Sector Overview
Electricity and Climate in Pennsylvania

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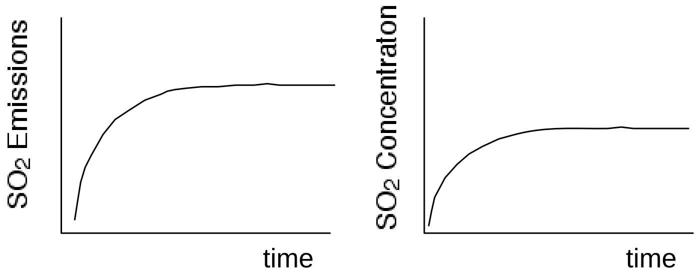
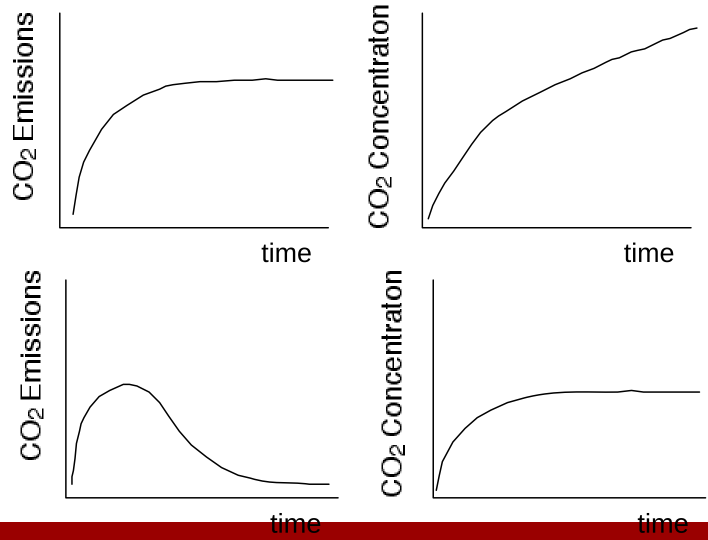
CO_2 and most other greenhouse gases are not like conventional air pollutants

Conventional pollutants like SO_2 or NO_x have a residence time in the atmosphere of just a few hours or days. Thus, stabilizing emissions of such pollutants results in stabilizing their concentration.



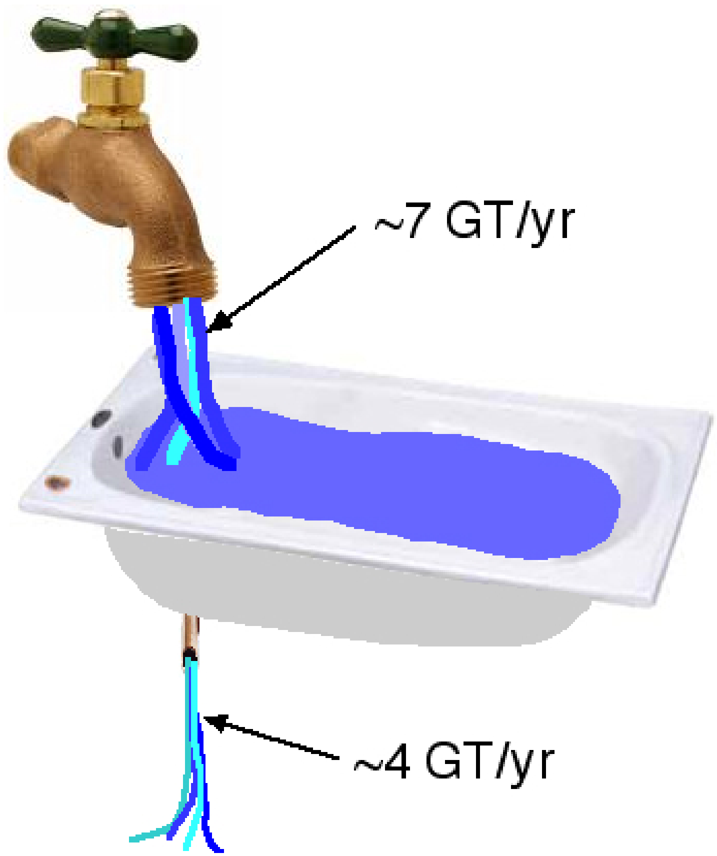
*This is **not** true of carbon dioxide.*

When CO_2 is emitted much of it lasts in the atmosphere for ~100 years. Thus, stabilizing atmospheric *concentrations* of CO_2 will require the world to reduce emissions *by at least 80%.*



A useful analogy is…

…a bath tub with a very large faucet and a much smaller drain:

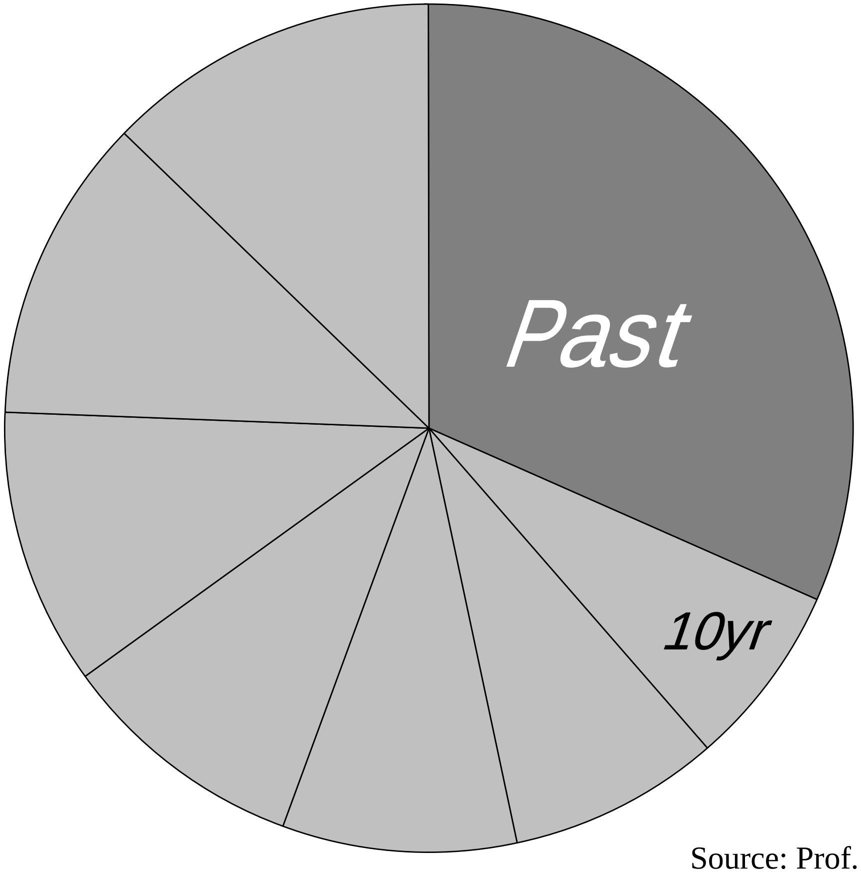


We will run out of atmosphere long before we run out of fossil fuels

Of the 5,000 billion tons of fossil fuels we know about, we have used about 300 billion tons.

900 billion tons C total

to stabilize concentration at 2 x preindustrial



Source: Prof. Klaus Lackner, Columbia University

What can we do to reduce climate change and minimize its adverse effects?

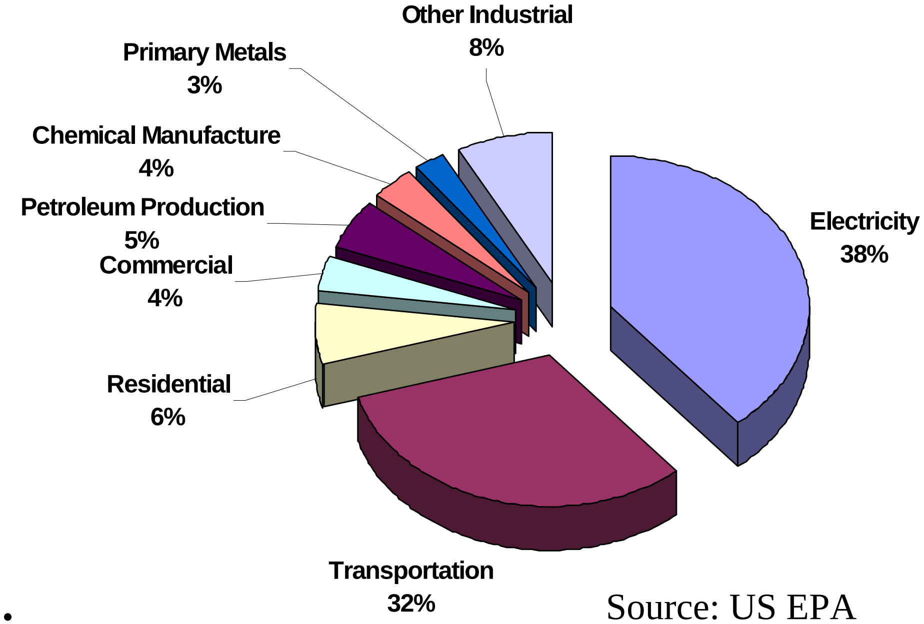
The simple answer is:

1. Reduce future emissions of greenhouse gases - especially CO_2 from burning coal, oil and natural gas.

2. Plan to adapt to the change to which the earth is already committed because of the greenhouse gases that we have already added to the atmosphere.

