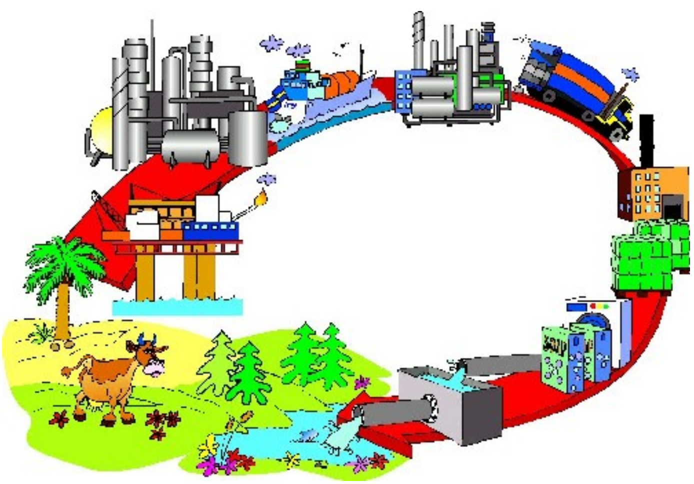
Environmental Life Cycle Assessment
PSE 476/FB 576

Lecture 4: Life Cycle Inventory: Units and Material and Energy Balances



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Physical Quantities:

- **Any physical quantity consists of two parts:**
  - **Unit: gives the standard of measure (the units)**
  - **Number: how many units in the quantity**

- **There are three *standard* systems of units:**
  - **SI (International System of Units)**
  - **CGS (centimeter gram second)**
  - **FPS (foot pound second)**

- **Out of convenience, often non-standard units or mixed units are used, for instance, mph**

Base Units: Can not be broken into sub-quantities

	Mass	Length	Time	Mole	Temp.
SI	kg	m	s	kg-mole	^oK
CGS	g	cm	s	g-mole	^oK
FPS	lb_m	ft	s	lb_m-mole	^oR

Scientific Notation:

- $7.0x10^{+4}$ = $7x10^4$ = 7 x 10 x10 x10 x10 = 70,000

- $8.1x10^{-3}$ = 8.1 / (10x10x10) = 0.0081

- $8.1x10^{-3}$ = 8.1E-3 (alternate form to express this)
- $7.0x10^{+4}$ = 7.0E+4 (alternate form to express this)

Standard Prefixes for the SI units of measure:

Standard prefixes for the SI units of measure

Multiples	**Name**		deca-	hecto-	kilo-	mega-	giga-	tera-	peta-	exa-	zetta-	yotta-
	Symbol		da	h	k	M	G	T	P	E	Z	Y
	Factor	10^0	10^1	10^2	10^3	10^6	10^9	10^{12}	10^{15}	10^{18}	10^{21}	10^{24}
Fractions	**Name**		deci-	centi-	milli-	micro-	nano-	pico-	femto-	atto-	zepto-	yocto-
	Symbol		d	c	m	µ	n	p	f	a	z	y
	Factor	10^0	10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}	10^{-24}

1,000,000,000 grams, express this in convenient form using a prefix:

0.000001 grams, express this in convenient form using a prefix:

FACTORS FOR UNIT CONVERSIONS

Quantity	Equivalent Values
Mass	$1\ \text{kg} = 1000\ \text{g} = 0.001\ \text{metric ton} = 2.20462\ \text{lb}_m = 35.27392\ \text{oz}$ $1\ \text{lb}_m = 16\ \text{oz} = 5 \times 10^{-4}\ \text{ton} = 453.593\ \text{g} = 0.453593\ \text{kg}$
Length	$1\ \text{m} = 100\ \text{cm} = 1000\ \text{mm} = 10^6\ \text{microns}\ (\mu\text{m}) = 10^{10}\ \text{angstroms}\ (\text{Å})$ $= 39.37\ \text{in.} = 3.2808\ \text{ft} = 1.0936\ \text{yd} = 0.0006214\ \text{mile}$ $1\ \text{ft} = 12\ \text{in.} = 1/3\ \text{yd} = 0.3048\ \text{m} = 30.48\ \text{cm}$
Volume	$1\ \text{m}^3 = 1000\ \text{L} = 10^6\ \text{cm}^3 = 10^6\ \text{mL}$ $= 35.3145\ \text{ft}^3 = 219.97\ \text{imperial gallons} = 264.17\ \text{gal}$ $= 1056.68\ \text{qt}$ $1\ \text{ft}^3 = 1728\ \text{in.}^3 = 7.4805\ \text{gal} = 0.028317\ \text{m}^3 = 28.317\ \text{L}$ $= 28{,}317\ \text{cm}^3$

