Energy on this world and elsewhere

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

Lecture 19, November 1, 2011
Announcements

• Hopefully have quiz graded by Thursday. Some people are still taking it.
• Tentative date for “midterm”, Tuesday November 15th.
• Problem set #2 will be posted later this week.
• Problem set #1 available soon.
Biofuels
(continued)
Biodiesel from Algae may be becoming a reality

July 14, 2009

Exxon to Invest Millions to Make Fuel From Algae

By JAD MOUAWAD

The oil giant Exxon Mobil, whose chief executive once mocked alternative energy by referring to ethanol as “moonshine,” is about to venture into biofuels.

On Tuesday, Exxon plans to announce an investment of $600 million in producing liquid transportation fuels from algae — organisms in water that range from pond scum to seaweed. The biofuel effort involves a partnership with Synthetic Genomics, a biotechnology company founded by the genomics pioneer J. Craig Venter.
Inside the Exxon algae biodiesel research facility
What type of production levels can we expect?

• Christi’s article in biodiesel claimed 6,279 to 14,644 gallons per acre per year.
• Solix claims they have reached 3000 gallons per acre per year.
• Exxon says that eventually, they might reach 2000 gallons per acre per year.

These varying estimates, with sources ranging from an academic journal article to a company’s existing product to a prediction from Exxon, underscores the fact that good numbers will only be available once serious production begins.
Bioreactor concept
Prototype Bioreactors
Algae-to-Biofuels

Plants such as soybeans and sunflowers produce oil, that can be used to make biofuels. Although these crops have received a lot of media attention in the last several years, they require intensive management and may not be sustainable in the long term due to rising development and production costs. We believe a different type of oil crop that holds great promise for the future is microalgae.

Extensive research was conducted to determine the utilization of microalgae as an energy source, with applications being developed for biodiesel, ethanol, and bioplastics. Independent studies have demonstrated that algae is capable of producing in excess of 30 times more oil per acre than corn and soybean crops. Biodiesel produced from algae contains no sulfur, is non-toxic and highly biodegradable.

Rio Hondo, Texas algae farm
This image does not seem to be displayed on PetroSun’s web site any longer, perhaps showing the growing pains of this nascent industry.
Solix actually sells this system

- Solix claims they have reached 3000 gallons per acre per year.
- Christi’s lesser algae number, 58,700 liters per hectare, comes to 6,279, not that much bigger.
Growing algae is not like growing corn!

Solix Biofuels pilot plant in Colorado
Solix’s Dream? (Their illustration anyway)

Artist’s conception of large-scale Solix Biofuels plant in Colorado
IGCC and algae production

Integrated Gasification Combined Cycle (IGCC) technology together with algae farms represent an interesting approach to both liquid fuel and electricity needs.

- An IGCC plant would cleanly produce electricity with roughly 40-50% efficiency from coal.
- A warm stream of relatively pure CO$_2$ would supply an adjacent algae production facility.
- Biodiesel would be produced from the algae.
- While the CO$_2$ from the coal would still be released into the atmosphere, 2-3 times the energy would be gained per pound of CO$_2$ released.
An actual IGCC application?

Not quite .... at least not for now
Clicker question

Which of the following provides the largest amount of energy for transportation in the United States?

A. Biodiesel
B. Corn-based ethanol
C. Natural gas
D. Electricity from the grid.
Wind
In late 2006, a Malawian newspaper first wrote about a remarkable young man from a remote rural village north of the capital city.

http://www.youtube.com/watch?v=arD374MFk4w
Moving Windmills, a film about William Kamkwanda

http://www.youtube.com/watch?v=arD374MFk4w
Wind: the fastest growing source of energy
Fraction of U.S. generation of electricity due to wind (%)

The growth is impressive, but how far can it go in terms of absolute fraction?
Notice the stall in growth between 2009 and 2010. According to the LA Times it has picked up again for this year, but I don’t know whether this agrees with official projections.
Researchers at DOE's Argonne National Laboratory are working to develop a geographic information system screening tool to identify lands at high risk of visual impacts from wind energy development. This information system will help developers and land managers choose project sites less likely to face community opposition related to aesthetic issues. The researchers will also develop visual impact mitigation measures for a potential wind site based on the site's topography, vegetation, and other site-specific environmental conditions.

