Examining Technology Scenarios for Achieving Stabilization of GHG Concentrations: A U.S. Perspective

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Background

“It is the sense of the Senate that Congress should enact a comprehensive and effective national program of mandatory, market-based limits and incentives on emissions of greenhouse gases that slow, stop, and reverse the growth of such emissions at a rate and in a manner that—

(1) will not significantly harm the United States economy; and

(2) will encourage comparable action by other nations that are major trading partners and key contributors to global emissions.”

United States Sense of the Senate Resolution

April 2006

Background: Sentiment Against GHG Mitigation Action

- **“Atmospheric stabilization is hopeless, so why try?”**

- **The notion is, specifically, that the increase in radiative forcing cannot be stopped before positive feedbacks kick in and tipping points are reached**
  - Water vapor (an amplification, but important)
  - Tundra thaws
  - Methane hydrate burps
  - Shifts in ocean currents
  - Collapse of arctic ice sheets
  - Bleaching of coral reefs

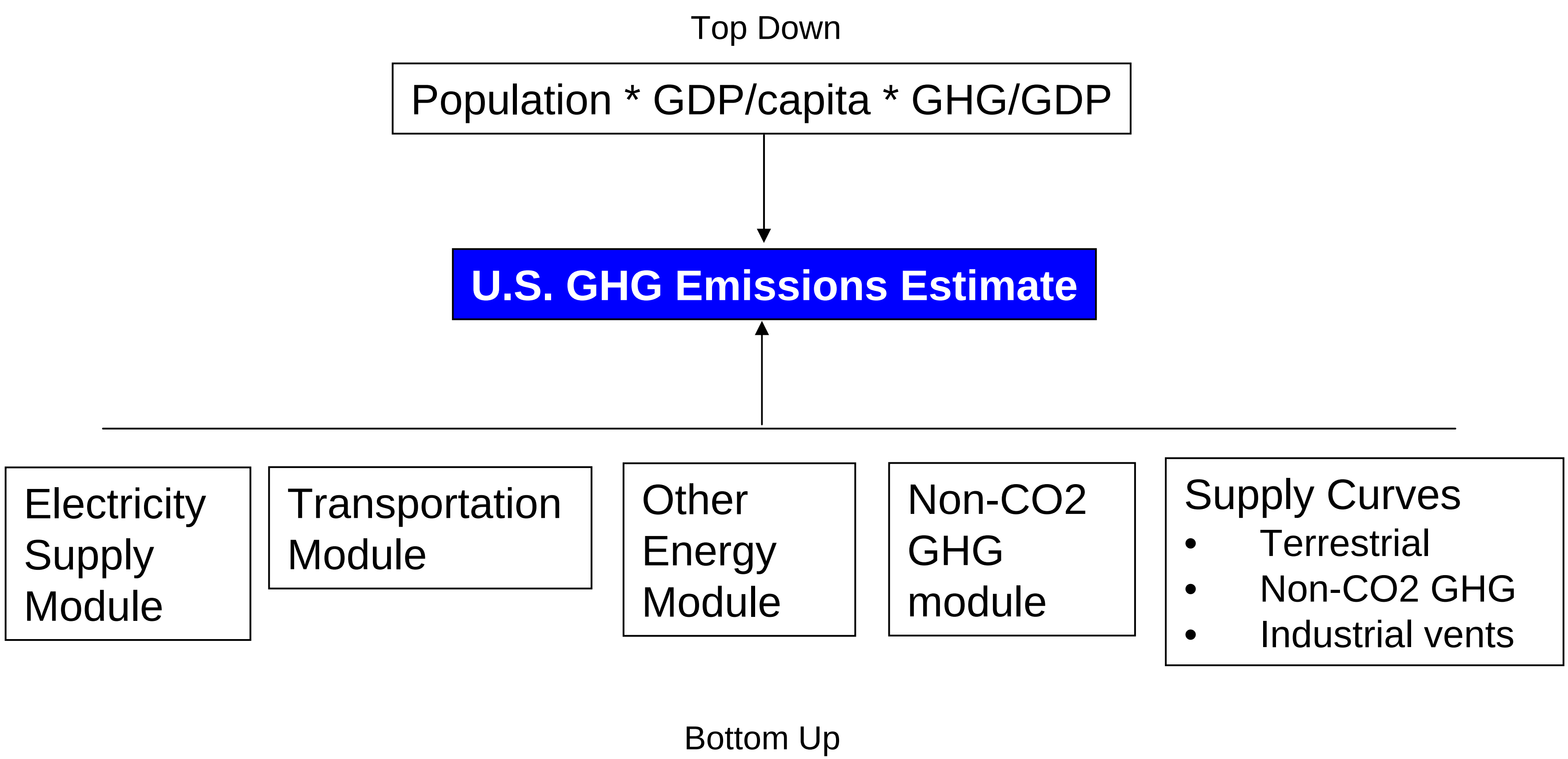
Background: U.S. Situation

- **Enormous coal resources (200 years at current rate)**
- **Declining oil resources**
- **High rate of population increase compared to other developed nations**
- **Increased global prices for natural gas and crude oil have a caused a shift to increased coal use**
  - Long-lived, carbon-intensive assets are being planned and put in place (mines, railroad lines, power plants, coal-liquid facilities)
- **Interest in CO_2 sequestration, considerable geologic storage capacity**

Analysis

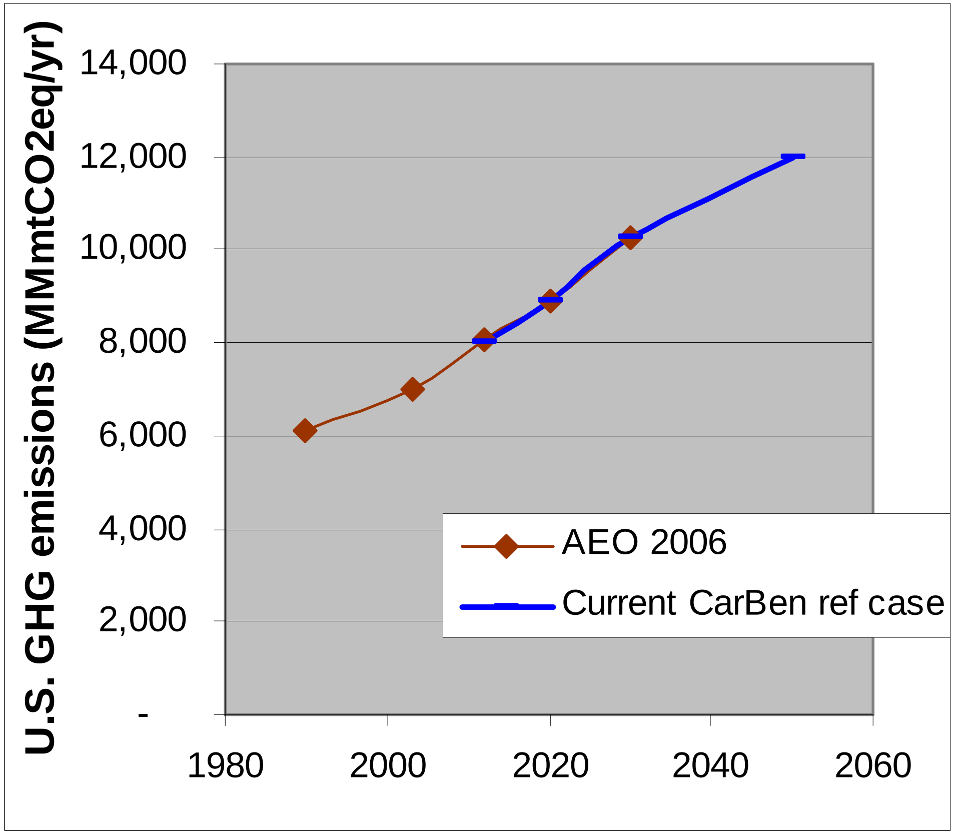
- **Objective**
  - Build a U.S. emissions scenario consistent with stabilization of GHG concentrations in the atmosphere
- **Approach**
  - Detailed sector-by-sector analysis
  - Optimal mix of market and policy approaches
  - Comprehensive portfolio of GHG mitigation options
    - Includes terrestrial and non-CO_2
  - Stages of implementation
    - **2007-2012**
    - **2013-2020**
    - **2021-2030**
    - **2031-2050**

