Power Generations

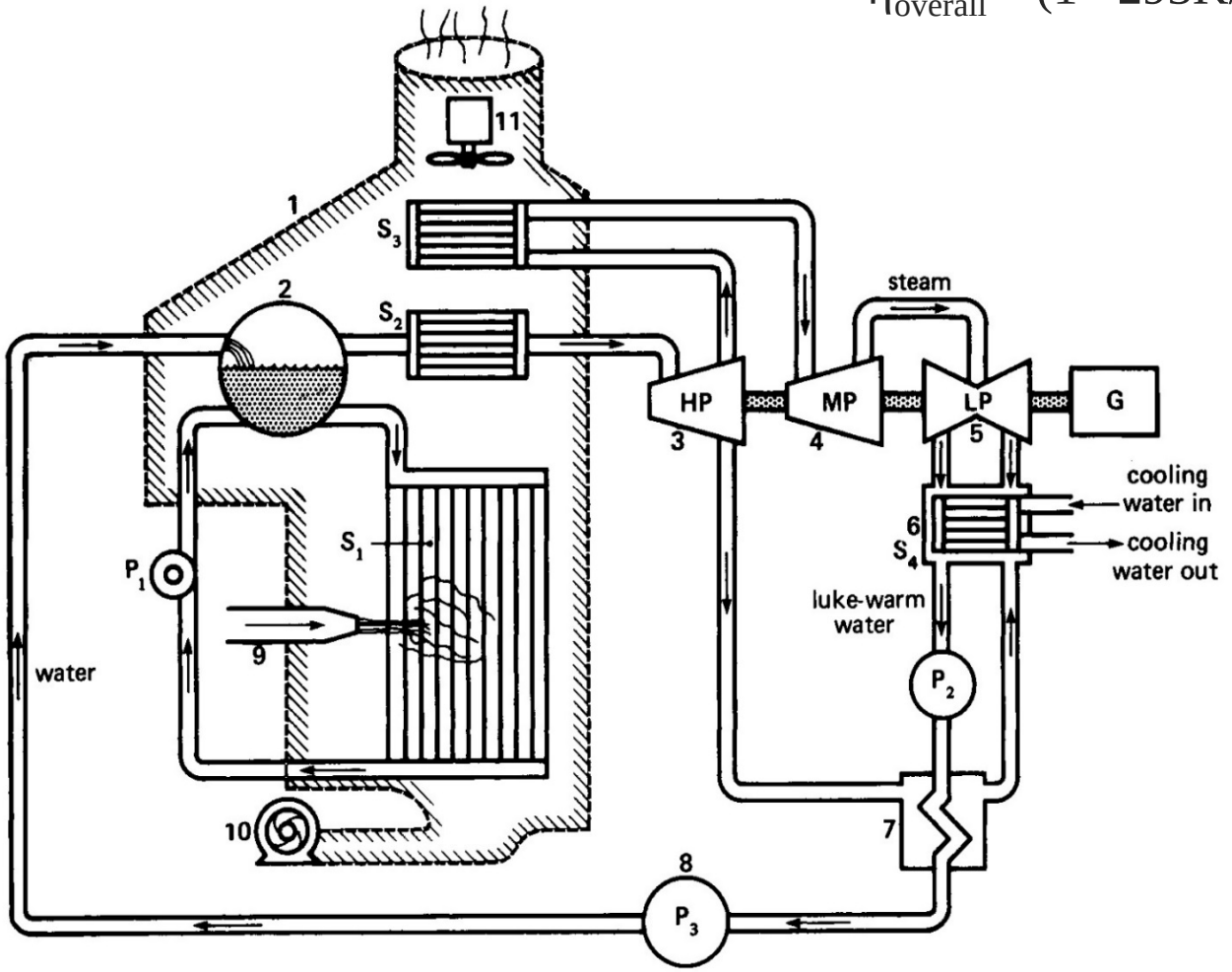
Principal Components of a Thermal Power Plant

- Generation of electricity from heat

$$\eta_{overall}=(1-T_{out}/T_{in})\times \eta_{others}$$

If $T_{out}=20^{o}C$, $T_{in}=550^{o}C$, $\eta_{others}=70\%$, then

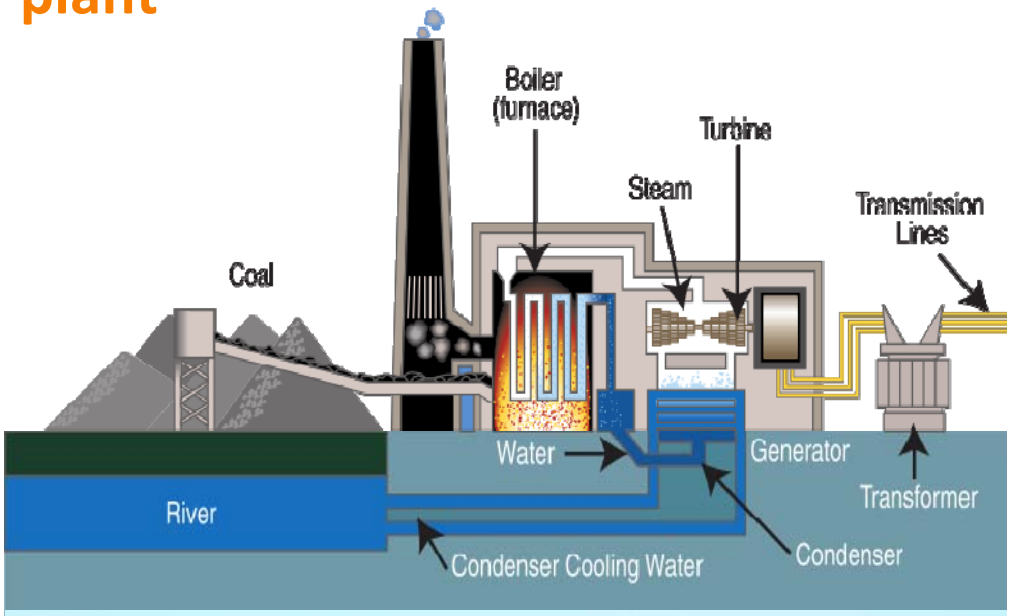
$\eta_{overall} = (1- 293K/823K)\times 70\% = 0.64\times 70\% = 45\%$



