

# Greenhouse Gas Reduction Options for the Electric Power Sector

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# Outline of Talk

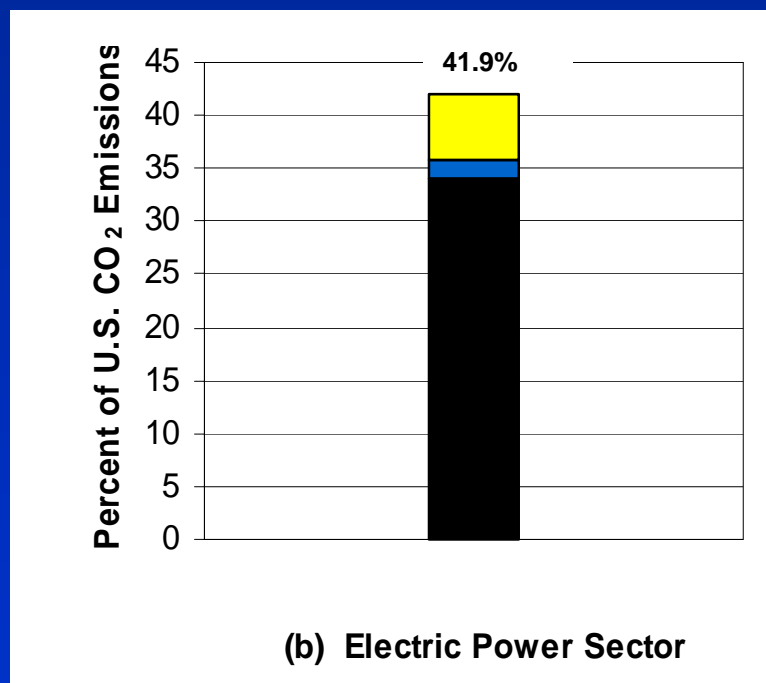
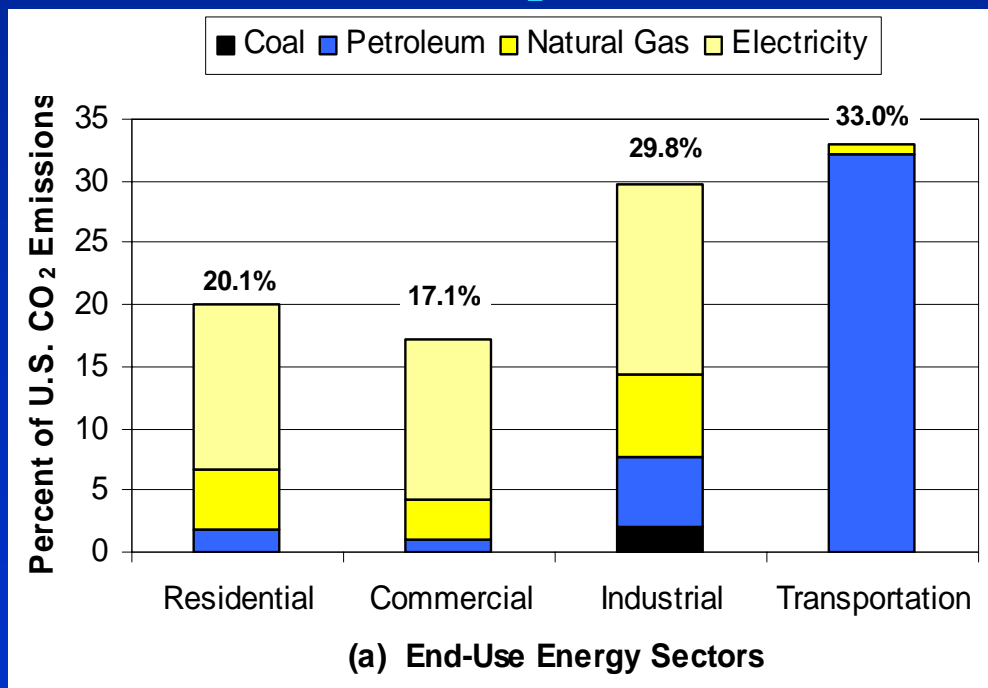
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- Why focus on the electric power sector?
- What options are available to reduce power sector GHG emissions?
- What are some of the key policy options and considerations?