Carbon Sequestration Benefits (CarBen) Model Structure



Reference Case Scenario

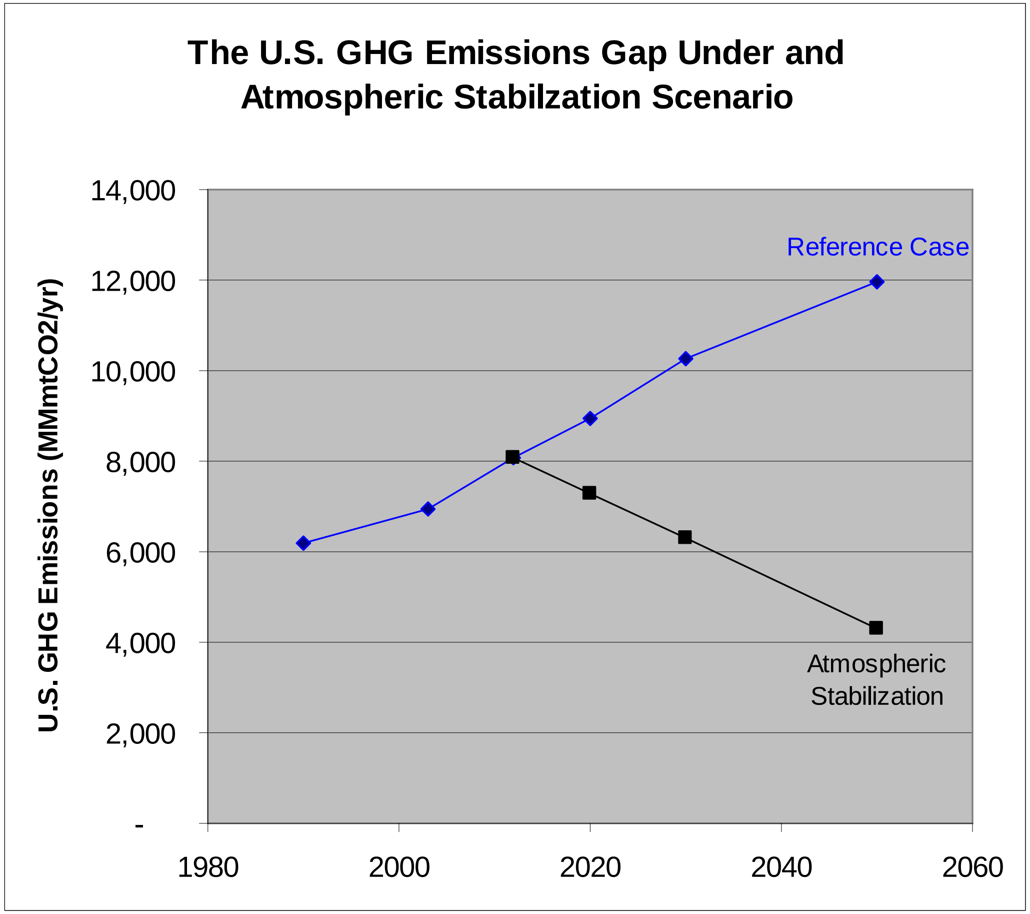
- **Growth in Population**
  - 0.7 – 0.9 %/yr
- **Growth in GDP per capita**
  - 2.4 – 1.9 %/yr
- **Decline in GHG intensity of GDP**
  - 1.8 – 1.4 %/yr



2003 U.S. GHG = 290 MM people * $36,000 GDP per capita * 0.68 kg CO2eq per $ GDP = 7 MMmt CO2/yr

2050 U.S. GHG = 420 MM people * $89,000 GDP per capita * 0.32 kg CO2eq per $ GDP = 12 MMmt CO2/yr

Gap Analysis: Reduced Emissions Scenario



The analysis methodology is to make changes the different inputs to the sector-level models to determine the magnitude of policy actions, market incentives, and technology performance improvements needed to change emissions from the reference case level to the atmospheric stabilization scenario.

The atmospheric stabilization target of 4,400 MMmtCo2eq/yr in 2050 represents 1/9 of the global GHG emissions budget under the WRE 550 ppm scenario. *Nature* VOL 379

How to Fill the Gap

- **Market incentives**
  - Planned $30 per mt CO_2 equivalent avoided emissions incentives level, all sectors
  - Market incentives drive use of terrestrial sequestration and non-CO_2 GHG abatement
- **Policy**
  - Accelerated retirement of pre-1990 coal-fired power plants
  - Vehicle efficiency closer to technically achievable level
- **Accelerated technology development**
  - CO_2 capture and sequestration
  - Improved efficiency of power generation, fuel conversion, and end-use
  - Lower cost ethanol and hydrogen production technologies

