Power Systems 1
Cornerstone Electronics Technology and Robotics III

(Notes primarily from "Underwater Robotics – Science Design and Fabrication", an excellent book for the design, fabrication, and operation of Remotely Operated Vehicles ROVs)

- **Administration:**
  - Prayer
- **Work, Energy, Power, and Efficiency:**
  - **Work:** The word "work" as used in mechanical systems has a narrower meaning than it does in everyday life. Work is done when a force pushes an object and the object moves some distance in the direction it's being pushed. When the force exerted on an object is in the same direction as the displacement of the object, calculating work is a simple matter of multiplication:

$$W = F\,d,$$

Where:

W = Work in ft-lbs (SI units: newton-meters or joules since 1 joule = 1 N x 1 meter)
F = Force in lbs (SI units: newton)
d = Displacement or distance moved in ft (SI units: meters)

If you push a really heavy object a certain distance, you do more work than if you push a lighter object that same distance. However, according to this definition, if you push on a heavy object and you are unable to move it, you have not performed any work since d = 0.
Work is further defined as the product of the magnitude of the displacement (d) times the component of the force parallel to the displacement (F * cos θ).

$$W = F_{parallel} * d$$

$$W = (F * \cos \theta) * d$$

Where:

θ = The angle between the force and the displacement.

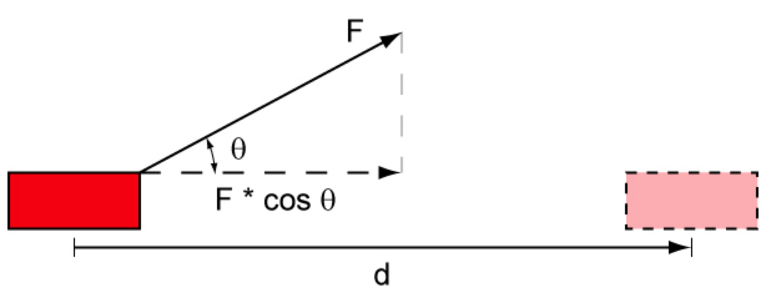

Figure 1: Work Is the Product of the Distance (d) Times the Component of Force Parallel to the Distance (F * cos θ)

See: http://canu.ucalgary.ca/map/content/position/posivect/simulate/applet.html
http://phet.colorado.edu/en/simulation/forces-and-motion
http://lectureonline.cl.msu.edu/~mmp/kap5/work/work.htm

- **Energy:** Energy is the ability to do work. The more energy you have, the more work you can do. Both energy and work are measured in the same units.
  - Energy exists in six basic forms: heat, magnetic, mechanical, chemical, light, and electrical energy. Energy is commonly converted from one of these forms to another.
  - According to the law of conservation of energy, the total energy of a system remains constant, though energy may transform into other forms.
  - Units:
    - In the International System of Units (SI), energy is measured in joules (J).

$$1\ J = 1\ N*m = 1\ (kg*m^2)/s^2 = 1\ Pa * m^3 = 1\ W * s$$

Where:

J = Joules
N = Newtons
m = Meters
kg = Kilograms
s = Seconds
Pa = Pascals
W = Watts

- In imperial units, energy is measured in foot-pounds (ft-lb) or British Thermal Units (BTUs).

1 ft*lb = 0.001285 BTUs = 1.356 J

Where:

ft*lb = Foot-pounds
BTU = British Thermal Units
J = Joules

- **Power:**
  - Power is the rate at which work is done or energy is transferred. It is the work/time or energy/time ratio. Mathematically, it is computed using the following equation.

$$P = W/t = E/t$$

Where:

P = Power in watts
W = Work in joules
E = Energy in joules
t = Time in seconds

Sometimes, work is done quickly and at other times the work is done rather slowly. If more power is available, the same amount of work can be performed more quickly. Also, let's look at an example of power as the rate that energy is transferred. The rate at which a light bulb transforms electrical energy into heat and light is measured in watts—the more wattage, the more power, or equivalently the more electrical energy is used per unit time.

Figure 2: The Maximum Power Output of Hoover Dam Is 2.08 Gigawatts
From: http://wedoitallvegas.com/

  - Units:
    - In SI units, power is in watts (W).

$$1 \text{ Watt} = 1 \text{ joule/second}$$

    - In imperial units, power is measured in horsepower (hp).

$$1 \text{ hp} = 746 \text{ W}$$

- Power Transmission:
  - Power normally must be conveyed from one location to another. For example, the car engine drives belts, shafts, and gears to transfer its power to the air conditioner compressor, power steering, wheels, and other powered features offered in the car.
  - In mechanical systems, power is transferred with belts, shafts, gears, pulleys, levers, sliding rods, or other mechanisms. Also, pressurized liquids or gases can convey power through pipes, tubes, valves, and pistons. Liquids are favored over gases since gases compress and store part of the energy rather than transfer it.
  - Electrical power is moved through a conductor such as wires.