*Why focus on the  
electric power sector ?*

# CO<sub>2</sub> from Fuel Combustion is the Dominant Greenhouse Gas

## U.S. Sources of CO<sub>2</sub> Emissions

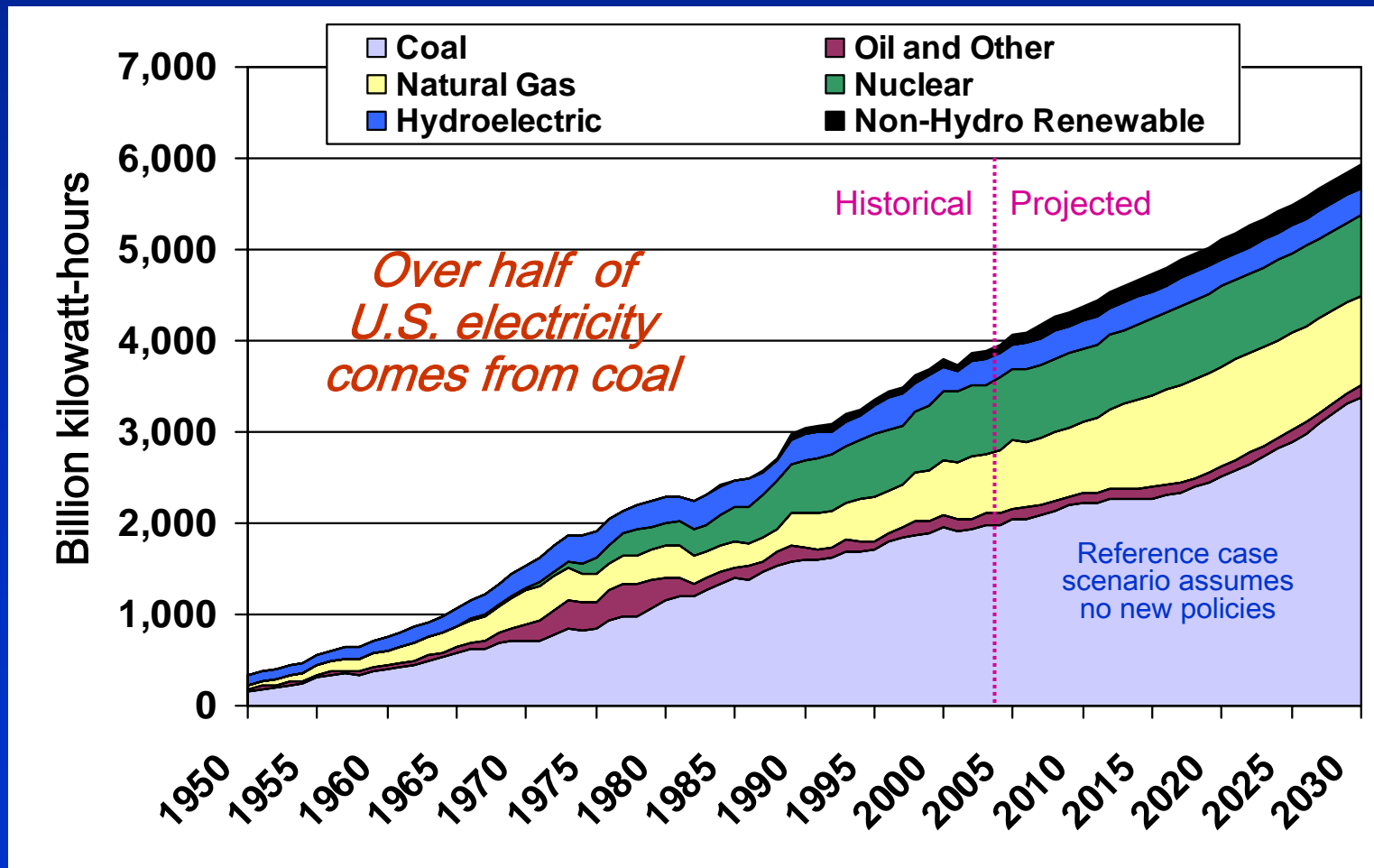


Source: Based on USDOE, 2002

*Electric power plants are the largest source of U.S. carbon dioxide emissions*

# U.S. Electricity Generation by Fuel

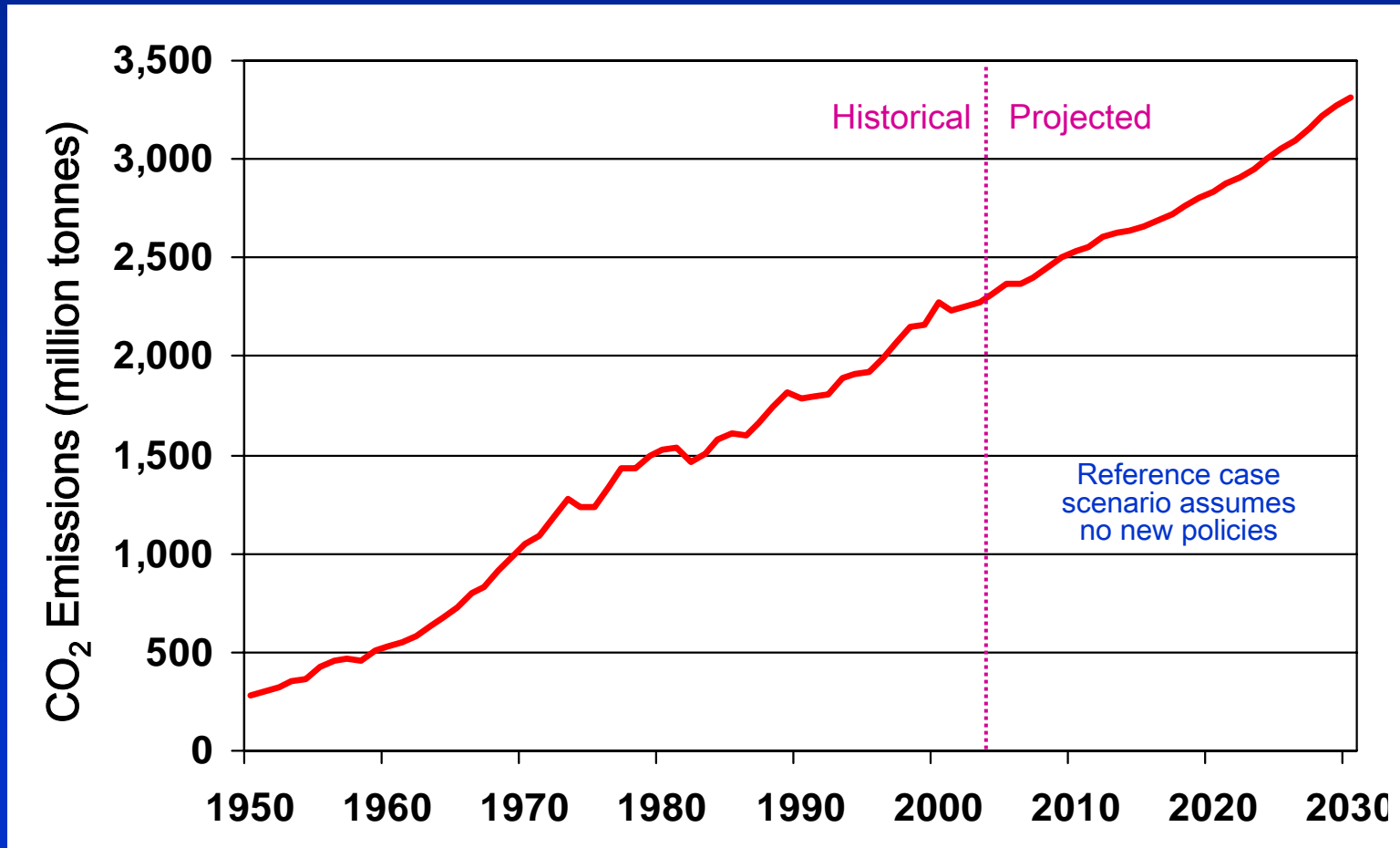
(1950–2004 with EIA Reference Case projections to 2030)



Source: Based on USEIA/DOE, 2006

# U.S. Power Sector CO<sub>2</sub> Emissions

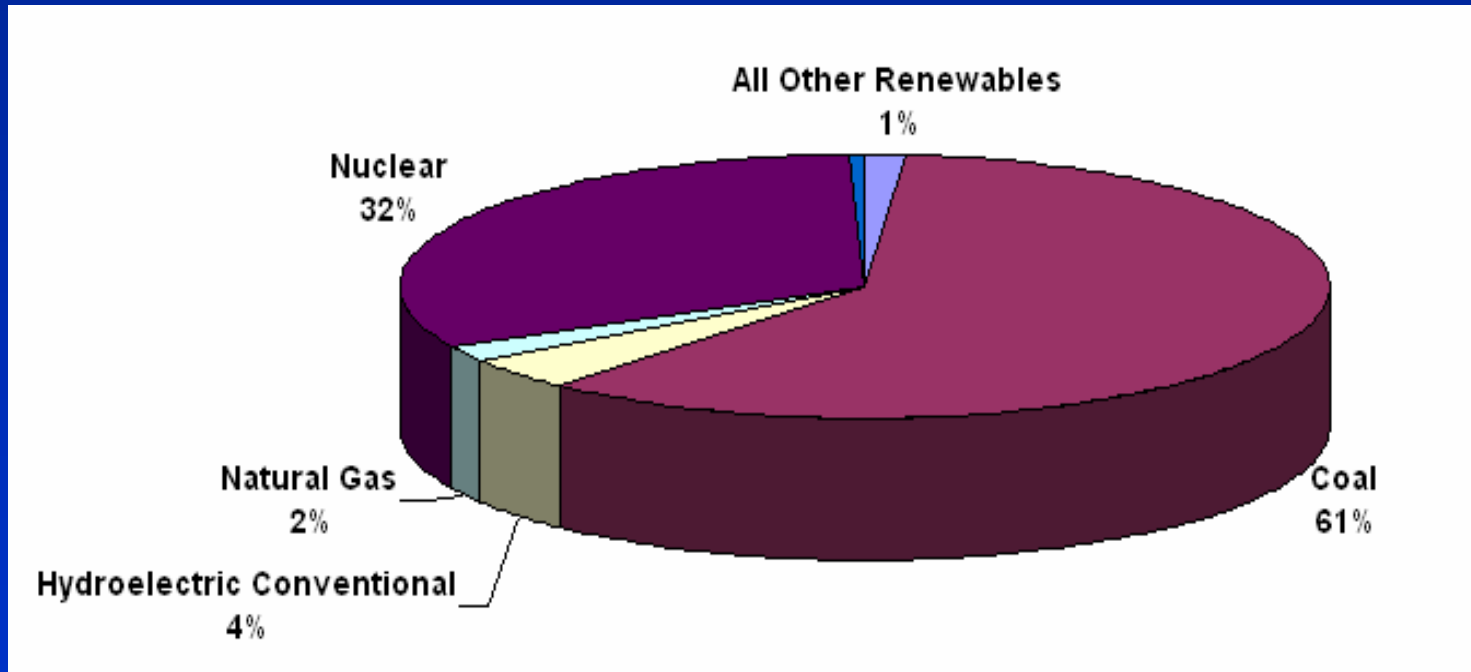
(1950–2004 with EIA Reference Case projections to 2030)



Source: USEIA/DOE, 2006

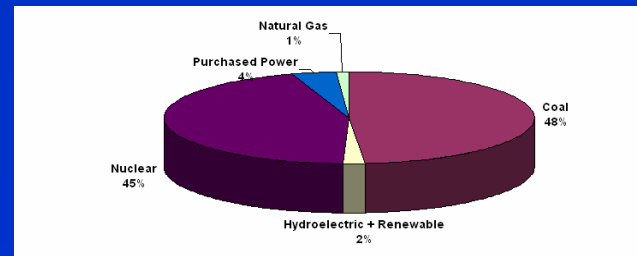
# Fuel Sources for Power Plants in North Carolina