Resource Assessment

The Wind Program has been producing high-resolution wind resource maps for decades. Based on advanced meteorological models, and validated with real data at 50 meters above the ground, the latest versions of these maps can be enhanced with overlays that describe important features such as power lines, park boundaries, and roads. These resource maps help developers and policy makers determine which areas are best suited for wind energy development. The Wind Program has upgraded these maps to indicate the wind resource at 80 to 100 meters above the ground to provide information for developers using larger turbines on taller towers. Using highly accurate Global Positioning System mapping tools, data from satellites, weather balloons, and meteorological towers, and much-improved numerical computer models, the Wind Program is working with U.S. companies to produce higher resolution maps of resources at higher heights above ground for the United States and other countries. Improved horizontal resolution of these maps (1 kilometer or better) allows for more accurate siting of wind turbines, and has led to the recognition of higher wind speed areas where no such winds were thought to exist.
Rapid growth of wind energy

To put this in perspective, the generation capacity of the U.S. is around 998 GW, so wind is around 3.0% of generating capacity. The average power generated in the U.S. is around 460 GW (~46% of peak capacity). Wind operates at an average of around 23% of peak capacity.

Source: AWEA project database

Figure 1. Annual and Cumulative Growth in U.S. Wind Power Capacity
Rapid growth of wind energy

Source: EIA, Ventyx, AWEA, IREC, Berkeley Lab

Figure 2. Relative Contribution of Generation Types in Annual Capacity Additions

Wind now commands the largest share of fractional growth and second largest share of absolute growth in generation capacity.
Multiple sources suggest that the limits in the U.S., like Denmark, may be around 20% of all electrical generation.
If wind were responsible for 20% of U.S. generation, that would take a huge bite out of fossil fuel use.
This report from the National Renewable Energy Laboratory (NREL) provides lots of great information on Wind Power.
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Computing the power carried by wind

Power = \( \frac{1}{2} \cdot A \cdot \rho \cdot v^3 \)

Here the area “A” is the area swept out by the blades of the windmill.
Computing the power carried by wind

Consider the energy per unit time passing the indicated plane.

Power associated with the wind = \( \frac{\text{kinetic energy contained in "box" of air}}{\text{time it takes box to pass the plane}} \)
Computing the power carried by wind

What is the kinetic energy carried by the air?
KE = \( \frac{1}{2} \) (mass of air) (velocity of air)^2

mass of air = \( L^3 \) \cdot density = \( L^3 \) \cdot \( \rho \)

KE = \( \frac{1}{2} \) (\( L^3 \) \cdot \( \rho \)) \( v^2 \)
Computing the power carried by wind

Assume the length of the side of the box is “L”
How much time does it take the box to pass the plane?

We know that (velocity x time) equals distance: \( v \times t = d \),
Here the distance is just “L”, thus:
\[ t = \frac{d}{v} = \frac{L}{v} \]
Computing the power carried by wind

Power = \( \frac{KE}{\text{time it takes box to pass}} = \frac{1}{2} \left( \frac{L^3 \cdot \rho}{L/v} \right) v^2 = \frac{1}{2} L^2 \cdot \rho \cdot v^3 \)

Power = \( \frac{1}{2} \cdot A \cdot \rho \cdot v^3 \)
Computing the power carried by wind

Power = \( \frac{1}{2} \cdot A \cdot \rho \cdot v^3 \)

Here the area “\( A \)” is the area swept out by the blades of the windmill.
How much power goes by a real windmill?

\[ \text{Power} = \frac{1}{2} A \rho v^3 \]

\[ A = \pi r^2 \]

\[ r = 40 \text{ meters} \]

\[ \rho_{\text{dry air}} = 1.29 \text{ kg/m}^3 \]

\[ v = 4 \text{ m/s} = 8.9 \text{ mph} \Rightarrow P = 207.5 \text{ kW} \]

\[ v = 15 \text{ m/s} = 33.6 \text{ mph} \Rightarrow P = 10,942.2 \text{ kW} \]

\[ v = 25 \text{ m/s} = 55.9 \text{ mph} \Rightarrow P = 50,658.2 \text{ kWh} \]
How much power is carried by the wind for a wind speed of 15 meters per second?

\[ v = 15 \text{ m/s} = 33.6 \text{ mph} \Rightarrow P = 10,942.2 \text{ kW} \]

efficiency at 15 m/s = \( \frac{2}{10.94} = 18.3\% \)
At 10 m/s, the graph indicates power output of roughly 1.4 MW.

The power of the wind at 10/m/s = 3.42 MW

efficiency = 1.4 MW / 3.42 MW = 40.9% !!!
The braking mechanism on the windmill shown in this video is not working, resulting in the destruction of the windmill in high winds.

http://www.youtube.com/watch?v=MvuP5IApfu4