



# **Sector Overview**

# **Electricity and Climate in Pennsylvania**

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**Carnegie Mellon University**

**January 22, 2009**

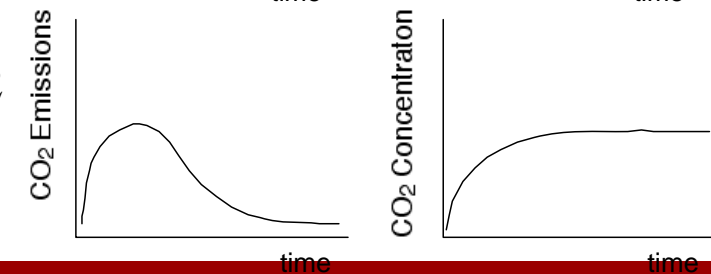
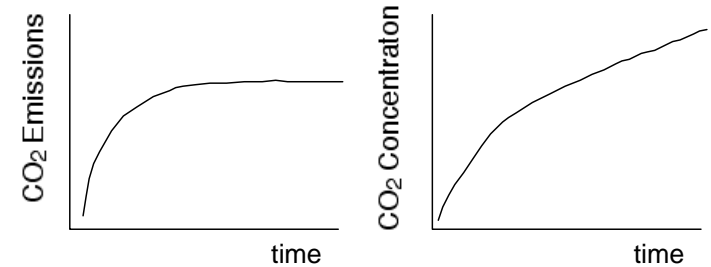
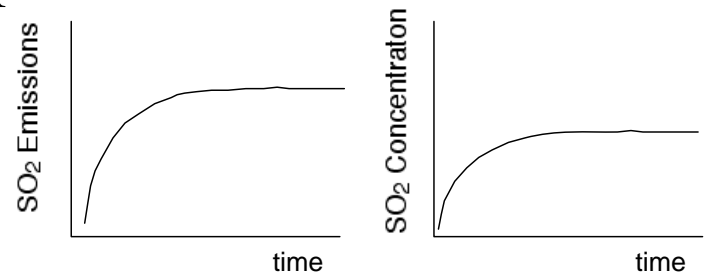


# CO<sub>2</sub> and most other greenhouse gases are not like conventional air pollutants

Conventional pollutants like SO<sub>2</sub> or NO<sub>x</sub> 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.

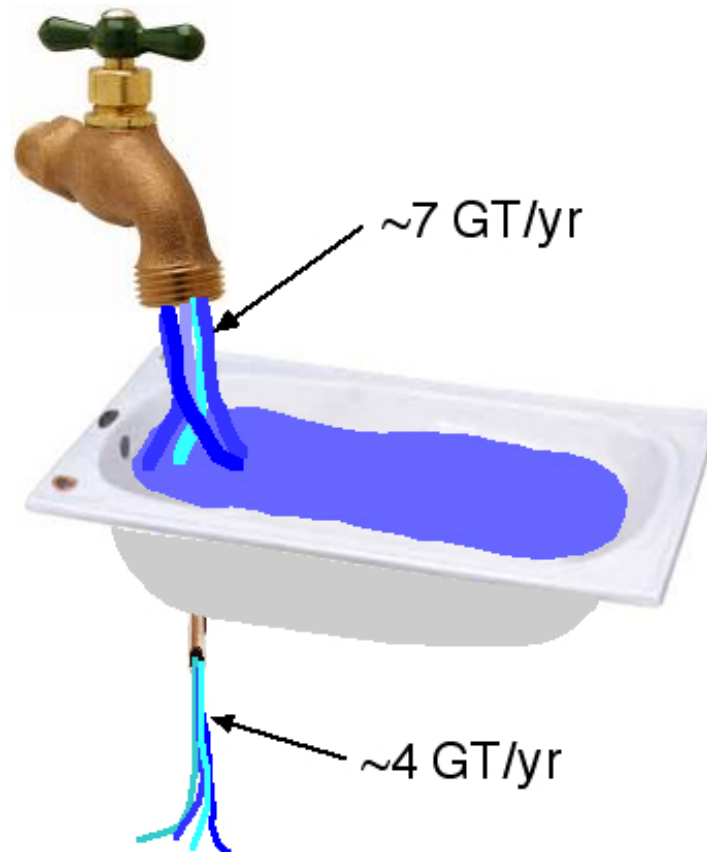
*This is **not** true of carbon dioxide.*

When CO<sub>2</sub> is emitted much of it lasts in the atmosphere for ~100 years. Thus, stabilizing atmospheric *concentrations* of CO<sub>2</sub> will require the world to reduce emissions *by at least 80%*.



# A useful analogy is...

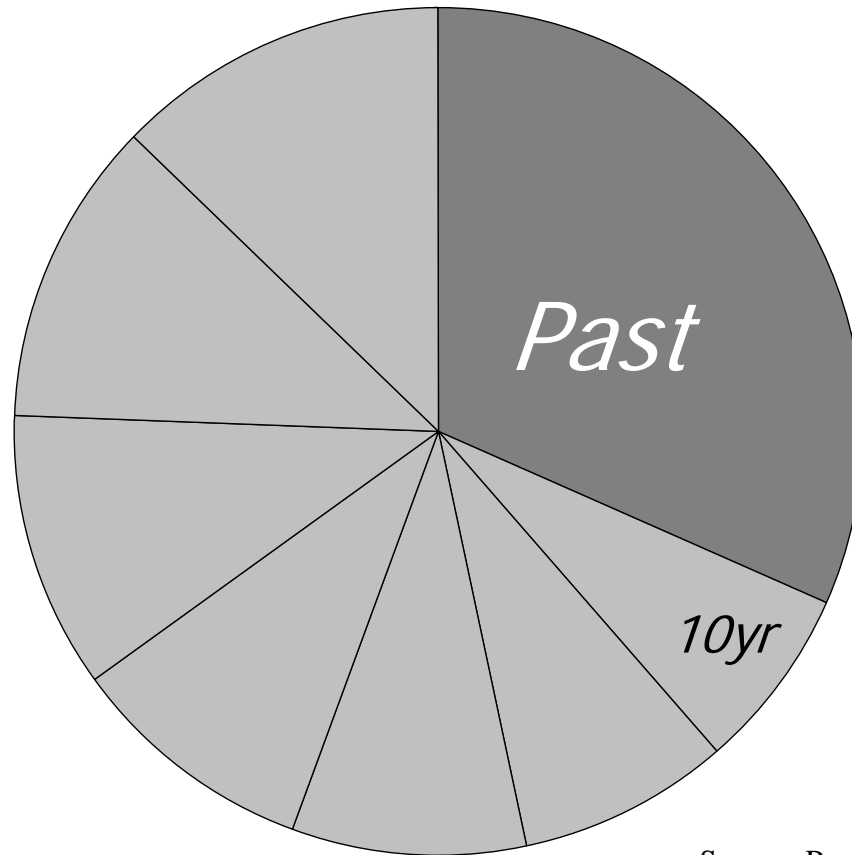
...a bath tub with a very large faucet and a much smaller drain:



# 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<sub>2</sub> 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<sub>2</sub> emissions...

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

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

## Today

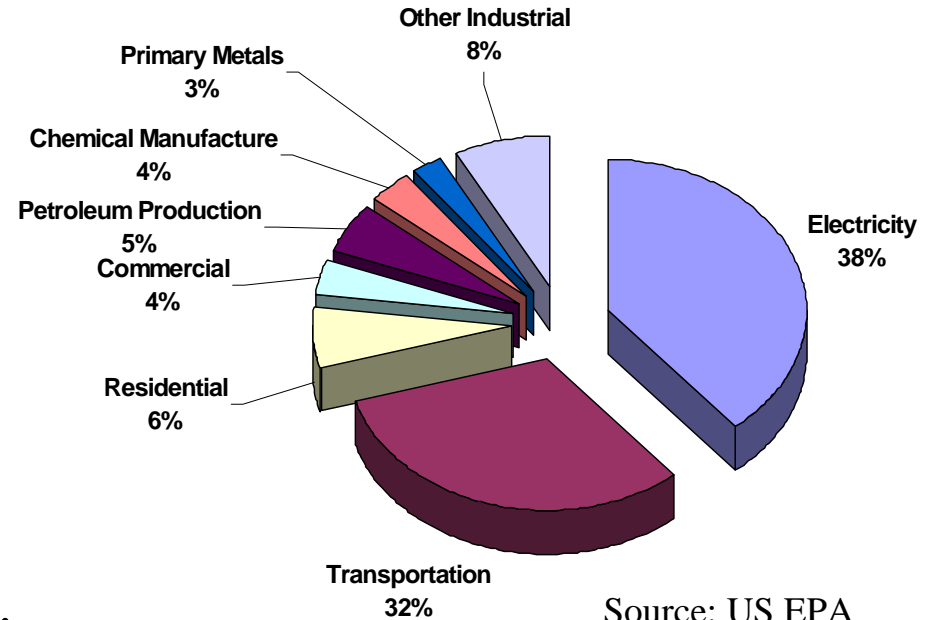
- Conservation/efficiency
- Fuel switching
- DG w/CHP
- Nuclear
- Wind
- Biomass

