OSU~EmEa – 3

Energy, Exergy and Thermodynamics

Thermodynamics, Maximum power, Hierarchies, and Material cycles

Energy …

The joule is named after James Prescott Joule. As with all SI units whose names are derived from the proper name of a person, the first letter of its symbol is uppercase (J).

When an SI unit is spelled out in English, it should always begin with a lowercase letter (joule),

SI multiples for joule (J)

Submultiples			Multiples		
Value	Symbol	Name	Value	Symbol	Name
10^{-1} J	dJ	decijoule	10^{1} J	daJ	decajoule
10^{-2} J	cJ	centijoule	10^{2} J	hJ	hectojoule
10^{-3} J	**mJ**	**millijoule**	10^{3} J	**kJ**	**kilojoule**
10^{-6} J	**µJ**	**microjoule**	10^{6} J	**MJ**	**megajoule**
10^{-9} J	**nJ**	**nanojoule**	10^{9} J	**GJ**	**gigajoule**
10^{-12} J	**pJ**	**picojoule**	10^{12} J	**TJ**	**terajoule**
10^{-15} J	fJ	femtojoule	10^{15} J	PJ	petajoule
10^{-18} J	aJ	attojoule	10^{18} J	EJ	exajoule
10^{-21} J	zJ	zeptojoule	10^{21} J	ZJ	zettajoule
10^{-24} J	yJ	yoctojoule	10^{24} J	YJ	yottajoule

Common multiples are in bold face

Energy …

- the energy required to lift a small apple one meter straight up.
- the energy released when that same apple falls one meter to the ground.
- the amount of energy, as heat, that a quiet person generates every hundredth of a second.
- the energy required to heat one gram of dry, cool air by 1 degree Celsius.
- one hundredth of the energy a person can get by drinking a single drop of beer.
- the kinetic energy of an adult human moving 17 cm every second.

Source: Wikipedia,

Energy….

In physics, energy is defined as the ability to do work...

Since work is defined as a force acting through a distance, energy is always equivalent to the ability to exert pulls or pushes along a path of a certain length.

Energy….

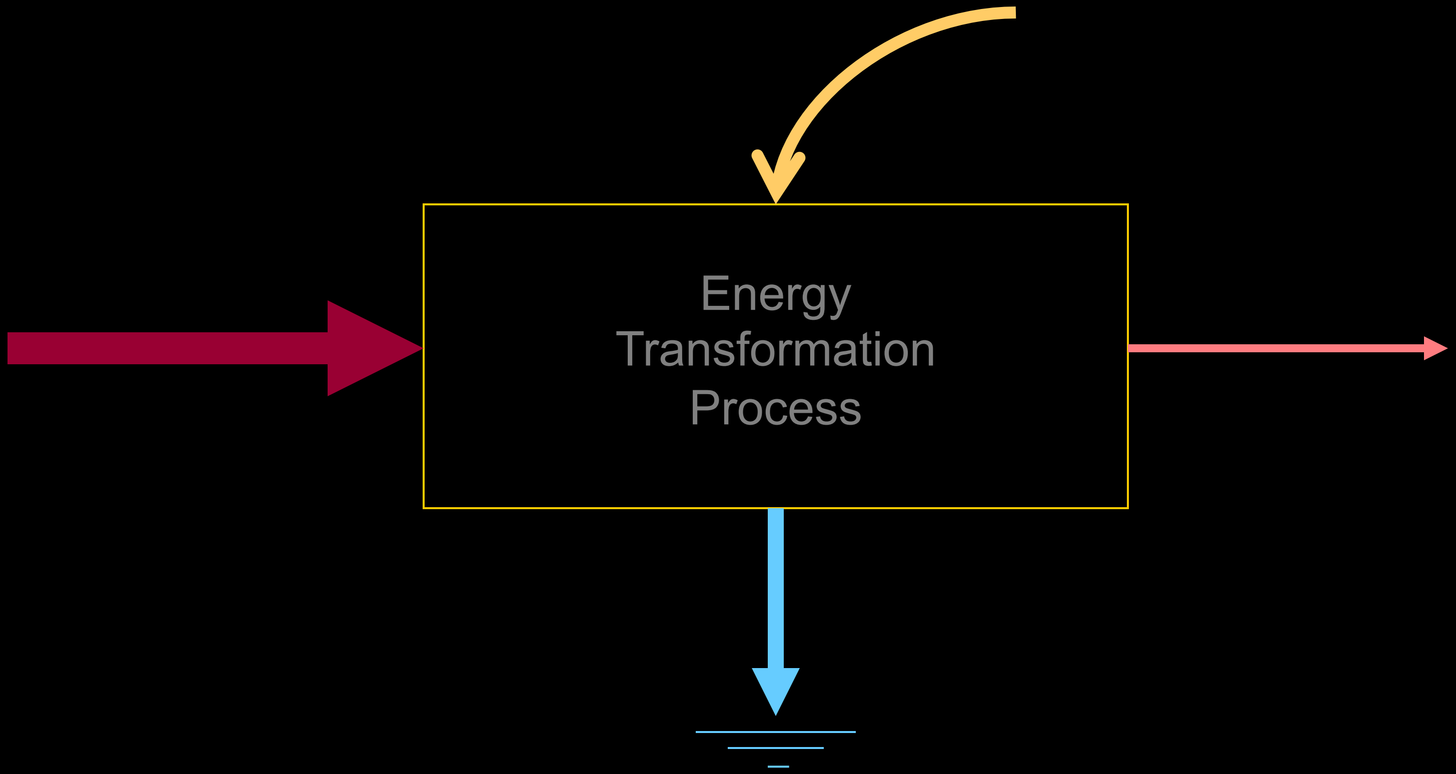
In chemistry, energy is an attribute of a substance as a consequence of its atomic, molecular or aggregate structure, and a chemical transformation that is accompanied by a change in one or more of these kinds of structures.

Energy….

In this course...Energy is the ability to cause work…

and WORK is defined as any useful energy transformation

…in most kinds of work, one type of energy is transformed into another with some going into a “used form” that no longer has potential for further work WITHIN THAT SYSTEM.



All transformations require at least two different forms of energy and they produce a third form of energy.

Two types of energy….

Potential and kinetic

1. Potential - energy capable of driving a process of energy transformation

Potential energy from outside energy sources provides the means for keeping systems generating work.

Storages within systems have potential energy that can also drive work processes

Two types of energy….

Potential and kinetic

2. Kinetic - the energy of movement as in a spinning top or traveling car

Kinetic energy can be converted to potential and back again, in some systems without a loss of potential energy to heat..

The amount of kinetic energy that a body possesses is dependent on the speed of its motion and its **mass**.

At the *atomic scale*, the kinetic energy of atoms and molecules is sometimes referred to as **heat energy**.

Energy = Heat

In practice energy is defined and measured by the heat that is formed when converted into heat!

There are many types of energy and they can all be quantitatively related by converting them into heat...

