Energy and Power

Outline

- First Law
- Heat and Friction
- Thru and Across Variables
- Energy Supply of Planet Earth
  Go-Cart

  (platform for converting electrical to mechanical energy)

TRUE / FALSE

1. Heat is a form of energy, and has units of Joules. _____

2. Friction is the main source of heat loss for all mechanical systems. _____

3. Power is a measure of how much energy is delivered per unit time. _____

ENERGY: a very old and basic notion.

What is energy?
Energy is the ability to do useful work. It is the ability to move something, heat something, grind something, light something ...

All other engineering disciplines study energy conversion they just choose different energy inputs and outputs (electrical, mechanical, chemical ...)

James Joule (1818-1889)

SI unit of energy ~ Joule ~ [J]
1 J = 1 N m

Joules/seconds = Watts

Portrait in Public Domain

One joule in everyday life is approximately:

- 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 thousandth of the energy a person can receive
    by drinking a 1mm diameter drop of juice
        (Note: 1 food Calorie = 4184 Joules. 1 food Calorie is the amount of energy
    required to raise the temperature of one kilogram of water by one degree Celsius)

- the kinetic energy of an adult human
    moving a distance of about a handspan every second.

How many calories do you need to eat per day?

Let's make a block diagram of a system and consider energy flows in and out of the system:
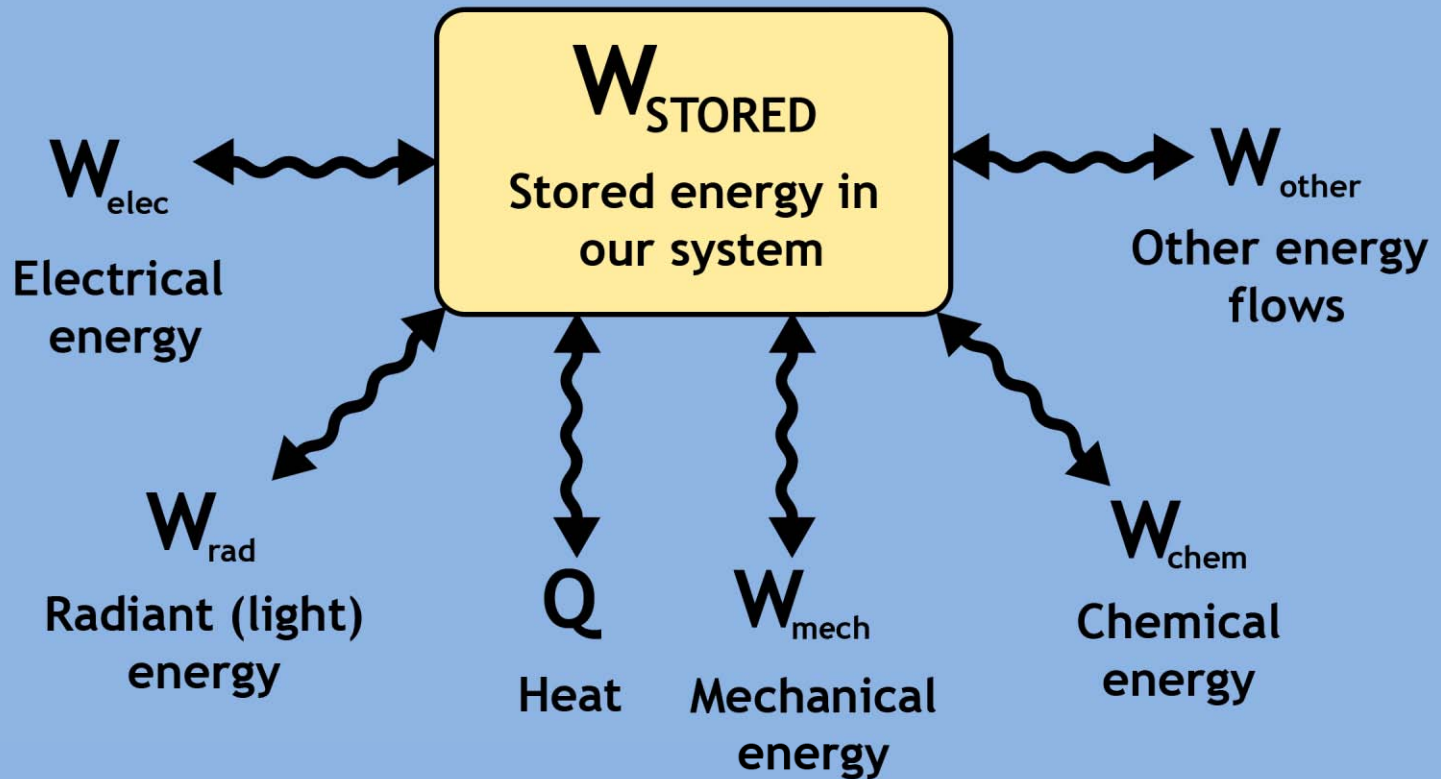
The **FIRST LAW of thermodynamics** governs the behavior of energy conversion systems. This "law" is not provable. It is an accepted observation of how the universe always works.

Ignoring nuclear reactions, in which energy can be converted to mass and vice-versa, the first law of thermodynamics says:

Energy is conserved

There are a number of equivalent ways to make this same statement. If the various energy flows W (electrical, mechanical, chemical, etc.) are all measured to be "positive" quantities when flowing OUT of the system (i.e., positive when the system is acting as a "source") and Q is understood to be "positive" when flowing IN to the system (by thermodynamic convention), then the first law can also be written as:

$$W_{stored} = Q - \sum W$$

This statement of the first law says that the energy stored in the system is equal to the difference between the heat flowing IN to the system and the sum of all of the other energy flows OUT of the system.

Another way to describe the first law is by considering a "closed cycle" of operation of the system. The definition of a closed cycle of operation is a sequence or pattern of system behaviors that start and end at the same system state. That is, over a closed cycle of operation, the change in stored energy is zero. In this case, we can express the first law this way:

$$dW_{stored} = 0$$

if and only if

$$\oint dQ = \oint dW$$

That is, the sum of all of the infinitesimal flows of heat energy into a system over a closed cycle of operation must be offset by an equivalent sum of infinitesimal work flows out of the system over the cycle in order for the net change in stored energy to be zero.

Why do we make a special symbol, Q, to distinguish heat energy flow from the other types of energy that could flow into or out of the system?

Heat is a special energy flow

All of the other types of flow are flows of energy, e.g., measured in joules.

Heat flow, which also can be measured in joules, affects the universe in a special way. It increases the vibrational energy of the materials in which it flows. Extra vibrational energy in atoms leads to "randomness" or disorder in the material structure. This disorder is called "entropy". Generation or flow of heat is unique in that it increases entropy. Heat flow always increases entropy when real (lossy, with friction, resistance, etc.) systems are involved.

The entropy of a lump of material may apparently be lowered, e.g., by cooling the material. This apparent reduction in entropy always occurs at the expense of a greater increase in entropy somewhere else. That is, your refrigerator may cool your bubbly beverage, lowering the entropy of the drink. However, the entropy of your kitchen, where the heat from the beverage is transferred by the refrigerator, will increase more than the reduction of entropy in the beverage.