## In 5 - 15 years

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

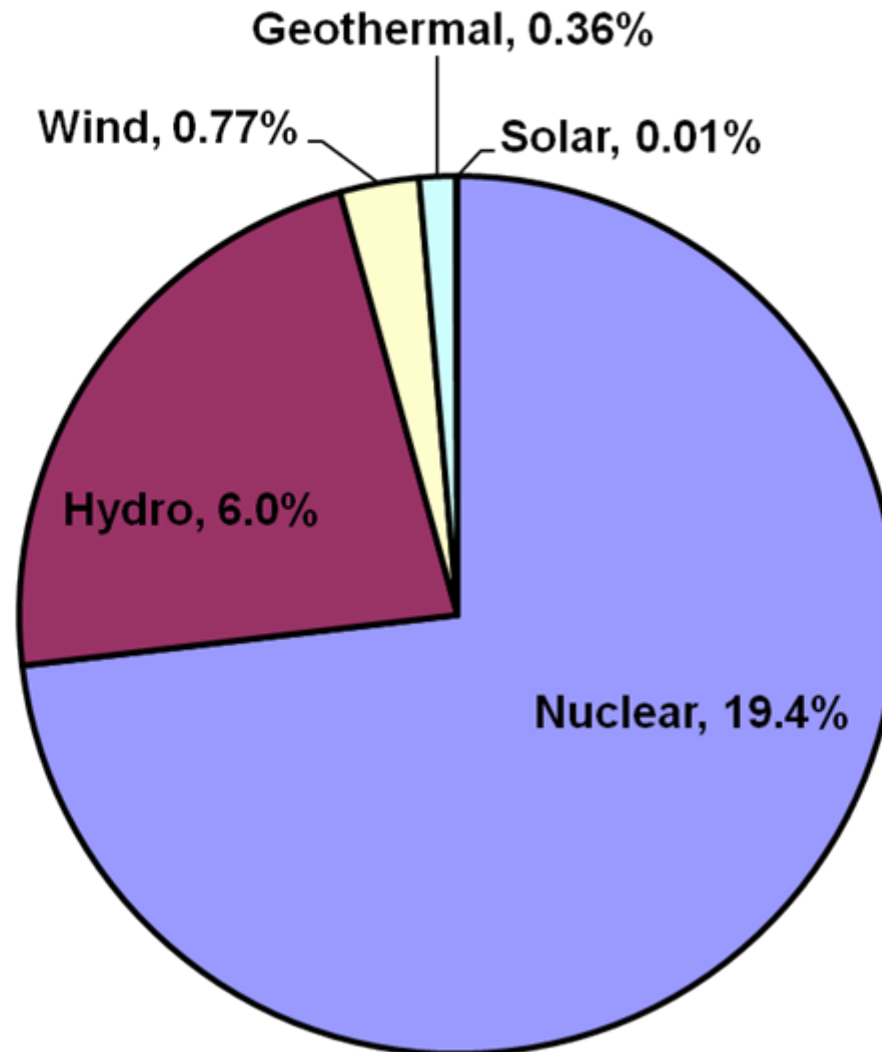
## >15 years

- Solar photovoltaics?
- Others?





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





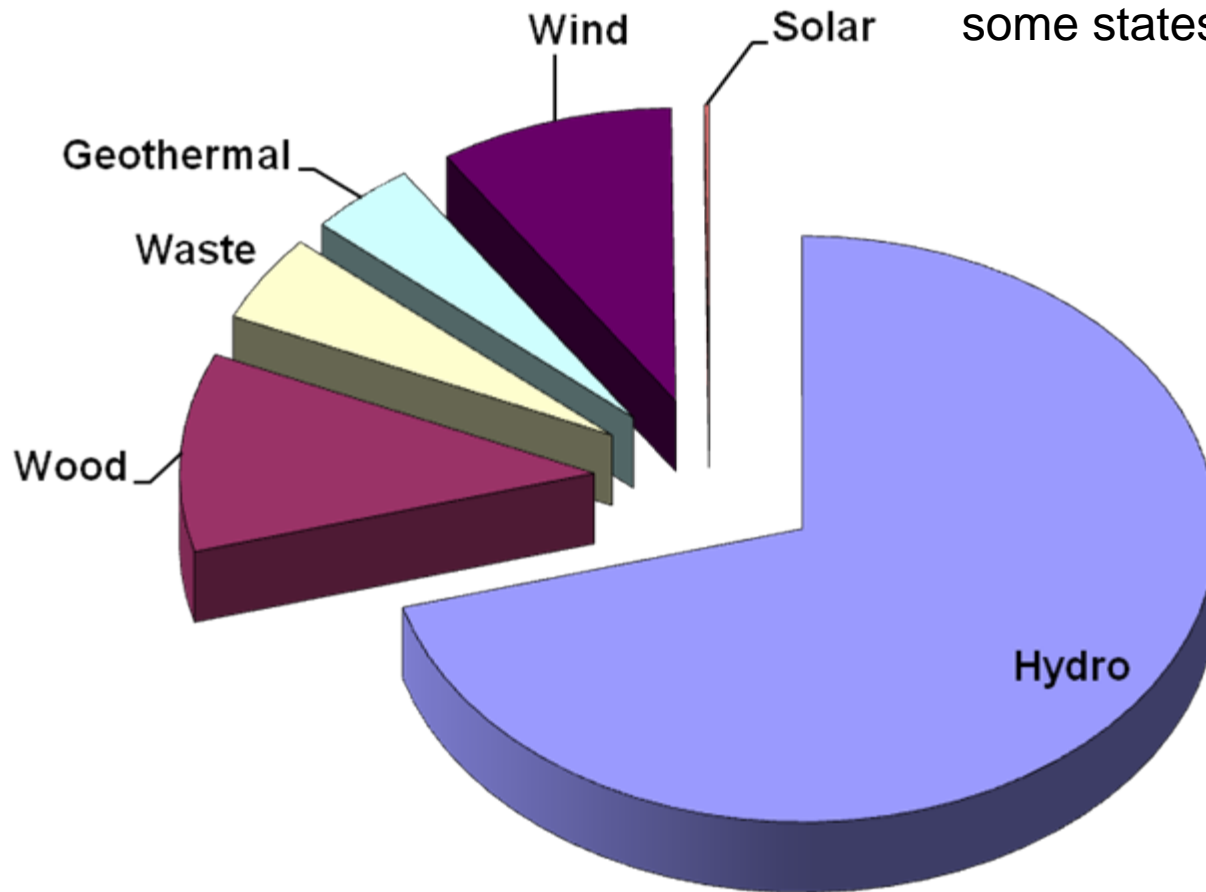


**“Low Carbon”  
and  
“Renewable”  
are not the same thing**



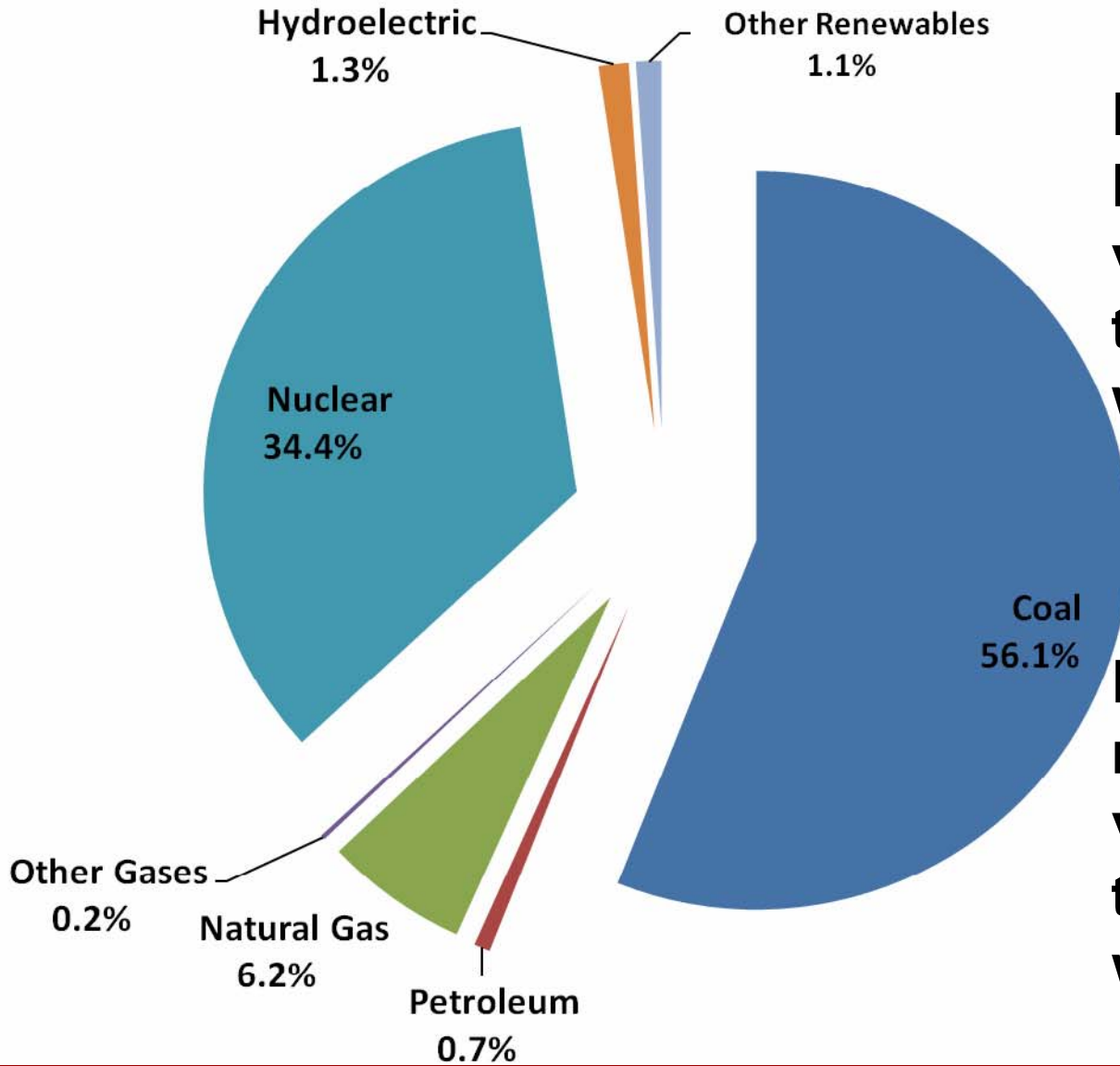
# US "Renewables" Net Generation 2007 8.4% of total electric net generation

