Engineering the Modern World

Session 1

Jim Rauf

The Modern World

Electricity

Agriculture

Automobiles

Airplanes

Highways

Appliances

Satellites

Water

Medical Technology

Computers

Electronics

Automated Manufacturing

Engineering the Modern World

Scientists study the world as it is

Engineers create the world that has never been

Theodore von Karman

Engineering is the:

- Science
- Discipline
- Art
- Profession

Of acquiring and applying:

- Technical
- Scientific
- Mathematical knowledge

To design and implement:

- Materials
- Structures
- Machines
- Devices
- Systems
- Processes

That safely realize a desired objective or invention

Engineering

- Modern engineering is based on physical sciences
  - Physics
  - Chemistry
  - Material science
  - Biology
- Modern engineering uses mathematics that describe laws of science to analyze designs of products and systems
- Products and systems make use of scientific discoveries and engineering developments from many different disciplines/areas of study
- Engineering does not seek new knowledge for knowledge's sake
- Engineering seeks to apply knowledge to some **practical purpose**
  - A product or service

Branches of Engineering

Military-the first engineers?
Civil
Mechanical
Electrical
Chemical
Materials
Aeronautical
Bio engineering

Lots of overlap

Lots of sub-disciplines or specialties within major branches

- Mechanical
  - Structural
  - Thermodynamics
  - Fluid mechanics
- Electrical
  - Power
  - Electronic
  - Computer
- Materials
  - Metallurgical
  - Composites

Some Engineering Functions

Research
- Investigations to extend knowledge for specific applications

Development
- Bridge the gap between the lab and production

Testing
- Test to verify product integrity, reliability and quality

Design
- Detailed specifications of products

Analysis
- Use math models/computer tools to support design, development, research

Systems
- Integration of components/systems into functioning product

Manufacturing/Construction
- Turn drawings and specifications into real products

Operations and Maintenance
- Oversee ongoing performance of production facility

Technical /Customer Support
- Technical/business link between customer and product

Consulting
- Technical expertise for organizations that do not have their own

Management
- Technical and general

Advances in one field used in other fields/products

- Electronics applied to automobiles
  - Engine Controls, Anti-lock Brakes,etc
- Computers used in manufacturing
  - Computer controlled metal machining, Additive Manufacturing (3D printing)
- Nuclear magnetic resonance used in medical imaging (MRI)
- Computers in internet and cell phones
- Software/computers used in analysis and design of many products
- Advances in materials technology applied to many products
- Electromechanical controls used in robots in manufacturing
- Satellites provide weather and GPS information for agriculture
- Titanium material used in aircraft and golf clubs

A Few Useful Equations

Kinematics

$\vec{X}_f = \vec{X}_i + \vec{v}_i t + \frac{1}{2}\vec{a} t^2$

$\vec{v}_f = \vec{a} t + \vec{v}_i$

$\vec{v}_f^{\,2} = \vec{v}_i^{\,2} + 2\vec{a}\Delta\vec{x}$

Dynamics

$\Sigma F = m\vec{a}$

Forces

$\vec{f} = \mu\vec{n}$

$F_{spring} = -k\Delta\vec{x}$

$\vec{F}_{gravity} = m\vec{g}$

$F_G = G\frac{m_1 m_2}{r^2}$ $\left[\text{where } G = 6.7\times10^{-11}\frac{Nm^2}{Kg^2}\right]$

$F_e = K\frac{q_1 q_2}{r^2}$ $\left[\text{where } K = 9\times10^{9}\frac{Nm^2}{C^2}\right]$

Energy

$E_{elastic} = \frac{1}{2}K\Delta x^2$

$E_G = mgh$

$E_K = \frac{1}{2}mv^2$

$E_{T\,(by\ friction)} = f\Delta x$

$\text{Work} = \vec{F}\Delta\vec{x}\cos\theta = \Delta\,\text{Energy}$

$\text{Power} = \frac{\Delta E}{\Delta t} = \frac{W}{\Delta t} = \frac{F\Delta x}{\Delta t} = Fv$

Momentum

$\vec{p} = \overrightarrow{mass} * \overrightarrow{velocity}$

$F\Delta t = m\Delta v$

(Really a reworking of $F = ma$)

Circular Motion

$\vec{a}_c = \frac{v^2}{r}$

$F_c = \frac{mv^2}{r}$

Circuits

$V = IR$

$P = IV$

$\frac{1}{R_{Tp}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

$R_{TS} = R_1 + R_2 + \cdots$

$Q = VC$

Algebra

Equations for a line

$y = mx + b$

$y - y_1 = m(x - x_1)$

A Few Useful Equations

Kinematics

$\vec{x}_f = \vec{x}_i + \vec{v}_i t + \frac{1}{2}\vec{a}t^2$

$\vec{v}_f = \vec{a}t + \vec{v}_i$

$\vec{v}_f^{\,2} = \vec{v}_i^{\,2} + 2\vec{a}\Delta\vec{x}$

Dynamics

$\Sigma F = m\vec{a}$

Forces

$\vec{f} = \mu\vec{n}$

$F_{spring} = -k\Delta\vec{x}$

$\vec{F}_{gravity} = m\vec{g}$

$F_G = G\frac{m_1 m_2}{r^2}$ $\left[\text{where } G = 6.7\times10^{-11}\frac{Nm^2}{kg^2}\right]$

$F_e = k\frac{q_1 q_2}{r^2}$ $\left[\text{where } k = 9\times10^{9}\frac{Nm^2}{C^2}\right]$

Energy

$E_{elastic} = \frac{1}{2}k\Delta x^2$

$E_G = mgh$

$E_K = \frac{1}{2}mv^2$

$E_{T\,(by\ friction)} = f\Delta x$

Work $= \vec{F}\Delta\vec{x}\cos\theta = \Delta$ Energy

Power $= \frac{\Delta E}{\Delta t} = \frac{W}{\Delta t} = \frac{F\Delta x}{\Delta t} = Fv$

Momentum

$\vec{p}$ = mass * $\overrightarrow{velocity}$

$F\Delta t = m\Delta v$

(Really a reworking of $F = ma$)

