5th Annual Energy Week
Notre Dame

Wednesday, September 14th
Nieuwland Science Hall 123; 6 pm - 7pm
Dr. Peter Burns - "Nuclear Energy: Past Mistakes, Current Challenges, Future Prospects"

Thursday, September 15th
Carey Auditorium in the Hesburgh Library; 7-8:30 pm
Dr. Joan Brennecke, Dr. Prashant Kamat, Dr. Jenny Mish, And Dr. Kenneth Sayre
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Room: 180C NSH

Office Hours: Thursdays 2:00-3:30 pm
              Thursdays 5:00-6:30 pm
Efficiency & Power loss in Transmission of Electricity
Energy Flow by Sector and Source for 2009
Total = 94.6 Quadrillion Btu
How do we get energy from fossil fuels?

Steam-powered Generator

One example....
How Do Fossil Fuels and Biomass Pollute?

All fossil fuels and biomasses consist of carbon and hydrogen atoms. When these fuels are burned, or "combusted," carbon atoms unite with oxygen in the air to form carbon dioxide.
Energy content of various fuels:

Energy from fuels $\rightarrow$ Direct heat, lighting

$\rightarrow$ Run an engine $\rightarrow$ Heat, Other work

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Energy (Joules)</th>
</tr>
</thead>
<tbody>
<tr>
<td>gallon of gasoline</td>
<td>$1.3 \times 10^8$</td>
</tr>
<tr>
<td>AA battery</td>
<td>$10^3$</td>
</tr>
<tr>
<td>standard cubic foot of natural gas (SCF)</td>
<td>$1.1 \times 10^6$</td>
</tr>
<tr>
<td>candy bar</td>
<td>$10^6$</td>
</tr>
<tr>
<td>barrel of crude oil (contains 42 gallons)</td>
<td>$6.1 \times 10^9$</td>
</tr>
<tr>
<td>pound of coal</td>
<td>$1.6 \times 10^7$</td>
</tr>
<tr>
<td>pound of gasoline</td>
<td>$2.2 \times 10^7$</td>
</tr>
<tr>
<td>pound of oil</td>
<td>$2.4 \times 10^7$</td>
</tr>
<tr>
<td>pound of Uranium-235</td>
<td>$3.7 \times 10^{13}$</td>
</tr>
<tr>
<td>ton of coal</td>
<td>$3.2 \times 10^{10}$</td>
</tr>
<tr>
<td>ton of Uranium-235</td>
<td>$7.4 \times 10^{16}$</td>
</tr>
</tbody>
</table>

Unit of energy is Joules
What you need to know about energy

http://needtoknow.nas.edu/energy/
What is the problem????????

**Efficiency**

Engines:

Efficiency = work done/energy put into the system

= What you got out/What you put in

100% efficiency not possible....

friction, viscosity
insulation
other

A *heat engine* is a physical or theoretical device that converts thermal energy to mechanical output. The mechanical output is called *work*, and the thermal energy input is called *heat*.
Think of an engine as operating between two thermal reservoirs…
One at High Temperature…engine takes the heat ($Q_H$ from hot reservoir) does work with it and returns the rest to the cooler reservoir…

Energy Conservation………………………. $Q_H$=Work + $Q_C$

If you want engine to operate you must provide $Q_H$

Efficiency = $W/Q_H$
Efficiency of a Real power plant...or other fuel source

Example: A heat engine operates between a geothermal steam source at 210\(^\circ\) C and a river at 20\(^\circ\) C...It has an efficiency of 20% ....What percentage of its theoretical maximum Efficiency is it achieving?

Efficiency of an ideal engine (Carnot):

\[
(1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}) \times 100\% = (1 - \frac{293}{485}) \times 100\% = 39.6\%
\]

Temperature in Kelvin....
1 Celsius = 273.15 + 1=274 K
No perfect engines............
We can only convert some of the heat to work
not all of it.........