All energy can be converted into heat at 100% efficiency

Heat

- the collective motions of molecules, whose average intensity is the temperature which may be measured by expansion of matter in a thermometer

Available energy (exergy)...

Potential energy capable of doing work and being degraded in the process

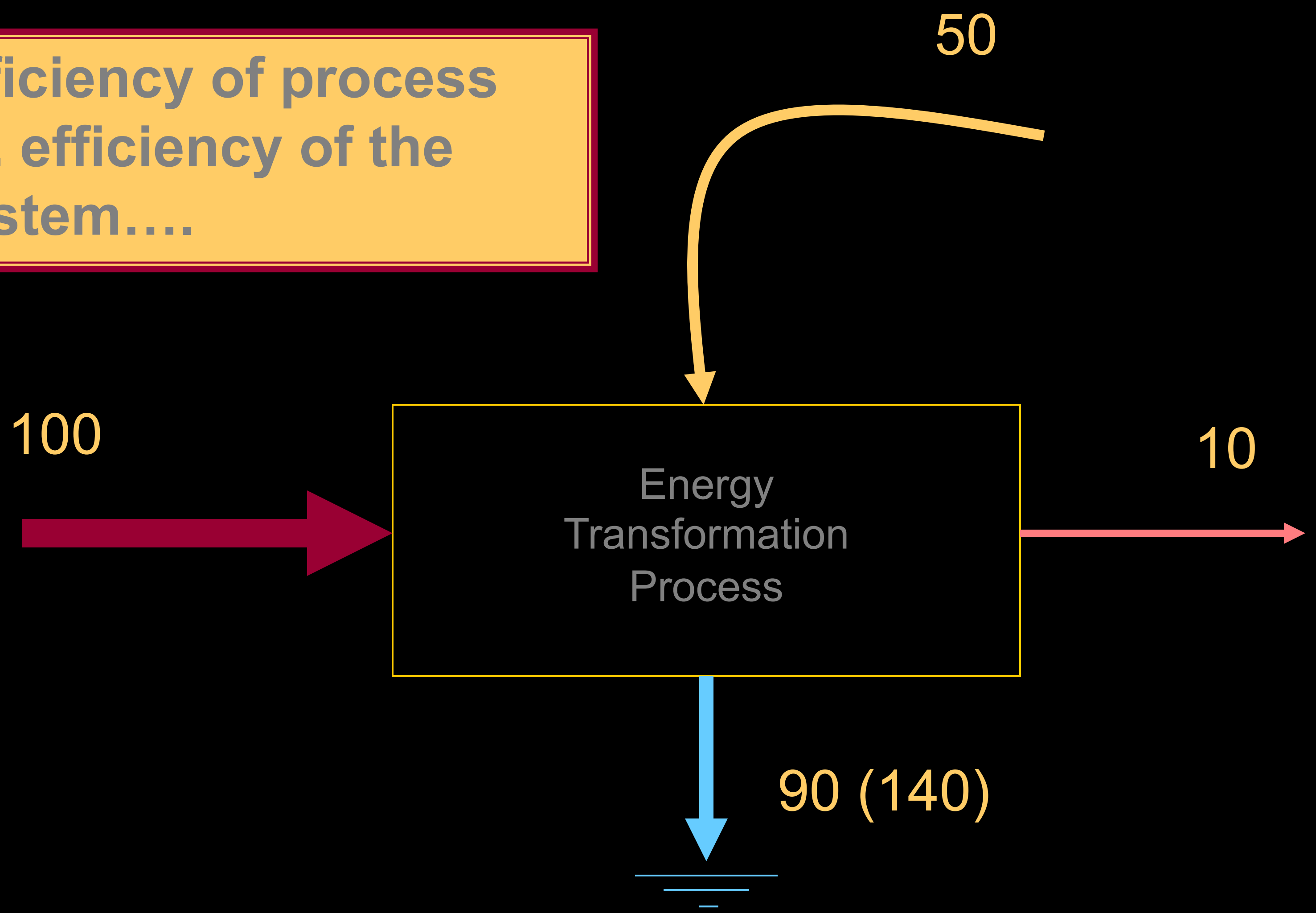
As long as comparisons are made between energies of the same form, we may say that available energy measures the ability to do work

Efficiency...

The ratio of the useful energy delivered by a dynamic system to the energy supplied to it...

Time's speed regulator- power in an energy transformation depends on the workload. Maximum output power occurs with an intermediate efficiency

Efficiency of process vs. efficiency of the system….



1st law efficiency = 10/100 = 10%

System efficiency = 10/150 = 6.67%

Work:

Mechanical work - a force operated against an opposing force for a distance, the energy transformed is the product of the force times the distance.

In this course….

Work.. A useful transformation - work means a useful energy transformation where useful can be defined as contributing to the survival of the system

Power:

Energy flow per unit time. Engineers restrict the term to the rate of flow of energy in useful work transformations

joules per second = J/sec
Calories per day = Cal/da
Etc.

Thermodynamics

Closed System Thermodynamics

The term "thermodynamics" comes from two root words: "thermo," meaning heat, and "dynamic," meaning power. Thus, the Laws of Thermodynamics are the Laws of "Heat Power."

Open System Thermodynamics

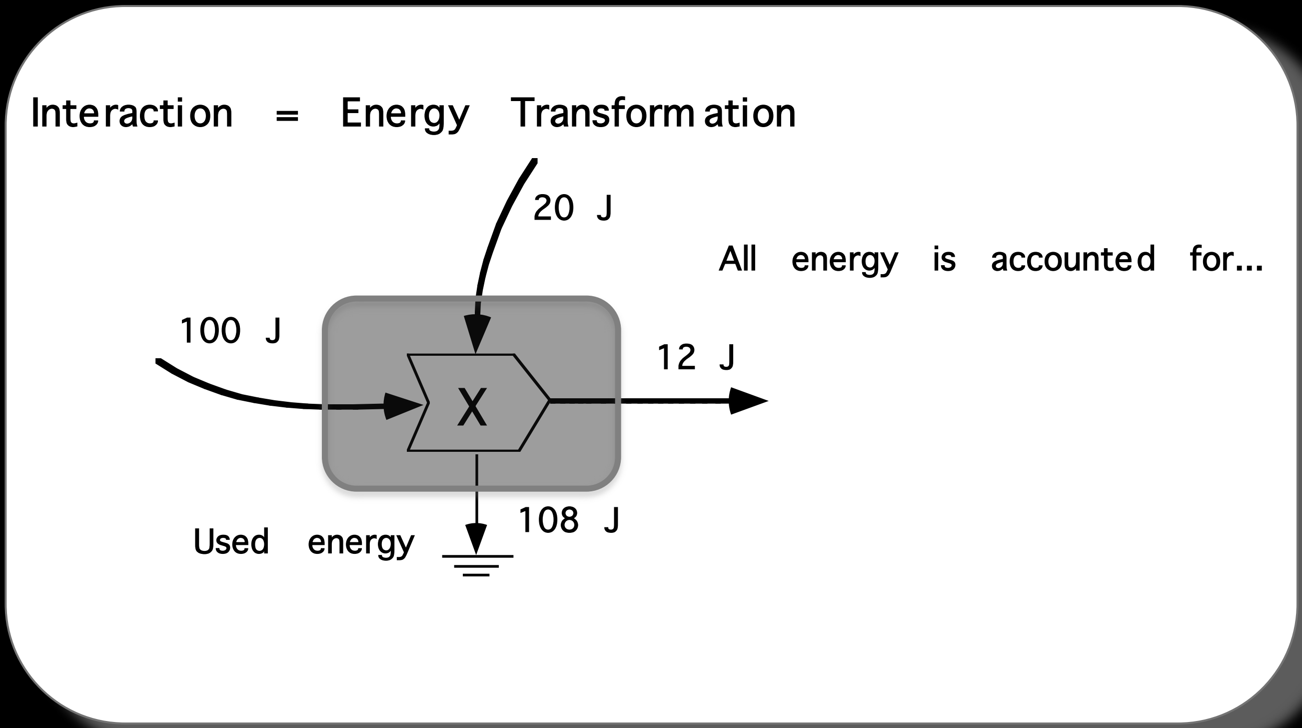
- 1st Law of Thermodynamics
- 2nd law of Thermodynamics
- 3rd law of Thermodynamics

