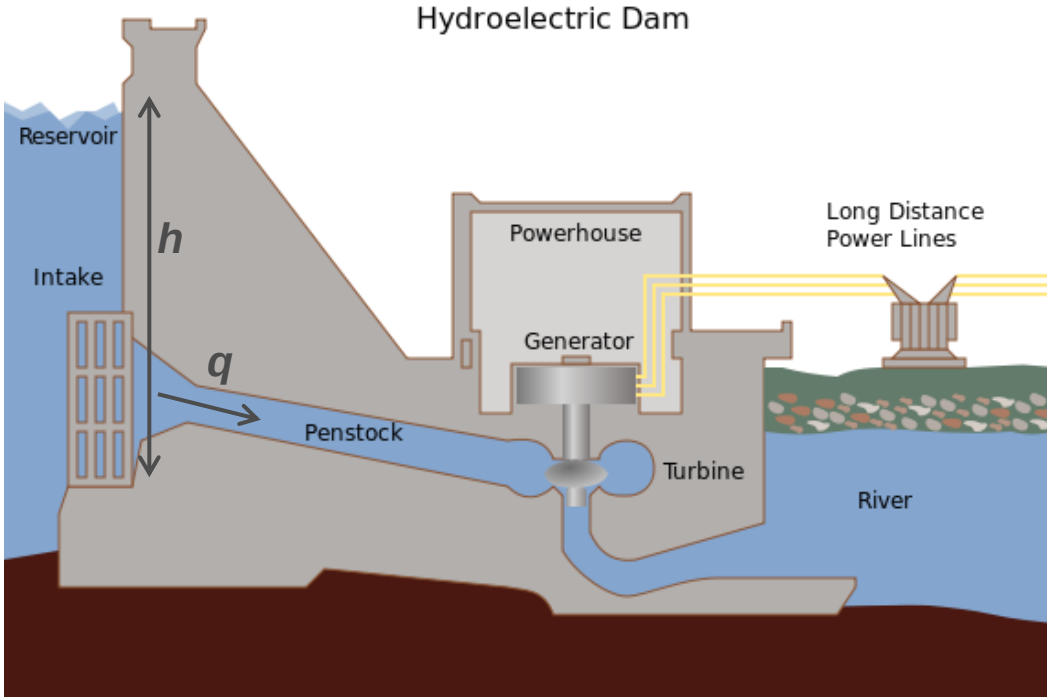
h – effective head of water (m)

q – rate of flow (m^3/s)

ρ - density of water ≈1000kg/m^3

g ≈9.81m/s^2

Norris Dam: 1st major TVA project built in the mid-1930s



(source: wikipedia.org)

Types of Hydropower Plants

- Run-of-the-river plants
  - Use the nature flow of rivers
  - Cheap; very little environmental impact
  - Power outputs may have seasonal fluctuations
- Pumped-storage plants
  - Typically have two reservoirs at two elevations
  - Energy storage function: during off-peak times, the generator can operate as a synchronous motor (pump) to save surplus electricity by elevating water
  - Fast: a few minutes from startup to full power


Pumped storage Plant in Rönkhausen, Germany

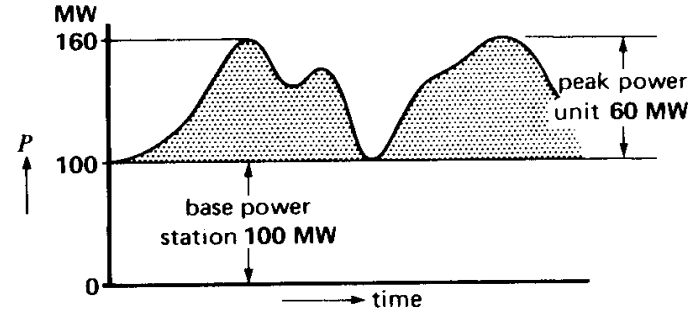


Figure 24.14
A 100 MW base power station and a 60 MW peak power station can supply the network demand.

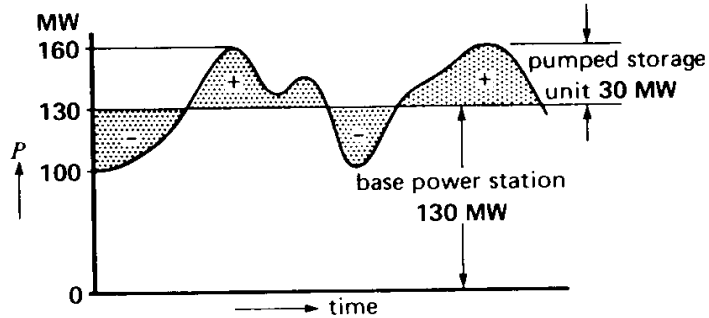
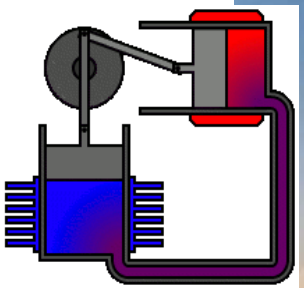


Figure 24.15
A 130 MW base power station and a 30 MW pumped storage unit can also supply the network demand.