2\textsuperscript{nd} Law of Thermodynamics............... Entropy
............... Time Travel
............... “Beam me up Scotty”
............... “perfume “

$$\Delta S = \frac{Q}{T}, \quad \Delta S = \int \frac{\delta q}{T}.$$
Example: In the US, 85% of the electricity is generated by burning fossil fuels to produce steam, which in turn drives alternators that produce electricity. Power plants can produce steam with a temperature as high as $600^\circ C$ by pressurizing the steam. The resulting waste heat must be exhausted into the environment at a temperature of $20^\circ C$

$$(1- \frac{T_{\text{cold}}}{T_{\text{hot}}}) \times 100\% = \text{maximum efficiency}$$

$600 + 273 = 873$ degree Kelvin
$20 + 273 = 293$

$$[1-(293/873)] \times 100\% = 66.4\%$$

Real power plants .................. $40\%$
Efficiency of an ideal engine (Carnot):

Temperature in degree Kelvin

\[(1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}) \times 100\%\]

Example: \(T= 1 \text{ degree C} + 273.15 = 274.15 \text{ degree Kelvin}\)

Power = rate of Energy dispersion = Work/time

Power loss... \(P = I^2R\)

\(I = \) current in Amperes; \(R = \) resistance in Ohms

Power production \(P = IV\)

\(I = \) current in Amperes; \(V = \) Voltage in volts

Temperature Conversion

\(\text{°F to °C}\)
Deduct 32 and multiply by 5/9

\(\text{°C to °F}\)
Multiply by 9/5 then add 32

\(\text{°C to °K}\)

\(\text{°C add 273.15 degrees} = \text{°K}\)
Example:

An inventor claims to have developed a wonderful new heat engine that operates with a relatively cool flame at 150°C and discharges waste heat to the environment at 20°C.

All his PR literature advertises that 45% of the fuel energy is converted to useful work.

What is the maximum efficiency that can be expected for this engine?

\[
\text{Efficiency} = (1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}) \times 100\%
\]

\[
150 + 273 = 423 \text{ Kelvin}
\]

\[
20 + 273 = 293 \text{ Kelvin}
\]

\[
(1 - \frac{20}{423}) \times 100\% = 30.7\%
\]
Example
A power plant has an efficiency of 30%
It burns 7938 tons of coal per day
Coal produces $2 \times 10^4$ Btu/kg

What is the electric power output of the plant in kilowatts?

1 ton = 907.18474 kilograms

7201232.466 Kg
1.44 x$10^{11}$ Btu
4.32 x$10^{10}$ Btu
1 day=24 hrs 1.8 x$10^9$ Btu

1 kilowatt hr = 3413 Btu .......... $5.27 \times 10^5$ KWatts
So...what does this mean for energy and society?

Electricity is a manufactured product. It is not something you pump out of the ground or mine or collect from the sun or wind. Electric power is manufactured from a rotating machine that we call an electrical generator. After it is generated, (manufactured) it is then delivered through copper wires to where it is utilized.
...the invention of the machine to generate power is right next to the invention of the printing press in the list of major contributions to the advancement of human civilization.
A "generator" and "motor" are essentially the same thing: what you call it depends on whether electricity is going into the unit or coming out of it.

Electric generators are essentially very large quantities of copper wire spinning around inside very large magnets, at very high speeds.

Example: A commercial utility electric generator -- for example, a 180-megawatt generator -- can be quite large. It is 20 feet in diameter, 50 feet long, and weighs over 50 tons. The copper coils (called the "armature") spin at 3600 revolutions per minute. Although the principle is simple (copper wire and magnets), it's not necessarily easy!

Steam turbine generators, gas turbine generators, diesel engine generators, alternate energy systems (except photovoltaics), even nuclear power plants all operate on the same principle - magnets plus copper wire plus motion equals electric current. The electricity produced is the same, regardless of source.
So where do all the different fuels come in?

It's all a question of how to get (and keep) the system moving (i.e. how to keep the copper wire spinning around).

In a **steam power plant**, fuels (such as petroleum, coal, or biomass) are burned to heat water which turns into steam, which goes through a turbine, which spins... *turning the copper wire (armature) inside the generator and generating an electric current.*
A geothermal power plant is pretty much a steam power plant, since what comes out of the earth is steam. Rainwater soaks into the ground and goes down, down, down...far enough until it reaches a region which is really hot (in Hawaii, that's about 6000 feet). A well is drilled, the steam comes out, goes through a heat exchanger, and spins a turbine... turning the copper wire (armature) inside the generator and generating an electric current. By the time the steam has gone through the heat exchanger, it has cooled off and become warm water. It is then re-injected into the ground.

