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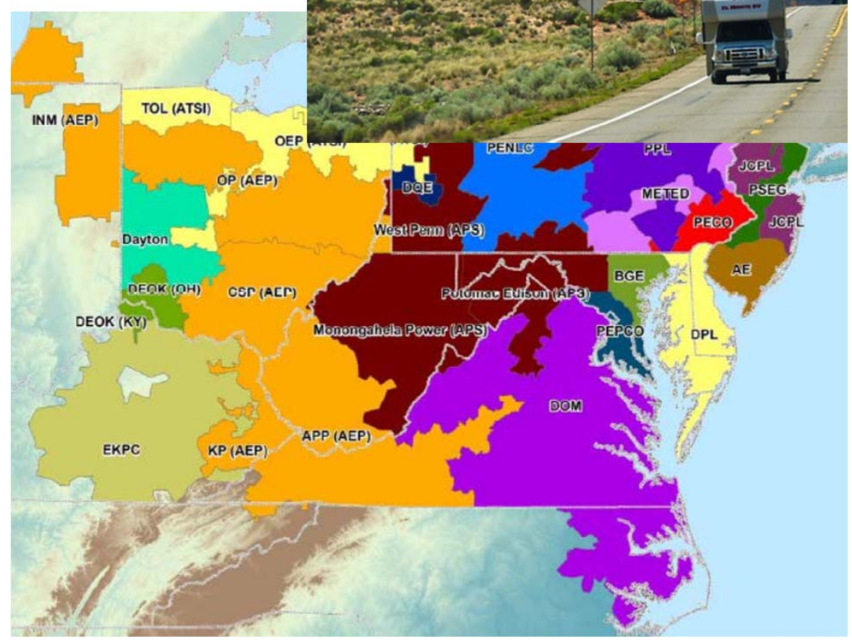
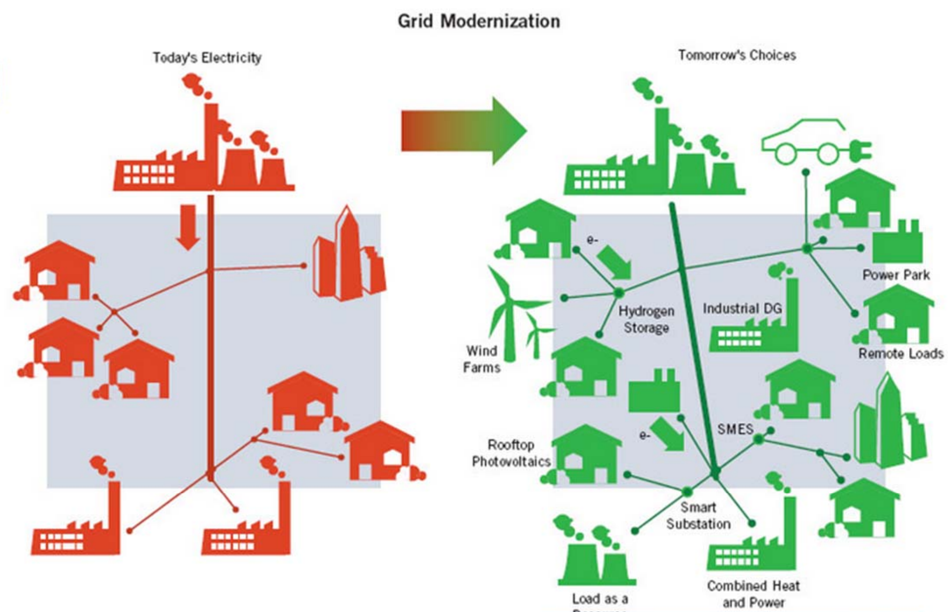
Electric Power Industry

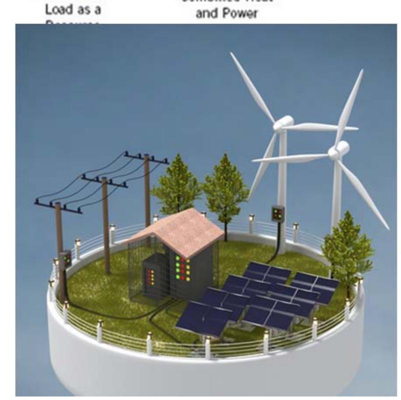
- Electric Power Industry in US (Before 1980)
  - One of the largest enterprises
  - One of the most polluting industries
    - Emissions
      - Sulfur Oxides (SOx)
      - Carbon Dioxide (CO2)
      - Nitrogen Oxides (NOx)
  - Regulated utilities
  - Monopoly franchises
  - Vertical Integration with Generation, Transmission, and Distribution
  - Serving their own customers



Electric Power Industry

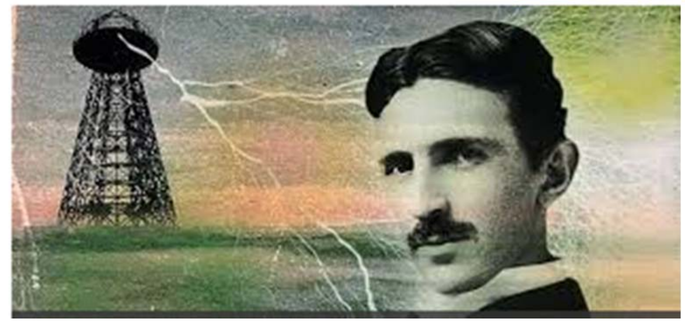
- Electric Power Industry in US (From 1980s)
  - Own power on-site, or perhaps buy it directly from non-utility providers.
  - Break of the natural monopoly
  - Enter in to a new competitive power industry → “deregulation” → California’s failed experiment →Mixed structure
  - Global warming and emission reduction mandate
  - “Smart Grid”
  - Renewable energy in to action
  - Changes in Technological and Regulatory Systems

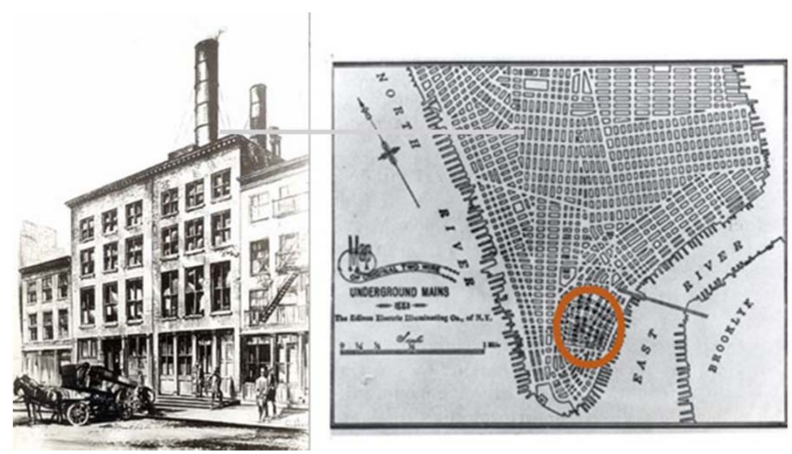




Early Pioneers

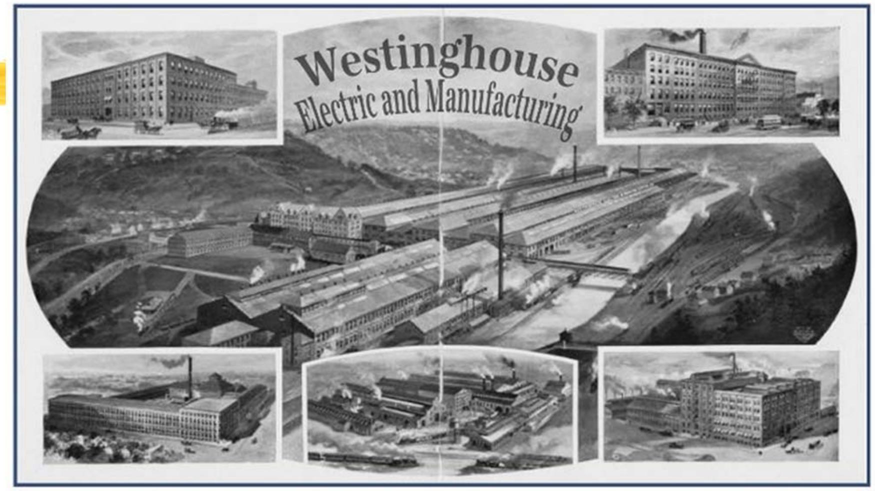
- Electricity and Magnetism
  - Has Christian Oersted, Andre Ampere, and James Clerk Maxwell
- Electro-Mechanical Conversion
  - 1831 DC Dynamo -- Maxwell, H. Pixil (France)
  - 1880s AC Generation and AC induction motor --- Nikola Tesla
- Electric Power Market
  - Thomas Edison – Edison Electric Light Company – Illumination
  - 1882 Pearl Street in Manhattan – distribution of electricity for lights → 1st investor-owned utility in the nation
  - DC system: flicker-free light, easy control of DC motors, difficulty in voltage change, low-voltage DC led to high line losses →customers are to be located nearby

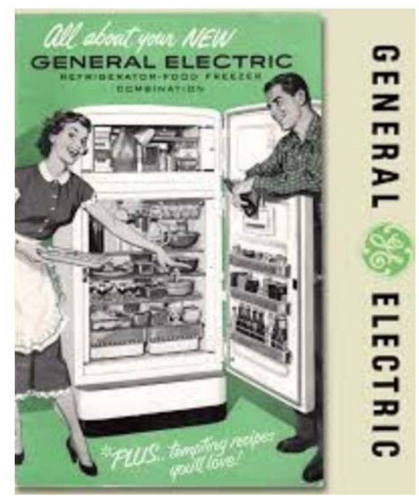




Early Pioneers

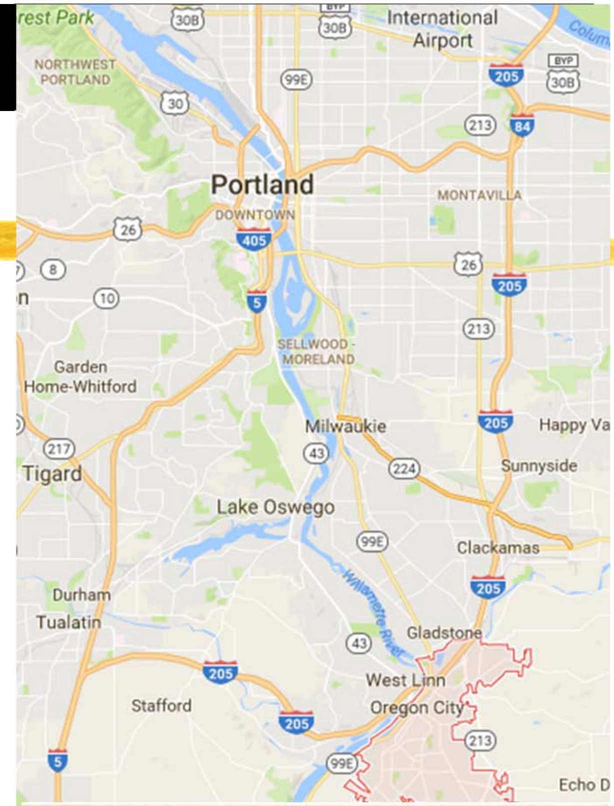
- Electric Power Market
  - George Westinghouse --- based on Tesla’s AC system – Westinghouse Electric Company (1886)
  - Big feud between Westinghouse and Edison (DC vs. AC): “high voltage’s safety hazard”
  - AC system prevailed (advantage of high voltage transmission). Edison’s DC system disintegrated → new incorporation in 1892 as ***General Electric Company*** with shifted focus from a utility to manufacturing electrical equipment for utilities and customers

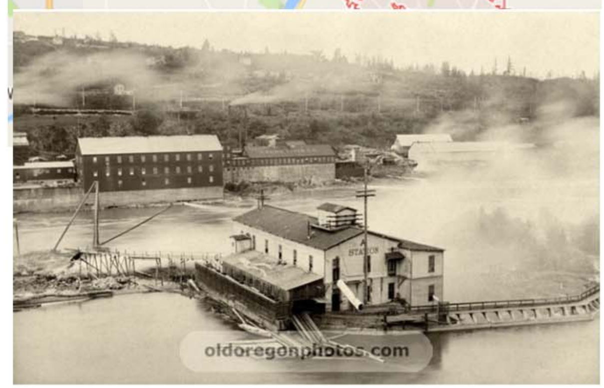




Long Distance Power Delivery

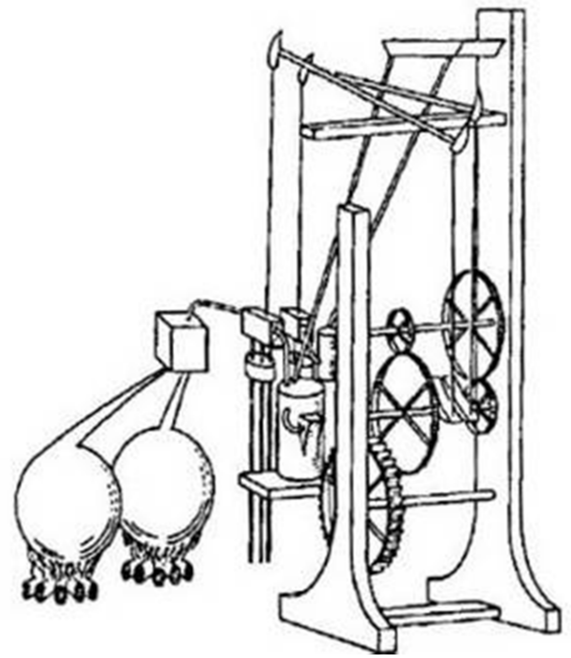
- First transmission line in the US (1890)
  - 1-phase, 3.3kV, 13 mile, Hydroelectric station (Oregon City) – Portland, OR
- First 3-phase demonstration (1891)
  - 3-phase, 106-mile, 30kV, 75kW between Hauffen and Frankfurt, Germany
- Solving the flickering lamp problem
  - US --- 60Hz system is standardized (1930s)
  - 50Hz countries – Japan and some European countries
- Economy side of electric power companies
  - Big capital investment
  - Monopoly → Regulated monopoly [franchise territory and price controlled by public utility Commissions (PUCs)]





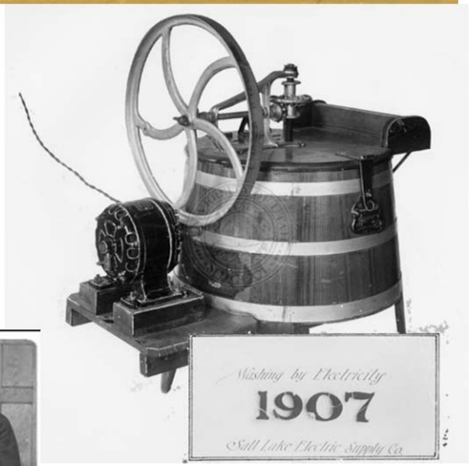
Major Electricity Milestones - 1

- 1800 First electric battery (A. Volta)
- 1821 First electric motor (M. Faraday)
- 1832 First dynamo (H. Pixil)
- 1839 First fuel cell (W. Grove)
- 1872 Gas turbine patent (F. Stulze)
- 1879 First practical incandescent lamp (T. A. Edison and J. Swan, independently)
- 1882 Edison's Pearl Street Station opens
- 1883 Transformer invented (L. Gaulard and J. Gibbs)
- 1884 Steam turbine invented (C. Parsons)



Major Electricity Milestones - 2

- 1886 Westinghouse Electric formed
- 1888 Induction motor and polyphase AC systems (N. Tesla)
- 1890 First single-phase ac transmission line (Oregon City to Portland)
- 1891 First three-phase ac transmission line (Germany)
- 1903 First successful gas turbine (France)
- 1907 Electric vacuum cleaner and washing machines
- 1911 Air conditioning (W. Carrier)
- 1913 Electric refrigerator (A. Goss)



Major Electricity Milestones - 3

- 1962 First nuclear power station (Canada)
- 1973 Arab oil embargo, price of oil quadruples
- 1979 Iranian revolution, oil price triples; *Three Mile Island* nuclear accident
- 1986 *Chernobyl* nuclear accident (USSR)
- 1990 Clean Air Act amendments introduce tradeable SO2 allowances
- 1998 California begins restructuring
- 2001 Restructuring collapses in California; *Enron* and *Pacific Gas and Electric (PG&E)* bankruptcy
- 2011 Fukushima Daiichi Accident

Major Electricity Milestones - 4

REACTORS THAT COMPLETED DECOMMISSIONING (ISFSI-ONLY OR LICENSE TERMINATED)	
Big Rock Point	Shippingport
Fort St. Vrain	Shoreham
Haddam Neck	Trojan
Maine Yankee	Yankee Rowe
PathfinderRancho Seco	

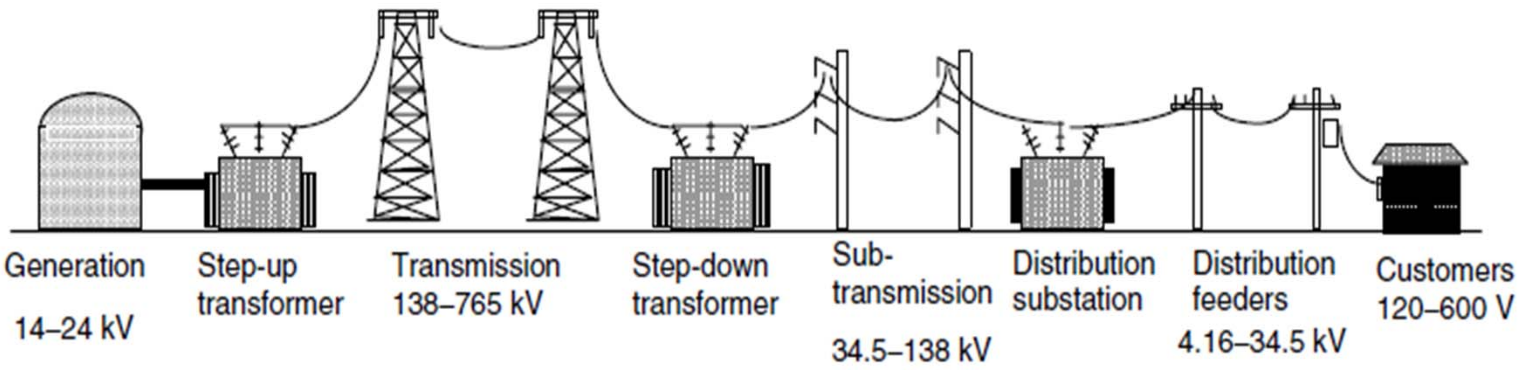
Countries that have decided on a phase-out

- Austria.
- Belgium.
- Germany.
- Italy.
- Philippines.
- South Korea.
- Sweden.
- Switzerland.

