ENVIRONMENTAL ENTREPRENEURS

Toward 100% Renewable Power

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Members Meeting 10/7/08

Tony Bernhardt
Environmental Entrepreneurs
afbernhardt@comcast.net

Outline

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- Potential for renewable power
- The reliability problem at high penetration levels
- Short term (6 hour) operating reserve solutions
- Long term power replacement solutions
- A path to renewable natural gas

There are two proposals for increased renewable energy in the U.S.

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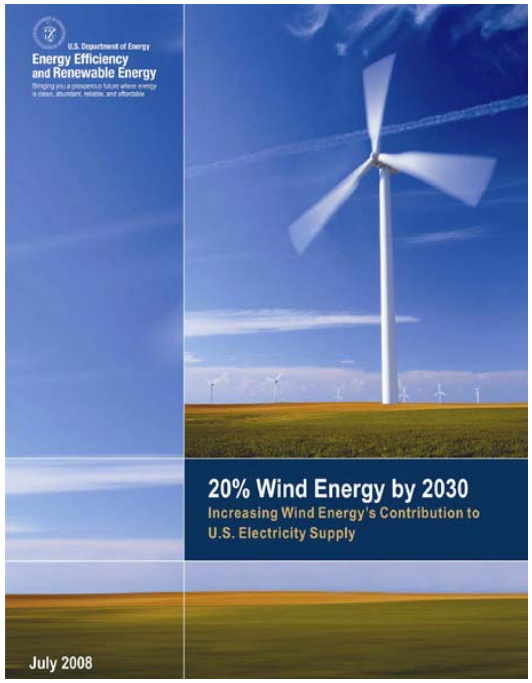
- 20% Wind Energy by 2030 (DOE)

- 100% Renewable Energy in 10 years (Al Gore)



How much is realistic? When?

20% of Electricity Can be Generated by Wind by 2030 according to the DOE plan

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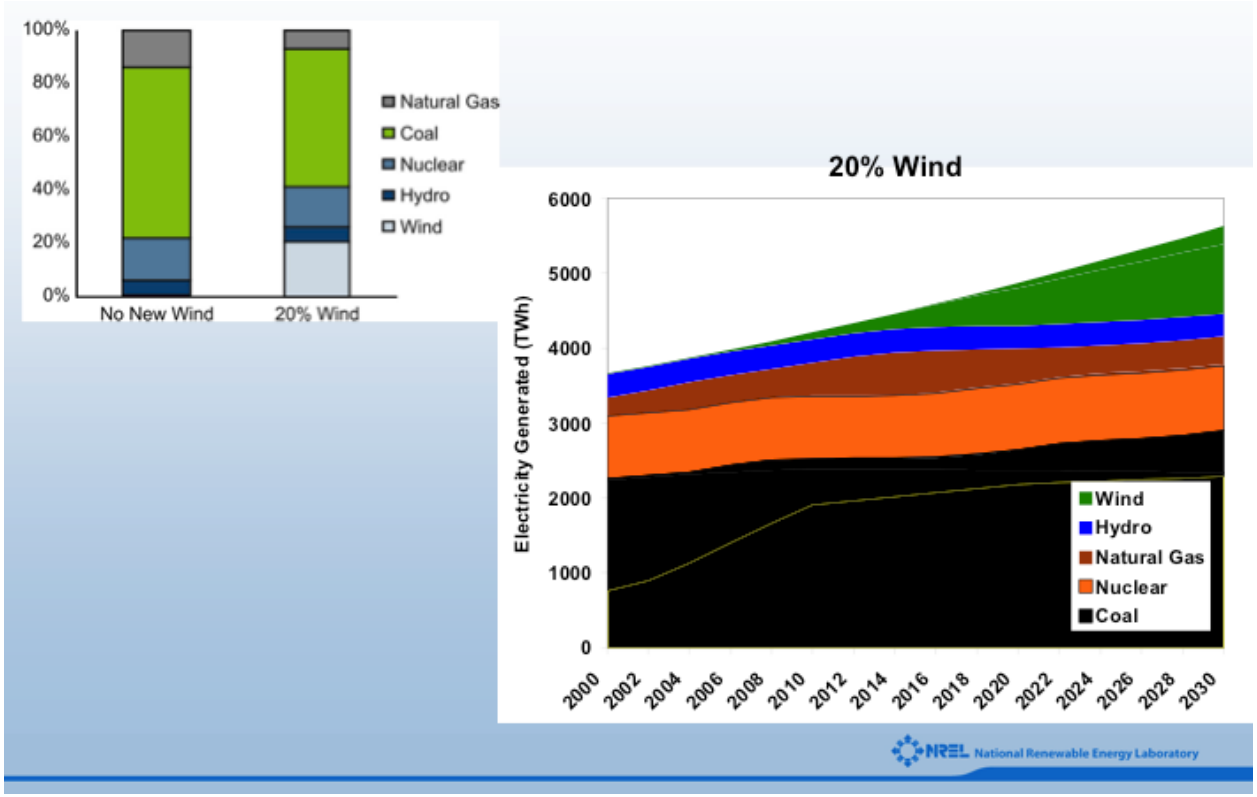
The net effect by 2030 is to substitute wind for increased coal