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





# Pennsylvania Generation 2006



**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**





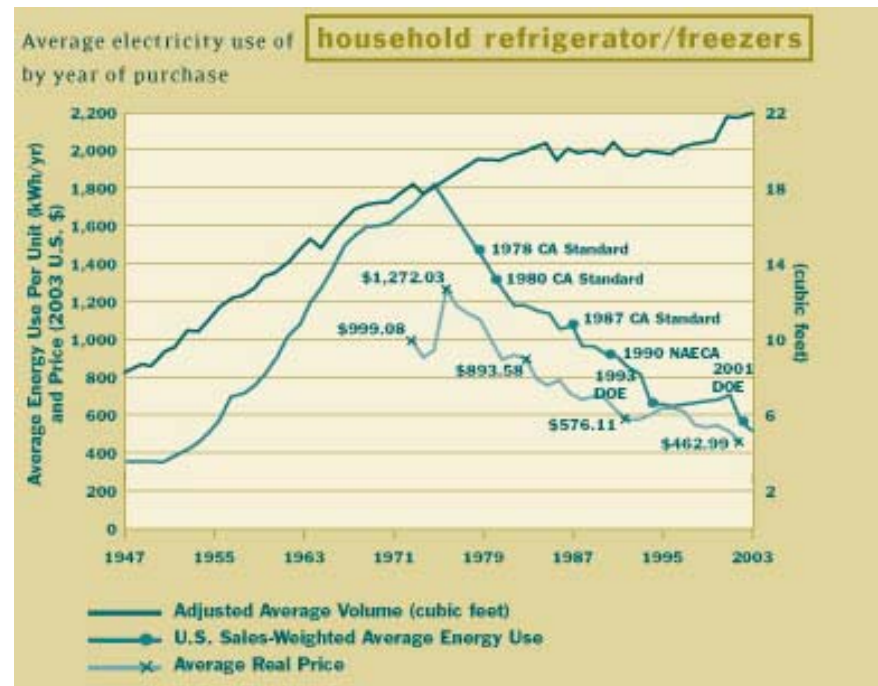
# Options to become lower carbon

# Conservation

There is an enormous potential to reduce CO<sub>2</sub> 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:

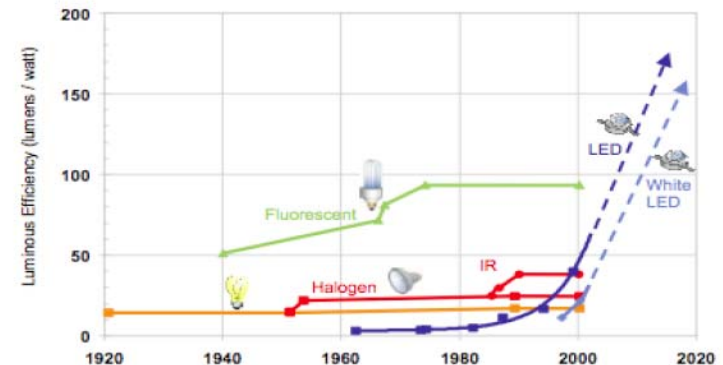


Source: Marilyn Brown, Frank Southworth, and Theresa Stovall, *Towards a Climate Friendly Built Environment*, a Report of the Pew Center on Global Climate Change, 2005.

# 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.

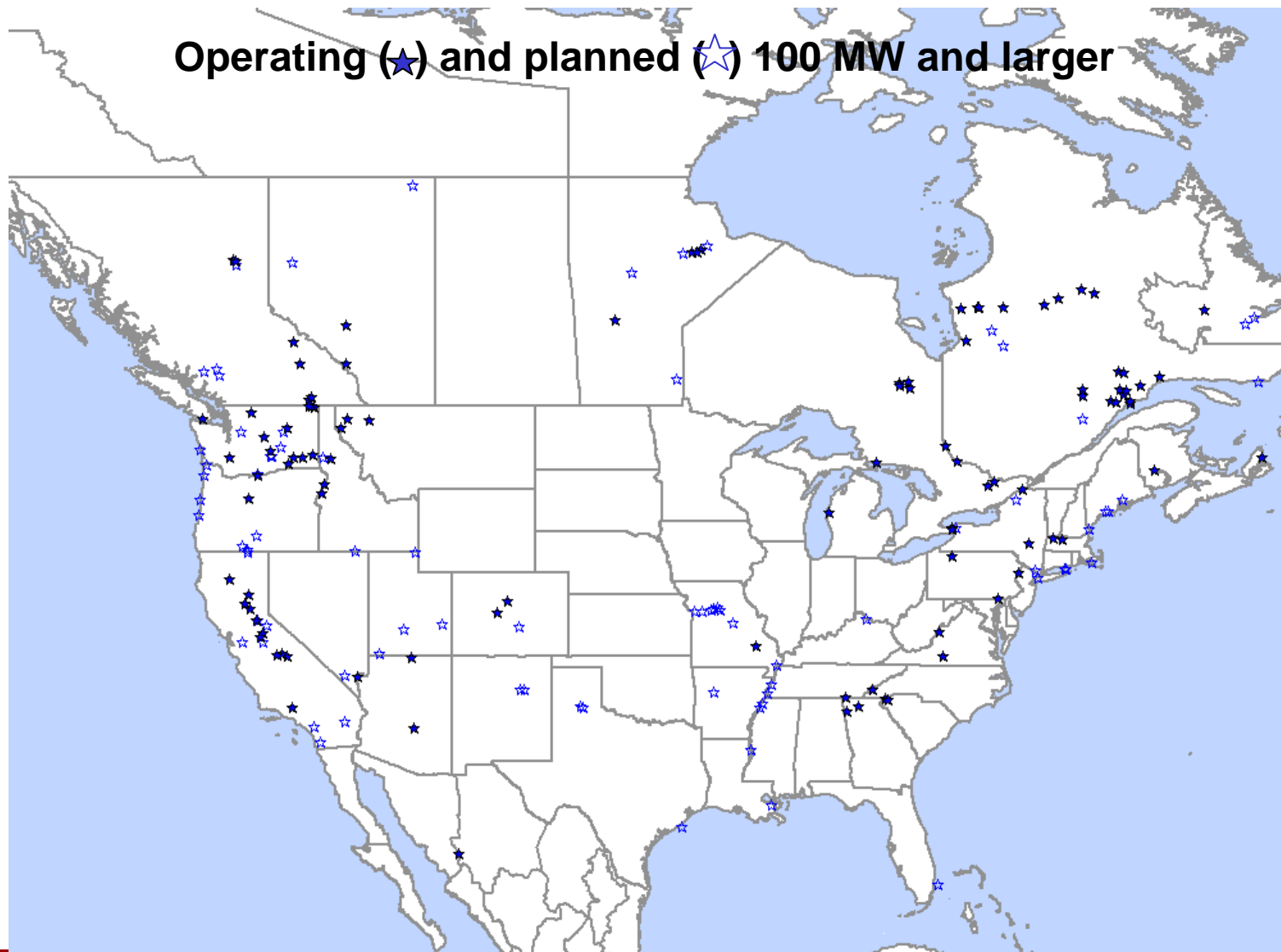


There are a number of State programs promoting end-use efficiency. Vermont and California are two of the best examples.

