OSU~EmEa – 4

Calculating Exergy of Materials & Energy Sources

Available energy using Gibbs Free Energy of materials
and kinetic energy of renewable sources.

Energy of Renewable Sources…

Computing Available Energy ...

Renewable Sources

- Sunlight
- Kinetic Energy of Wind
- Chemical Potential Energy in Rain
- Chemical Potential Energy in River
- Geopotential Energy of Rivers
- Geopotential Energy of Rain (runoff)
- Energy of Ocean Waves Absorbed at the Shore
- Tidal Energy Absorbed in Estuaries

Energy of Renewable Sources…

Sunlight

Energy(J) = (area)*(avg insolation)*(1-albedo)

= (____m^2)(____$Cal/cm^2/y$)(E+04cm^2/m^2)(4186J/Cal)

= 1m^2 * 150 $Cal/cm^2/y$ * 0.70 * 1E4 cm^2/m^2 * 4186 J/Cal

= 4.4 E9 J m^{-2} yr^{-1}

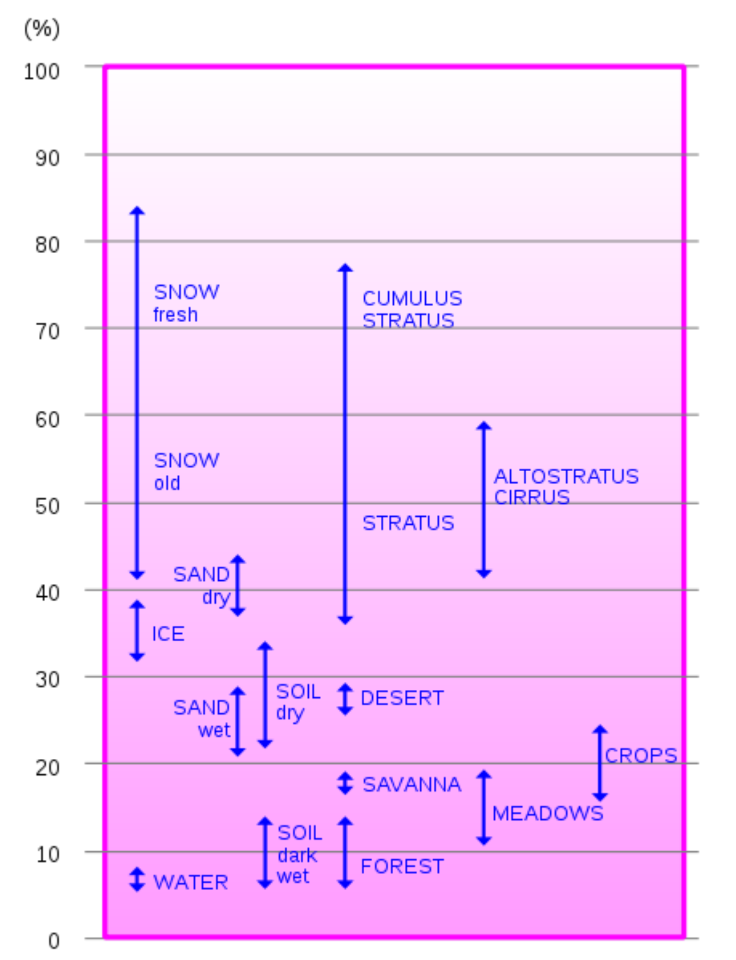
Solar Insolation varies with latitude…

Gainesville ~ 150 Cal cm^{-2} y^{-1}

Albedo = 30%

Sunlight

The average overall albedo of Earth, its *planetary albedo*, is 30, but varies widely due to local conditions across the surface,



Energy of Renewable Sources…

Tide Absorbed in Estuaries

Energy (J) = (area)((0.5)(tides/yr)($height^2$)(density)(gravity)

= (1 m^2)(0.5)(706/yr)(0.8m^2)(1.025E3 kg/m3)(9.8 m/sec^2)