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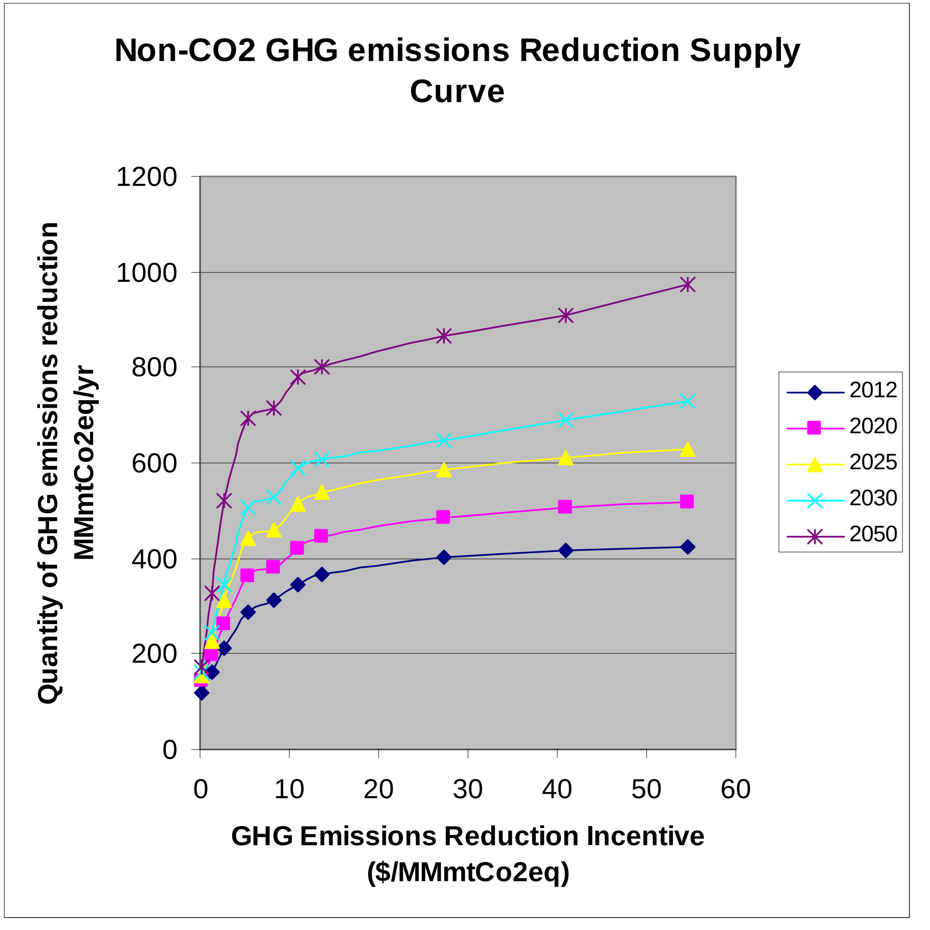
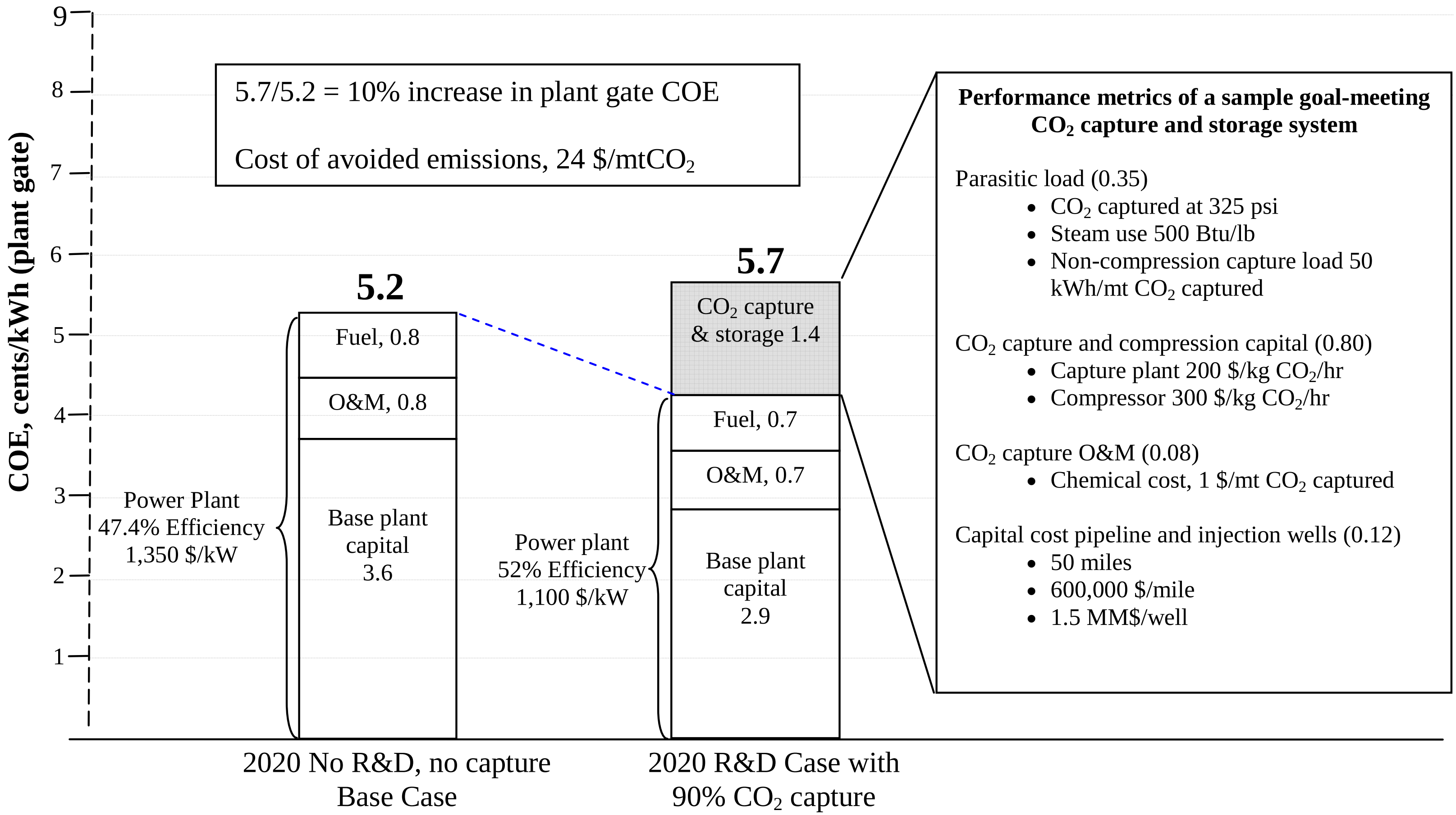
Market-based Incentives
\$30 per ton CO_2