Proposed

- Maximum EmPower Principle (4th law)
- Hierarchically organized systems (5th law)

1st Law of Thermodynamics

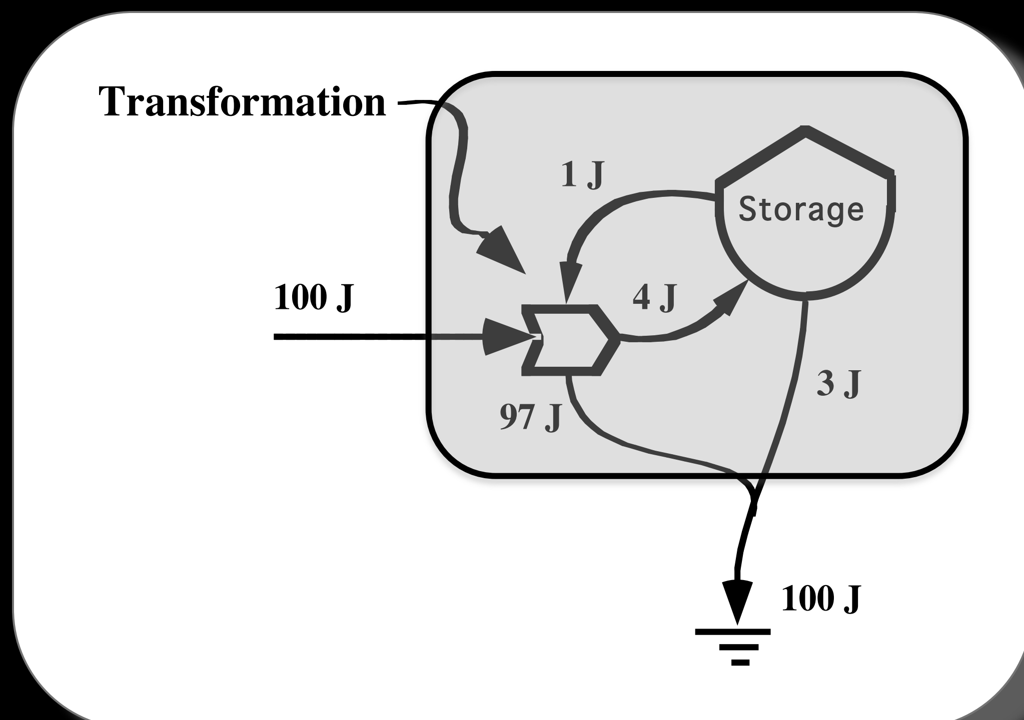
During energy transformations,
Energy cannot be created or destroyed
Energy cannot be created or destroyed



2nd Law of Thermodynamics

Energy transformations in real processes create energy of higher quality by degrading some energy of lower quality.

The state of entropy in any closed isolated system, will always increase over time….or the changes in the entropy in a closed system can never be negative.



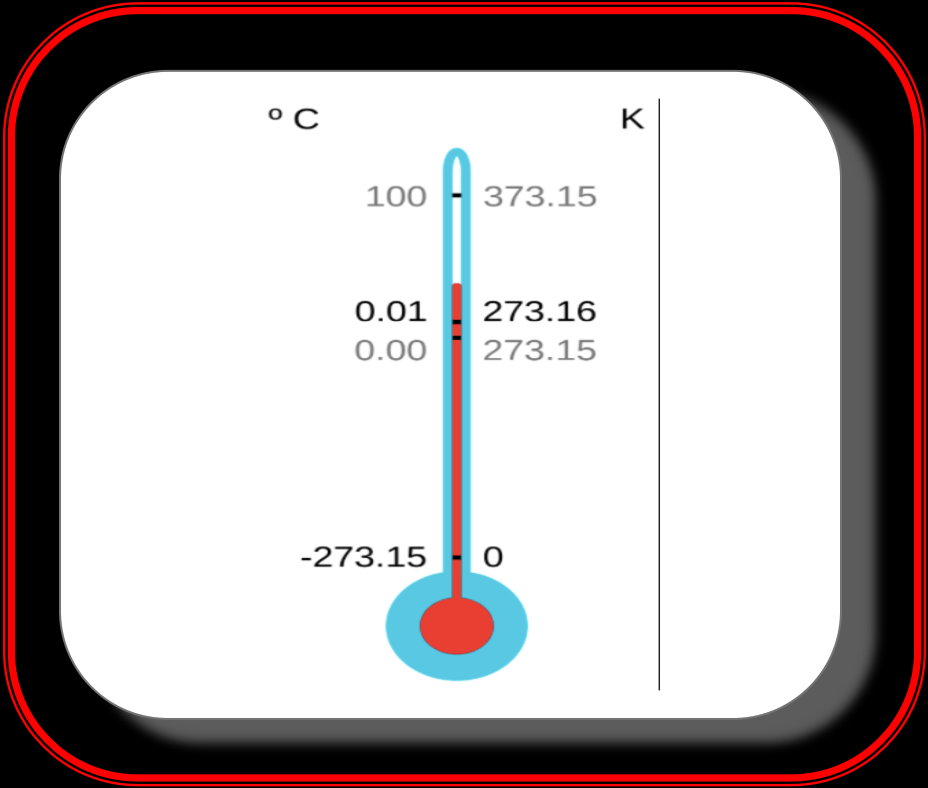
There are as many statements of the 2nd Law as there are researchers studying it…

3rd Law of Thermodynamics

As heat content approaches absolute zero, molecules are in crystalline states, and the entropy of the state is defined as zero

Absolute Zero Exists… or…. The entropy of a perfect crystal at absolute zero is exactly equal to zero.