Solar Power

- Photovoltaic (PV)
  - Photoelectric effect: Light->electricity (η ~ 15%)
- Concentrated solar power (CSP)
  - Light->heat->electricity
    - Parabolic dish concentrators (Dish Stirling, η ~30%)
    - Parabolic Troughs,
    - Solar Tower

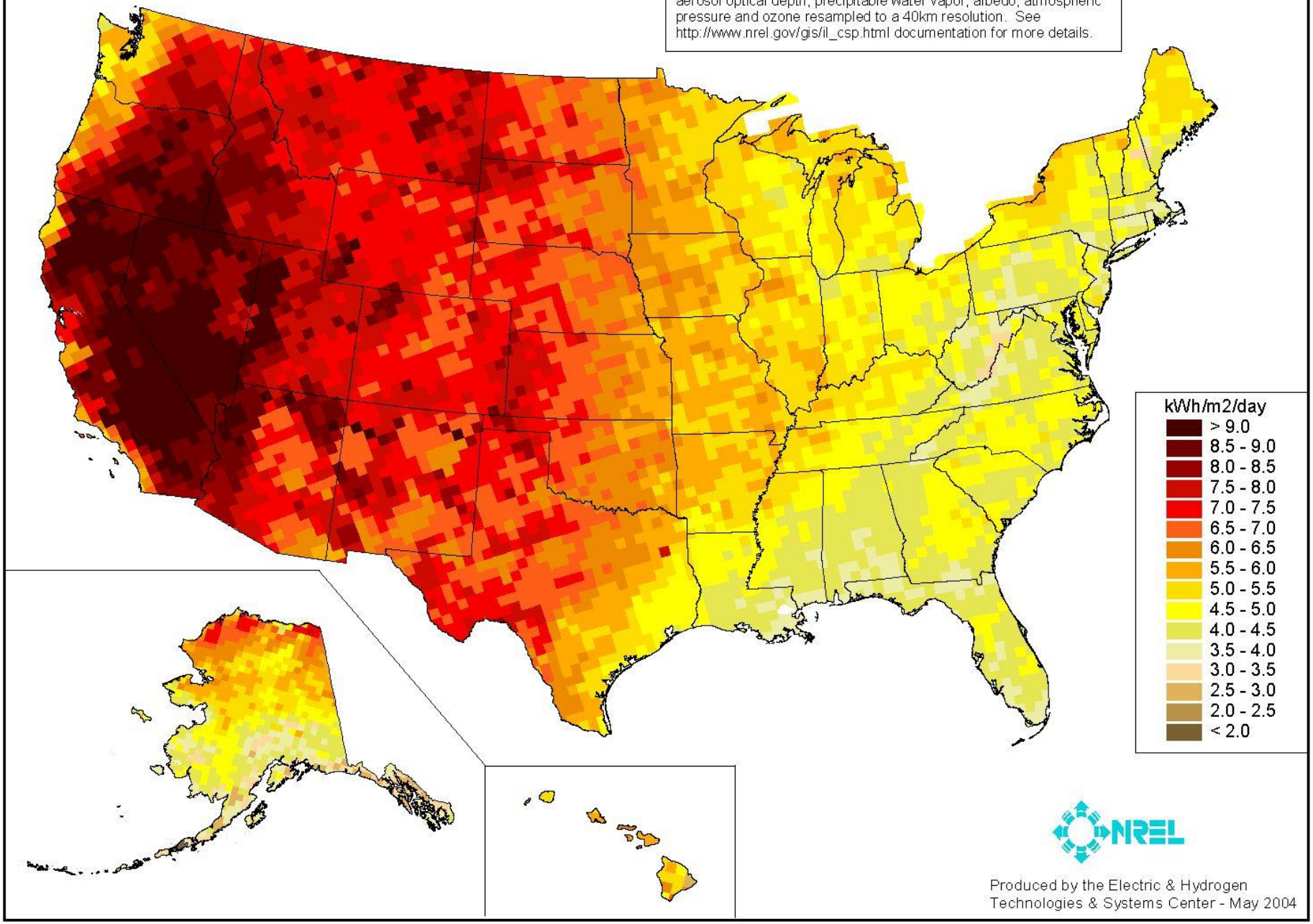


Stirling Engine

Direct Normal Solar Radiation (Two-Axis Tracking Concentrator)

July

Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_csp.html documentation for more details.



Produced by the Electric & Hydrogen Technologies & Systems Center - May 2004

Wind Power Plants

- Generated electric power:

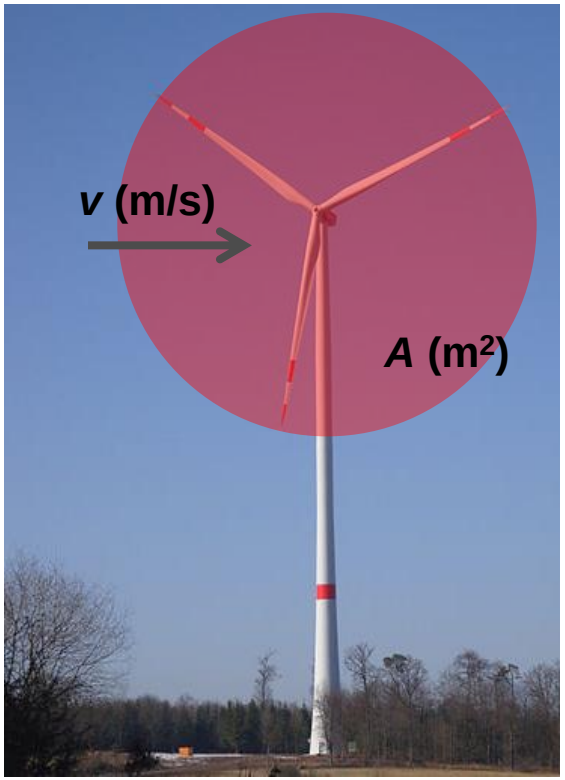
$$P_W = \frac{E_K}{t} = \frac{mv^2}{2t} = \frac{A\rho vt \cdot v^2}{2t} = \frac{A\rho v^3}{2} = \frac{\pi D^2 \rho v^3}{8} \text{(W)}$$