A Quick Word About Heat
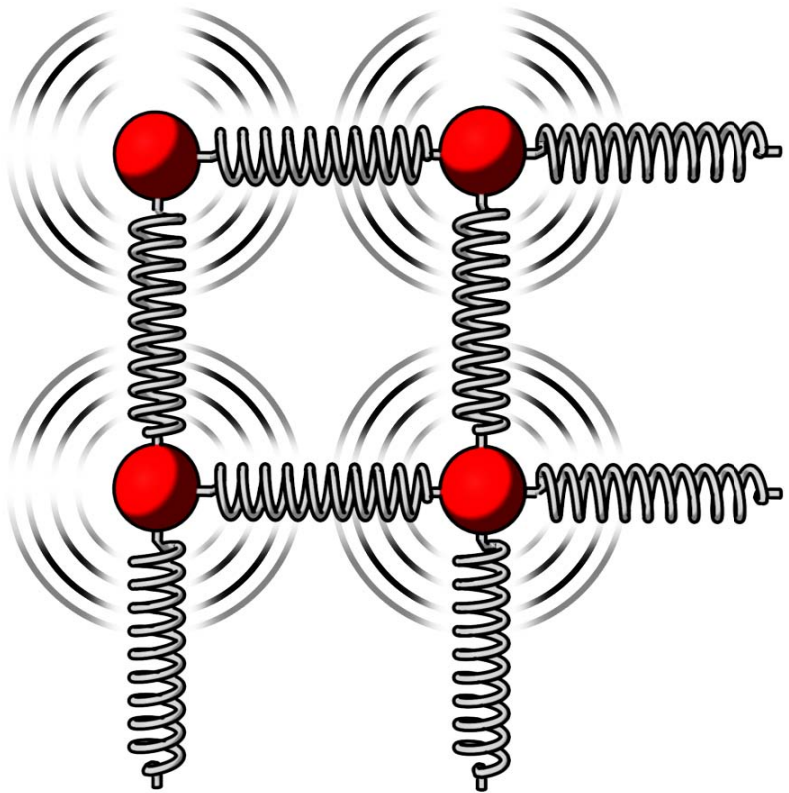
Temperature is a measure of random kinetic
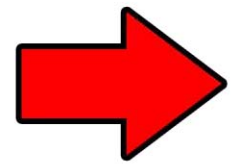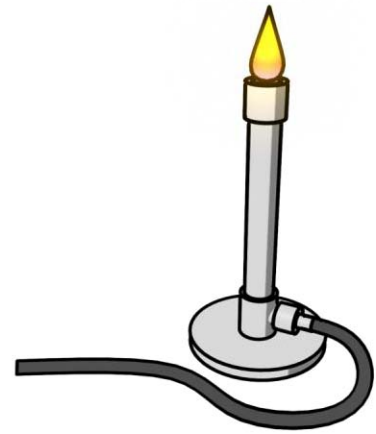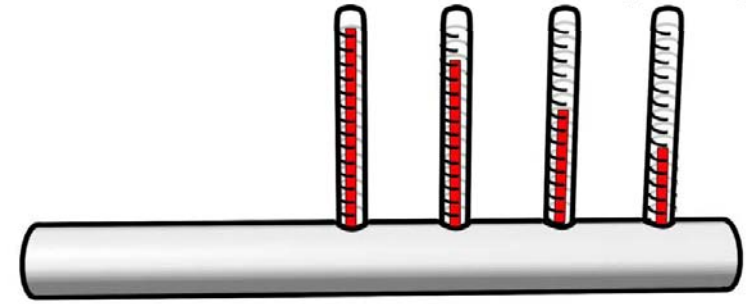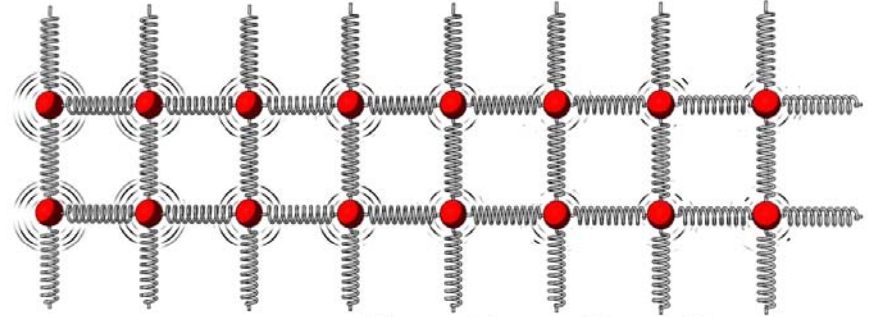
Transmission of increased K.E.
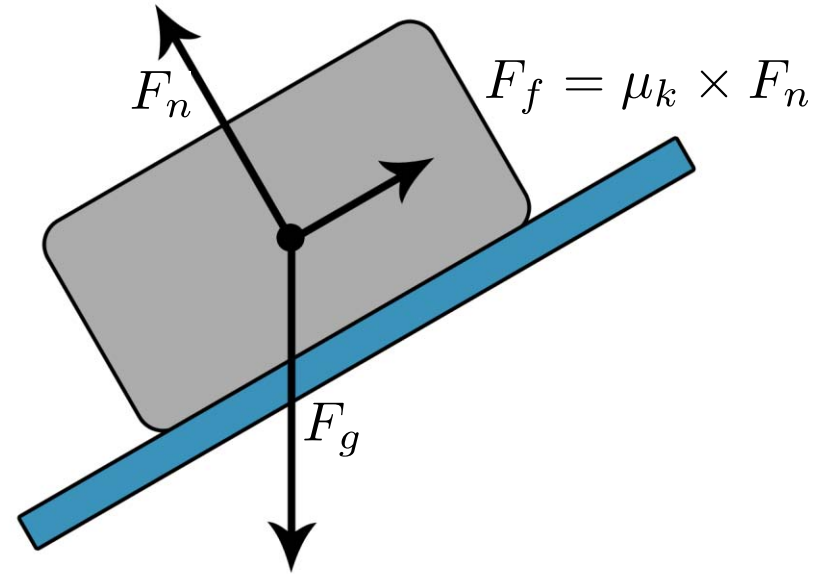
Atomic Origin of Friction

At the microscopic level even the smoothest of surfaces is dotted with little "mountain peaks"

The tips of the peaks are the only parts that touch the other material

Only a very small portion of the apparent surface area is in contact with the other surface

This causes extremely high pressures to form on the parts that touch. This causes the two surfaces to become "welded" almost at the points of contact

Why does friction depend on the normal force ?

F_n

$F_f = \mu_k \times F_n$

F_g

Even a smooth material like mica is not smooth in close-up!