- **Efficiency:**
  - When energy is used to perform useful work, the original energy is transformed into two or more other forms of energy during the process. Some part of the energy is always converted into the forms of energy (such as vibration and heat) that are not useful for the task at hand.

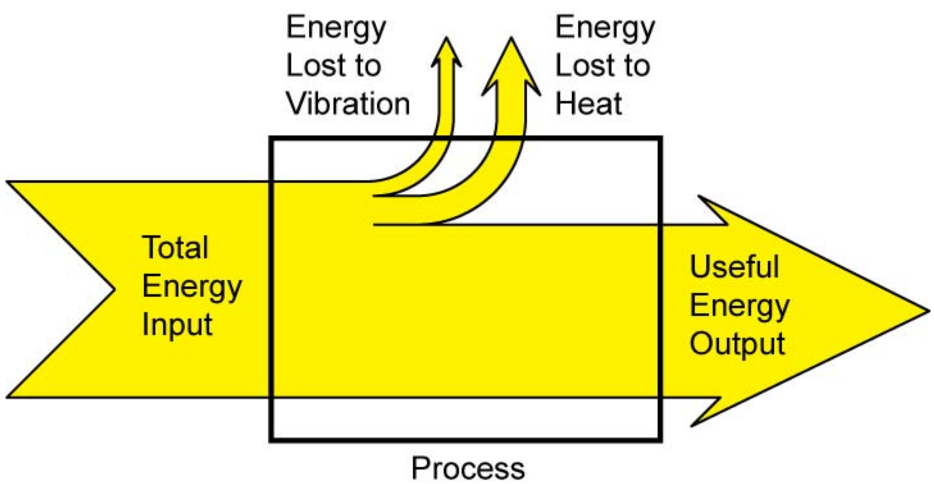

Figure 3: Some Energy is Lost during a Process

The percentage of the energy that comes out of a process as useful energy compared to the total energy input is called efficiency.

$$\text{Efficiency} = \frac{\text{Useful Energy Output}}{\text{Total Energy Input}} \times 100\%$$

Efficiency is a valuable model whether it is applied to performing useful work, converting energy from one form to another, or conveying energy from one location to another. In the later case, energy is lost in all conventional methods of power transmission. In mechanical systems, the loss can be in the form of friction and in electrical systems, the loss is from resistive heating.

- Design implications for your ROV:
  - Most energy conversions in well designed machines have efficiency between 10% and 40%. Each conversion step in your design will compound the losses. For example, if you have four conversion steps in a vehicle system and each step has an efficiency of 40%, your overall efficiency is the product of all the efficiencies.

  Overall Efficiency = 40% x 40% x 40% x 40%

  Overall Efficiency = 0.4 x 0.4 x 0.4 x 0.4 = 0.0256 = 2.56%

  It is clear that you want to limit the number of energy conversion steps in your vehicle design.
  - You will need to put much more power into vehicle systems than you will get out of them. Your systems will encounter losses from heat, vibration, unwanted sound generation, friction, and drag.
  - One of the major contributors to energy loss is heat.
    - Allowed to go unchecked, heat can cause damage or even failure in a ROV system.
    - One advantage of working in a water environment is that cool bodies of water readily absorb heat, that is, they are superb heat sinks.
    - On the other hand, most of the heat producing components on a ROV are packaged in confined, airtight canisters. For this reason, metal canisters are preferable to plastic since they are better conductors of heat to the outside water. As a rule, if a ROV component is warm to the touch in open air, then you need to be concern about confining it in a plastic canister.

- **Vehicle Power Choices:**
  - A variety of power systems are available to the underwater vehicle designer. They include solar power, onboard rechargeable electrical batteries, tethered battery power, ultra-capacitors, fuel cells, nuclear reactors, and ocean thermal power.
  - Criteria for evaluating underwater power systems:
    - Can the power system store sufficient energy to accomplish the entire mission?
    - Can the power system meet the peak power demands of your vehicle?
    - How much space will the power system require?
    - Can the system operate under water?
    - How easy is it to obtain, install, use, maintain, and retire the power system?
    - How easily can energy be distributed from the source to the various systems that need it?
    - What forms of power are required by the various vehicle systems?
    - How safe is it?
    - How much does it cost?

- Electrical power – a logical choice for small ROV and AUV projects:
    - The advantages of electrical power are:
        - Convenience
        - Simplicity
        - Air-independent
        - Low cost
        - Flexibility and scalability
        - Ease of maintenance
        - Ease of power distribution
        - Compatibility with a variety of sensors, motors, lights, and other electrical components
        - Safety with low-voltage batteries