Reduction of greenhouse gas emissions from electricity generation depends on carbon sequestration in this plan.

Wind Power in the mid-U.S. and Offshore Could Supply > 20% of U.S. Electricity

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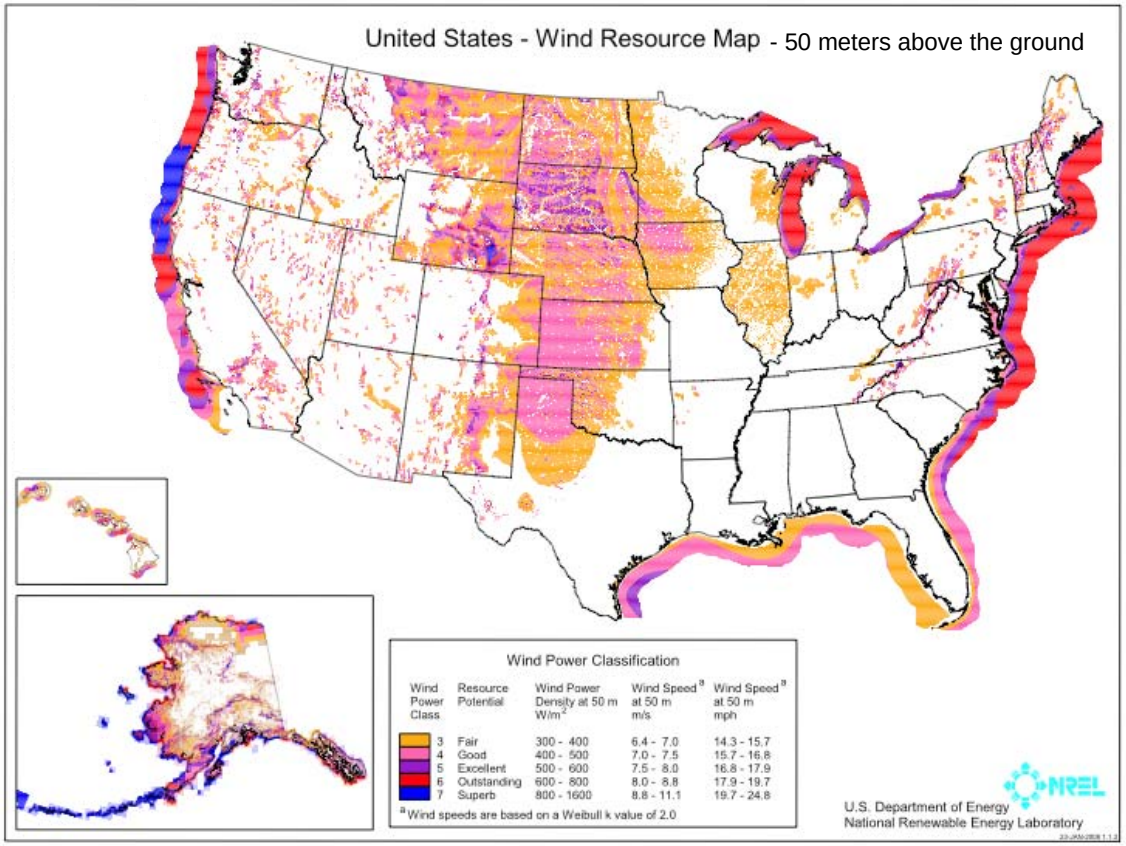

The problem is that wind is not reliable so replacement power is required.