REACTORS IN DECOMMISSIONING	
Crystal River 3	Millstone 1
Dresden 1	Peach Bottom 1
Fermi 1	San Onofre 1
Fort Calhoun	San Onofre 2*
GE ESADA Vallecitos	San Onofre 3*
GE Vallecitos BWR	Three Mile Island 2
Humboldt Bay*	Vermont Yankee
Indian Point 1	Zion 1*
Kewaunee	Zion 2*
LaCrosse*	

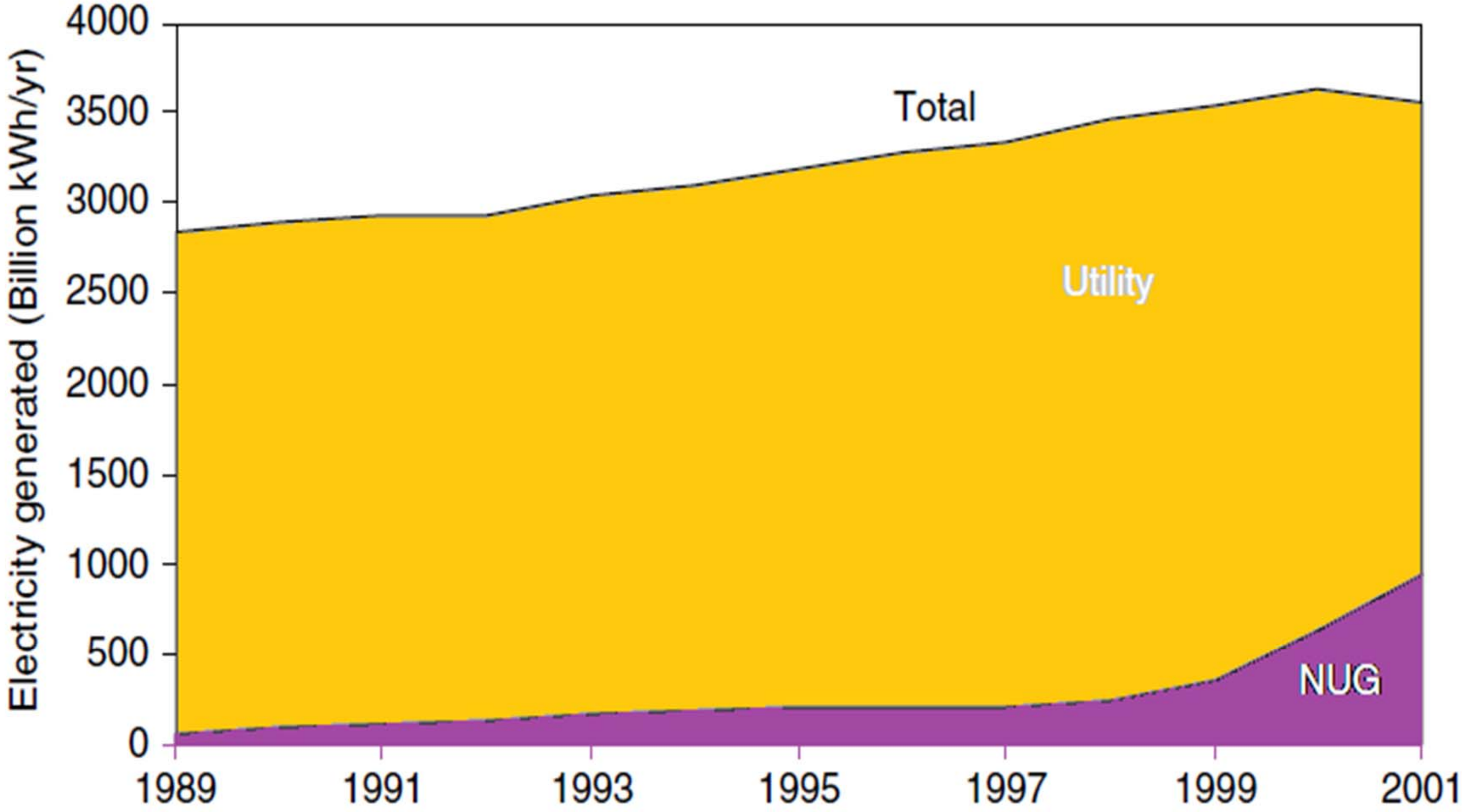
Electric Utility Industry Today

- Conventional Power System



-
  - Utilities: Regulated Monopoly Franchise over a fixed geographical area
    - Investor Owned utilities (IOUs)
    - Federally Owned Utilities: TVA, BPA, etc
    - Other Publicly Owned Utilities: State and Local Government agencies
    - Rural Electric Coop: Rural Electric Administration
  - Non-Utility Generators (NUG)
    - Privately owned for own use and/or for sale to utilities

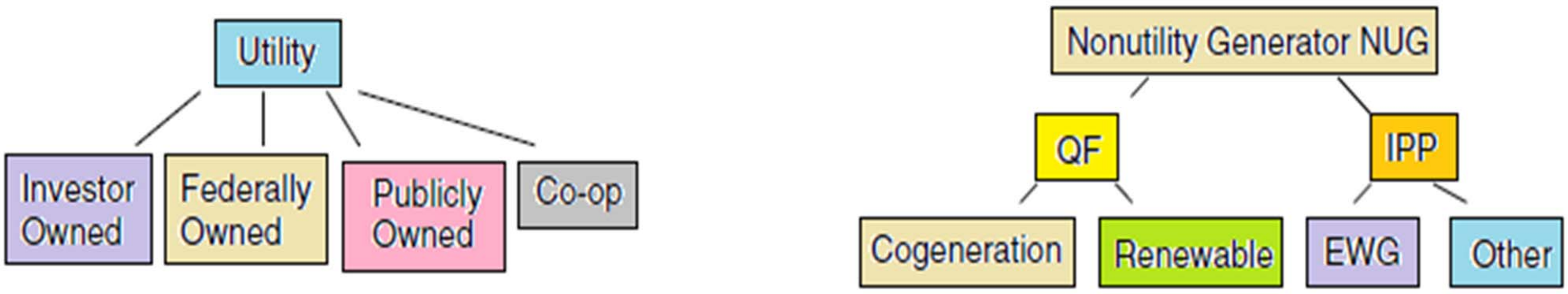
NUG Portion of Total Electricity Generation



Nonutility generators have become a significant portion of total electricity generated in the United States. From *EIA Annual Energy Review 2001* (EIA, 2003).

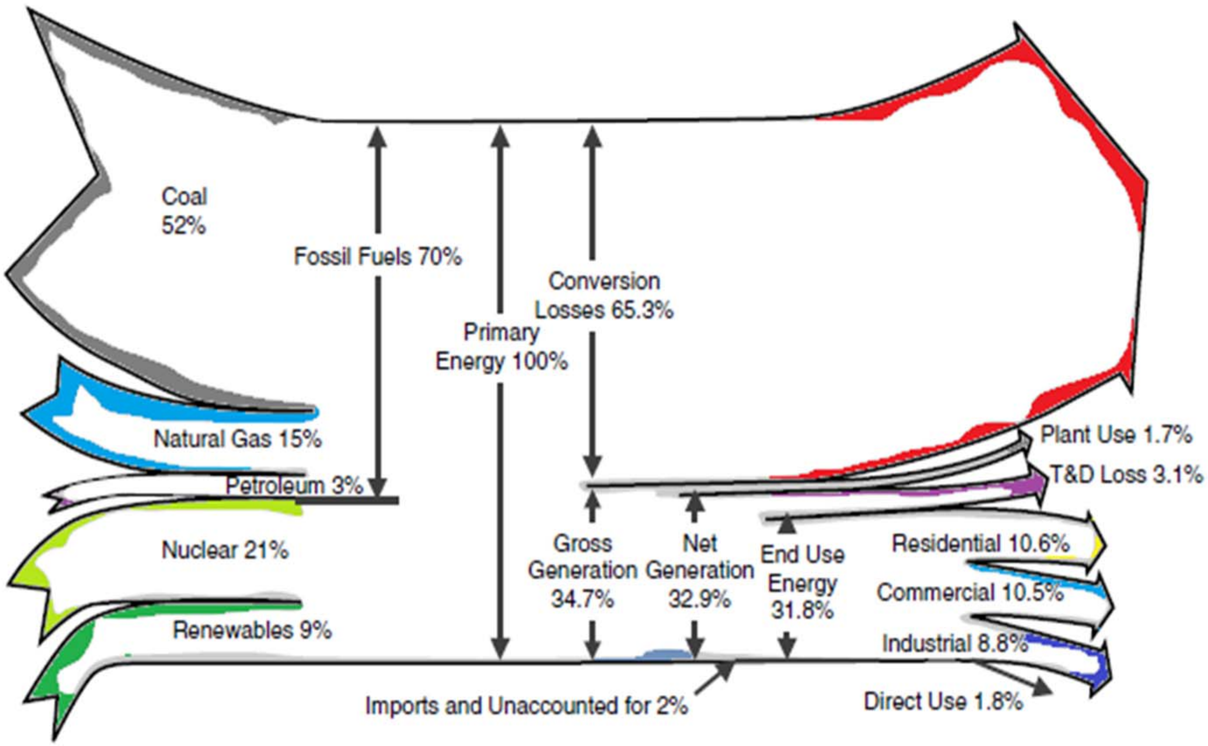
Utilities (IOUs) and Nonutility Generators (NUGs)

- Utilities and Non-utilities



- QF: Qualifying Facility ← PURPA
- IPP: Independent Power Producer ← EPAct
- EWG: Exempt Wholesale Generator ← EPAct, PUHCA

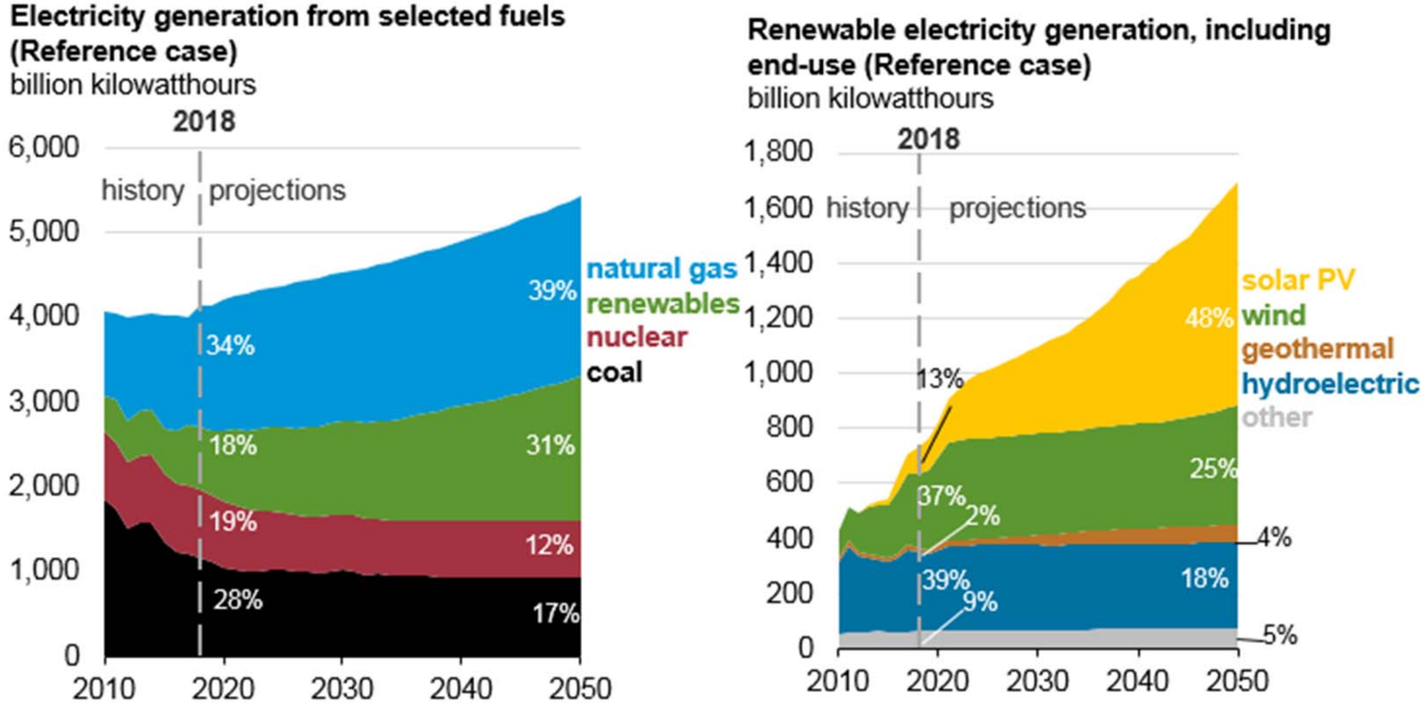
Industry Statistics: Energy Sources & Electricity Flow



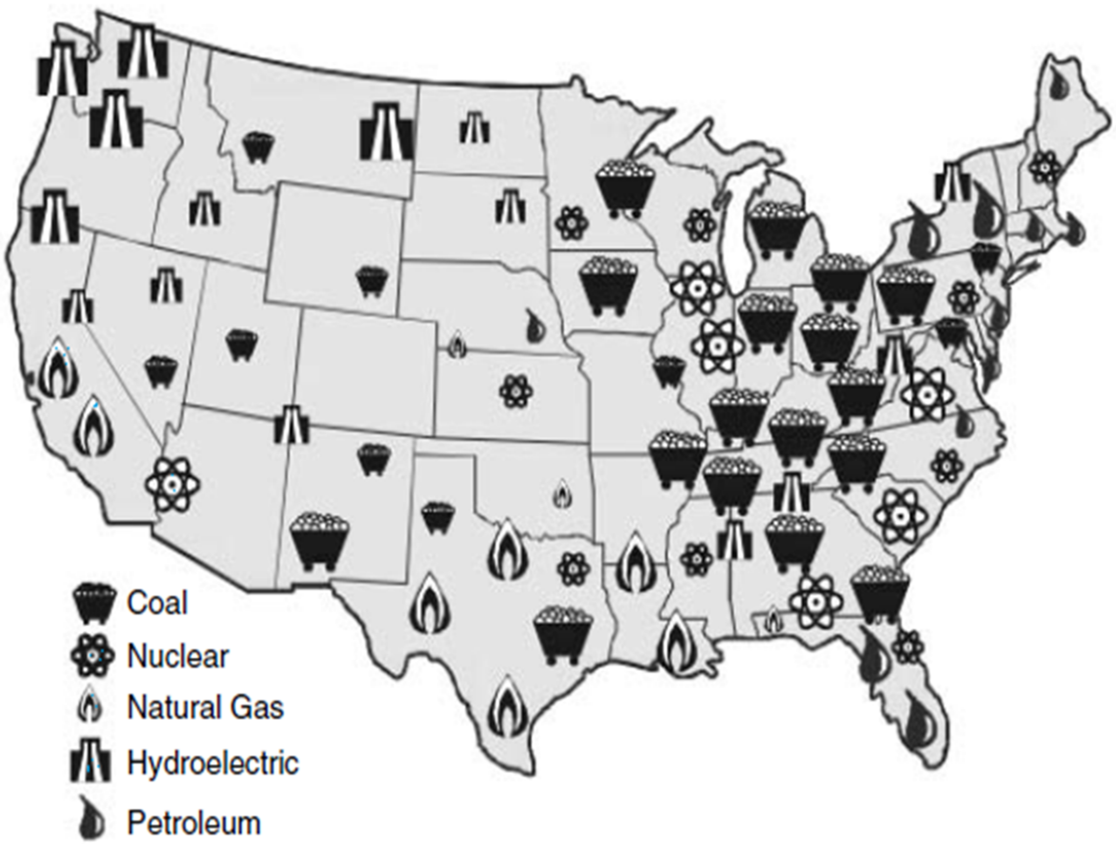
Electricity flows as a percentage of primary energy. Based on *EIA Annual Energy Review 2001* (EIA, 2003).

Industry Statistics: Electricity Generation

Electricity generation from natural gas and renewables increases, and the shares of nuclear and coal generation decrease—



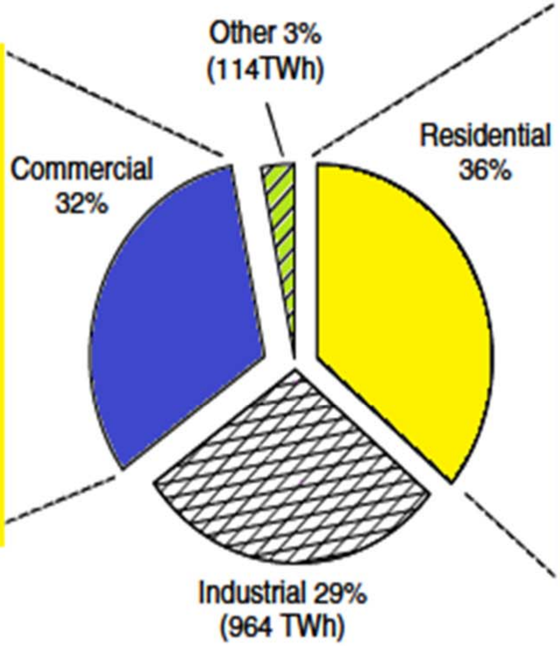
Industry Statistics: Energy Sources by States



Energy sources for electricity generation by region. Each large icon represents about 10 GW of capacity, small ones about 5 GW. From *The Changing Structure of the Electric Power Industry 2000: An Update* (EIA, 2000).

Industry Statistics: Distribution of Electricity Sales

COMMERCIAL	PERCENTAGE
Lighting	32
Space Cooling	12
Office Equipment	7
Ventilation	5
Refrigeration	5
Space Heating	3
Water Heating	3
Computers	2
Cooking	1
Other Office	9
Non-Building Uses	21
TOTAL (TWh)	1089

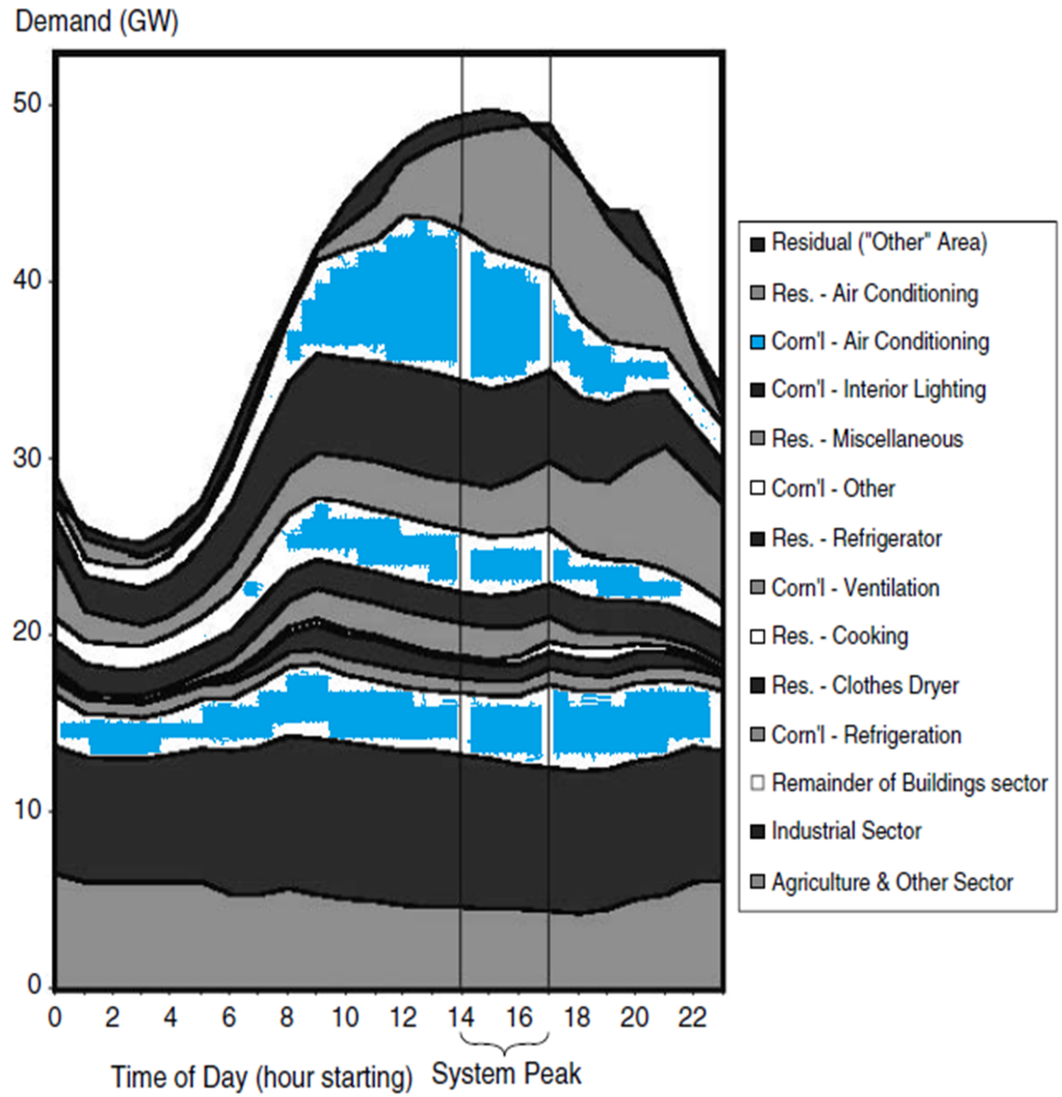


RESIDENTIAL	PERCENTAGE
Space Cooling	13
Refrigerators	11
Motors	11
Heating	10
Water Heating	10
Electronics	9
Lighting	9
Heating Elements	9
Clothes Dryers	6
Cooking	3
Freezers	3
Televisions	3
Computers	2
Clothes Washers	1
TOTAL (TWh)	1203

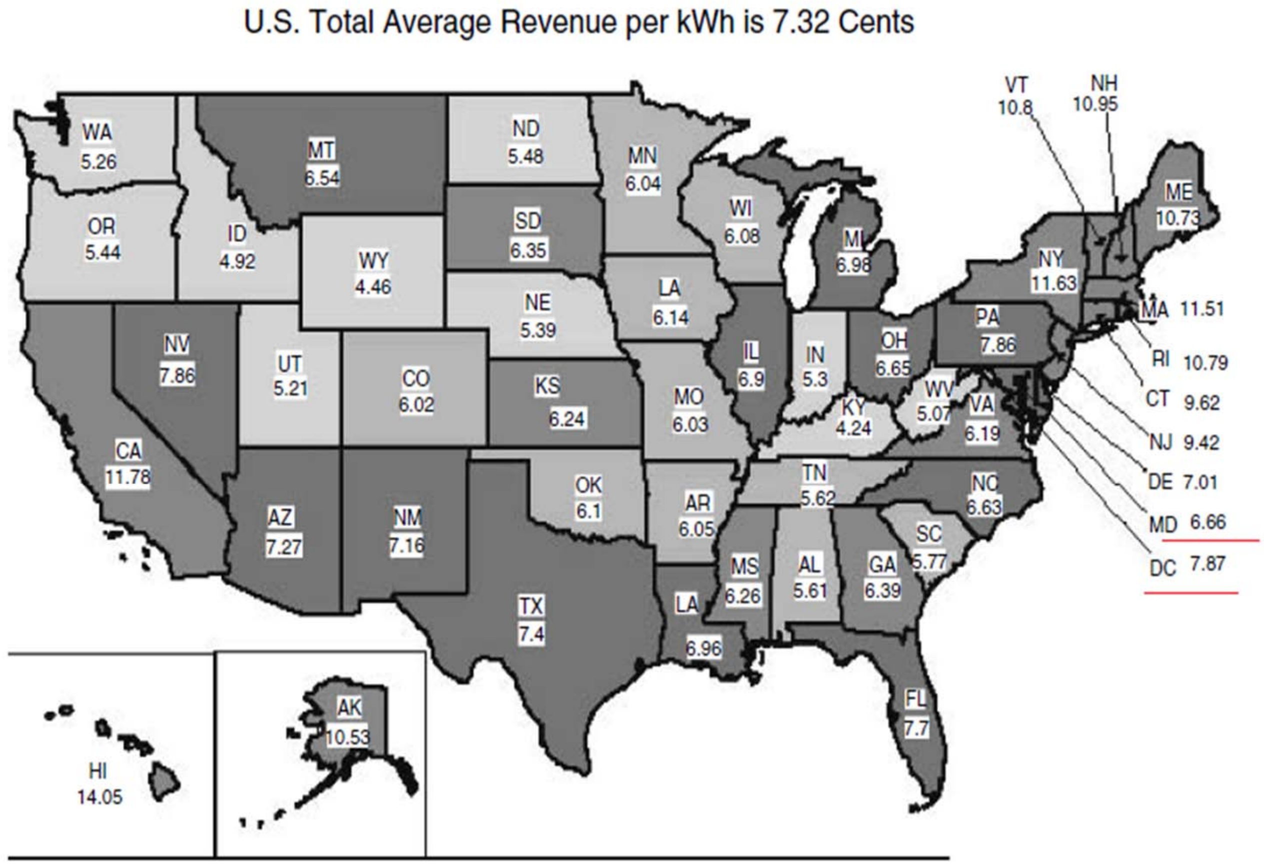
Distribution of retail sales of electricity by end use. Residential and commercial buildings account for over two-thirds of sales. Total amounts in billions of kWh (TWh) are 2001 data. From EIA (2003).