Circular Motion

$\vec{a}_c = \frac{v^2}{r}$

$F_c = \frac{mv^2}{r}$

Circuits

$V = IR$

$P = IV$

$\frac{1}{R_{Tp}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

$R_{TS} = R_1 + R_2 + \dots$

$Q = VC$

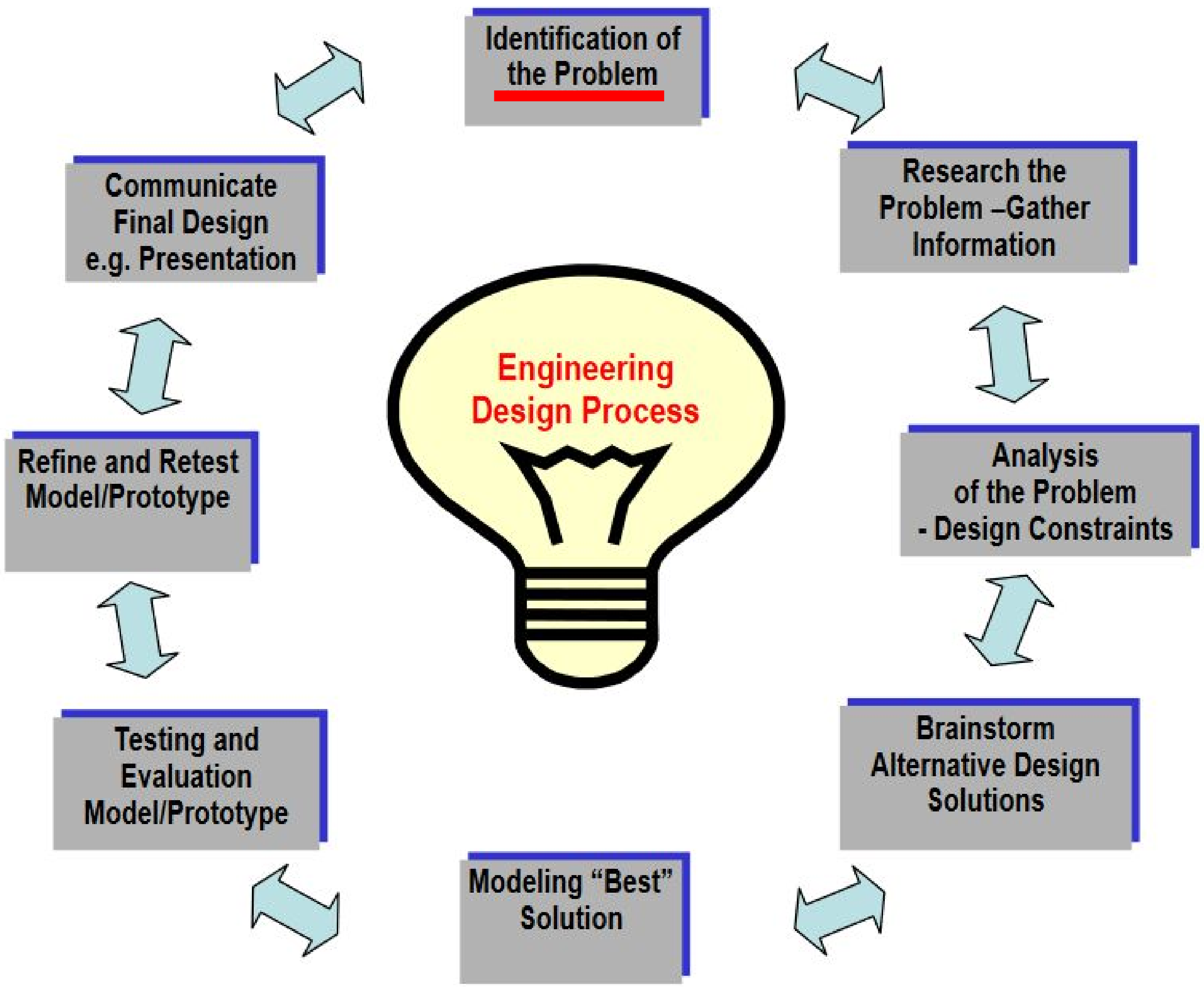
Algebra

Equations for a line

$y = mx + b$

$y - y_1 = m(x - x_1)$

Design (Problem Solving) Process

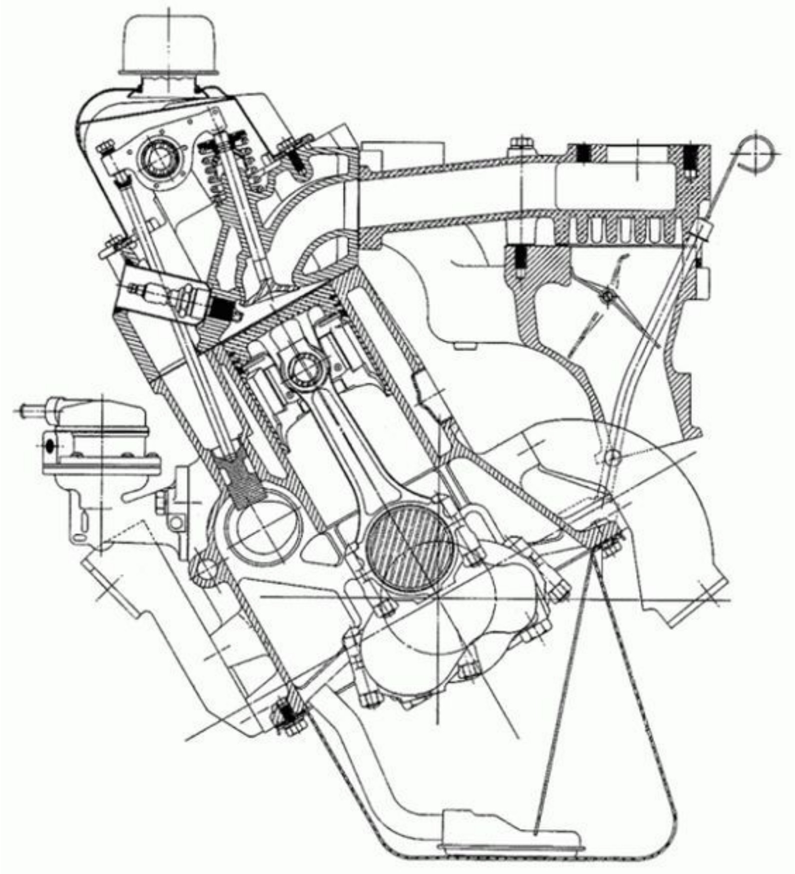


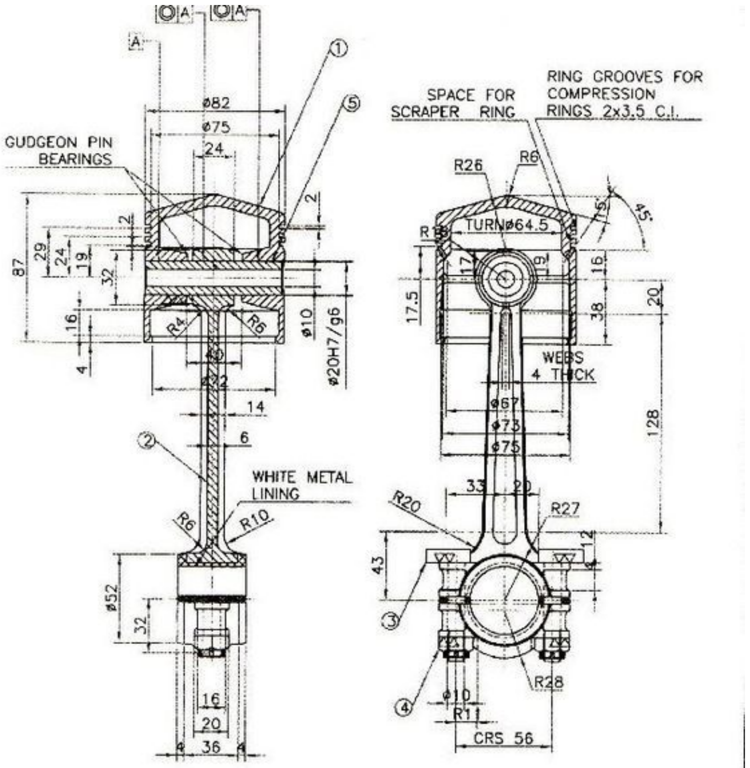
Some Design Considerations

- Strength
- Cost
- Flexibility
- Reliability
- Safety
- Control
- Thermal properties
- Weight
- Stiffness
- Corrosion
- Life
- Surface finish
  Wear

- Noise
- Lubrication
- Friction
- Styling
- Maintenance
- Ergonomics
- Shape
- Volume
- Utility
- Size
- Liability
- Manufacturability
- Speed

Engineering Drawings – Layout and Detail





PART LIST

PART No.	PART NAME	MELT.	QTY.
1	PISTON	ALL. ALLOY	1
2	CONNECTING ROD	FORGED STEEL	1
3	BIG-END BOLT	M.S.	2
4	CASTLE NUT	M.S.	2
5	GUDGEON PIN	HARDENED STEEL	1

Design must be “Manufacturable”

The Cup Is ?

- Optimist says:

  Half full

- Pessimist says:

  Half empty

The Cup Is ?

- Engineer says:

  Twice as big as it needs to be!