Solar Power in the Southwest Can Supply All U.S. Electricity

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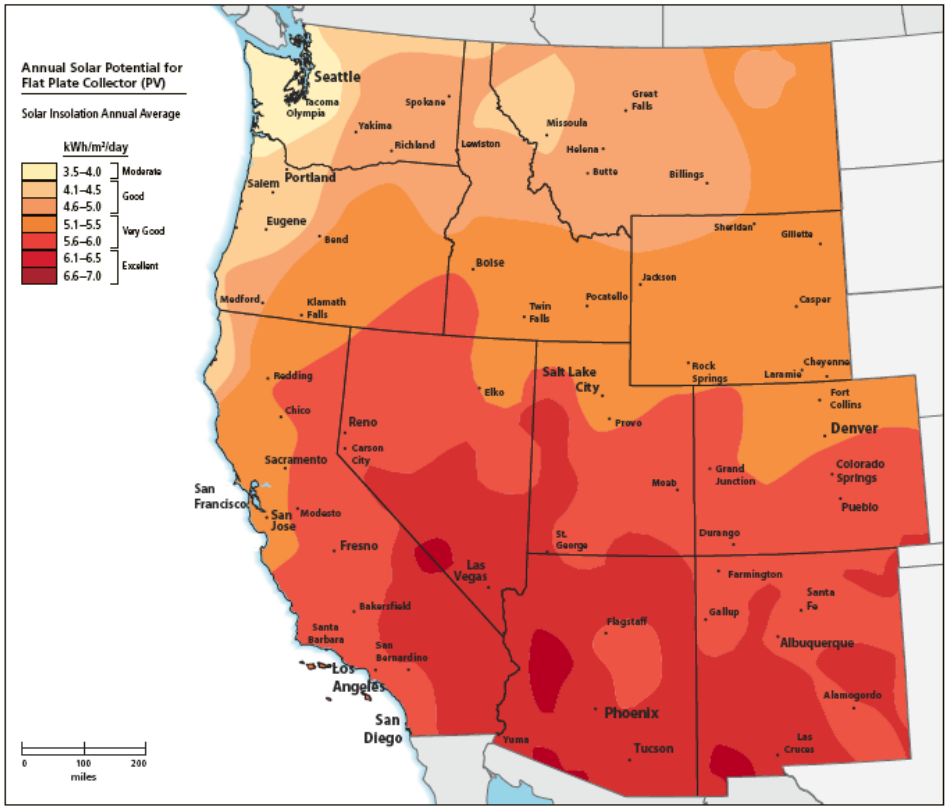

- **An area 100 miles by 100 miles can generate 100% of U.S. electrical demand**

The problem is that solar power changes during the day and clouds reduce output.