= 2.27 E6 J m^{-2} yr^{-1}

Area = area of estuary

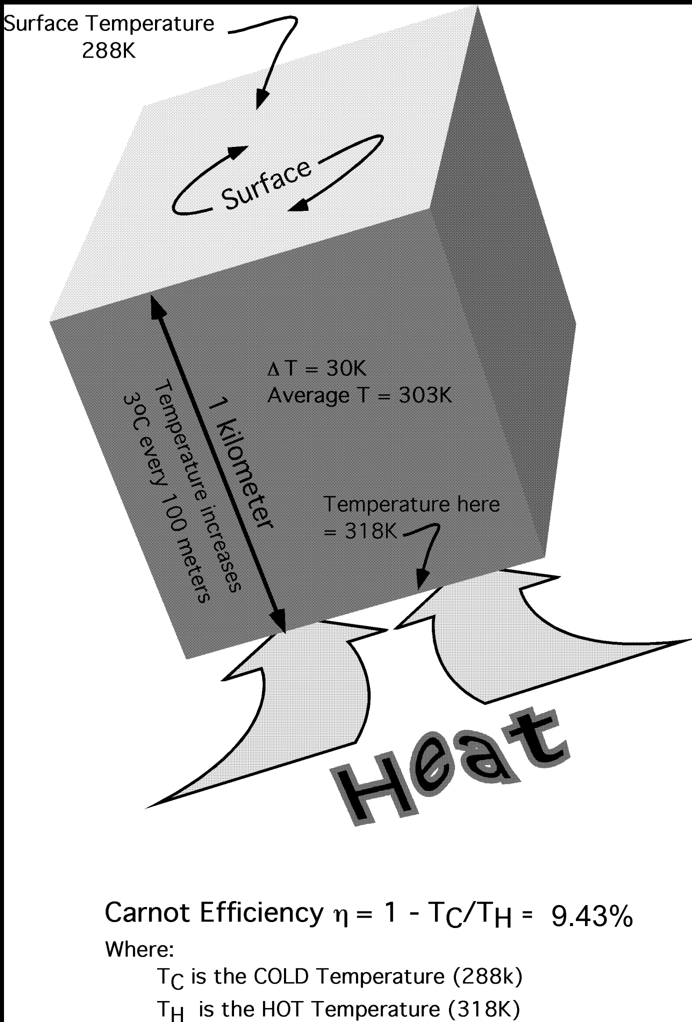
Height = tidal height

Center of gravity = 0.5 * height

Geothermal energy

Calculation of geothermal exergy relies on computing a Carnot efficiency for the energy in the thermal gradient between the average temperature of the heat source and the average temperature of the reference environment.