Industry Statistics: Load Profile

The load profile for the a peak summer day in California (1999) shows maximum demand occurs between 2 P.M. and 4 P.M. Lighting and air conditioning accounts for over 40% of the peak. End uses are ordered the same in the graph and legend. From Brown and Koomey (2002).

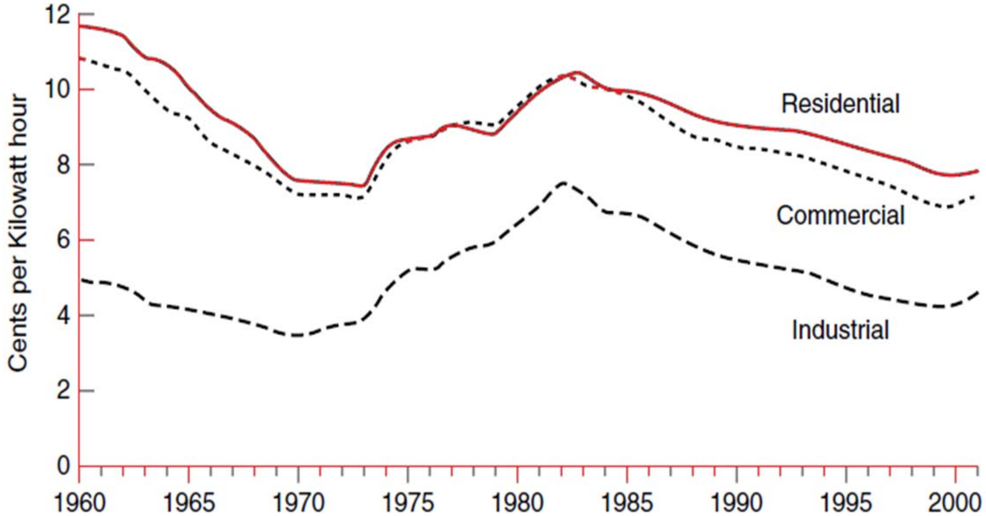


Industry Statistics: Electricity Price ($/kWh)

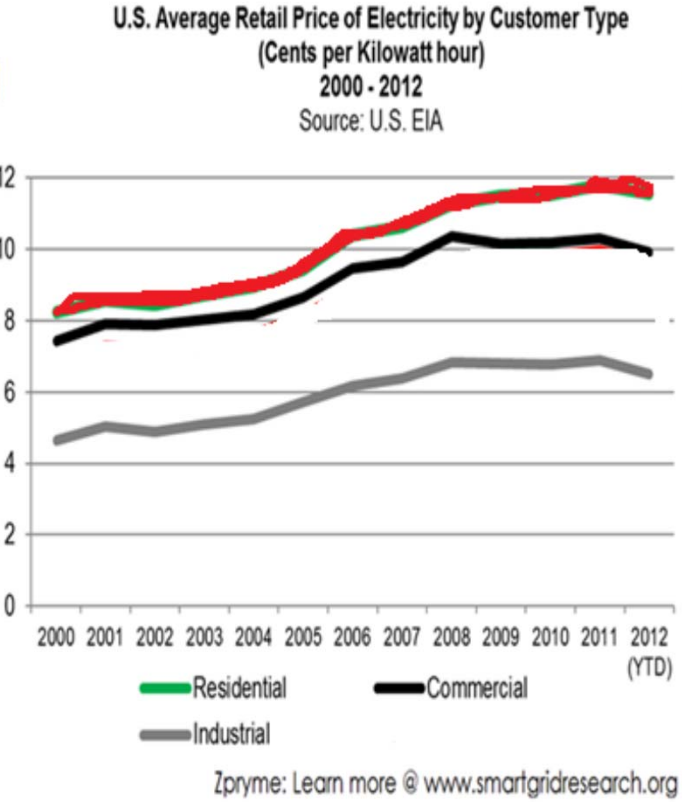


Average revenue per kilowatt-hour for all sectors by state, 2001. California in 1998 before restructuring was 9.03 ¢/kWh. *Source*: Energy Information Administration.

Industry Statistics: Price ($/kWh) Change

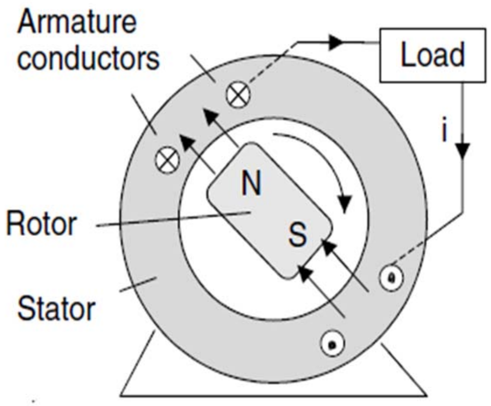


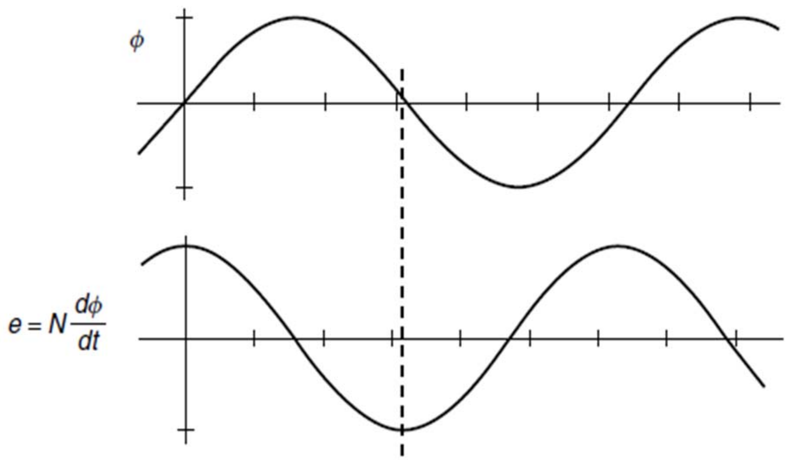
Average retail prices of electricity, by sector (constant $1996). From *EIA Annual Energy Review 2001* (EIA, 2003).



Synchronous Generators

- Simple Generator
- Theory: Electromagnetic Induction (1831) by Michael Faraday
- Rotating Magnetic Field (DC excited Rotor) + Armature (Stator)



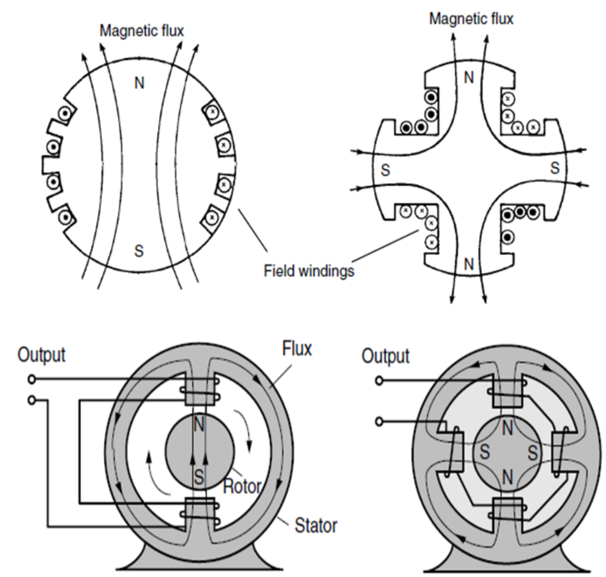


Changing flux in the stator creates an emf voltage across the windings.

Single-phase Synchronous Generators

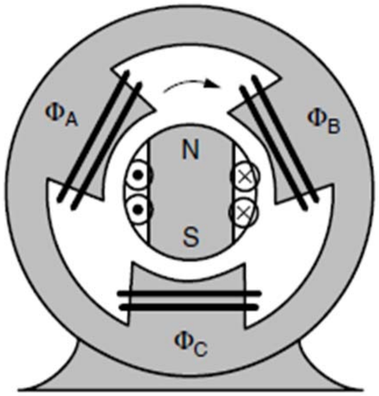
- Generation of voltage at 60 Hz
- Each revolution of the rotor gives one voltage cycle for a 2-pole generator
- The speed of rotor for 60Hz? (for a 2-pole generator)
  - 60 rps (revolutions per second) = 60 * 60 (min/sec) rpm (revolutions per minute) = **3600** rpm
  - Fixed speed machine = synchronous generator (synchronized with the utility system)
- 2-pole machine vs 4-pole machine
  - Speed for 4-pole machine for 60 Hz voltage?
  - 4-pole generator makes 2 voltage cycles per revolution
    →**1800** rpm
- General Equation for RPM (N_s) $$N_s = \frac{120f}{p}$$

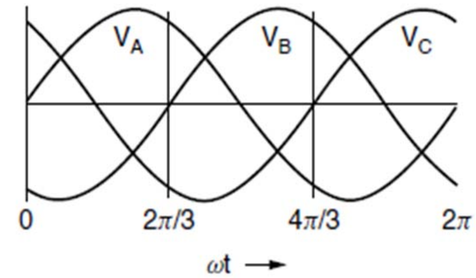
Poles p	50 Hz rpm	60 Hz rpm
2	3000	3600
4	1500	1800
6	1000	1200



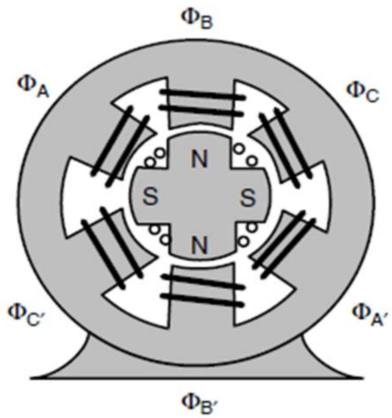
3-phase Synchronous Generators

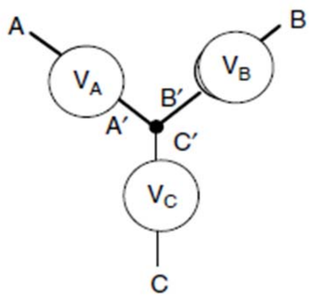
- Single magnetic rotor (2-pole)
- 3-winding stator 120 degrees apart
- Rotor sweeps by each winding
- Induces a voltage at each winding





- 4-pole 3-phase generator
- Salient-pole rotor
- 3 pairs of stator winding
- Half the rotor speed of 2-pole machine



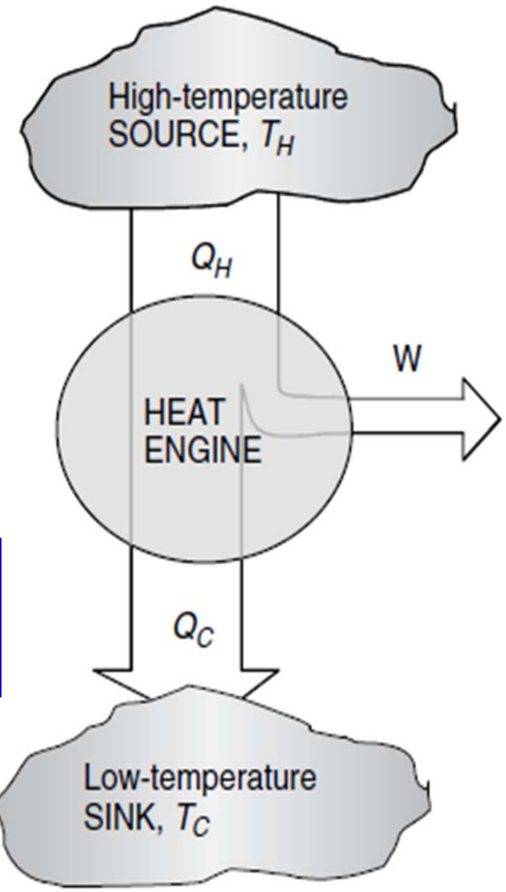


Heat Engines

- Conversion of heat into mechanical work
- Heat Sources:
  - nuclear reaction
  - fossil-fuel combustion
  - solar heater
- Heat (Q_H) → Boiled Water → Steam → Steam Turbine Spin (Work: **W**) + Remaining Heat (Q_C) → Other works by Remaining Heat (Q_C)
- $Q_H = W + Q_C$
- Thermal Efficiency = W/Q_H

$$\text{Efficiency} = \frac{\text{Net Work Output}}{\text{Total Heat Input}}$$

- Thermal Efficiency = $(Q_H - Q_C)/Q_H = 1 - Q_C/Q_H$
- Maximum Efficiency = $1 - T_C/T_H$

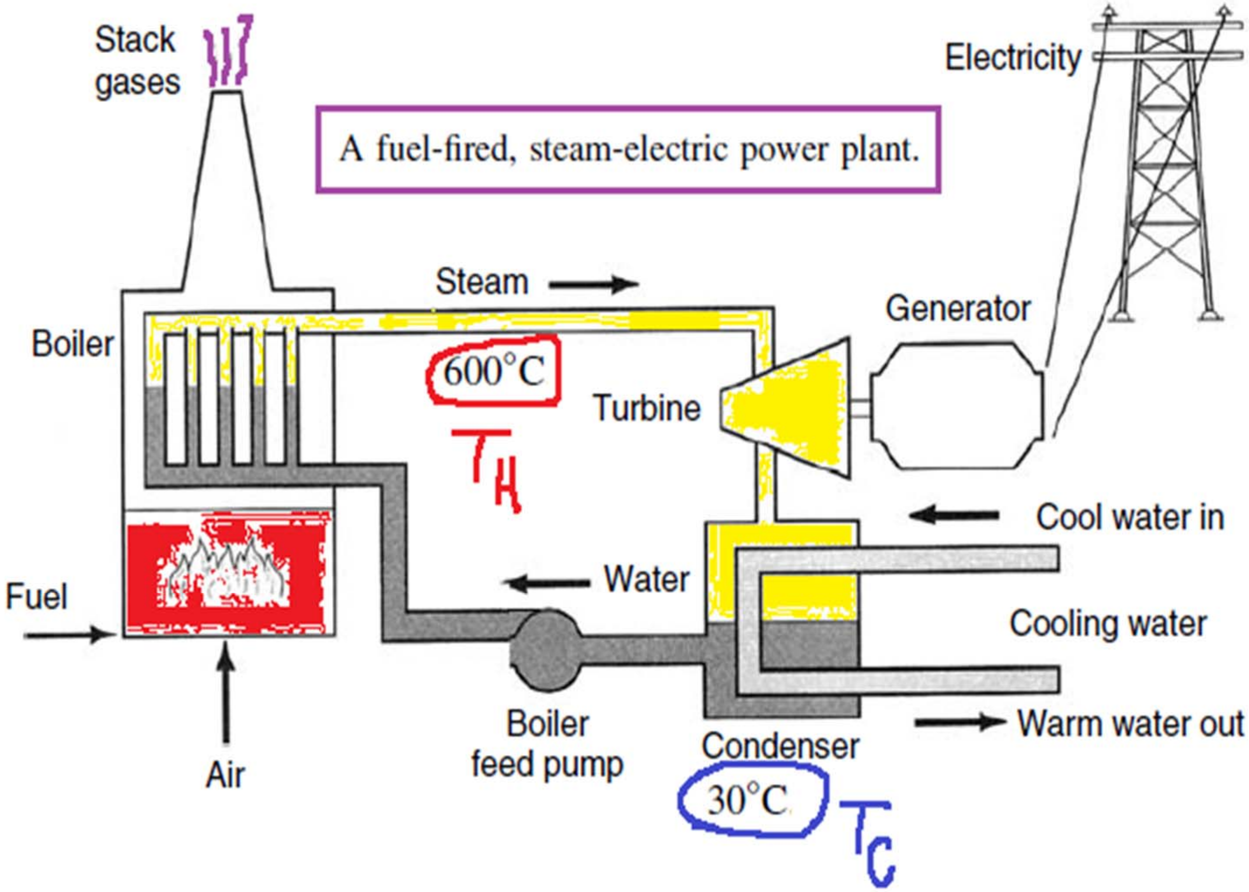


Thermodynamic Cycle

- Thermodynamic Cycle in converting heat into work
  - **Rankine Cycle**: A working fluid is alternately vaporized and condensed; Most baseload thermal power plants → steam is the working fluid
  - **Brayton Cycle**: Working fluid remains a gas throughout the cycle; Most peaking plants (on line as needed) with gas turbine.
  - **Combined Cycle**: Both of the above two cycles in use

Steam-Cycle

⌘ Basic Steam Cycle



A fuel-fired, steam-electric power plant.