Atomic Origin of Friction

- *The true surface contact area is proportional to the normal force because the peaks will deform plastically when force is applied increasing the contact area*
    - Plastic deformation: to change shape permanently without fracturing

(a)   (b)   (c)   (d)
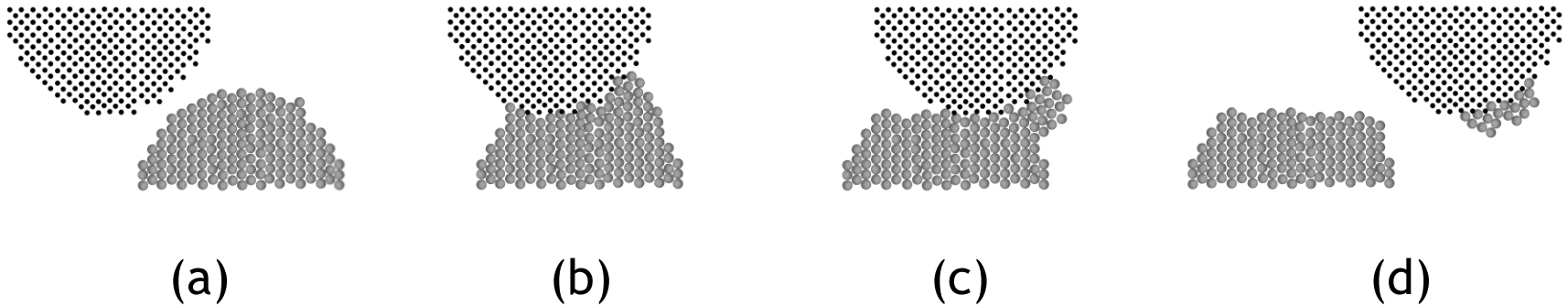
- *Other lesser reasons for friction*
    - Surface adhesion between pure metals
    - Ploughing of one surface by the other harder one
    - Elastic deformation

Atomic Origin of Friction
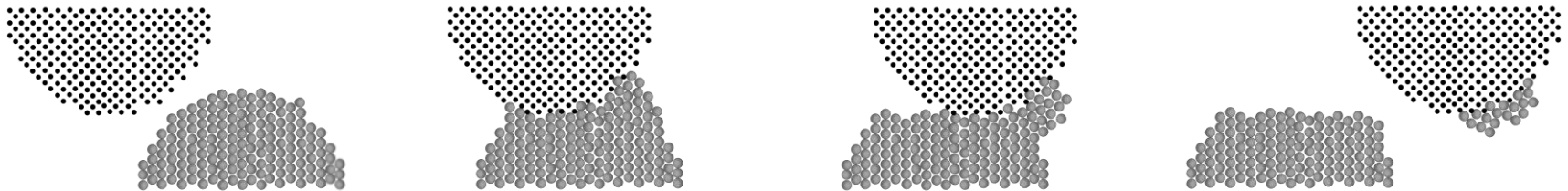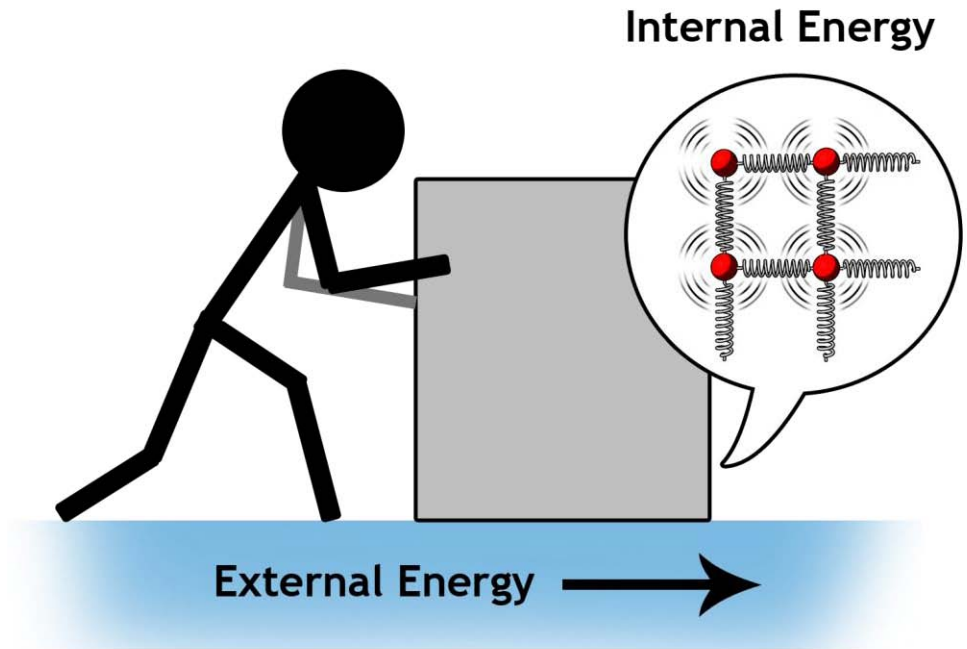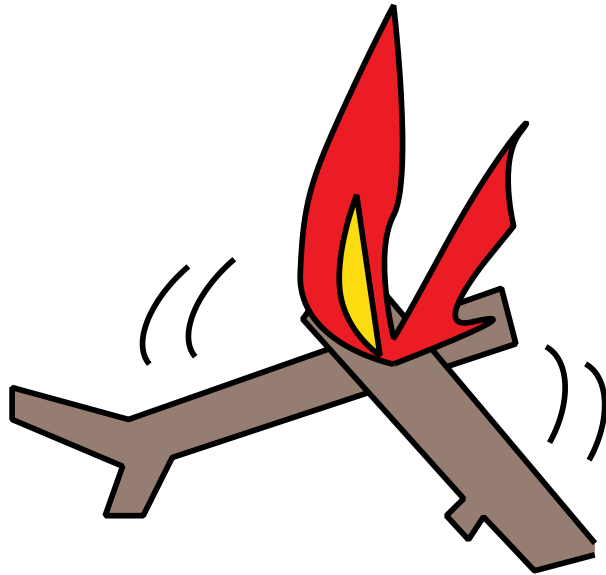
Today's Culture Moment

James Prescott Joule was an English physicist and brewer, born in Salford, Lancashire. Joule studied the nature of heat, and discovered its relationship to mechanical work. This led to the theory of conservation of energy, which led to the development of the first law of thermodynamics. The SI derived unit of energy, the joule, is named after him. He worked with William Thomson (later Lord Kelvin) to develop the absolute scale of temperature.

From Wikipedia article on James Prescott Joule.