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

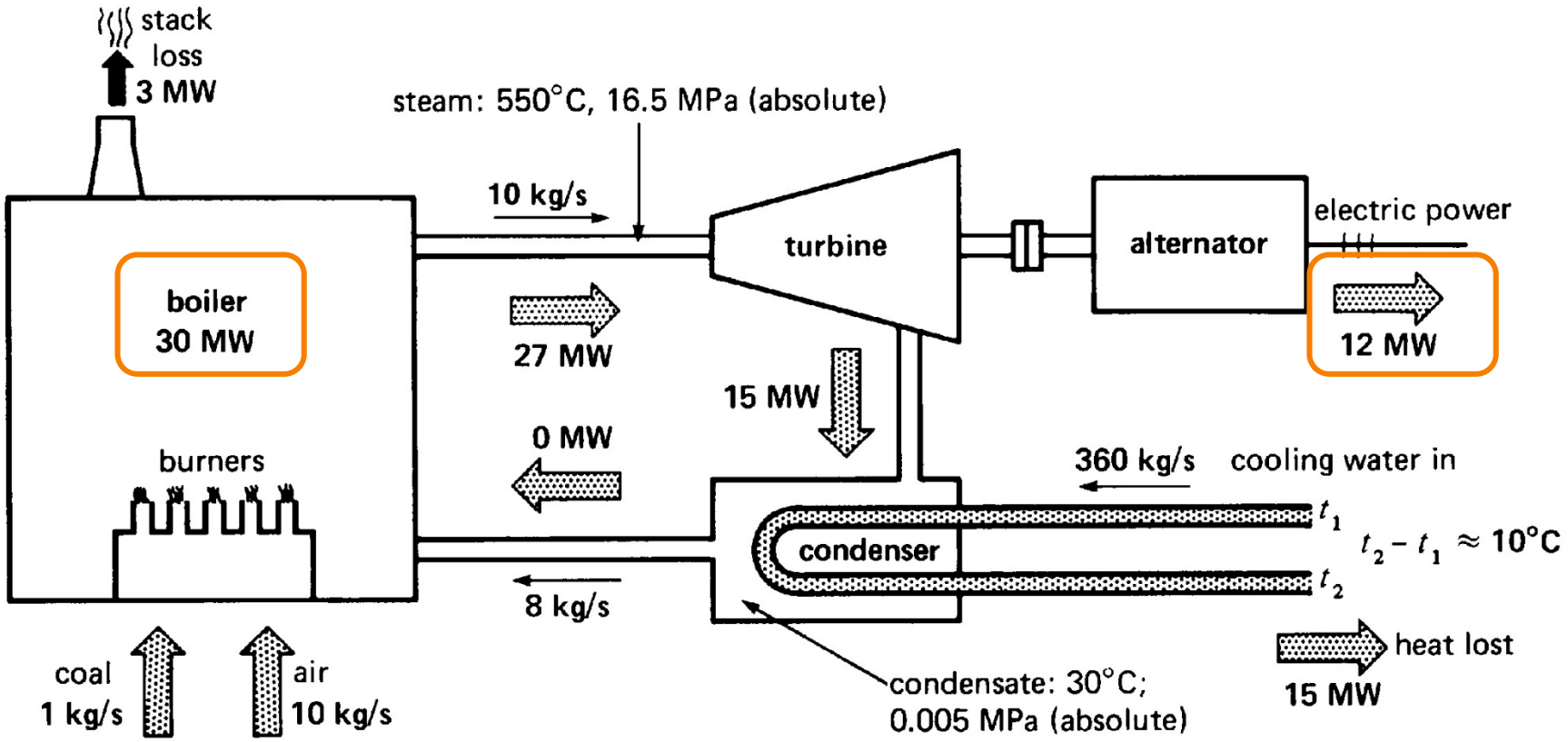
Coal-fired steam turbine power plant

- 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

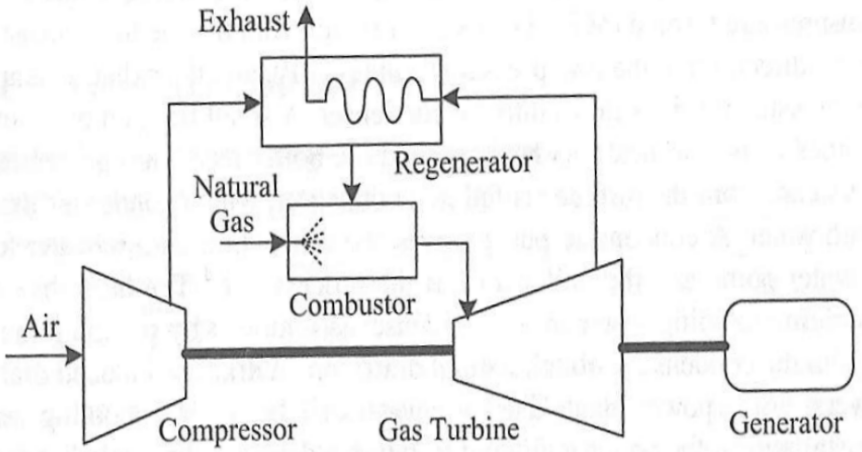


FIGURE 1.3
Schematic diagram of a simple gas turbine power plant.

- 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%)

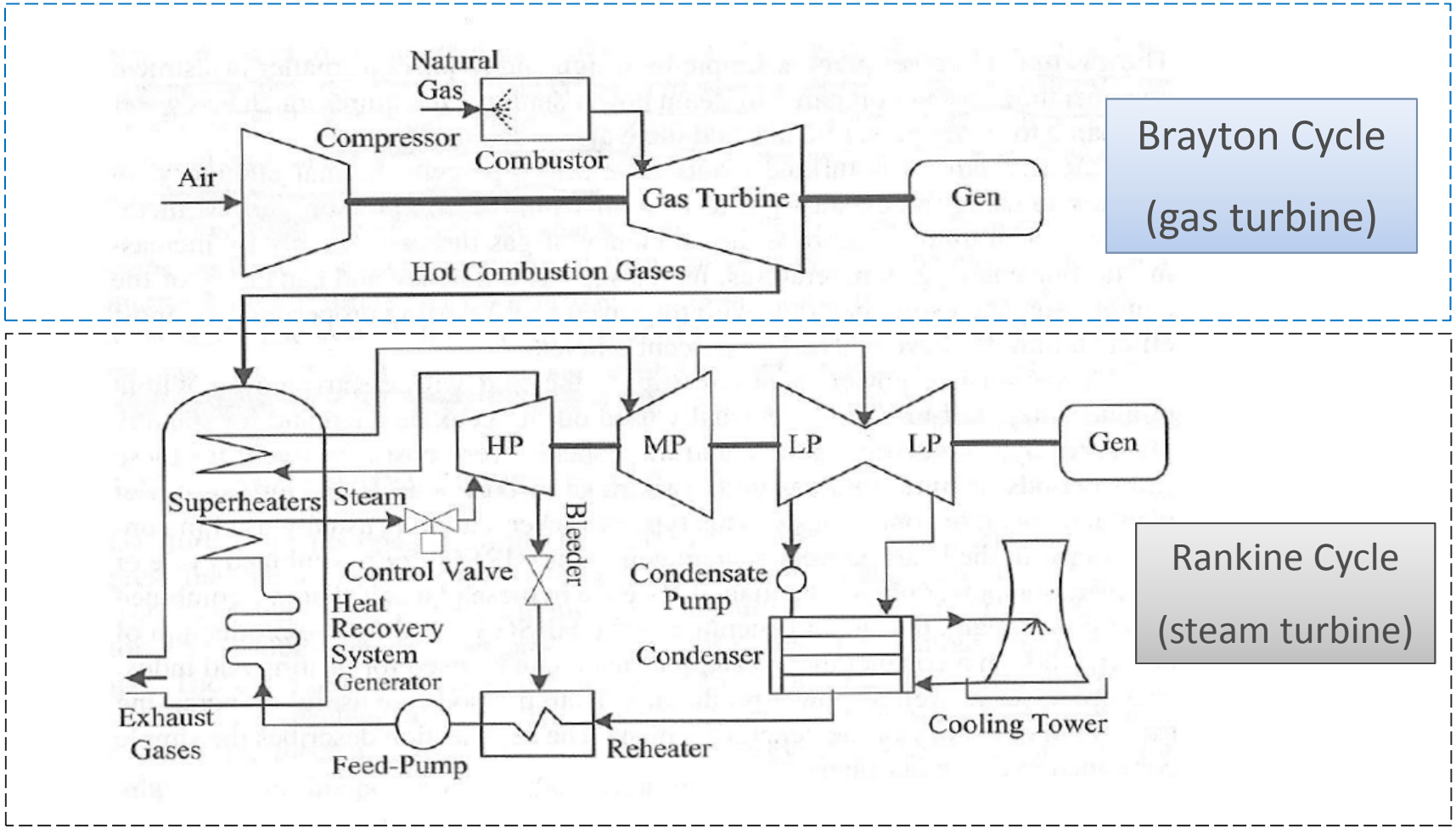


FIGURE 1.4
Schematic of a combined-cycle power plant.