Wind power per m²: $\frac{P_W}{A} = \frac{\rho v^3}{2} \approx 0.6v^3 (\text{W/m}^2)$

$$P_O = \eta C_P P_W = \eta C_P \frac{\pi D^2 \rho v^3}{8} \quad \text{(W)}$$

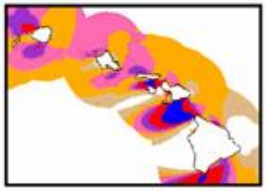
C_P – power coefficient ≈0.4< 16/27 or 0.59 (Betz Limit)

ρ – air density ≈1.2kg/m³ at 70°F

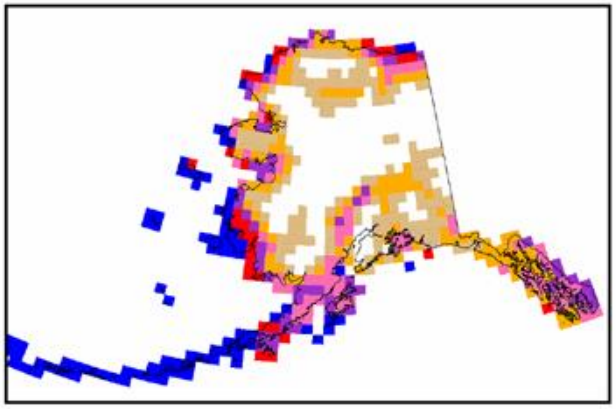


Wind Resources and Transmission Lines

NREL Updated Maps:
Arizona (2003)
California (2002)
Colorado (2004)
Connecticut (2001)
Delaware (2002)
Hawaii (2004)
Idaho (2002)
Illinois (2001)
Indiana (2004)
Maine (2001)
Maryland (2002)
Massachusetts (2001)
Michigan (2004)
Missouri (2005)
Montana (2002)
Nebraska (2005)
Nevada (2003)
New Jersey (2002)
New Hampshire (2001)
New Mexico (2003)
North Carolina (2002)
North Dakota (2000)
Ohio (2004)
Oregon (2002)
Pennsylvania (2002)
Rhode Island (2001)
South Dakota (2001)
Texas mesas (2000)
Utah (2003)
Vermont (2001)
Virginia (2002)
Washington (2002)
West Virginia (2002)
Wyoming (2002)



The remaining states use data from the 1987 "Wind Energy Atlas of the United States".



Transmission Lines
Voltage (kV)
345 - 499
500 - 699
700 - 799
1000 (DC)

Source: POWERmap, powermap.platts.com, ©2007 Platts, a division of the McGraw-Hill Companies

