Energy on this world and elsewhere

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or at http://people.virginia.edu/~gdc4k/phys111/fall11

Lecture 26 - December 1, 2011
Transportation: the most immediate energy problem
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.)

Source: Lutsey and Sperling, 2005
Implications of The Energy Independence and Security Act of 2007

Today
179 billion gallons

CAFE: $\frac{22}{35}=0.63$

Perhaps 2030?
113 billion gallons

Less 36 billion gallons of biofuels

77 billion gallons

Easily covered by domestic production of oil, 66% covered even with other uses of oil taken into account.
What about plugin hybrids?

- Plug-in hybrid electric vehicles (PHEVs), which charge their batteries from the electric grid, could reduce gasoline consumption by more than 60 percent assuming a full fleet of PHEVs with a range on batteries alone of at least 40 miles. However, plug-in hybrids require more efficient and more durable batteries, able to withstand deep discharges, that are not yet in commercial large-scale production. Given the technical difficulties faced in developing the batteries, it cannot be assumed that plug-in hybrids to replace the standard American family car will be available at affordable prices in the near term.

Easily covered by domestic production of oil, 66% covered even with other uses of oil taken into account.
When might plug-in hybrids really penetrate the market?

- Maybe ten years to let the technology mature?
- Perhaps another 16 years to replace the entire motor-vehicle fleet? (If we are being wildly optimistic)
- 2035?
Implications of The Energy Independence and Security Act of 2007 plus extensive introduction of plug-in hybrids

Perhaps 2035? 90 billion gallons

Only 40% from liquid fuels

36 billion gallons

Less 36 billion gallons of biofuels

0 billion gallons

The combination of better fuel efficiency, plug-in hybrids, and biofuels could eliminate the need for oil for transportation.
So what’s the answer?

at least for the short to medium term...

• Pick the low hanging fruit .... greater efficiency!
  – Conventional but efficient models
  – Hybrids
  – Diesels
• Continue to ramp up the production of biofuels, intelligently.
• Shift some of the burden to the electric grid using plug-in hybrids and all-electric vehicles.
• Flexible-fuel cars that can run on a variety of fuels.
• Nonconventional sources of oil - tar sands, oil shale, even fuel from coal.
What about hydrogen?

- **Produce hydrogen using any of several techniques:**
  - Renewables such as wind and solar
  - Nuclear power plants that produce hydrogen directly by breaking down water.
  - Can also be produced using coal and natural gas.

- **Run hydrogen through fuel cells to produce electricity.**
  - Efficiency is generally around 50%, more than a factor of two better than in internal combustion engines.
  - The "exhaust" is water vapor and heat.

- **Vehicles use only highly-efficient electric motors.**
  - Electric motors can easily have efficiencies in the high 90% range.
  - Regenerative braking can be used to recover energy that would otherwise be lost in city driving.
Fuel Cell

Converts fuel directly into electricity, it is not a heat engine!
Methanol as a hydrogen storage technique?

• Hydrogen is difficult to store ..... 
• ... but methanol can be converted into hydrogen using an on-board “reformer”.
• Methanol packs half the punch of gasoline, but fuel cells can be around 50% efficient, 2-3 times better than internal combustion engines.
• Methanol would likely be produced from biomass (or coal or natural gas), by hydrogen can be produced in many ways, including splitting water into hydrogen and oxygen.....
Sources of methanol

- Petroleum
  - gasoline
  - diesel
- Coal
  - methanol
  - diesel
- Natural gas
  - methanol
- Biomass
  - ethanol
  - methanol
  - biodiesel

There are many potential sources of methanol.
Other issues:

- Fuel cells are currently prohibitively expensive
- There are currently no truly practical ways to store hydrogen on a car.
- Even with better efficiency, the range of purely electric cars is an important and unresolved issue.
Chevy Equinox Fuel Cell

- Fuel cell converts hydrogen and oxygen directly into electricity.
- Emissions are essentially just water vapor.
- Uses only hydrogen, something that can in principle be produced in many different ways.
- Test program beginning soon, but costs are still way too high.
Clicker question

What is the longest amount of time that we might hope to get power from nuclear fuels such as uranium or thorium?

A. 10-20 years.
B. 20-100 years
C. 100 to 1000 years
D. More than 1000 years
Energy Elsewhere
Energy Elsewhere

• How can we use the available energy in our solar system?
• What are some of the issues?
• How do we get started?
• What are some of the big issues?
Think Big

There is a lot of energy that one could in principle use within the solar system. This number is just what hits the earth alone!