- **Consistent with cost of avoided emissions from a coal fired power plant with CO_2 capture**
- **Favorable region on terrestrial and non-CO_2 GHG emissions marginal abatement cost curves**
- **In the range of current prices paid for CO_2 for EOR**



Market-based Incentives

Cost of Avoided CO_2 from a Power Plant – U.S. DOE



Analysis based on coal cost of 1.1 $/mmBtu, 80% power plant capacity factor, 18% cost of capital, 50 kWh generation loss per mmBtu steam use, 80% CO_2 compressor efficiency, 2,200 psi pipeline pressure, CO_2 pipeline velocity 3 mph, injection well capacity, 1,300 mt CO_2/day/well.

Market-based Incentives
Cost of Avoided Emissions from a Power Plant

- **Cost of avoided emissions**

$$\frac{COE_{wcapture} - COE_{wout}}{Cl_{wout} - Cl_{wcapture}}$$

- **From Roadmap "meeting the goal" figure**

$$\frac{(5.71 - 4.36)\ cents/kWh}{(0.625 - 0.0675)\ kgCO_2/kWh} = 24.2\ \$/mtCO_2\ avoided$$

- **Consistent with estimates contained in IPCC report**
  - New IGCC 13-37 $/mtCo2 avoided (compressed, at plant gate)

Market Incentives

Use of Terrestrial Sequestration and Non-CO_2 GHG Abatement

- **Low-cost opportunities provide large share of early reductions (53% in 2020)**
- **85% of terrestrial reductions come from forestation of pastureland and marginal farmland**
- **Non-CO_2 GHG abatement options do not include N_2O emissions from applied fertilizer**
- **Technically possible quantities from MAC are discounted 50-75% to account for temporal and other barriers**