Combining Geographically Dispersed Wind Sources Improves Reliability

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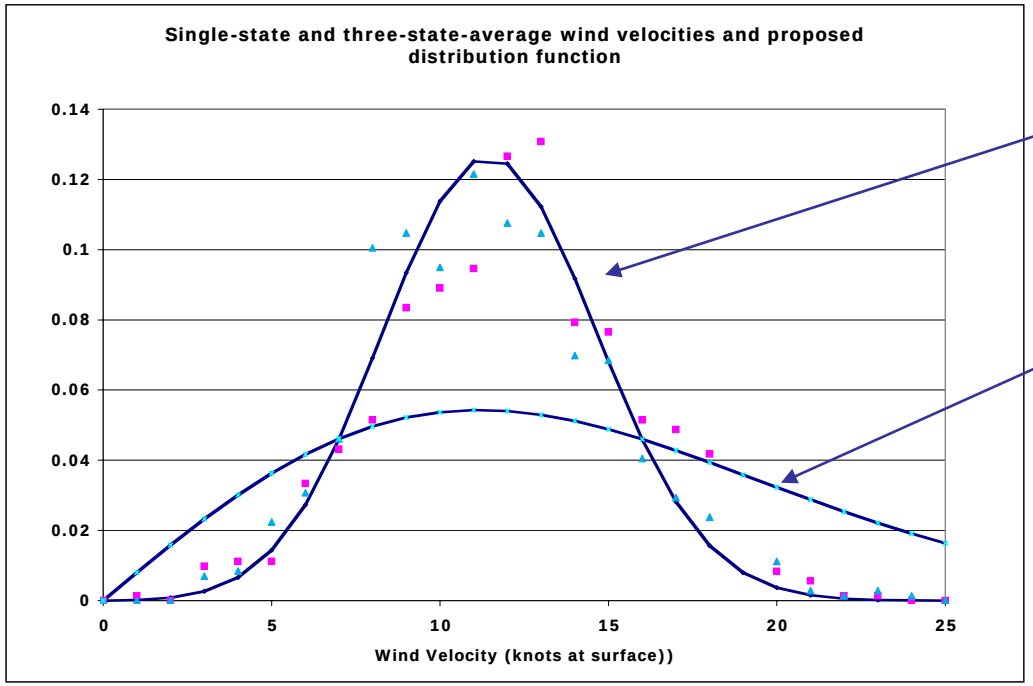

Surface wind distribution for average of stations in TX, KS, IA, and BC, January 2007

Surface wind distribution for a single station

The frequency of low power and excessive power conditions is greatly reduced but not eliminated.

Integration of Renewables Requires an Expansion of the Grid

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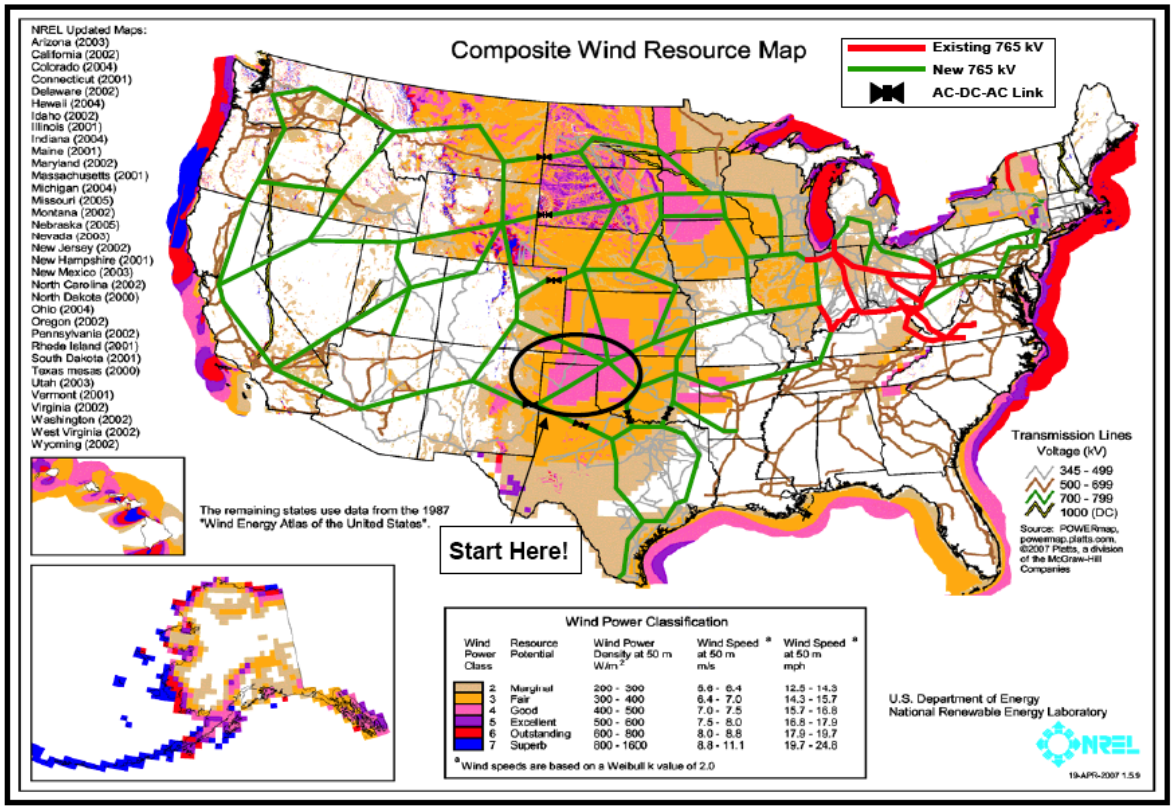