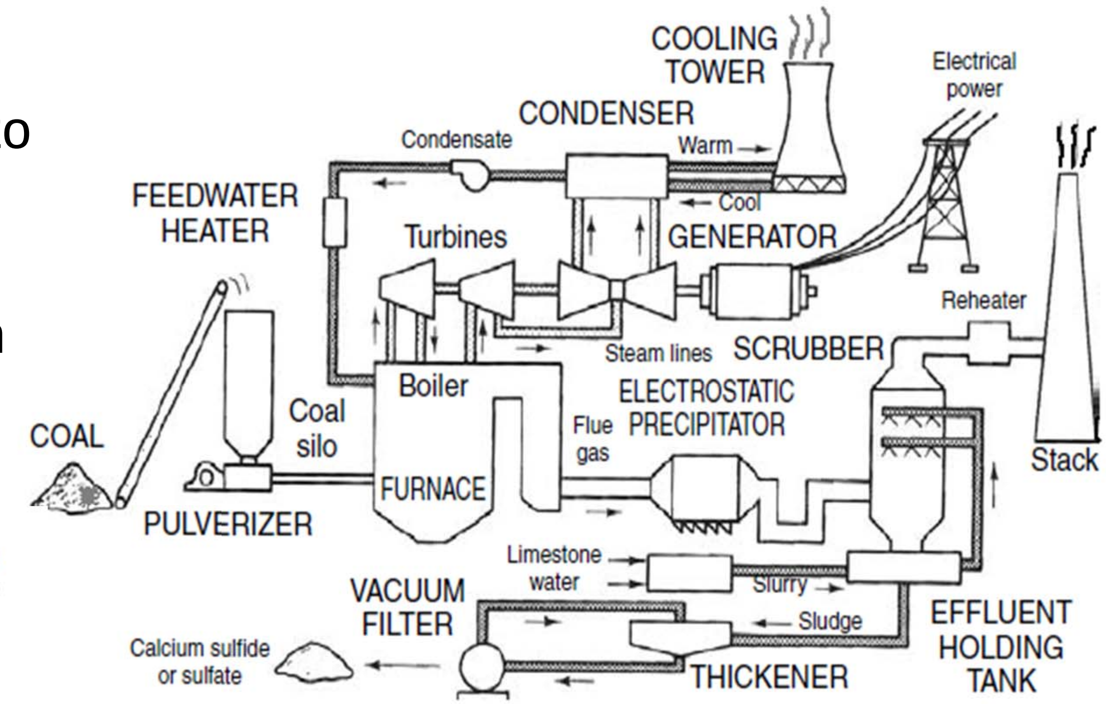
$$\eta = 1 - \frac{T_C}{T_H}$$

$$= 1 - \frac{30+273}{600+273}$$

$$\simeq 0.65$$

Steam-Cycle

- Coal-Fired Steam Cycle
- "Heat Rate" = "Thermal Input (Btu or kJ) required to deliver 1kWh of Electrical Output"
- 1 Btu/kWh = 1.055 kJ/kWh
- Heat Rate & Efficiency



SO2 Scrubber

$$\text{Heat rate (Btu/kWh)} = \frac{3412 \text{ Btu/kWh}}{\eta}$$

$$\text{Heat rate (kJ/kWh)} = \frac{3600 \text{ kJ/kWh}}{\eta}$$

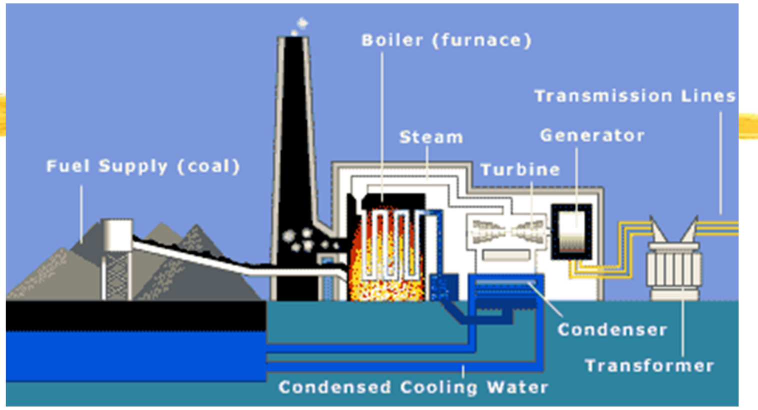
1 Btu = 3412 kwh

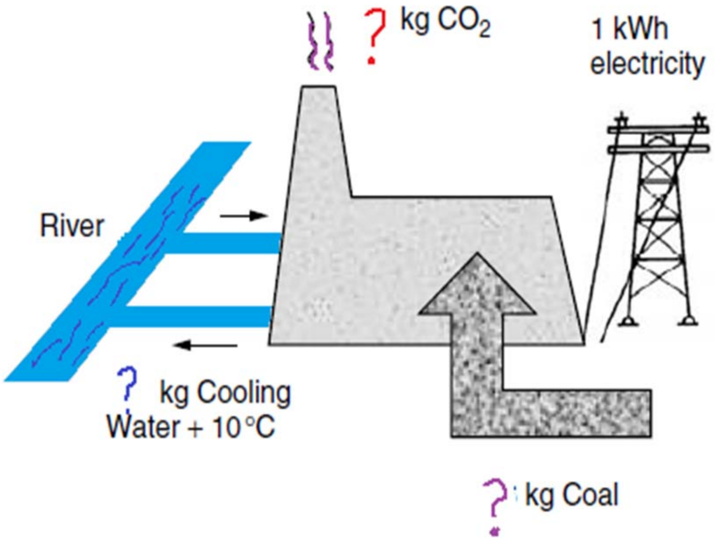
Edison's first plat
70,000 Btu/kWh
= 0.05 (efficiency)

Average steam plant
10,000 Btu/kWh
= 0.34 (Efficiency)

Material Balance - Example - Handout

- A power plant with a heat rate of 10,800 kJ/kWh
- Fuel: Bituminous Coal with 75% Carbon and a heating value (energy released when it is burned) of 27,300 kJ/kg.
- 15% of thermal losses are up the stack, and the remaining 85% are taken away by cooling water
- Q1: Find the efficiency of the plant
- Q2: Find the mass of coal that must be provided per kWh delivered
- Q3: Find the rate of carbon and CO2 emission from the plant in kg/kWh
- Q4: Find the minimum flow of cooling water per kWh if its temperature is only allowed to increase by 10 C.





Material Balance Example - Solution

- A power plant with a heat rate of 10,800 kJ/kWh
- Fuel: Coal with 75% Carbon and a heating value of 27,300 kJ/kg.
- 15% of thermal losses are up the stack, and the remaining 85% are taken away by cooling water

$$\text{Heat rate (kJ/kWh)} = \frac{3600 \text{ kJ/kWh}}{\eta}$$

- A1:

$$\eta = \frac{3600 \text{ kJ/kWh}}{10,800 \text{ kJ/kWh}} = 0.333 = 33.3\%$$

- A2:

$$\text{Coal rate} = \frac{10,800 \text{ kJ/kWh}}{27,300 \text{ kJ/kg}} = 0.396 \text{ kg coal/kWh}$$

- Q3:

$$\text{Carbon emissions} = 0.75 \times 0.396 \text{ kg/kWh} = 0.297 \text{ kgC/kWh}$$

molecular weight of CO_2 is $12 + 2 \times 16 = 44$, there are 12 kg of C in 44 kg of CO_2.

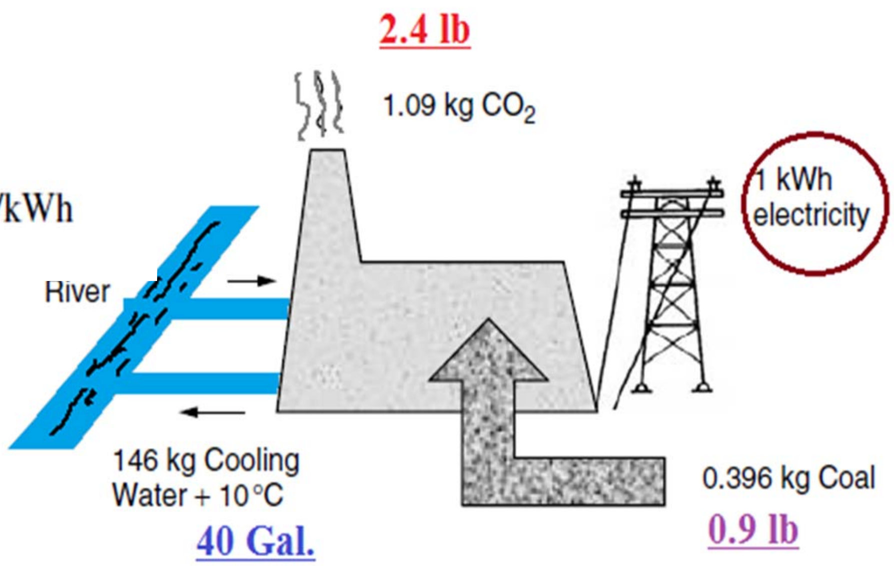
$$CO_2 \text{ emissions} = 0.297 \text{ kgC/kWh} \times \left(\frac{44 \text{ kg } CO_2}{12 \text{ kg C}}\right) = 1.09 \text{ kg } CO_2\text{/kWh}$$

Material Balance Example - Solution

- A power plant with a heat rate of 10,800 kJ/kWh
- Fuel: Coal with 75% Carbon and a heating value of 27,300 kJ/kg.
- 15% of thermal losses are up the stack, and the remaining 85% are taken away by cooling water
- A4:

Two-thirds of the input energy is wasted, and 85% of that is removed by the cooling water. It takes 4.184 kJ of energy to raise 1 kg of water by 1°C (the specific heat), so the minimum flow rate for cooling water to increase by less than 10°C will be

$$\text{Cooling water} = \frac{0.85 \times \left(\frac{2}{3}\right) \times 10{,}800\ \text{kJ/kWh}}{4.184\ \text{kJ/kg}^\circ\text{C} \times 10^\circ\text{C}} = 146.3\ \text{kg/kWh}$$



Material Balance – Class Activity 1

2/1/2017

Name: ______________________ ID #: ______________

Class Activity 1 on Material Balance

A new coal-fired power plant with a heat rate of 9000 Btu/kWh burns coal with an energy content of 24,000 kJ/kg. The coal content includes 62-% carbon, 2-% sulfur and 10-% unburnable minerals called *ash*.

heating value

a. What will be the carbon emission rate (g C/kWh)?

b. What will be the uncontrolled sulfur emission rate (g S/kWh)?

c. If 70% of the ash is released as particular matter from the stack (called *fly ash*), what would be the uncontrolled particulate emission rate (g/kWh)?

Answer ______________________

d. Efficiency?

Material Balance – Class Activity 1

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Activity 1- Material Balance

A new coal-fired power plant with a heat rate of 9000 Btu/kWh burns coal with an energy content of 24,000 kJ/kg. The coal content includes 62-% carbon, 2-% sulfur and 10-% unburnable minerals called *ash*.

a. What will be the carbon emission rate (g C/kWh)?

b. What will be the uncontrolled sulfur emission rate (g S/kWh)?

c. If 70% of the ash is released as particular matter from the stack (called *fly ash*), what would be the uncontrolled particulate emission rate (g/kWh)?

d. Efficiency?

$eHeatRate := 9000$ Btu / kWh

$HeatRate := eHeatRate \cdot 1.055 = 9495$ kJ / kWh

$HeatValue := 24000$ kJ / kg

$CoalRate := \frac{HeatRate}{HeatValue} = 0.3956$ kg / kWh

$Carbon := CoalRate \cdot 0.62 = 0.2453$ kg C /kWh

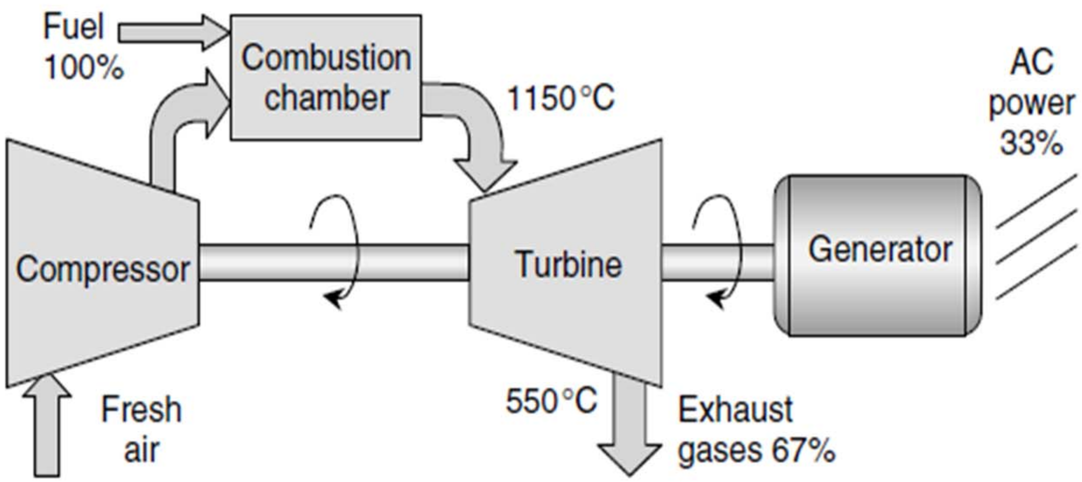
$Sulfur := CoalRate \cdot 0.02 = 0.0079$ kg S /kWh

$Ash := CoalRate \cdot 0.1 \cdot 0.7 = 0.0277$ g Ash/kWh

$\eta := \frac{3600}{HeatRate} \cdot 100 = 37.9146919$ percent

Combustion Gas Turbines

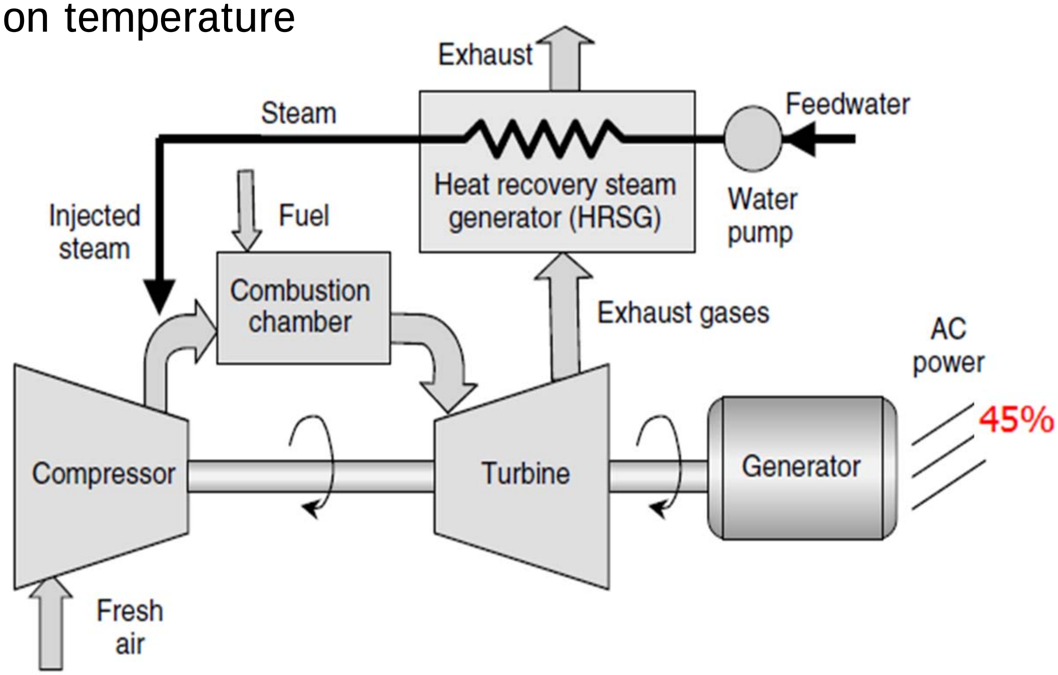
- Fuel: Natural Gas
- Compressor and Turbine shares a connecting shaft
  - ½ the rotational energy created by the spinning turbine is used to power the compressor
- Basic gas turbine



- High Efficiency Gas Turbine: Derivatives of Jet Aircraft; "Aeroderivative turbine"; small-size; quick and numerous up/down

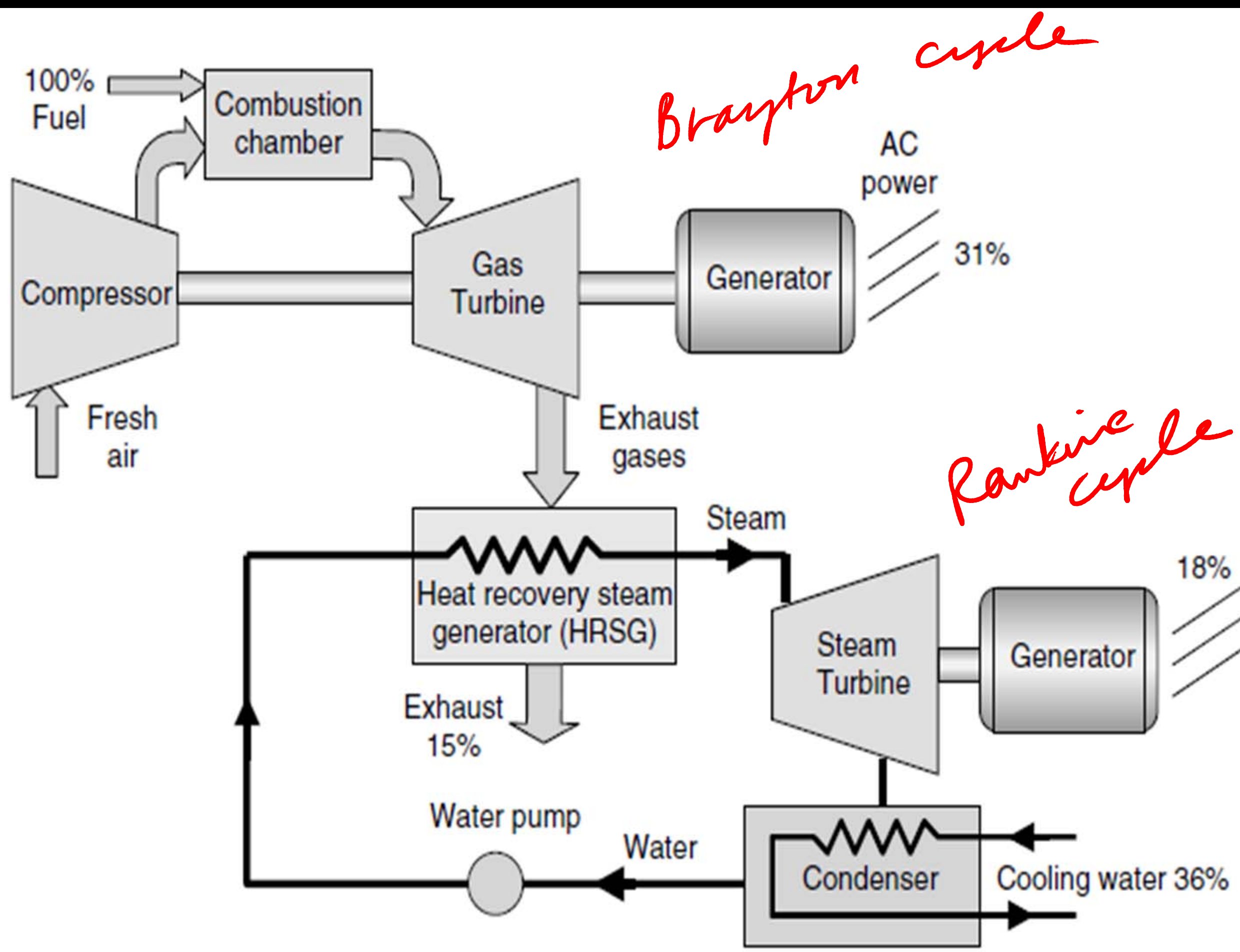
Combustion Gas Turbines

- Steam-Injected Gas Turbine (STIG)
  - Increased Efficiency by a heat exchanger
  - Heat Recovery Steam Generation (HRSG)
    - Injected Steam
    - Effect of fuel reduction
  - HRSG reduces the combustion temperature
    - Reduced NOx emission
  - Efficiency 45%
  - More Expensive



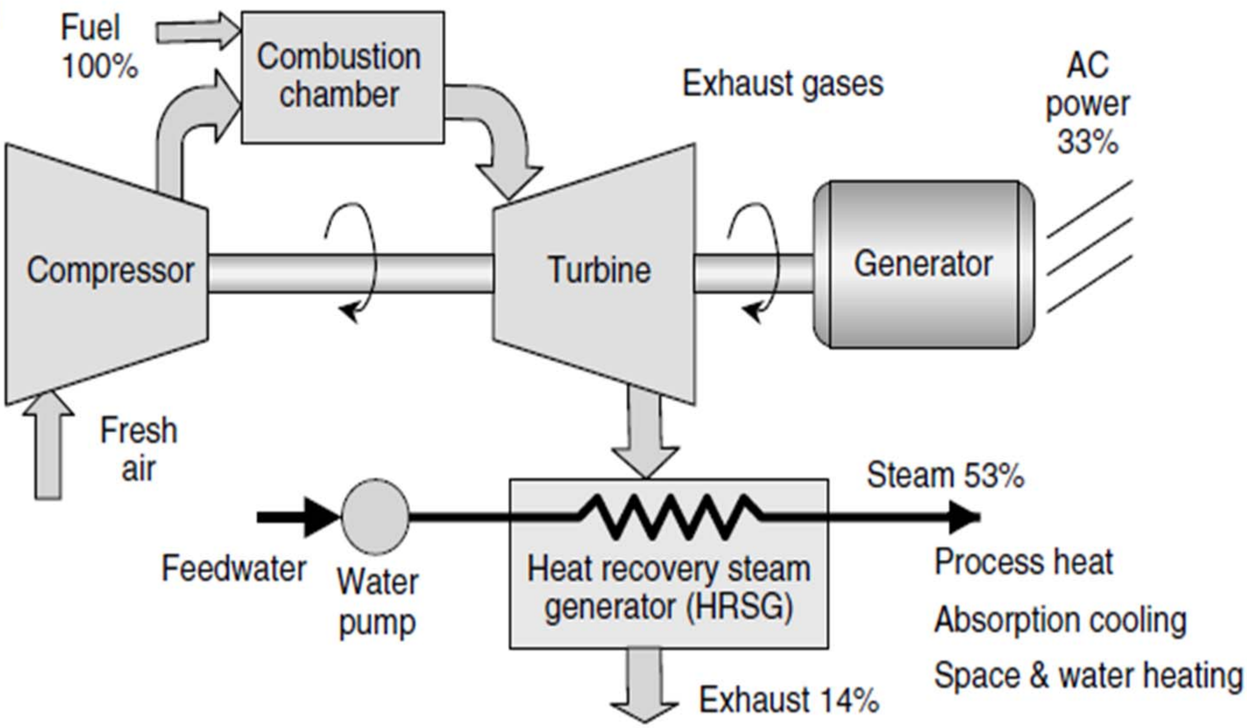
Combined-Cycle Power Plant

- Gas turbine waste heat can be used to power a second-stage steam turbine →Coupling a gas turbine and steam turbine → Combined Cycle Plant
- 49% Efficiency