CO_2 emissions…

…from electric power make up over a third of U.S. emissions from fossil fuel…the largest single source.



Source: US EPA

A variety of strategies are available to reduce these emissions in a cost-effective way:

<u>Today</u>

- Conservation/efficiency
- Fuel switching
- DG w/CHP
- Nuclear
- Wind
- Biomass

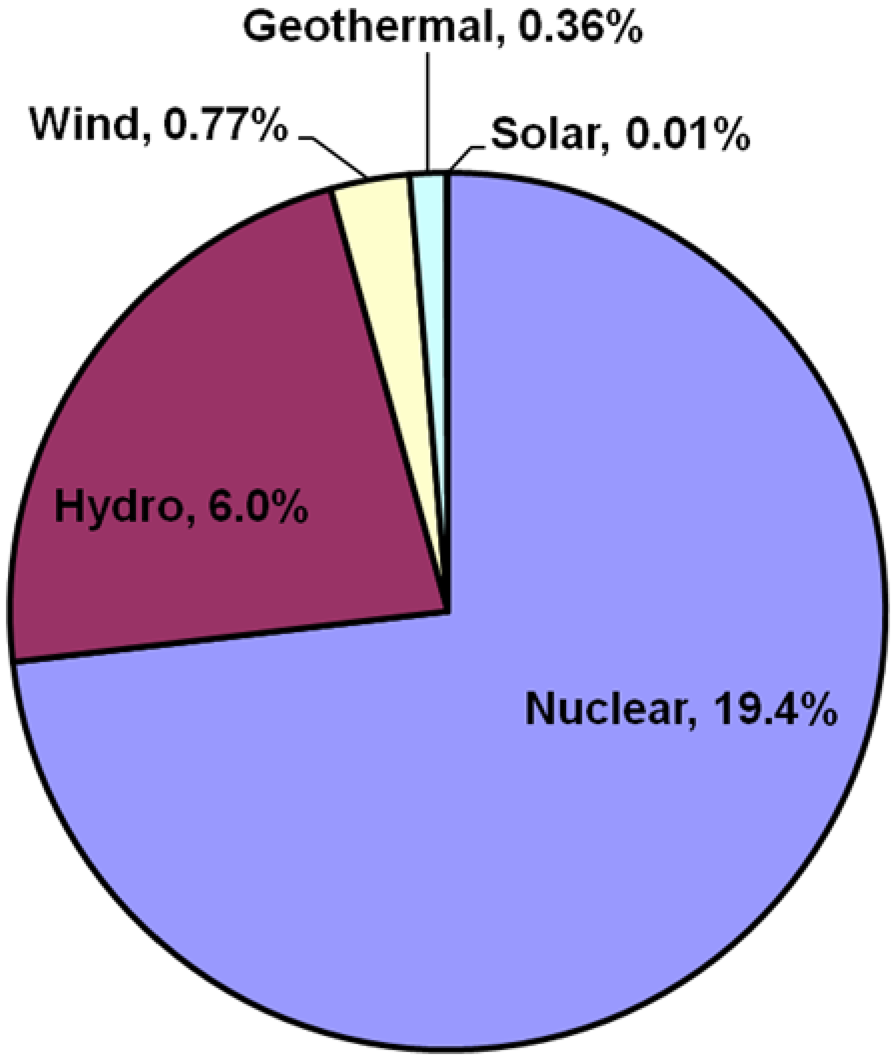
<u>In 5 - 15years</u>

- Coal w/carbon capture and deep geological sequestration
- Solar thermal

<u>>15 years</u>

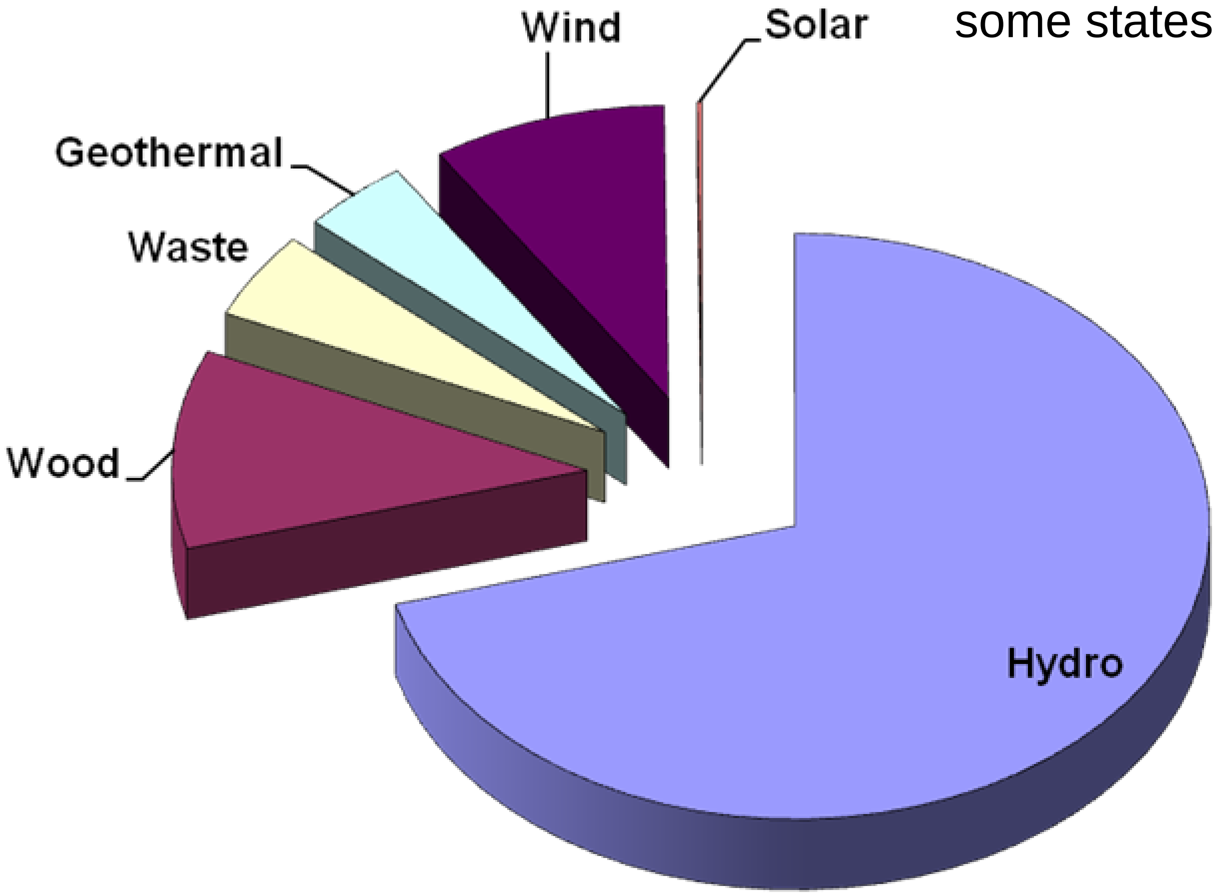
- Solar photovoltaics?
- Others?

Low Carbon Dioxide Electric Power Production in the US in 2007 as a percent of total US electric power production