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)

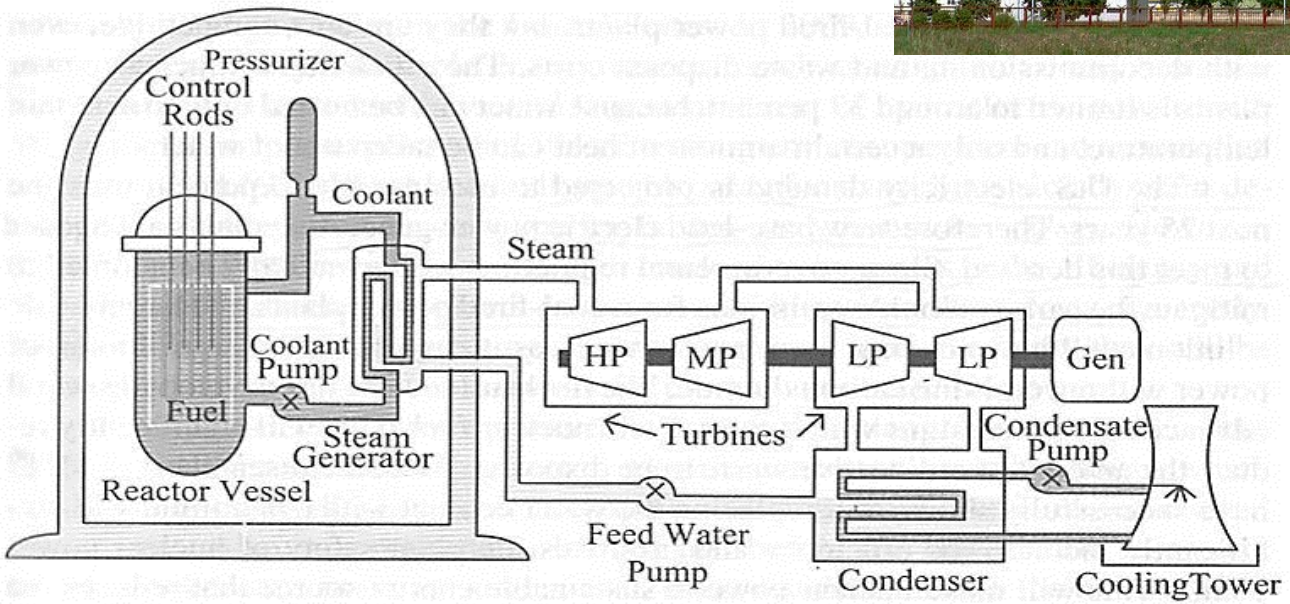


FIGURE 1.5
Schematic diagram of a pressurized water reactor.

Hydropower Plant

- *Generated electric power:*

$$P_{Water} = E_{Potential} / t = V\rho gh / t = q\rho gh$$

$$P_{Out} = \eta P_{Water} = \eta q\rho gh = 9.81qh\eta \quad (\text{kW})$$

η - *overall efficiency (~90%)*

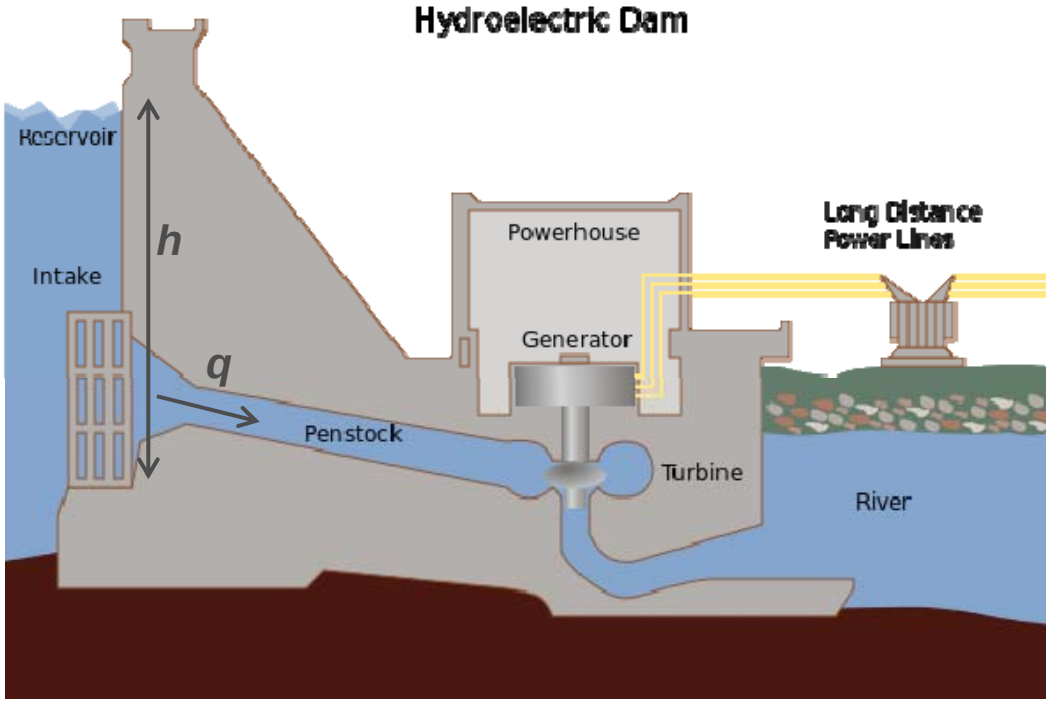
h – effective head of water (m)

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 natural 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

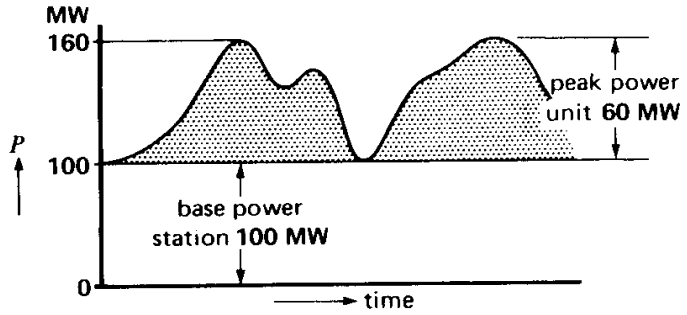


Figure 24.14
A 100 MW base power station and a 60 MW peak power station can supply the network demand.

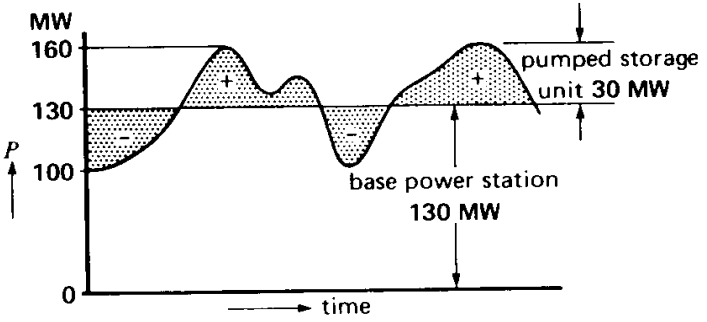
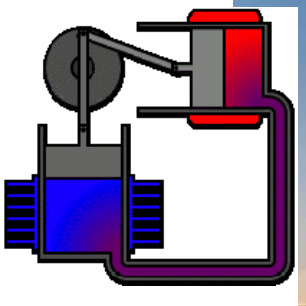


Figure 24.15
A 130 MW base power station and a 30 MW pumped storage unit can also supply the network demand.