(Joule noted that a waterfall is an energy conversion system that allows us to quantify energy)

Joule (1818-1889)

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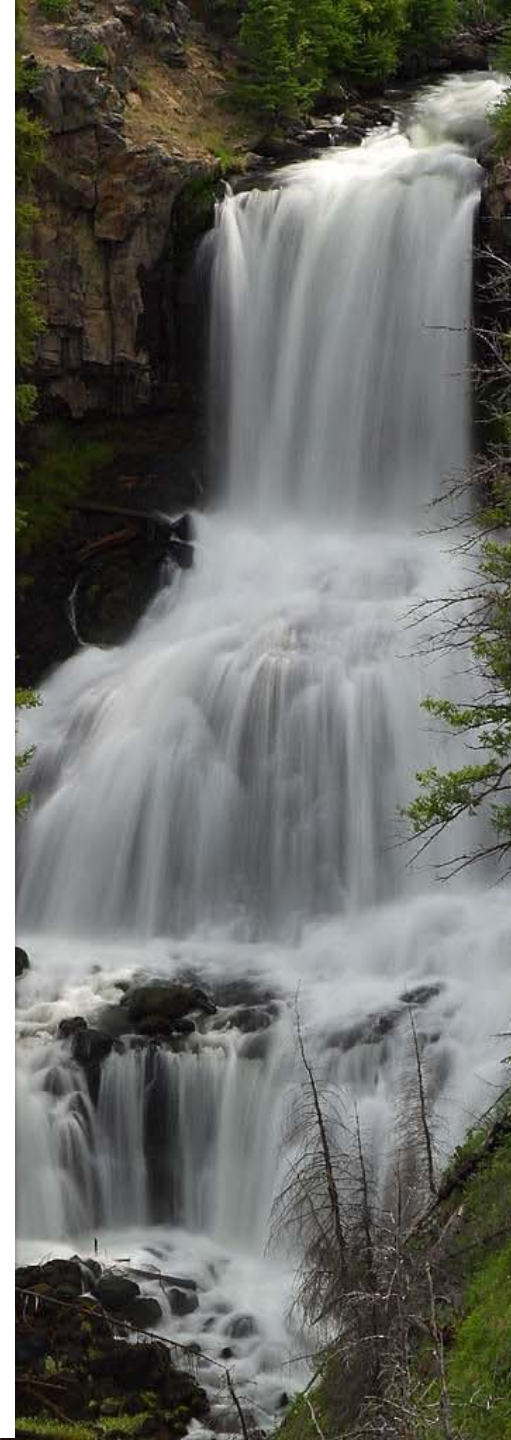
The SECOND LAW of thermodynamics states that
a net increase in the entropy of the universe
always accompanies heat flow in practical systems

As with the first law, there are a number of different ways to state the second law.

A practical consequence of the second law is that any practical machine that converts energy from one form to another, e.g., a motor that converts electrical energy to mechanical energy, will have an efficiency of conversion less than unity. That is, the efficiency or the ratio of mechanical power OUT divided by electrical power IN will be less than one. Any heat flow generated by inevitable real world loss mechanisms like friction and resistance will lead to unrecoverable energy losses during the conversion process.

Because heat flow is also associated with changes in entropy, it receives a special symbol, Q. Some energy conversion systems, like a refrigerator or a steam engine, are designed to make use of or to affect heat flows in their conversion process.

Other practical systems, like electric motors or generators, inevitably generate some heat, but only as an unfortunate, inevitable consequence of losses in the conversion process. For this second class of systems, we will often choose to mentally "move" the heat generating loss mechanisms out of the "box" that describes the system, so that we can focus on the pure conversion from one non-heat energy flow (e.g., electrical energy from a battery) to another non-heat energy flow (e.g., mechanical speed of a motor shaft).

For example, we might model a motor this way:
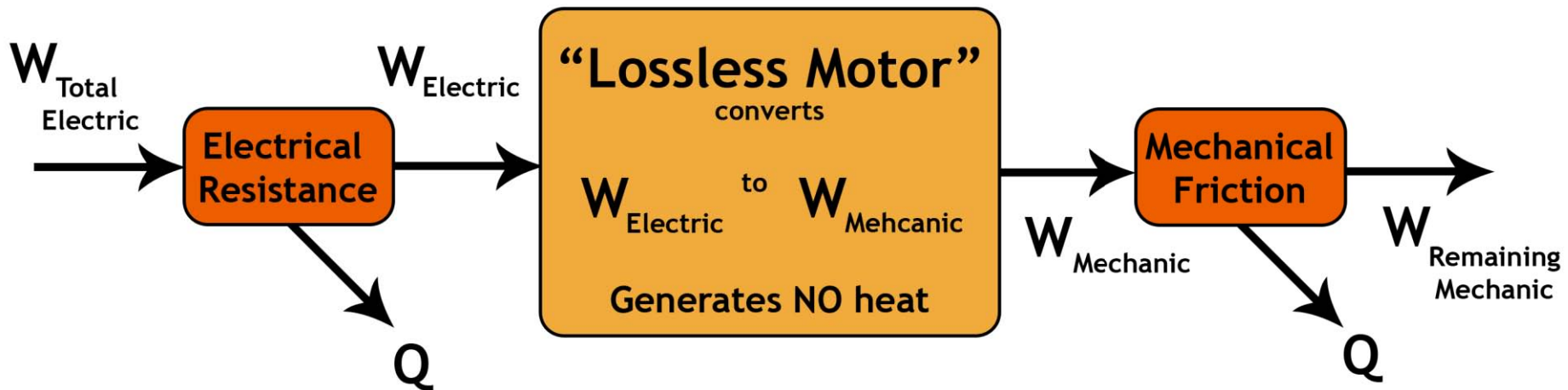
If we consider the total system, we have to account for the heat transfers in applying the first law. That is, we need an equation with W's and Q's.

If we focus on the "lossless motor", then we can look at equations that just involve W's. Of course, we have to be careful to focus on the "right" W's, the energy flows that occur after we "pay" for the resistive losses and "before" we pay for the friction losses. Done carefully, this focus on the lossless motor will let us study the "pure" conversion process from one domain (electrical) to another (mechanical). In a practical system, we must remember that, after studying the lossless system, the losses must also be accounted.

$W_{Total\ Electric}$ → **Electrical Resistance** → $W_{Electric}$ → **"Lossless Motor"** converts $W_{Electric}$ to $W_{Mehcanic}$ Generates NO heat → $W_{Mechanic}$ → **Mechanical Friction** → $W_{Remaining\ Mechanic}$

Q

Q
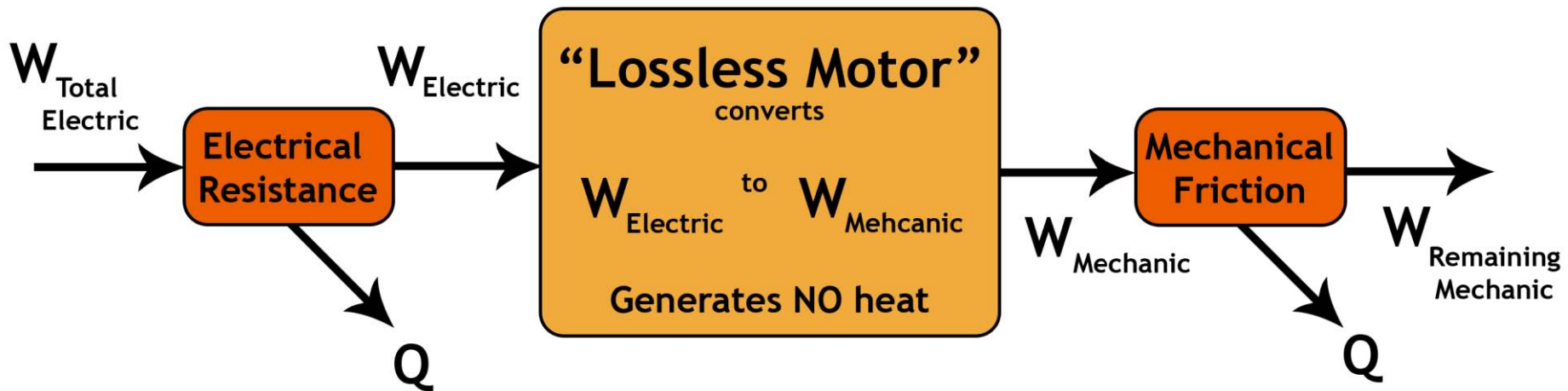
POWER is the rate at which energy is delivered
The same job accomplished more quickly
implies a higher power applied to the job

A typical farm horse, for example, can pull harder and make a heavy stone block move at a higher velocity than a typical person.
→ The horse is more powerful than the person.