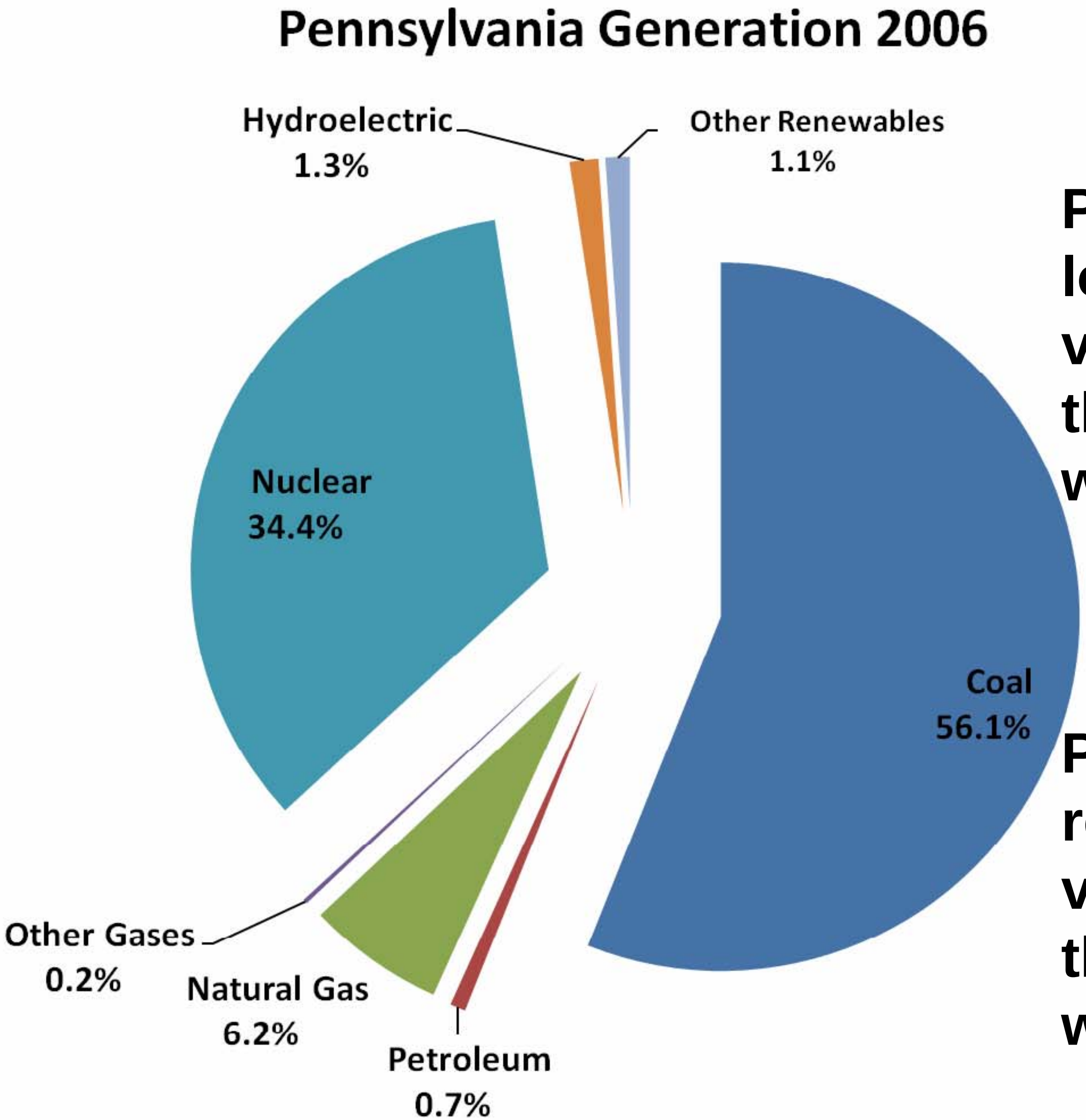


“Low Carbon”
and
“Renewable”
are not the same thing

US "Renewables" Net Generation 2007
8.4% of total electric net generation



Large Hydro,
Waste, and Wood are not considered “renewable” in some states



PA is 37% low carbon, vs. 26% for the US as a whole

PA is 2.4% renewable, vs. 8.4% for the US as a whole

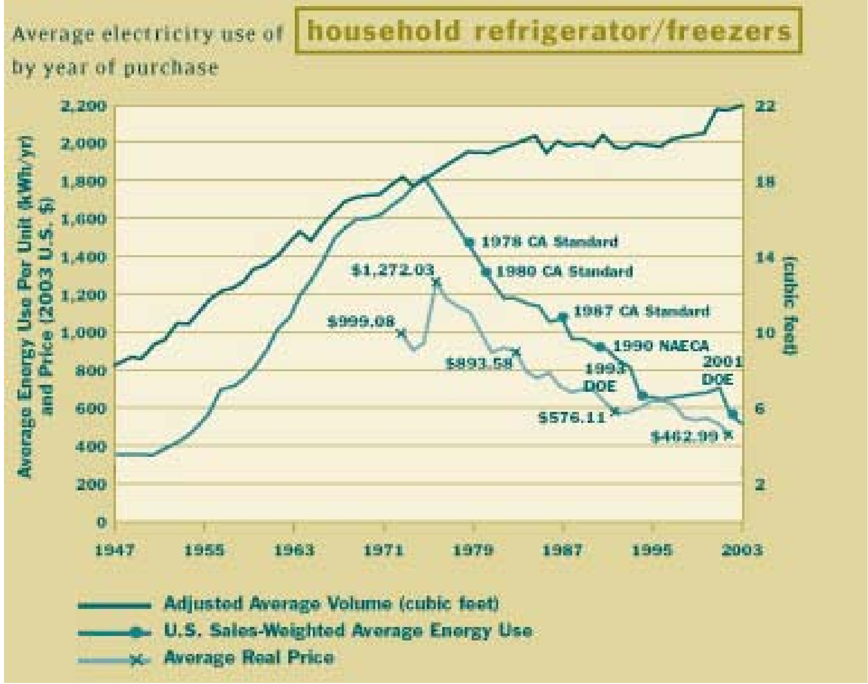
Options to become lower carbon

Conservation

There is an enormous potential to reduce CO_2 emissions through more efficient use of electricity. Many, but by no means all, firms adopt energy efficient technologies as they become cost-effective.

However, regulation and standards are essential, especially in the consumer market.

Consider the case of refrigerators:

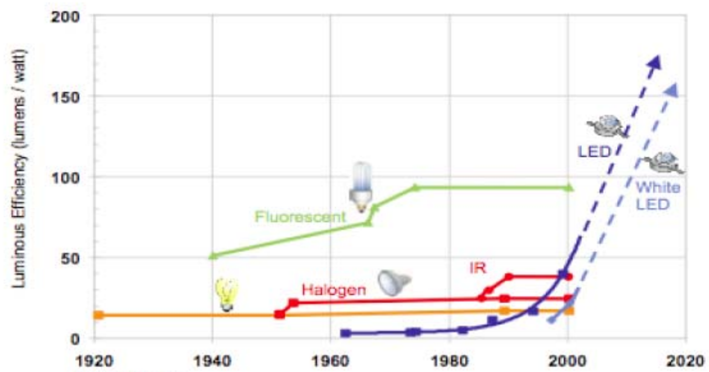


Source: Marilyn Brown, Frank Southworth, and Theresa Stovall, *Towards a Climate Friendly Built Environment*, a Report of the Pew Center on Global Climate Change, 2005.

Conservation/efficiency…(Cont.)

Lighting is 20% of all electricity.

Incandescent bulbs are horribly inefficient. Solid state lighting has great potential.

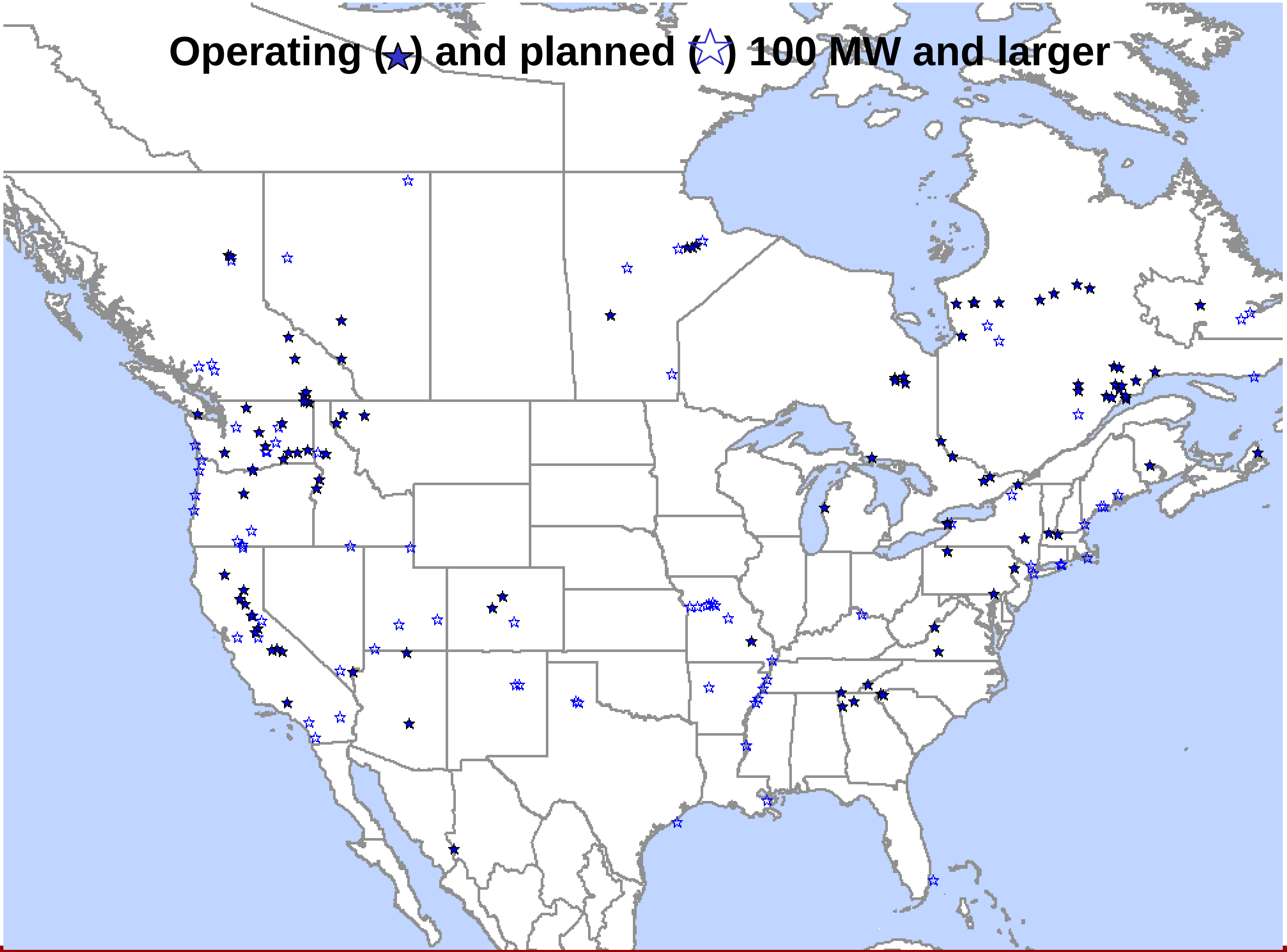


Other examples are power supplies and plasma TVs.