Force	$1\ \text{N} = 1\ \text{kg}\cdot\text{m/s}^2 = 10^5\ \text{dynes} = 10^5\ \text{g}\cdot\text{cm/s}^2 = 0.22481\ \text{lb}_\text{f}$ $1\ \text{lb}_\text{f} = 32.174\ \text{lb}_\text{m}\cdot\text{ft/s}^2 = 4.4482\ \text{N} = 4.4482 \times 10^5\ \text{dynes}$
Pressure	$1\ \text{atm} = 1.01325 \times 10^5\ \text{N/m}^2\ (\text{Pa}) = 101.325\ \text{kPa} = 1.01325\ \text{bar}$ $= 1.01325 \times 10^6\ \text{dynes/cm}^2$ $= 760\ \text{mm Hg at } 0°\text{C (torr)} = 10.333\ \text{m } H_2O \text{ at } 4°\text{C}$ $= 14.696\ \text{lb}_\text{f}/\text{in.}^2\ (\text{psi}) = 33.9\ \text{ft } H_2O \text{ at } 4°\text{C}$ $= 29.921\ \text{in. Hg at } 0°\text{C}$
Energy	$1\ \text{J} = 1\ \text{N}\cdot\text{m} = 10^7\ \text{ergs} = 10^7\ \text{dyne}\cdot\text{cm}$ $= 2.778 \times 10^{-7}\ \text{kW}\cdot\text{h} = 0.23901\ \text{cal}$ $= 0.7376\ \text{ft-lb}_\text{f} = 9.486 \times 10^{-4}\ \text{Btu}$
Power	$1\ \text{W} = 1\ \text{J/s} = 0.23901\ \text{cal/s} = 0.7376\ \text{ft}\cdot\text{lb}_\text{f}/\text{s} = 9.486 \times 10^{-4}\ \text{Btu/s}$ $= 1.341 \times 10^{-3}\ \text{hp}$

Example: The factor to convert grams to lb_m is $\left(\dfrac{2.20462\ \text{lb}_\text{m}}{1000\ \text{g}}\right)$.

Example Problem:

Convert 450 lb_m into metric tonnes (a metric tonne has 1000 kg) ?

Convert 24 in^3/day to m^3/second?

Derived Quantities: Force

- Force: A push or pull on an object
- Force: Force = mass * acceleration
- Units:
  - SI 1 newton = 1 kg m / sec^2
  - CGS 1 dyne = 1 g cm / sec^2
  - FPS 1 lb_f = 32.174 lb_m ft / sec^2

$$g_c = \frac{1 kg \cdot m / \sec^2}{1 newton}$$

$$g_c = \frac{1\,g \cdot cm / \sec^2}{1\,dyne}$$

$$g_c = \frac{32.174\,lb_m \cdot ft / \sec^2}{1\,lb_f}$$

$$F = \frac{ma}{g_c}$$

If an object is accelerating at 10 m/s2 and has a mass of 5 grams, what is the force acting on it?

Derived Quantities: Energy or Work

- Defined as a force applied over a distance
- Energy = Force * Distance
- Energy and work are equivalent and have same units
- What is the energy expended if we move an object 10 meters with a force of 5 Newtons?

units:	Mechanical	Thermal
SI	Joule = Newton meter	Joule
CGS	erg = 1 dyne cm	cal = 4.18×10^7 erg
FPS	Ft lb force = 1 ft lb_f	BTU = 778 ft lb_f

Derived Quantities: Power

- Defined as rate of spending energy or doing work
- Power = energy /time

units:

SI	Watt = 1 Joule/sec
CGS	ergs/sec
FPS	HP = 550 ft lb_f/sec = 33,000 ft lb_f/min

- What is the power in Watts if we expended 40 Joules in 8 seconds to run a motor?