James Watt studied energy conversion by observing the work of a horse (mine pony) in lifting coal out of a coal mine. He found that, on the average, a mine pony could pull (lift by means of a pulley) 22,000 foot-pounds per minute. Rather than call this "pony" power, he increased these test results by 50 percent, and called it **horsepower (hp)** i.e. 33,000 foot-pounds of work per minute.

*James Watt
(1736-1819)*

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1 hp = 746 Watts (units used in Watt's honor)

*Aside:
R. D. Stevenson and R. J. Wasserzug published an article in Nature 364, 195-195 (15 July 1993) calculating the upper limit to an animal's power output. The peak power over a few seconds has been measured to be as high as 14.9 hp. However, for longer periods an average horse produces less than one horsepower. - Wikipedia*

horse stable inside a mine

From Wikipedia article on horsepower.
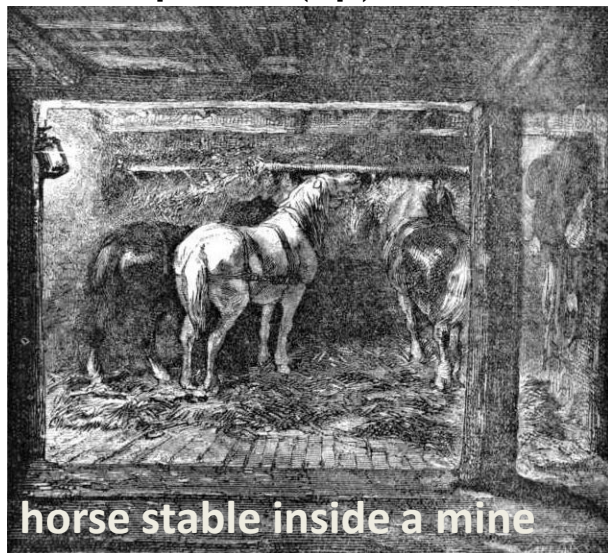
Across and Through Variables

The ports of many energy conversion systems are conveniently described by a set of "through" and "across" measurements or variables. The different types of "through" and "across variables" distinguish different types of engineers (electrical, mechanical, chemical, etc.). The first and second laws apply to everyone.

<u>"ACROSS" variables</u> typically measure how hard we are "pushing".
 Typical "across" variables include:

Force, from mechanical engineering, measured in Newtons (N = kg*m/(s*s))
Voltage, from electrical engineering, measured in volts (V)
Torque, or twisting force, from mechanical engineering, measured in N-m
Pressure, from ocean/aero engineering, measured in N/(m*m)

Associated <u>"THROUGH" variables</u> typically measure how much "stuff" is flowing:

Velocity, from mechanical engineering, measured in meters/sec (m/s)
Current, from electrical engineering, measured in Coulombs/sec or Amps
Angular Velocity, from mechanical engineering, measured in rads/sec
Flow, from ocean/aero engineering, measured in volume/sec or m*m*m/s

Power is a very old and basic concept
    for any moving, living being on the earth.

Power is the product of an "across" variable and a "through" variable.

In more colloquial terms, it is a composite metric or product of
"how hard we're pushing" (the across variable) and
"how much is flowing in response to the pushing" (the through variable).

FOR EXAMPLE:

   - Mechanical power is **force** times **velocity**.

   - Electrical power is **voltage** times **current**.

   Power, whether electrical, mechanical, or in some other discipline,
          is measured in units of **Watts** in the SI/MKS system.

How many Joules are in one kW hour ?

U.S. Energy Use

Coal
We have lots of it.
Twice as much CO_2 per kW-h as Gas,
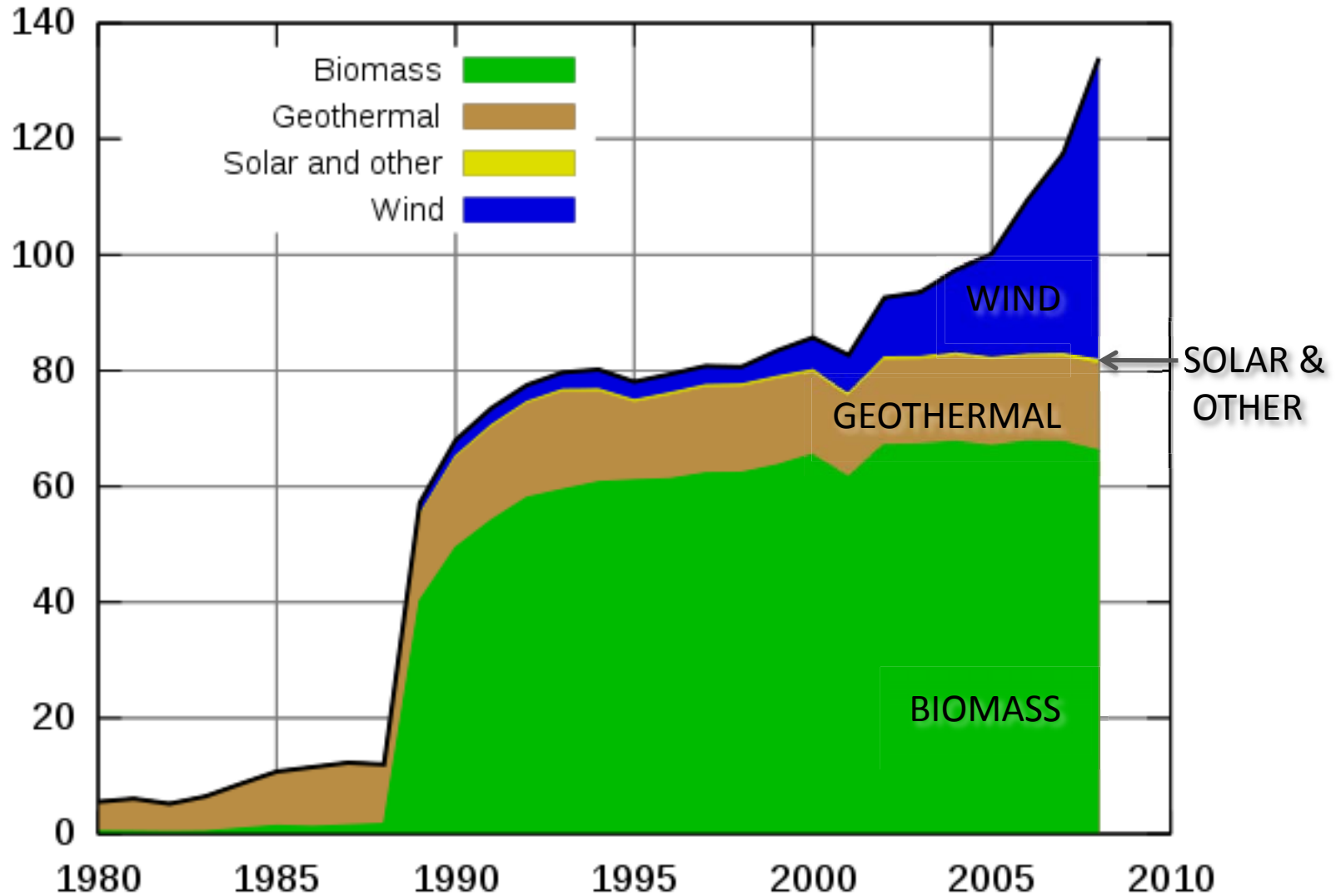50% more than oil; can only rely on it if sequestration is practical and stable.