Solar Power

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

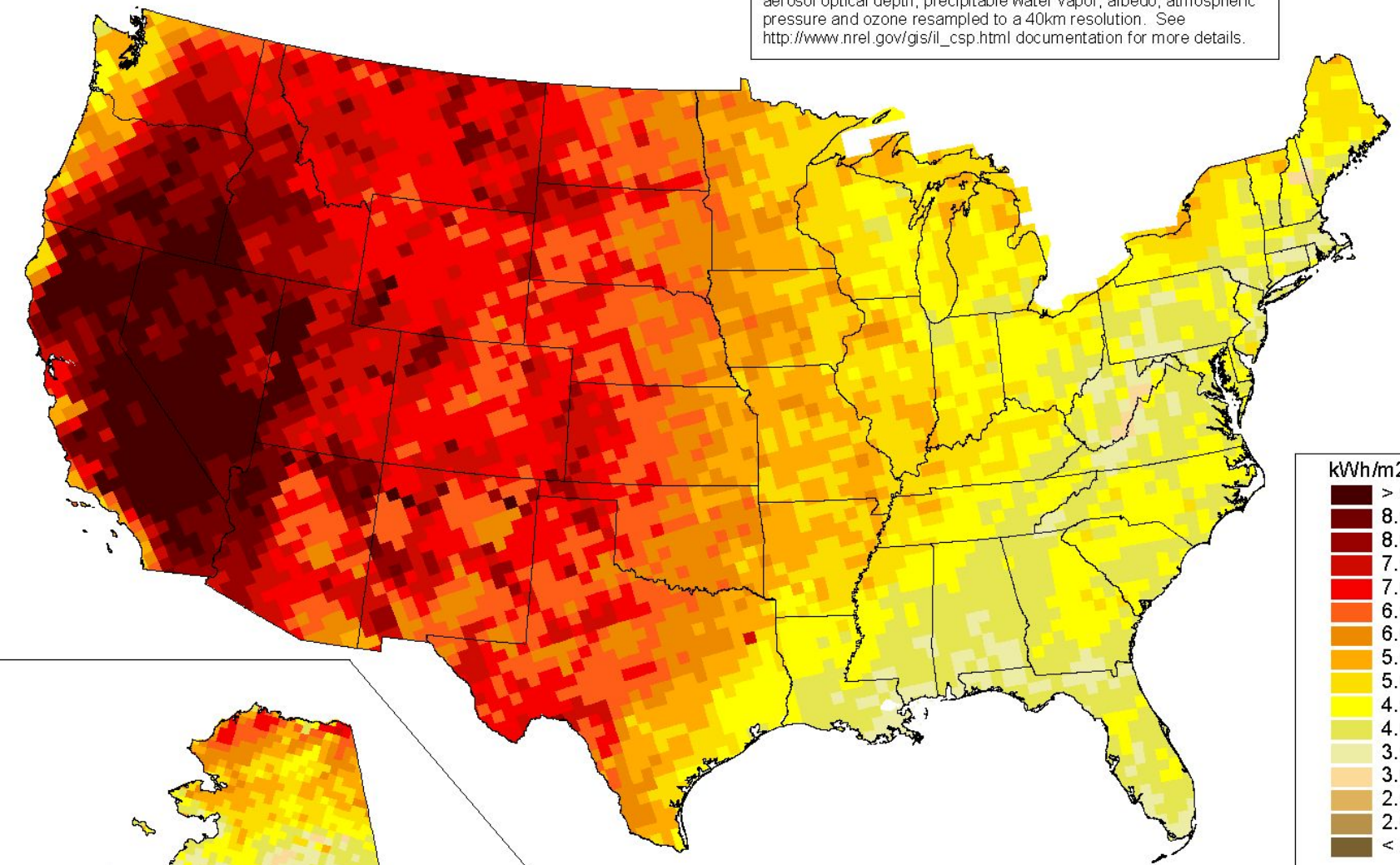


Stirling Engine

Direct Normal Solar Radiation (Two-Axis Tracking Concentrator)

July

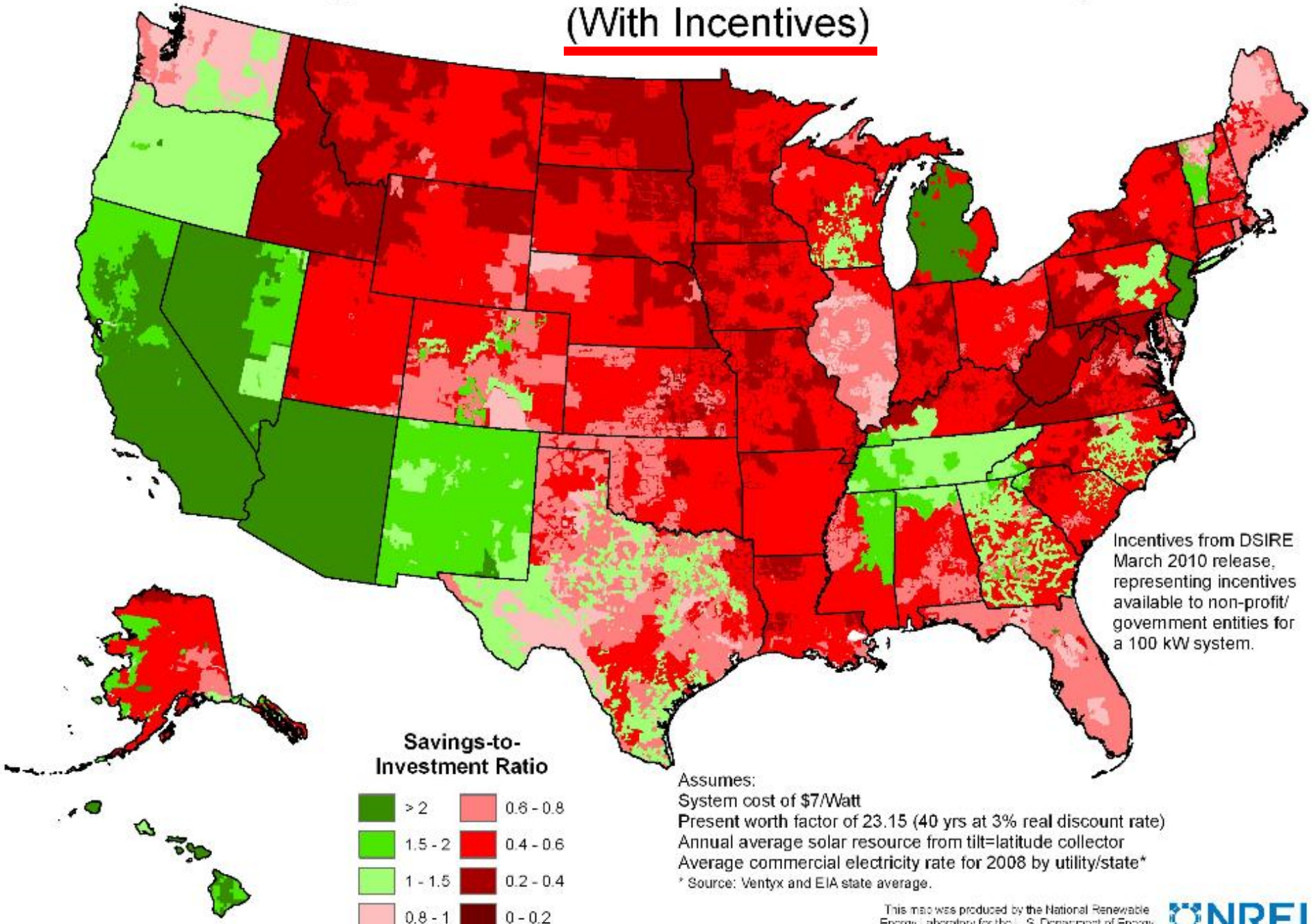
Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_csp.html documentation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



NREL

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

Savings-to-Investment Ratio for Photovoltaic Systems (With Incentives)



Incentives from DSIRE March 2010 release, representing incentives available to non-profit/ government entities for a 100 kW system.

Assumes:
System cost of $7/Watt
Present worth factor of 23.15 (40 yrs at 3% real discount rate)
Annual average solar resource from tilt=latitude collector
Average commercial electricity rate for 2008 by utility/state*
* Source: Ventyx and EIA state average.

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy
Map created by Donna Heimiller Oct 4, 2010

NREL

Wind Power Plants

- Generated electric power:

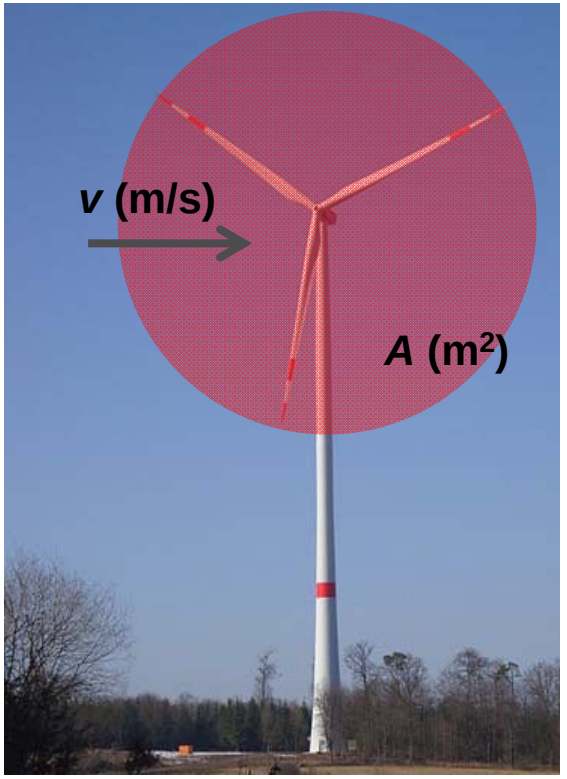
$$P_W = \frac{E_K}{t} = \frac{mv^2}{2t} = \frac{A\rho vt \cdot v^2}{2t} = \frac{A\rho v^3}{2} = \frac{\pi D^2 \rho v^3}{8} \text{ (W)}$$