American Electric Power proposal for expansion of the grid:

$60 billion for 19,000 miles of 765 kV lines

UWIG price estimate ~ 3 cents per kWh

Wind in the Mid U.S. Blows Day and Night

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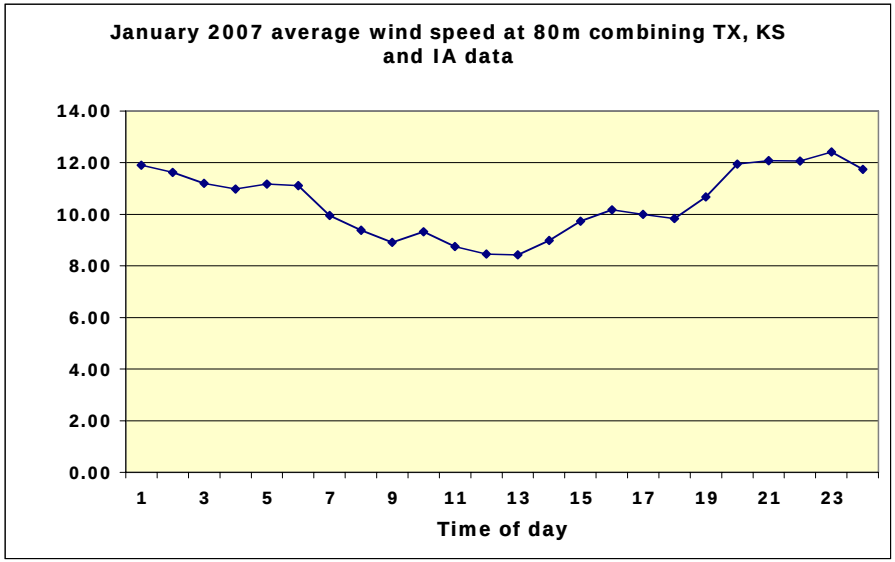

- **Wind can be used as a component of baseload power**
- **Solar power can provide power during the day and can partially compensate for seasonal variation of wind power**
- **But a drop in wind velocity causes a bigger drop in electrical power output which has to be accommodated by other generation**

When There Is No Replacement Power Prices for Electricity Skyrocket

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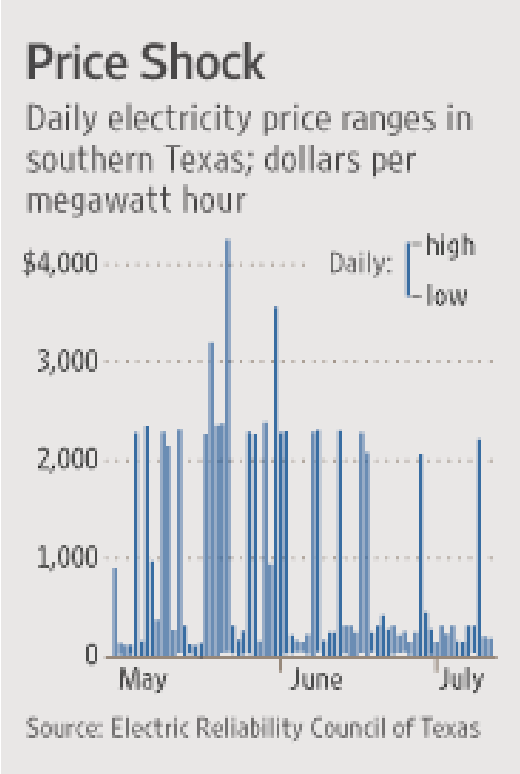
- On February 26 wind power output in Texas dropped to less than 80% of average in a few hours
- Prices in West Texas jumped to over $1 per kWh
- On March 1 wind output again dropped and prices hit $2.25 per kWh
- Normal Texas wholesale prices are 4 cents per kWh
- These were not isolated incidents →

Price jumps show the effect that renewable power outages have on the economy.