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<th>Item</th>
<th>Amount relative to TPES</th>
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<tr>
<td>TPES</td>
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<tr>
<td>Solar input</td>
<td>8000</td>
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<tr>
<td>All the world’s winds</td>
<td>60</td>
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<td>All the ocean’s waves</td>
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<td>All the Earth’s tides</td>
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<td>Geothermal world potential</td>
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<td>All the world’s photosynthesis</td>
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<tr>
<td>All the world’s rivers</td>
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Table 8.1 Natural energy sources compared to the total primary energy supply of 2004
A vision for both the colonization of space as well as using space as an energy resource.
Gerard O’Neill invented the modern “collider” used in particle physics.

Storage-Ring Synchrotron: Device for High-Energy Physics Research*

GERARD K. O’NEILL
Princeton University, Princeton, New Jersey
(Received April 13, 1956; revised version received April 23, 1956)

As accelerators of higher and higher energy are built, their usefulness is limited by the fact that the energy available for creating new particles is that measured in the center-of-mass system of the target nucleon and the bombarding particle. In the relativistic limit, this energy rises only as the square root of the accelerator energy. However, if two particles of equal energy traveling in opposite directions could be made to collide, the available energy would be twice the whole energy of one particle. Kerst, among others, has emphasized the advantages to be gained from such an arrangement, and in particular of building two fixed-field alternating gradient (FFAG) accelerators with beams interacting in a common straight section.

Fig. 1. Plan view of particle orbits in a hypothetical arrangement of storage rings at a 3-Bev proton synchrotron.

Fermilab, near Chicago, the Large Hadron Collider, or LHC at CERN are both examples.
Near Geneva, Particles Finally Come Together With a Bang

A screen at the European Organization for Nuclear Research showed the collision detectors inside the Large Hadron Collider.

By DENNIS OVERBYE
Published: November 23, 2009

Call it First Bang.

The Large Hadron Collider, the world’s biggest and most expensive science experiment, produced its first collisions on Monday, said scientists at CERN, the European Organization for Nuclear Research, outside Geneva.
O’Neill envisioned solar-power generation plants in space

- Idea first introduced by Peter Glaser around 1968
- Electricity is generated in orbit.
- Electricity is beamed down to Earth using microwaves.
- Power station is manufactured in space to save energy
In case you think the idea died with O'Neill
In case you think the idea died with O'Neil
In case you think the idea died with O’Neill

EADS Astrium develops space power concept

By Jonathan Amos
Science reporter, BBC News

Europe’s biggest space company is seeking partners to fly a demonstration solar power mission in orbit.

EADS Astrium says the satellite system would collect the Sun’s energy and transmit it to Earth via an infrared laser, to provide electricity.

Space solar power has been talked about for more than 30 years. However, there have always been question marks over its cost, efficiency and safety.

But Astrium believes the technology is close to proving its maturity.
In case you think the idea died with O’Neill

Japan to Beam Solar Power from Space on Lasers

By Jeremy A. Kaplan
Published November 09, 2009 | FOXNews.com

Japan is aiming to collect solar power in space and zap it down to Earth using laser beams or microwaves. The government has picked companies and researchers to turn the multi-billion pound dream of unlimited clean energy into reality by 2030.
So what are we talking here?

- Assume we want 1 GW (10^9 Watts) of power generation.
- In space, the sun shines 24/7, so we take Intensity = 1,400 W/m^2

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

\[
\text{Area} = \frac{10^9 \text{ Watts}}{0.20 \times 1,400 \text{ W/m}^2} = 3.6 \times 10^6 \text{ m}^2 = 1.9 \text{ km} \times 1.9 \text{ km}
\]

So a 1 GW power generating station would need a collection area of roughly 2 kilometers by 2 kilometer ..... that is pretty big! (at least for space)
Something like the International Space Station Just Isn’t Big Enough
If we manufacture things in space, the people doing it will need someplace to live
One thought was that early habitats could be built out of the shuttle’s external fuel tanks.
How do we put things in space?

Let’s start by putting things in orbit...

This is a problem that was considered by Newton...

For one thing, they must be going fast enough that as they “fall”, they follow a circular path.
How fast is fast enough?

This is a problem that was considered by Newton...

For low earth orbit:
\[ v = 7.63 \times 10^3 \text{ m/s} \]
\[ = 17.068 \text{ mph} \]
For low earth orbit, the key is not going up, its getting going fast enough sideways ...