- Strive for efficiency
- Minimize waste of resources
- Minimize energy, material, labor used
- Must accomplish the intended purpose
- Must be economically viable

Engineering the Modern world

- **Electrification**

- Automobile
- Airplane
- Spacecraft

- Electronics
- Radio and Television
- Telephony

- Computers
- Internet

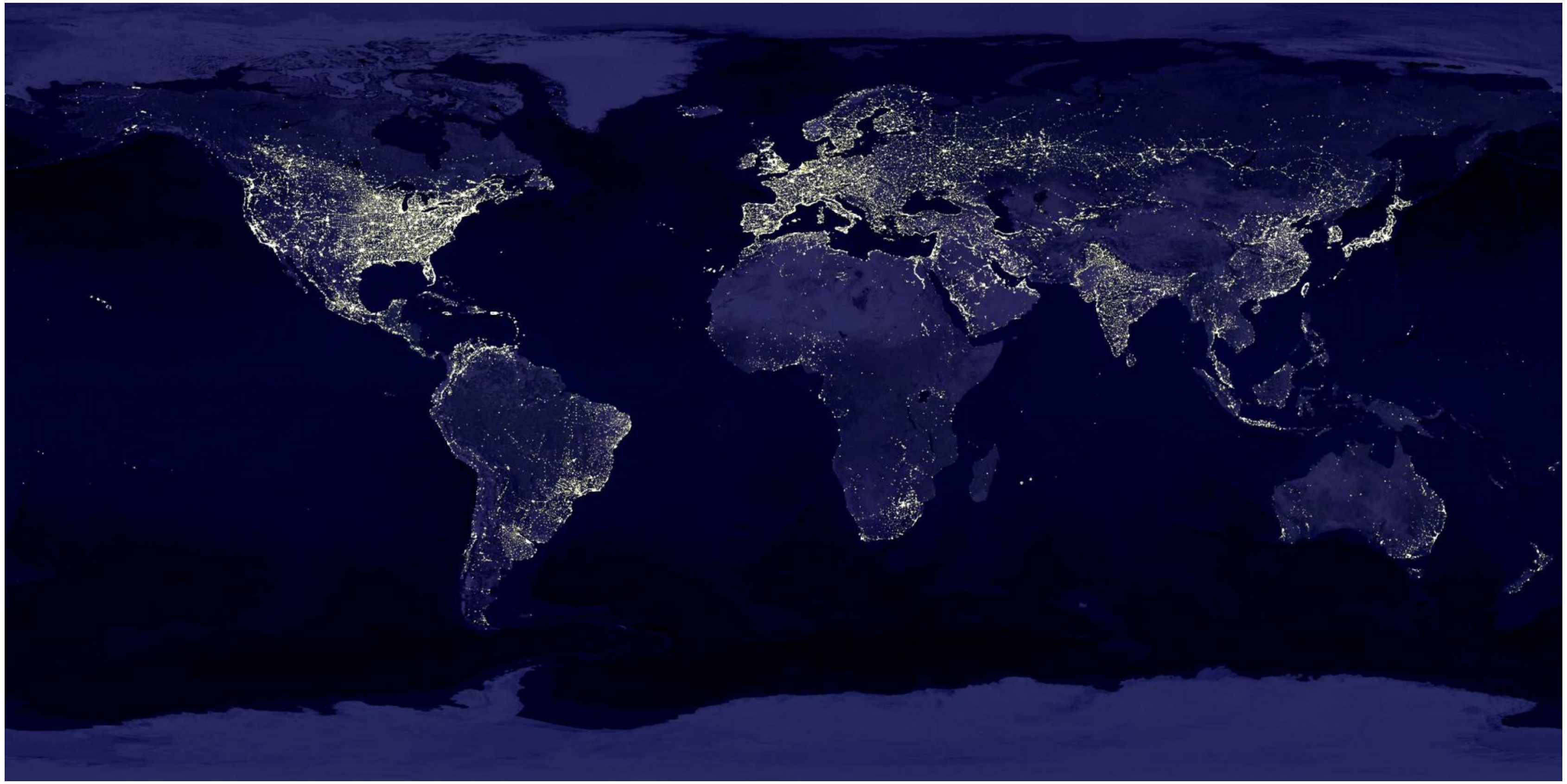
- Highways
- Water Supply and Distribution
- Agriculture Mechanization

- Air Conditioning and Refrigeration
- Household Appliances
- Petroleum and Petrochemical Technologies

- Imaging
- Health Technologies
- Laser and Fiber optics

- High Performance materials
- Manufacturing

Electrification of the World

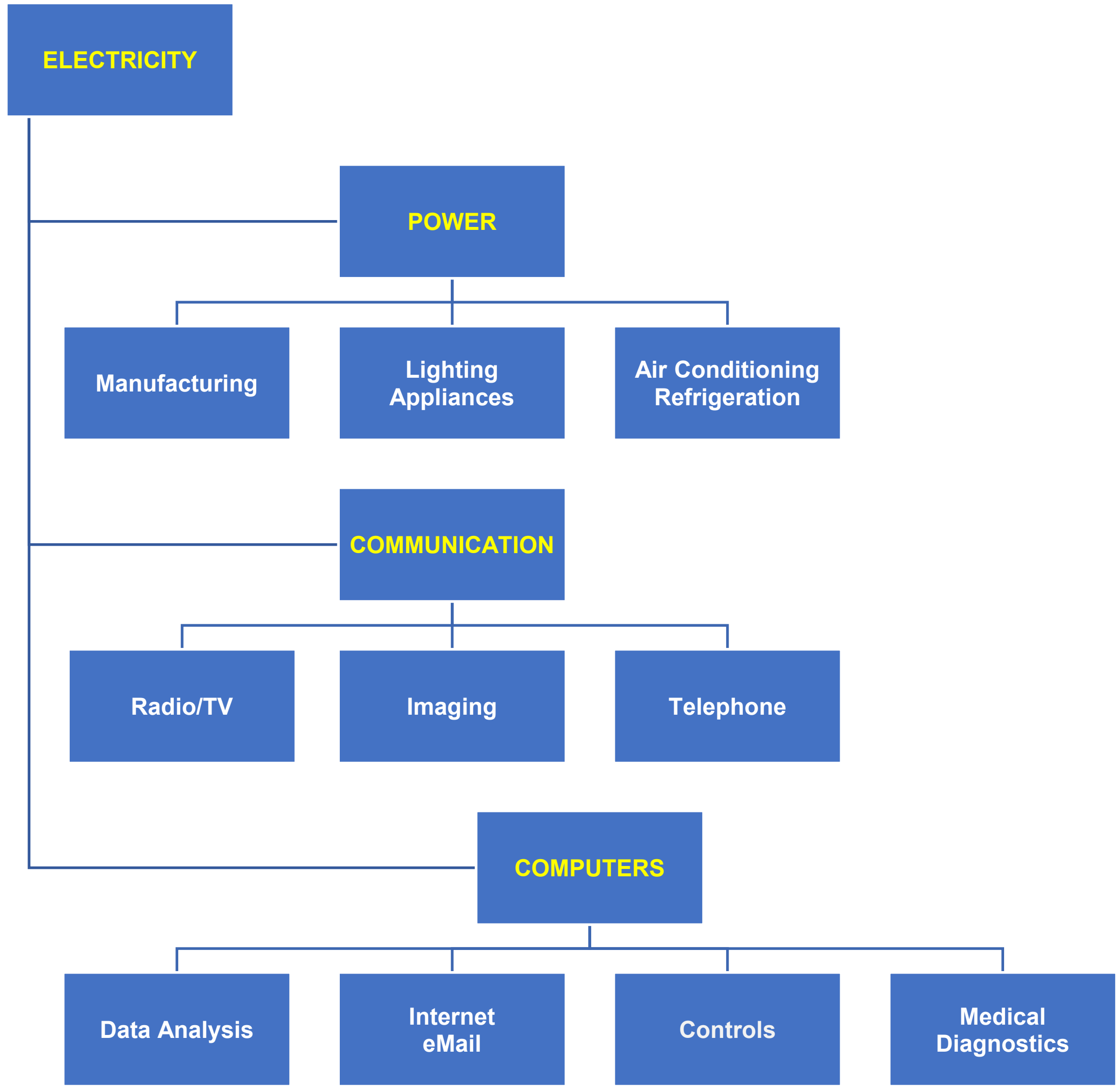


Electrification

- **Most of the engineering achievements that that make our modern world would not have been possible without the harnessing of electricity**
- Without the **power plants** and countless miles of wire, without the constant monitoring of the **electric power grid** and the juggling of supply and demand, the modern world as we know it would not exist