## In-state Generation

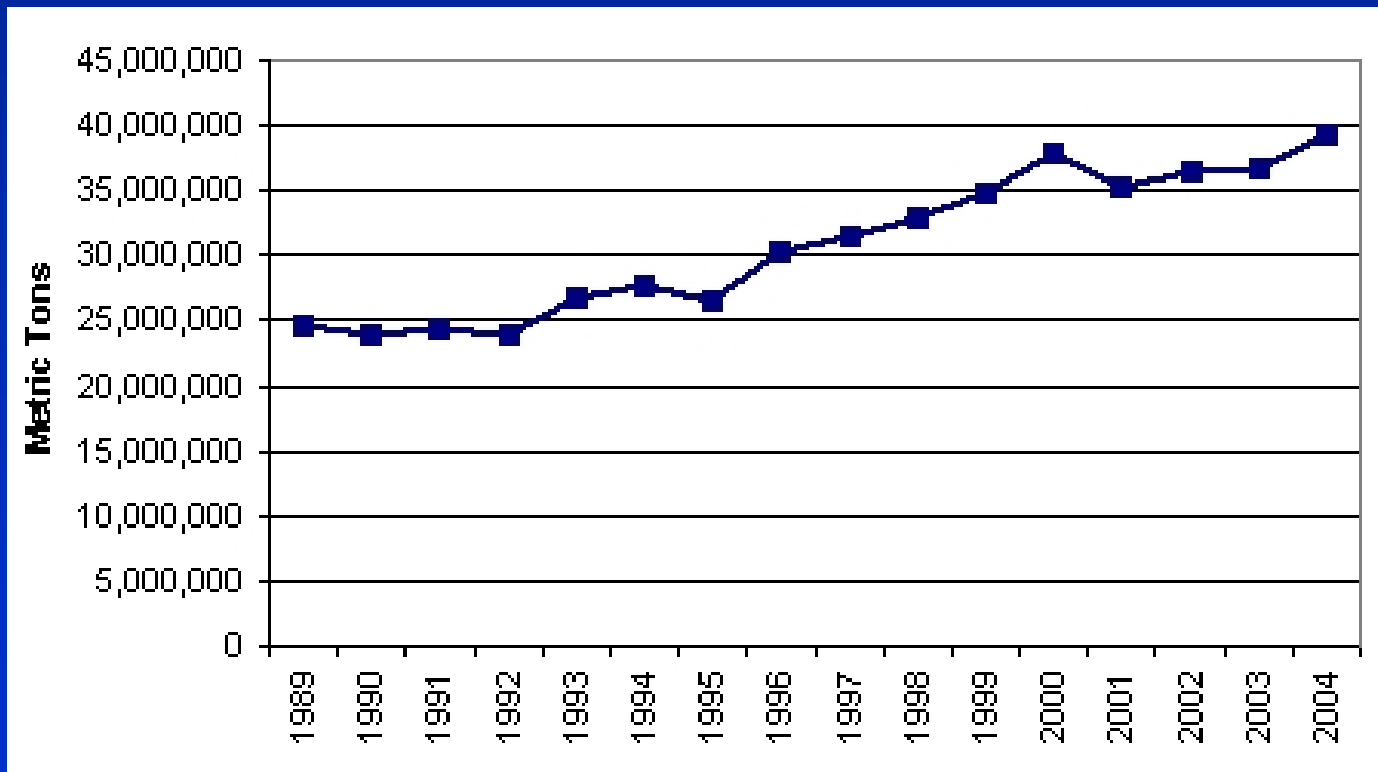


Source: Pew Climate Center, 2006

*In-state consumption uses less coal and more nuclear*



# CO<sub>2</sub> Emissions from Power Plants in North Carolina



Source: EIA/DOE, 2005

# The Climate Change Driver

- 1992 U.N. Framework Convention on Climate Change called for “**stabilization of greenhouse gas concentrations** in the atmospheric at a level that would prevent dangerous anthropogenic interference with the climate system”
- This implies a long-term need to drastically reduce CO<sub>2</sub> emissions, *no matter what target is selected for stabilization*

*What options are available to  
reduce CO<sub>2</sub> emissions from  
the electric power sector?*

# General Approaches to Reduce Power Sector CO<sub>2</sub> Emissions

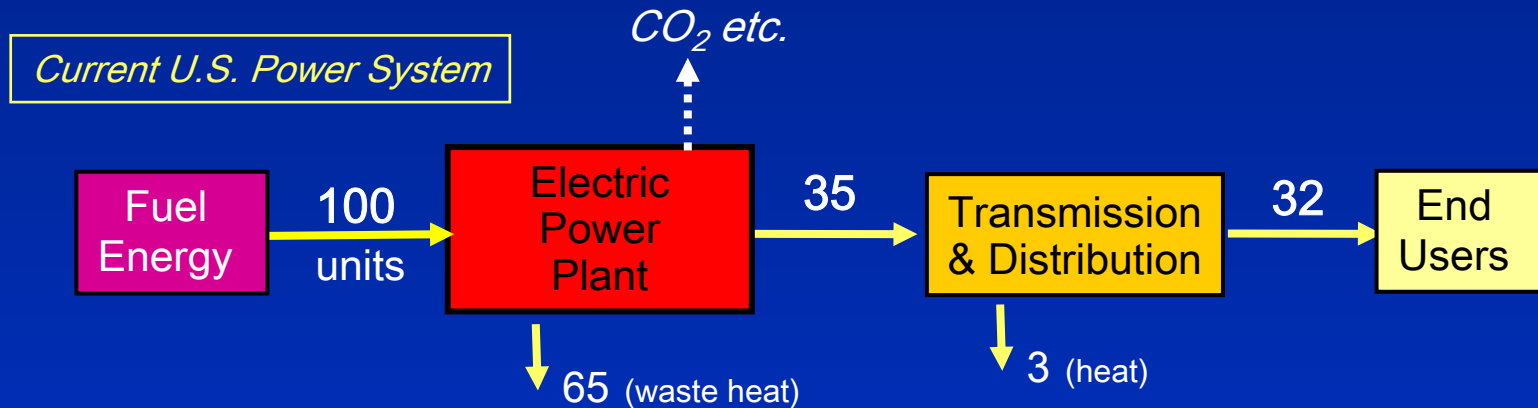
- Technologies that **reduce demand** for electricity
- **More efficient technologies** for power generation, transmission and distribution
- Power generation technologies using **alternative energy sources** with lower or no GHG emissions
- Technologies to **capture and store** (sequester) CO<sub>2</sub> produced at power plants

*... a brief word about each ...*

# Options to Reduce Demand

- Other speakers on today's panel will elaborate on the potential to reduce demand for electricity via improved building designs and more efficient end-use technologies; GHG emissions are reduced roughly proportionally (assuming all else constant)
- Demand-side management (DSM) programs employing changes in pricing and/or technology to meter and control customer loads may further reduce GHG emissions; but system-specific studies are required
  - Past DSM programs had generally small impacts and relatively high costs, but results varied widely by region and company

# Options to Increase Efficiency



- More efficient power generation technologies are available today, including
  - Natural gas-fired combined cycle plants (NGCC)
  - Supercritical pulverized coal plants (SCPC)
  - Integrated gasification combined cycle plants (IGCC)

# Options to Increase Efficiency (2)

- Smaller-scale distributed generation (DG) can reduce needs for transmission and distribution and facilitate greater use of co-generation (combined heat and power) to significantly improve overall system efficiency
  - Technologies include internal combustion engines, micro-turbines, fuel cells
  - Applications must consider local energy demands, air quality impacts, and other factors
  - CO<sub>2</sub> impacts depend on fuel mix and system efficiency
- Micro-grids and improved grid technologies (power electronics, superconductors, etc.) can further enhance overall system efficiency

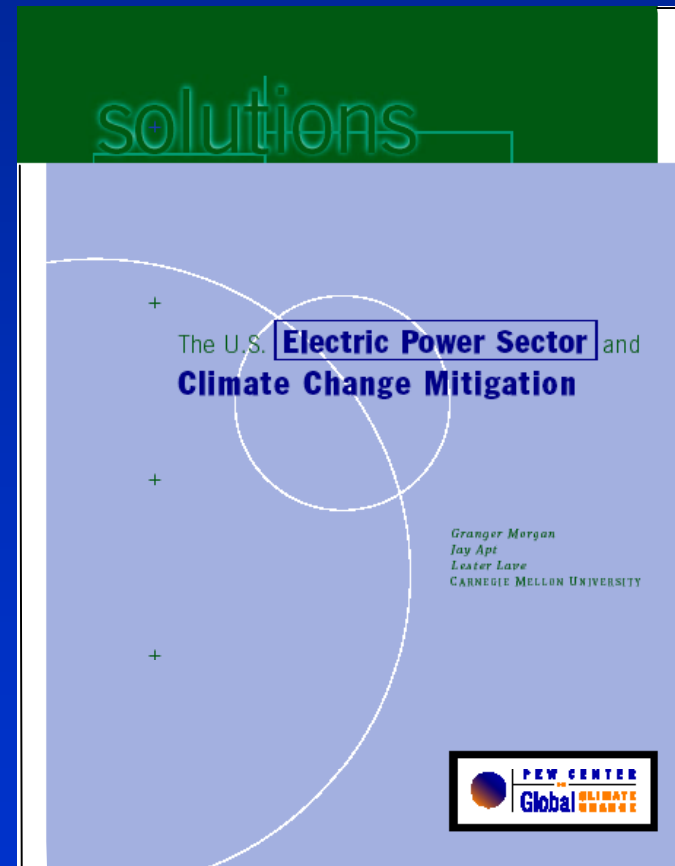
# Options for Alternate Energy Sources

(with low or zero carbon)