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

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

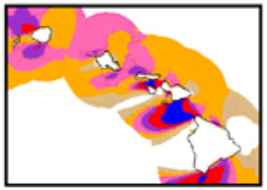
C_P – power coefficient ≈0.4< 16/27 or 0.59 (Betz Limit)

ρ – air density ≈1.2kg/m³ at 70°F

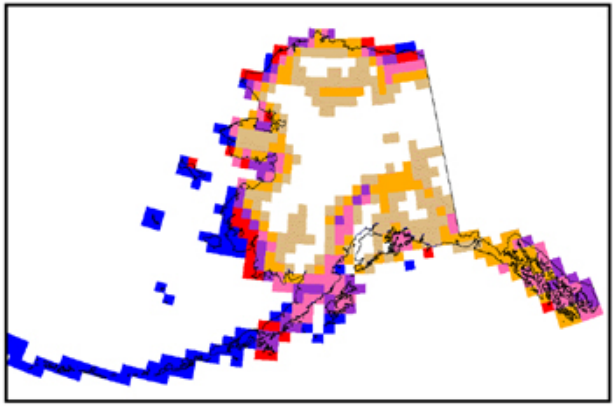


Wind Resources and Transmission Lines

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

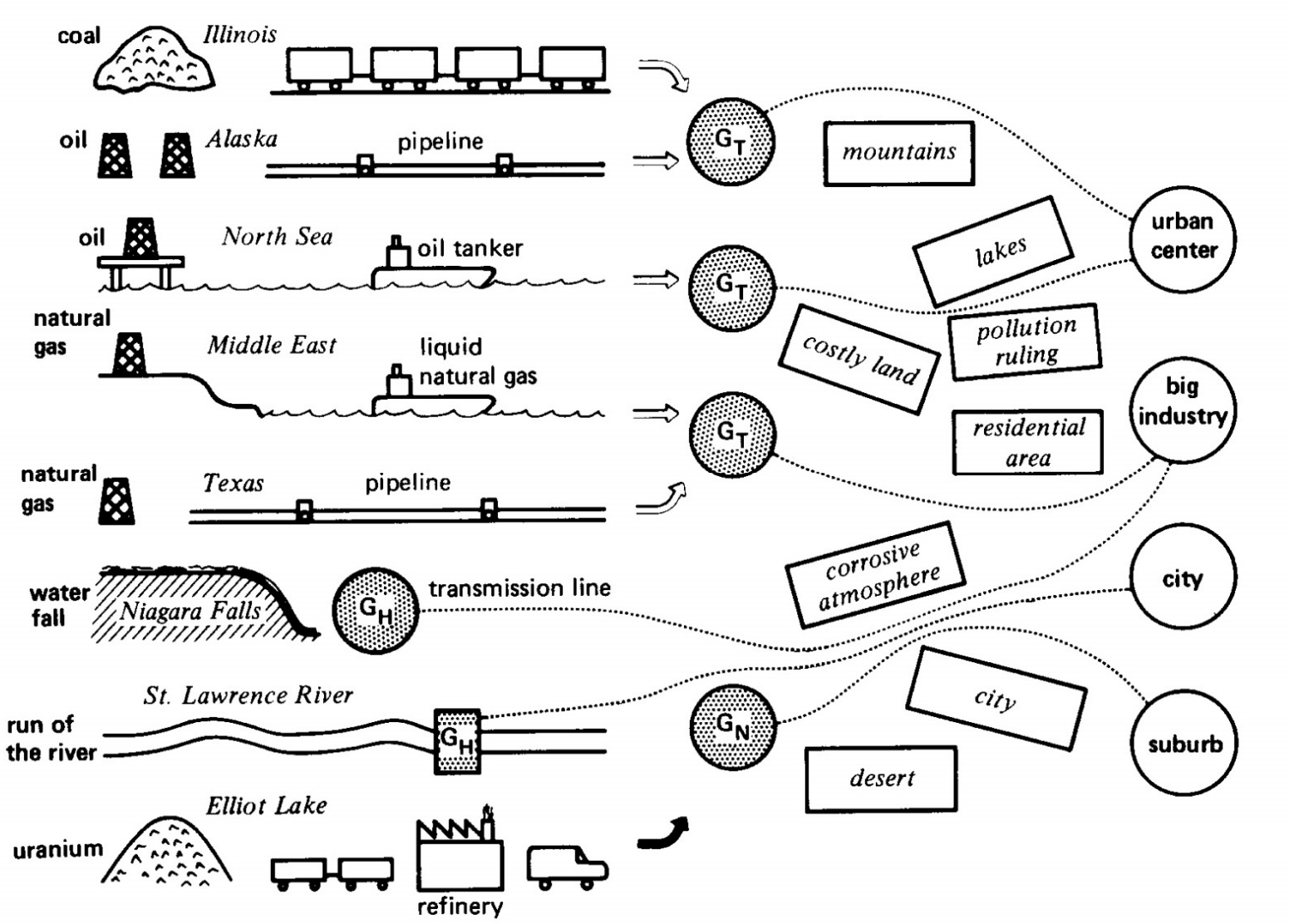
NREL

19-APR-2007 1.5.9

Question

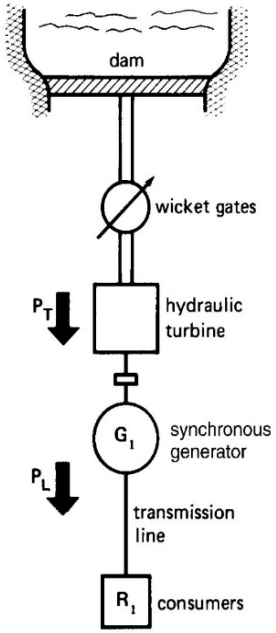
- Which of these generation resources utilize steam turbines in generating electric power?
  - Coal-fired power plant
  - Combined-cycle power plant
  - Pressurized water nuclear reactor
  - Offshore wind farm
  - Solar Tower
  - Parabolic trough solar farm

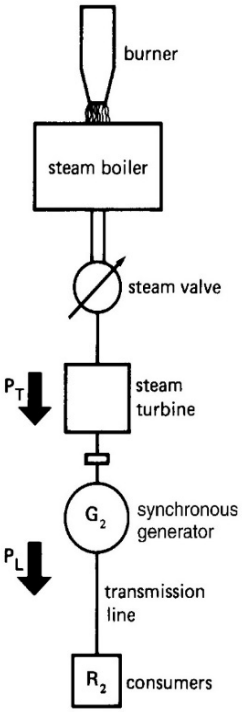
Power Generation and Delivery

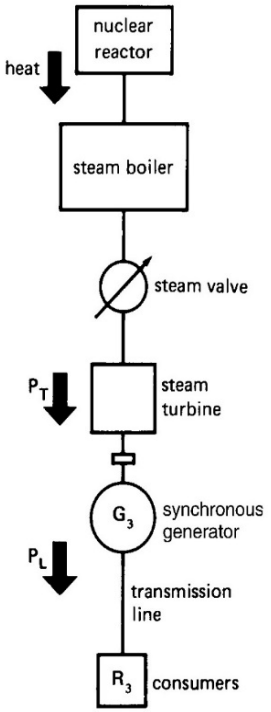


Why Interconnect?