Gas
Candidate "transition" fuel,
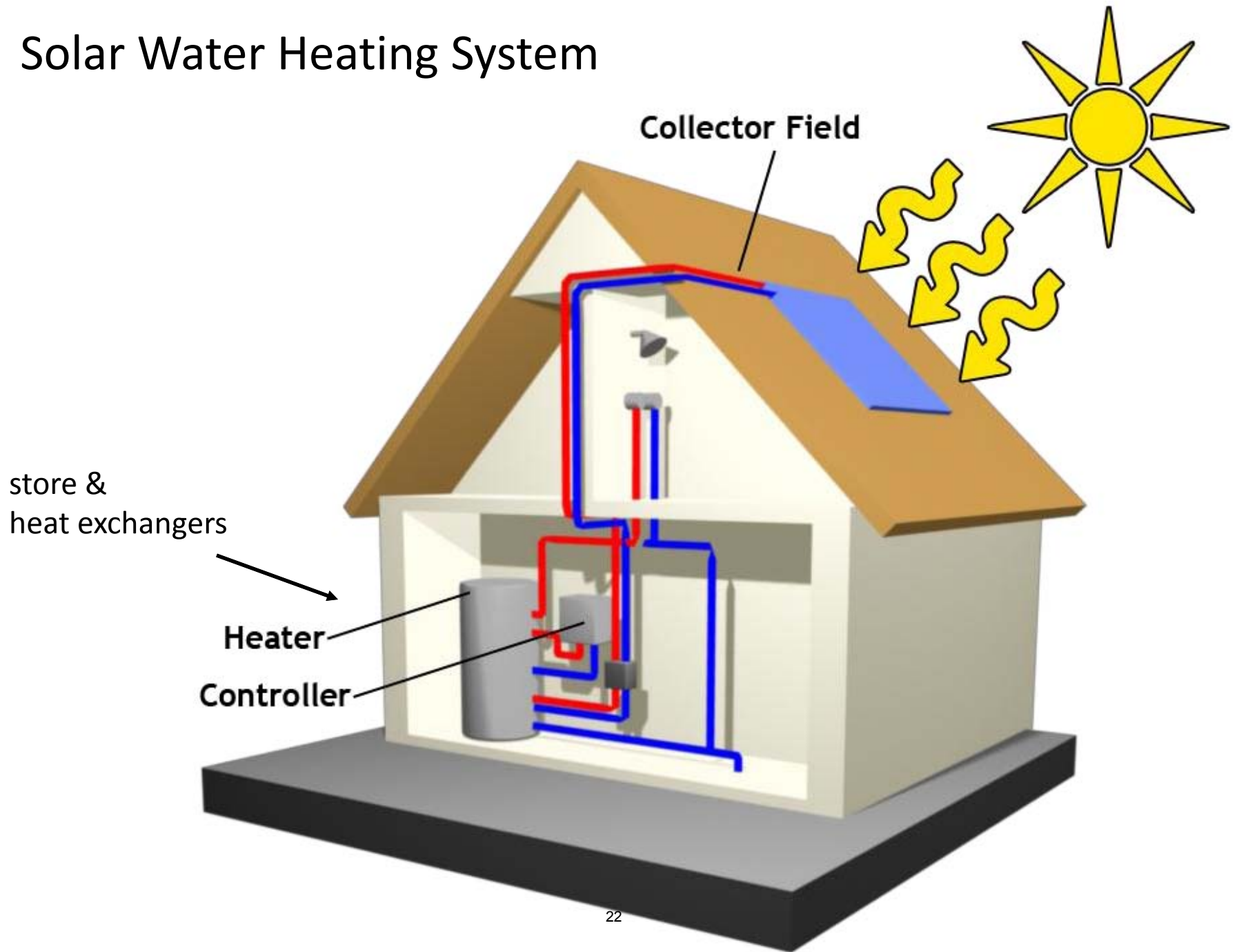but will have same supply issues as oil (just delayed).