In a gas turbine power plant, fuels are burned to create hot gases which go through a turbine, which spins...turning the copper armature inside the generator and generating an electric current.
In a nuclear power plant, nuclear reactions create heat to heat water, which turns into steam, which goes through a turbine, which spins... *turning the copper armature inside the generator and generating an electric current.*

In a wind turbine, the wind pushes against the turbine blades, causing the rotor to spin... *turning the copper armature inside the generator and generating an electric current.*

In a hydroelectric turbine, flowing (or falling) water pushes against the turbine blades, causing the rotor to spin... *turning the copper armature inside the generator and generating an electric current.*
Expansion and Modernization of the nation's electrical Transmission and distribution systems are urgently needed expansion and modernization would enhance reliability and security, accommodate changed in load growth and demand, and deploy new energy efficiency technologies...and to supply on occasion electricity intermittently from other sources...wind/solar/etc...

Report America's Energy Future
Power is rate of energy...rate at which work is done.

1 Watt = 1 J/sec = 3.41 BTU/hr

United States transmission grid
Source: FEMA

Grid transfers energy from power plant to enduser.
Energy Basics...

Energy is the ability/capacity to do work.
Work is the transfer of energy.

**Work** = force \times distance

Angle between force and distance

Work is done when a force is exerted over a distance.

1 J = 1 N m
A force of 1 N moving a body over 1 m does 1 J of work.

Power = the rate at which work is performed.
What is electricity?
Electricity & Magnetism are closely related....

Electricity...is a **flow/stream** of charges....**Current (I)**
- charge is conserved
- charge is quantized (coulomb)

**Resistance** to flow of Electricity or current....$R=\frac{\text{Voltage}}{\text{Current}}$

Units of Current: Amperes....1 coulomb/second= 1 A

**Electrical Force**...attraction between opposite charges
...repulsion between similar charges

**Energy**...electrical potential energy....**Voltage (V)**
$V=IR$  energy transferred is equal to current x resistance

**Work** = force x distance

\[ |F_{Q-q}| = |F_{q-Q}| = k \frac{|q| \times |Q|}{r^2} \]
Electric force per unit charge: Electric Field \( \frac{N}{\text{coulomb}} = \frac{\text{Volt}}{\text{m}} \)
Power transmitted over lines...is lost at a rate of \( P = I^2R \)

\( I \) is the current
\( R \) is the resistance of the wires

**Example:** 735 kV line is used to transmit electric energy from a hydroelectric plant in Quebec to Montreal, 1000 km away. Suppose that the current is 500 Amperes...what is the power loss? Resistivity is 0.220 Ohms/km

\[ P = I^2R \]
\[ = (500A)^2 \times (220 \text{ Ohms/km}) \times 1000 \text{ km} = 55.0 \text{ MW} \]
What is rate at which energy is supplied?

Total power supplied:
P = Volts × Current
   = 735 kV × 1000 V/kV × 500 A
   = 365 MegaWatts

Loss is 55 MW
Supply is 365 MW

\[(\frac{55}{365}) \times 100\% = 15\%\text{ lost}\]
What if you doubled Current from 500 A to 1000 A
And cut the Volts to half of 735 KV?

Supply would be the same....
Loss would be much greater....

\[ P = I^2R \]
\[ P = (1000 \text{ A})^2 \times (220 \text{ Ohms/km}) \times 1000 \text{ km} \]
\[ = 220 \text{ MW is the amount lost now} \ldots. \]

\[ \frac{220 \text{ MW}}{368 \text{ MW}} \times 100\% = 60\% \text{ lost} \]
So...we want to minimize losses... $P = I^2 R$

Low current transmission
high voltage

But we want to use the energy when it arrives safely.....

Solution... **Transformers**....

Input $V/(N_{in}) = \frac{Output V}{N_o}$
output $V = input V \times (N_o/N_{in})$