Derived Quantities: Power

- Defined as the rate of spending energy or doing work
- Power = energy /time
- What is the energy in kWh if we are required to run a 60 Watt light bulb for 5 minutes? For one year? How much does it cost? (11 cents/kWh in NC, residential)

Derived Quantities: Pressure

- Pressure = Force / Area
- Note absolute pressure is the real pressure, sometimes gauge pressure (pressure above atmospheric is reported)
- What is the pressure if we apply 200 lb_f evenly on a rectangular plate with dimensions of 5 by 4 inches, in psi?

units:

SI	Pascal = 1 N/ m^2	[N = Newton]
CGS	atm = 1.012×10^6 dyne/cm^2	
FPS	lb_f /in^2 (psi)	

Derived Quantities: Density

- Density = Mass / Volume
- Volume = Mass/Density
- What is the volume of a piece of pine if it weighs 5 lb_m and it has a density of 25 lb_m/ft^3 in units of in^3 ?

units:

SI	kg/m^3
CGS	g/cm^3
FPS	lb_m/ft^3

Volume or Weight Limited Problem:

A trailer truck is 48 feet long, 8’6” wide and 13’6” feet high. The truck can carry 40,000 lb_m payload maximum. If it is transporting oak at 47 lb_m/ft^3 is it volume or weight limited? What total mass of wood can it carry?

Material Balances:

- **At steady state,   Total Mass In = Total Mass Out**

- Total Mass is neither created or destroyed.

- May have a material balance on **total mass** or **on any individual component**.

- For individual components (there may be reactions possible):

  Amt of component A In = Amt of component A Out +/- Amt of A produced/consumed in a reaction

Material (Mass) Balances Solution Procedure:

1. Draw a picture, label flows with knowns and unknowns
2. If a basis for calculation is not given, one must be established.
3. Construct a table of inputs and outputs. Rows should be streams, columns should be mass or component balances.
4. To solve the material balance problem, you must formulate X independent equations to solve for X unknowns.
5. Check your balances for consistency.

Example Problem: Mass Balances:

- **Example: We are making a product C at a rate of 100 kg/hr out of a component A and a component B. If we are using 20 kg/hr of component A, how much component B do we need? There is no waste in the process.**

Example Problem: Mass Balances:

- **We want to make 100 kg/hr of a maple syrup product containing artificial syrup solids and water. The product must have a solids content of 4%. A feed stream that has 92% syrup solids will be diluted with a pure water stream. What mass flowrate of water must be added? If the density of the water is 62.4 lb_m/ft^3, what volumetric flowrate is the dilution stream?**

Mass Balances:

- **A certain process has as an input 500 lbm/hr of solids and 1000 lbm/hr of water. Toothpaste is produced. Due to problems with the mixing process, there is an 8 % rate of waste based on the total mass flow of the incoming ingredients. How much toothpaste is produced per hour?**

Mass Balances:

- **A certain process produces roasted peanuts. Three percent of all the bags produced are rejected. If the roasted peanut product has 80 grams of peanuts and 4 grams of salt per bag, then what amount of peanuts and salt are needed to produce 5000 bags of sellable product? If 100 bags are produced every hour and the machinery has a power consumption of 6 kW how much electricity is needed per bag?**

Energy Balances:

- **At steady state: In = Out (no variable changes with time)**

- **At non steady state: Storage = In – out (at least one variable changes with time.**

- Energy may not be created or destroyed, it simply is converted into different forms.