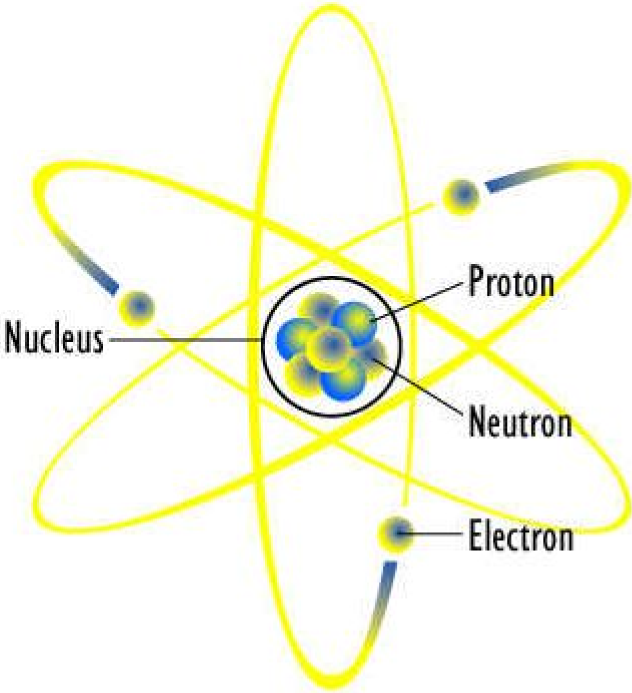
- **Electric motors** allow us to start our car engines
- Powerful **electric motors** make **elevators** possible
- Without elevators, **skyscrapers** wouldn't exist
- Without electricity, **medical diagnostic machines** would not function
- Without electricity to power **factories,** we wouldn't have most of the manufactured products we use everyday

Electrification



Electricity

- The flow of **electric charge**
- Flow of **electrons**-negatively charged sub-atomic particles through a **conductor** is **electrical current**



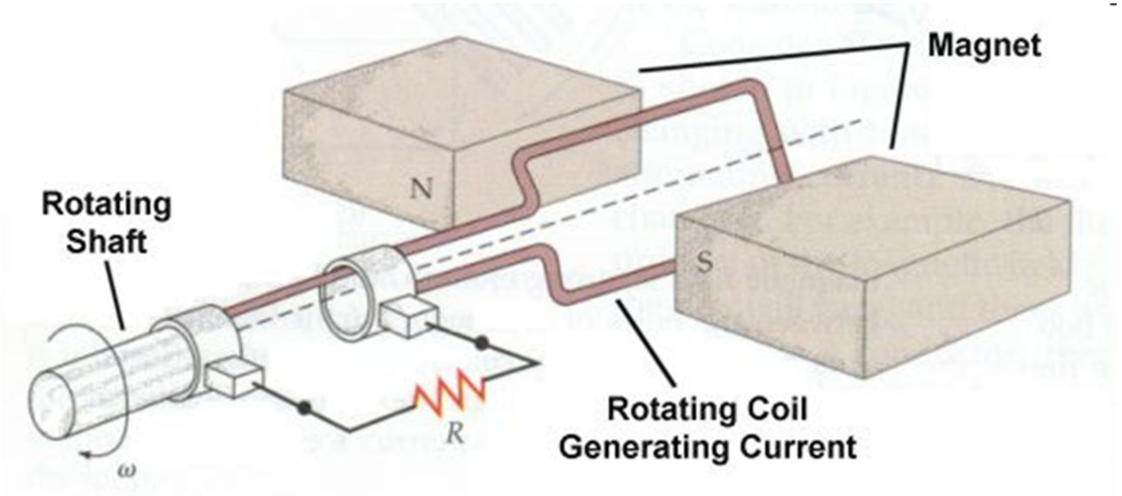
Electric current is driven by **voltage** and resisted by **resistance**

I=V/R

Power =V*I

Electrification

- 1831-1832 **Michael Faraday** showed that changing currents in one circuit induce currents in a neighboring circuit
- Faraday discovered the operating principle of **electromagnetic generators**
- **Faraday's law**: a potential difference is generated between the ends of an electrical conductor that moves perpendicular to a **magnetic field**
- Basis of electricity **generators** and electric **motors**



Electric Motors – Some Uses

- Furnace Fans
- Air conditioning Compressors
- Dish Washers
- Clothes Washers
- Clothes Dryers
- Power Tools
- Pumps (pool, fountain, etc)
- Dehumidifiers
- DVD and VCR Players
- Record Players
- Tape Players
- Tooth Brushes
- Microwave Fans

- Food Processers
- Refrigerator/freezer Compressor
- Shoe Shine machines
- Power Windows
- Power Seats
- Convertible Tops
- Mini Van Power Sliding Doors
- Retractable Headlights
- CD/Tape Players
- Air Conditioner Fans
- Air Circulation Fans
- Suspension Automatic leveling Systems
- Electric Fans (Attic)

Electrification

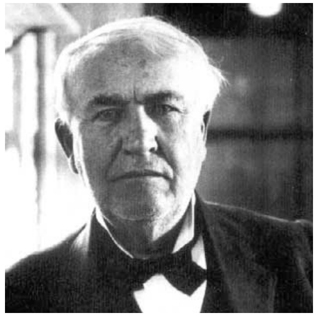
- **Electrical energy** must be created by **conversion** of one form of energy into electricity
  - **Conservation of Energy**
- Chemical-Coal/Gas/Oil
- Thermal-geothermal/nuclear
- Solar energy
- Wind energy
- Potential-Falling Water-Hydro

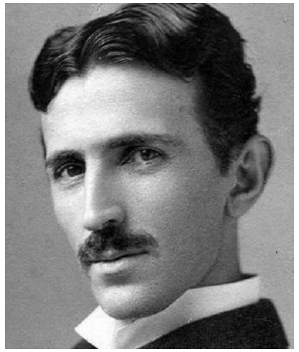
- Most power plants create electricity mechanically by driving a generator
- Steam Turbines
- Gas Turbines
- Water Turbines
- Wind Turbines

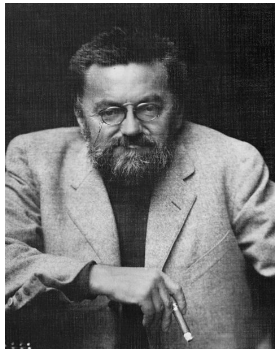
- **Sun's energy** can be converted into electricity
- Directly
- **Photovoltaic** (PV) cells
- Indirectly
- **Concentrate** solar energy to heat oil to boil water to drive steam turbines to power generators

DC or AC

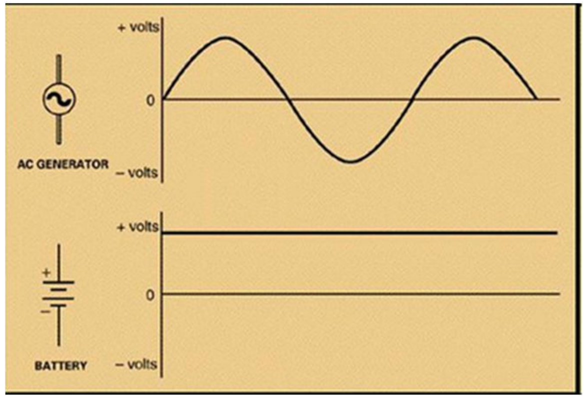
- In the late 1880's there was a great debate over which type of electricity should be generated and transmitted
- **Direct Current** or **Alternating Current**
- The **DC** proponents included **Edison** whose many devices ran on DC
- The **AC** proponents included **Tesla, Steinmetz** and **Westinghouse**