Nuclear
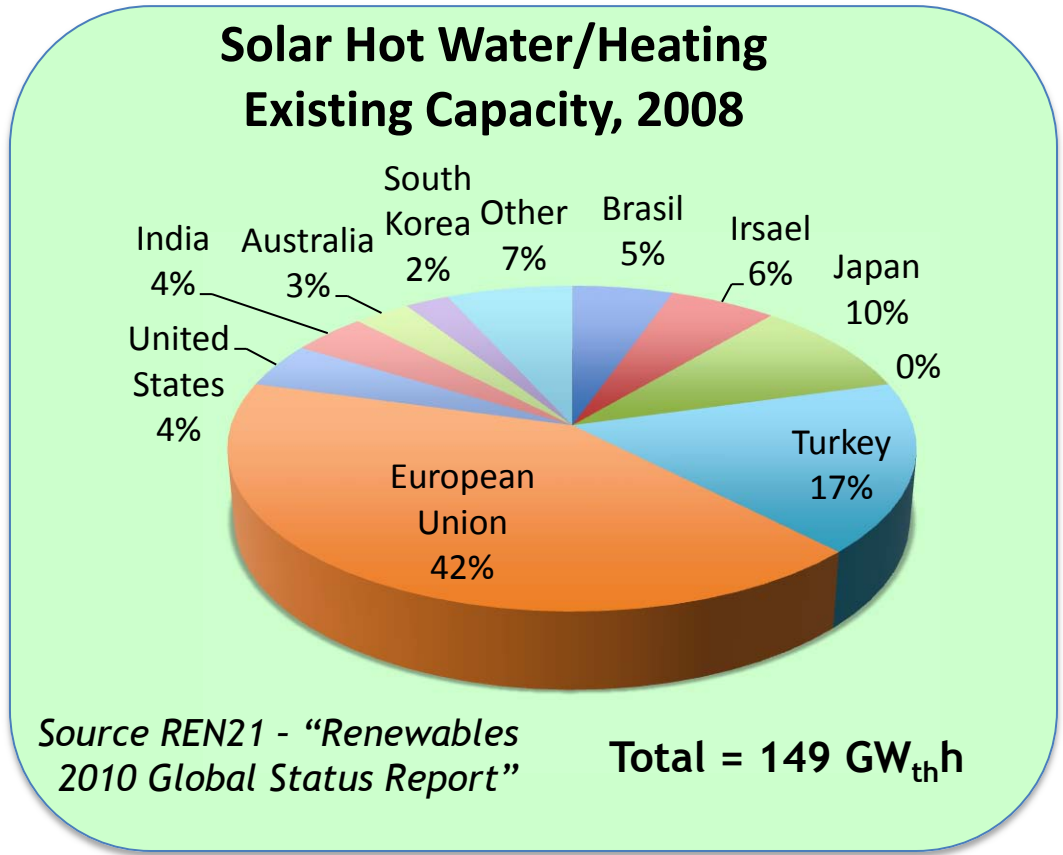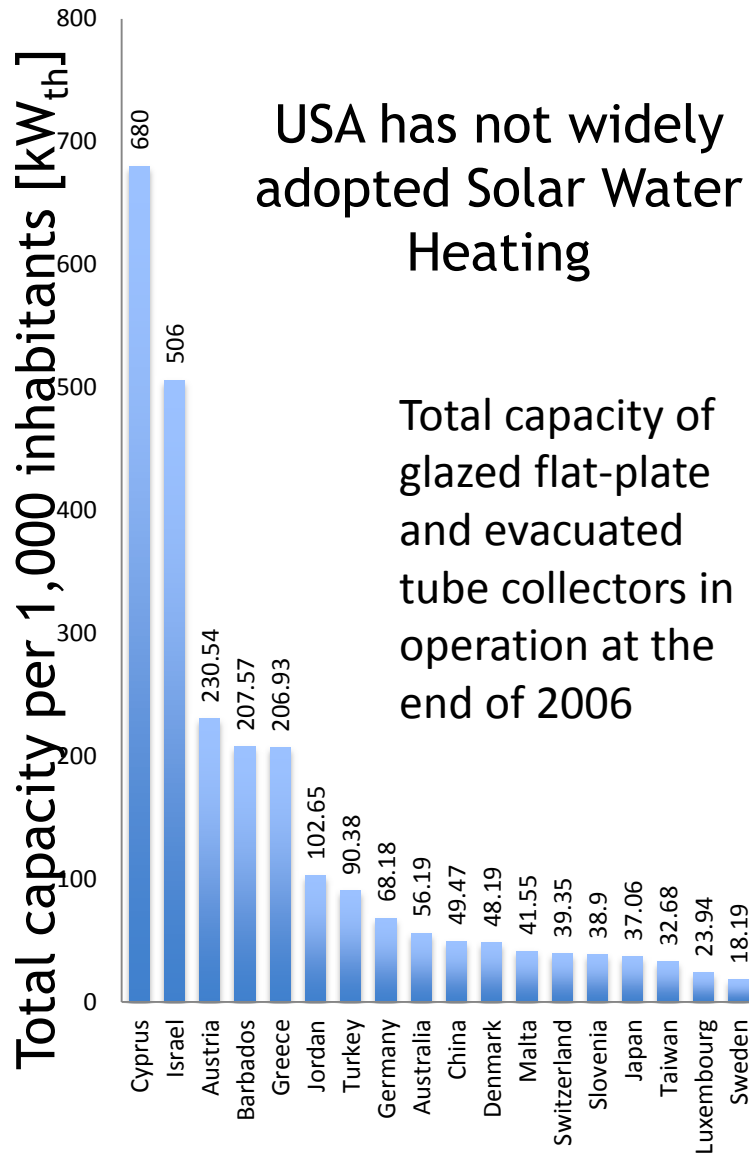Challenges in disposal, proliferation

Non-Hydro Renewable Electricity Generation in the USA (TWh)

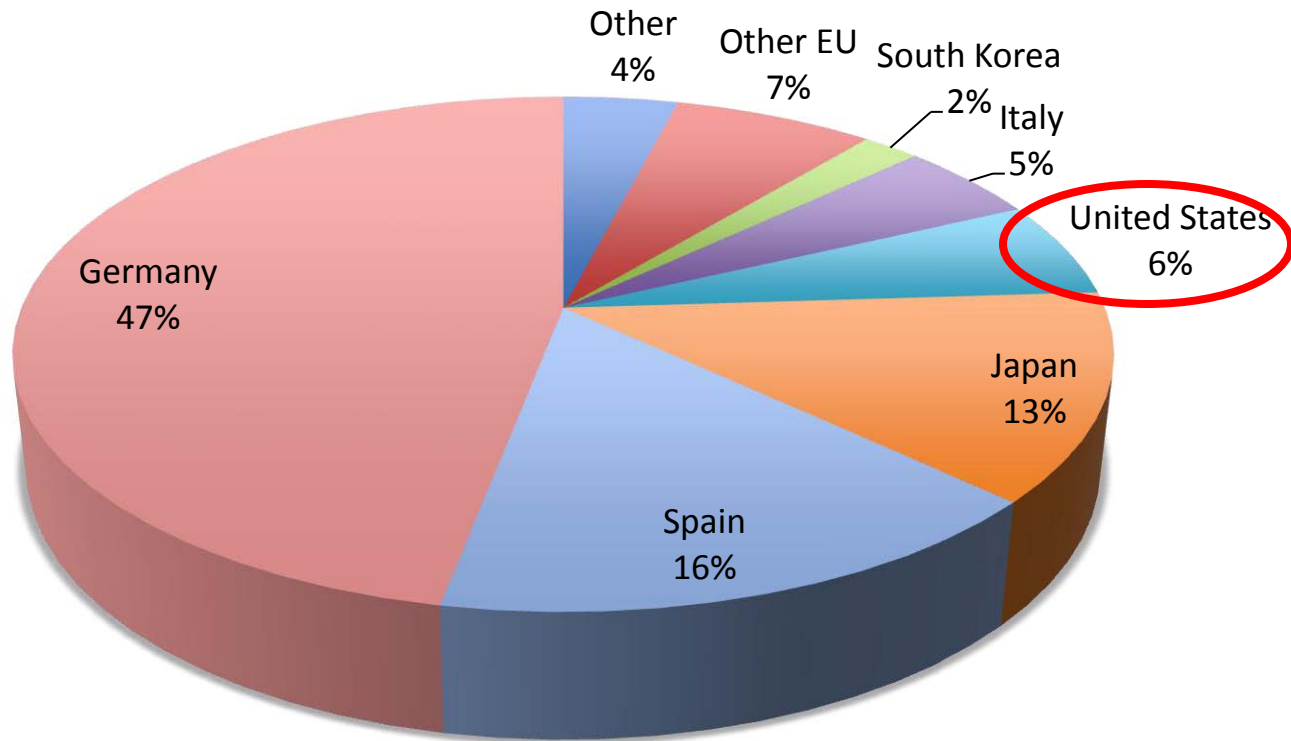**WIND IS THE FASTES GROWING RENEWABLE TECHNOLOGY**