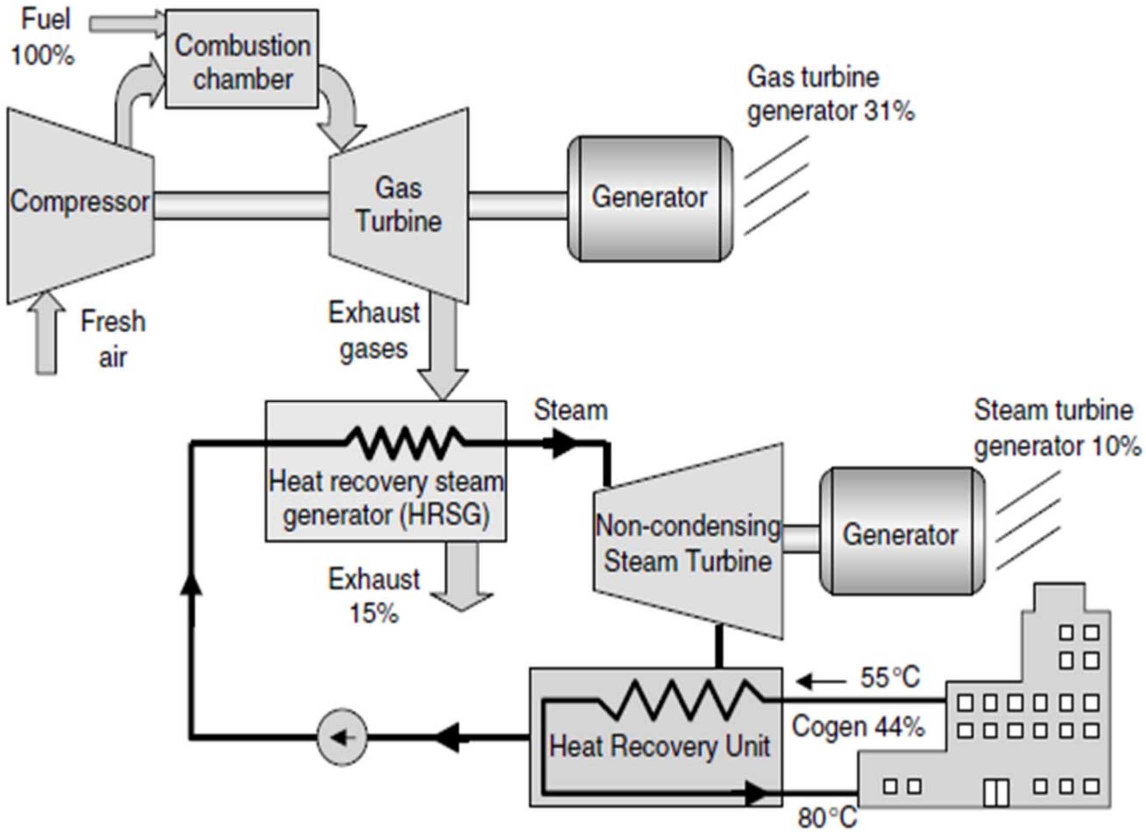
Combined-Cycle Cogeneration 1

- Gas turbine exhaust heat > 500 C
- Cogeneration: Electricity + Thermal Energy
- Use of thermal energy
  - Industrial heating
  - Space heating



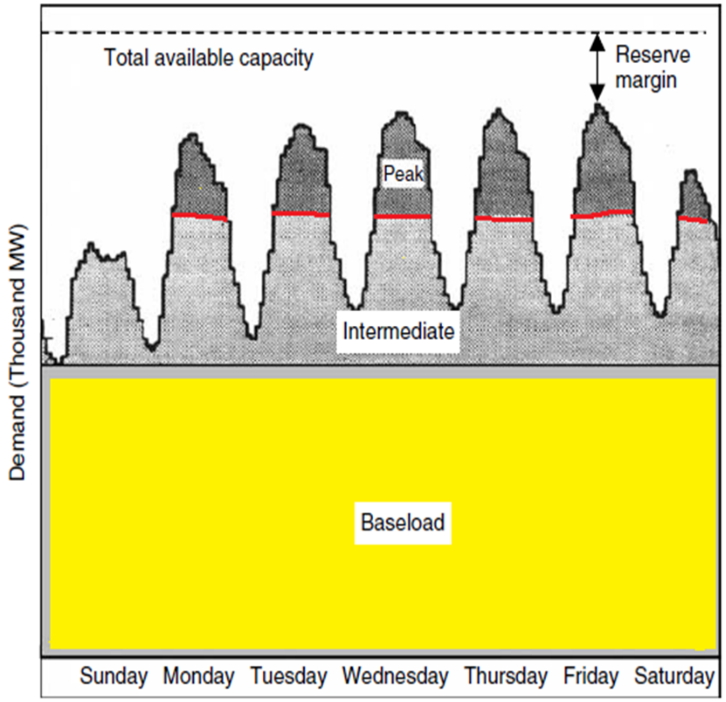
Combined-Cycle Cogeneration 2

- Cogeneration: Electricity + Thermal Energy (Steam Turbine Electricity Generation + Heating)



Roles of Different Power Plants

- Load: Daily Patterns (Day and Night), Weekly Patterns, and Seasonal Patterns
- Baseload plants:
  - **Coal-fired plants**
  - **Hydroelectric plants**
  - **Nuclear plants**
- Intermediate load plants
  - Day-time operation
  - **Combined-Cycle plants**
- Peak load plants
  - **Gas turbines**
- Economic dispatch
  - Economic characteristics of different types of power plants
  - Cost Parameters → Screening Curve



Dispatch

- **Dispatch**: "Selection process of plants to operate at a given time"
- Dispatch plants by the **operating costs** from lowest to highest
- **Renewables** (intermittent operational characteristics) (very low operating costs) should be dispatched first whenever they are available → so they are part of the **baseload**
- **Hydro** is useful as a dispatch-able source that may supplement **baseload, intermittent, or peak loads**, especially when existing facilities are down for maintenance or other reasons.

Cost Parameters

- **Fixed cost**:
  - cost must be spent even if the power plant is turned off
  - Capital costs, taxes, insurance, fixed O&M cost, etc
- **Variable cost**:
  - added cost associated with actually running the plant
  - Fuel cost
  - operational O&M costs
- **Fixed Charge Rate (FCR)**:
  - FCR per year accounts for interest on loans, acceptable returns of investors, fixed O&M charges, taxes, etc.
  - 11 – 18% per year

Cost Parameters

- **Annualized fixed cost** ($/yr-kW)

  = Capital Cost ($/kW) x FCR(/year)
- **Annualized variable cost** ($/yr-kW)

  = [Fuel ($/Btu) x Heat_Rate (Btu/kWh) + O&M ($/kWh] x H/yr

  H: Operating hour per year
- **Total Cost**

  = [Annualized fixed cost] + [annualized variable cost]
- **Electricity Cost**

  = Total_Cost ($/yr) /Total_Generation (kWh/yr)

Example Cost Parameters

Example Cost Parameters for Power Plants

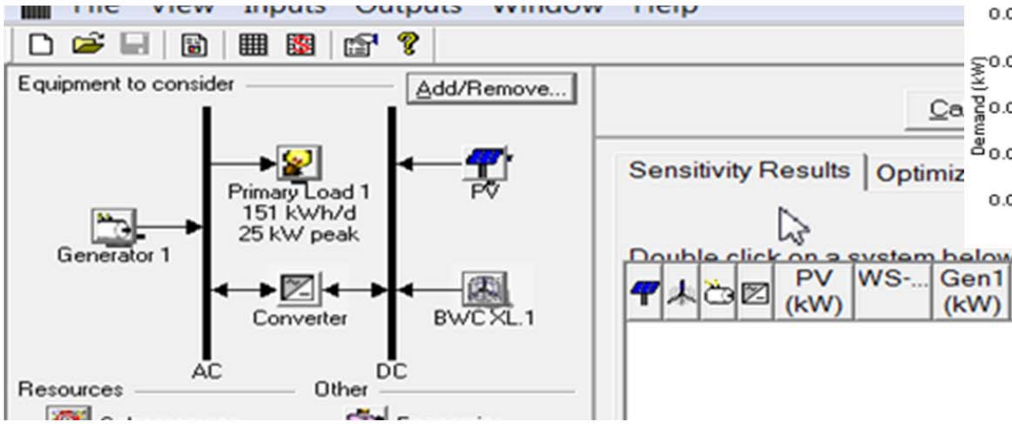
Technology	Fuel	Capital Cost ($/kW)	Heat Rate (Btu/kWh)	Fuel Cost ($/million Btu)	Variable O&M (¢/kWh)
Pulverized coal steam	Coal	1400	9,700	1.50	0.43
Advanced coal steam	Coal	1600	8,800	1.50	0.43
Oil/gas steam	Oil/Gas	900	9,500	4.60	0.52
Combined cycle	Natural gas	600	7,700	4.50	0.37
Combustion turbine	Natural gas	400	11,400	4.50	0.62
STIG gas turbine	Natural gas	600	9,100	4.50	0.50
New hydroelectric	Water	1900	—	0.00	0.30

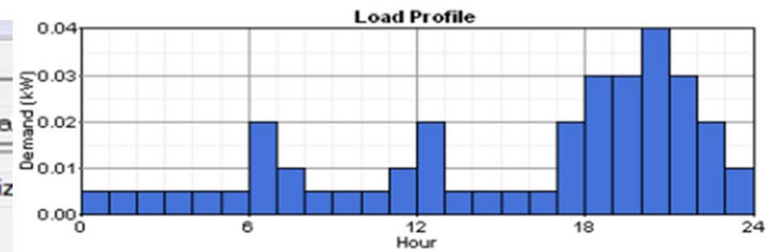
Source: Based on data from Petchers (2002) and UCS (1992).

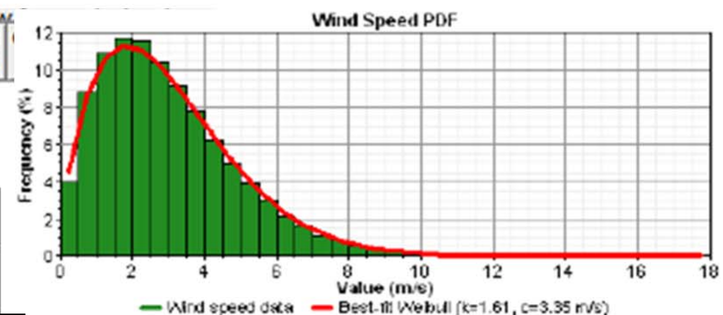
⌘ Note: Cost for renewable electricity will be studied using HOMER (legacy, free) software (Preview – next page)

PV Cost Parameters for HOMER (Preview)

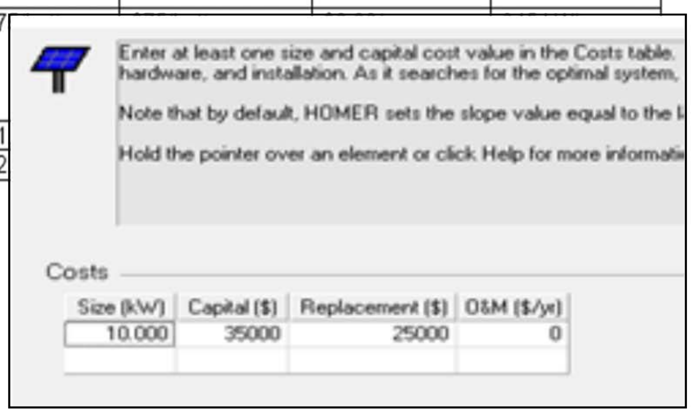
⌘ Cost for renewable electricity will be studied using HOMER (legacy, free) software

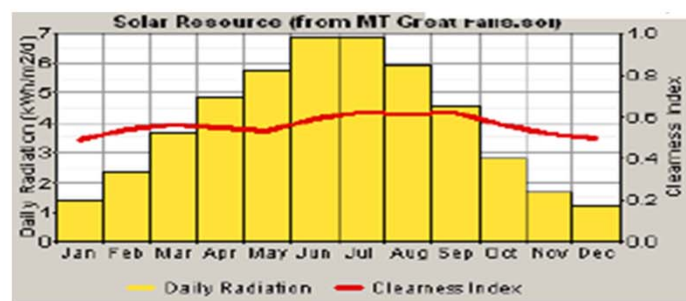






Component	Size	Capital Cost ($)	Replacement Cost	O&M Cost ($)	Lifetime
PV Panels	0.05 – 5.0 kW	$7,500/kW	$7,500/kW	0.00	20 years
Trojan T-105 Batteries	225 Ah / 6 volt (bank size: 1 – 54 batteries)	$7			
Converter	0.1 – 4.0 kW	$1			
Generator	4.25 kW	$2			





Electricity Cost Example - Handout

- A pulverized-coal Steam Plant
- A fixed charge rate (FCR) = 0.16/yr
- Operating hours per year = 8000
- Q1: Find the annualized revenue required?
- Q2: What should be the price of electricity from this plant?

Technology	Fuel	Capital Cost ($/kW)	Heat Rate (Btu/kWh)	Fuel Cost ($/million Btu)	Variable O&M (¢/kWh)
Pulverized coal steam	Coal	1400	9,700	1.50	0.43
Advanced coal steam	Coal	1600	8,800	1.50	0.43

Plant Operation and CF(Capacity Factor)

- In the Example, the operating hours per year is assumed to be 8000 hours with full power → 760 hours of no (zero) power
- It could be that: plant operated 8760 hours per year but not always at the full power
- Annual Output (kWh/yr)

  = Rated_Power (kW) x 8760 h/yr x CF (Capacity Factor)
- CF (in the example)

  = 8000/8760 = 0.9132
- Capacity Factor (CF)

  = {Average_Power}/ {Rated_Power}

Plant Operation and CF(Capacity Factor)

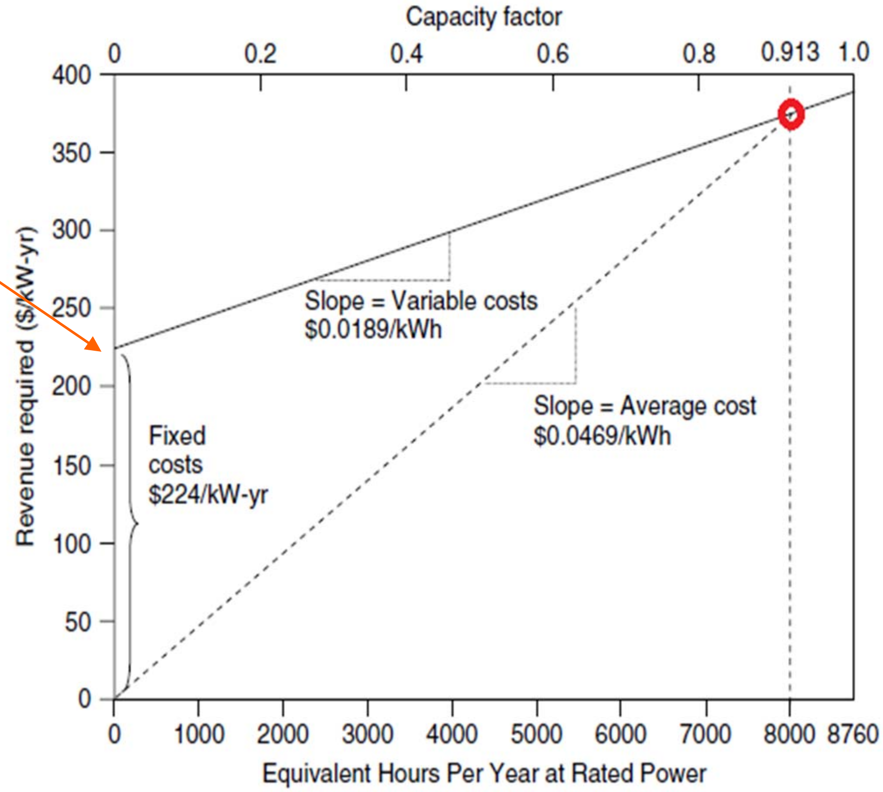
- Fixed Costs

= 1400 [$/kW] x 0.16/yr

= **224 [$/kW-yr]**

(FCR) = 0.16/yr

Technology	Fuel	Capital Cost ($/kW)	Heat Rate (Btu/kWh)	Fuel Cost ($/million Btu)	Variable O&M (¢/kWh)
Pulverized coal steam	Coal	1400	9,700	1.50	0.43
Advanced coal steam	Coal	1600	8,800	1.50	0.43



Plant Operation and CF(Capacity Factor)

(FCR) = 0.16/yr Technology	Fuel	Capital Cost ($/kW)	Heat Rate (Btu/kWh)	Fuel Cost ($/million Btu)	Variable O&M (¢/kWh)
Pulverized coal steam	Coal	1400	9,700	1.50	0.43
Advanced coal steam	Coal	1600	8,800	1.50	0.43

- Fixed Costs

= 1400 [$/kW] x 0.16/yr

= **224 [$/kW-yr]**

- Variable Costs

=(1.5/10^6 [$/Btu] x 9700 [Btu/KWh]

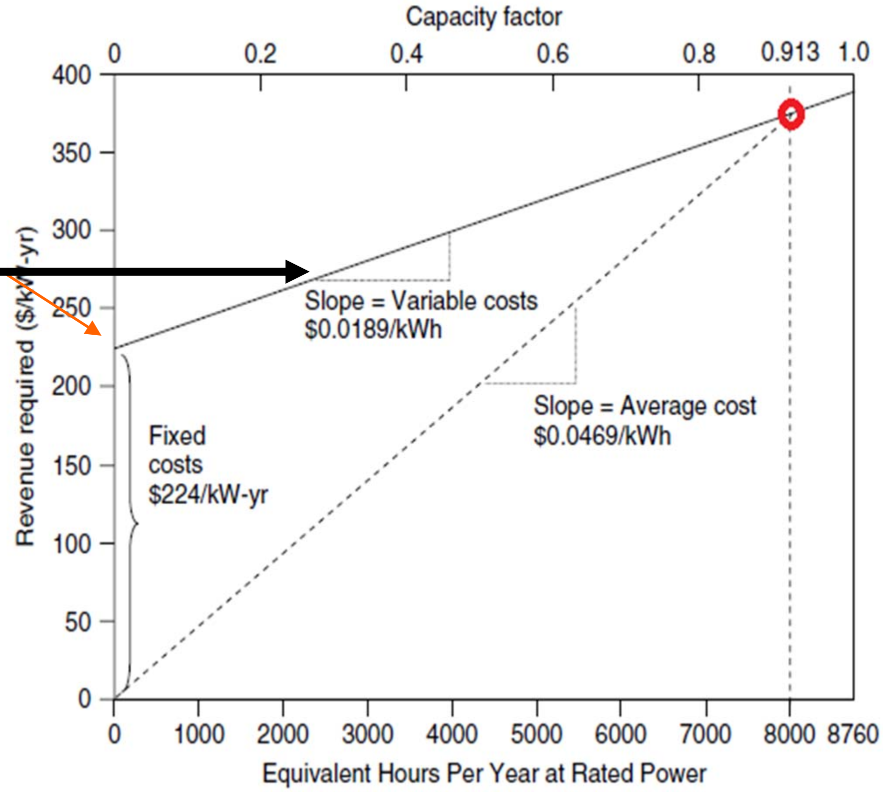
+ 0.0043 [$/kWh])

x 8000 [h/yr]