- Electrons **alternate directions** in **AC** electricity
- **Voltage oscillates** from positive to negative
- Electrons move in one direction with **DC** electricity
- Voltage does not oscillate



High voltage AC and **low current** had lower losses than equivalent **DC**
AC won out on its merits as the dominant power supply medium

Electricity Generators

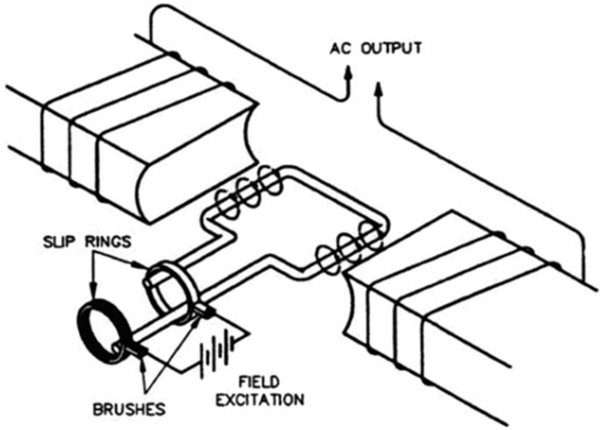
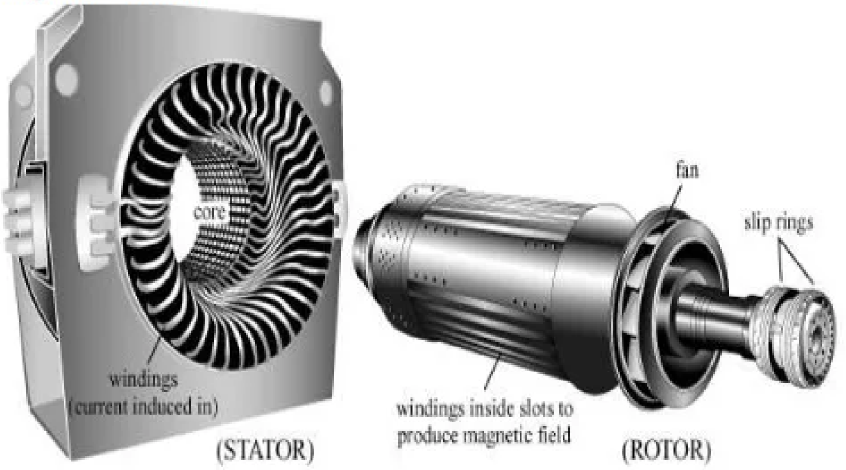


Figure 2. Rotating Field Generator



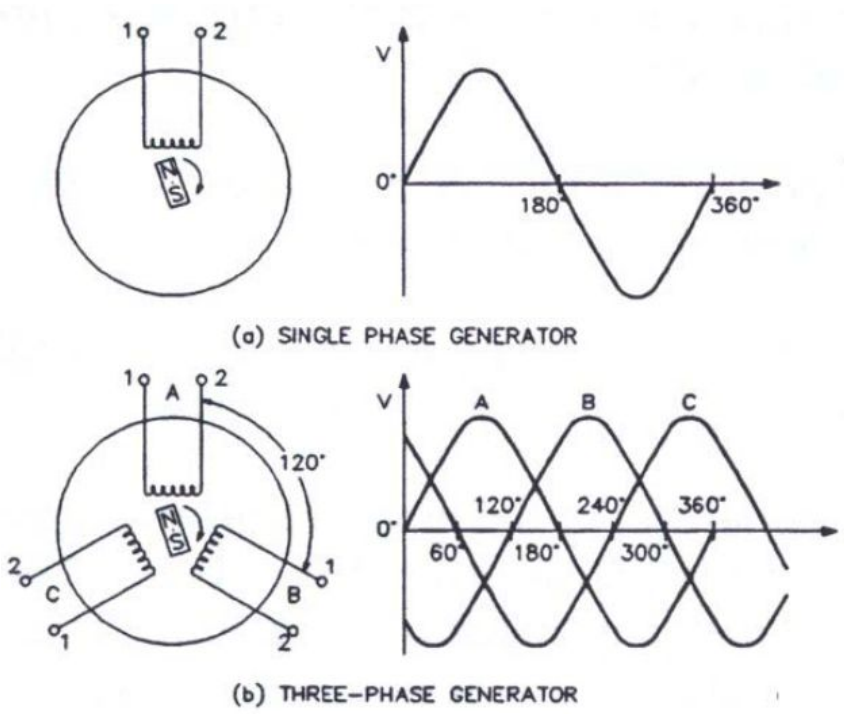
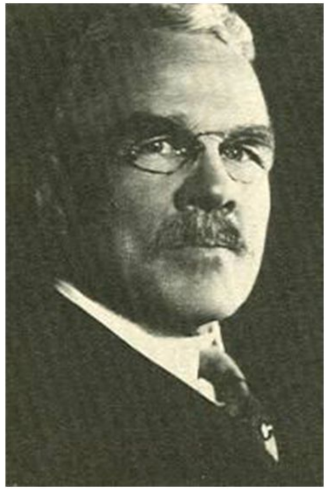


Figure 4. Voltage Output of a Three-Phase Generator

Steam Turbine Generators

- 19th century generators were driven by **reciprocating steam engines**
- 1903 -The **steam turbine generator** invented by **Charles G. Curtis** and developed into a practical steam turbine by **William Le Roy Emmet**
- Required one-tenth the space and weighing one-eighth as much as reciprocating steam engines of comparable output
- It generated 5,000 kilowatts (5MW)



Steam Turbine Generators

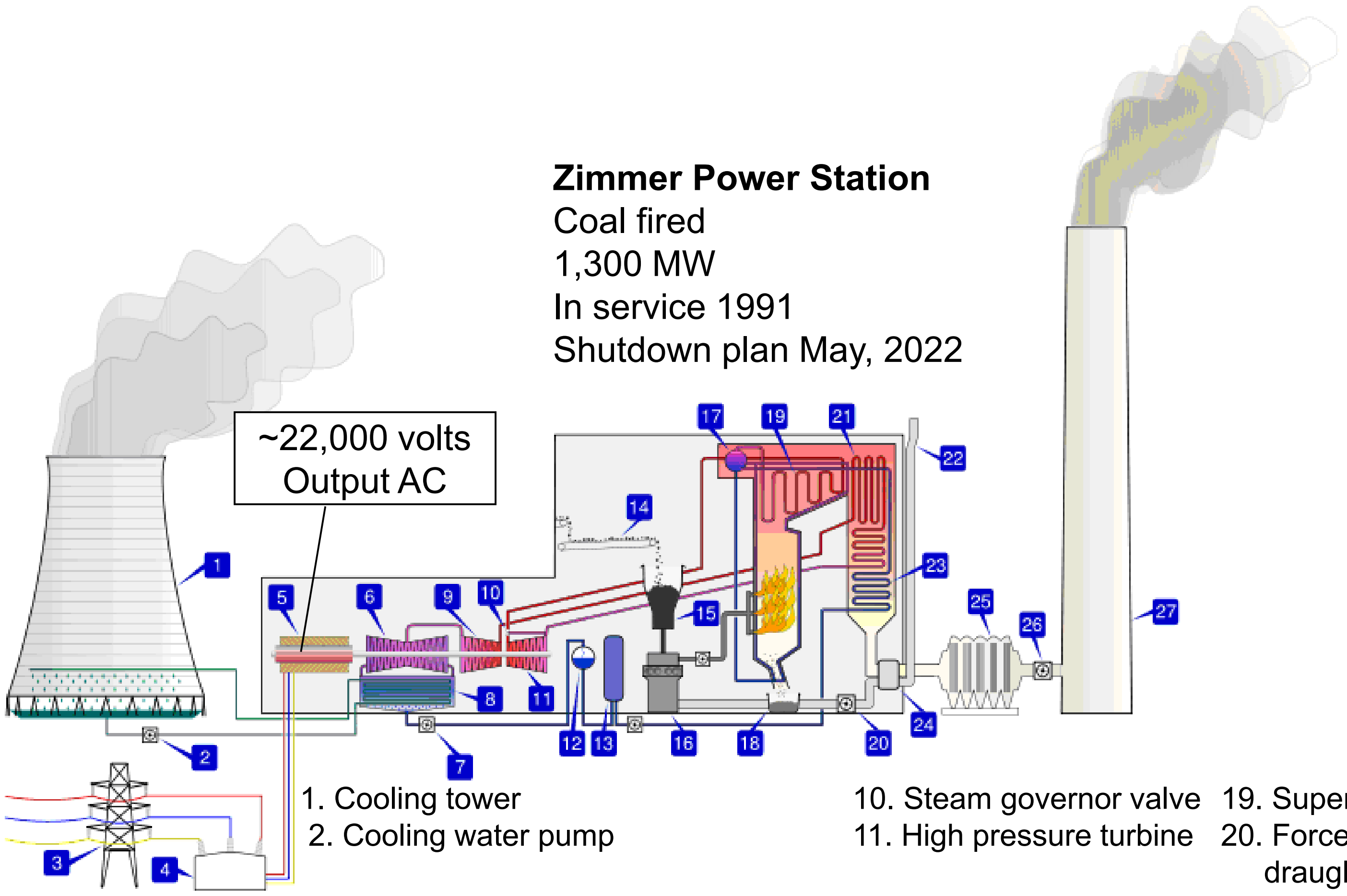
- **Steam turbines**—powered first by coal, then later by oil, natural gas, and eventually nuclear reactors—took a major leap forward in the first years of the 20th century.
- By the 1920s utilities began using **high-pressure steam** power plants
- At a time when the common rate of power generation by steam pressure was **1 kilowatt hour per 5 to 10 pounds of coal**
- **High pressure** turbines operating at 1,200 psi generated electricity at the rate of **1 kilowatt-hour per 1 pound of coal**
- **Do more with less**