(- 273^o C)



4th Law of Thermodynamics (proposed)

Maximum Empower Principle

Self-organization tends to develop network connections that use energies in feedback actions to aid the process of getting more resources or using them more efficiently...

4th Law of Thermodynamics (proposed)

The principle of natural selection (Lotka's Maximum Power Principle) reveals itself as capable of yielding information which the first and second laws of thermodynamics are not competent to furnish. The two fundamental laws of thermodynamics are, of course, insufficient to determine the course of events in a physical system. They tell us that certain things cannot happen, but they do not tell us what does happen.

(Lotka, 1922b: p151)

Lotka’s Maximum Power Principle…

It has been pointed out by Boltzmann that the fundamental object of contention in the life-struggle, in the evolution of the organic world, is available energy. In accord with this observation is the principle that, in the struggle for existence, the advantage must go to those organisms whose energy-capturing devices are most efficient in directing available energy into channels favorable to the preservation of the species.

A.J.Lotka 1922a, p. 147

Elements of Physical Biology

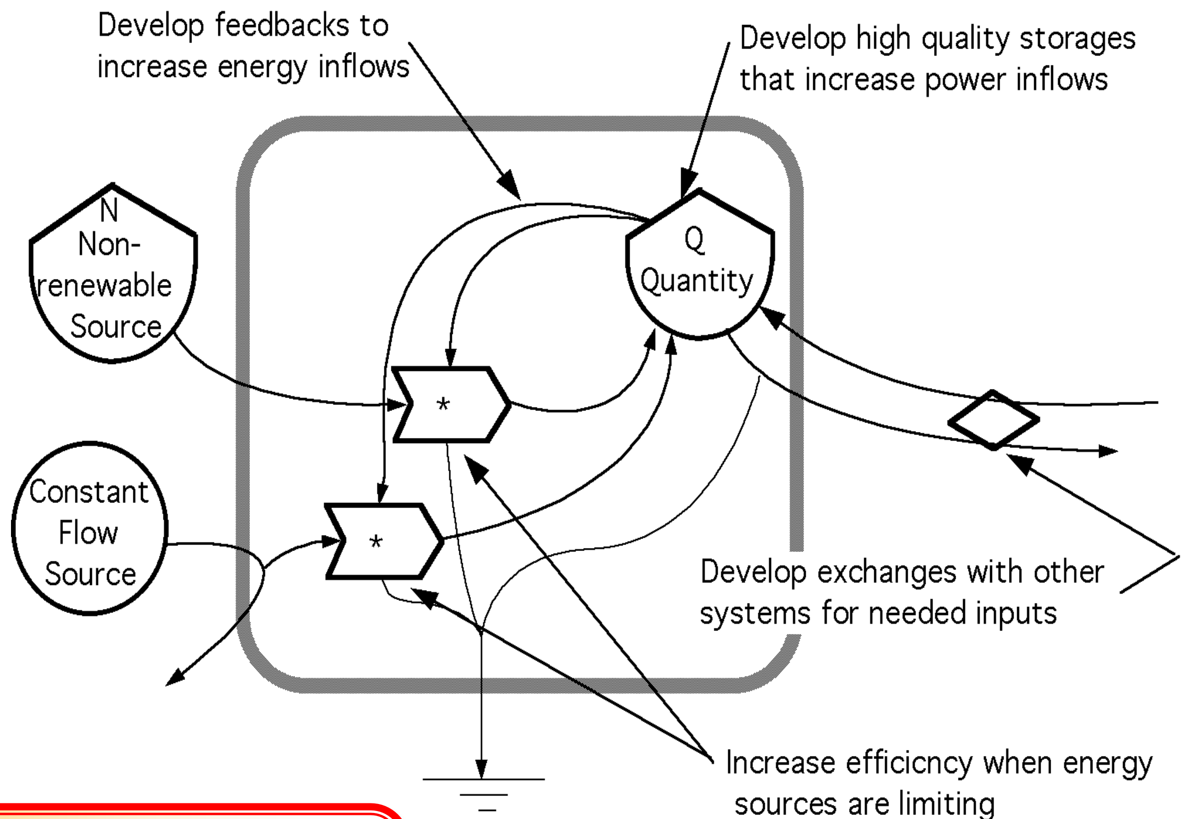
Ludwig Boltzmann

The struggle for existence is the struggle for energy...

Available energy is the main object at stake in the struggle for existence and the evolution of the world.

Boltzmann...Austrian physicist who established the relationship between entropy and the statistical analysis of molecular motion in 1877, founding the branch of physics known as statistical mechanics.

Wikipedia

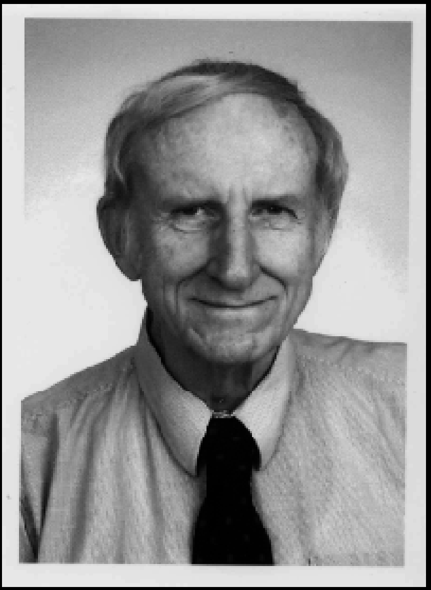


Maximum Empower

Maximum Empower Principle…

"In time, through the process of trial and error, complex patterns of structure and processes have evolved...the successful ones surviving because they use materials and energies well in their own maintenance, and compete well with other patterns that chance interposes."

H.T. Odum, ca. 1990



5^{th} Law of Thermodynamics (proposed)

All systems are organized hierarchically

Energy flows of the universe are organized in energy transformation hierarchies. Position in the energy hierarchy can be measured by the amount of available energy transformed to produce it.

Energy Transformation Hierarchy

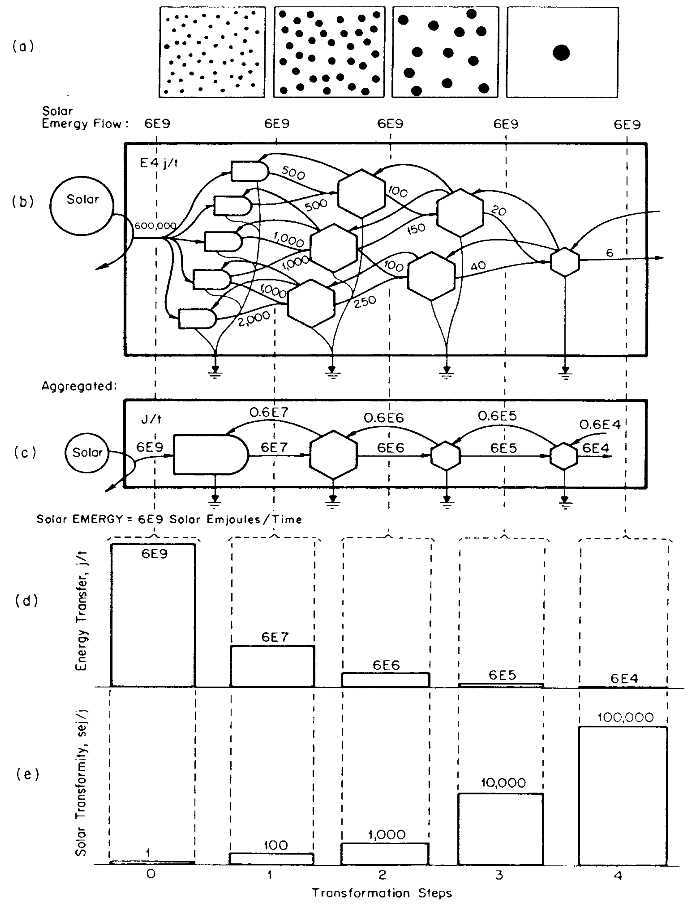
Spatial view of units and their territories