Sources: lumiled, mobilephoneaccessories, cpamerica & plasmas-direct

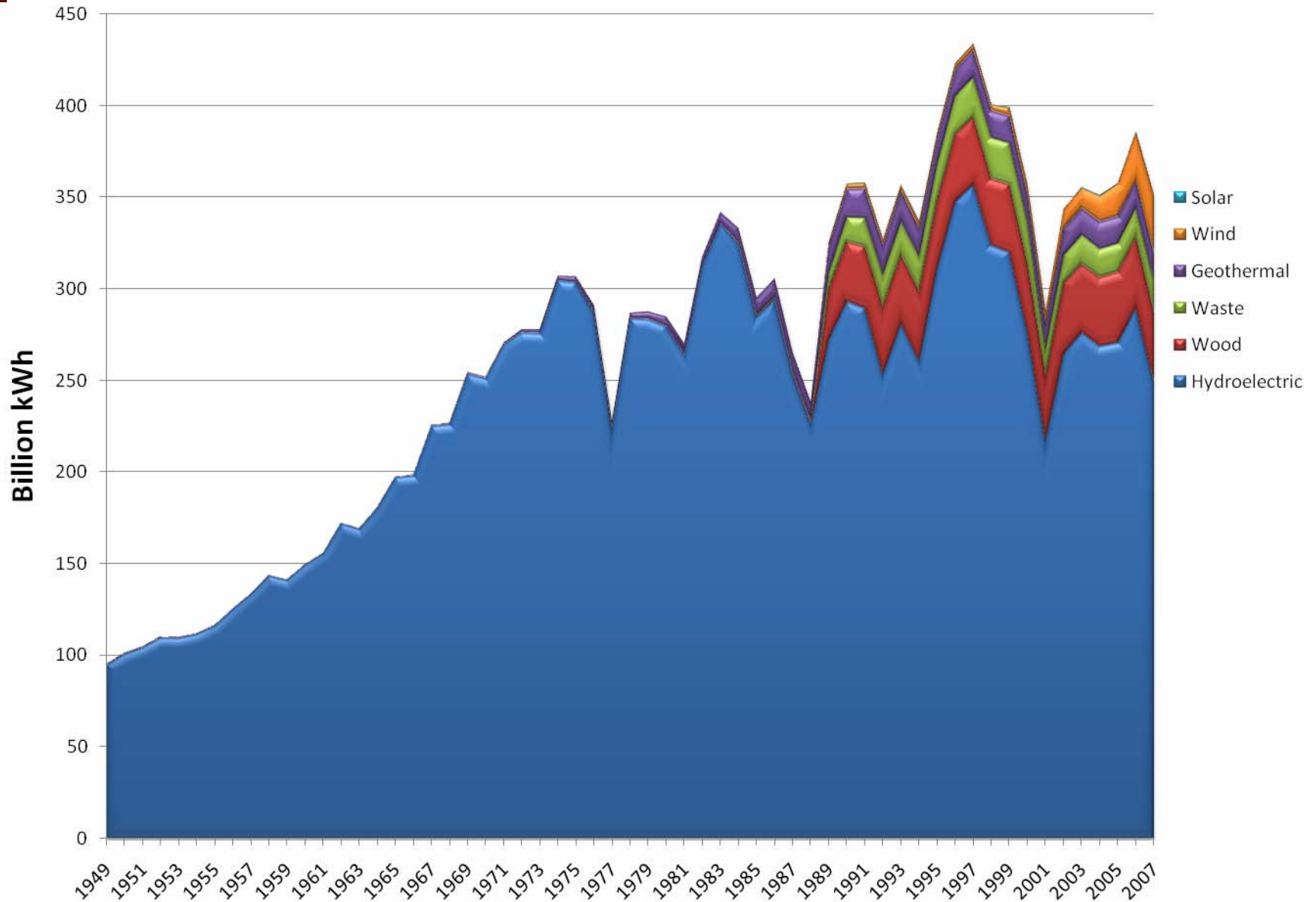


# Hydroelectric





# Hydro (and probably wind) have annual variations

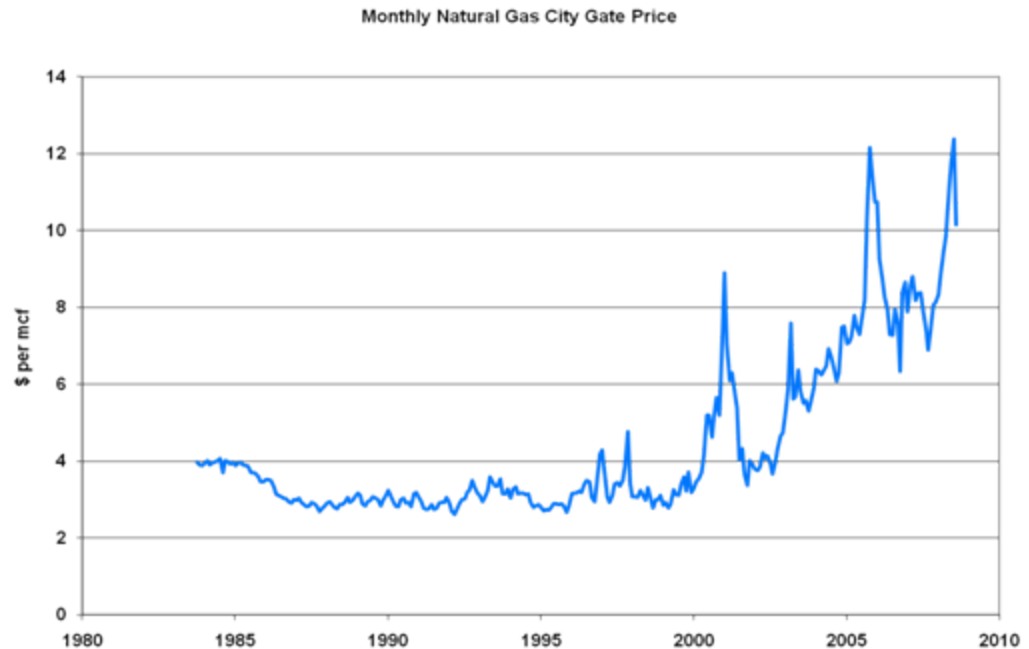




# Fuel Switching

Today the U.S. makes over half its electricity from coal. Natural gas produces only about half as much CO<sub>2</sub> 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  $\geq 80\%$  as opposed to  $\sim 40\%$  or less for central station power plants.



Source: Capstone

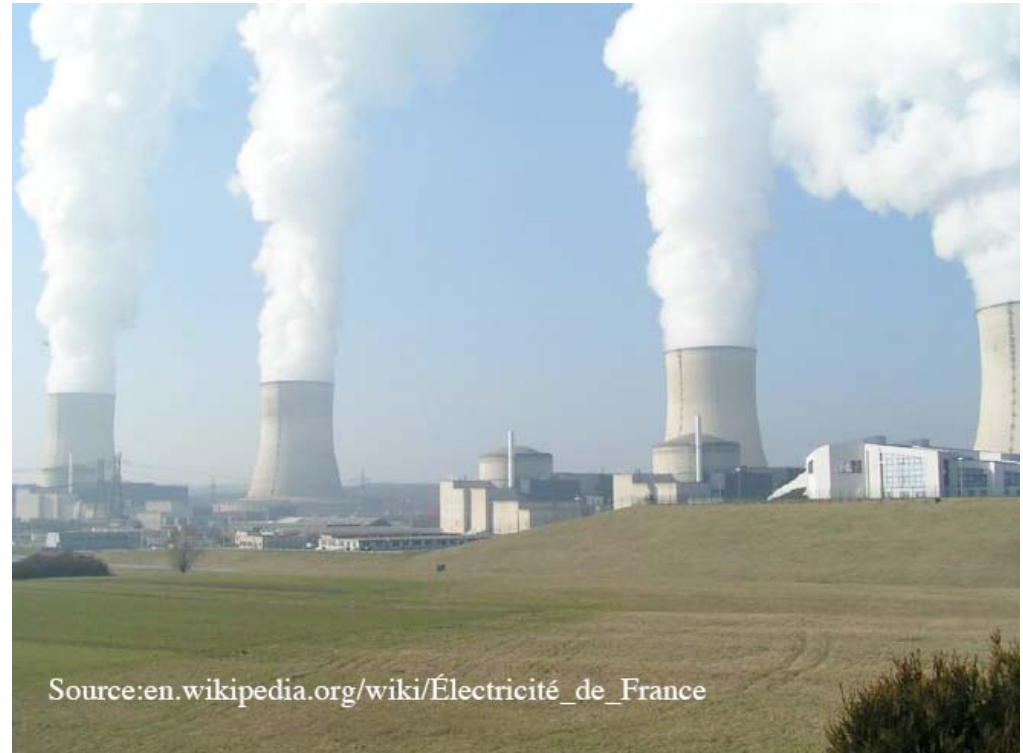


Source: Siemens



# Nuclear

As the French have clearly shown, despite its various issues, nuclear power is capable of serving a nation's electricity needs without CO<sub>2</sub> 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](http://www.edf.fr/12025m/txt/Homefr/EDFEnergies/Nuclearpower.html)

# Wind



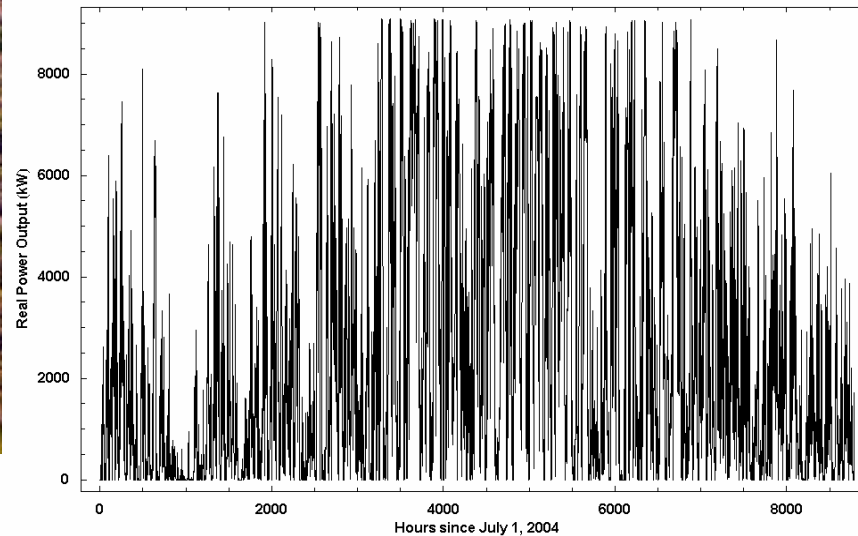
Costs are becoming competitive.