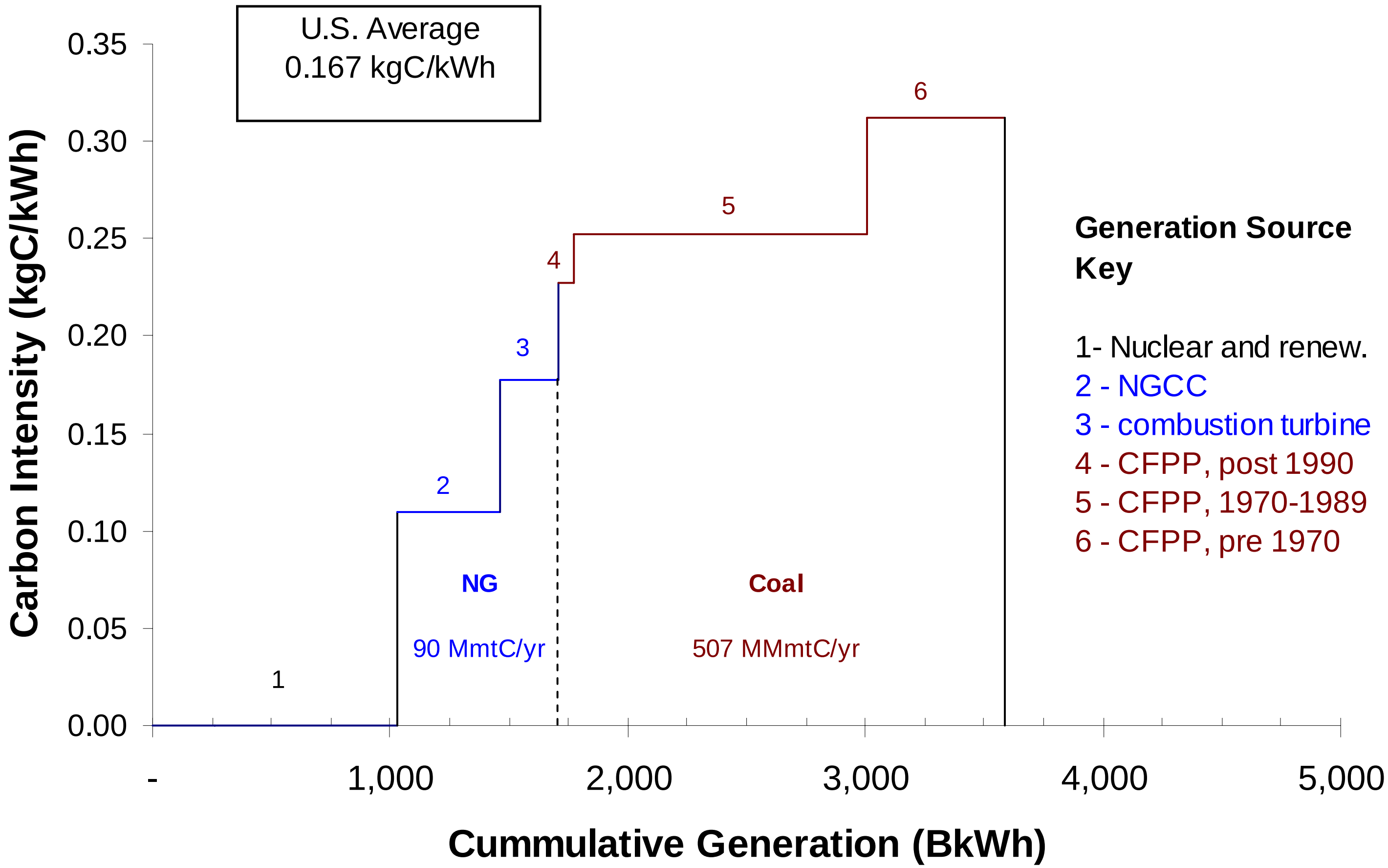
Policy

Earlier Retirement of Power Plants Built Before 1970

- **In 2004 pre-1970 power plants provided 14% of total generation and produced 26% of power sector emissions**
  - Total coal was 50% of generation and 80% of CO_2 emissions
- **Accelerated retirement of old coal plants creates market opportunity for renewables, nuclear, and advanced fossil fuel conversion technologies**
- **Step improvement in efficiency combined with CO_2 capture provide significant change in carbon intensity in coal-coal replacement**
- **Early action is important – generation assets are long-lived**