= 150.80 [$/kW-yr]

= 150.80 [$/kW-yr]/8000 [h/yr]

= **0.0189 [$/kWh]**



Plant Operation and CF(Capacity Factor)

(FCR) = 0.16/yr

Technology	Fuel	Capital Cost ($/kW)	Heat Rate (Btu/kWh)	Fuel Cost ($/million Btu)	Variable O&M (¢/kWh)
Pulverized coal steam	Coal	1400	9,700	1.50	0.43
Advanced coal steam	Coal	1600	8,800	1.50	0.43

⌘ Fixed Costs

= 1400 [$/kW] x 0.16/yr

= **224 [$/kW-yr]**

⌘ Variable Costs

=(1.5/10^6 [$/Btu] x 9700 [Btu/KWh]

+ 0.0043 [$/kWh])

x 8000 [h/yr]

= 150.80 [$/kW-yr]

= 150.80 [$/kW-yr]/8000 [h/yr]

= **0.0189 [$/kWh]**

⌘ Annualized Revenue required

= Fixed costs + variable costs

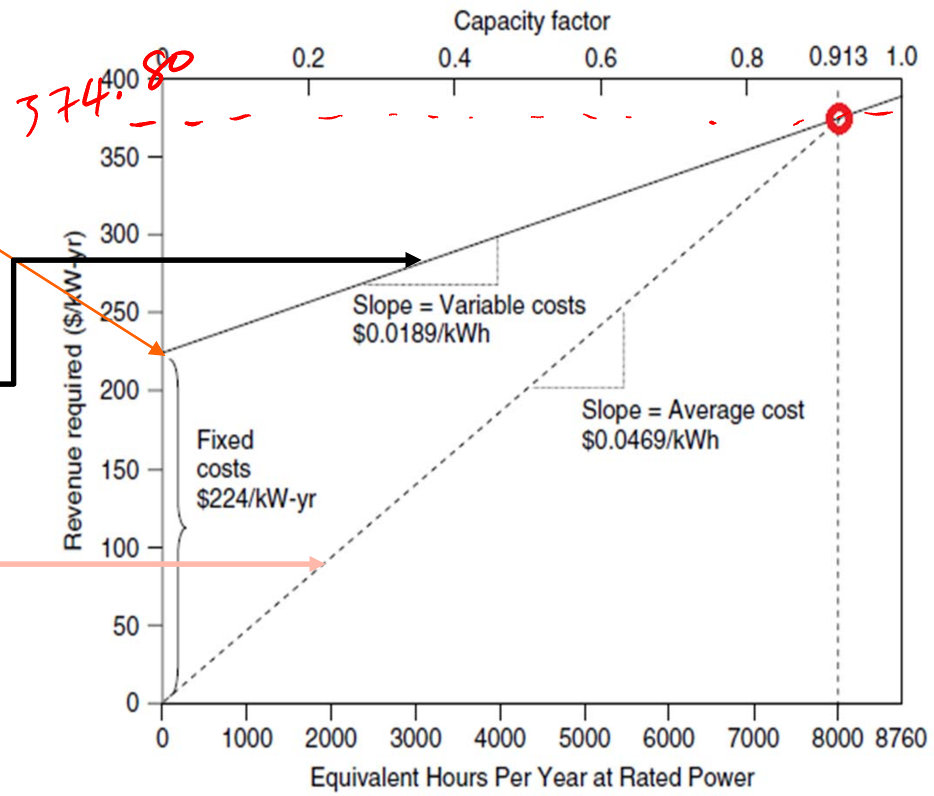
= (224+150.80) [$/kW-yr]

= 374.80 [$/kW-yr]

=374.80 [$/kW-yr]/8000 [h/yr]

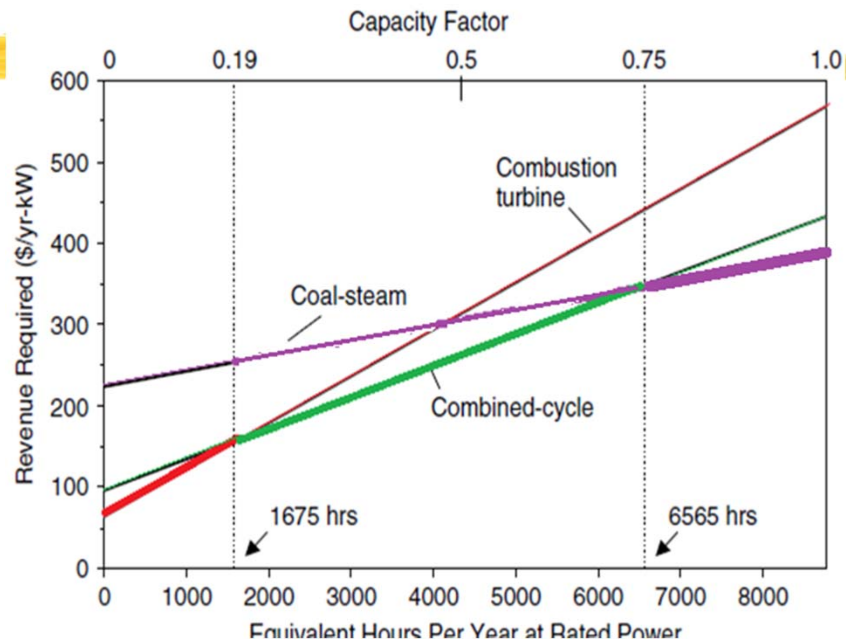
= **0.0469 [$/kWh]**

⌘ **CF at the circle = 0.913**



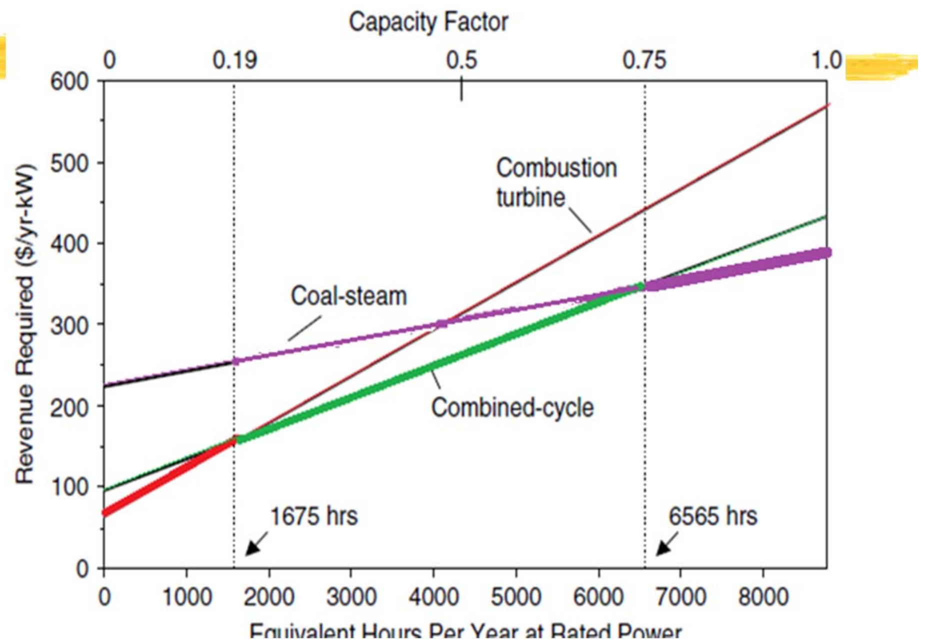
Screening Curves

- **Screening Curve**:
- Annual revenue as a function of operation hours per year required to pay fixed and variable costs
- Cost curves for different power plants on the same axis
- Example Curves
  - Coal-Steam
  - Combustion Turbine
  - Combined-Cycle



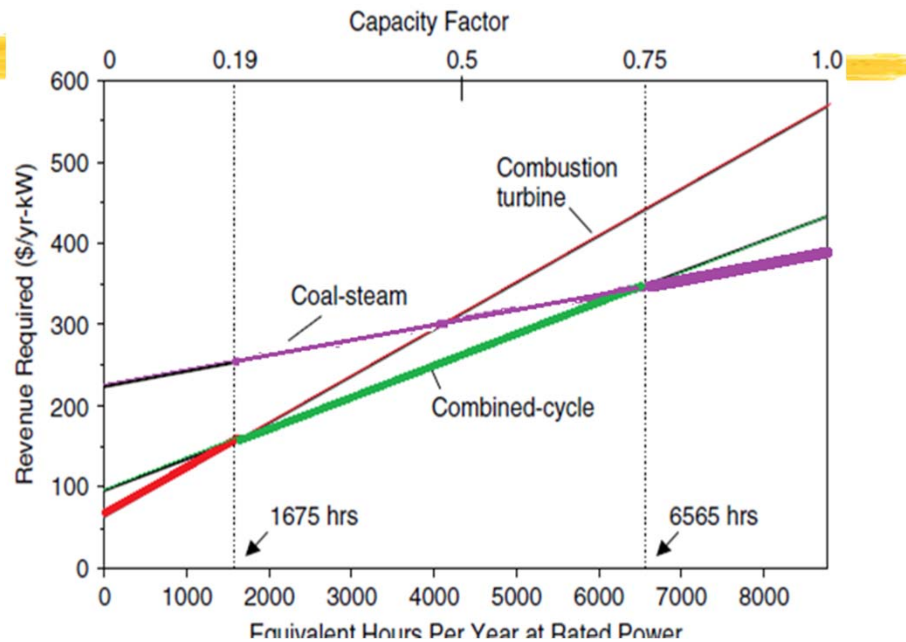
Screening Curves

- **Screening Curve**: Annual revenue as a function of operation hours per year required to pay fixed and variable costs
- Cost curves for different power plants on the same axis
- **Combustion turbine**
  - cheapest to build (Lowest fixed cost)
  - expensive to operate (steepest variable cost slope)
  - viable when operating no more than 1675 hours per year with CF < 0.19
  - best choice for peaking plant



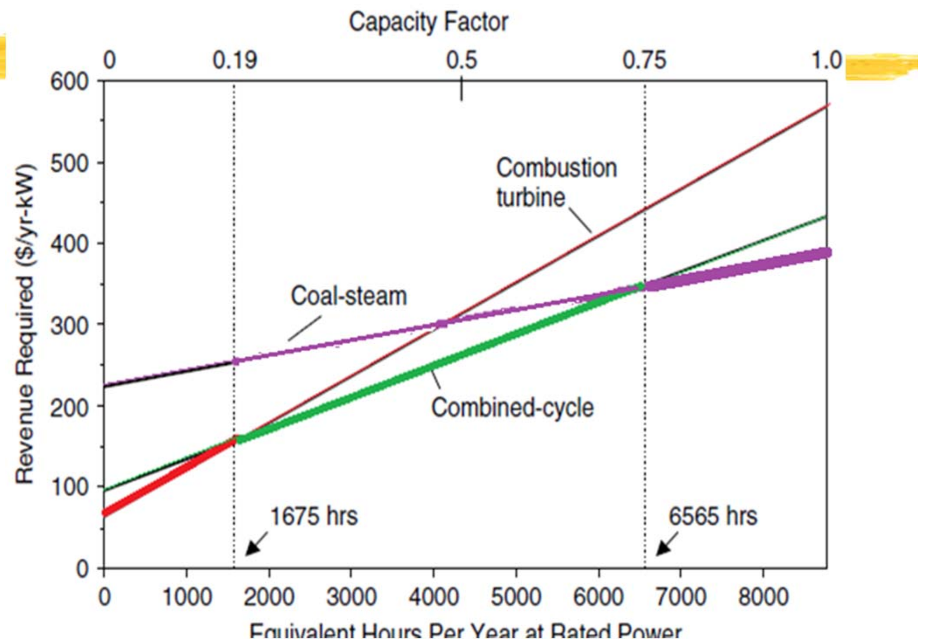
Screening Curves

- **Screening Curve**: Annual revenue as a function of operation hours per year required to pay fixed and variable costs
- Cost curves for different power plants on the same axis
- **Coal-steam plant**
  - high capital cost
  - low fuel cost
  - least expensive as long as it runs at least 6565 hours per year (CF > 0.75)
  - best choice for baseload plant



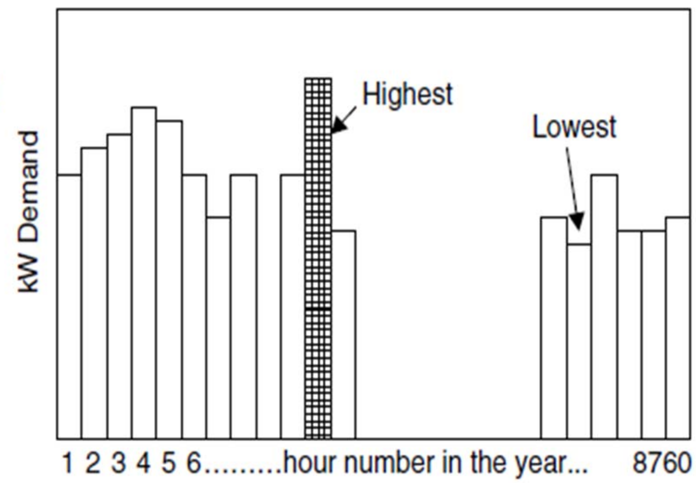
Screening Curves

- **Screening Curve**: Annual revenue as a function of operation hours per year required to pay <u>fixed</u> and <u>variable costs</u>
- Cost curves for different power plants on the same axis
- **Combined cycle plant**
  - cheapest if it operates between 1675 and 6565 hours (0.19 <CF <0.75)
  - best intermediate load plant



Load-Duration Curves

- Hourly Load Curve
  - Hourly kW demand → The area is kWh or energy used in that hour

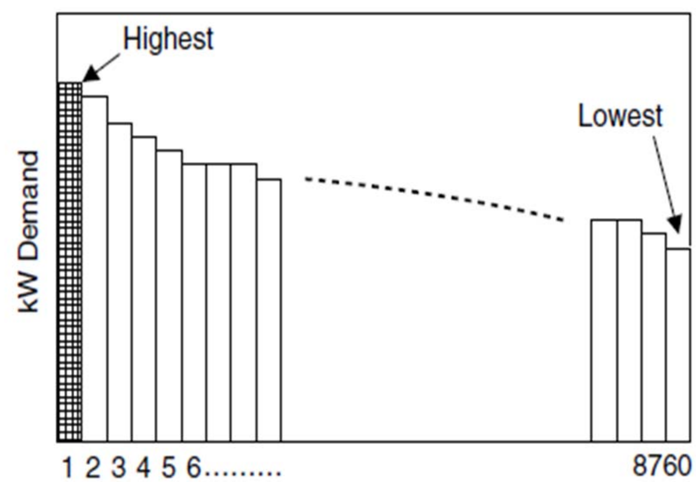


HOUR-BY-HOUR LOAD CURVE...

Area of each rectangle is kWh of energy in that hour...

Total area is kWh/yr

- Load-Duration Curve
  - Rearranged Hourly load curve in the order of load magnitude



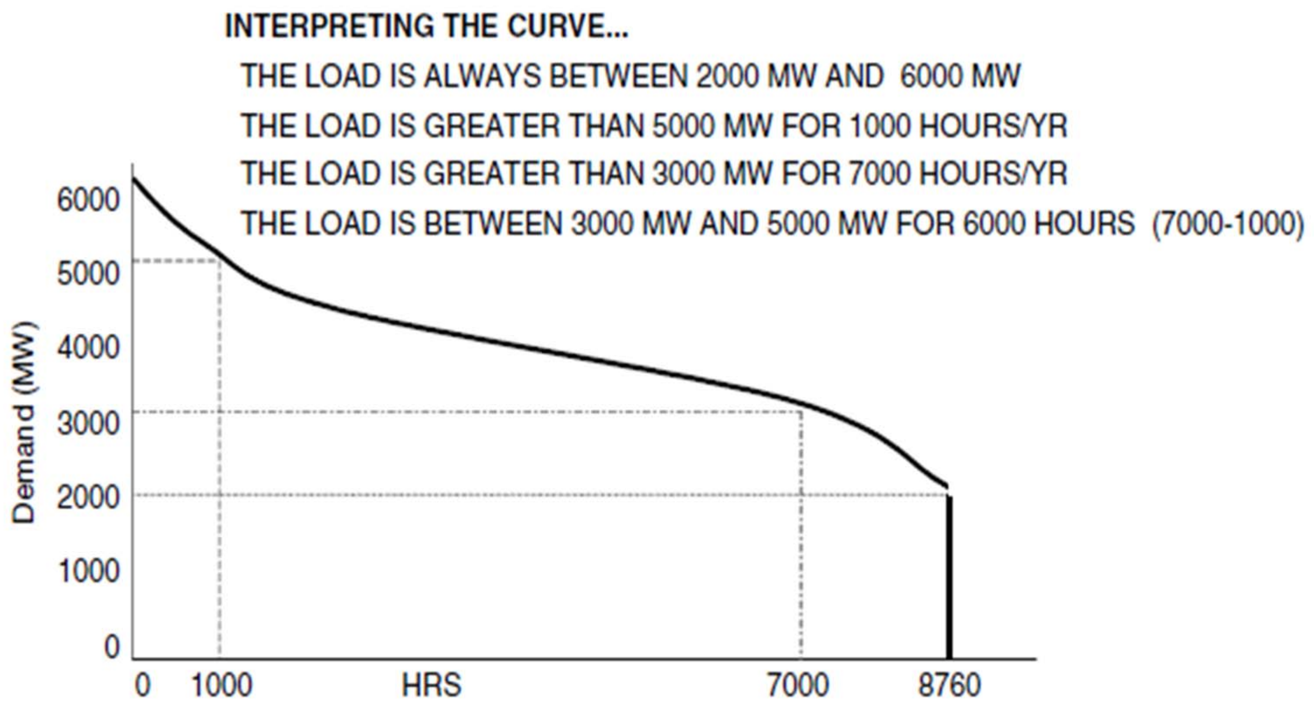
LOAD CURVE REORDERED FROM HIGHEST TO LOWEST..

Total area is still kWh/yr

"LOAD–DURATION CURVE"

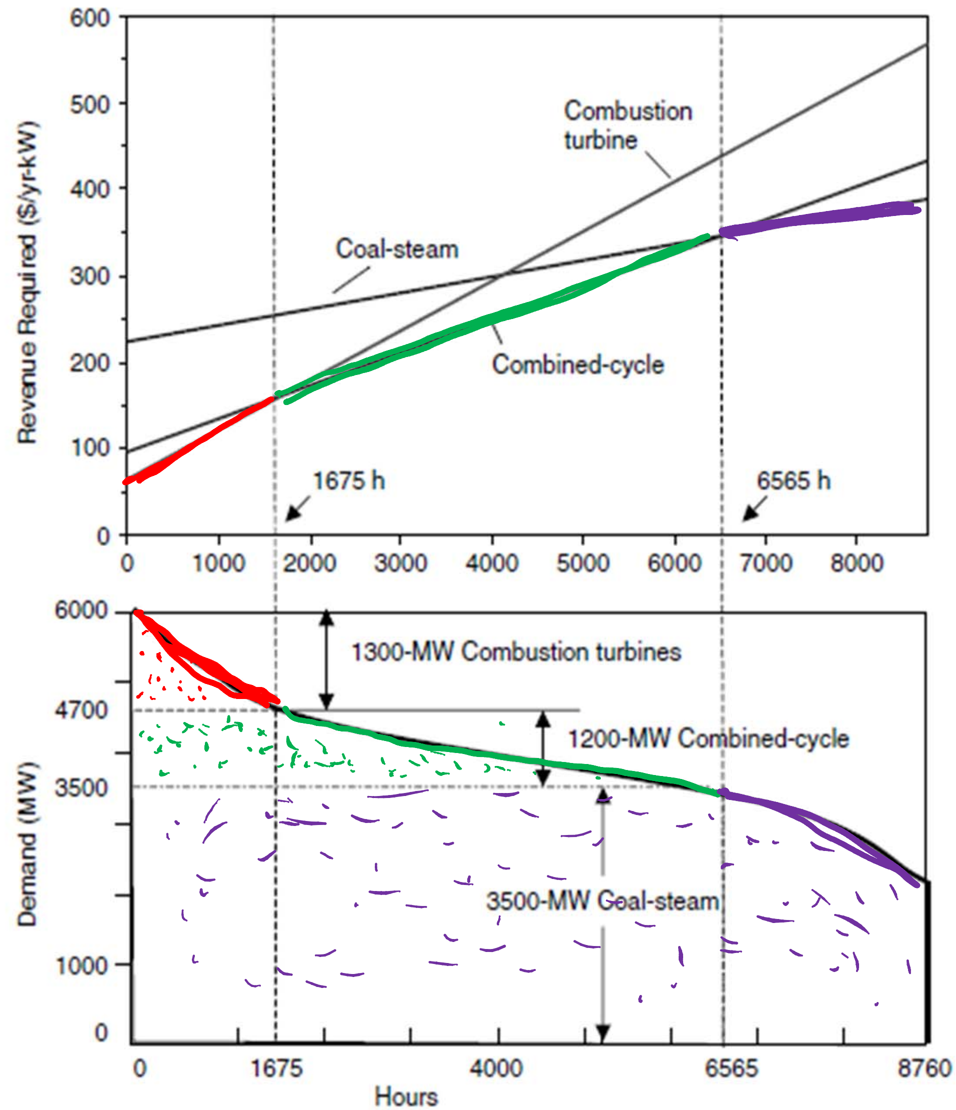
Load Duration Curve

- A smooth version of a load-duration curve



Screening Curve and Load-Duration Curve

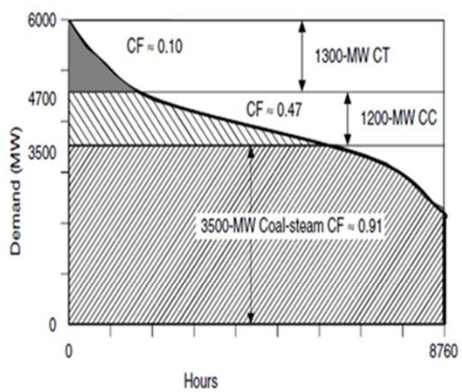
- Determination of on optimum mix of power plants
- Crossover Points for the first Cut Estimate of Generation Mix
- > 6565 hours → Demand of 3500 MW → Coal-Steam
- < 6565 hours → Demand of 1200 MW → Combined-Cycle
- < 1675 hours → Demand of 1300 MW → Combustion Turbine



CF and Generation Mix - Handout

- CF for each power plant is the fraction of the shaded area to the horizontal rectangular
- EXAMPLE of Unit Cost of Electricity for the generation mix
- The peaker plant electricity is much more expensive
  - Lower efficiency
  - Expensive fuel – natural gas
  - Capital cost is spread over so few kW-hour of output --- they are used so little

Using the Generation mix and cost table, fill the boxes for each of the generation types.