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](http://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

source: Scottish Power



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<sub>2</sub> emission.



source: NREL

# 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](http://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.

## POLICY FORUM

### ECOLOGY

### Managing Soil Carbon

Rattan Lal,<sup>1\*</sup> Michael Griffin,<sup>2</sup> Joy Ajai,<sup>22</sup> Lester Love,<sup>22</sup> H. Granger Morgan<sup>3</sup>

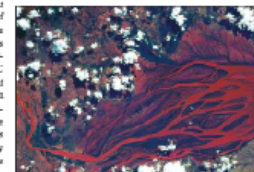
Restoring soil carbon is essential to enhancing soil quality, sustaining and improving food production, maintaining clean water, and reducing increases in atmospheric CO<sub>2</sub>. Short-sighted farming practices have resulted in loss of an estimated 4 ± 1 gigatonnes (Gt) of carbon from soils of the United States, and 78 ± 12 Gt from the world's soils, a large fraction of which ended up in the atmosphere (1). Soil carbon loss has come principally from plowing that turns over the soil, making it susceptible to accelerated erosion (2). This is exemplified by the Dust Bowl in the United States and is a serious issue in most developing countries (see the figure).

Although some carbon is sequestered (3), accelerated water erosion is responsible for net emission of about 1.1 Gt C/year (4). Leaving crop residues after harvest increases the carbon content of soil and controls erosion, but the benefits are lost if the biomass is plowed under, because microorganisms rapidly degrade residue C to CO<sub>2</sub> (5). Essential nutrients that adhere to soil organic carbon (SOC) disappear with its depletion. Thus, farmers require more fertilizer, irrigation, and pesticides to preserve yield. Water quality can deteriorate when less SOC is available for natural filtering.

No-till agriculture (in which seeds are implanted without turning the soil with a plow) reduces the loss of the SOC pool (6–8), while conserving soil water and inhibiting weeds. Soil C enhancement would improve agronomic productivity (9) and resource-use efficiency of impoverished soils. The beneficial effects of enhanced SOC cannot be fully replaced by increased levels of fertilizer, especially in soils of the tropics (10). No-till, in combination with mulching and crop rotation to enhance the SOC pool (11–14), is also a

viable strategy for sustainable management of soils of the tropics in general and those of sub-Saharan Africa in particular (15). No-till would decrease till in rivers and lakes, which would lower transport of SOC and pollutant-laden sediments to aquatic ecosystems and reduce hypoxia, as in the Gulf of Mexico.

Of all cultivated land (1.759 Mha globally), no-till is currently practiced on only 5% of the world's cropland (16). Rapid adoption of no-till farming in South America is attributed to cooperative agricultural extension education efforts (in which university staff work with the farming community), use of crop residue for mulch rather than for fodder or fuel, and development of systems to make no-till farming work. The success of no-till sowing of wheat after rice in the South Asian rice-wheat belt is encouraging (17).



Soil erosion due to agriculture practices in the drainage basin of Madagascar's Betanoka River. [NASA Photo 31351A-34-40]

However, intense plowing of water-saturated soil (puddling) for the rice crop and lack of residue mulch because of prior removal or burning at the time of sowing wheat minimize benefits. Furthermore, expansion into Africa and Asia remains a challenge, because crop residues are removed from the land, and animal waste is primarily used as fuel not as fertilizer. Identifying economic, clean, and healthy sources of household cooking fuel remains a challenge in developing countries.

Topsoil is even used for bricks to meet the demand for housing. Farmers in India, for example, sell topsoil to 1-m depth for up to \$2,000/ha (US \$120/acre). Identifying alternate material for brick making is a high priority, but finding agriculturally marginal

lands from which soil can be mined to deeper depths may also be needed. Using topsoil for brick making must be banned.

No-till agriculture, together with leaving crop residue in fields, does have costs. The yield may be lower in poorly drained and compacted soils and in places where springtime soil warming is slow. Initially, more fertilizer may be required, but, as SOC increases, the soil becomes more productive, requiring the same or even less fertilizer. Crop residue left in the fields would not be available for animal feed-energy production, biofuels (ethanol or hydrogen), or other uses, and may increase incidence of pests and pathogens.

Implementing a program to increase SOC requires that governments mandate no-till agriculture or provide financial incentives to farmers. The United States has a large subsidy program (18) to preserve soil quality. Whether current funding is sufficient to pay for SOC restoration is unclear. However, developing nations lack such opportunities and institutions. Subsidy programs must be consistent and long-lived because carbon gains are easily reversed. Careful policies that combine short- and long-term incentives, extension programs, education, and changes in public norms will be required. Aid programs should place far greater emphasis on mulching and providing technical and other assistance for soil restoration. As an option that wins globally and locally, adoption of no-till farming deserves attention now.

#### References and Notes

1. R. Lal, *Prog. Environ. Sci.* **1**, 307 (1998).
2. R. Lal et al., *J. Soil Water Conserv.* **54**, 376 (1999).
3. V. Srinivasan et al., *Global Biogeochem. Cycles* **15**, 607 (2001).
4. R. Lal, *Environ. Sci. Technol.* **26**, 427 (2002).
5. D. C. Reesley et al., *Soil Tillage Res.* **41**, 105 (1997).
6. R. C. Dalal et al., *Adv. Soil Sci.* **3**, 303 (1992).
7. J. C. Germon, *Soil Sci. Soc. Am.* **45**, 1485 (1981).
8. C. O. Sinsley, *Soil Sci. Soc. Am.* **44**, 1035 (1980).
9. A. Basu et al., *Soil Sci. Soc. Am.* **58** (1994).
10. M. Bannerman, *PL. Inq.* **Agri. Ecosyst. Environ.** **66**, 121 (2004).
11. D. S. Jefferies, *Agro. J.* **72**, 1024 (1980).
12. E. Sreeni, D. S. Jefferies, *Soil Sci. Soc. Am.* **49** (2000).
13. L. E. Delwiche et al., *Mayra* **506**, 282 (1992).
14. S. Usher, *J. Environ. Agric. Sci.* **1**, 141 (1992).
15. R. Lal, *Soil Sci. Soc. Am.* **65**, 1000 (2001).
16. F. Daponte, J. R. Iqbal, *Soil Sci. Soc. Am. Congress on Conservation Agriculture*, 13 to 15 August 2003, Ispahan, Iran, Brazil.
17. F. Daponte, *Soil Sci. Soc. Am. Congress on Conservation Agriculture and the International Rice-Wheat System* (Dobbs, New York, 2004).
18. For example, the Conservation Reserve Program pays farmers up to \$50 per acre per year for planting high-yield and stable farm activities.
19. Supported in part by the Carbon Management and Sequestration Center, Oak Ridge, Ohio State University, the United States Department of Energy, Bioenergy Research Institute, and the Center for Global Change Science, Cornell University (CNS), and the Green Design Institute at OMI, Weizmann Institute, H. D. Oviatt, and G. H. Robertson.