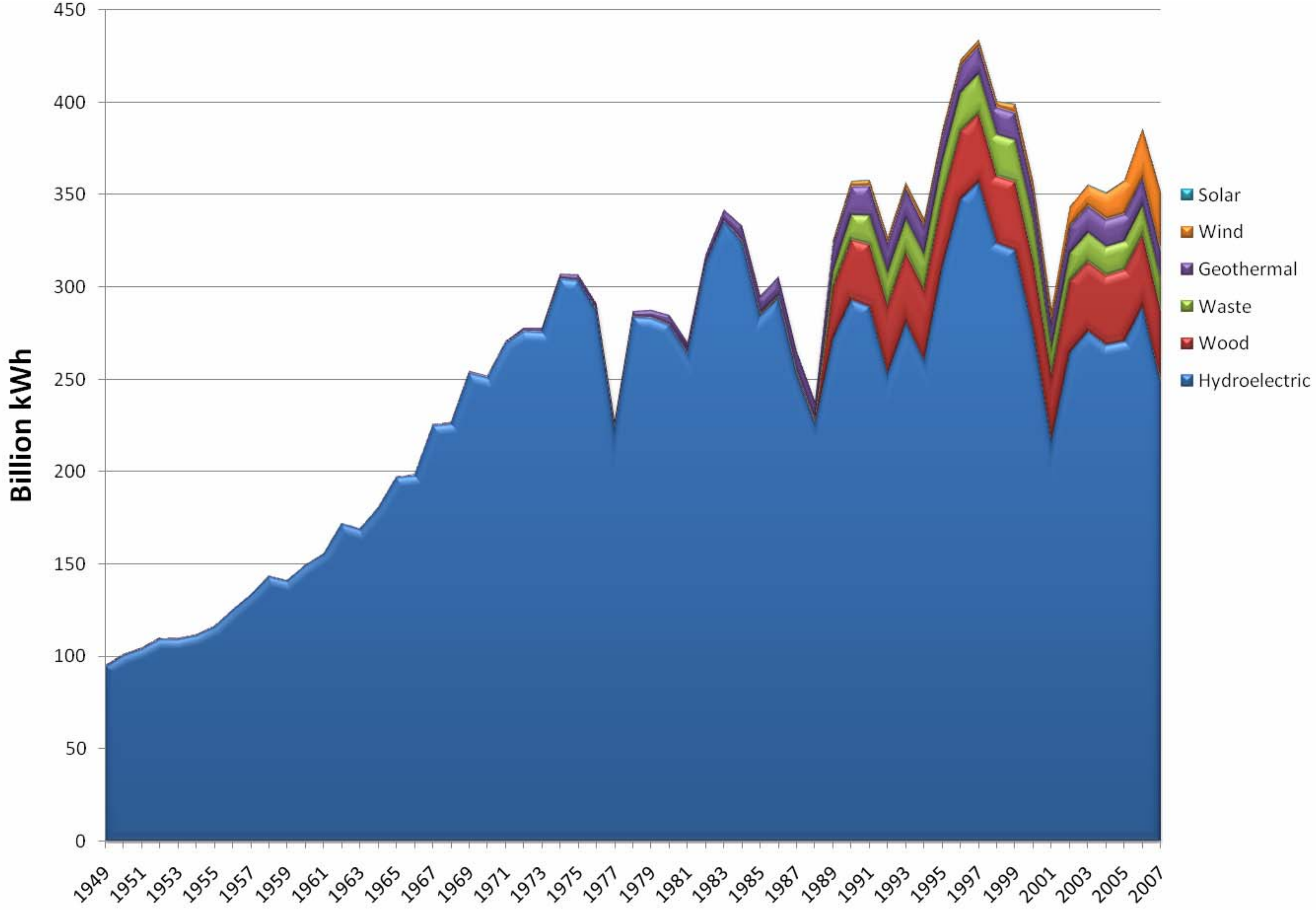
There are a number of State programs promoting end-use efficiency. Vermont and California are two of the best examples.

Sources: lumiled, mobilephoneaccessories, cpamerica & plasmas-direct

Hydroelectric



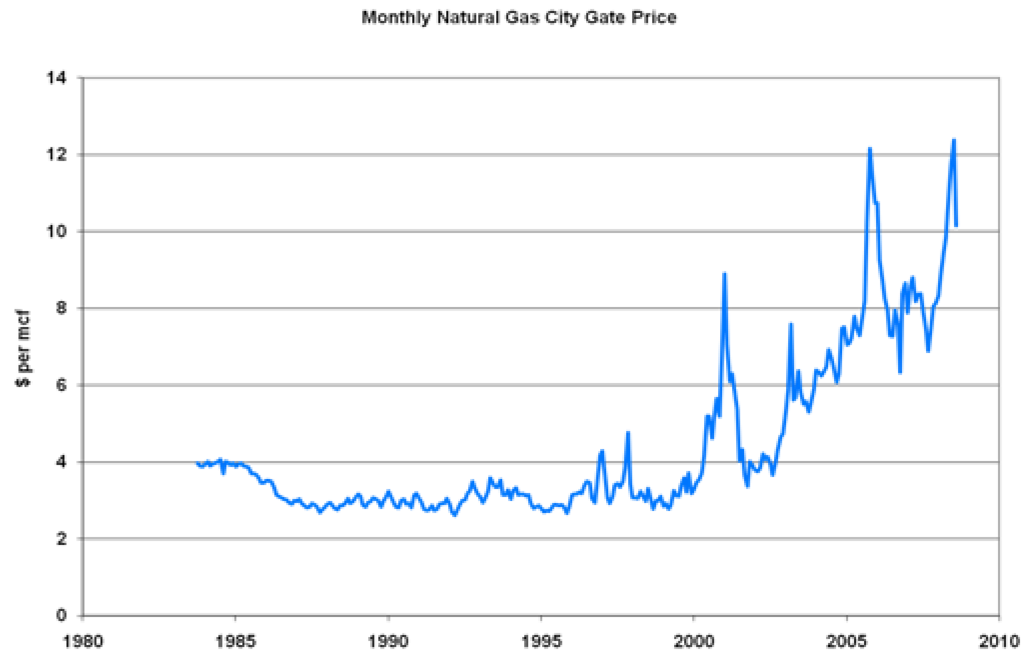
Hydro (and probably wind) have annual variations



Fuel Switching

Today the U.S. makes over half its electricity from coal. Natural gas produces only about half as much CO_2 per kWh of generated electric power as coal.

Thus, switching generation to gas can rapidly reduce emissions. BUT, gas prices have been highly volatile and…



…US supplies are limited.

Combined Heat and Power

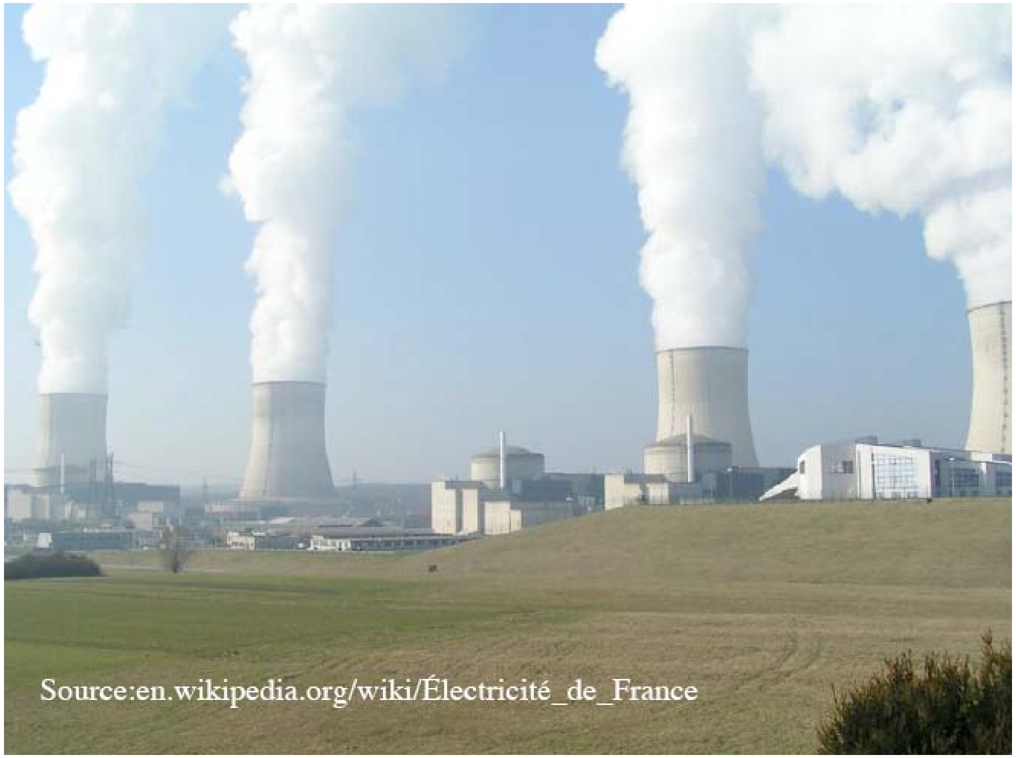
Because these systems use the "waste heat" rather than throwing it away, overall energy efficiency can be ≥80% as opposed to ~40% or less for central station power plants.