Energy network including transformations and feedbacks

Aggregation of energy network into an energy chain

Bar graph of the energy flows for the levels in the energy hierarchy

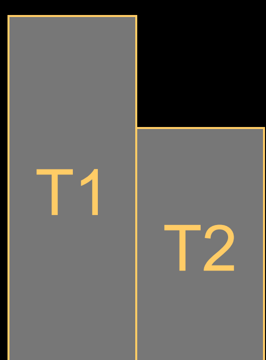
Bar graph of solar transformities



Heat and Entropy…

If there is a difference in temperature within a system, the difference can drive other transformations.

The useable heat in any system is the difference between the inflowing temperature and the outflowing temperature



$$T1 - T2 = \Delta T$$

$$\text{Efficiency} = \frac{T2 - T1}{T2} = \frac{\Delta T}{T2}$$

Heat and Entropy…(continued)

The Carnot Ratio ($\Delta T/T$) is called a thermodynamic force since it indicates the intensity of delivery of a potential energy flow from a storage of heat relative to one at a lower temperature.

Heat and Entropy…(continued)

Heat Capacity - of a substance is the ratio of the amount of heat energy absorbed by that substance to its corresponding temperature rise.

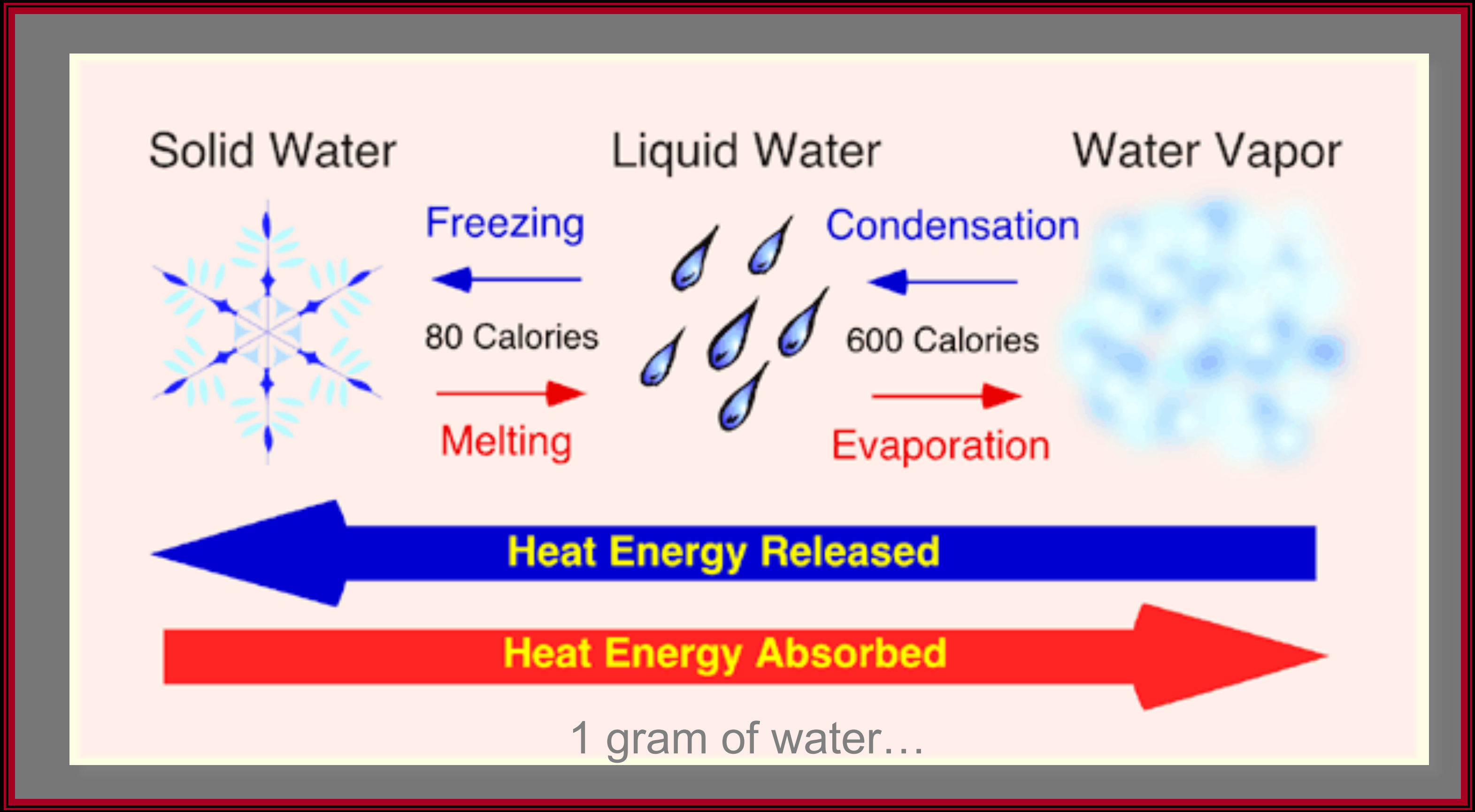
Specific Heat - is the heat capacity of a unit mass of a substance or heat needed to raise the temperature of 1 gram (g) of a substance 1 degree Celsius.

Sensible Heat - is heat that can be measured by a thermometer, and thus sensed by humans. Several different scales of measurement exist for measuring sensible heat. The most common are: Celsius scale, Fahrenheit scale, and the Kelvin scale.

Latent Heat - is the energy required to change a substance to a higher state of matter. This same energy is released from the substance when the change of state is reversed.

Heat and Entropy…(continued)

Latent heat exchanges of energy involved with the phase changes of water….