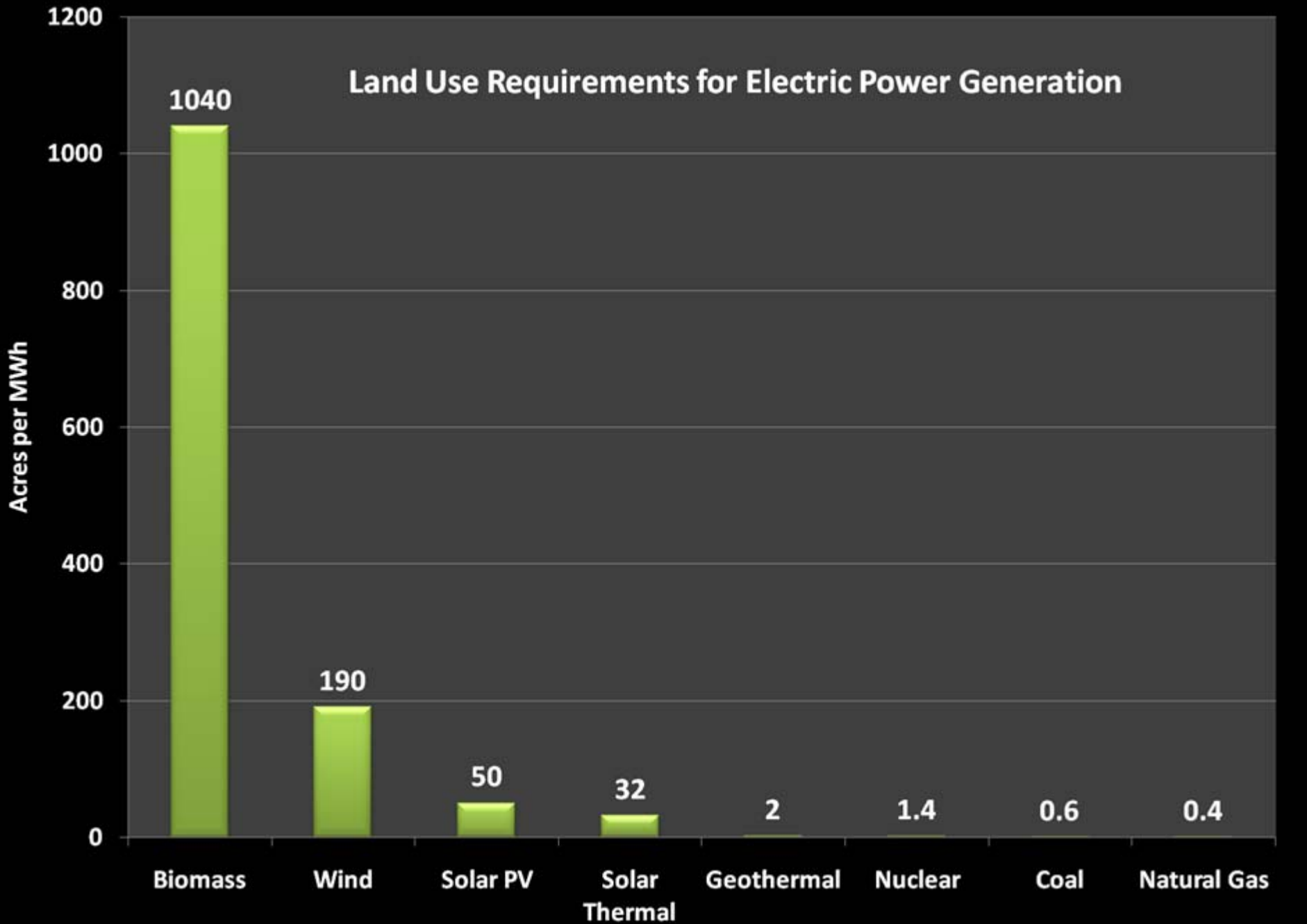
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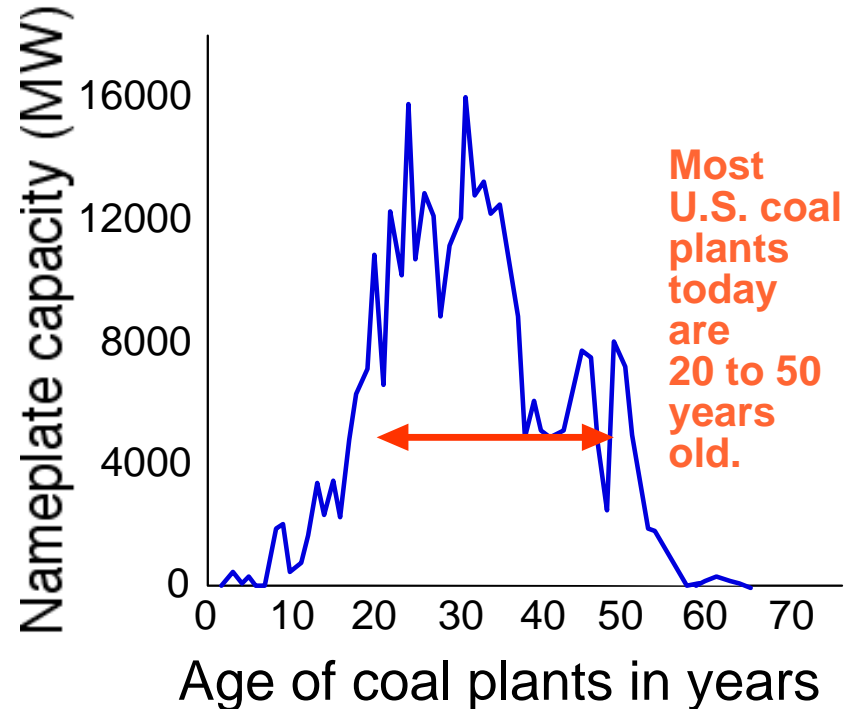
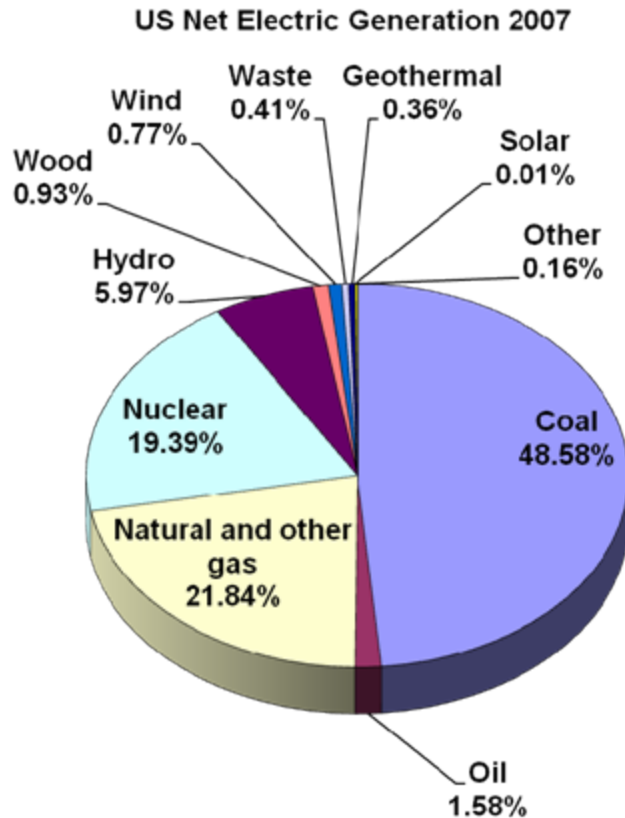
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# Land Use Requirements for Electric Power Generation



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<sub>2</sub> 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



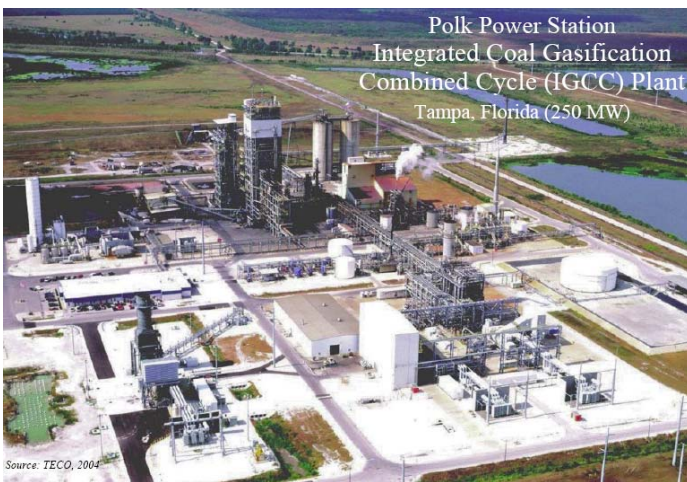
All the pieces exist today at  
commercial scale

Sources: [www.free-pictures-photos.com](http://www.free-pictures-photos.com) and [movementbuilding.org](http://movementbuilding.org)

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



The Wabash Valley Plant in Indiana, 262 MW<sub>e</sub>.  
Repowered an existing old coal unit.



The Tampa Electric Polk Station, 250 MW<sub>e</sub>. A new plant.

