Tuesday, December 4th…. 

Announcements…. 

• Homework 9 due today.
Australian Leader Ratifies Kyoto Pact

By REUTERS
Published: December 3, 2007

Filed at 2:49 a.m. ET

CANBERRA (Reuters) - Australia's new prime minister, Kevin Rudd, took the oath of office on Monday and immediately signed documents to ratify the Kyoto Protocol, ending his country's decade of opposition to the global climate agreement.

The move isolates the United States, which will now be the only developed nation not to ratify the agreement which sets binding limits on developed countries to curb the carbon emissions blamed for **global warming**.

"This is the first official act of the new Australian government, demonstrating my government's commitment to tackling climate change," Rudd said in a statement.
The Bali conference of the UNFCCC on a successor to the Kyoto Protocol has begun. No real news yet… Obviously the tough issue is what commitments can be obtained from the U.S., China and India.

Casual dress code for Bali summit

From correspondents in Nusa Dua
December 03, 2007 07:34am

TIES and jackets are out and casual clothes are in, to save on air conditioning at this week’s global climate change summit in steamy Bali, a UN spokesman said today.

"The dress code is to be relaxed, not to wear tie or jacket," said John Hay, spokesman for the United Nations Framework Convention on Climate Change secretariat.

In a note on its website, the UNFCCC hoped that the dress code "will allow participants to conduct discussions in a more comfortable environment, as well as limit the use of air conditioning and thereby reduce greenhouse gas emissions".

Yvo De Boer, the body’s executive secretary, set the tone today, appearing in a trademark Indonesian batik shirt aimed to weather local temperatures hovering around a humid 28 degrees Centigrade.

Hosted by the United Nations, the December 3-14 Bali conference aims to draft a roadmap for negotiating cuts in heat-trapping carbon emissions from 2012, when current pledges under the Kyoto Protocol run out.
Meanwhile in Washington..

Lawmakers Set Deal on Raising Fuel Efficiency

By JOHN M. BRODER and MICHÉLINE MAYNARD
Published: December 1, 2007

WASHINGTON, Nov. 30 — Congressional negotiators reached a deal late Friday on energy legislation that would force American automakers to improve the fuel efficiency of their cars and light trucks by 40 percent by 2020.

The proposal, which would require automakers to achieve 35 miles per gallon on average, is similar to a measure that was passed in the summer by the Senate but was bitterly opposed by the auto companies, who argued they did not have the technology or the financial resources to reach that goal.

The auto companies gave up their long-held opposition to fuel economy increases not long before the Senate version was passed, but proposed a much weaker alternative. In recent weeks, the chief executives of General Motors, the Ford Motor Company and Chrysler visited Capitol Hill in an effort to fend off a stronger measure, but the compromise announced Friday showed those efforts had little effect.

The compromise emerged after days of difficult negotiations between House and Senate members and their staffs. The final deal was hammered out by the two main antagonists, the speaker of the House, Nancy Pelosi, Democrat of California, and Representative John D. Dingell, the Michigan Democrat who is the auto industry’s most effective advocate on Capitol Hill.
The package nearly fell apart this week when Mr. Dingell insisted on leaving sole authority to regulate automobile mileage standards with the National Highway Traffic Safety Administration, an arm of the Transportation Department. That would have weakened the power of the Environmental Protection Agency and the states, led by California, to regulate auto emissions of carbon dioxide, which are in large measure a function of the amount of fuel burned.

Federal court rulings this year have decided this so-called pre-emption issue in favor of the E.P.A. and the states, decisions that Mr. Dingell hoped to undo by Congressional action. The traffic safety administration has had authority over fuel-efficiency standards since 1975 but has not imposed any significant increase since 1985. The E.P.A. is currently writing rules to comply with a Supreme Court ruling this year that gave it the authority to regulate carbon dioxide emissions and is weighing an application by California and 14 other states to set their own emissions standard.

The authority of the E.P.A. to regulate tailpipe emissions and the right of California and other states to set their own, higher standards were considered deal-breakers by Ms. Pelosi and her fellow California Democrat, Senator Dianne Feinstein. Arnold Schwarzenegger, the Republican governor of California, weighed in late in the week to tell negotiators that he would oppose the bill if the Mr. Dingell’s preemption language stayed in.
The House version of the energy bill also includes a mandate for 15% of electric power to come from (non-hydro) renewable sources by 2020. Currently the figure is about 2.5%.
We’re talking about less carbon intensive energy options….