Estimates for Levelized Cost of Electricity

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LCOE answers the question, "if a power plant were built today, how much would the electricity produced cost"

Technology	price of electricity (cents/kWh)	
Scrubbed Coal*	11	
Natural Gas peaker*	12	9 in full time operation
Nuclear*	15	
Wind*	12	
Solar Photovoltaic*	29	10 by 2012 (industry)
Solar Thermal	14	8 by 2020 (DOE)

* Moody's "New Nuclear Generating Capacity" May 2008

Wind and solar LCOE does not include replacement/backup capacity. Such storage will add to electricity prices.

Cost for Wind Replacement Capacity

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Natural gas turbines can provide continuous backup at 1-2 cents/kWh

Most of the cost of normal natural gas power is not capital but fuel. As backup capacity, fuel cost is low! This is the only viable long term backup (> 24 hours) today.

Flow batteries can provide 6 hours of backup at 3 cents per kWh

This covers all operating reserve needs. Shifting wind power to peak demand periods pays for the extra cost but in the long term we'll have solar power for peak demand.

Molten salt can provide 6-12 hours of backup for solar thermal power at an estimated 0 - 3 cents per kWh

Storing More Than a Day's Energy Output Is Very Expensive

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Natural gas is stored underground in geological formations so there is not much container cost.

Most other storage media require a container. Worse, that container usually has to be either thermally insulating (e.g.liquid hydrogen, molten salt for CSP, electrolytes for flow batteries) or a high pressure vessel (e.g. hydrogen gas).

A Path to Grid Stability and Beyond

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- **Natural Gas power plants are 41% of U.S. capacity**
  Don't decommission these plants prematurely

- **Learn to make renewable natural gas economically**

Renewable natural gas is a much harder problem to solve economically than renewable electricity and not one we set out to solve. However...

A Path to Renewable Natural Gas

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1) Use Renewable Power to make Hydrogen

2) Convert hydrogen chemically to Natural Gas

(4H2 + CO2 -> CH4 + 2H2O Sabatier reaction)

3) Locate the production near a CO2 sequestration site

(electricity and natural gas distribution permit flexible siting)

An added benefit is that CO2 geological storage sites (50-100 years capacity) fill more slowly.

Can this be cost effective??

Renewable Natural Gas Is Possible in 2030

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The above process becomes economical in the 2030 time frame if a combination of the following occur

- **cost of renewable power is reduced significantly**
- **cost of natural gas rises**
- **carbon emission pricing is established**

The cost of renewable electric power does not increase but the price of natural gas does.

By 2030 it could be more economical to use electricity to make natural gas.

Are these changes plausible??

A Path to Renewable Natural Gas (cont'd)