- Energy forms:
  - Kinetic Energy, energy associated with motion
  - Potential Energy, energy stored due to the height of an object in a gravitational field
  - Internal energy, chemical and thermal energy of a material
-
- Energy Balance at steady state:
- 0 = mass flow in * energy/mass – mass flow out *energy/mass + Q + W_S
- Storage = mass flow in * energy/mass – mass flow out *energy/mass + Q + W_S

- Where Q is the heat flow into the system (positive)
- Where W_S is the mechanical energy into the system, called shaft work
- Q and W are positive if energy enters the system, negative if energy leaves the system

Energy Balances:

- **In thermal systems, we basically have two ways that materials can store energy**
  - **Specific heat: the energy required to raise the temperature of a material with no phase change**
  - **Calculated as $Q=mC_p(T_{final}- T_{initial})$, for instance C_p of water is 1 cal/g**
  - **Latent heat: the energy required to change the phase of a material with no temperature change, $Q=m\lambda$ where λ is the heat of vaporization or of melting**

Heats of combustion:

- **The energy released as heat when a compound combusts with oxygen at a standard condition. (conversion of chemical to thermal energy)**

- **When hydrocarbon fuel is reacted with oxygen, CO_2 and water vapor are the main products**
  - $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ + energy (898 KJ/mol methane, ideal)

  - $2\ CH_4 + 3\ O_2 \rightarrow 2\ CO + 4\ H_2O$ (in addition, in air)
  - $N_2 + O_2 \rightarrow 2\ NO$ (in addition, in air)
  - $N_2 + 2\ O_2 \rightarrow 2\ NO_2$ (in addition, in air) – this is different from N_2O nitrous oxide, a potent GHG

- **When hydrogen is reacted with oxygen, water vapor is the product**
  - $2\ H_2 + O_2 \rightarrow 2\ H_2O(g)$ + heat (286 KJ/mol of H_2, ideal)

Heats of combustion:

- **HHV: higher heating value, includes the water vapor generated as an energy source**
- **LHV: lower heating value, does not include the water vapor as an energy source, more realistic for practical applications**
- **Gross heating value: for fuels that have water in them, such as wood or coal, the gross heating value accounts for the loss of energy due to the water present in the fuel (it must be evaporated)**

- Q= mass flow out* energy/mass – mass flow in*energy/mass
- **Q= mass flow* Heat of combustion**

Higher (HHV) and Lower (LHV) Heating values of some common fuels[3]

Fuel	HHV MJ/kg	HHV BTU/lb	HHV kJ/mol	LHV MJ/kg
Hydrogen	141.80	61,000	286	121.00
Methane	55.50	23,900	889	50.00
Ethane	51.90	22,400	1,560	47.80
Propane	50.35	21,700	2,220	46.35
Butane	49.50	20,900	2,877	45.75
Pentane				45.35
Gasoline	47.30	20,400		44.4
Paraffin	46.00	19,900		41.50
Kerosene	46.20	19,862		43.00
Diesel	44.80	19,300		43.4
Coal (Anthracite)	27.00	14,000		
Coal (Lignite)	15.00	8,000		
Wood (MAF)	21.7	9,400		
Peat (damp)	6.00	2,500		
Peat (dry)	15.00	6,500		

Heats of combustion example calculation:

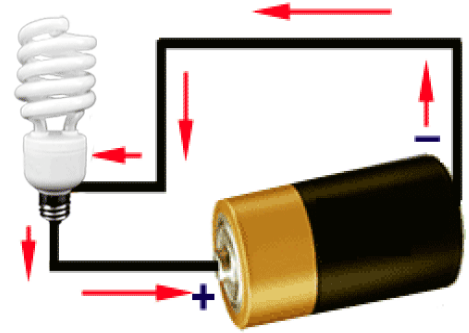
- **Gasoline is being combusted fully in a furnace to run an electrical generator. Five gallons is combusted over a period of 10 hours. The generator efficiency is 18% what is the maximum power available in watts? Density of the gasoline is 6 lbm/gallon.**

Energy Balances with Storage:

- **In thermal systems, we basically have two ways that materials can store energy**
  - **Specific heat: the energy required to raise the temperature of a material with no phase change**
  - **Calculated as Q=mCp(Tfinal- Tinitial), for instance Cp of water is 1 cal/g C**
  - **How many kWhr does it take to heat water from 20 to 40 C for 10 kg of water?**