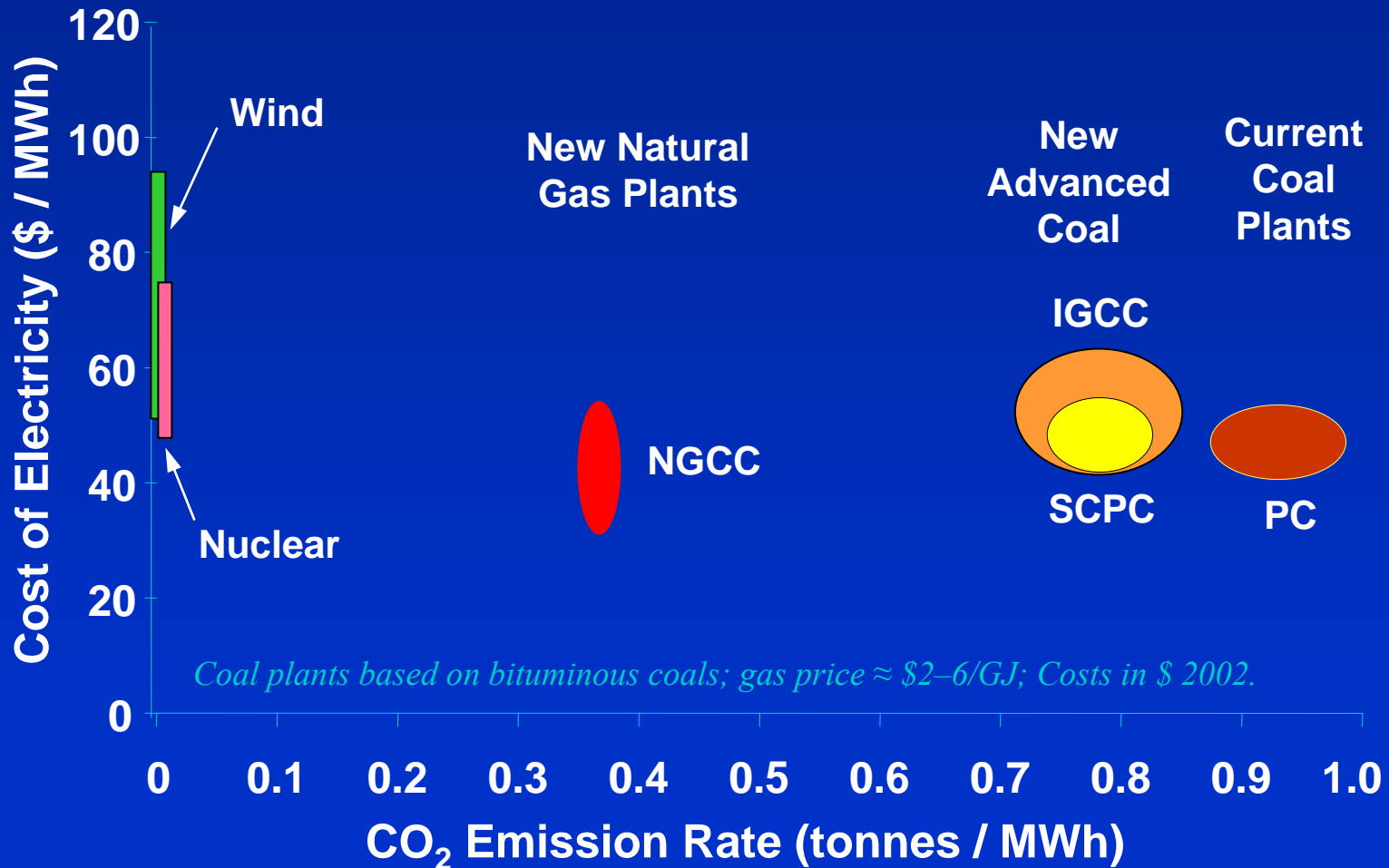
- Available today, with potentially wide deployment
  - Natural gas
  - Nuclear
- Available today, with more limited deployment
  - Wind
  - Biomass
  - Geothermal
- Also available for niche applications
  - Low-head hydro
  - Solar photovoltaics

# All of the options above have issues and limitations that must be considered

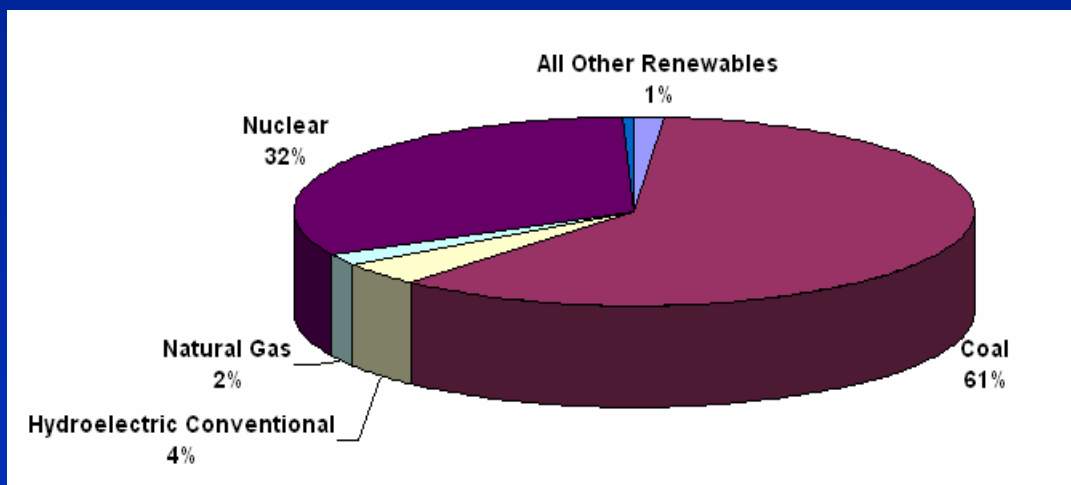
- Several of my Carnegie Mellon colleagues recently produced a report for the Pew Center on Climate Change that addresses the full range of issues and options related to climate change mitigation and the U.S. electric power sector
- Available at: [www.pewclimate.org](http://www.pewclimate.org)



# Approximate Cost of Options



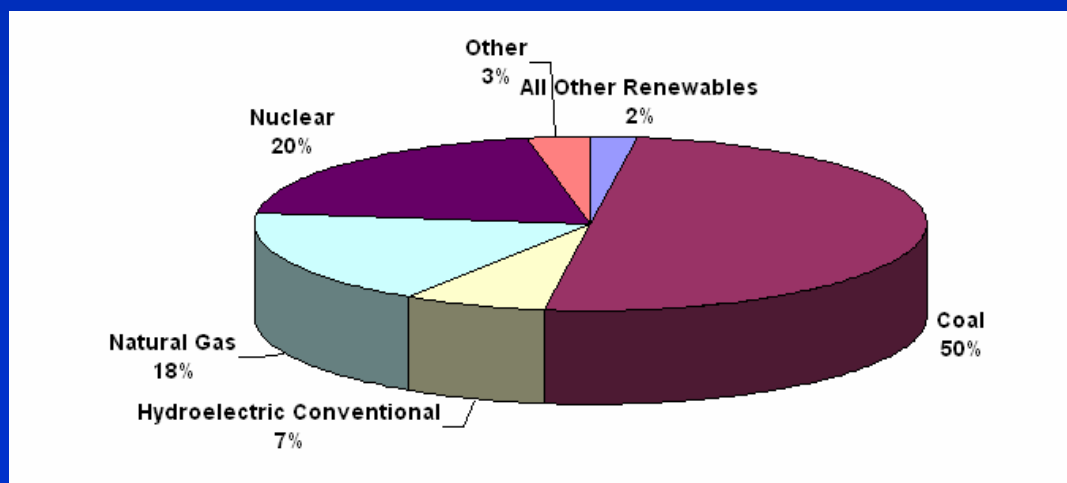
# Reminder: Currently, We make most electricity from coal