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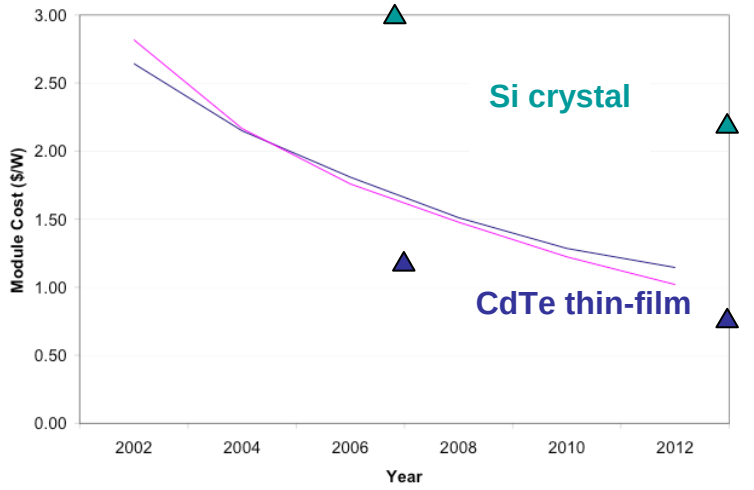
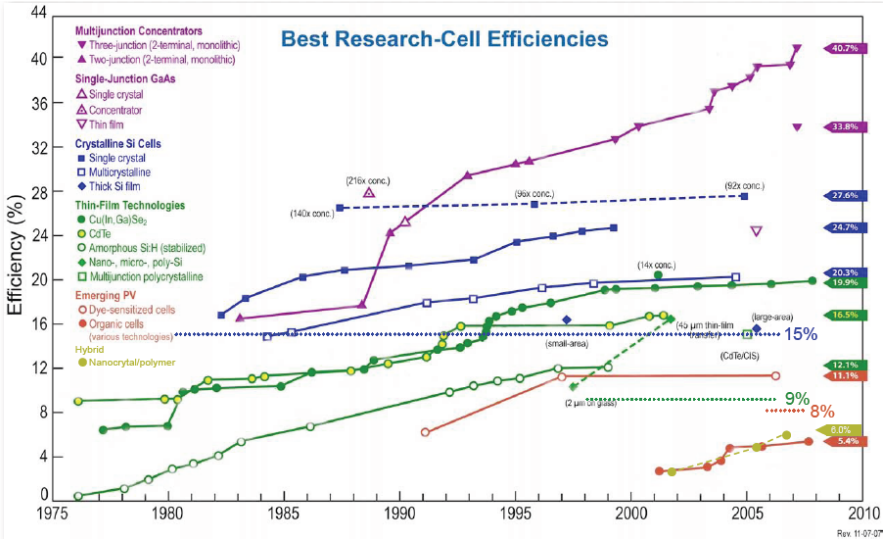
- **The cost of solar power continues to drop as manufacturing cost is reduced and light-to-electricity efficiencies increase**

- **Both wind and solar prices will come down as feed-in tariffs in Europe diminish and as supply increases**





A Path to Renewable Natural Gas (cont'd)

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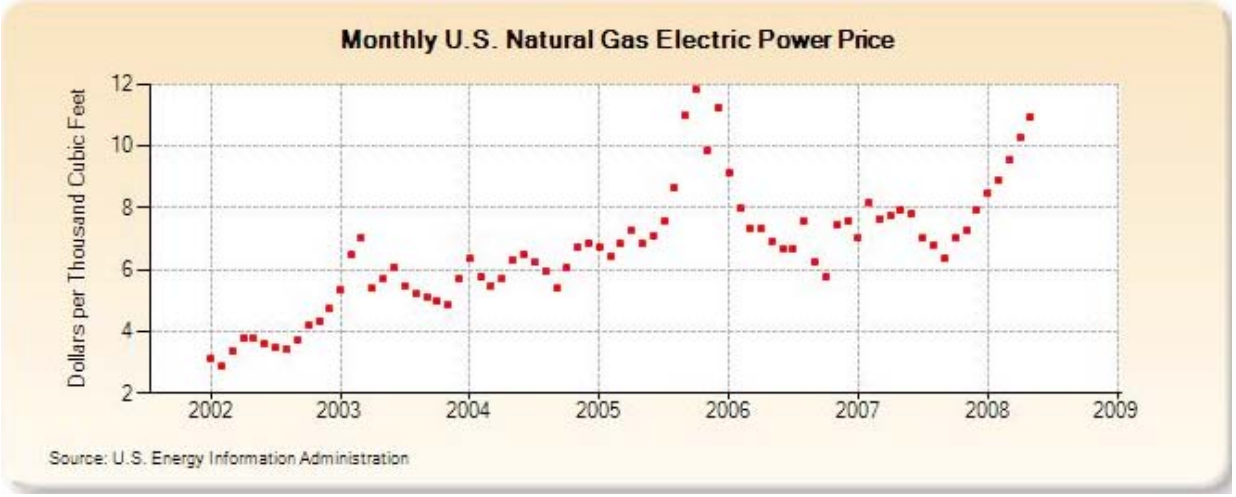
The cost of natural gas has tripled since 2002. Where will it be in 2030?



Carbon emission pricing will increase the cost of natural gas

At today's European exchange price ($31.85 per ton CO2 on 10/3/08), the price for natural gas for electricity would go up 18%.

Conclusions

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- There is a path to 100% renewable power
- Backup storage for 6-12 hours has shown economic feasibility
- Natural gas power can provide longer term backup
- It is plausible that natural gas can be made economically from renewable power in the 2030 time frame to provide backup power and other uses