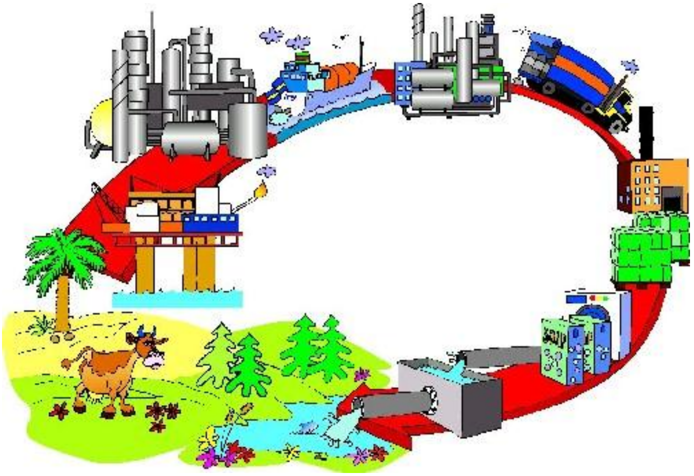
Environmental Life Cycle Assessment
PSE 476/WPS 576/WPS 595-005

Lecture 6: Life Cycle Inventory: Units and Material Balances



Fall 2012

Richard A. Venditti
Forest Biomaterials
North Carolina State University
Raleigh, NC 27695-8005

Richard_Venditti@ncsu.edu
Go.ncsu.edu/venditti

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 subquantities

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

Standard units for the SI system:

SI base units[13][14]

Unit name	Unit symbol	Quantity name	Quantity symbol	Dimension symbol
metre	m	length	*l* (a lowercase L), *x*, *r*	L
kilogram [note 1]	kg	mass	*m*	M
second	s	time	*t*	T
ampere	A	electric current	*I* (an uppercase i)	I
kelvin	K	thermodynamic temperature	*T*	Θ
candela	cd	luminous intensity	I_v (an uppercase i with lowercase non-italicized v subscript)	J
mole	mol	amount of substance	*n*	N

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}

Derived Quantities: 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 lbm ft / sec^2

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

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

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

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

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 1 meter with a force of 1 Newton?

units:	Mechanical	Thermal
SI	Joule = Newton meter	Joule
CGS	erg = 1 dyne cm	cal = 4.18 x 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
- What is the power if we expended 40 Joules in 8 seconds to run a motor?

units:

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

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 of 5 by 4 inches, in psi?

units:

SI	Pascal = 1 N/ m^2	[N = Newton]
CGS	atm = 1.012 x 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 wood if it weighs 5 lb_m and it has a density of 50 lb_m/ft^3 in in^3 ?

units:

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

Electricity:

- **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, natural gas, oil, nuclear, and other natural sources (primary energy sources)**

- **When electricity flows through a resistance to current, work can be done, for instance a light bulb can light up**

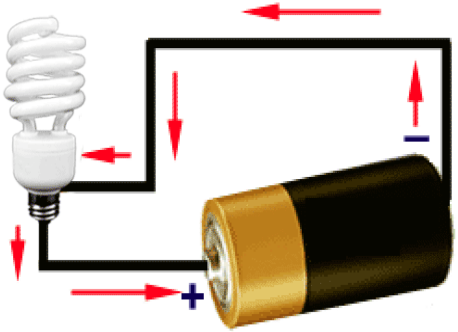
- **http://inventors.about.com/library/inventors/blelectric1.htm**

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.**

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



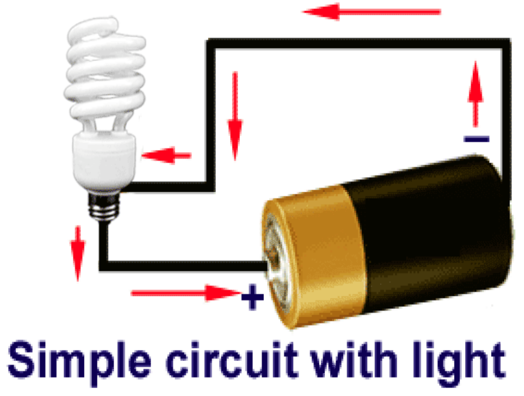
Simple circuit with light

Electricity:

- Power = (electrical current)^2 * resistance
- P = I * V
- P = I^2 * R
- Units: Watts or kilowatts