Chemical Potential Energy… (continued)

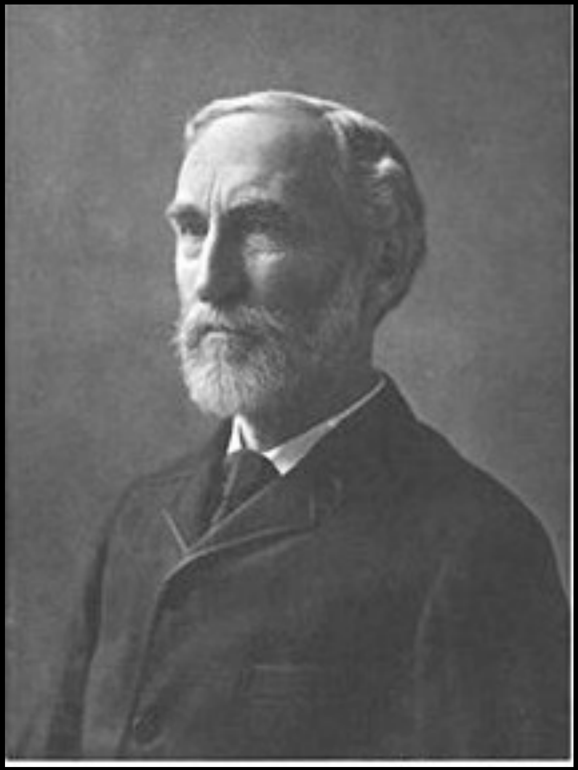
Gibbs Free Energy - free energy of a chemical reaction where pressure is held constant during the change.

Helmholtz Free Energy - free energy where volume is held constant during the change.

Gibbs Free Energy…

In 1873, in a footnote, Gibbs defined what he called the "available energy" of a body as:

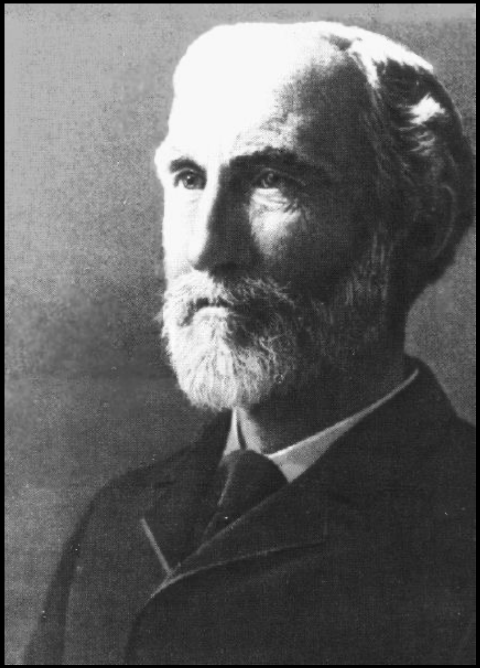
The greatest amount of mechanical work which can be obtained from a given quantity of a certain substance in a given initial state, without increasing its total volume or allowing heat to pass to or from external bodies, except such as at the close of the processes are left in their initial condition.



Exergy …

Exergy is available energy. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment.

Exergy is then the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero.



J. Willard Gibbs

Zoran Rant

The term was coined by Zoran Rant in 1956, but the concept was developed by J. Willard Gibbs in 1873.

Exergy …

"Exergy is the amount of work obtainable when some matter is brought to a state of thermodynamic equilibrium with the common components of the natural surroundings by means of reversible processes, involving interaction only with the above mentioned components of nature".

"In contradiction to energy, exergy is exempt from the law of conservation."

"Every irreversible phenomenon causes exergy losses leading to the reduction of the useful effects of the process or to an increased consumption of energy from whatever source the energy was derived."

"The chief aim of exergy analysis is to detect and to evaluate quantitatively the causes of the thermodynamic imperfection of the process under consideration."

Szargut, Jan, David R. Morris, Frank R. Steward, Exergy analysis of thermal, chemical, and metallurgical processes, Hemisphere Publishing Corporation,1988, ISBN 0-89116-574-6.

Exergy …

exergy

is a measure of work potential or disequilibrium from the environment

While exergy can be destroyed, energy cannot

exergy is the useful portion of energy

exergy

is what most mean when they say energy

W. Hermann. QGER. Energy 2006;31(12):1349-1366.

Earth's Exergy Resources, Hermann, 2006.
http://gcep.stanford.edu/pdfs/DyUMPHW1jsSmjoZfm2XEqg/1.3-Hermann.pdf

Exergy …

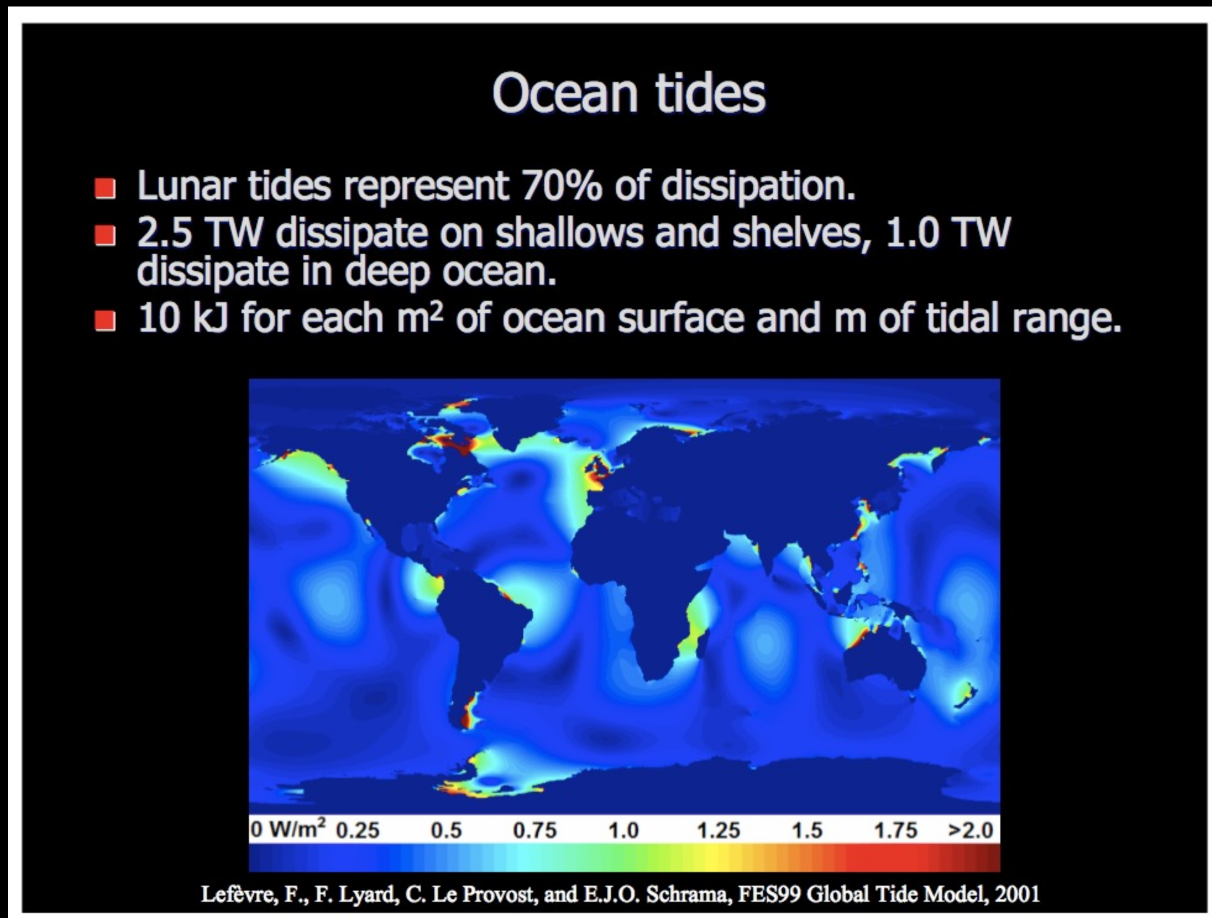
Kinetic and gravitational exergy

- Motion relative to the environment or height relative to the "ground".
- Kinetic and gravitational exergy always have Q = 1, or the exergy and energy are equal.
- No temperatures, compounds, or internal degrees of freedom.