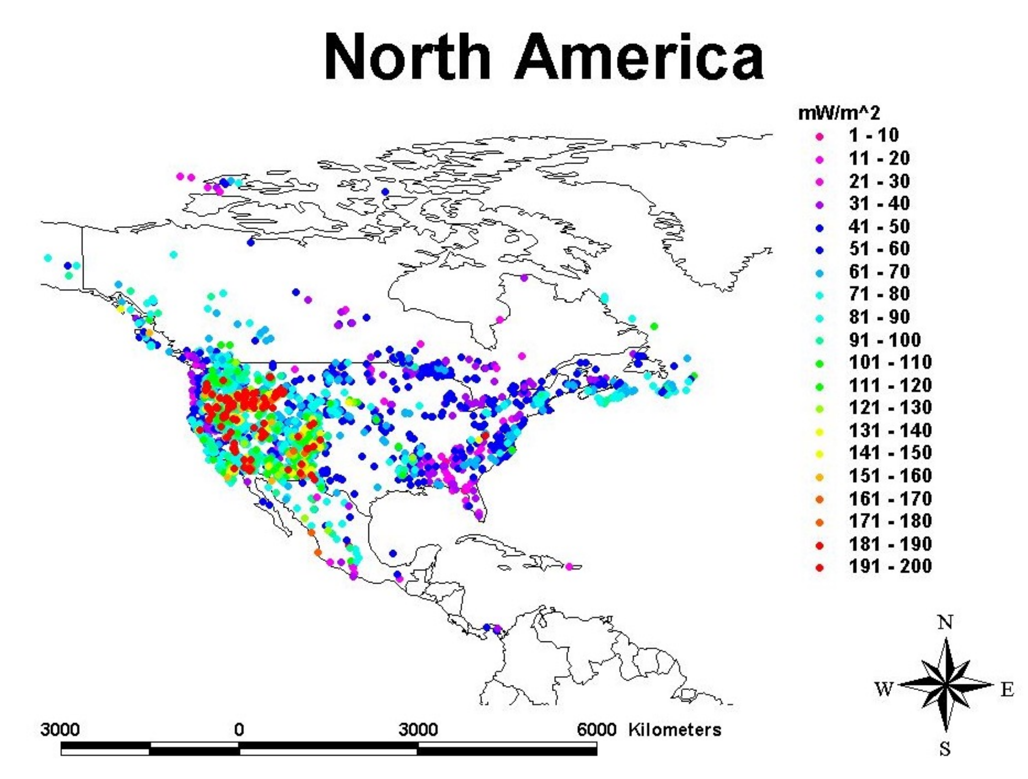
Carnot Eff. = 1 - Tc / Th
= 1 – 288/318
= 9.43%



Geothermal energy

Mean heat flow is 65 mW/m2 (2.05 E6 J/m²/yr) over continental crust and 101 mW/m2 (3.19 E6 J/m²/yr) over oceanic crust.

$$\frac{(mW / m^2)}{1{,}000} \times 3.15E7 s / yr = J / m^2 / yr$$



Geothermal energy

$$\text{Energy(J)} = \frac{(\text{mW m}^{-2})}{1000} * 3.15\text{ E7 sec y}^{-1}$$

$$= \frac{(65\text{ mW m}^{-2})}{1000} * 3.15\text{ E7 sec y}^{-1}$$

$$= 2.05\text{ E6 J m}^{-2}\text{ y}^{-1}$$

Carnot Eff. = 9.43%

Therefore,

$$\text{Energy} = 2.05\text{ E6 J m}^{-2}\text{ y}^{-1} * 9.43\%$$

$$= 1.93\text{ E5 J m}^{-2}\text{ y}^{-1}$$

Kinetic Energy of Wind

Energy (J) = (area)(air density)(drag coefficient)(wind velocity absorbed^3)*sec/y
= (_____m^2)(1.3 kg/m^3)(1.64 E-3)(_______mps^3)(3.14 E7 s/yr)
= 1m2 * 1.23 kg/m^3 * 1.64E-3 * $(7.54)^3$ mps * 3.14 E7 s/yr
= 2.72 E7 J m^{-2} yr^{-1}

Wind velocity absorbed is difference between geostrophic wind (10.4 mps) and surface wind observed…

Gainesville wind average = 2.86 mps

Therefore wind absorbed =10.4 – 2.86 = 7.54

Drag coefficients

Land = .00164

Ocean .00126

Chemical Potential Energy in Rain

First: Gibbs free energy in water.

Gibbs free energy for 10ppm rain relative to seawater salinity in evapotranspiring plants or to estuaries receiving fresh water…

$$G = \frac{RT}{w} \ln\left(\frac{C_2}{C_1}\right)$$

Important!

$$G = \frac{8.33 J / mole / \deg}{18 g / mole} \ln\left(\frac{999{,}990\, ppm}{965{,}000\, ppm}\right)$$