  - **Latent heat: the energy required to change the phase of a material with no temperature change, for instance melting or boiling**
  - **Calculated as Q=m * H, where H is the latent heat of melting or vaporization**
  - **How many kWhr does it take to boil 10 kg of water? H=2257 kJ/kg**

Revised Set: Electricity:

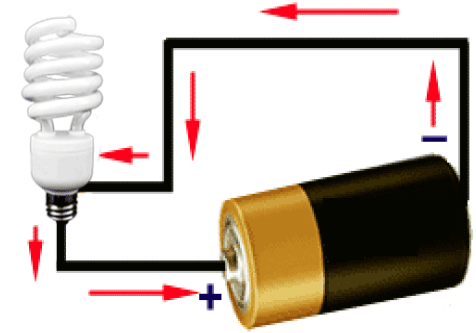


Simple circuit with light

- Electricity is a form of energy
- It is the flow of electrons (negative charges), called a current

- Electricity (a secondary energy source) is produced from other sources of energy, such as coal, raw oil, natural gas, nuclear, sun, streaming water, wind (primary energy sources)
- Primary energy sources are found in nature and not subjected to conversion or transformation
- Secondary energy sources are forms of energy that have been generated by conversion of primary energy

Electricity:



Simple circuit with light

- **When electricity flows (current) through a resistance work can be done, for instance a light bulb (a resistance) will glow when electricity passes through it.**

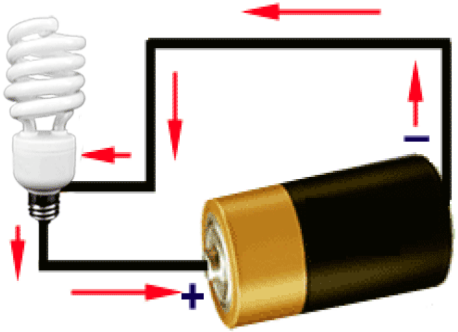
- **Analogy: electricity=water, pump=battery, pipe=electrical wire, the movement of the water can do work just as electricity can do work**

- **http://inventors.about.com/library/inventors/blelectric1.htm**

Electricity:

- Voltage = electrical current * resistance
- V = I * R
- Units: Volts [=] amperes * ohms

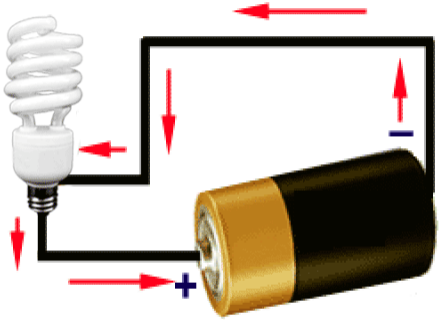
- Voltage is the Electrical potential that drives electrical current through resistances to do work (the pump).



Simple circuit with light

- Flashlight: 1.5 Volts
- Car batteries: 12 Volts
- Houses: 110-120 Volts
- Transmission lines: 110,000-120,000 Volts or 110-120 kV

Electricity:



Simple circuit with light

- Power = (electrical current)^2 * resistance
- Rate of doing work or consuming energy
- $P = I^2 * R$
- $P = I * V$ --- has units of watts when current in amps and voltage in volts

- Units of power: Watts (Joule/second) or kilowatts

- 26,500 W electric furnace 2000 sqr ft cold climate (or 26.5 kW)
- 3,500 W ac central air conditioner (or 3.5 kW)
- 4,400 W clothes dryer
- 2,000 W oven at 350 F
- 250 W Computer and monitor
- 60 W light bulb
- 4 W clock radio

- http://michaelbluejay.com/electricity/howmuch.html

Calculating Energy Use with Electricity:

- **For power, the watt is used. Watt is a very small quantity (750 watts = 1 hp)**
- **Or, commonly used, kW, kilowatt, = 1000 watts**

- **For energy, the kWhr is used, equal to the energy of 1000 watts expended for one hour.**

