Energy on this world and elsewhere

Instructor: Gordon D. Cates
Office: Physics 106a, Phone: (434) 924-4792
email: cates@virginia.edu

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 25 - November 29, 2011
Announcements

• Final will be on December 15th, 2pm.
• Will have one last brief 6-8 problem homework.
Transportation: the most immediate energy problem
Primary energy sources for transportation in the United States

<table>
<thead>
<tr>
<th>Source</th>
<th>Units of $10^{12}$ BTU</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>677</td>
<td>2.4%</td>
</tr>
<tr>
<td>Petroleum</td>
<td>26,332</td>
<td>94.3%</td>
</tr>
<tr>
<td>Biomass</td>
<td>833</td>
<td>3.0%</td>
</tr>
<tr>
<td>Electricity</td>
<td>82</td>
<td>0.3%</td>
</tr>
</tbody>
</table>
Energy densities

By volume,
in MJ/liter

By mass,
in MJ/kg
Transportation Energy Infrastructure: exploring the possibilities

Primary energy

Energy carrier

Final use

- coal
- biomass
- nuclear
- oil
- natural gas
- renewables
- methanol
- biodiesel
- hydrogen
- gasoline
- ethanol
- batteries
- internal combustion engines
- fuel cell/electric
- batteries/electric
- hybrids
- plug-in hybrids
What's the problem?
Energy density of certain energy carriers

<table>
<thead>
<tr>
<th>Energy Carrier</th>
<th>Energy Density ($10^6$ J/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>44</td>
</tr>
<tr>
<td>Gasoline</td>
<td>44</td>
</tr>
<tr>
<td>Ethanol</td>
<td>30</td>
</tr>
<tr>
<td>Methanol</td>
<td>19.7</td>
</tr>
<tr>
<td>Lithium ion</td>
<td>0.54</td>
</tr>
<tr>
<td>Lead Acid</td>
<td>0.08</td>
</tr>
</tbody>
</table>

units of $10^6$ J/kg
Consider a specific example

Chevy Volt Battery stores 16 kW-hrs and has mass of 175 kg
Chevy Volt Battery stores 16 kW-hrs and has mass of 175 kg

Energy density in battery pack = $3.3 \times 10^5$ Joules/kg

Energy density of gasoline = $44 \times 10^6$ Joules/kg
(133 times better)

Equivalent mass of gasoline = \[
\frac{5.76 \times 10^7 \text{ Joules}}{44 \times 10^6 \text{ Joules/kg}} = 1.3 \text{ kg gasoline} = 0.48 \text{ gal gasoline}
\]
The Challenge of going all electric

• Even the most advanced lithium-ion batteries still have an energy density that is 50-100 times lower than that of gasoline.

• The quantity of batteries required to provide decent range are both heavy and very expensive.

• Even if the batteries were lighter and cheaper, the time required to charge them is MUCH GREATER than the time required to fill a gas tank.
Compensating factors: efficiency and on-demand power

- Internal combustion engines only average around 20% efficiency.
- Usually, internal combustion engines run whether they are needed or not (idling, either when at rest or when no power is required).
- Batteries and electric motors can approach nearly 100% efficiencies.
- Lost energy, when braking, can be partially recovered and stored back in the battery.
- When all of this is taken into account, the factor of 50-100 advantage of gasoline in energy density is greatly reduced, perhaps to something like a factor of 10 - 20.
How does it work out in a real-life example?

• Battery of Nissan Leaf - 24 kW-hours
• Range of Nissan Leaf - about 100 miles
• Energy content of 1 gallon of gasoline - 33 kW hrs
• A car with a 12 gallon tank carries 16.5 times more energy (and the gasoline weights MUCH less).
• At say, 30 mpg, the gasoline powered car has a range of 360 miles.
• Thus, the Leaf has a range of about 28% that of the gasoline-powered car. Not 1-2%, as one might expect by energy density alone.
Another example: the Tesla Roadster