North Carolina  
Generation

*Source: Pew Climate Center, 2006*

United States  
Generation



# Can We Have Our Cake and Eat it Too?



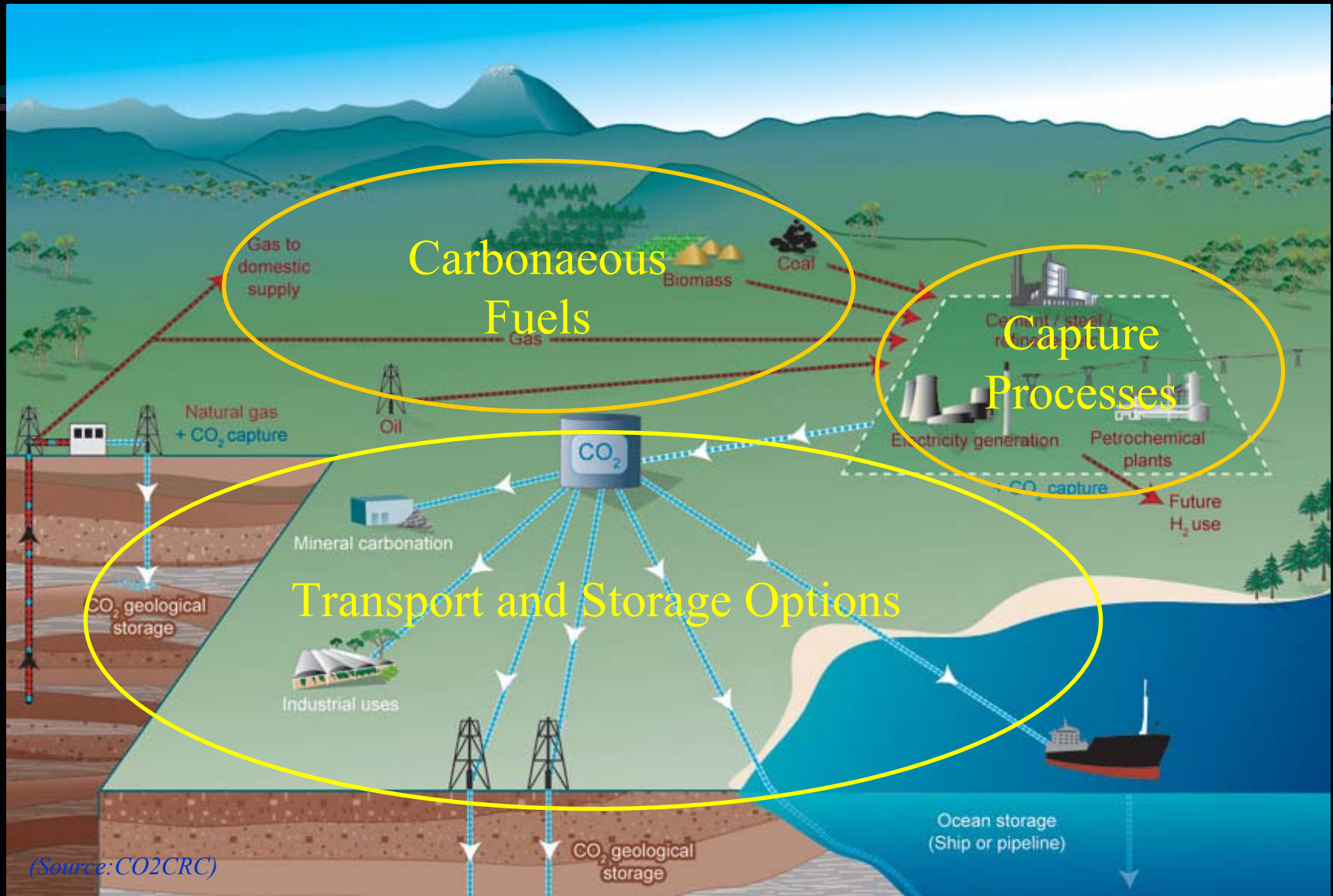
Can We  
Have Our Coal  
Without CO<sub>2</sub>?



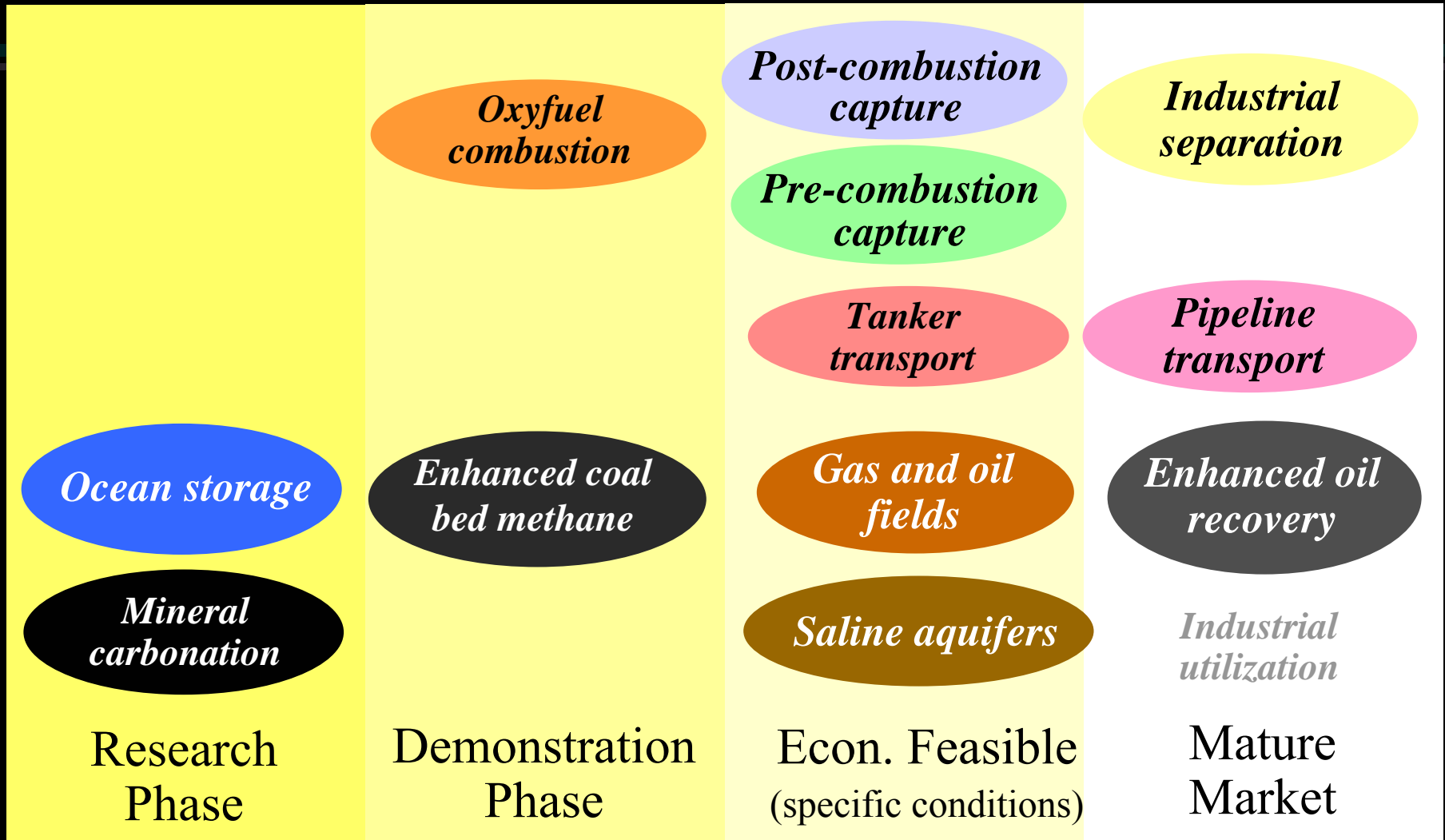
# Options for CO<sub>2</sub> Capture and Storage

- Fossil fuels will continue to be used extensively for many decades to come—alternatives are not likely to achieve large CO<sub>2</sub> reductions in time frames of policy interest
- CCS offers a way to allow fossil fuels (especially coal) to be used with little or no CO<sub>2</sub> emissions—a potential bridging strategy
- Energy models indicate that the availability of CCS in a portfolio of options can significantly lower the cost of mitigating climate change

# CO<sub>2</sub> Capture and Storage Systems



# Maturity of CCS Technologies



(Source: Based on IPCC, 2005)

# Leading Candidates for CCS

- Fossil fuel power plants
  - Integrated coal gasification combined cycle
  - Advanced pulverized coal combustion
  - Natural gas combined cycle
- Other large industrial sources of CO<sub>2</sub>
- Focus on pipeline transport with geological storage

*This option is relatively new and less familiar to many policymakers. The next few slides show some potential applications to power plants as the largest source of CO<sub>2</sub>*

# PC Plant with CO<sub>2</sub> Capture

**Combustion Controls**

Fuel Type:

NOx Control:

**Post-Combustion Controls**

NOx Control:

Particulates:

SO<sub>2</sub> Control:

Mercury:

CO<sub>2</sub> Capture:

**Solids Management**

Disposal:

**Plant Diagram**

The diagram illustrates the flow of a power plant with CO<sub>2</sub> capture. It starts with a boiler (red trapezoid) on the left, which feeds into a steam turbine (green trapezoid). The turbine is connected to a generator (pink rectangle). The generator feeds into a condenser (blue vertical lines). The condenser feeds into a pump (red trapezoid), which feeds into a steam generator (green circle). The steam generator feeds into a CO<sub>2</sub> capture unit (green circle). The CO<sub>2</sub> capture unit feeds into a storage tank (green circle) labeled "To Storage". The boiler has a chimney on top. The condenser has a cooling tower on top. The steam generator has a cooling tower on top. The CO<sub>2</sub> capture unit has a cooling tower on top. The storage tank has a chimney on top. The boiler has a hopper at the bottom. The condenser has a hopper at the bottom. The steam generator has a hopper at the bottom. The CO<sub>2</sub> capture unit has a hopper at the bottom. The storage tank has a hopper at the bottom.

