Energy on this world and elsewhere

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Course web site available at www.phys.virginia.edu, click on classes and find Physics 1110.
or at http://people.virginia.edu/~gdc4k/phys111/fall11

Lecture 21, November 8, 2011
Announcements

• Homework will be posted tonight.
• Homework will be due on Tuesday November 15th.
• Midterm will be on November 17th.
• Homework grading done, will be returned on Thursday.
Average = 7.6 +/- 1.5 points
Average = 63.1 +/- 12.7 %
Above is the letter-grade distribution if it were to mimic final grades last year.

- A's = 23.7%
- B's = 54.6%
- C's (or lower) = 21.6%
Solar Energy
Solar energy technologies

Despite the fact that the sun is ultimately behind most (but not all) forms of renewable energy, there are basically two technologies that we are referring to when we speak about solar energy:

- Solar cells or photovoltaics
- Solar thermal (electrical generation)
- Solar heating (space heating and water)
Photovoltaic cells

• For single-layer silicon-based solar cells:
  – Maximum theoretical efficiency is around 33%.
  – Around 25% has been achieved.
  – Around 10-15% is typical of economical cells.

The different crystalline orientations are visible in the photo of a polycrystalline solar cell shown above.
The concept of intensity

In the context of sunlight:

Intensity of sunlight = \( \frac{\text{Incident power of sunlight}}{\text{area over which it falls}} \)
Intensity of sunlight hitting the earth

• Above the atmosphere: about 1.4 kW/m$^2$
  – This is for a surface FACING the sun.

• On the Earth’s surface: about 1.0 kW/m$^2$

• Averaged over day and night, all the seasons, for the 48 contiguous states in the U.S.: around 200 W/m$^2$
Area needed to generate electricity using solar power

\[
\text{Power} = \text{efficiency} \times \text{Intensity} \times \text{Area}
\]

\[
\text{Area} = \frac{\text{Power}}{\text{efficiency} \times \text{Intensity}}
\]
Area needed to generate electricity using solar power

83.4 mi. x 83.4 mi., area needed to produce (on average) all electricity currently used (assuming 200 W/m²).

Assumes 470.3 GW (2010 number) average generation, and 13% efficiency
Area needed to generate electricity using solar power

83.4 mi. x 83.4 mi., area needed to produce (on average) all electricity currently used (assuming 200 W/m²).

118 mi. x 118 mi. (twice the above mentioned land area).

Assumes 470.3 GW (2010 number) average generation, and 13% efficiency
Area needed to generate electricity using solar power

441 million acres devoted to cropland (for comparison).

83.4 mi. x 83.4 mi., area needed to produce (on average) all electricity currently used (assuming 200 W/m$^2$).

118 mi. x 118 mi. (twice the above mentioned land area).

Assumes 470.3 GW (2010 number) average generation, and 13% efficiency
Nuclear Power
Nuclear energy: pros

- No emission of greenhouse gases.
- Relatively abundant resources are available.
- Potentially quite economical? (It is at least true that operating existing plants is quite economical.)
- Some aspects of the technology are quite mature.
- Advanced (less mature) technology could make the resources truly vast.
Nuclear energy: cons

- Meltdowns can potentially release large amounts of radioactivity.
- The storage of waste is not a settled issue.
- Reactors produce plutonium which can be made into nuclear weapons.
- Terrorist attacks on nuclear reactors could change the equation of what is and is not safe.
- Is the release of radioactivity during routine operation a problem?
Existing sources of radioactivity

- Radon
- Cosmic rays
- Medical procedures
- Coal plants
Existing sources of radioactivity

- Radon
- Cosmic rays
- Medical procedures
- Coal plants
- Fallout from above-ground testing
“Burning” nuclear fuel

- When nuclear fuel is “burned”, nuclear reactions take place instead of chemical reactions.
- Because nuclear forces are so strong, the potential energy stored (per unit mass) in nuclei is much greater than the potential energy stored chemical bonds.
- The primary nuclear reaction that releases the energy is something called “fission”.
- The two fuels that are most commonly used are uranium-235, plutonium-239.
Energy Density

- Coal: $29 \times 10^6$ J/kg
- Gasoline: $44 \times 10^6$ J/kg
- Natural Uranium: $580 \times 10^9$ J/kg
- Pure U-235: $82 \times 10^{12}$ J/kg
- Pure U-235 has an energy density almost 3 million times that of coal.
The relative size of nuclear fuel

- 1 gram of uranium-235 can release $8.2 \times 10^{10}$ J
- To get the same energy from oil you need 563 gallons of oil
- Uranium is so dense that a 1 gram cube would measure less than 4 mm per side.
- In practical nuclear fuel, however, the uranium is NOT pure uranium-235, nor is it in the form of a pure metal. Instead it is usually nuclear fuel is usually 3% U-235 and 97% U-238 and it is in the form of uranium oxide.
- Even so, 1 gram of uranium-235 within the mixture still fits into a cube around 1.6 cm on a side.
The relative abundance of nuclear fuel

- U.S. Reserves @ $100/lb or less: 1,227 million pounds uranium oxide (557 thousand metric tons)
- U.S. Reserves plus estimated additional resources @ $100/lb or less: 6,077 million pounds (2.76 million metric tons).
- Loaded into U.S. reactors in 2008 51.3 million pounds.
- Reserves at this rate would last 23.9 years.
- Reserves and resources at this rate would last 118.5 years.
- Most uranium ore is presently imported.
- The above times estimates are based on a “once-through” fuel cycle.
The relative abundance of nuclear fuel

Note the number reported in this pie chart for the U.S. (342 thousand metric tons at roughly $60/lb) is from the 2006 numbers from the World Energy Council.
Price is VERY important in determining the size of available resources

Figure 6-2  Development of uranium spot market prices*, 1968–2006
Source: adapted from NEA/IAEA, 2006
Uranium comes in two isotopes: one is fissionable, one is not
(at least not with slow neutrons)

$^{238}\text{U}$

99.28% of all uranium is U-238
When hit by a neutron it will sometimes undergo fission, but most of the time the neutron is just absorbed.

$^{235}\text{U}$

0.72% of all uranium is U-235
When hit by a neutron it will almost always undergo fission.
Conventional reactors vs. fast breeders

- Conventional reactors burn the U-235 almost exclusively.
- Fast breeders convert large amounts of the U-238 into Pu-239 in the process of burning the U-235.
- In principle, a fast breeder can make more fuel than it burns (at least until the U-238 runs out).
- Early in the “atomic age”, there was great enthusiasm for fast breeders, and it was almost assumed that we would go in that direction.
- Today, fast breeding is used only very little. Among other things, people aren’t too enthused over manufacturing huge quantities of plutonium.
- Fast breeding may never come into its own, but it is worth remember that if it did, we would have energy for many many centuries, if not millenia. cycle.
The relative abundance of nuclear fuel

**Figure 6-7** Years of uranium availability for nuclear power

Source: IAEA, 2007

<table>
<thead>
<tr>
<th>Reactor/fuel cycle</th>
<th>Years of 2005 world nuclear electricity generation with identified resources</th>
<th>Years of 2005 world nuclear electricity generation with total conventional resources</th>
<th>Years of 2005 world nuclear electricity generation with total conventional and unconventional resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current once-through fuel cycle with light water reactors</td>
<td>85</td>
<td>270</td>
<td>675</td>
</tr>
<tr>
<td>Pure fast reactor fuel cycle with recycling</td>
<td>5000 – 6000</td>
<td>16 000 – 19 000</td>
<td>40 000 – 47 000</td>
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