- New, more heat-resistant steel alloys that enabled turbines to generate even more power were used
- This is an example of advances in one field, **metallurgy**, being used to advance technology in another field - **power generation**
- New **materials** lead to increased efficiencies
- In 1903 the biggest steam turbines generated 5,000 kilowatts (**5 MW**)
- Current steam turbines are up to **1200+ MW range**

Coal Fired Power Plant

Efficiency ~ 30 to 45%

Zimmer Power Station
Coal fired
1,300 MW
In service 1991
Shutdown plan May, 2022



1. Cooling tower
2. Cooling water pump
3. Transmission line (3-phase)
4. Unit transformer (3-phase)
5. Electric generator (3-phase)
6. Low pressure turbine
7. Boiler feed pump
8. Condenser
9. Intermediate pressure turbine
10. Steam governor valve
11. High pressure turbine
12. Deaerator
13. Feed heater
14. Coal conveyor
15. Coal hopper
16. Pulverized fuel mill
17. Boiler drum
18. Ash hopper
19. Superheater
20. Forced draught fan
21. Reheater
22. Air intake
23. Economizer
24. Air preheater
25. Precipitator
26. Induced draught fan
27. Chimney Stack

Wind Turbines

- 1920s--Windmills with modified airplane propellers marketed by Parris-Dunn and Jacobs Wind are used to drive 1- to 3- kilowatt DC generators on farms in the U.S. Plains states

- 1980s --In California more than 17,000 wind machines, ranging in output from 20 to 350 kilowatts, are installed on wind farms
- At the height of development, these turbines have a collected rating of more than 1,700 MW

GE's Haliade-X offshore wind turbine

Haliade-X prototype

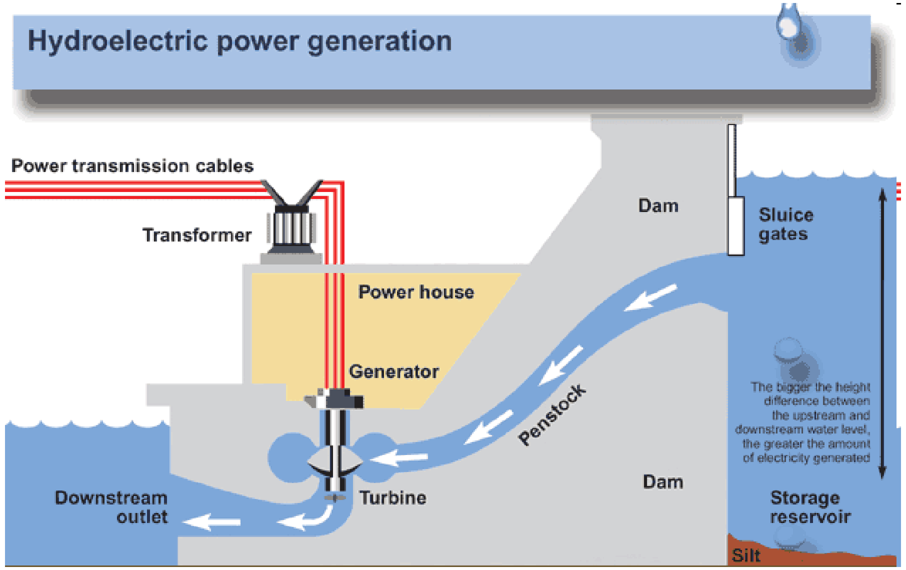
- **14 MW** capacity
- **220**-meter rotor (~715 ft)
- **107**-meter long blades
- **260** meters high (~850 ft)
- **74 GWh** gross AEP
- **61%** capacity factor
- **38,000** m² swept area

AEP Annual Energy Production

Theoretical maximum efficiency of wind turbines ,the Betz limit, is 59%

Hydroelectric Generation

- 1930s—Large dams provide hydroelectric generation
  - Tennessee Valley Authority 1933
  - Hoover Dam 1935
  - Grand Coulee Dam-1942



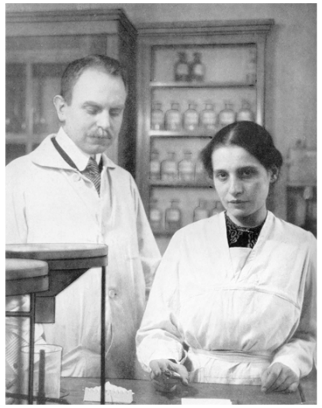
Water Turbine Converts Energy of Falling Water into Electrical Energy