# Examples of Post-Combustion CO<sub>2</sub> Capture Systems



(Source: ABB Lummus)

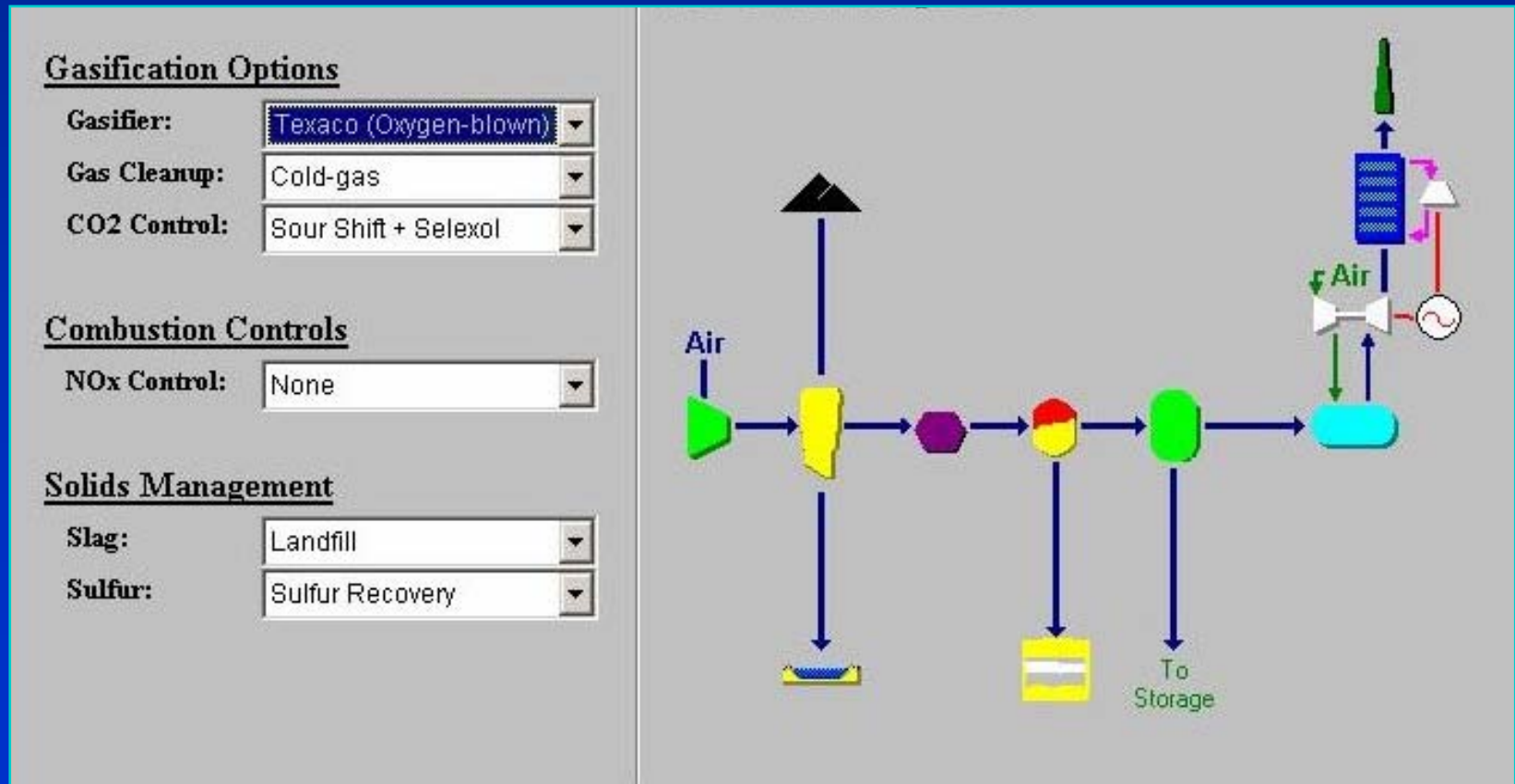
Coal-Fired Power Plant Flue Gas  
(Oklahoma, USA)



(Source: Mitsubishi Heavy Industries)

Gas-Fired Process Flue Gas  
(Keda, Malaysia)

# IGCC Plant with CO<sub>2</sub> Capture





Polk Power Station  
Integrated Coal Gasification  
Combined Cycle (IGCC) Plant  
Tampa, Florida (250 MW)

Source: TECO, 2004

# Examples of Pre-Combustion CO<sub>2</sub> Capture Systems



*(Source: Dakota Gasification)*

Coal Gasification to Produce SNG  
(North Dakota, USA)



*(Source: Chevron-Texaco)*

Petcoke Gasification to Produce H<sub>2</sub>  
(Kansas, USA)

# CO<sub>2</sub> Pipelines for Enhanced Oil Recovery



Source: USDOE/Battelle



Source: NRDC

# Existing/Proposed CO<sub>2</sub> Storage Sites

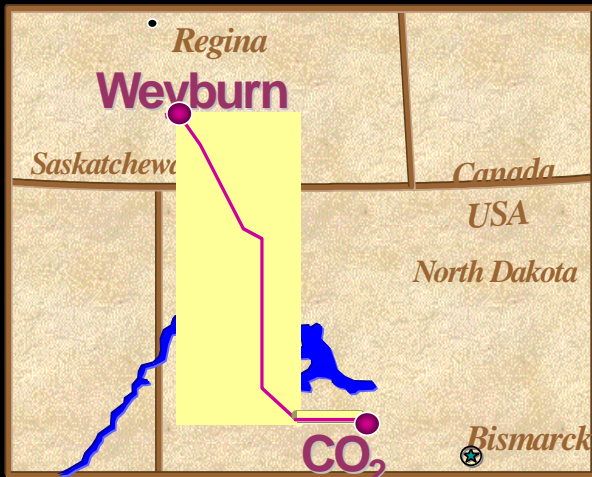


Source: S. Benson, LBNL

## EOR at Weyburn



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



Sources: USDOE; NRDC



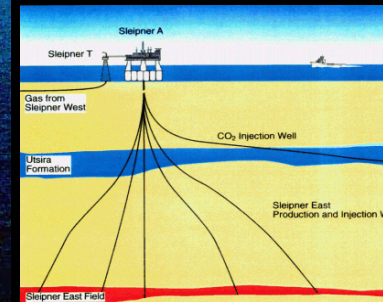
## Dakota Coal Gasification Plant

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



Source: Statoil

Sleipner (Norway)