Generation Type	Rated Power (MW)	CF	Fixed Cost (million $/yr)	Variable ($/kWh)	B Output (billion kWh/yr)	A Total Cost (billion $/yr)	A/B Unit Cost (¢/kWh)
Coal-steam	3500	0.91	784.0	0.0189			
Combined-cycle	1200	0.47	115.2	0.0390			
Combustion turbine	1300	0.10	83.2	0.0556			

Annual output (kWh/yr)
= Rated power (kW) × 8760 h/yr × CF

(a) Coal: annualized Fixed Cost= [$/yr]
annualized Variable Cost = [$/yr]
TotalCost = annualized Fixed Cost + annualized Variable Cost [$/yr]
Pout = RatedPower * CF * 8760 hours [kWh/yr]
UnitCost = TotalCost/Pout [$/kWh]

(b) Combined Cycle

CF and Generation Mix - Handout

- CF for each power plant is the fraction of the shaded area to the horizontal rectangular
- EXAMPLE of Unit Cost of Electricity for the generation mix
- Worked-Out for Coal Steam

Given

$RatedPowerCOAL := 3500$ MW

$cfCOAL := 0.91$

$annualizedFixedCostCOAL := 784 \cdot 10^{6}$ \$ / yr

$VariableCostCOAL := 0.0189 = 0.0189$ \$ /kWh

Calculation

$PoutCOAL := RatedPowerCOAL \cdot 10^{3} \cdot 8760 \cdot cfCOAL = 2.7901 \cdot 10^{10}$ kWh / yr

$annualizedVariableCostCOAL := VariableCostCOAL \cdot PoutCOAL = 5.2732 \cdot 10^{8}$ \$ / yr

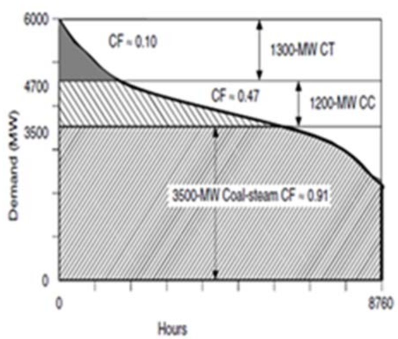
$TotalCostCOAL := annualizedFixedCostCOAL + annualizedVariableCostCOAL = 1.3113 \cdot 10^{9}$ \$ / yr

$UnitCostCOAL := \frac{TotalCostCOAL}{PoutCOAL} = 0.047$ \$ / kWh

CF and Generation Mix - Handout

- CF for each power plant is the fraction of the shaded area to the horizontal rectangular
- EXAMPLE of Unit Cost of Electricity for the generation mix
- The peaker plant electricity is much more expensive
  - Lower efficiency
  - Expensive fuel – natural gas
  - Capital cost is spread over so few kW-hour of output --- they are used so little

Using the Generation mix and cost table, fill the boxes for each of the generation types.



Generation Type	Rated Power (MW)	CF	Fixed Cost (million $/yr)	Variable ($/kWh)	B Output (billion kWh/yr)	A Total Cost (billion $/yr)	A/B Unit Cost (¢/kWh)
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Combustion turbine	1300	0.10	83.2	0.0556			

Annual output (kWh/yr)
= Rated power (kW) × 8760 h/yr × CF

(a) Coal:
annualized Fixed Cost= [$/yr]
annualized Variable Cost = [$/yr]
TotalCost = annualized Fixed Cost + annualized Variable Cost [$/yr]
Pout = RatedPower * CF * 8760 hours [kWh/yr]
UnitCost = TotalCost/Pout [$/kWh]

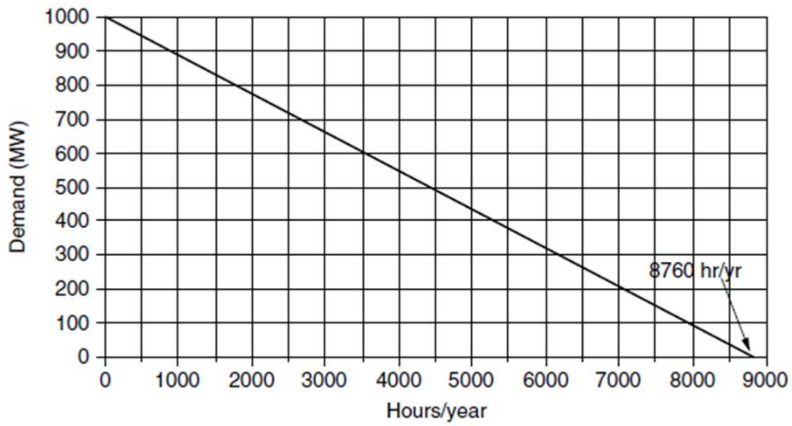
(b) Combined Cycle

27.99	1.312	4.69
4.94	0.308	6.23
1.14	0.147	12.87

SOLUTION

Class Activity - Handout

Consider the following very simplified load duration curve for a small utility:



a. How many hours per year is the load less than 200 MW?

b. How many hours per year is the load between 300 MW and 600 MW?

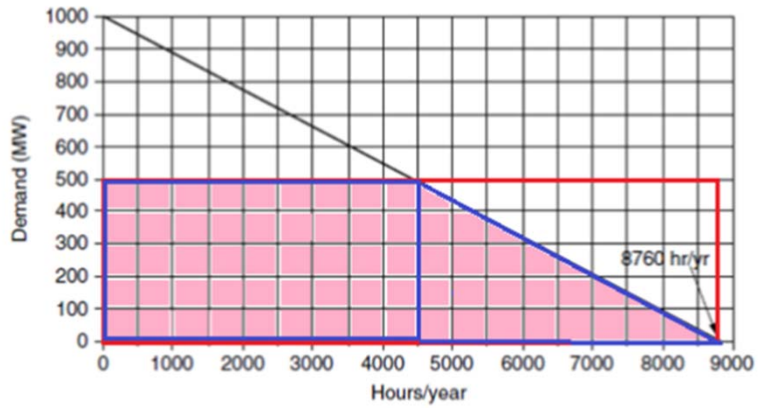
c. If the utility has 500 MW of base-load coal plants, what would their average capacity factor be?

d. How many kWh would those coal plants deliver per year?

Example Cost Parameters for Power Plants FCR=0.16

Technology	Fuel	Capital Cost ($/kW)	Heat Rate (Btu/kWh)	Fuel Cost ($/million Btu)	Variable O&M (¢/kWh)
Pulverized coal steam	Coal	1400	9,700	1.50	0.43
Combined cycle	Natural gas	600	7,700	4.50	0.37
STIG gas turbine	Natural gas	600	9,100	4.50	0.50

Class Activity - Solution for Coal



Load duration curve

$$D\,[MW] = 1000 - \frac{1000}{8760} \cdot H$$ (H: hour, D: MW)

$$\rightarrow H\,[hr] = \frac{8760}{1000} \cdot (1000 - D)$$

H[200] = 1752

H[300] = 6132

H[600] = 3504

H[MW<200] = 1752

H[300<MW<600]
= 6132 - 3504 = 2628

c.CF for Coal

$$CF := \frac{RatedCoal \cdot H(500) + \frac{RatedCoal \cdot (8760 - H(500))}{2}}{RatedCoal \cdot 8760} = 0.75$$

d. Energy Output

$PWcoal := RatedCoal \cdot 8760 \cdot CF = 3.285 \cdot 10^{9}$ kWh/yr

e. Total Cost

$CapitalCoal := 1400$ \$/kW

$FCR := 0.16$

$FuelCostCoal := 1.5 \cdot 10^{-6}$ \$/Btu

$HeatRateCoal := 9700$ Btu/kWh

$OMCoal := 0.43 \cdot 10^{-2}$ \$/kWh

$FixedCostCoal := CapitalCoal \cdot FCR = 224$ \$ /kW-yr

$annualizedFixedCostCoal := FixedCostCoal \cdot RatedCoal = 1.12 \cdot 10^{8}$ \$ /yr

$VariCostCoal := ((FuelCostCoal \cdot HeatRateCoal + OMCoal)) = 0.01885$ \$ /kW-yr

$annualizedVariCostCoal := VariCostCoal \cdot PWcoal = 6.1922 \cdot 10^{7}$ \$ /yr

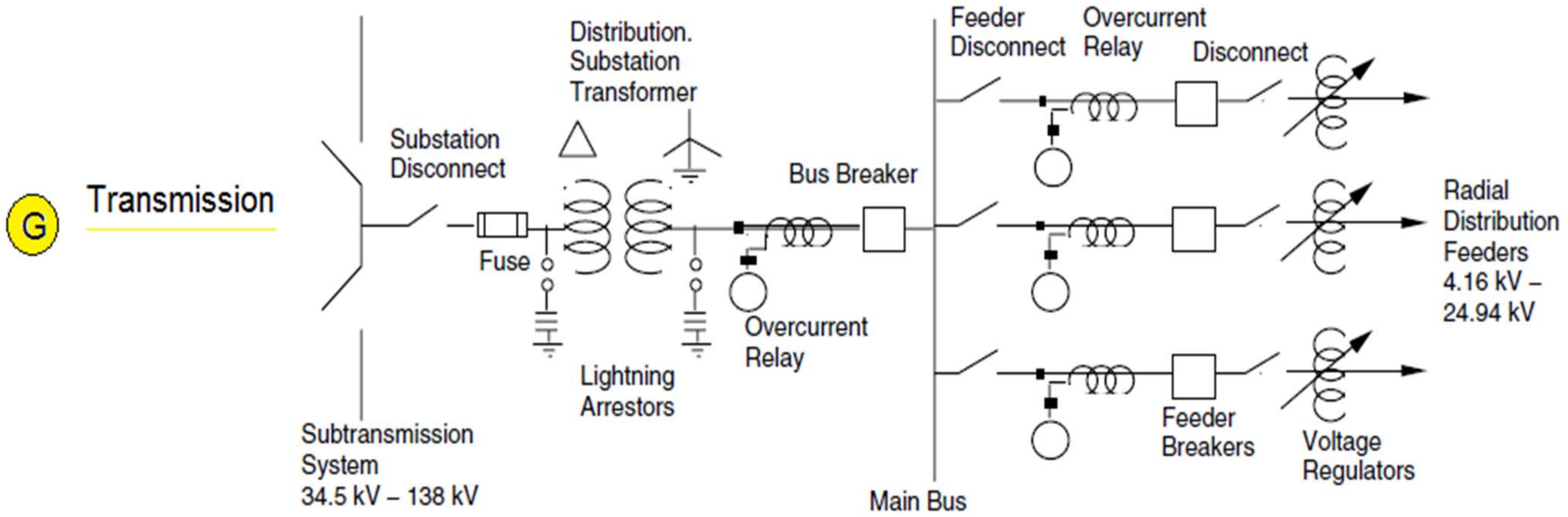
$annualizedTotalCostCoal := annualizedFixedCostCoal + annualizedVariCostCoal = 1.7392 \cdot 10^{8}$ \$ /kW-yr

$$EnergyCostCoal := \frac{annualizedTotalCostCoal}{PWcoal} = 0.0529$$ \$ /kWh

Do you work on Combined-Cycle and Gas Turbine too !!

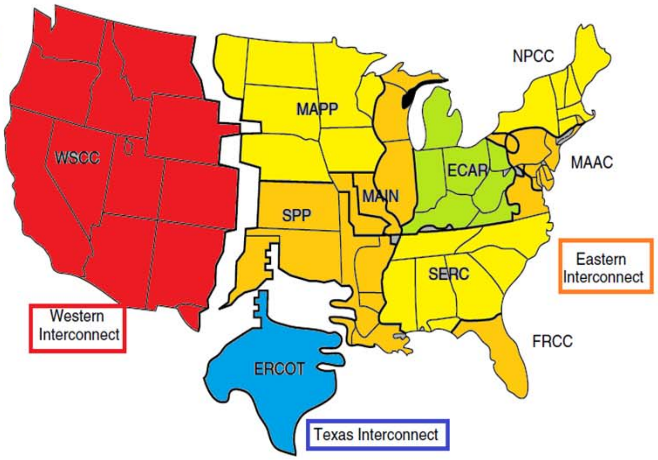
Transmission and Distribution

- Utility Grid System: Voltage Levels
- Distribution Systems
  - Protection and Isolation Components: Switches, Circuit Breakers, Fuses, Sectionalizers



National Transmission Grid

- US: 275,000 miles of transmission lines
- US Transmission Network
  - NERC (North American Electric Reliability Council) was formed after 1965 Northeastern blackout
  - 3-Major Power Grids: Eastern Interconnect, Western Interconnect, and Texas Interconnect

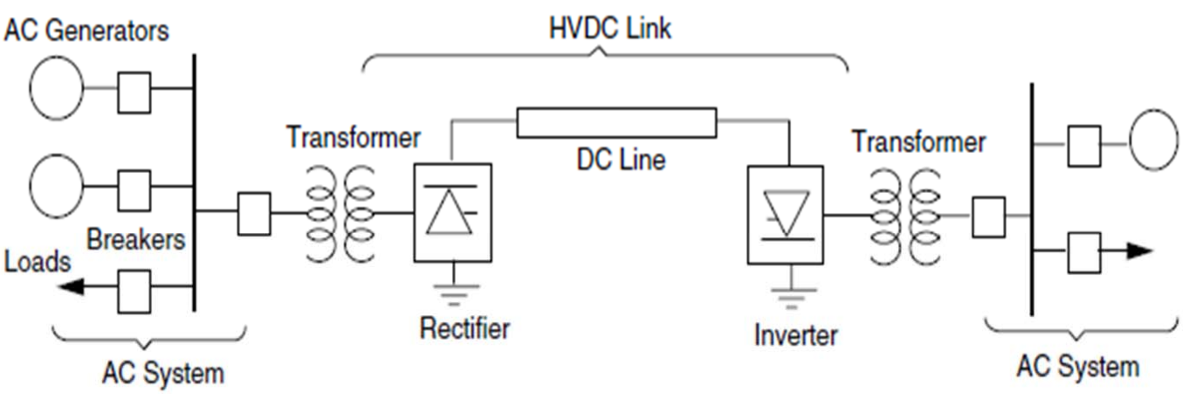


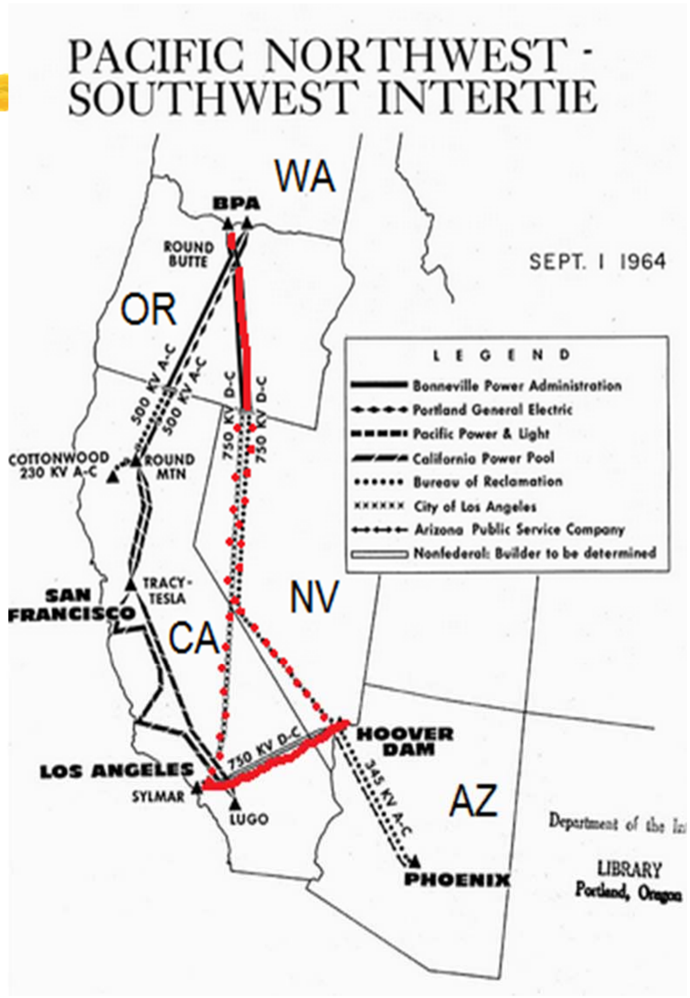
- 10 NERC Regions

  ECAR (East Central Area Reliability Coordination Agreement); ERCOT (Electric Reliability Council of Texas); FRCC (Florida Reliability Coordinating Council); MAAC (Mid-Atlantic Area Council); MAPP (Mid-Continent Area Power Pool); MAIN (Mid-America Interconnected Network); NPCC (Northeast Power Coordinating Council); SERC (Southeastern Electric Reliability Council); SPP (Southwest Power Pool); WSCC (Western Systems Coordinating Council).