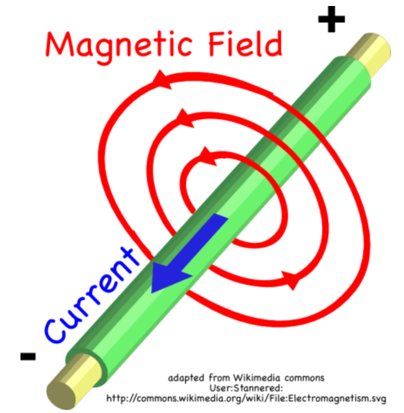
- 26,500 W electric furnace 2000 sqr ft cold climate
- 3,500 W ac central air conditioner
- 4,400 W clothes dryer
- 2,000 W oven at 350 F
- 250 W Computer and monitor
- 60 W light bulb
- 4 W clock radio

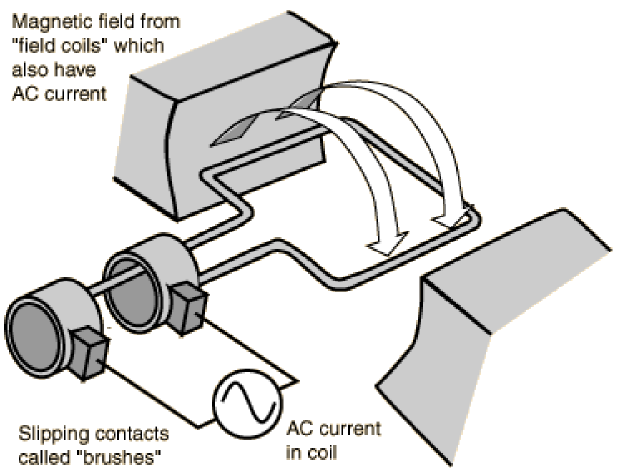
- http://michaelbluejay.com/electricity/howmuch.html



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.**

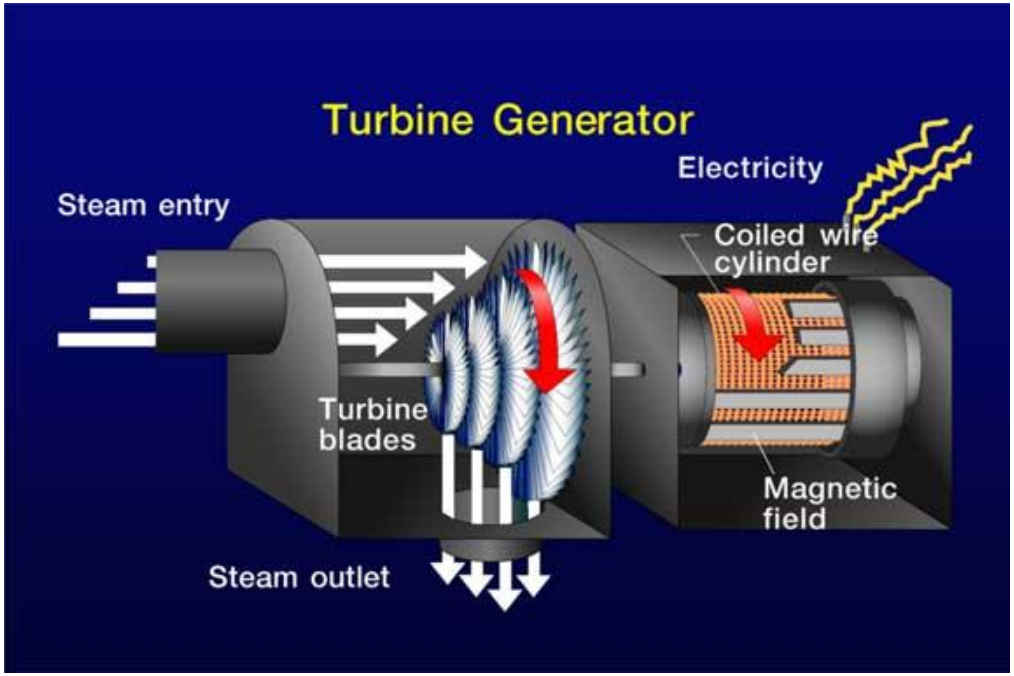




hyperphysics.phy-astr.gsu.edu

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.**
- **Coal, oil, natural gas, biomass, waste are burnt to generate steam to run turbine. EMISSIONS:**
- **In 1998, 3.62 trillion kilowatt hours of the US electricity produced**
  - **52% from coal,**
  - **3% from petroleum**
  - **19% nuclear**
  - **9% hydro**