W. Hermann. QGER. Energy 2006;31(12):1349-1366.

Earth's Exergy Resources, Hermann, 2006.
http://gcep.stanford.edu/pdfs/DyUMPHW1jsSmjoZfm2XEqg/1.3-Hermann.pdf

Exergy …



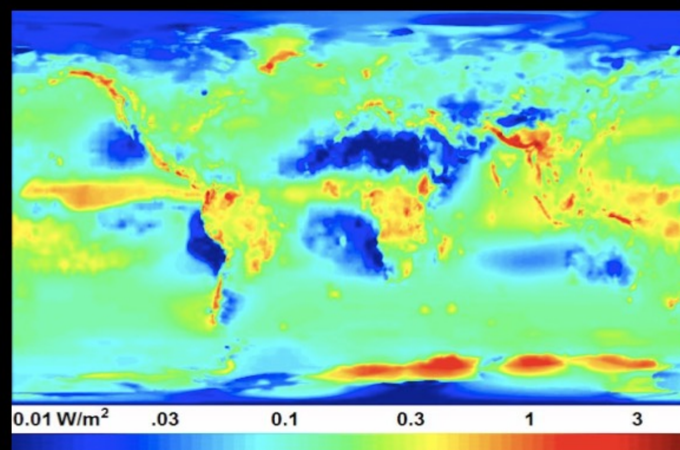
W. Hermann. QGER. Energy 2006;31(12):1349-1366.

Earth's Exergy Resources, Hermann, 2006.
http://gcep.stanford.edu/pdfs/DyUMPHW1jsSmjoZfm2XEqg/1.3-Hermann.pdf

Exergy …

Precipitation

- Average precipitation is 18 Tg/s.
- Total flux is 25 TW gravitational and 19 TW chemical.
- Global average specific gravitational exergy is 6.6 kJ/kg and specific chemical exergy is 4.9 kJ/kg.

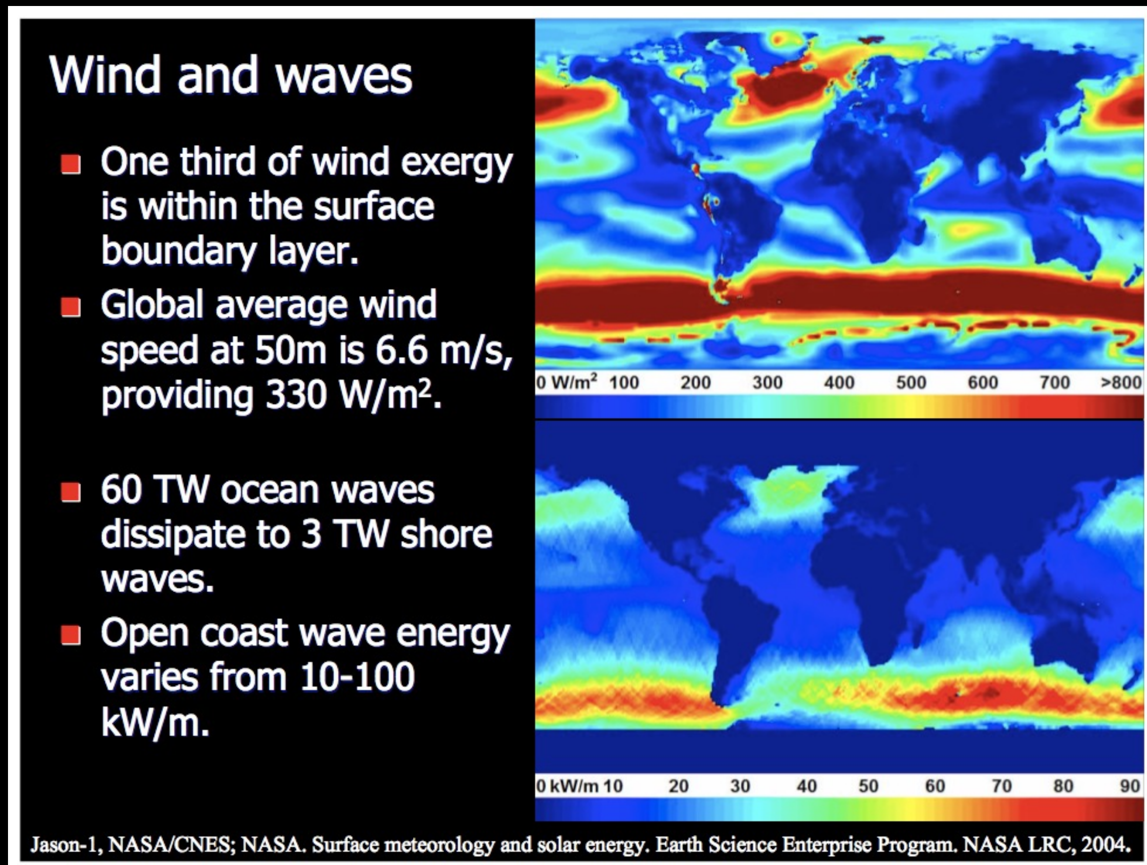


Legates DR, Wilmont CJ. NASA GSFC 2005; GLOBE Project, NOAA NGDC 2005

W. Hermann. QGER. Energy 2006;31(12):1349-1366.

Earth's Exergy Resources, Hermann, 2006.
http://gcep.stanford.edu/pdfs/DyUMPHW1jsSmjoZfm2XEqg/1.3-Hermann.pdf