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

EOR at Weyburn



# Geological Storage of Captured CO<sub>2</sub> with Enhanced Oil Recovery (EOR)



Sources: USDOE; NRDC



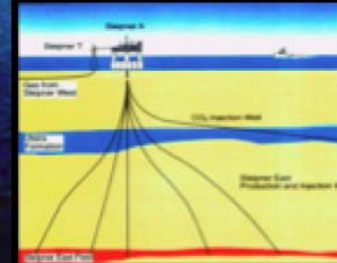
Dakota Coal Gasification Plant

# CO<sub>2</sub> Capture from Natural Gas Treatment with Deep Saline Aquifer Storage



Source: Statoil

**Sleipner (Norway)**



**In Salah /Krechba (Algeria)**

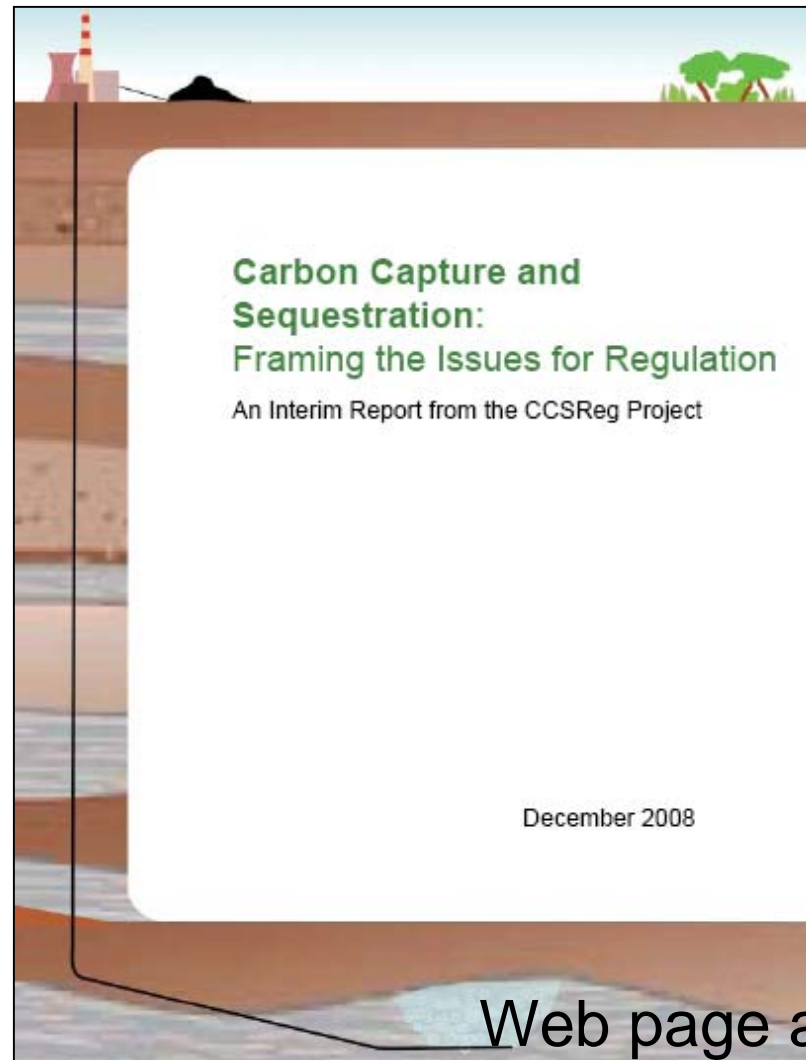


Source: BP

E.S. Rubin, Carnegie Mellon

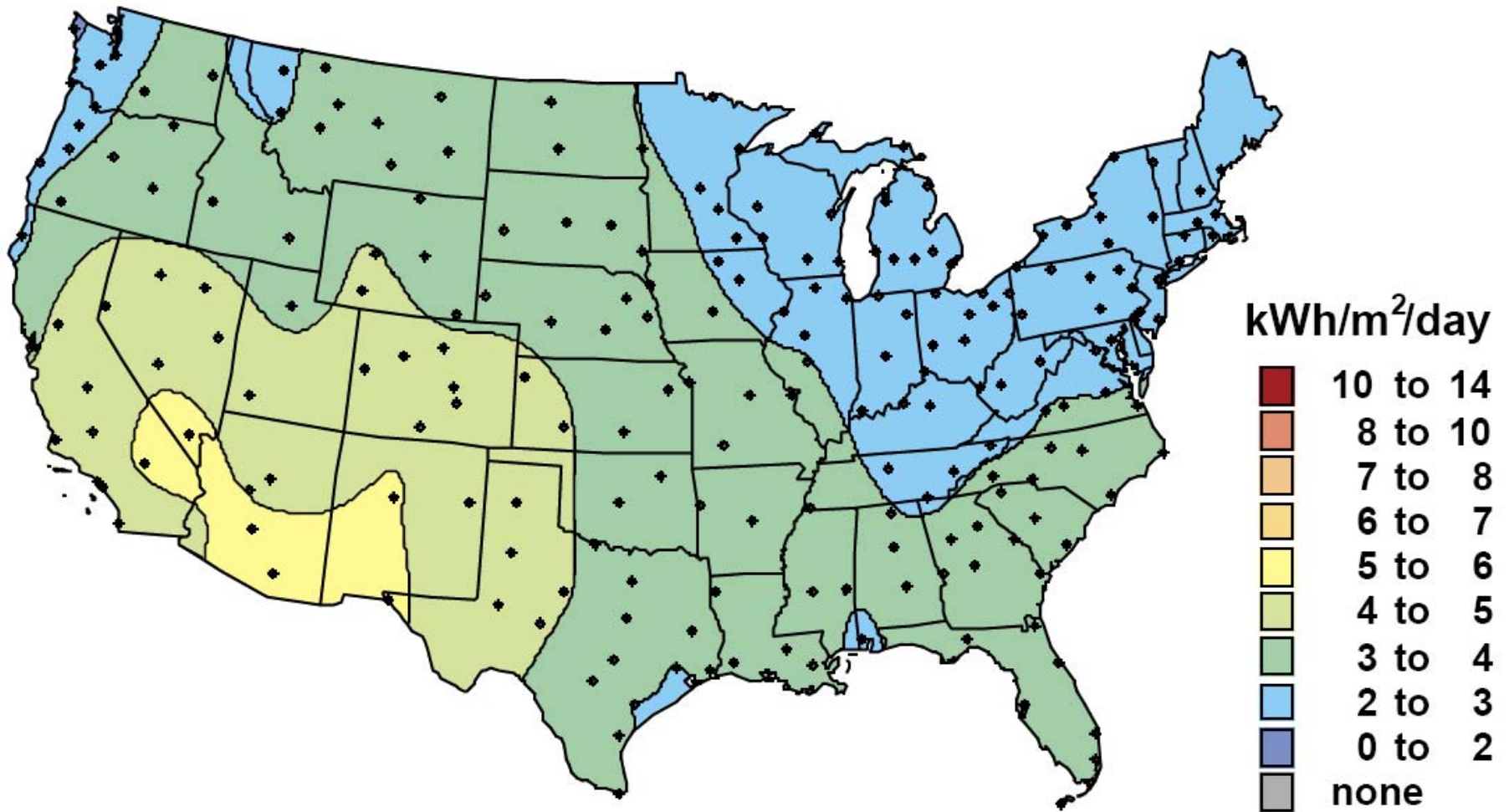


# We have been looking at regulatory aspects of where you put the CO<sub>2</sub>





# 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.

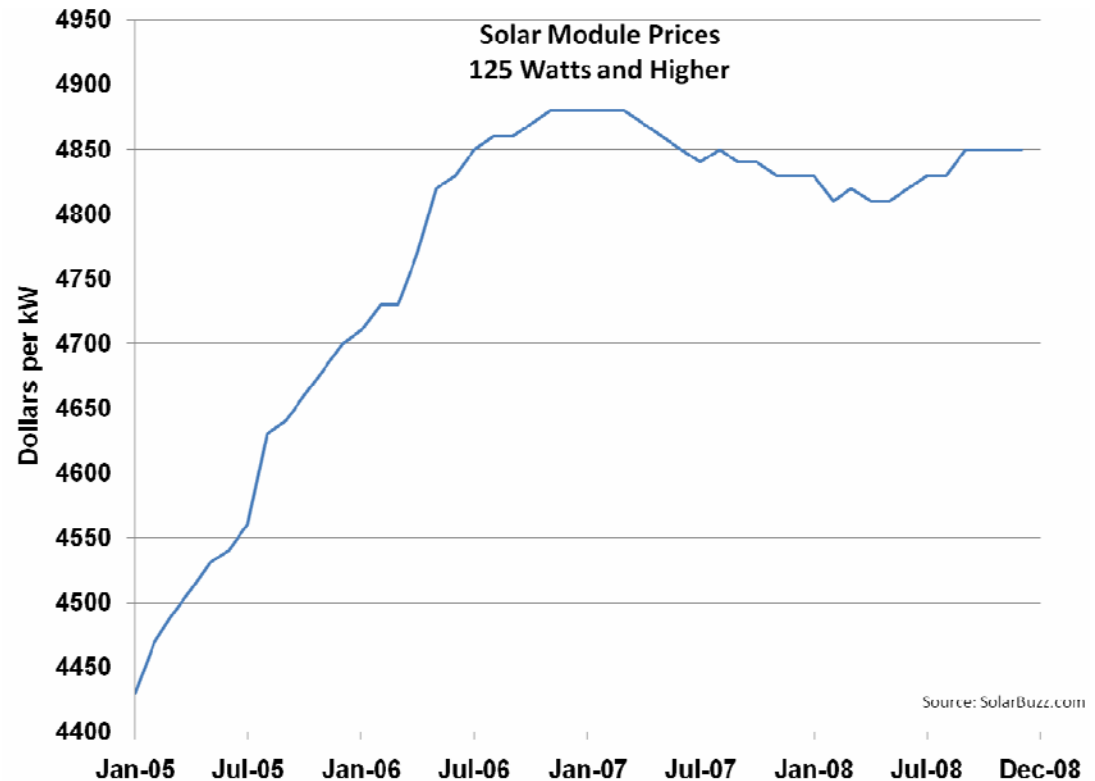
Perhaps research will get prices down to competitive levels, but that will take decades and major innovation.



# Solar Photovoltaic

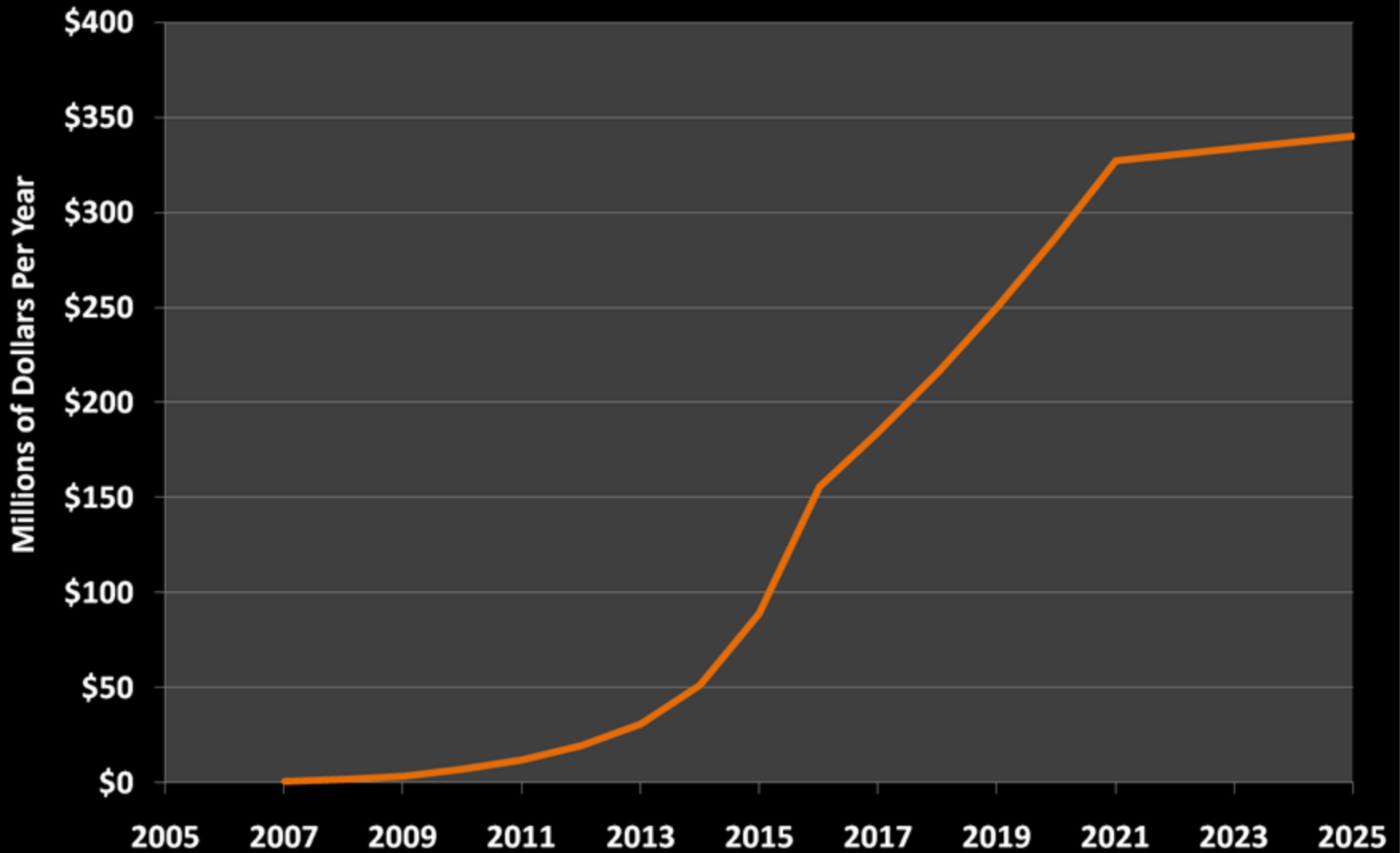
Unsubsidized cost is ~ 45 cents per kWh, 8 times the cost of electricity produced by a conventional coal-fired power plant.