Source: Capstone

Source: Siemens

Nuclear

As the French have clearly shown, despite its various issues, nuclear power is capable of serving a nation's electricity needs without CO_2 emissions. About 88% of EdF's electricity is generated in 58 nuclear power plants at 19 different sites.



But before a nuclear renaissance can happen here, cost and performance must be demonstrated.

Source: www.edf.fr/12025m/txt/Homefr/EDFEnergies/Nuclearpower.html

Wind

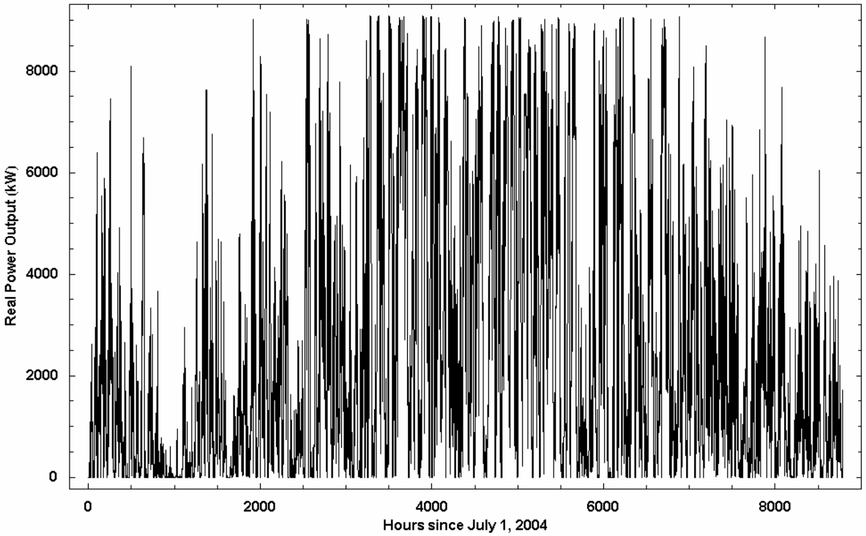
Costs are becoming competitive.

About 1% of U.S. electricity now comes from wind.

One problem is intermittency.

Land use is controversial.

Supplying present US electric needs with wind would require that an area roughly the size of Colorado be used for wind farms.



Source: www.uvi.edu

Transmission

- American Electric Power did a 2008 study for AWEA.
- Forecasts that an investment of $60 billion of transmission projects is required to support a 20% wind RPS.
  - *Interstate Vision for wind Integration*, 2008. American Electric Power and the American Wind Energy Association. Available at http://www.aep.com/about/i765project/docs/WindTransmissionVisionWhitePaper.pdf.

Bottom line on wind

Wind can be a serious contributor to producing low carbon electricity. However, for it to play a major role we will need:

- Fast response hydro (available only in a few places in the U.S.) or pumped hydro (problems with siting). Or, more natural gas with better emissions control.
- Fly wheel storage, battery storage or ultra capacitors.
- Lots of transmission.
- Fast response load control.

All are possible but will take time and will likely limit rate and amount of deployment.

Biomass

While there are a number of power plants that use 100% biomass fuel today, the most promising opportunity in the short run is to mix up to about 10% of biomass with coal in conventional pulverized coal plants, thus achieving about a 10% reduction in net CO_2 emission.

Biomass to liquids

Currently the US is making ethanol from corn. While the net energy balance is weakly positive, this is basically just a big farm subsidy program.

Source: www.usep.edu.ph

Source: usda

Source: Abengoa Bioenergy

A much more promising technology is cellulosic ethanol. This is not yet economic at commercial scale, but lots of investors are making bets.

See: Farrell et al., Science, 2006 Jan 27

Problems are…

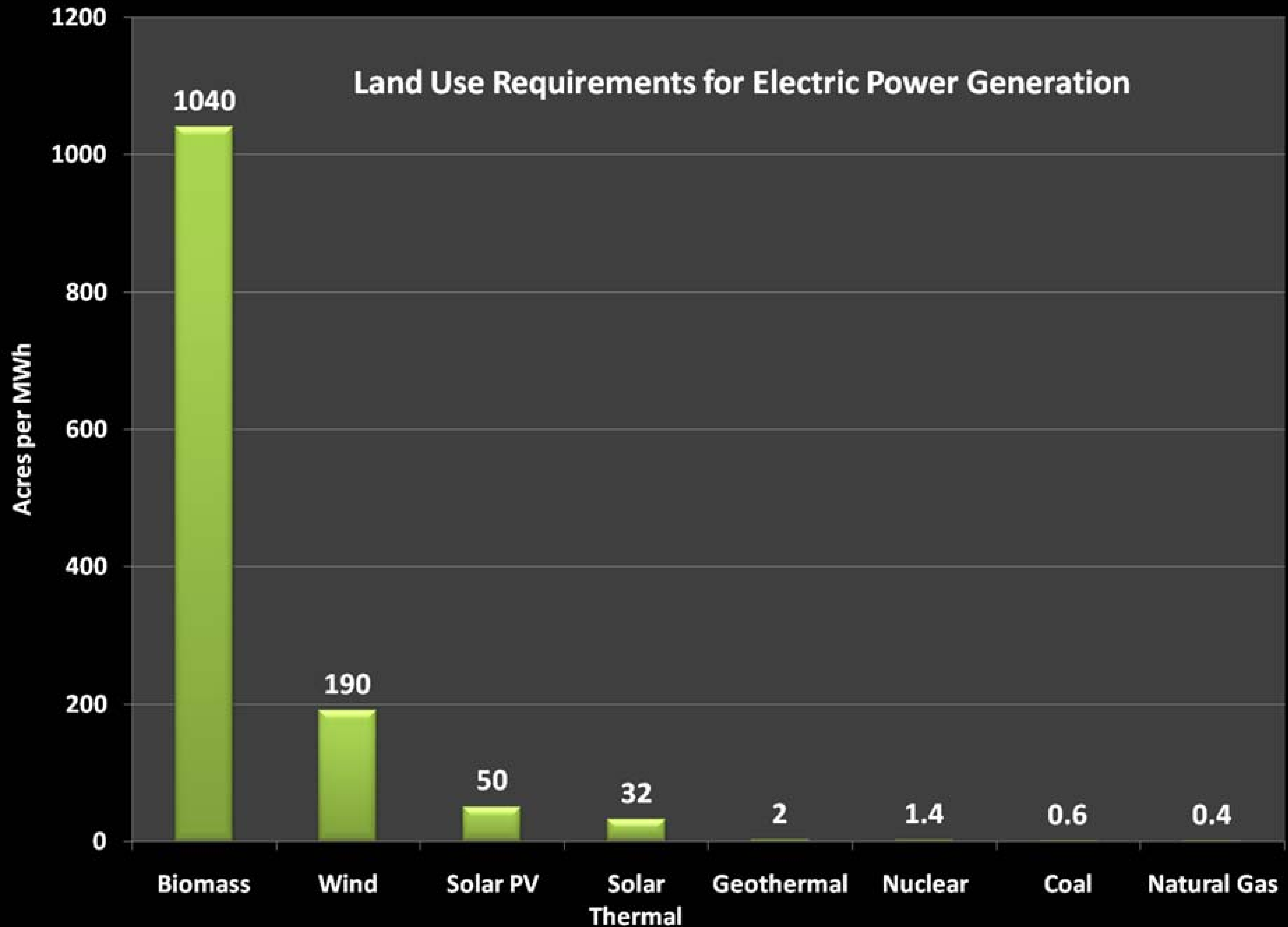
Land use (to power the US auto fleet with cellulosic ethanol need about as much land as is now in crops)