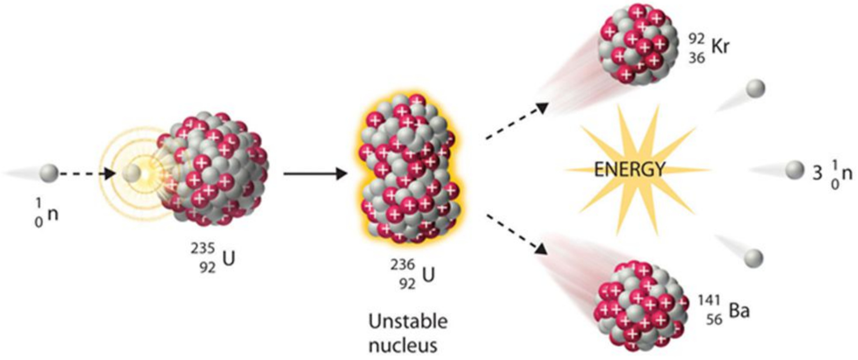
Efficiency ~ 85%

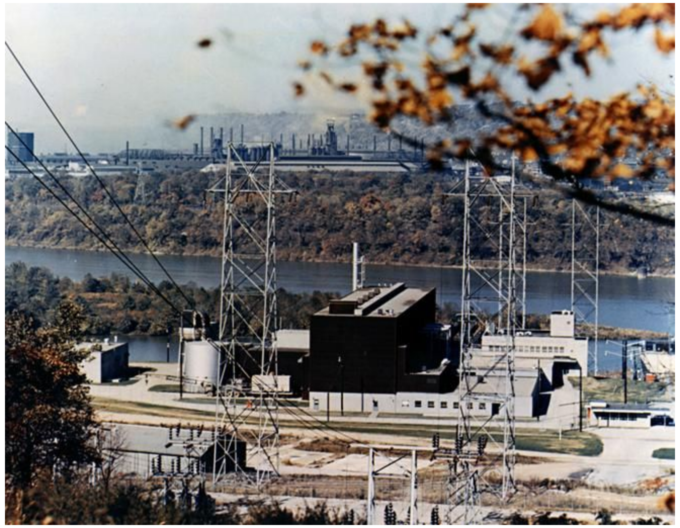
Nuclear Power Electricity Generation

- 1938-- **Otto Hahn** and **Liese Meitner** discovered **nuclear fission** -- the splitting of the atom
  - Nuclear fission of uranium is basis of electrical power generation **nuclear reactors**
- 1958--First nuclear power generation plant in U.S. comes online
  - Shippingport, Pennsylvania

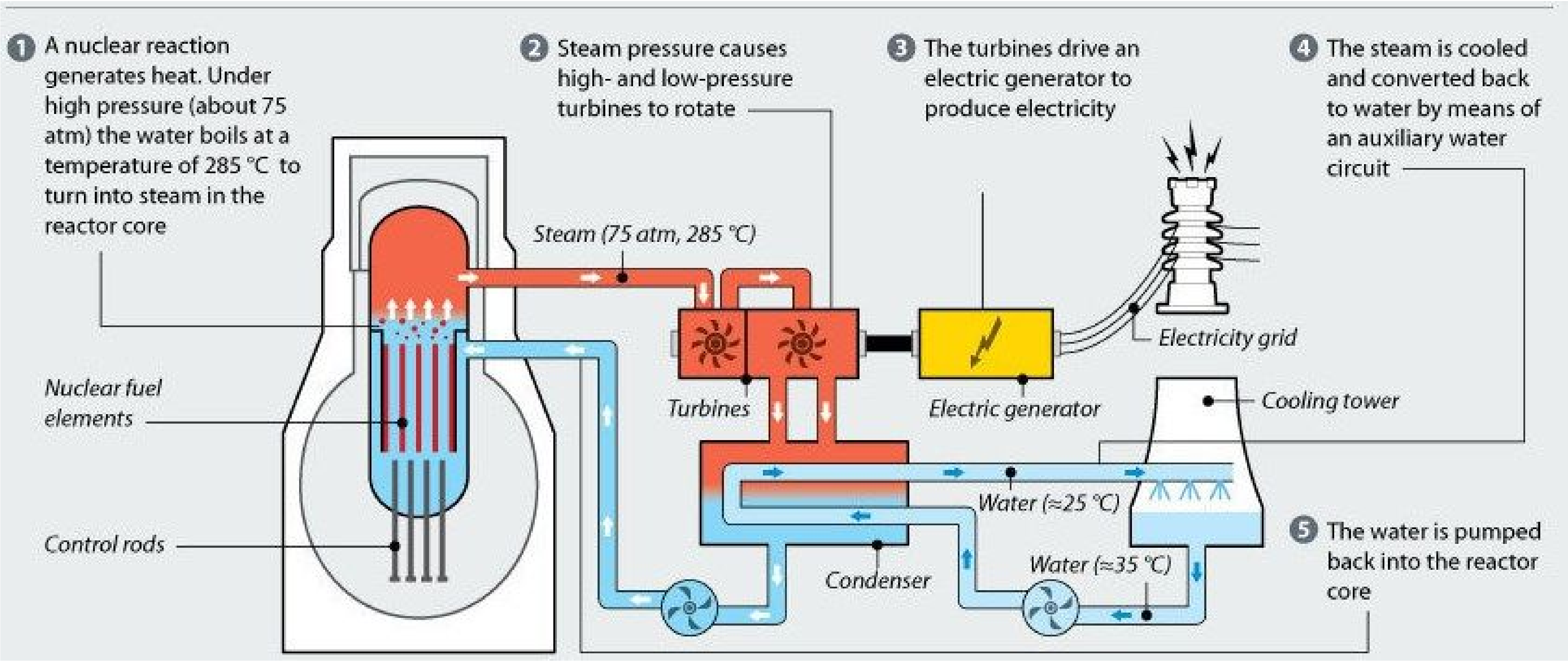
- U.S. has 96 nuclear reactors (two under construction)
- Produced 789 billion kWh in 2020
- About 20% of total (4,009 terawatt hours)electrical output