- **kWhr can be calculated by multiplying the power (number of kW's required) by the number of hours of use.**

- **Energy (kWhr) = power (watts) * time (hours)**

- **A KWhr costs about 10 cents**

Calculating Energy Use with Electricity:

- **What is the kWhr for the list of items ranging from an electric furnace to the clock radio run for 1 day? What is the cost if we assume about 10 cents per kWhr?**

Example Electricity Calculation:

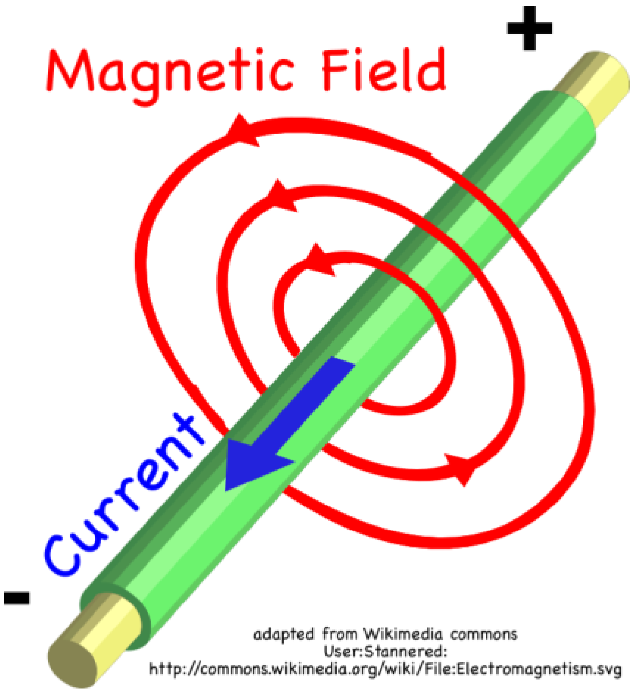
- **Calculate the power consumption for a stove that is 40 amp and runs on 240 volts. What is the cost to run the stove for four hours if we assume about 10 cents per kWhr?**

Electricity:

- **How is electricity generated?**

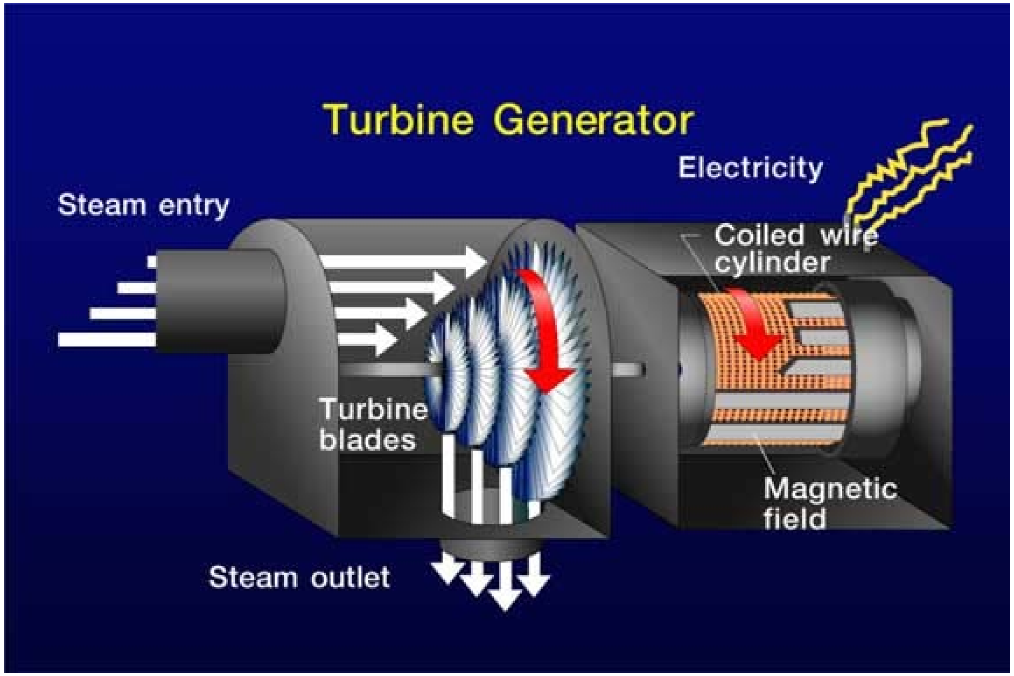
- **When a wire or any other electrically conductive material moves across a magnetic field, an electric current occurs in the wire.**