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

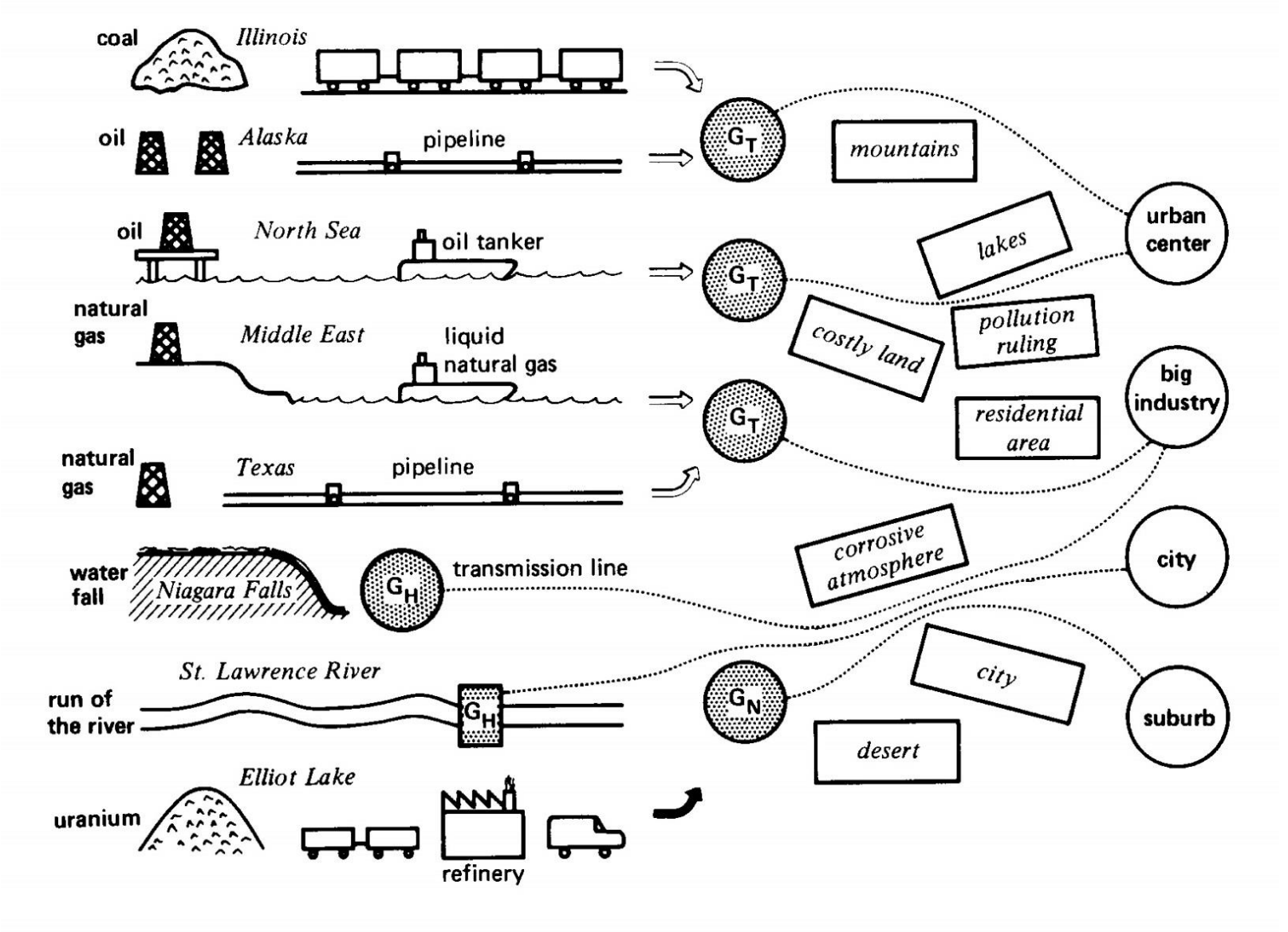
U.S. Department of Energy
National Renewable Energy Laboratory

19-APR-2007 1.5.9

Question

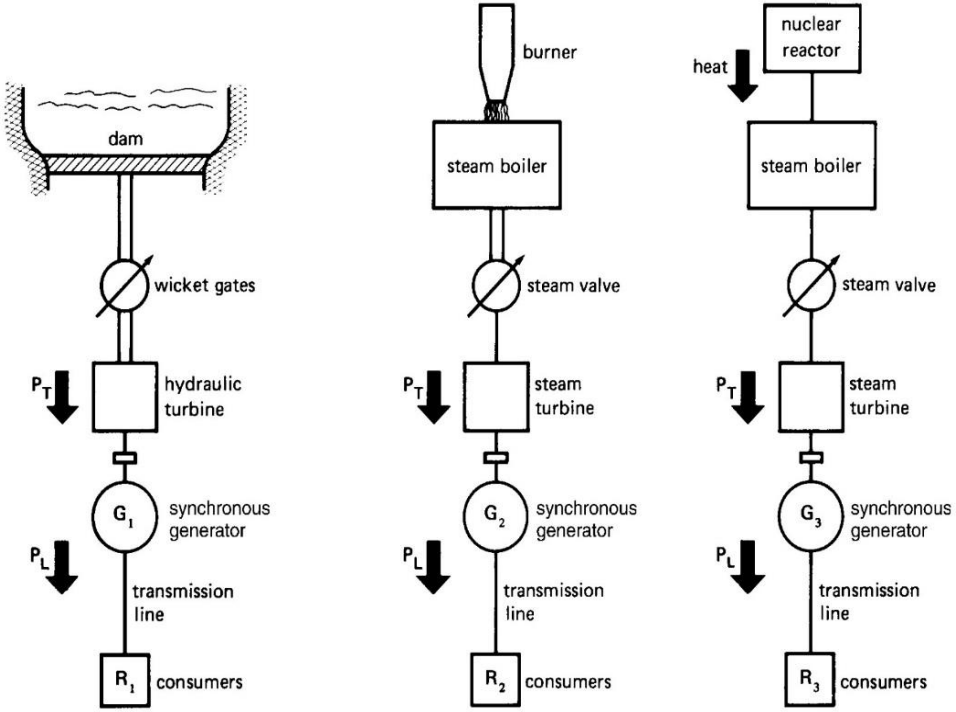
- Which of these generation resources utilize steam turbines in generating electric power?
  - Coal-fired power plant
  - Combined-cycle power plant
  - Pressurized water nuclear reactor
  - Offshore wind farm
  - Solar Tower
  - Parabolic trough solar farm

Power Generation and Delivery



Why Interconnect?