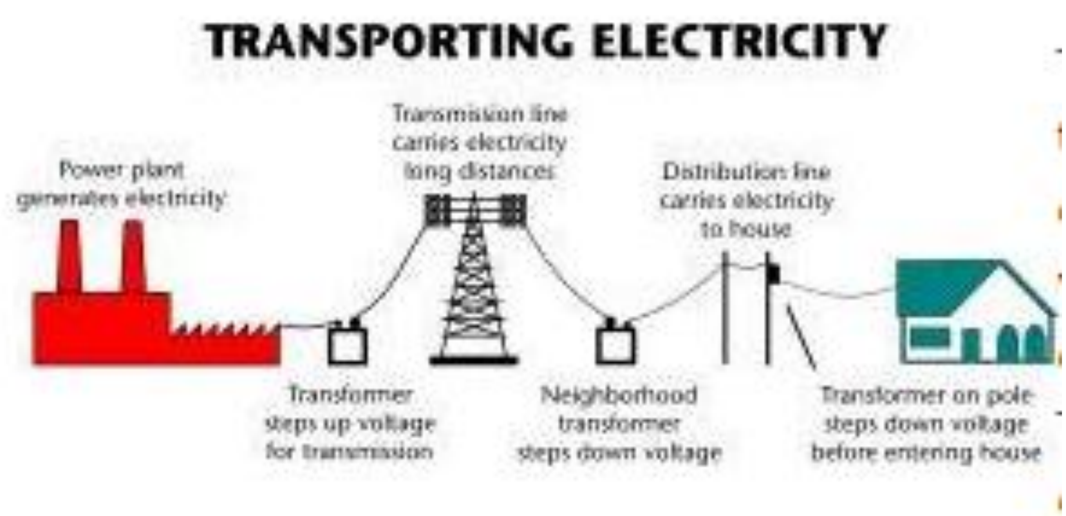


geothermal.marin.org

Electricity:

- **How is electricity transported?**

- **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….**



Example Electricity Calculation:

- **For power, the watt is used. A very small quantity (750 watts = 1 hp)**
- **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 number of kW's required by the number of hours of use.**

- **What is the kWhr for a 40 watt light bulb run for 5 hours? What is the cost? Avg cost is 12 cents per kWhr. http://michaelbluejay.com/electricity/cost.html**

Conversion Factors:

FACTORS FOR UNIT CONVERSIONS

Quantity	Equivalent Values
Mass	$1\ \text{kg} = 1000\ \text{g} = 0.001\ \text{metric ton} = 2.20462\ \text{lb}_\text{m} = 35.27392\ \text{oz}$ $1\ \text{lb}_\text{m} = 16\ \text{oz} = 5 \times 10^{-4}\ \text{ton} = 453.593\ \text{g} = 0.453593\ \text{kg}$
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 $\left(\dfrac{2.20462\ \text{lb}_\text{m}}{1000\ \text{g}}\right)$.

Summary Problem:

Convert 24 in^3/hr to m^3/minute?

If 20 joules are expended over a period of 2 days, how many hp does this indicate?

Summary 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 wood at 50 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:
  - Amt of component A In = Amt of component A Out +/- Amt of A reacted or produced

Material Balances:

- To solve material balance problem, you must formulate X independent equations to solve for X unknowns.
-
- Drawing a picture and setting up a table with all knowns and unknowns labeled is a good practice.
- If a basis for calculation is not given, one must be established.
- Check your balances for consistency.

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?**

Mass Balances:

- **Example: We want to make 100 kg/hr of a product containing solids and water. The product must have a solids content of 4%. A feed stream that has 92% solids and 8% water needs to 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 this?**

Energy Balances:

- **At steady state: In = Out**

- 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

- Where Q is the heat flow into the system
- 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

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, CO2 and water vapor are the main products**
  - $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ + energy (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)

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

Heats of combustion:

- **HHV: higher heating value, includes the water vapor 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**
- **Wikipedia: 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:

- **If there is a rate of 10 g/s of kerosene being combusted fully in a furnace, what is the maximum power available in watts?**