- Solar Power
- Wind Power
- Biofuels
- Hydrogen
- Nuclear Power

Today we will focus on wind power.

Wind mills in La Mancha, Spain
Traditionally, wind mills were used for raising water from wells, or grinding grain into flour.

Today we use wind turbine generators to produce electricity.

The potential for wind power is enormous. Simple estimates show that the amount of wind power available in the U.S. greatly exceeds total electrical usage.

However, there are many hurdles to overcome as well.
Basic physics of wind power….

A “perfect” wind turbine would extract all the kinetic energy of the wind passing through it.

\[ v = \text{velocity of wind (m/s)} \]
\[ A = \text{area spanned by turbine blades (m}^2\text{)} \]
\[ \rho = \text{mass density of air (kg/m}^3\text{)} \]

In one second the mass of air passing through the area spanned by the turbine blades is

\[ M = \rho A v \text{ (1 second)} \]
In one second the mass of air passing through the area spanned by the turbine blades is

\[ M = \rho A v (\text{1 second}) \]

The energy extracted from the wind by the turbine in 1 second is

\[ E = \alpha \left( \frac{1}{2} M v^2 \right) = \frac{1}{2} \alpha \rho A v^3 (\text{1 s}) \]

- \( v \) = velocity of wind (m/s)
- \( A \) = area spanned by turbine blades (m\(^2\))
- \( \rho \) = mass density of air (kg/m\(^3\))
- \( \alpha \) = efficiency of turbine
In one second the mass of air passing through the area spanned by the turbine blades is

$$M = \rho A v \text{ (1 second)}$$

The energy extracted from the wind by the turbine in 1 second is

$$E = \alpha \left( \frac{1}{2} M v^2 \right) \text{ (1s)} = \frac{1}{2} \alpha \rho A v^3 \text{ (1s)}$$

To get power, divide by the 1 second

$$P = \frac{1}{2} \alpha \rho A v^3$$
Wind power goes like the cube of the wind velocity.

Doubling the wind speed makes the power go up by a factor of 8!

Wind power works best in places with high wind speeds. Precise siting is very important.
Betz’s law puts a limit on the efficiency of wind turbines.

\[ \alpha < \frac{16}{27} \approx 0.59 \]

This comes about because the lower velocity area leaving the wind turbine creates a blockage. The slower it’s moving, the worse the blockage.

It turns out that a maximum efficiency is achieved if the wind leaving the turbine has 1/3 of the velocity it had when it entered.

Modern wind turbines have efficiencies in the range 0.4 - 0.5
In class exercise….

\[ P = \frac{1}{2} \alpha \rho A v^3 \]

Assume

- \( v = 9 \text{ m/s (about 20 miles/hour)} \)
- \( R = 50 \text{ m (length of turbine blades)} \)
- \( \alpha = 0.5 \)
- \( \rho = 1.2 \text{ kg/m}^3 \)

What is the power generated by the wind turbine?
In class exercise....

Assume

\( v = 9 \text{ m/s (about 20 miles/hour)} \)
\( R = 50 \text{ m (length of turbine blades)} \)
\( \alpha = 0.5 \)
\( \rho = 1.2 \text{ kg/m}^3 \)

What is the power generated by the wind turbine?

\[
P = \frac{1}{2} \alpha \rho A v^3
\]

\[
P = 1.7 \times 10^6 \text{ Watts} = 1.7 \text{ MW}
\]
For example the Enercon E-66 turbine has a 66 meter diameter and generates 1.8 MW of power for 12 m/s winds.

The German corporation Enercon is the world’s largest maker of wind turbines. Enercon’s largest turbine is rated at 6MW.
A big issue for wind power is **intermittency**. Sometimes the wind is blowing and sometimes it’s not.

A given wind turbine in a given location will not always supply its rated power.

\[
\text{capacity factor} = \frac{\text{actual average power}}{\text{rated maximum power}}
\]

A well sited wind turbine can have a capacity factor of 1/3.

When you hear or read about a wind project with a given rated output - e.g. 300 MW - keep in mind that the actual average output will be about 1/3 this amount.
Another aspect of intermittency…..