- **The large generators used by the electric utility industry have a stationary conductor (a ring wrapped with a long continuous piece of wire) and a magnet attached to a rotating shaft.**
- **When the magnet rotates inside the ring of wire, it induces a small electric current in each section of wire as it passes.**
- **The sum of all currents is large.**



Electricity:

- **How is electricity generated?**
- **Use a turbine, engine, water wheel to drive an electrical generator.**
- **Most is generated in a steam turbine.**
- **Turbine converts kinetic energy of a moving fluid (steam or other) into mechanical energy.**
- **Blades on a shaft are pushed by steam rotating the shaft running the generator.**



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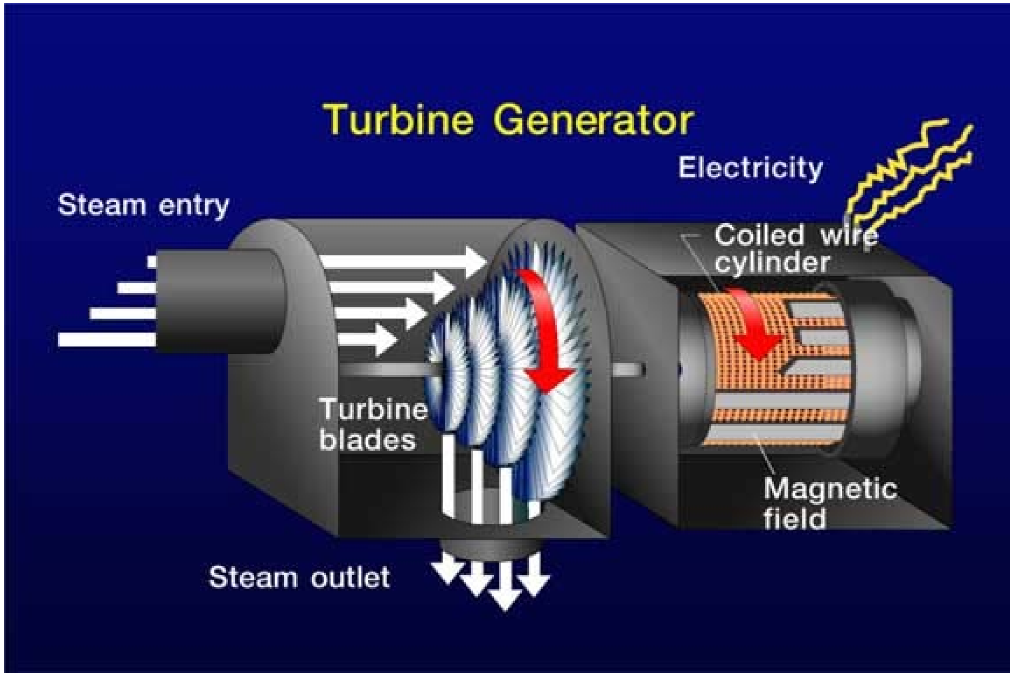
Electricity:

- How is electricity generated?