1. Stability
2. Continuity of service
3. Economy







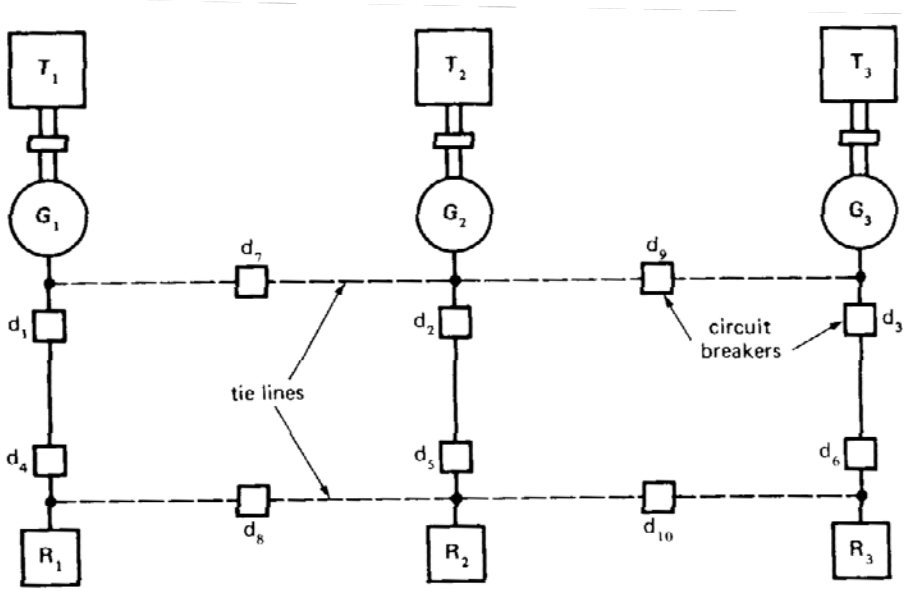
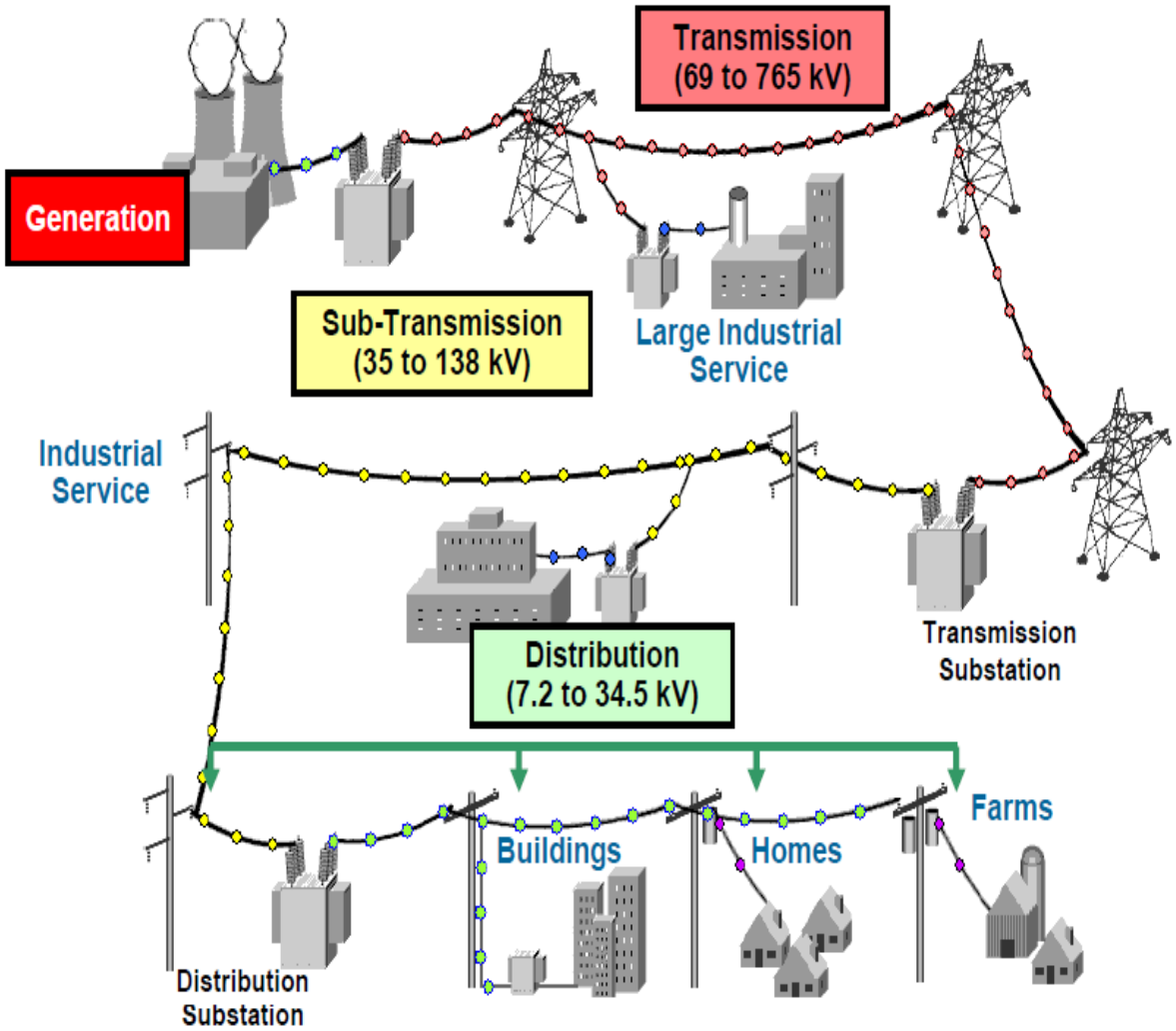


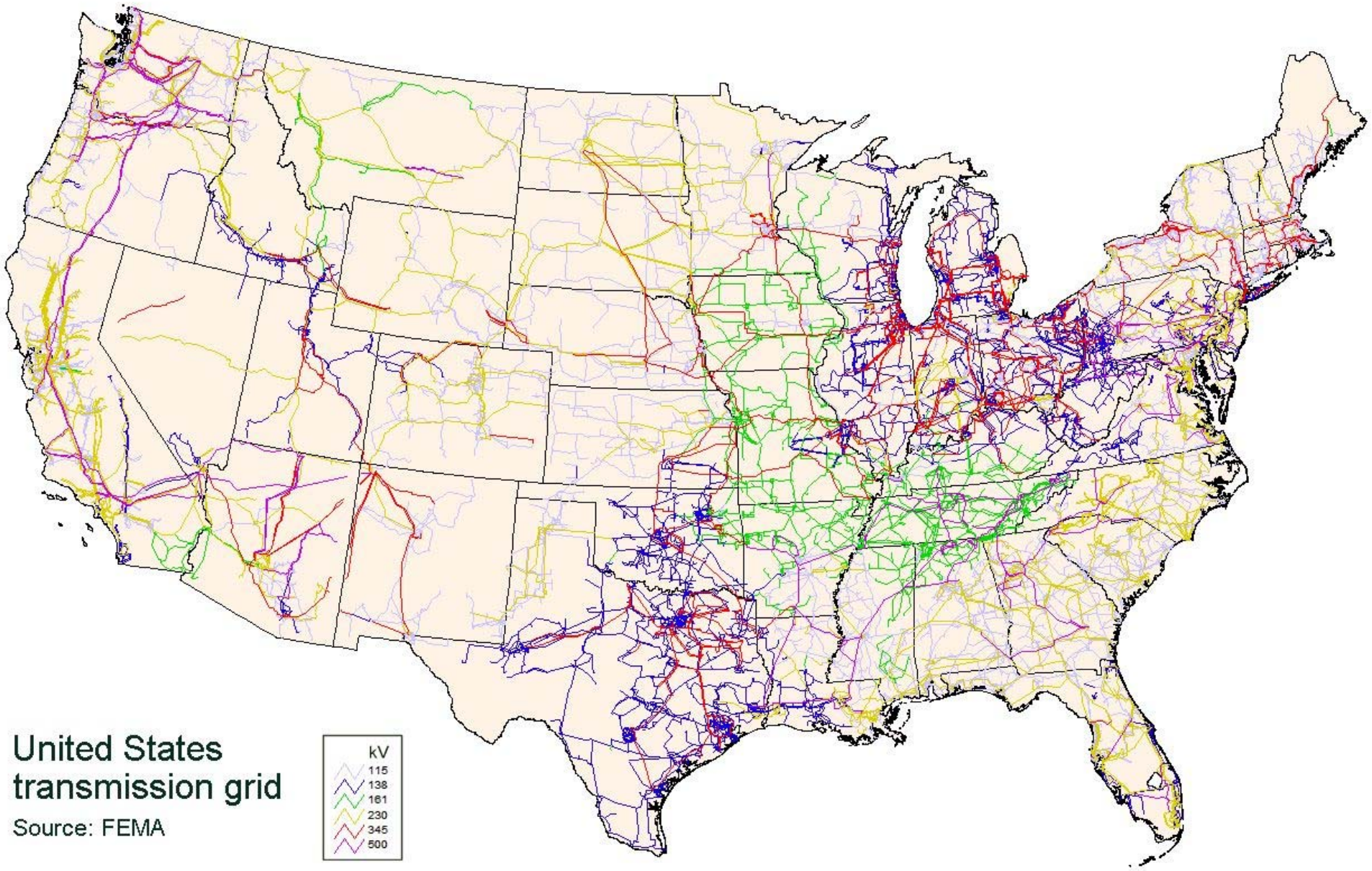
Figure 24.6
Three networks connected by four tie lines.