Exergy …



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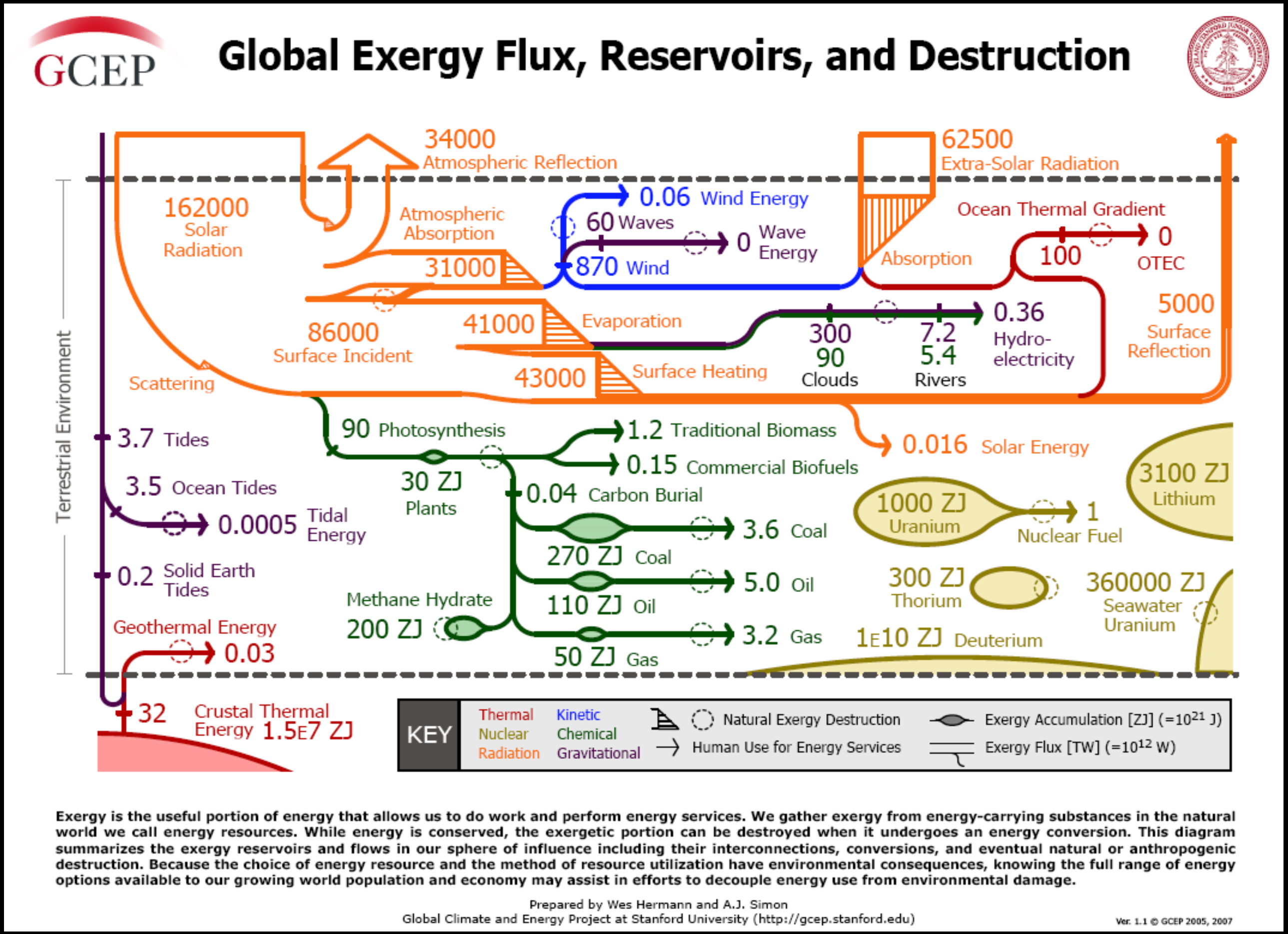
Earth's Exergy Resources, Hermann, 2006.
http://gcep.stanford.edu/pdfs/DyUMPHW1jsSmjoZfm2XEqg/1.3-Hermann.pdf

Exergy …

Of the 86 PW solar radiation exergy incident on the surface of the earth 90 TW is chemical exergy contained in net primary production (NPP).

(Accumulated standing biomass is indicated by ovals)



Herman & Simon, 2007. Global Climate & Energy Project.
http://gcep.stanford.edu

Exergy …

Detail of the Terrestrial Biome

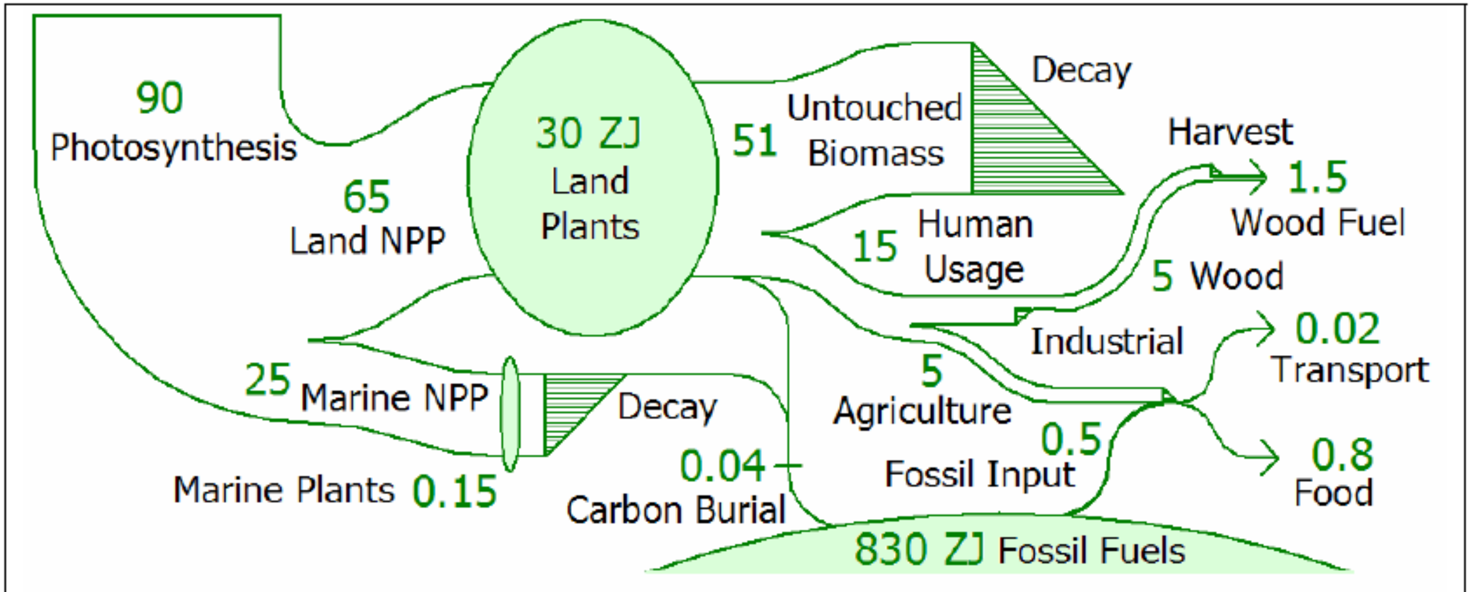


Figure 1: Exergy flow in TW through the natural and human appropriated terrestrial biomass system [4-9]

Herman & Simon, 2007. Global Climate & Energy Project.
http://gcep.stanford.edu

Questions?