- In 1998, 3.62 trillion kilowatt hours of the US electricity produced
  - 52% from coal,
  - 3% from petroleum
  - 19% nuclear
  - 9% hydro
- In 2012 4.054 trillion kilowatt hours of the US electricity produced
  - 37% coal
  - 30% natural gas
  - 19% nuclear
  - 7% hydropower
  - Other renewables, 5%
    - Biomass 1.42%
    - Geothermal 0.4%
    - Solar 0.11%
    - Wind 3.46%
  - 1% Petroleum
  - <1% other gasses
  - (US energy information administration)



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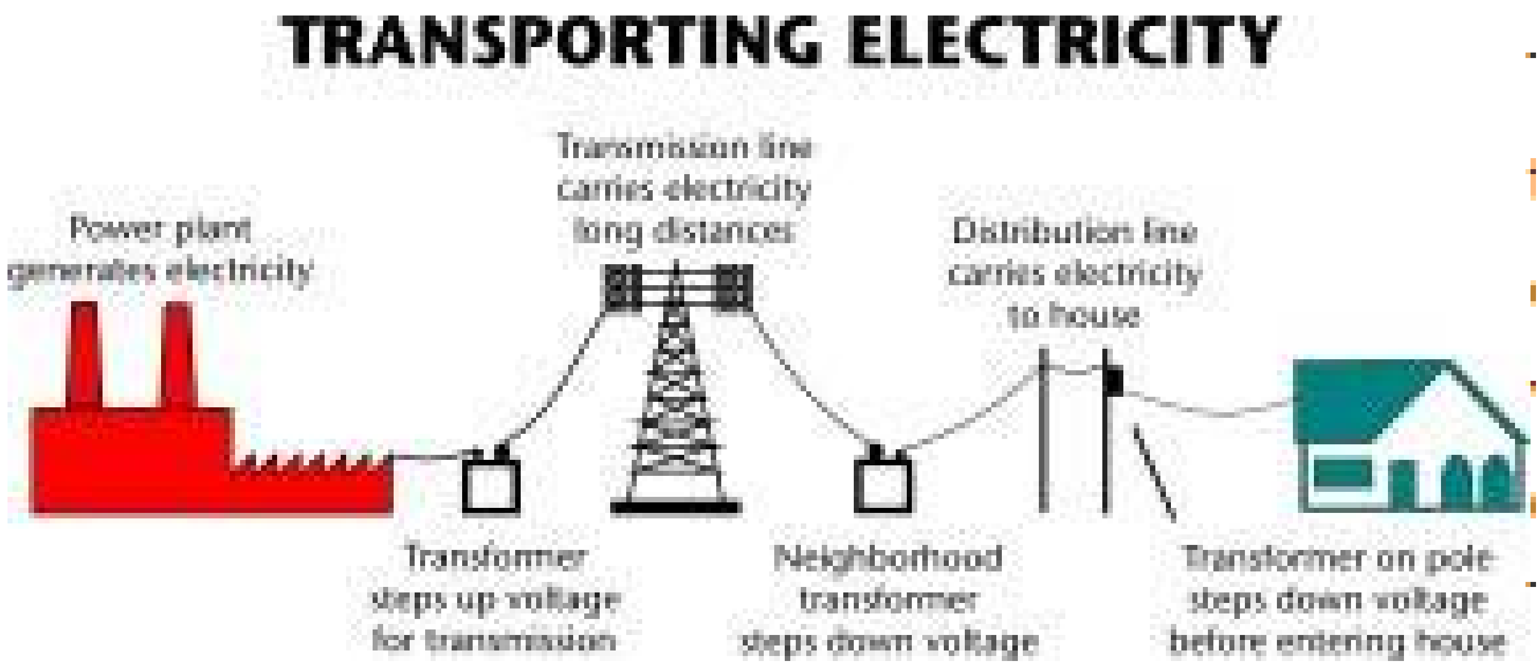
Electricity Storage and Transport:

- **Electricity can not be cost effectively stored, production must equal consumption at all times, causes issues.**
- **Transformers change electricity from low to high voltage, reducing losses, allowing electricity to be transported long distances.**
- **Substations transform the electricity to low voltage which can be used safely in houses, offices, factories….**



Summary:

- Standard system of units
- Base units
- Scientific notation
- Unit Conversions
- Force
- Energy
- Power
- Pressure
- Density
- Electricity
- Power = voltage * current
- Energy = power * time
- Turbine Generator
- Primary energy source
- Secondary energy source
- Conversion Factors
- Mass balance
- Component balance
- Energy Balance
- Heat of combustion
- Specific Heat
- Latent Heat