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
kV
115
138
161
230
345
500

US Electric Industry Structure

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

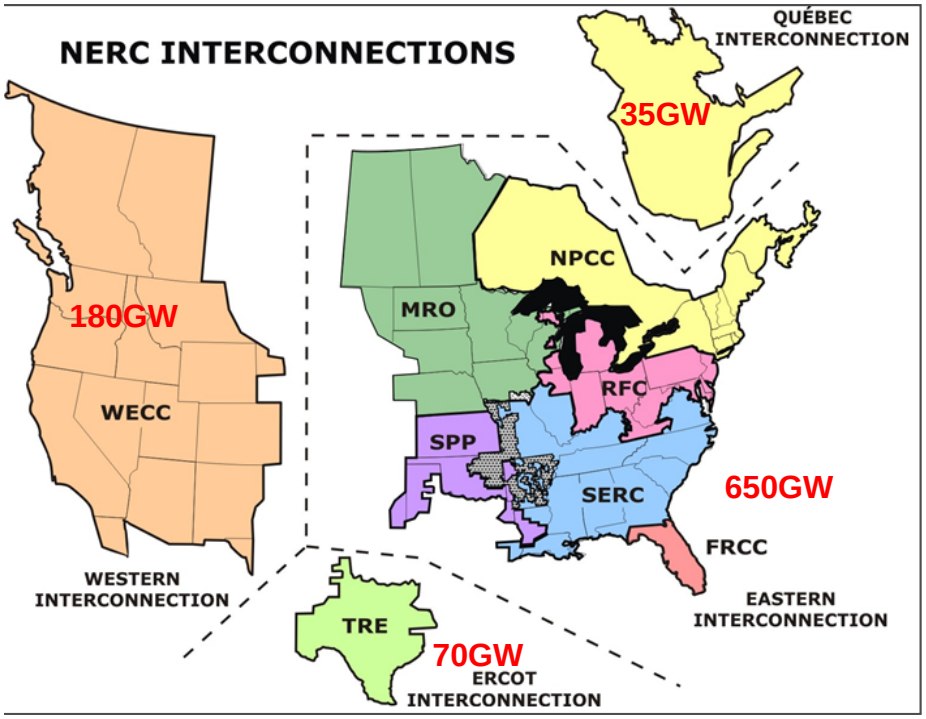
Categories	Examples
Investor-owned utilities 240+, 66.1% of electricity	AEP, American Transmission Co., ConEd, Dominion Power, Duke Energy, Entergy, Exelon, First Energy, HECO, MidAmerican, National Grid, Northeast Utilities, Oklahoma Gas & Electric, Oncor, Pacific Gas & Electric, SCE, Tampa Electric 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)

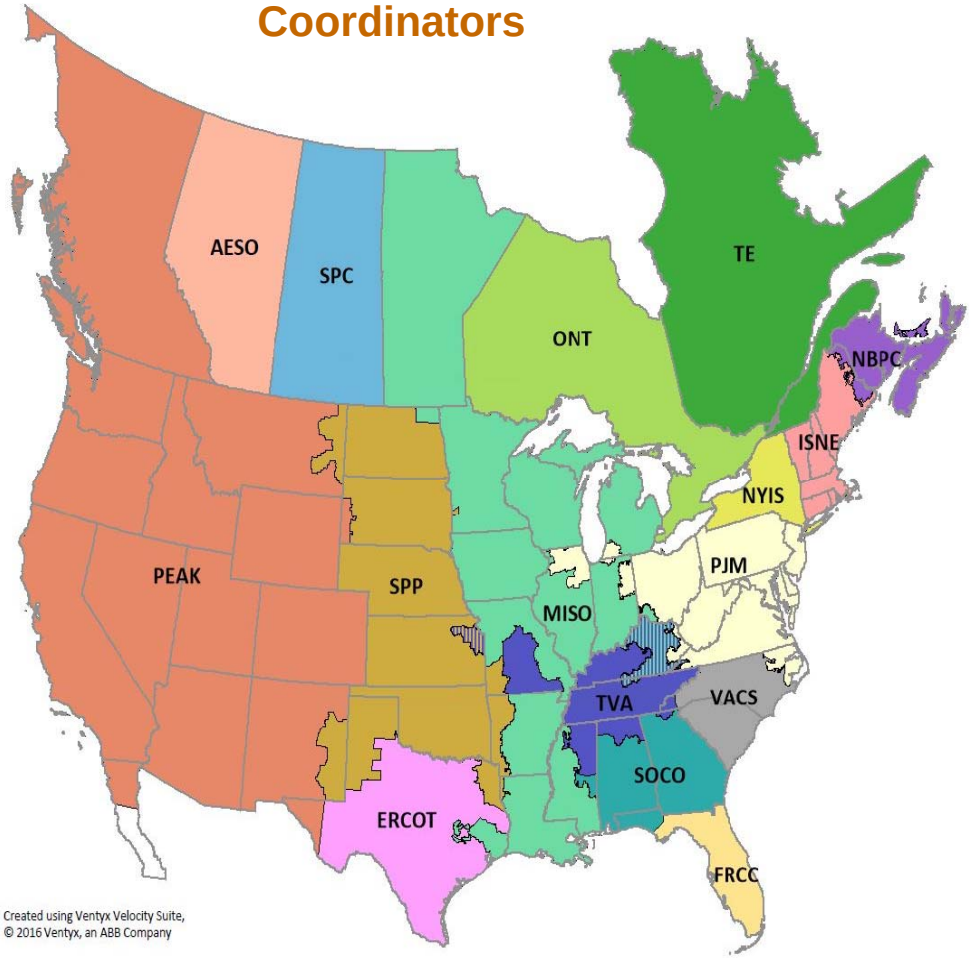
- As a non-government organization, formed by the electric utility industry in 1968 to promote the reliability of bulk power systems in North America.

- 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)



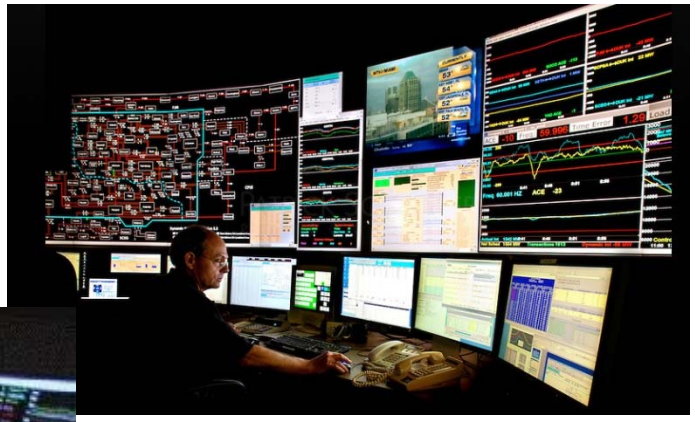
NERC Reliability Coordinators



Independent System Operators or Regional Transmission Organizations

(ISO/RTO)

System Control Centers



Duke Energy Control Center

(source: Patrick Schneider Photo.Com)