Chemical Potential Energy in Rain

Absolute zero = -273.15^{o} C

Average temperature of Earth at the surface = 14.1^{o}C

So T at earth surface = 287.25 K

If one includes the atmosphere to 1 kilometer, average temperature ~10^{o}C, and T = 283.15k

$$G_0 = 4.50 \text{ J g}^{-1}$$
$$G_{10} = 4.67 \text{ J g}^{-1}$$
$$G_{14.1} = 4.74 \text{ J g}^{-1}$$

Chemical Potential Energy in Rain

Chemical potential of rain

Energy (J) = (_m^3)(1E6g/m^3)(4.74 J/g)

= (1.4m^3/yr)(1 E6/g/m^3)(4.74 J/g)

= 6.63 E6 J m^{-2} yr^{-1}

Gainesville Rain = 1.4 m yr^{-1}

Geopotential Energy in Rain

Energy (J) =(area)(runoff)(density)(height)(gravity)

$=(2.26E9 m^2)(0.35 m/yr)(20\ m)(1E3 kg/m^3)(9.8\ m\ sec^{-2})$

$= 6.86E4\ J\ yr^{-1}$

Area Alachua County = $2.26E9 m^2$

Gainesville runoff avg. = 25% rainfall

= 1.4 m * 0.25

= 0.35m

Avg fall across Alachua County = 20 m

Chemical Potential Energy in River

Calculate Gibbs free energy of water relative to sea water…

$$G = \frac{8.33 J/mole/\deg}{18 g/mole} \ln\left(\frac{1E6 - Sppm}{965{,}000\, ppm}\right)$$

Where S is dissolved solids in ppm.

Chemical Potential Energy in River

Chemical potential of river discharge

Energy (J) = (_m^3)(1E6g/m^3)(Gibbs J/g)

= (1.0 m^3 yr^{-1})(1 E6 g m^{-3})(4.66 J g-^{1})

= 4.66 E6 J m^{-3} yr^{-1}

Assume 500 ppm dissolved solids... therefore G = 4.66

Geopotential Energy in River

Energy (J) = (flow volume)(density)(height)(gravity)

$= (1.0\ m^3\ yr^{-1})(1E3\ kg\ m^{-3})\ (10\ m)(9.8\ m\ sec^{-2})$

$= 9.8E4\ J\ m^{-3}\ yr^{-1}$

Height = inflow elevation - outflow elevation

Assume 10 meters across Alachua County

Waves Absorbed at the Shore

Energy (J) = (shore length)(1/8)(density)($height^2$)(velocity)

where:

velocity = $(gravity*depth)^{1/2}$

Energy (J) = (1m)(1/8)(1.025E3 kg m^{-3})(9.8 m sec^{-2})(.6 m)^2(3.96 m sec^{-1})(3.154E7 sec yr^{-1})

= 5.65 E10 J m^{-1} yr^{-1}

Height = wave height

Depth = water depth where height is measured

Available Energy of Non-Renewable Sources…

Fossil Fuels

Coal= 3.18 E10 J/mt = 31.8 kJ g^{-1}

Oil = 6.28 E9 J/bbl = 6.28 E9 / 158987.2 g/bbl = 39.5 kJ g^{-1}

Natural Gas = 1.1 E9 J/1000 ft^3 = 1.1 E9 J / 1.72 E4 = 63.8 kJ g^{-1}

^{235}U = 8.3 E10 J g^{-1}

Available Energy of Non-Renewable Sources…

Organic Substances

Organic Matter = 3.5 - 9.0 Cal g^{-1} dry weight (14.6 – 37.7 kJ g^{-1})

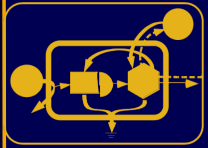
Carbs = 4 Cal/g (16.7 kJ g^{-1})

Proteins = 5 Cal/g (20.9 kJ g^{-1})

Fats = 7 - 9 Cal/g (29.3 – 37.7 kJ g^{-1})

Wood = 3.5 - 5.4 Cal/g (14.6 – 22.6 kJ g^{-1})

* note: Cal = kcal or 1000 calories



Questions?

Comments?

Concerns?