Soil degradation

Impacts on ecosystems

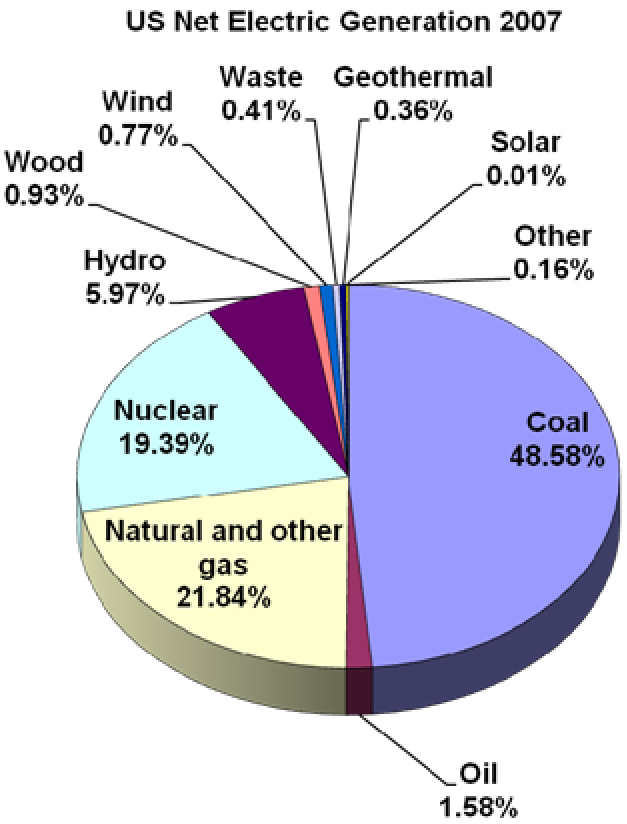
Increase in food prices

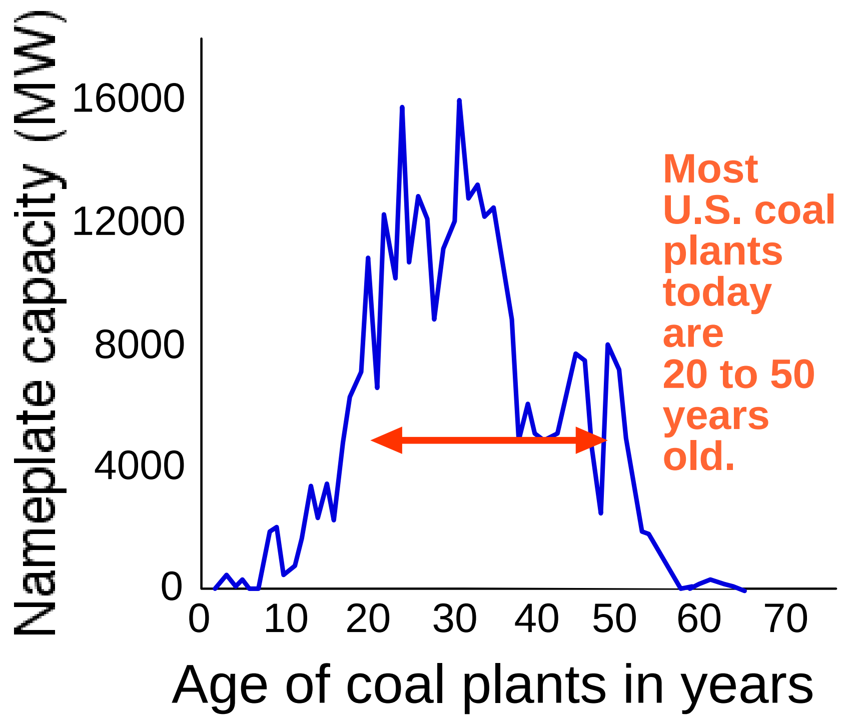
While it can be used for electric power, transportation uses are probably more valuable.



Coal includes surface mining land

The U.S. makes just under half of its electricity from coal





Many coal plants are old and will soon need to be replaced.

CO_2 Capture and Sequestration (CCS)

There are several strategies.

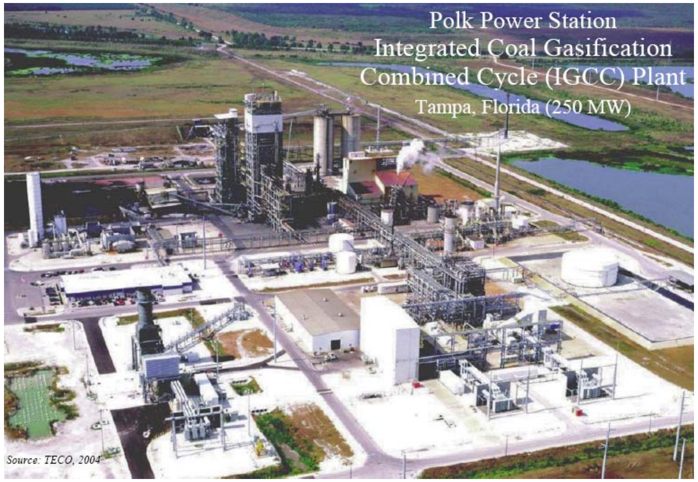
1. Post-combustion separation after combustion in air.

2. Pre-combustion separation.

3. Combustion in oxygen


This is not just pie in the sky
All the pieces exist today at
commercial scale
Sources: www.free-pictures-photos.com and movementbuilding.org

There are two IGCC plants now operating in the U.S.

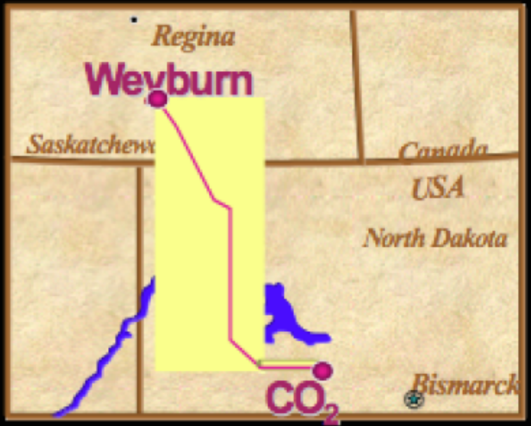


The Wabash Valley Plant in Indiana, 262 MW_e. Repowered an existing old coal unit.

The Tampa Electric Polk Station, 250 MW_e. A new plant.

For details on both plants see: http://www.fe.doe.gov/programs/powersystems/gasification/gasificationpioneer.html

Geological Storage of Captured CO_2 with Enhanced Oil Recovery (EOR)