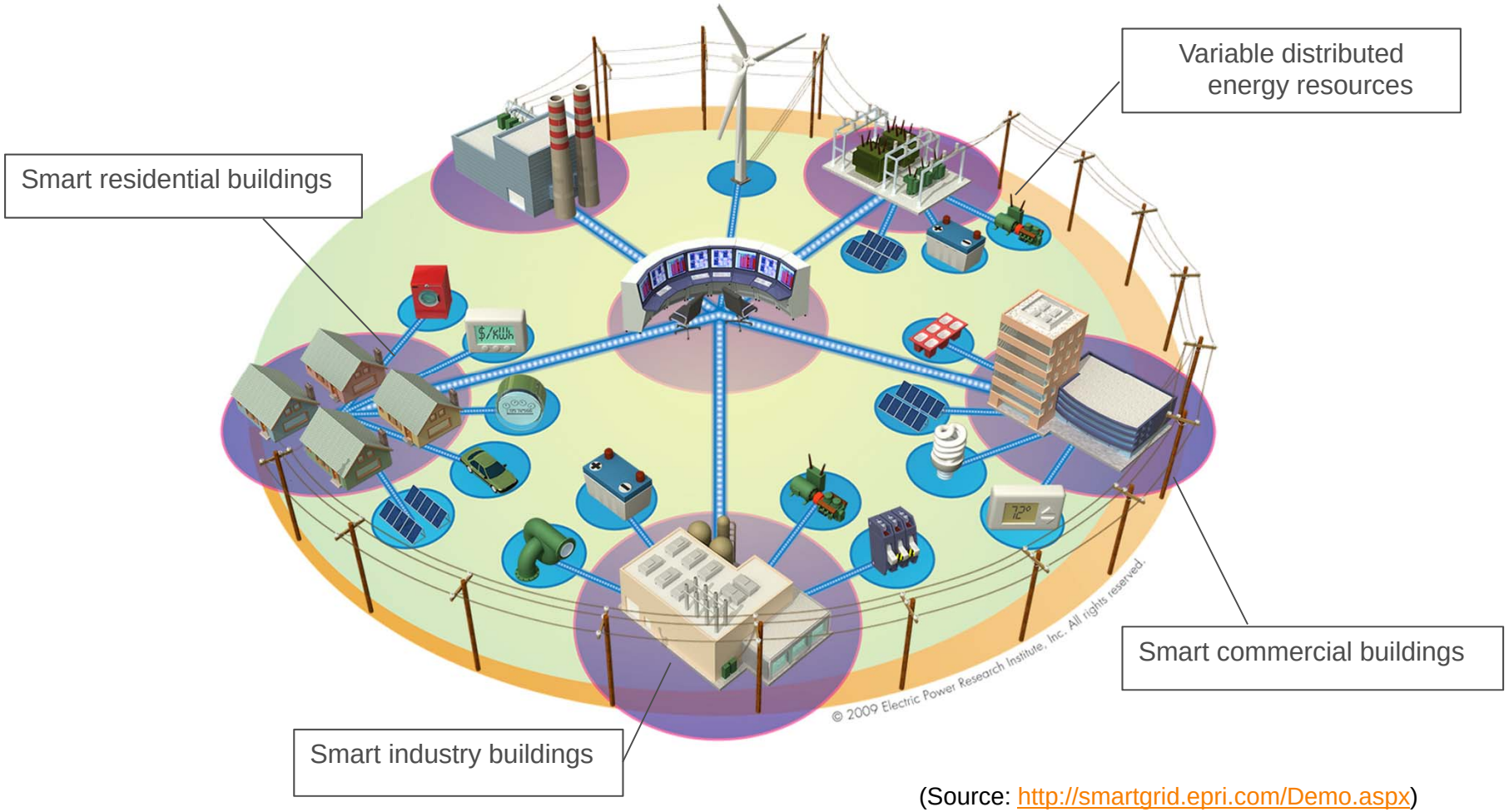
(Source: bayjournal.com)

TVA Control Center

(source: TVA.com

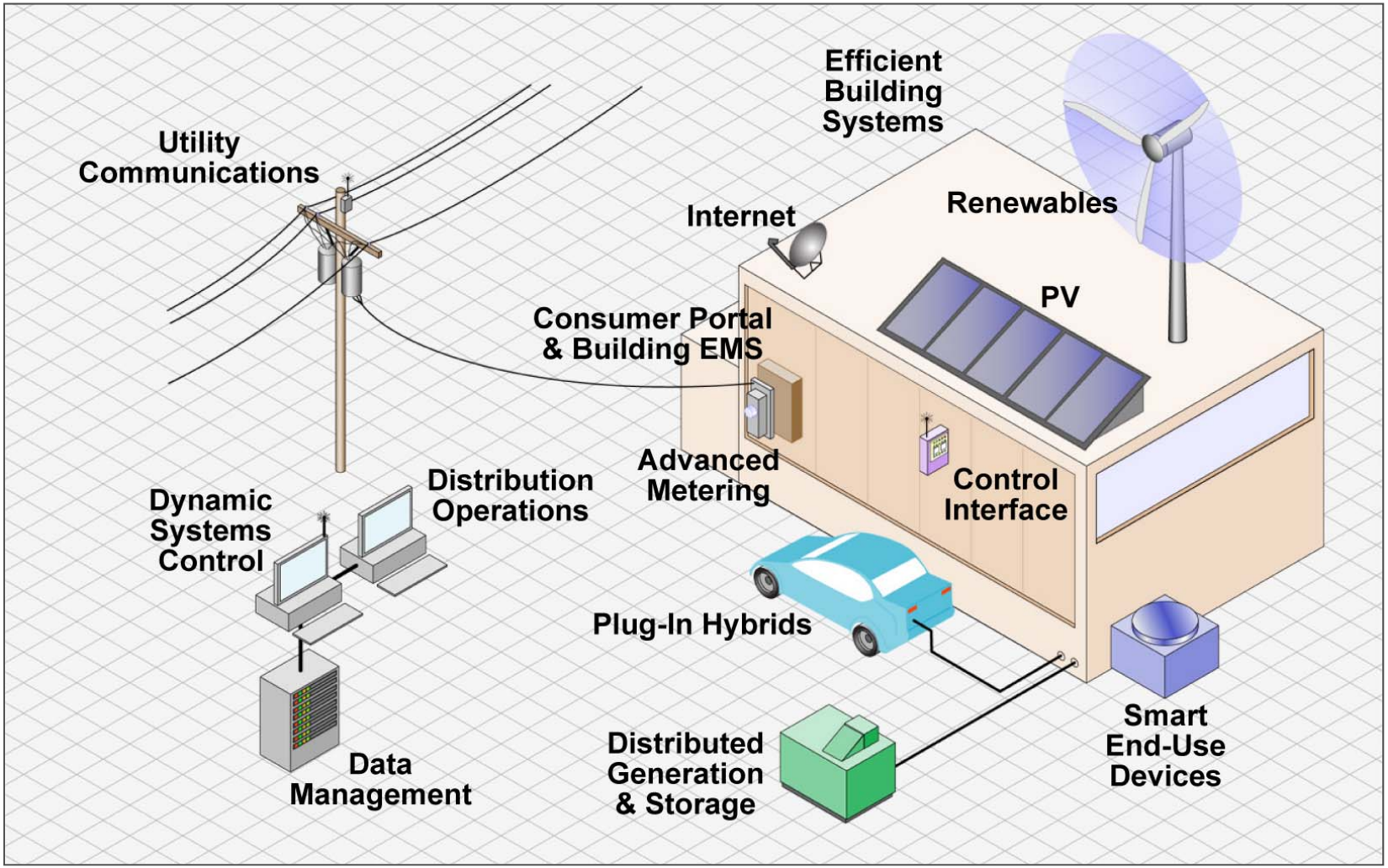
Smart Grid

- May be defined as a broad range of solutions that optimize the energy value chain. It brings the power of networked, interactive technologies into an electricity system to improve reliability, security and efficiency of the electric system.
- Some features: Digitalized, Interactive, Sustainable, Resilient, Robust, Autonomous and Efficient.



(Source: http://smartgrid.epri.com/Demo.aspx)

A future smart home



Source: news.cnet.com

Hiring Companies

- Power utilities, e.g.
  - TVA & TVA local pow companies (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, MISO, 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 ~ 24-9 (no need to submit)