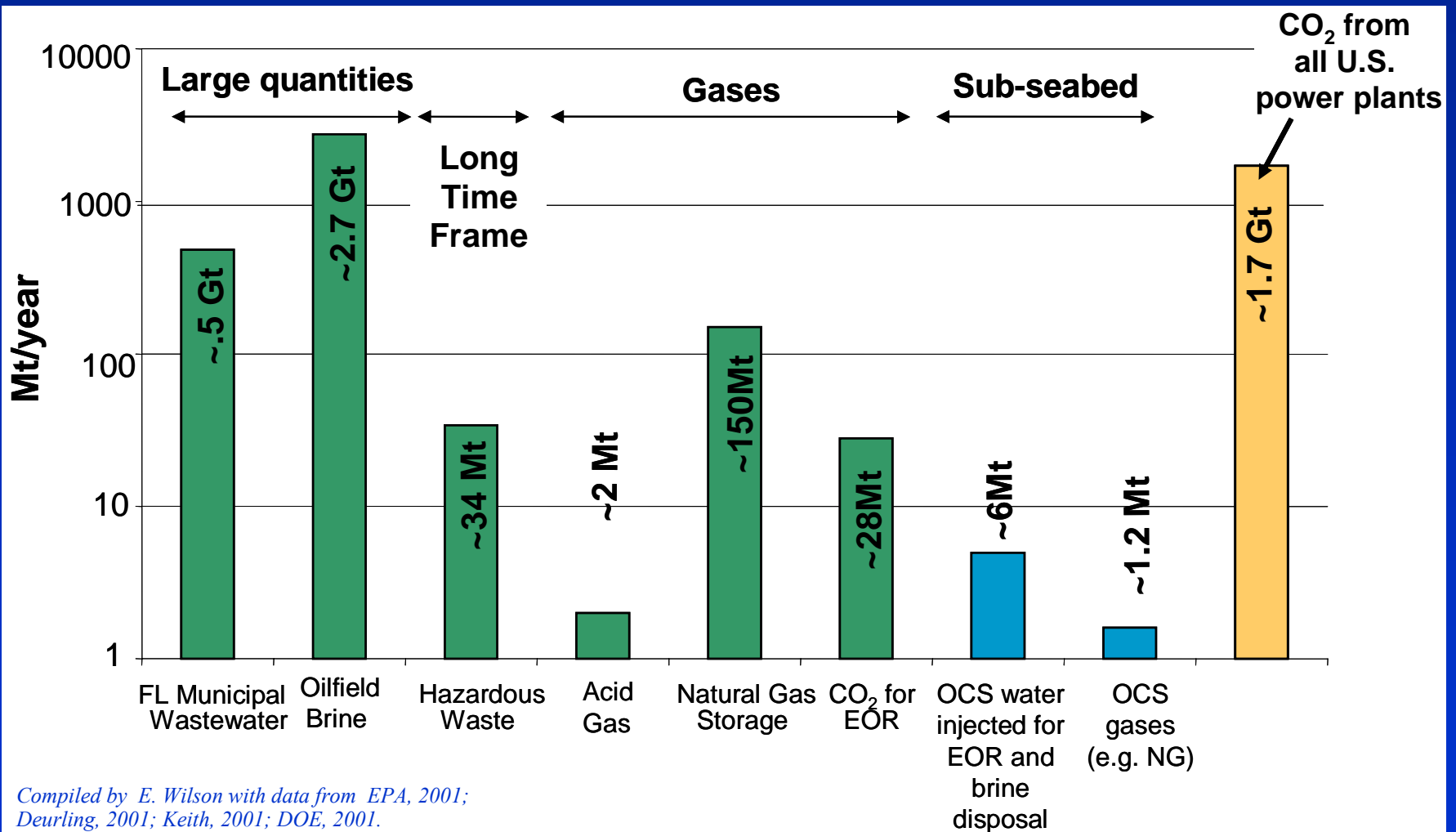


In Salah /Krechba (Algeria)



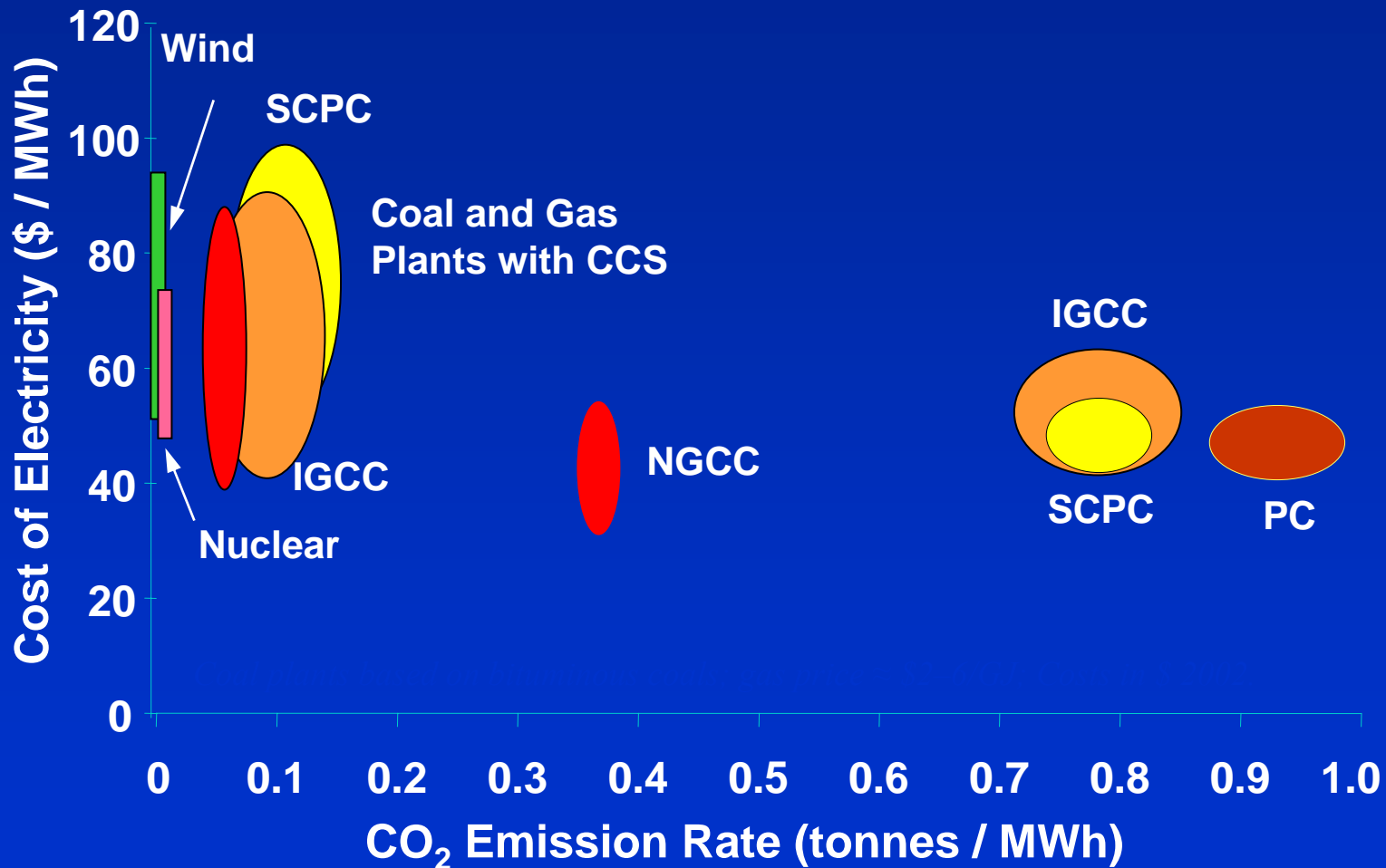
Source: BP

# Current U.S. fluid injections exceed the mass of all CO<sub>2</sub> from U.S. power plants



Compiled by E. Wilson with data from EPA, 2001; Deurling, 2001; Keith, 2001; DOE, 2001.

# Approximate Cost of Options (including power plants with CCS)



# Cost of CO<sub>2</sub> Avoided (Based on Current Technology)

(2002 US\$ per tonne CO<sub>2</sub> avoided)