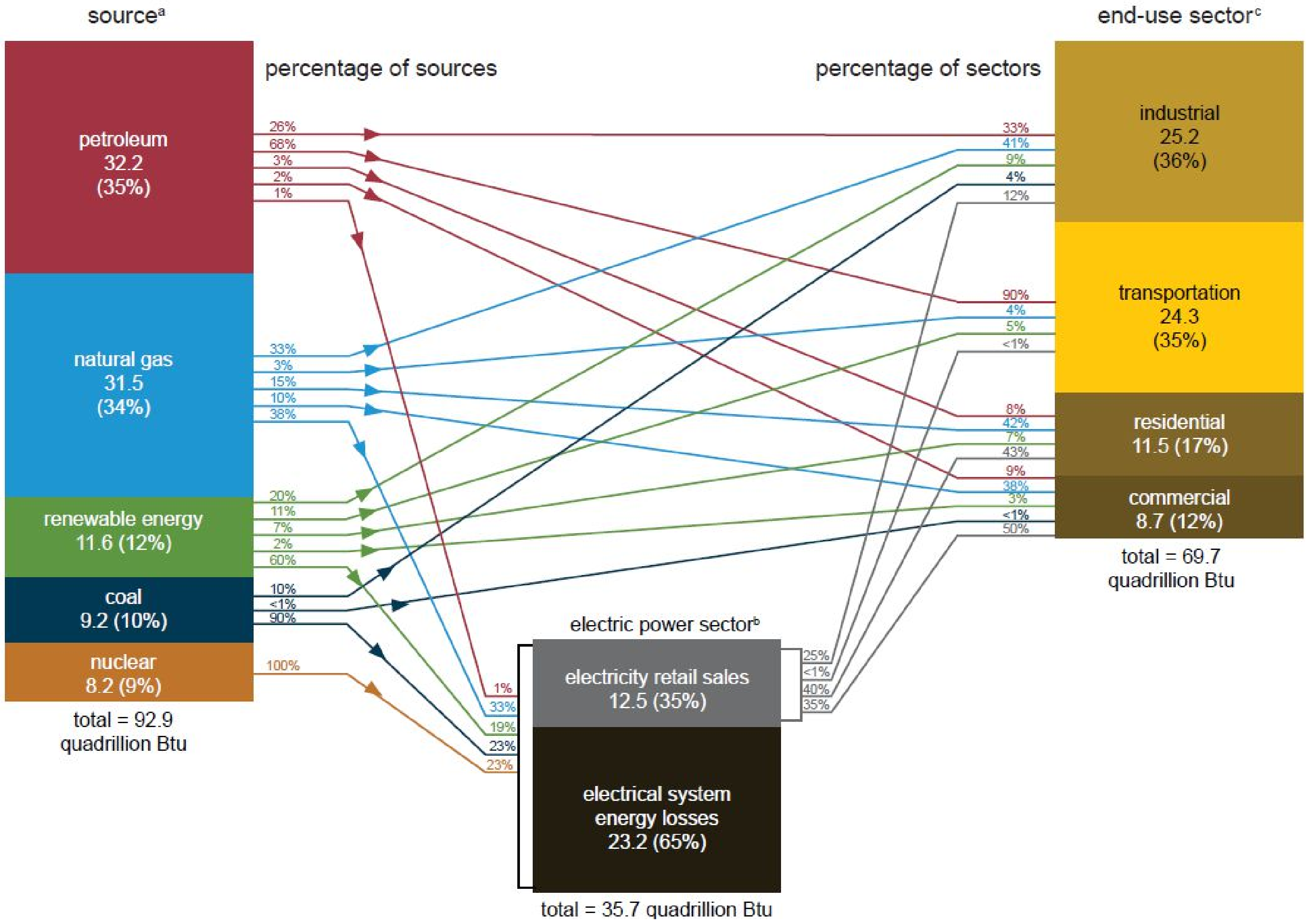


Nuclear Power Electricity Generation

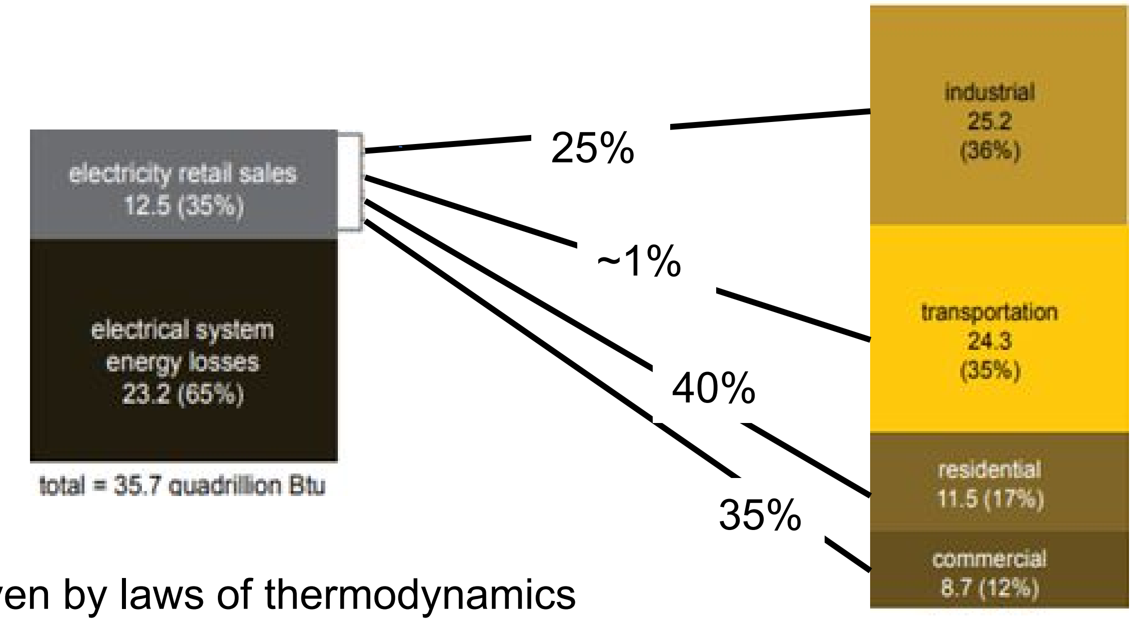


U.S. energy consumption by source and sector, 2020

quadrillion British thermal units (Btu)



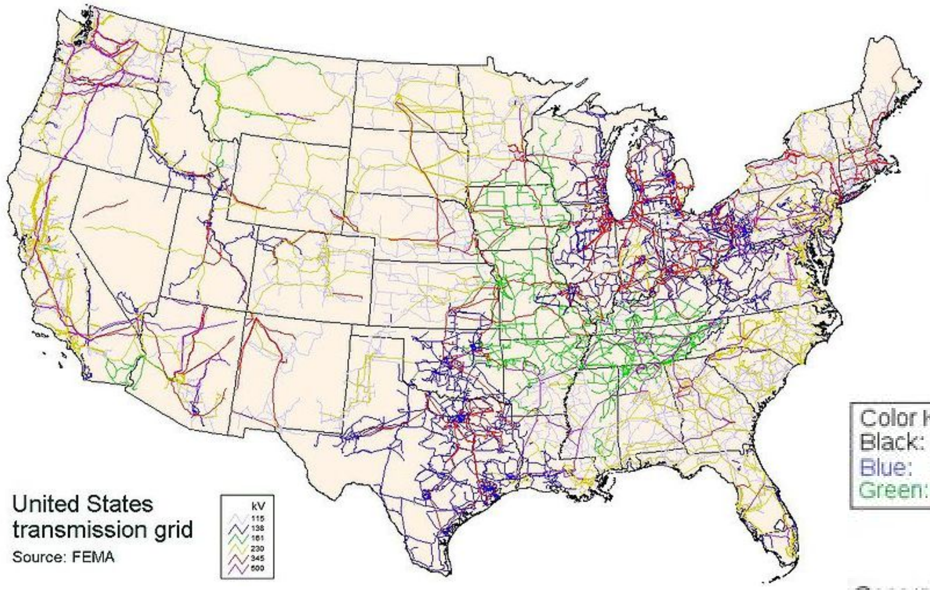
Electricity Consumption by Sector -- 2020

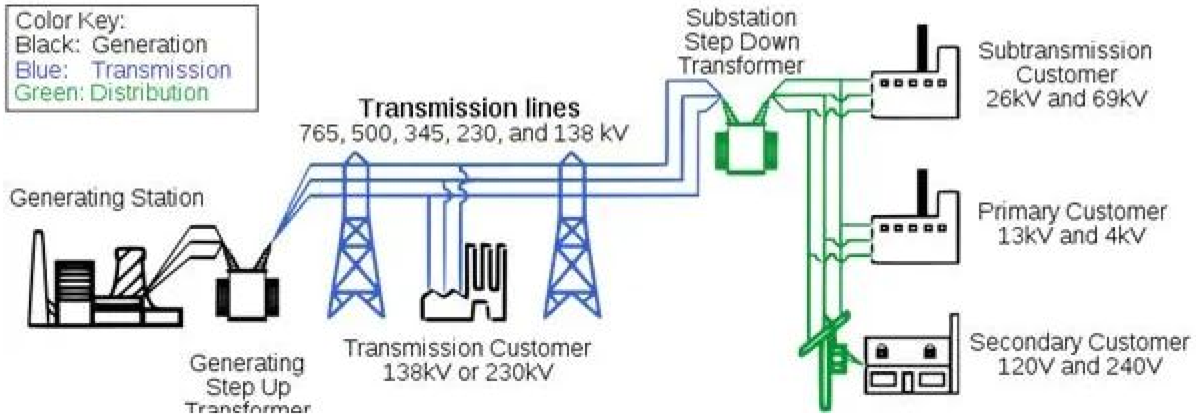


Losses driven by laws of thermodynamics

Electricity Transmission

- **Grid** system reduces the cost of transmission by sending power where and when it is needed rather than allowing all plants to work at less than full capacity





Electrification

- Generation, distribution and use of electricity can be said to the basis of many, if not most, of the features of the modern world:
  - Power for the manufacturing
  - Electronics
  - Communication systems
  - Computers
  - Automation
  - Lighting
  - Home appliances
  - Heating and air conditioning
  - Food processing
  - Medical diagnostic technology

Electrification

- New engineering challenges continue in electrification
  - Increase reliability- 99.99%- now goal 99.9999999%
  - Protect against electromagnetic pulse (**EMP**)
  - Higher voltage transmission
  - Generation with reduced emissions
  - Improve generation efficiencies
  - Higher efficiency/lower cost solar power generation
  - Lower cost wind power generation
  - Storage of solar/wind generated electricity-batteries?
  - Economical nuclear power generation
  - Decentralized generation?
  - Superconductor transmission
  - Fusion power?
- There is a lot more engineering work to do!

Next Session

- Automobiles
  - World’s major transportation
- Airplanes
  - Makes world accessible
- Transportation Infrastructure
  - Highways/Bridges