Operators of electrical grids must balance the amount of power generated with the amount being used. Electrical power can not be stored easily.

Wind power is quite predictable over long terms (seasons), but over short terms it varies considerably. There is great debate over what proportion of wind energy a grid system can make use of without compromising its stability.

20% wind power does not seem to be a problem. Since few countries have above 5% electricity from wind power, serious practical attention has not yet been brought to bear on this issue.
Electrical grid managers divide traditional power plants into two categories…

**Baseload generators** - are essentially always running. This includes nuclear power plants, which have very low fuel costs and also coal-fired plants.

**Peak generators** - are turned on only at times of peak demand. This usually includes natural gas fired power plants, which have the most expensive fuel.

Raw wind (or solar) power does not fit neatly into either category. Can it be combined with other technologies to better fit into electricity management needs?

For example, electrical demand peaks during heat waves, but winds tend to die down.
Storing electrical energy is difficult, but not impossible....

**Pumped storage hydroelectricity** is one method. A second method being explored is **compressed air energy storage** (CAES).

Electrical energy is used to compress gas and store it in underground geological reservoirs.
Planned to begin operating in 2011, the ISEP will combine a 75-150 MW wind farm with CAES storage and turbine generators.

- When wind is high and demand is low, compressed air is pumped into a porous sandstone reservoir.
- When demand is high the compressed gas is used to assist a natural gas fired turbine generator.
- A modern super-efficient gas turbine uses 7000 BTU/kW-hr, while the CAES generator uses only 4300 BTU/kW-hr. (More traditional gas turbines use 12,000 BTU/kW-hr).
Worldwide windpower facts….

- In 2005, wind power accounted for 1% of global electrical power production.
- Germany leads in installed wind generating capacity.
- Denmark gets about 20% of its electricity.
- Germany and Denmark are the leading producers of large wind turbines.
- In 2006 global wind power capacity was 74 GW.
- The World Wind Energy Association projects that installed capacity in 2010 will be 160MW, representing annual growth of 21%.

http://en.wikipedia.org/wiki/Wind_power
A map of U.S. wind resources......
Although California was the early leader in wind power, Texas now leads ….

- Texas - 3352 MW
- California - 2376 MW
- Iowa - 967 MW
- Minnesota - 897 MW
- Washington - 818 MW

Over 3000 MW of new wind power are expected in the U.S. in 2007, an increase of about 25%.

1000 MW provides electricity for about 250,000 homes in the U.S.

The great plains states of the midwest have great wind power potential.
Horse Hollow Wind Energy Center is the world's largest wind farm at 735.5 MW capacity. It consists of 291 GE Energy 1.5 MW wind turbines and 130 Siemens 2.3 MW wind turbines spread over nearly 47,000 acres (190 km²) of land in Taylor and Nolan County, near Abilene, Texas. (wikipedia)

Horse Hollow is owned by FPL Energy, which operates 53 wind farms in 16 states, with a capacity of over 4800 MW, making it one of the world’s largest generators of wind power.
One thing we haven’t gone into is the economics of wind power. It’s interesting to read what FPL Energy has to say on this topic…..

Wind power in Massachusetts......
Windmill Point, in the town of Hull, jutting out into Boston Harbor, has long been a site for wind power.

In 1985 the town erected a 40 KW turbine on an 80 foot tower to supply power to a nearby school. It operated until 1997, when it was damaged in a storm.

In 2001 the town installed a 660KW turbine (50 m tall, rotor diameter 47m, cost, $700,000, made by Danish firm Vestas), supplying power through the municipally owned electric grid.

In addition to supplying all town street lighting, electricity income generated $150,000 in its first year of operation.

In 2006, Hull Wind 2 - a 1.8 MW Vestas turbine began operation. The two turbines now supply 10% of Hull’s electricity.
The **Cape Wind** project on Horseshoe Shoal in Nantucket Sound would be the country’s first offshore wind farm.

- 130 Turbines with a rated capacity of 420 MW.
- Would produce on average 3/4 of Cape Cod’s electricity needs.
- Estimated to be completed in 2010.
- Great opposition from some local residents, including the Kennedy family.
- Broad support from environmental groups (Masspirg, Union of Concerned Scientists, Mass Climate Action Network, the Coalition for Buzzards Bay, ….)