1. Stability
2. Continuity of service
3. Economy



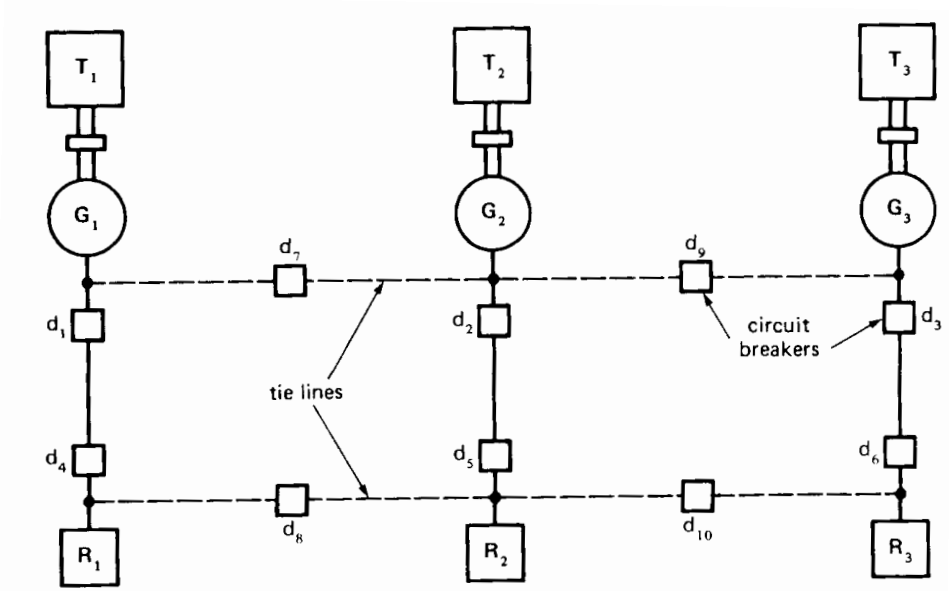
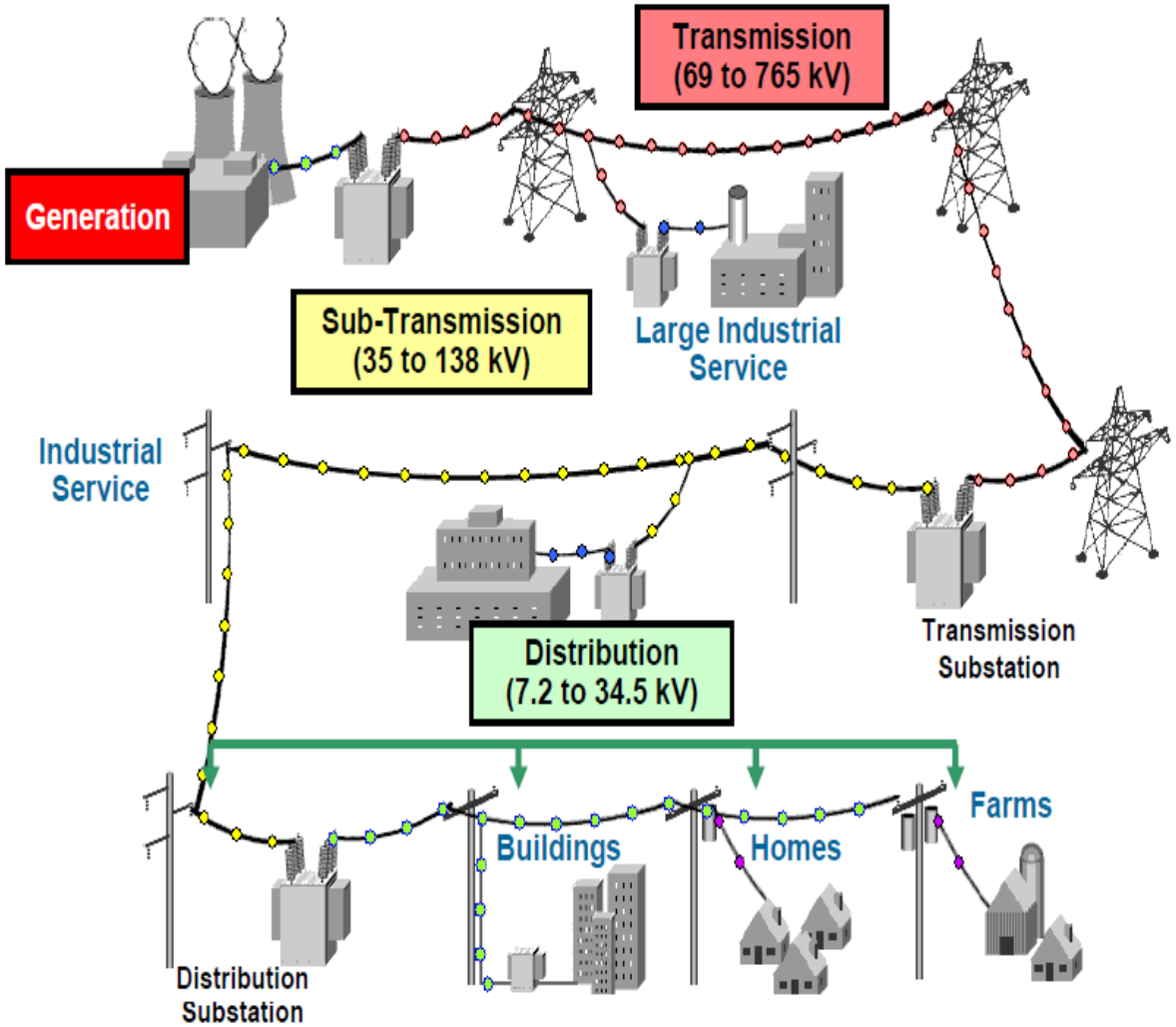