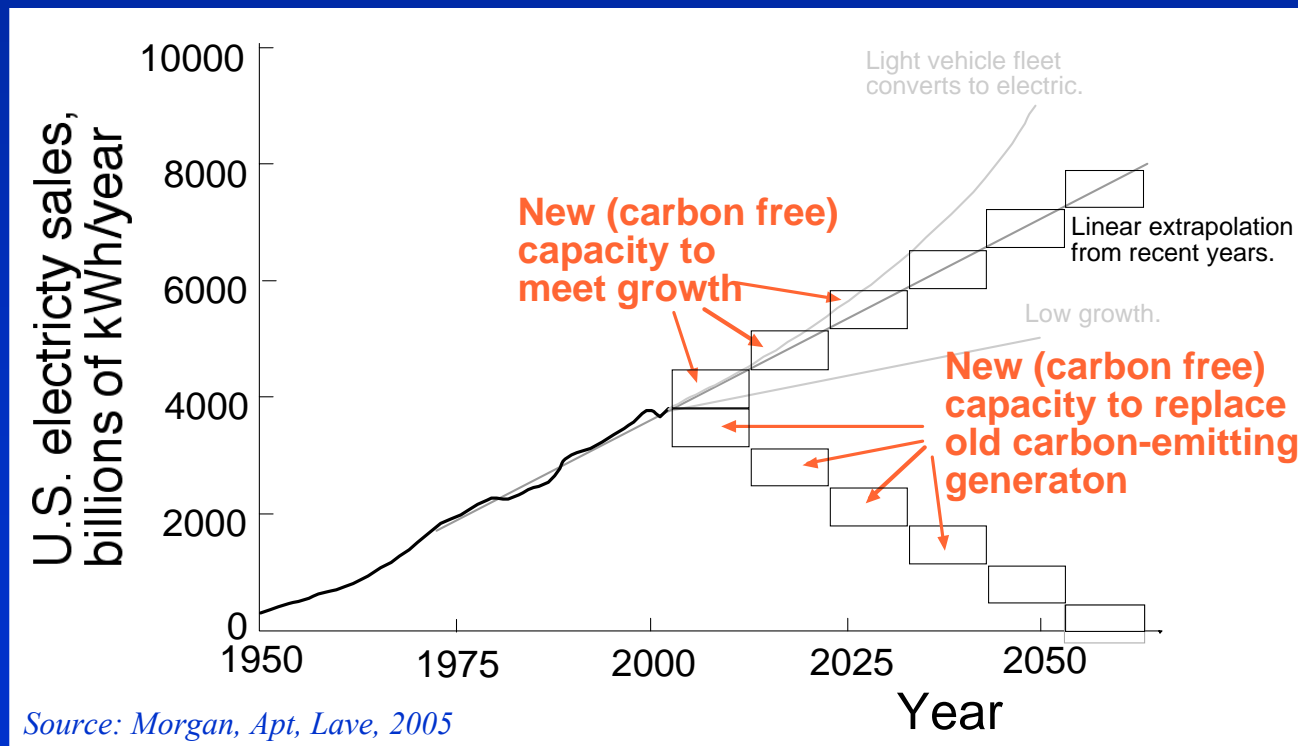
Power Plant System	Natural Gas Combined Cycle Plant	Pulverized Coal Plant	Integrated Gasification Combined Cycle Plant
Same plant with CCS (deep aquifer storage)	40–90	30–70	15–55
Same plant with CCS (EOR storage)	20–70	10–45	(-5)–30

Source: IPCC, 2005

*Analyses indicate that CCS can begin to play a significant role at carbon prices at or above roughly \$100/tC (\$27/tCO<sub>2</sub>)*

# Using carbon free technologies...

...and doubling current construction rates, the Pew Center report concludes it should be possible to essentially eliminate CO<sub>2</sub> emissions from the U.S. power sector in about 50 years.



# *Policy options and considerations*

# Examples of Policy Opportunities for the Electric Power Sector

## *Near-term recommendations from 2005 DENR report:*

- Cleaner coal and renewable energy capacity
- Mandatory GHG reporting
- Energy efficiency
- Center of low-carbon technology development
- Work with other states in the Southeast

## *Longer-term recommendations:*

- Public Benefit Fund
- Renewable Portfolio Standard

# Some Examples of Current Policies to Reduce GHG Emissions

- European Union Emission Trading System (*C/T*)
- Kyoto Protocol (*C/T, JI, CDM*)
- Northeast Regional Greenhouse Gas Initiative (*C/T*)
- California Climate Action Policy Proposals (*C/T*)
- California GHG Performance Standard for Power Plants
- Energy Policy Act of 2005 (*incentives*)

# Other Potential Policy Options to Reduce Power Sector GHG Emissions

- Incentives to Reduce GHG Emissions
- Carbon Tax
- Cap and Trade System
- Performance Standards for CO<sub>2</sub> Sources
- Technology Standards for CO<sub>2</sub> Sources
- Portfolio Standards for Power Retailers
- “Capture Ready” Design Requirements
- “Feebate” System for Existing Power Plants
- Combinations of the Above

# “Technology Policy” Options

## Direct Government Funding of Research and Development (R&D)

- R&D contracts with private firms
- R&D grants and contracts with universities
- Intramural R&D conducted at gov’t laboratories
- R&D contracts with consortia (2 or more of the actors above)

## Direct or Indirect Support for Commercialization and Production; Indirect Support for Development

- Patent protection
- R&D tax credits
- Production subsidies or tax credits to firms bringing new technologies to market
- Tax credits or rebates for new technology buyers
- Government procurement
- Demonstration projects

## Support for Learning and Diffusion of Knowledge and Technology

- Education and training
- Codification and transfer of knowledge
- Technical standard-setting (non-regulatory)
- Technology and/or industrial extension services
- Publicity and consumer information

- *These policies influence different phases of the innovation process*
- *Provide incentives for technological change & innovation*
- *Many of these options are available to state governments*

# Conclusions from Case Studies of Environmental Technology Innovation

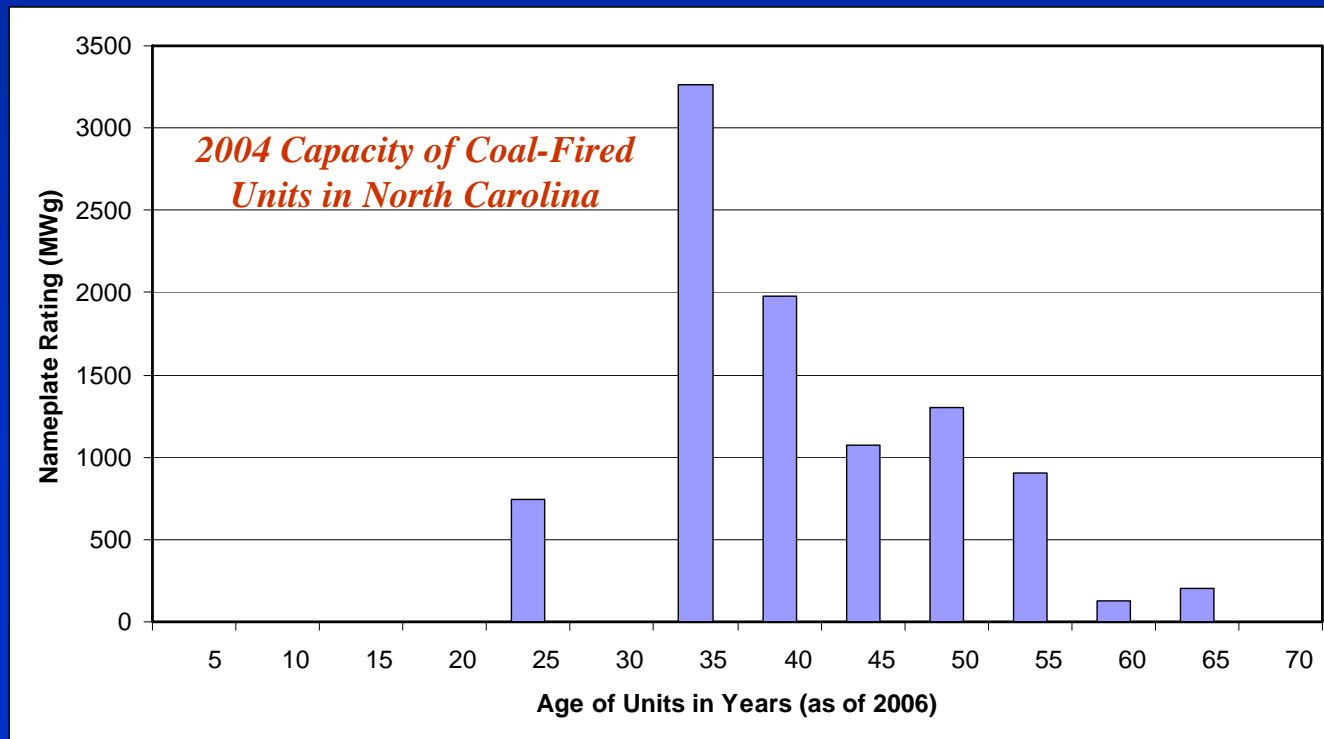
- The **stringency** of emission reduction requirements is a major factor in both *stimulating* and *directing* innovations and deployment of cleaner technologies
- The cost of achieving a given level of emissions reduction tends to fall with increasing technology deployment and sustained R&D
- The firms that innovate tend to capture large market share of environmental technology
- No strong empirical basis for comparing alternative environmental policy instruments

# Innovation Policies to Mitigate Climate Change

- Global climate change is an environmental problem that cannot be addressed by voluntary technology policies alone — *regulatory policies that limit GHG emissions* also are needed
- *Energy policies* can further help—or impede—progress and innovations that reduce GHG emissions
- A *combination* of traditional **technology policies** and **regulatory policies** that limit GHG emissions can most effectively foster innovations favored or required by markets in a carbon-constrained world

# North Carolina Power Plants are Aging ... little time to waste

- Current fleet of CO<sub>2</sub>-emitting power plants is 35–55 years old; decisions about replacement capacity will have a major impact on future GHG emissions



Source: Based on data from EIA/DOE, 2006

*Thank You .*