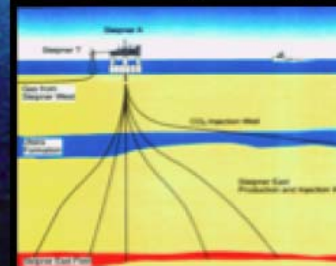
Sources: USDOE; NRDC

E.S. Rubin, Carnegie Mellon

CO_2 Capture from Natural Gas Treatment with Deep Saline Aquifer Storage

Source: Statoil

Sleipner *(Norway)*

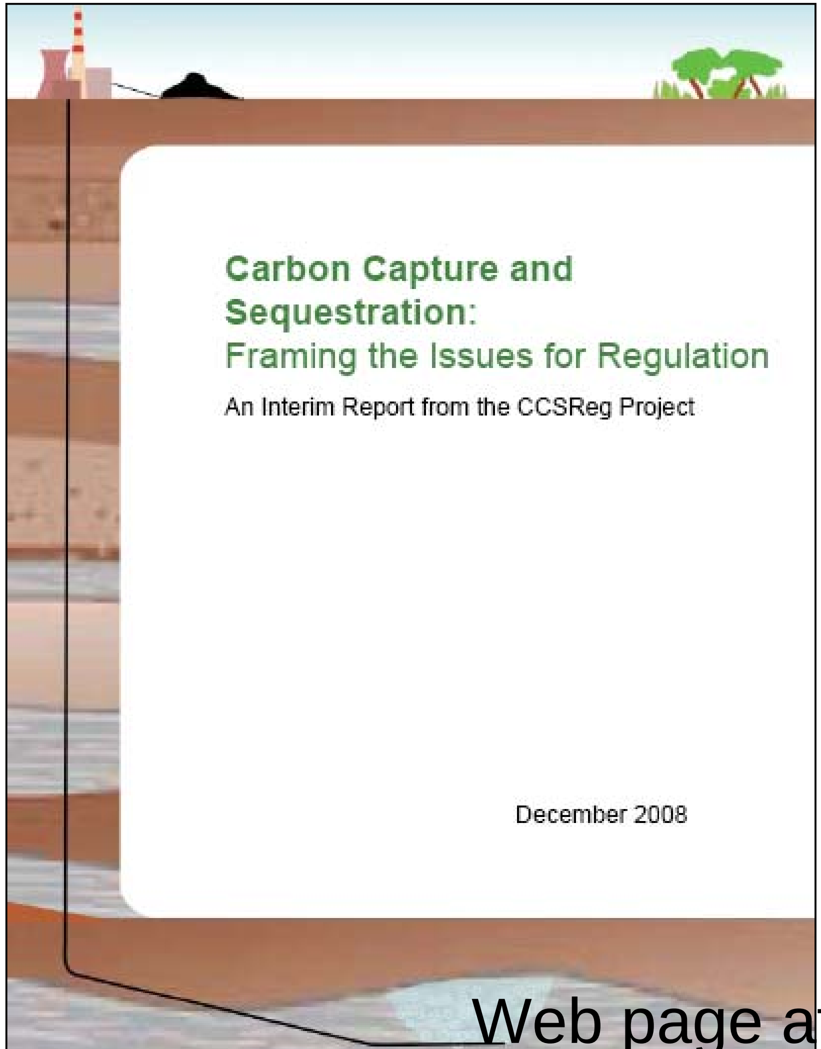


In Salah /Krechba *(Algeria)*

Source: BP

E.S. Rubin, Carnegie Mellon

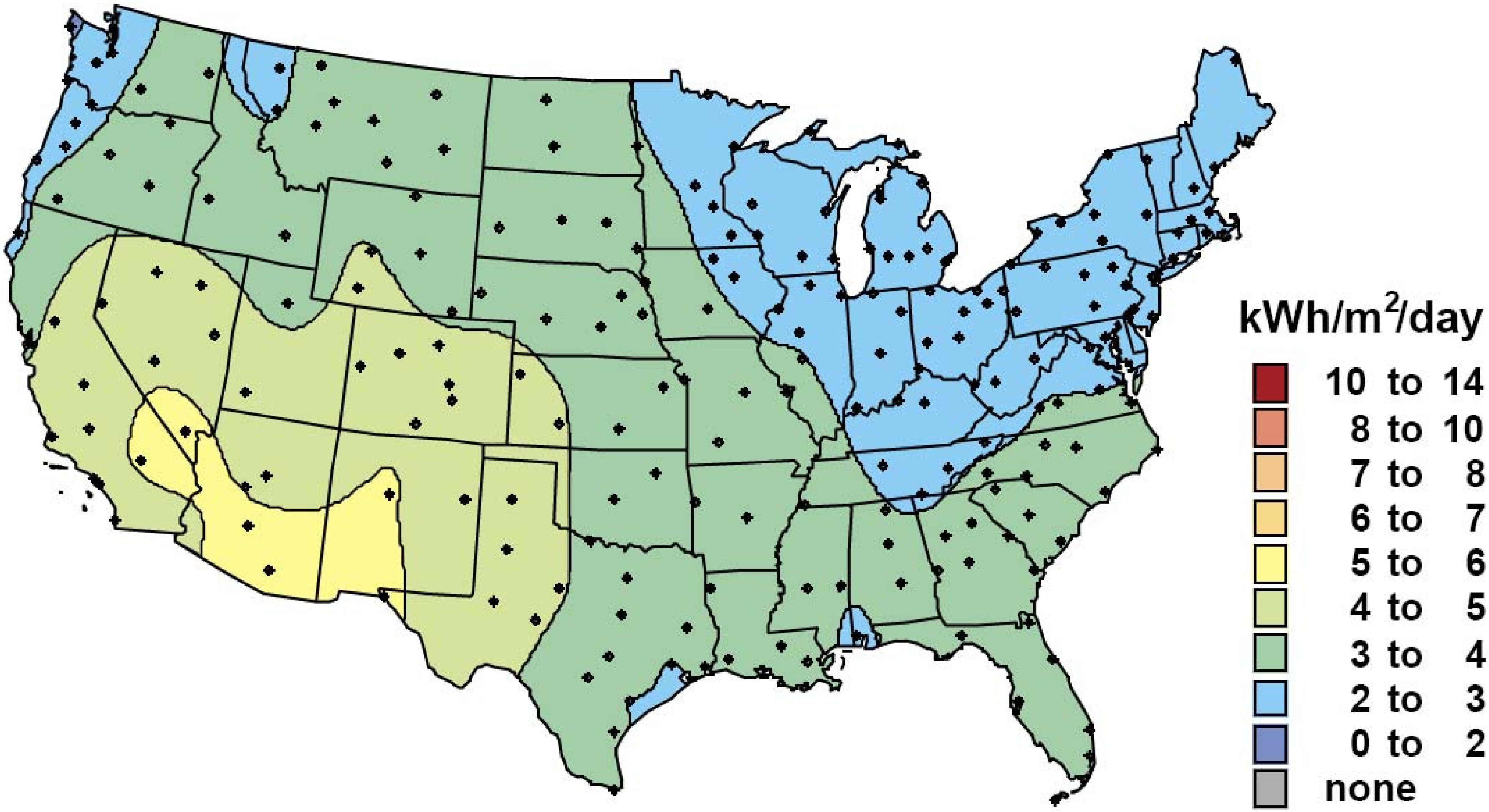
We have been looking at regulatory aspects of where you put the CO2


Carbon Capture and Sequestration:
Framing the Issues for Regulation
An Interim Report from the CCSReg Project

December 2008

Web page at www.CCSReg.org

Solar



Source: NREL

Solar thermal

Unlike wind, there is *much* more solar energy than humans need. While there are several solar thermal power plants now operating, and more in development, it is not yet clear how economical they will prove to be. Especially in Pennsylvania.

Solar Photovoltaic

The problem is cost - both the cost of the cells, and also the cost of the "balance of system" (which today is half the total cost). Solar is even more intermittent than wind (19% capacity factor in Arizona).

All developed world installations today are *heavily* subsidized.

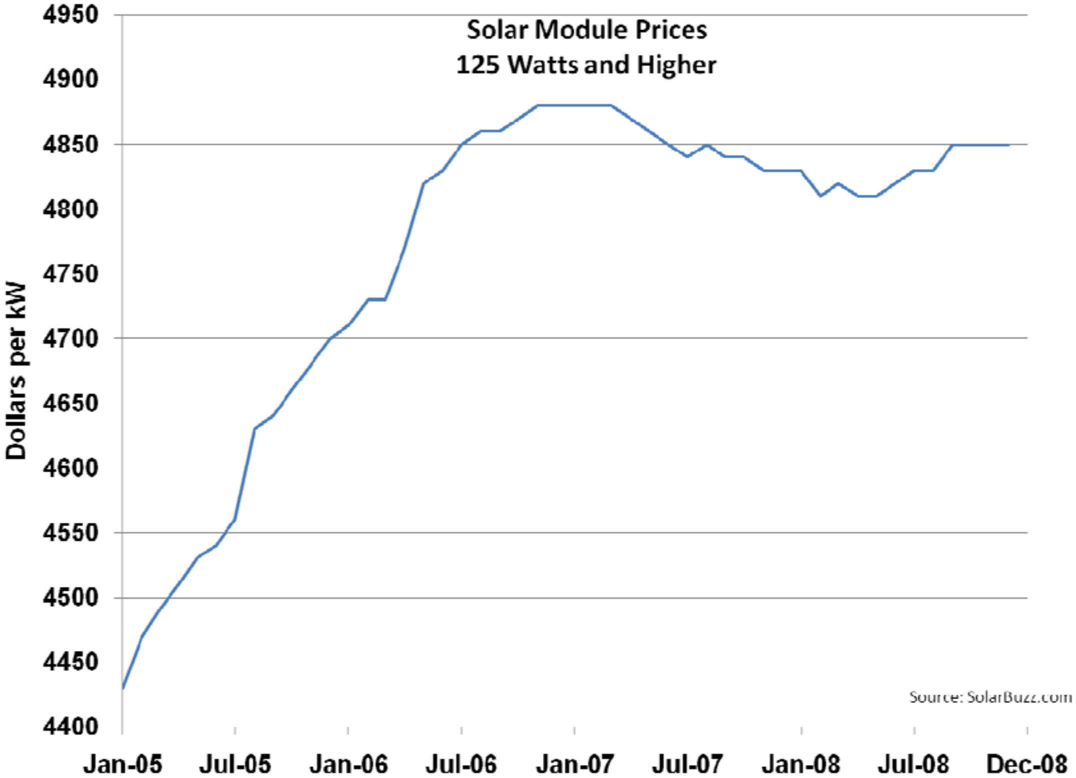
Perhaps research will get prices down to competitive levels, but that will take decades and major innovation.