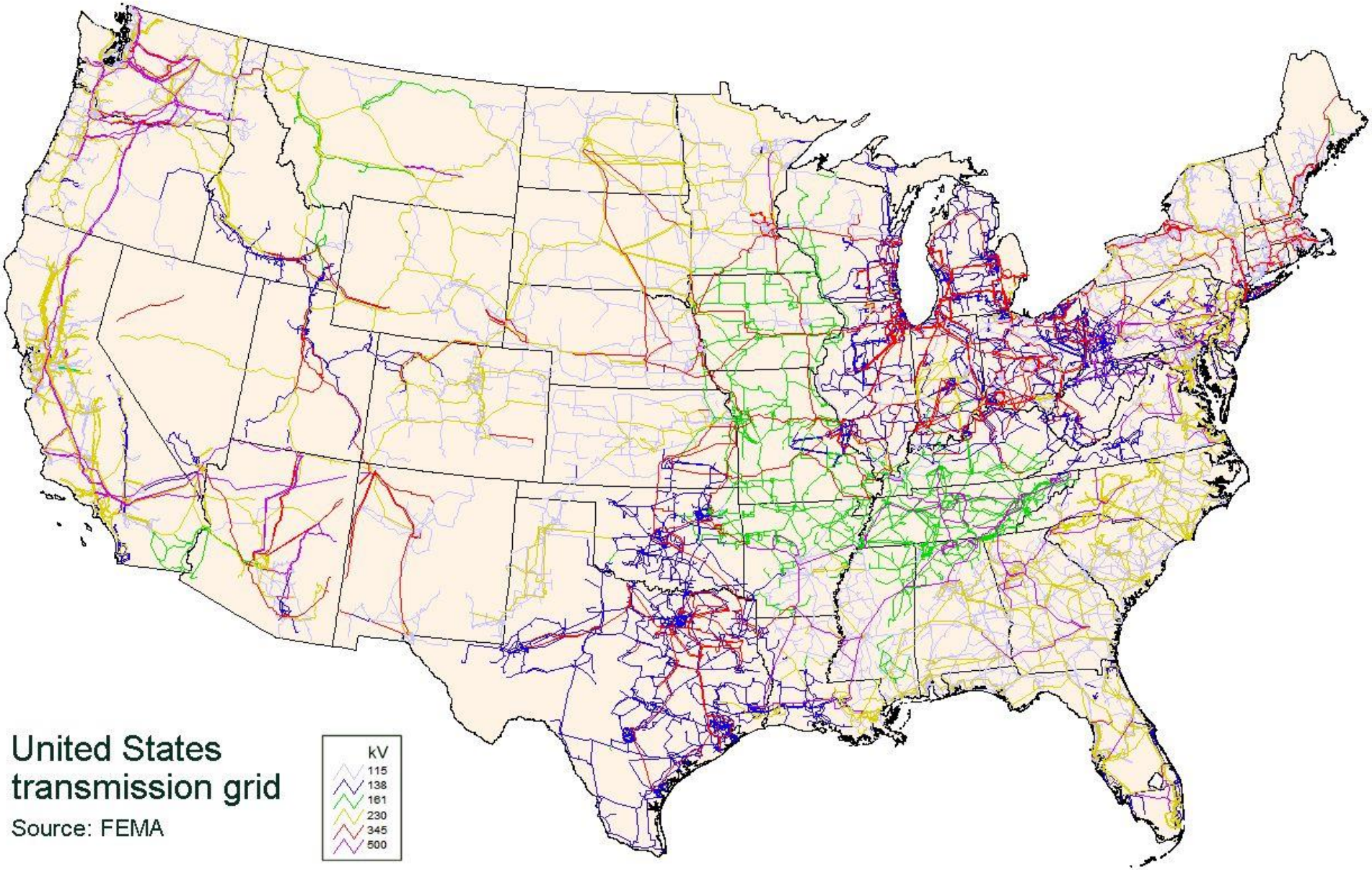
Figure 24.6
Three networks connected by four tie lines.

Structure of an AC Power System

- Generation
  - Low voltages <25kV due to insulation requirements
- Transmission system
  - Backbone system interconnecting major power plants (11~35kV) and load center areas
  - 161kV, 230kV, 345kV, 500kV, 765kV, etc.
- Sub-transmission system
  - Transmitting power to distribution systems
  - Typically, 35/69kV-138kV
- Distribution system
  - Typically, 4kV-34.5kV



Source: Green Transmission Efficiency Initiative: A Series of Workshops. EPRI PID 1019531, 2009.