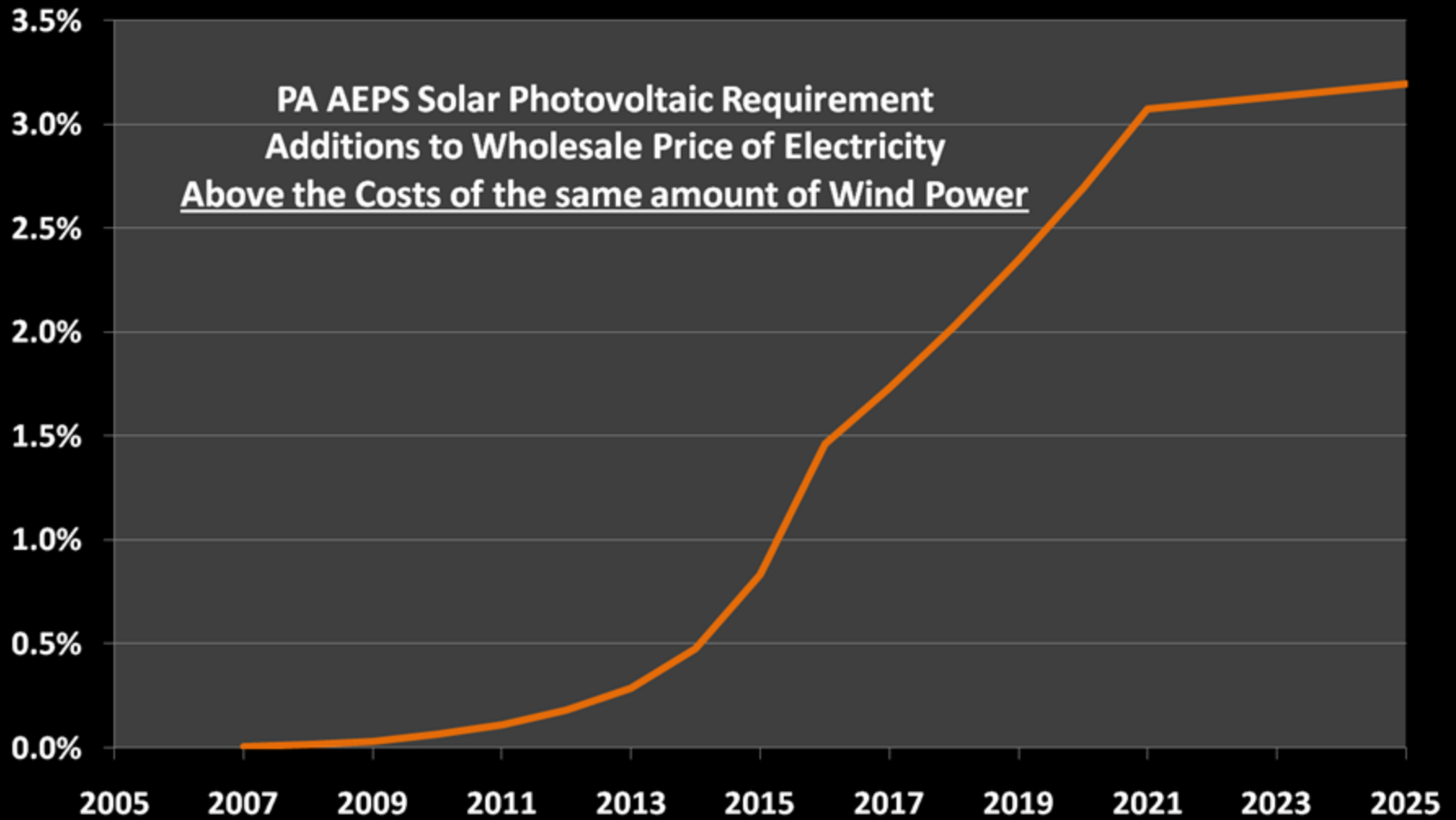
- Price of solar cells shot up in response to demand, then has not been decreasing much.
- Solar cells make up only 50-60% of the system price. The balance has not gotten less expensive.





### Cost of PA AEPS Solar Photovoltaic over the cost of wind 2007-2025





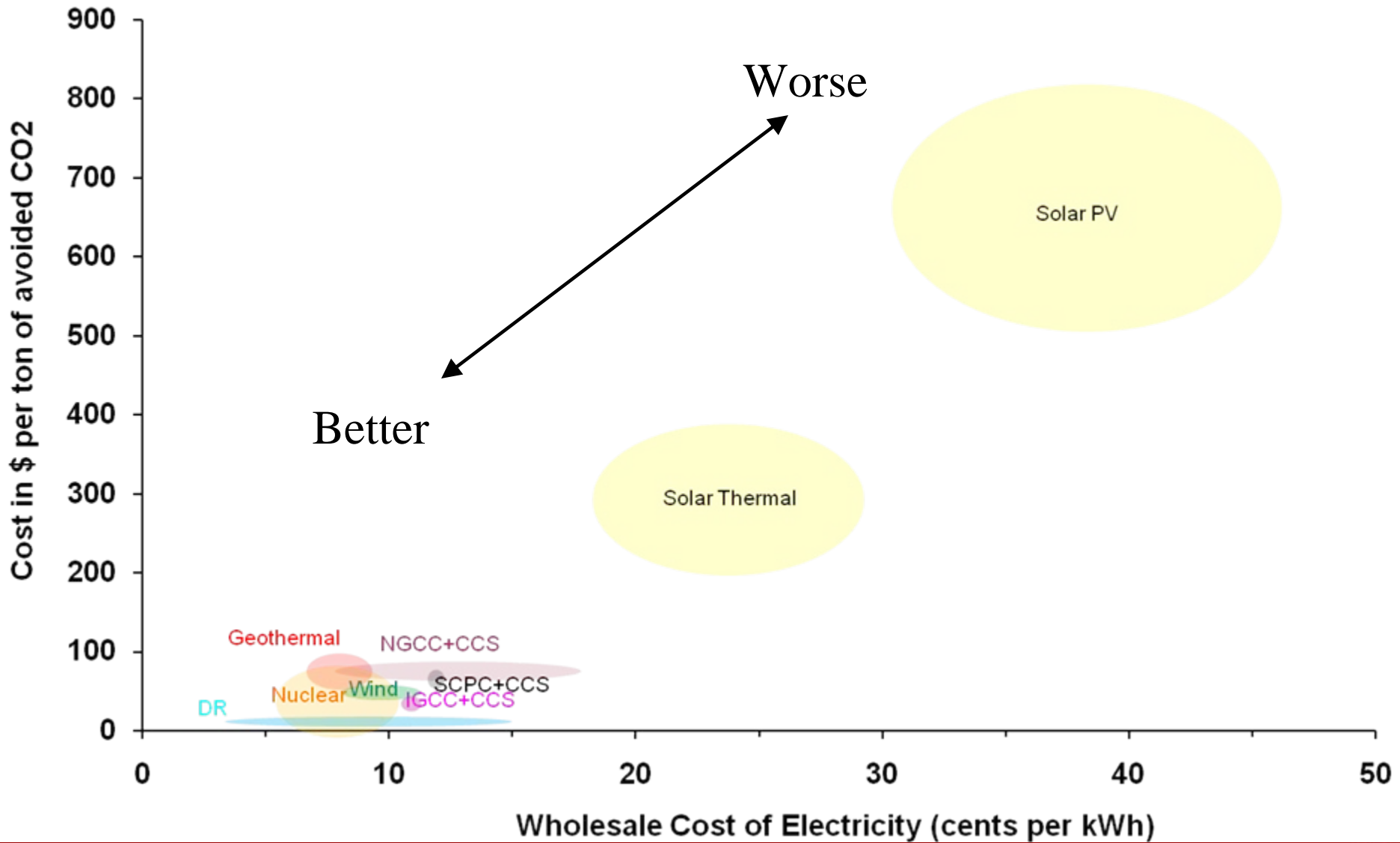


Can we afford low-carbon electricity?





# Cost per ton of CO<sub>2</sub>, Cost of electricity





The US electric power sector emits  
2.5 billion metric tons of CO<sub>2</sub> 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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