Solar Water Heating System

Collector Field

store &
heat exchangers

Heater

Controller

USA has not widely adopted Solar Water Heating

Total capacity of glazed flat-plate and evacuated tube collectors in operation at the end of 2006

Solar Hot Water/Heating Existing Capacity, 2008

Source REN21 – "Renewables 2010 Global Status Report"

Total = 149 GW$_{th}$h

Pie chart values:
- India 4%
- Australia 3%
- South Korea 2%
- Other 7%
- Brasil 5%
- Israel 6%
- Japan 10%
- 0%
- Turkey 17%
- European Union 42%
- United States 4%

Total capacity per 1,000 inhabitants [kW$_{th}$]

Bar chart values:
- Cyprus 680
- Israel 506
- Austria 230.54
- Barbados 207.57
- Greece 206.93
- Jordan 102.65
- Turkey 90.38
- Germany 68.18
- Australia 56.19
- China 49.47
- Denmark 48.19
- Malta 41.55
- Switzerland 39.35
- Slovenia 38.9
- Japan 37.06
- Taiwan 32.68
- Luxembourg 23.94
- Sweden 18.19
- New Zealand 17.47
- Portugal 16.18
- Spain 15.41
- Netherlands 13.61
- Tunisia 12.33
- France 11.97
- Brazil 11.69
- Slovak Republic 9.43
- Albania 9.12
- Italy 8.81
- Belgium 7
- Czech Republic 6
- Macedonia 5.89
- United States 5.48
- South Africa 3.45
- Poland 2.95
- United Kingdom 2.94
- Ireland 2.68
- Mexico 2.49
- Bulgaria 2.31
- Romania 2.27
- Finland 2.23
- Canada 1.89
- Norway 1.61
- Latvia 1.17
- Namibia 1.09

USA

23

Source: Weiss et al., "Solar Heat Worldwide"

Solar PV Existing Capacity, Top Six Countries, 2009

Global Total = 21 GW

Source REN21 – "Renewables 2010 Global Status Report"
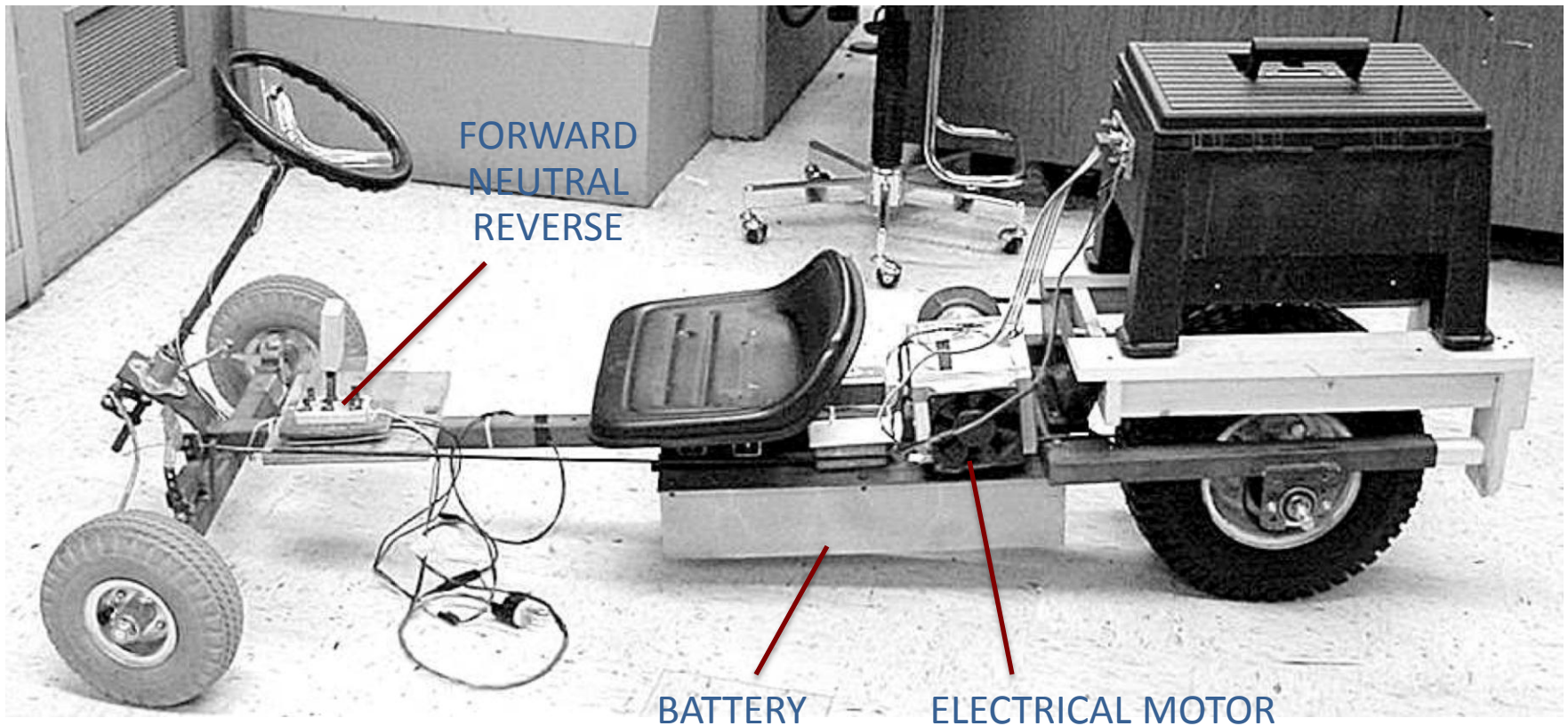
Here's an energy conversion system:
AN ELECTRIC GO-CART
(converts the electrical energy of the battery into mechanical motion)

FORWARD
NEUTRAL
REVERSE

BATTERY   ELECTRICAL MOTOR

Go-cart designed and built by Prof. Steven B. Leeb,

To begin to understand the value of liquid fuels
(and the origins of the energy crisis facing the world)
<u>tomorrow</u> we will make measurements and calculations on our go-cart.

TRUE / FALSE

1. Heat is a form of energy, and has units of Joules.

    _____T_____

2. Friction is the main source of heat loss for all mechanical systems.

    depends

3. Power is a measure of how much energy is delivered per unit time.

    _____T_____

KEY TAKEAWAYS

- The First Law of Thermodynamics is never violated
- Heat is simply the vibration of atoms, with vibrations transferable to other surfaces
- Friction originates from interaction of atoms on surfaces
- The Second Law of Thermodynamics necessitates that any practical machine that converts energy from one form to another will have an efficiency of conversion that is less than unity (for example electrical motor).

- Product of "Through" and "Across" variables is Power
- 1 kW-hr = 3.6 MJ

- Solar energy is abundant, but seldom used due to the low energy density of the solar flux, that makes solar energy capture relatively expensive.
- Well-being of an individual in a country increases with increased per-capita use of energy.

6.007 Electromagnetic Energy: From Motors to Lasers
Spring 2011