United States transmission grid

Source: FEMA

US Electric Industry Structure

- 3,195 utilities in the US in 1996. Fewer than 1000 engaged in power generation

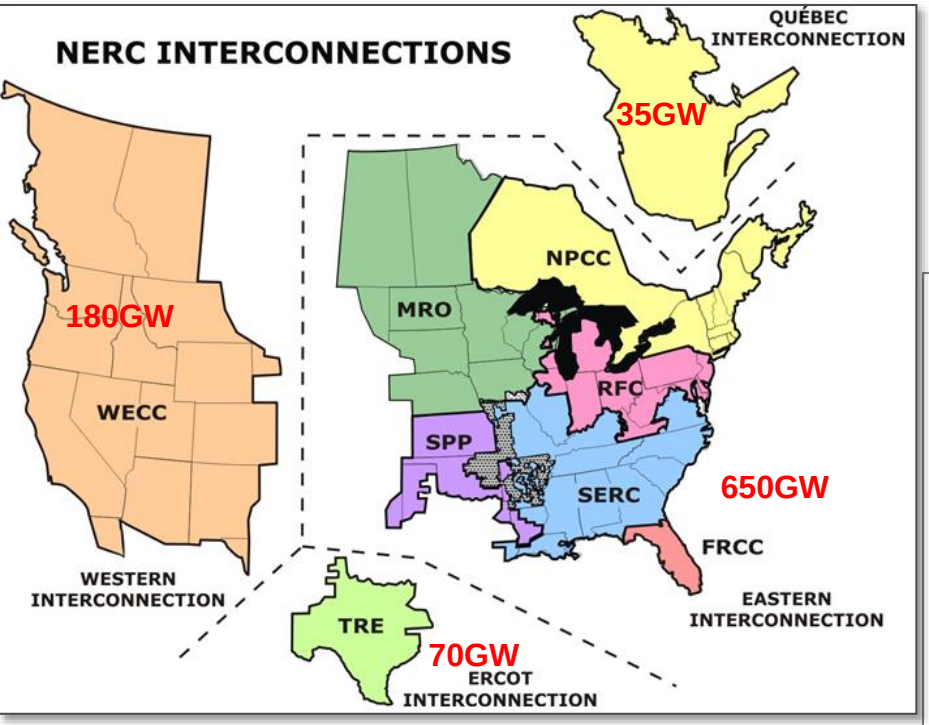
Categories	Examples
Investor-owned utilities 240+, 66.1% of electricity	AEP, American Transmission Co., ConEd, Dominion Power, Duke Energy, Entergy, Exelon, First Energy, HECO, MidAmerican, National Grid, Northeast Utilities, Oklahoma Gas & Electric, Oncor, Pacific Gas & Electric, SCE, Tampa Electric Co., We Energies, Xcel,
Publicly owned utilities 2000+, 10.7%	Nonprofit state and local government agencies, including Municipals, Public Power Districts, and Irrigation Districts, e.g. NYPA, LIPA,
Federally owned utilities ~10, 8.2%	Tennessee Valley Authority (TVA), Bonneville Power Administration (BPA), Western Area Power Administration (WAPA), etc.
Cooperatively owned utilities ~1000, 3.1%	Owned by rural farmers and communities
Non-utilities, 11.9%	Generating power for own use and/or for sale in whole-sale power markets, e.g. Independent Power Providers (IPPs)

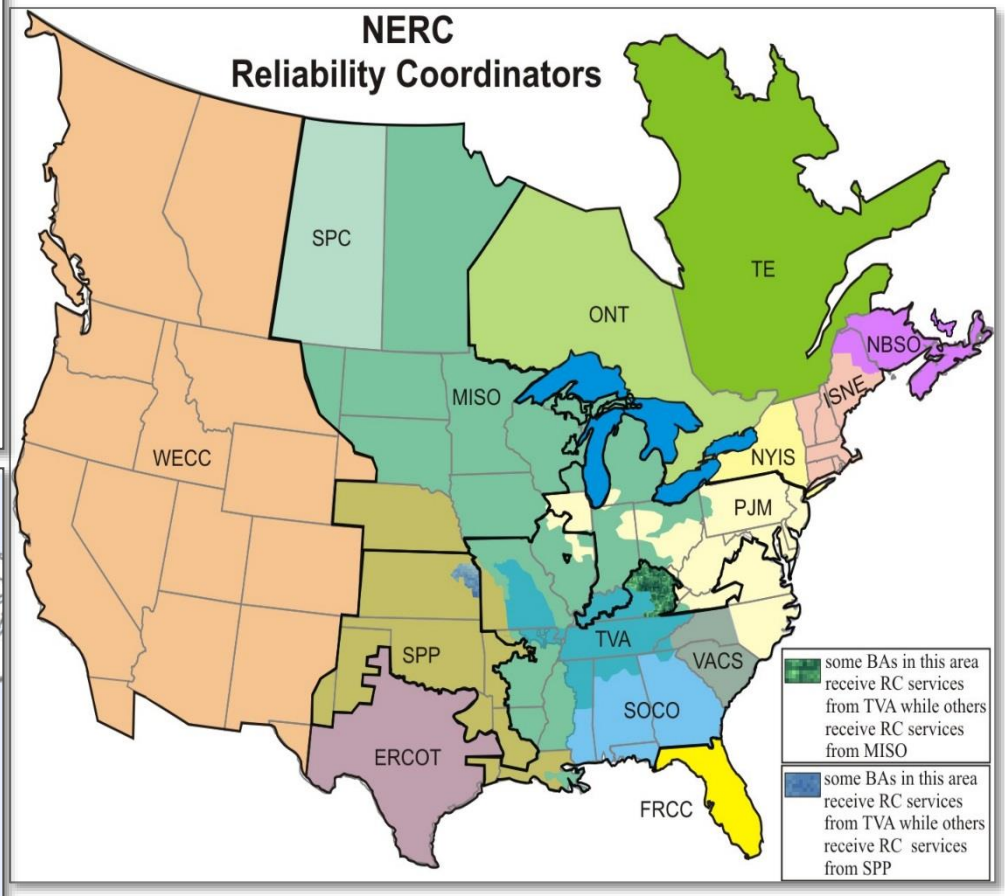
NERC (North American Electric Reliability Corporation)