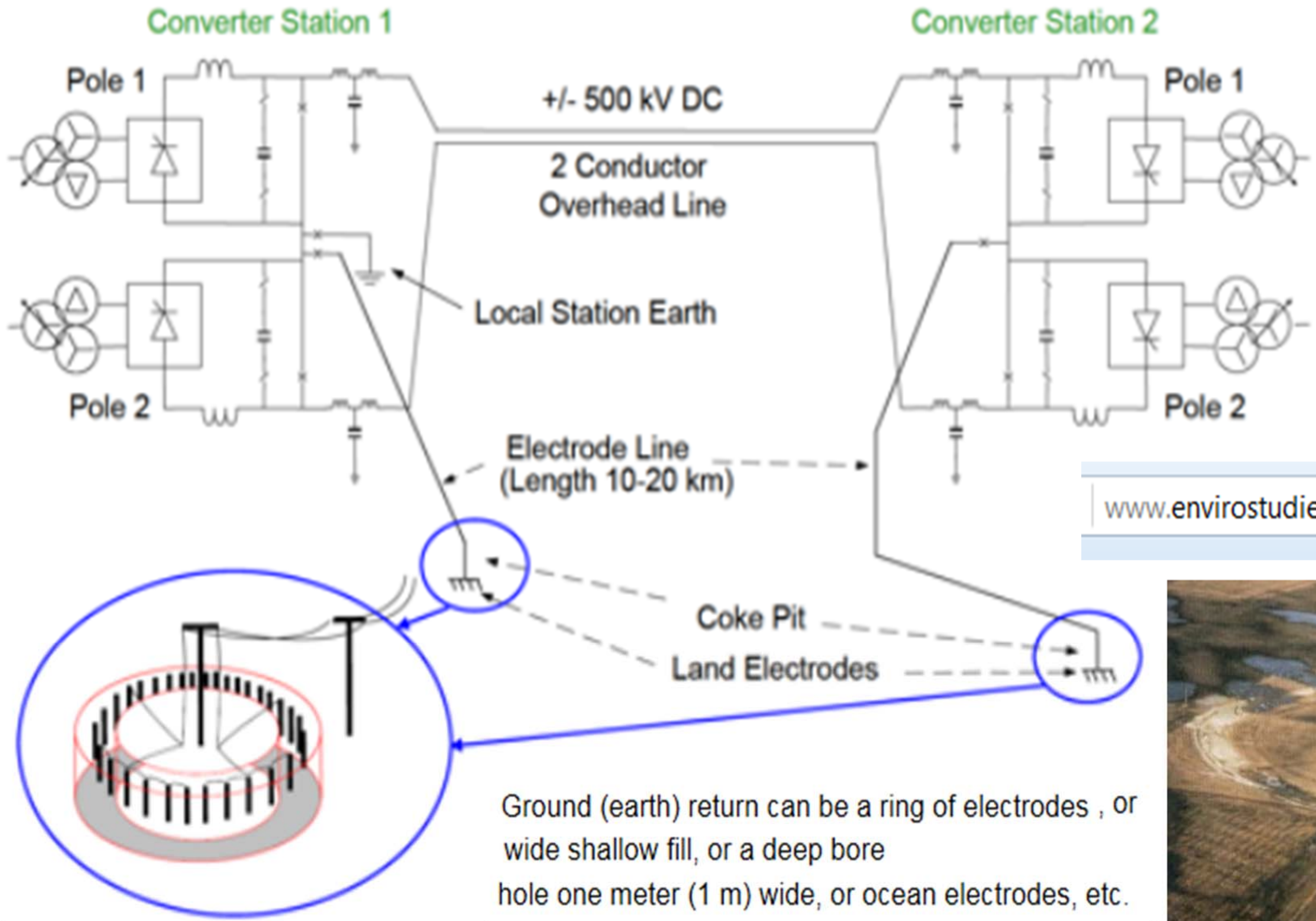
National Transmission Grid

- Transmission Configuration Types
  - 3-phase AC system (Almost all transmission system)
  - HVDC (High Voltage DC) transmission
    - More economical for 500 miles or longer tranasmission
    - Example: 600kV 6000-MW Pacific Intertie:
      Pacific Northwest – Southern California
    - Converters are required
      - Rectifiers and Inverters: AC – DC - AC





Pacific Intertie Ground



www.envirostudies.net/development/hvdc/

Ground (earth) return can be a ring of electrodes , or wide shallow fill, or a deep bore hole one meter (1 m) wide, or ocean electrodes, etc.

Ring of ground electrodes, 300 m radius, for 500 kV HVDC (Manitoba).

Pacific Intertie Ground

The problem with high voltage dc with earth return is in the grounding. Or getting enough ground contact to accept the current. The current will tend to dryout the local ground grid soil, at which point the grid resistance will increase. There are things you can do to increase the ground contact, like use charcoal, or some high metal supliment for the soil, but it is the same thing as increasing the ground grid size (I think it is cheeper than increasing the ground grid).

www.eng-tips.com/viewthread.cfm?qid=327869

Wiki says:

The grounding system at Celilo consists of 1,067 cast iron anodes buried in a two foot trench of petroleum coke, which behaves as an electrode, arranged in a ring of 3,255 m (2.02 mi) circumference at Rice Flats (near Rice, Oregon), which is 10.6 km (6.6 mi) SSE of Celilo. It is connected to the converter station by two aerial 644 mm2 steel-reinforced aluminum (ACSR) cables, which end at at a strainer situated at 45.4975865°N 121.0646206°W.

The Sylmar grounding system is a line of 24 silicon-iron alloy electrodes submerged in the Pacific Ocean suspended in concrete enclosures about one meter above the ocean floor. The grounding array is 48 km (30 mi) from the converter station and is connected by a pair of 644 mm2 aluminum cables.

Pacific Intertie Ground

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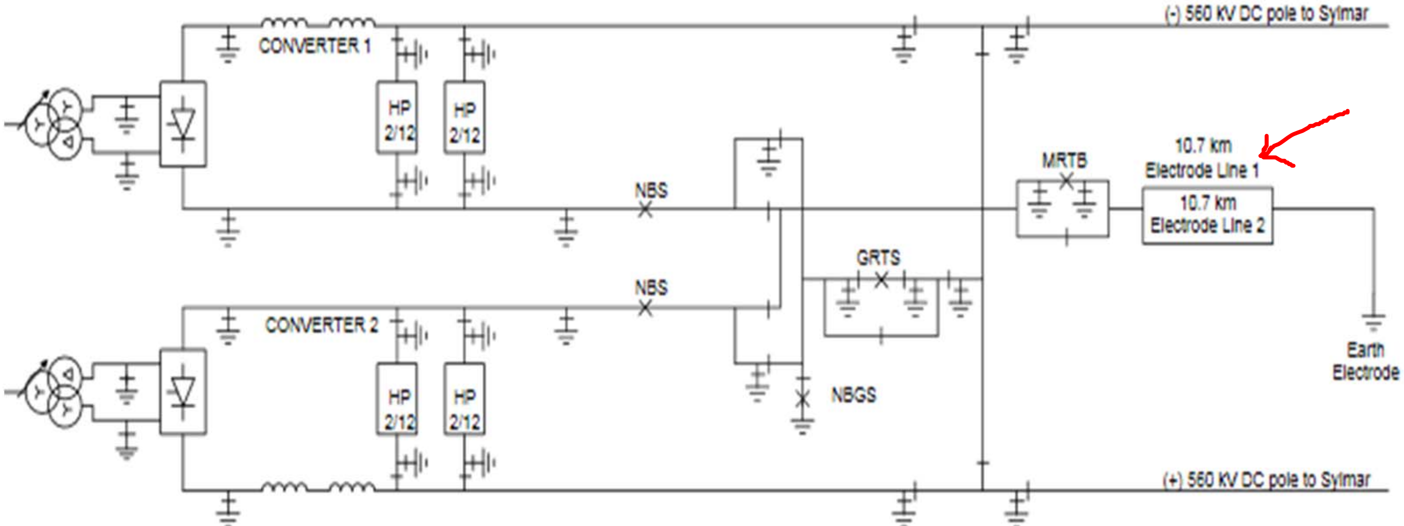


[PDF] Celilo Pacific DC Intertie Upgrade presentation - ABB
https://library.e.abb.com/.../Celilo%20Pacific%20DC%20Intertie%20Upg...

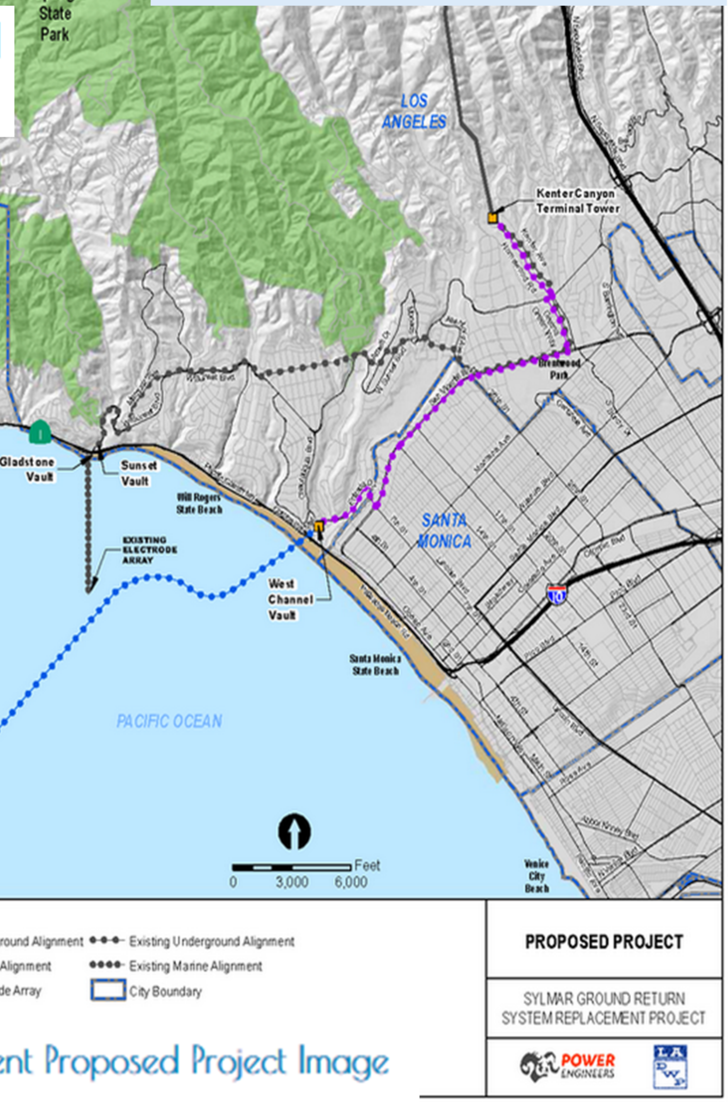
Pacific Intertie Ground

KTY: PACIFIC INTERTIE – SYLMAR OCEAN ELECTRODE LINE

https://en.wikipedia.org/wiki/Pacific

- The Sylmar grounding system is a line of 24 silicon-iron alloy electrodes submerged in the Pacific Ocean at Will Rogers State Beach[4] suspended in concrete enclosures about one meter above the ocean floor. The grounding array, which is 48 km (30 mi) from the converter station and is connected by a pair of 644 mm^2 ACSR conductors, which are in the sections north of Kenter Canyon Terminal Tower at 34°04′04.99″N 118°29′18.5″W installed instead of the ground conductors on the pylons. It runs from Kenter Canyon Terminal Tower, via DWP Receiving Station U (Tarzana; a former switching station), Receiving Station J (Northridge) and Receiving Station Rinaldi (also a former switching station) to Sylmar Converter Station. On the section between Receiving Stations J and Rinaldi, one of the two shielding conductors on each of two parallel-running 230 kV transmission lines is used as electrode line conductor.

thomassnyder.ieee-lac.org/?page_id=299



Sylmar Ground Return System Replacement Proposed Project Image

Contemporary Issues

- Energy Subsidy
  - Solar House
- Electric Car Subsidy
- Emission and Global Warming
  - Carbon Recapture
  - Carbon Tax
- “Green New Deal”

Assignment 1: Contemporary Issues

- Subject: "Contemporary Issues - Energy Subsidy: Argument for (or against)"
  - 1 subject to choose from: (a) Energy Subsidy or (b) Carbon Tax
- Specific questions:
  - **What is {energy subsidy} / {carbon tax} ?**
  - **What in different ways/types/methods is it applied in the United States and other countries? (List at least 3 different ways/types/methods).**
  - **Why you are for (or against) {energy subsidy}/{carbon tax}?**
- Length: 3 – 5 pages
- Submission File Format (MS Word): *Issue_LastName.docx* **+ Hardcopy**
- Due: TBD
- Essay Format
  - No cover sheet, 1 in margin in all 4 sides, page number, single spacing, font size 11 or bigger
  - First line: Date, Name , ID
  - Second line: Essay Title
  - **From the 3d line**
    - **First Paragraph --- Condensed** ***Answer to the Questions***
    - Main Body: **expansion of the contents and argument**

Successful Writing for EECE325 class

- People are more likely to read subjects/writings/emails that create curiosity or provide utility

Curiosity vs. Utility

- When they are busy
  - Curiosity fades in importance
  - They read only the ones with practical importance ["utility"]
- So, write as if you are a staff writer (targeting for busy people) for a newspaper, and remember that you have an editor whose job is to cut your article to fit into a limited space, maybe just 1 inch in a column.
  - Important things [Answer to the problem] in the first paragraph
    - Summary of the event/thing first so that it delivers message even though only that summary survives the "cutting"
  - Then expand your story after the First Paragraph
  - Use your own words → **Similarity Check**
- **Helpful tip**
  - **Write the main body first**
  - **Then, write the 1st paragraph**

www.cbsnews.com/8301-202_162-57600384/syria-strike-seems-inevitable-as-u.n-warns-against-unilateral-military-action-hunt-

Updated at 6:48 a.m. Eastern

DAMASCUS, SYRIA | U.N. chemical weapons experts investigating an alleged poison gas attack near Damascus left their hotel again Wednesday hoping to carry out their second field trip, which was delayed Tuesday for security reasons.

The team of about 20 inspectors left their hotel in the Syrian capital in a convoy of cars to visit the eastern Ghouta suburbs, where the Obama administration says President Bashar Assad's forces unleashed a chemical weapons attack on Aug. 21 that killed hundreds of people.

Local opposition activists told CBS News that the convoy had reached the town of Mleiha, in the sprawling Ghouta area, and videos posted online by the activists showed the U.N. inspectors interviewing patients at clinics in Mleiha and the nearby town of Zamalka.

Play **VIDEO**

Intercepted communications, tissue samples prove Syrian regime responsible for gas attack

On Tuesday, Vice President Joe Biden made it clear that regardless of what the U.N. inspectors find, the White House is now convinced the attack was carried out by Assad's forces.

The American government's assessment is based on the circumstantial evidence from videos posted on the internet, and, as CBS News correspondent David Martin reported Tuesday, intelligence -- much of it still classified -- ranging from intercepted Syrian communications to tests of tissue samples taken from victims.

Another key piece of circumstantial evidence which has been cited by both officials and analysts for days is the simple fact that the regime is the only entity in Syria known to have chemical weapons and the means to disperse them.

[redacted]

By Oliver Holmes and Erika Solomon

BEIRUT | Wed Aug 28, 2013 7:59am EDT

(Reuters) - The United Nations Security Council was set for a showdown over Syria on Wednesday after Britain sought authorization for Western military action that seems certain to be vetoed by Russia and probably China.

U.N. chemical weapons experts investigating an apparent gas attack that killed hundreds of civilians in rebel-held suburbs of Damascus made a second trip across the front line to take samples. Secretary-General Ban Ki-moon pleaded for them to be given the time they need to complete their mission.

But the United States and European and Middle East allies have already pinned the blame on Assad and, even without full U.N. authorization, U.S.-led air or missile strikes on Syria look all but certain, though the timing is far from clear.

That has set Western leaders on a collision course with Moscow, Assad's main arms supplier, as well as with China, which also has a veto in the Security Council and disapproves of what it sees as a push for Iraq-style "regime change" - despite U.S. denials that President Barack Obama aims to overthrow Assad.

Uncertainty over how the escalation of the conflict at the heart of the oil-exporting Middle East will affect trade, and the world economy sent oil prices, and gold, to their highest levels in months while stocks fell. Fears over the economy of Syria's hostile neighbor Turkey pushed its lira to a record low.

Analysis & Opinion

Western powers could strike Syria within days

West mustnâ€™t rush into Syrian conflict

Related Topics

World »
Russia »
United Nations »
Syria »

Related Video

U.N. resumes Syria chemical attack probe

4:20am EDT

Rebels gain ground in Northern Syria

Israel will respond with force to any attack from Syria

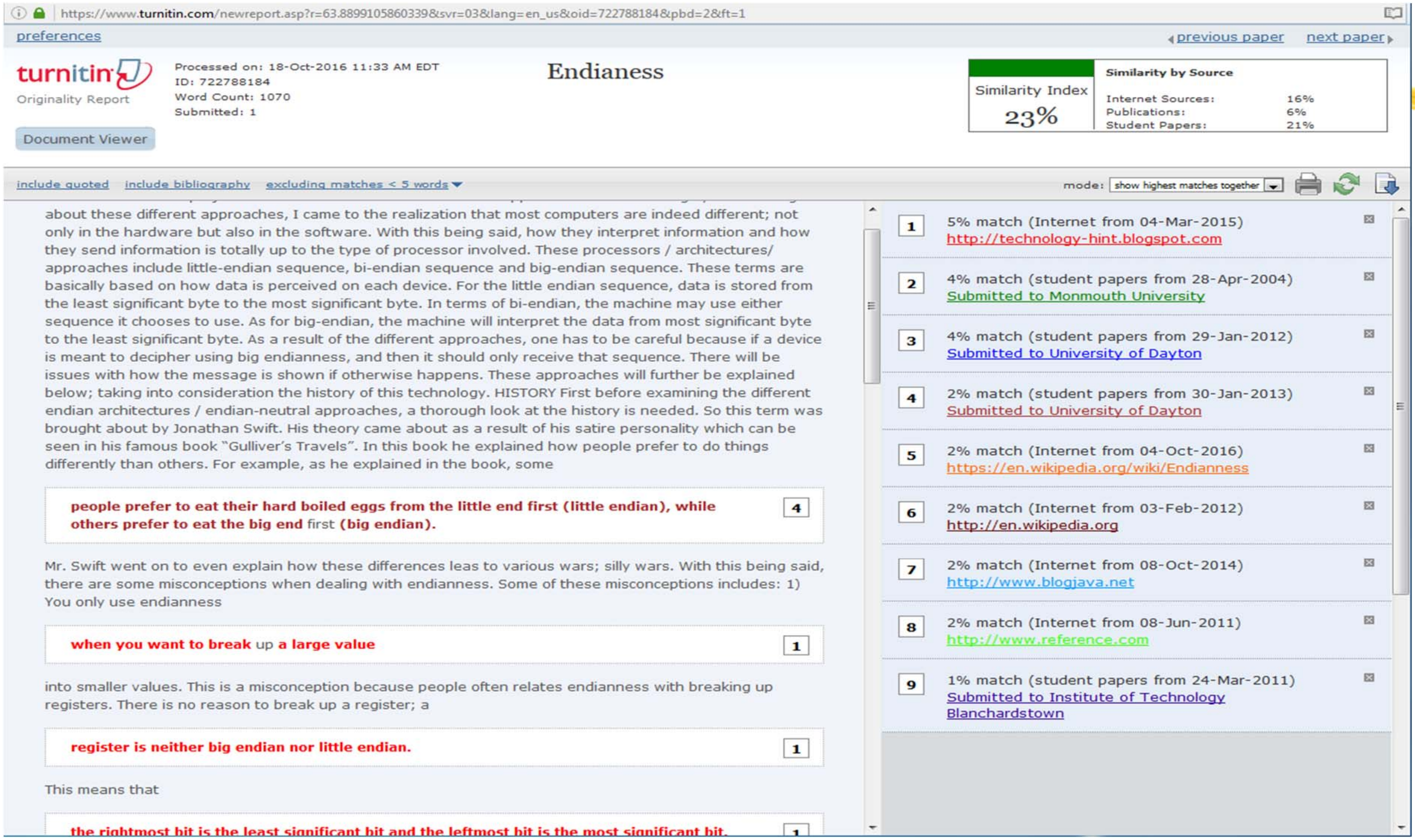
Biden: No doubt Syrian regime used chemical weapons

Similarity Check example

GradeMark Report | Edit assignment settings | E

TITLE	SIMILARITY	GRADE	RESPONSE	FILE	PAPER ID
Endianess	0%				721240419
Endian Neutrality	0%				722790195
Endianess	0%				721240795
Endianess	4%				721240622
Endianess	4%				721239601
Endianess	6%				721239965
Endian	7%				722787816
Endian Neutrality	9%				722789425
Endianess	10%				721239138
Endianess	12%				721238948
Endianess	12%				721239307
Endian	15%				721238481
ENdian	16%				721238850
Endianess	18%				721239770
Endian Neutrality	20%				722788840
Endianess	23%				722788184
Endian	39%				721237664
Endian	46%				721238156
Endianess	50%				721240290
Endianess	52%				721239474
Endianess	74%				721240162

Similarity Check – Sample Report



Assignment 1 - Recap

- Subject: "Contemporary Issues - Energy Subsidy: Argument for (or against)"
  - 1 subject to choose from: (a) Energy Subsidy or (b) Carbon Tax
- Specific questions:
  - **What is {energy subsidy} / {carbon tax} ?**
  - **What in different ways/types/methods is it applied in the United States and other countries? (List at least 3 different ways/types/methods).**
  - **Why you are for (or against) {energy subsidy}/{carbon tax}?**
- Length: 3 – 5 pages
- Submission Format (MS Word): *Issue_LastName.docx* **+ Hardcopy**
- Due: ______________________________
- Format: single spacing, 1 in margin all 4 sides, font size 11, no cover sheet, page number
- Helpful tip: "Write the main body first. Then, write the 1st paragraph."
- Grading (*Entire + First – Similarity*)
  - Entire Essay: 60% & First Paragraph: 40%
  - Similarity Deduction: Similarity % will be deducted from the sum of two scores.
  - Example: 60% 40% 15% → 85% (final score)
  - Example: 50% 40% 5% → 85 % (final score)