- Range: 245 miles
- Range of Nissan Leaf - about 100 miles
- Horsepower: 288 (215 kW)
- Top speed: 125 mph
- Acceleration: 0-60mph in 3.7-3.9 seconds.
- Price: about $110,000
Alternatives to going all-electric

- The Hybrid Electric/gas Vehicle (HEV). Examples include the Toyota Prius, Honda Insight, Ford Fusion Hybrid, etc.
  - The car still uses gasoline exclusively as its fuel, but by having the ability to derive power from a combination of an electric motor and an internal combustion motor, significant increases in gas mileage are achieved.
  - Hybrids vary in the fraction of power (horsepower) that they can derive from the electric motor. Hybrids can be relatively economical. For example, the Toyota Prius starts at around 22K.

- The Plugin Hybrid Electric/gas Vehicle (PHEV). Examples include the Chevy Volt and the PHEV version of the Toyota Prius.
  - In one version (the Chevy Volt) the car always runs by electric motor, and derives its power from batteries that provide sufficient power to drive roughly 40 miles. Afterwards, a gas motor/generator kicks in to keep the batteries charged. Limited numbers available in December 2010.
  - I don’t believe that these are available yet. Reportedly they will still typically derive some power from the engine, but will derive more power from the electric motor. By keeping the batteries charged, effective gas mileage in excess of 100 mpg have been predicted by some reviewers.
Hybrid Technology

- Car can run either from the engine, or from the batteries using electric motors, or both.
- Unused power from the engine charges the batteries.
- Engine is only coupled to the power train under conditions under which it has high efficiency or when the power is needed.
- Much of the time, the engine is OFF.
- When braking, the electric motors run backwards and generate power that is stored in the battery. Remember the bicycle demo?
This looks like a big number, but there are about 251 million vehicles in the United States. Prior to the economic downturn, about 17 million light vehicles were sold annually. So the total # hybrids on the road is around the 2.4% of what is sold annually.

If we want to change the character of our transportation fleet, the percentage of sales comprising hybrids (and in the future, plug-in hybrids) needs to be much higher, and even then, it will take a decade or more to have a large effect.
The Energy Independence and Security Act of 2007
The Energy Independence and Security Act of 2007

Summary

The Energy Independence and Security Act (P.L. 110-140, H.R. 6) is an omnibus energy policy law that consists mainly of provisions designed to increase energy efficiency and the availability of renewable energy. This report describes the key provisions of the enacted law, summarizes the legislative action on H.R. 6, and provides a summary of the provisions under each of the titles in the law.

The highlights of key provisions enacted into law are as follows:

- **Corporate Average Fuel Economy (CAFE).** The law sets a target of 35 miles per gallon for the combined fleet of cars and light trucks by model year 2020.
- **Renewable Fuels Standard (RFS).** The law sets a modified standard that starts at 9.0 billion gallons in 2008 and rises to 36 billion gallons by 2022.
- **Energy Efficiency Equipment Standards.** The adopted bill includes a variety of new standards for lighting and for residential and commercial appliance equipment. The equipment includes residential refrigerators, freezers, refrigerator-freezers, metal halide lamps, and commercial walk-in coolers and freezers.
- **Repeal of Oil and Gas Tax Incentives.** The enacted law includes repeal of two tax subsidies in order to offset the estimated cost to implement the CAFE provision.

The two most controversial provisions of H.R. 6 that were not included in the enacted law were the proposed Renewable Energy Portfolio Standard (RPS) and most of the proposed tax provisions, which included repeal of tax subsidies for oil and gas and new incentives for energy efficiency and renewable energy.
Where is the low-hanging fruit?
Fuel economy vs. fuel efficiency

Figure 6
U.S. fuel economy vs. fuel efficiency

Fuel economy and fuel efficiency for cars and light trucks in the United States for the period 1975 to 2004. (The unit of efficiency in this figure only is ton-miles per gallon. This is the fuel efficiency mentioned in the text multiplied by the weight of the vehicle.)

Passenger cars

Fuel economy (mpg)

Efficiency

Fuel economy


Source: Lutsey and Sperling, 2005