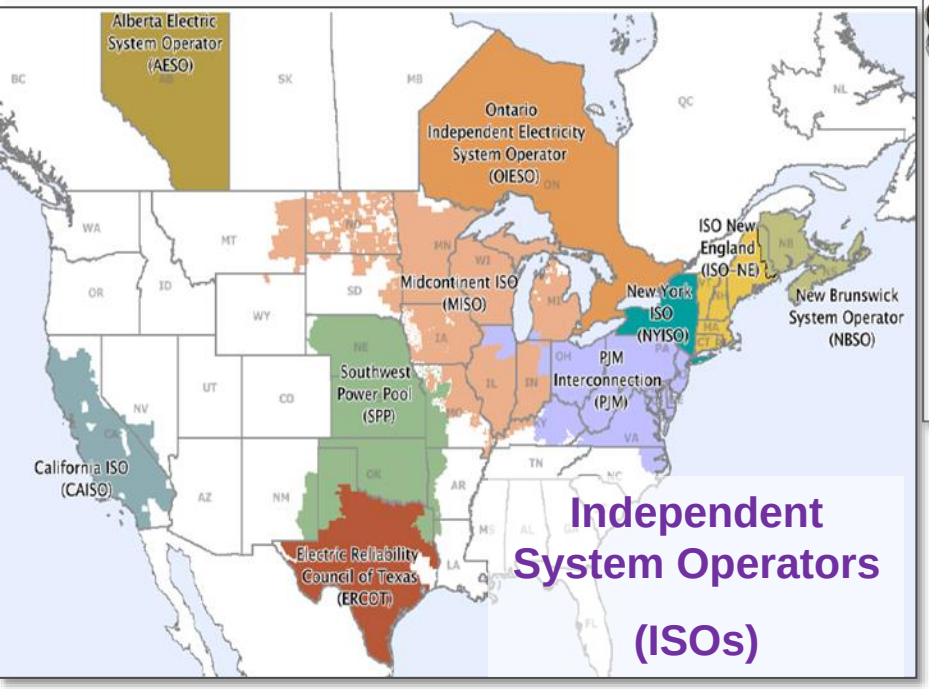
- As a non-government organization, formed by the electric utility industry in 1968 to promote the reliability of bulk power systems in North America.

- From 2007, FERC (U.S. Federal Energy Regulatory Commission) granted NERC the legal authority to enforce reliability criteria with all users, owners, and operators of bulk power systems in the U.S.

- NERC Membership is mandatory. Member companies comply with NERC's Reliability Standards (approved by FERC) to promote reliable operations and avoid costly monetary penalties if caught non-compliant (visit http://www.nerc.com for more information)


NERC INTERCONNECTIONS
QUÉBEC INTERCONNECTION
35GW
NPCC
MRO
180GW
WECC
RFC
SPP
SERC
650GW
FRCC
WESTERN INTERCONNECTION
EASTERN INTERCONNECTION
TRE
70GW
ERCOT INTERCONNECTION


NERC
Reliability Coordinators
SPC
TE
ONT
NBSO
ISNE
MISO
WECC
NYIS
PJM
TVA
VACS
SPP
SOCO
ERCOT
FRCC
some BAs in this area receive RC services from TVA while others receive RC services from MISO
some BAs in this area receive RC services from TVA while others receive RC services from SPP


Alberta Electric System Operator (AESO)
Ontario Independent Electricity System Operator (OIESO)
ISO New England (ISO-NE)
New Brunswick System Operator (NBSO)
Midcontinent ISO (MISO)
New York ISO (NYISO)
PJM Interconnection (PJM)
Southwest Power Pool (SPP)
California ISO (CAISO)
Electric Reliability Council of Texas (ERCOT)
Independent System Operators (ISOs)

System Control Centers

Duke Energy Control Center

(source: Patrick Schneider Photo.Com)

(Source: bayjournal.com)

TVA Control Center

(source: TVA.com

Hiring Companies

- Power utilities, e.g.
  - TVA, TVA distributors (e.g. KUB, LCUB, etc.), Duke Energy, Southern Company (Georgia Power, Alabama Power, Gulf Power and Mississippi Power), etc.
- Independent System Operators
  - PJM, SPP, ISO New England, NYISO, Midwest ISO, CAISO and ERCOT

Positions: planning/operation engineers

Hiring Companies (cont'd)

- Manufacturers and service providers
  - GE, ABB, Siemens, Alstom, Texas Instruments, etc.

Positions: R&D, engineers, consultants, etc.

Hiring Companies (cont'd)

- Government and Non-profit organizations
  - US DOE and National Laboratories (ORNL, PNNL, NREL, etc.)
  - NERC
  - EPRI (Electric Power Research Institute)

Positions: scientists, engineers, analysts, etc.

- Read Ch. 24 and Ch. 25.0-25.3
- Answer Questions 24-1 ~ 24-8 (submission is not needed)