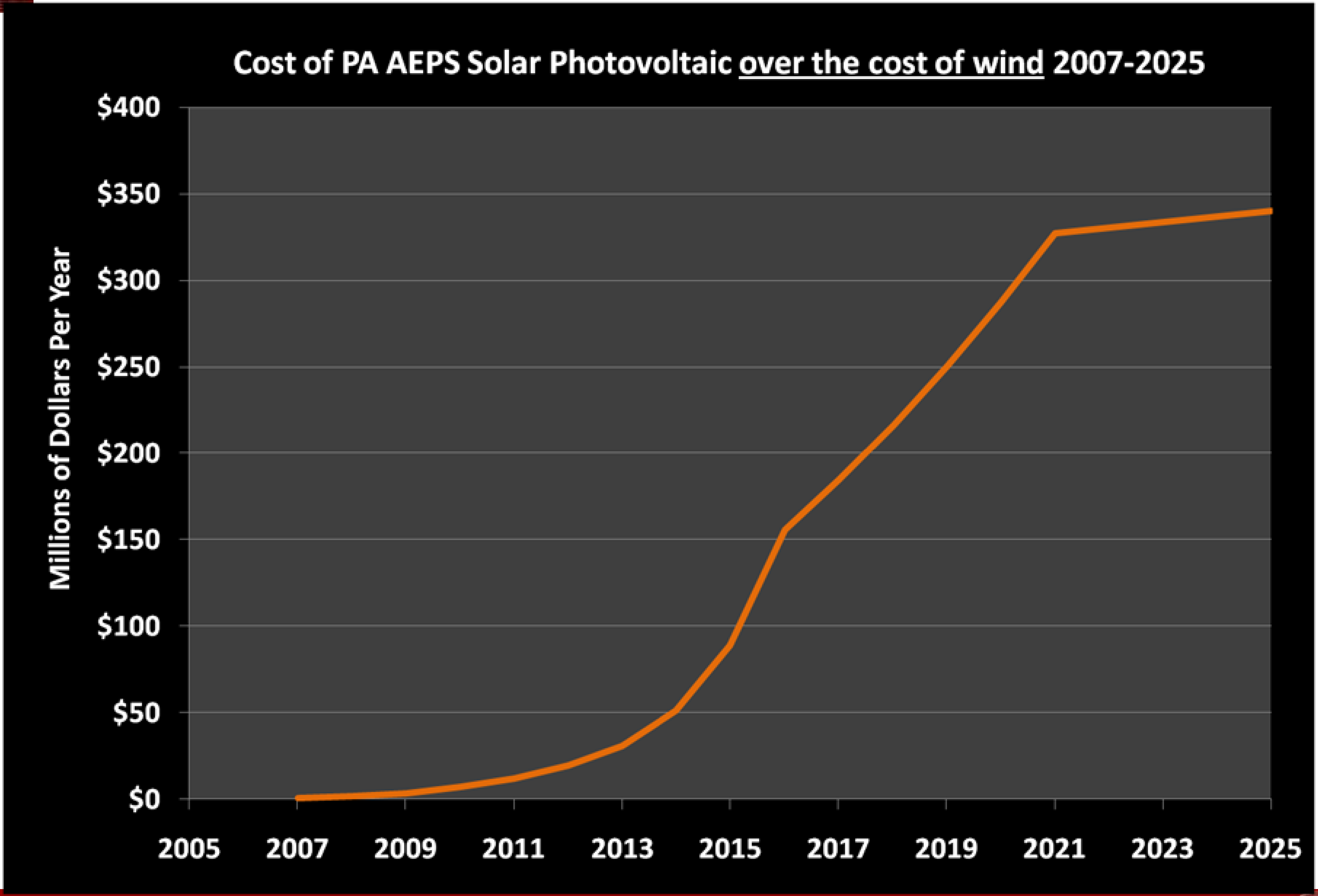
Solar Photovoltaic

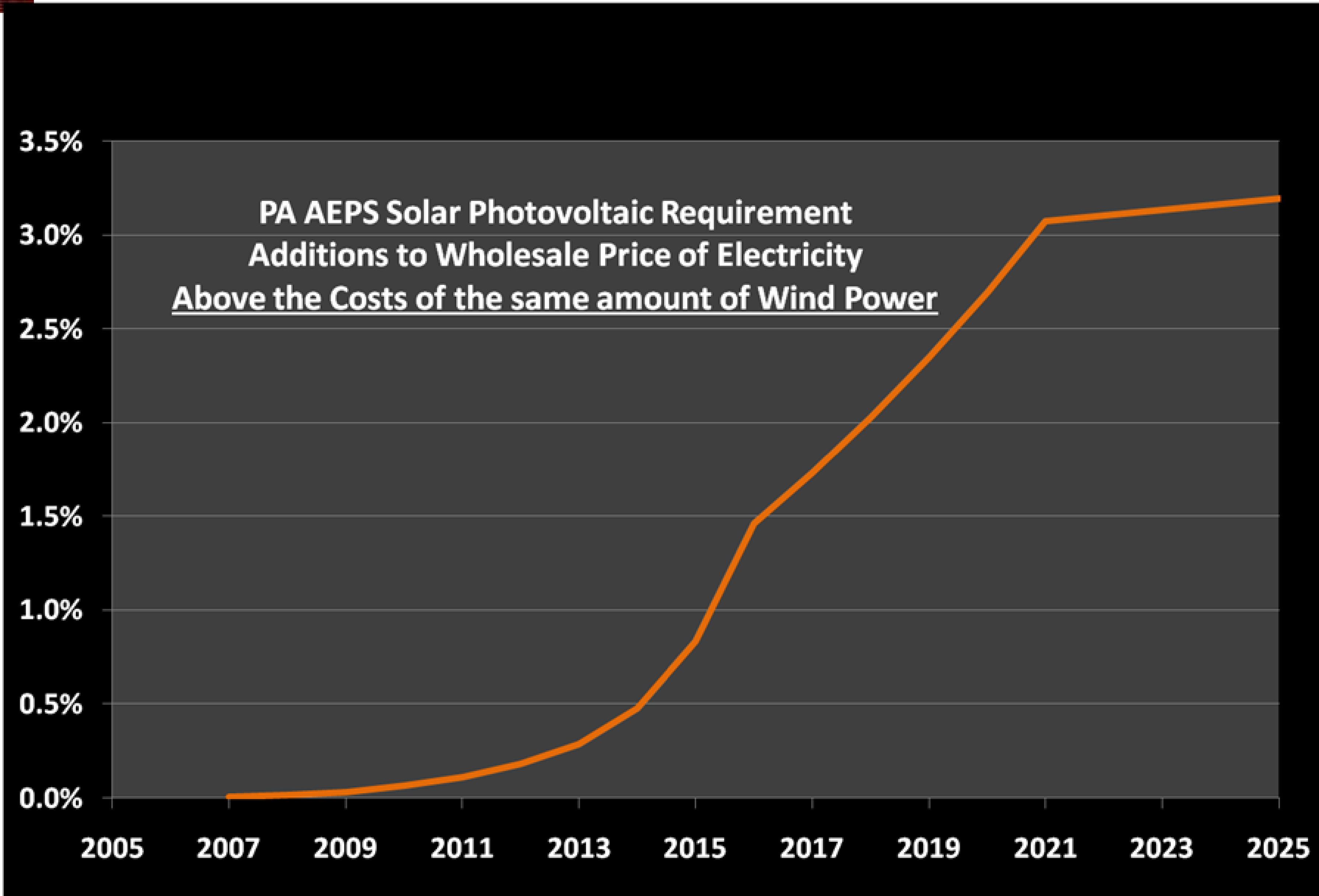
Unsubsidized cost is ~ 45 cents per kWh, 8 times the cost of electricity produced by a conventional coal-fired power plant.

- **Price of solar cells shot up in response to demand, then has not been decreasing much.**

- **Solar cells make up only 50-60% of the system price. The balance has not gotten less expensive.**



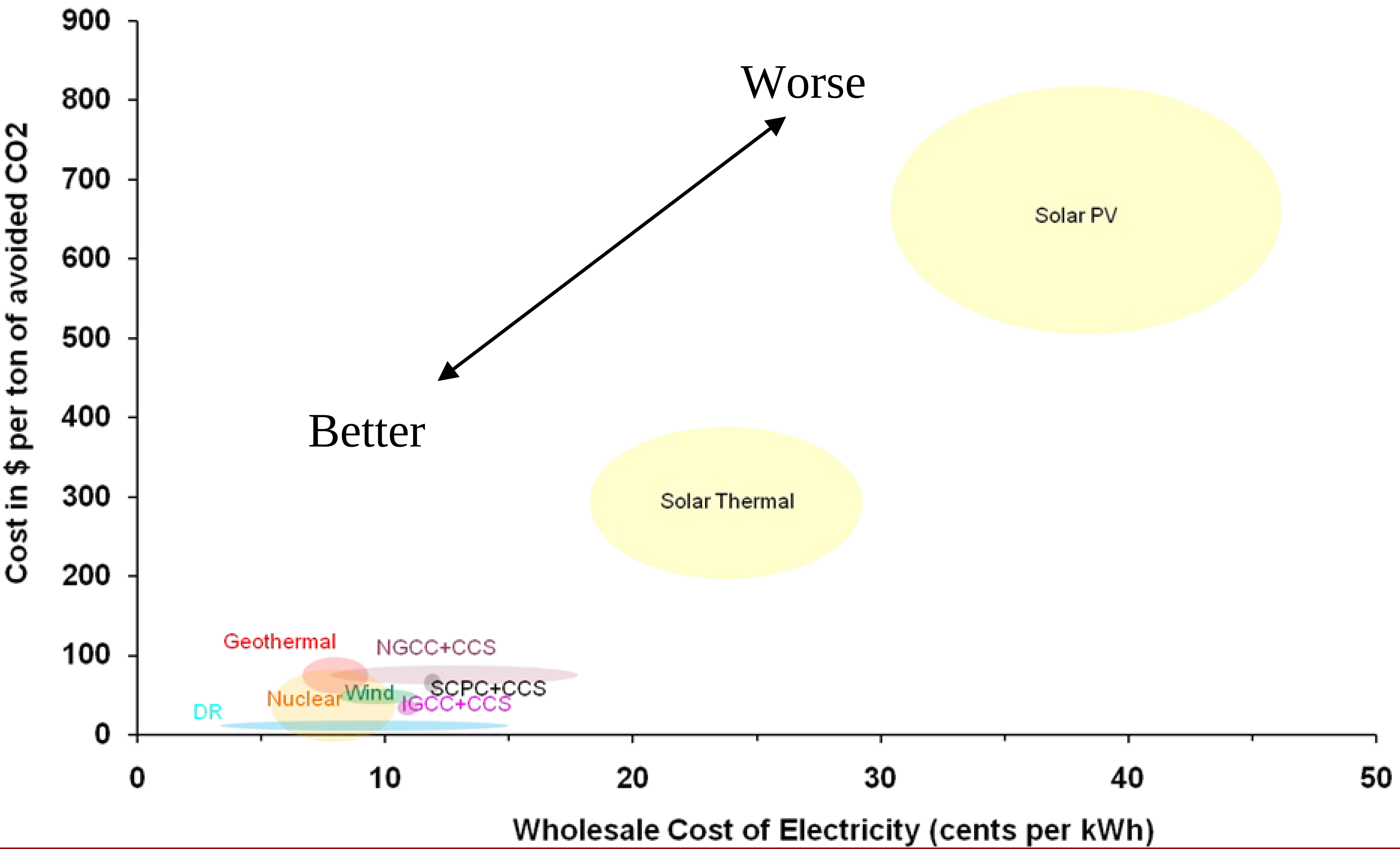

Cost of PA AEPS Solar Photovoltaic over the cost of wind 2007-2025
Millions of Dollars Per Year
$400
$350
$300
$250
$200
$150
$100
$50
$0
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025



PA AEPS Solar Photovoltaic Requirement
Additions to Wholesale Price of Electricity
Above the Costs of the same amount of Wind Power
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025

Can we afford low-carbon electricity?

Cost per ton of CO_2, Cost of electricity



The US electric power sector emits
2.5 billion metric tons of CO_2 per year.
At $35/ tonne: $88 billion.
A 25% increase in what we pay for electricity.

Looked at another way, that $88 B is 0.65% of US GDP.

The EPA's retrospective study on the cost of compliance with the Clean Air Act showed costs peaked in the mid-1970's at 0.65% of that era's GDP.

Clean Water Act costs most likely brought the total to 1.5 - 2 % of GDP.

Thank You!

Questions?

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