Policy

Marginal Carbon Intensity Curve, U.S. Electricity Supply



Policy

Vehicle Efficiency Closer to Technically Achievable

- **In the AEO 2006 fleet average light duty vehicle efficiency increases from 20.2 miles per gallon (mpg) in 2004 to 22.5 mpg in 2030.**
- **Technically achievable is in the 50-80 mpg range**
- **Demand for vehicle travel and big cars is largely price inelastic over a wide range – CAFÉ-like policy standards are the optimal approach**
- **Improved platform efficiency combined with increased use of hydrogen and ethanol provides accelerated reduction in GHG emissions per mile**
- **Policies contribute to both GHG emissions abatement and energy security objectives**

Accelerated Technology Development

CO_2 capture and sequestration

	2012	2020	2030	2050
Rate of CO_2 capture, MMmtCO_2/yr *	50	200	650	2,000
Approximate number of CO_2 injection wells required **	250	1,000	3,250	10,000

* Includes capture from power plants, industrial vents, and ethanol and hydrogen fuels

** Average well capacity 200,000 mt CO_2 per year

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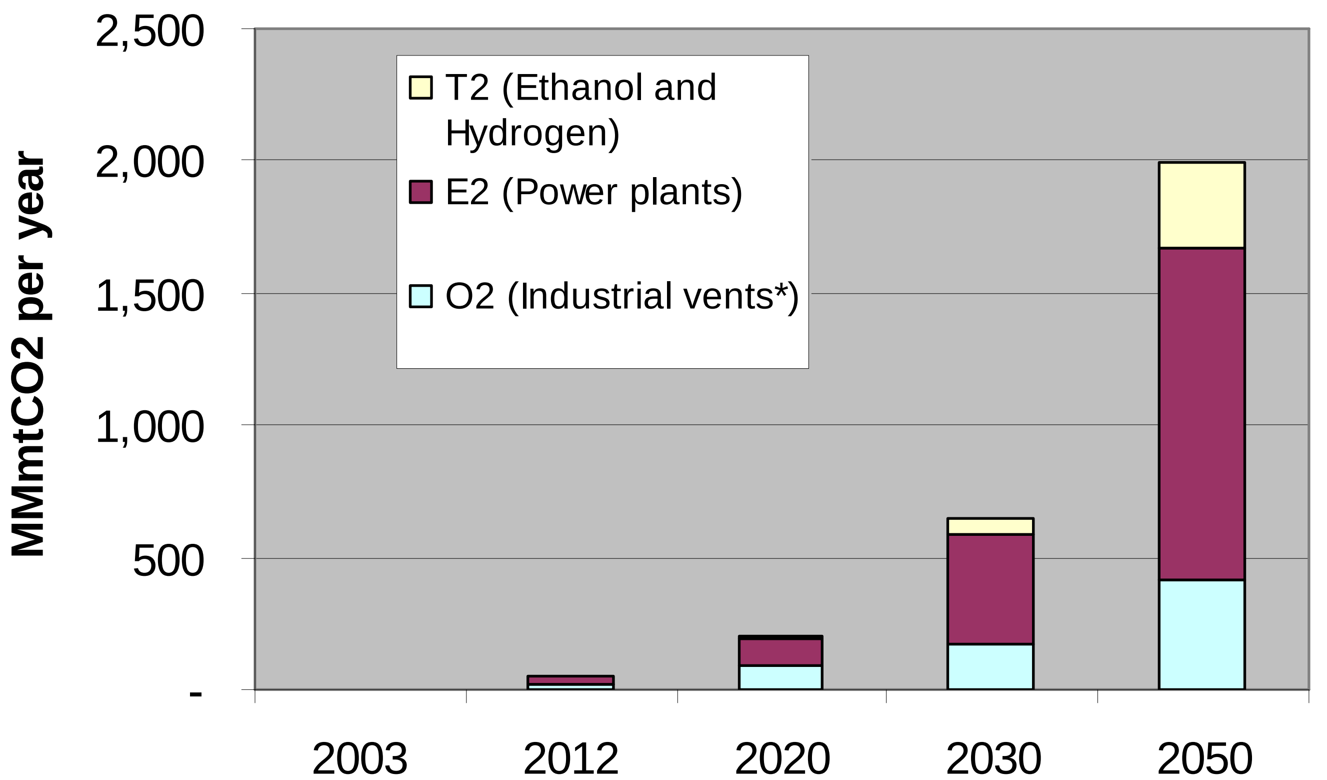
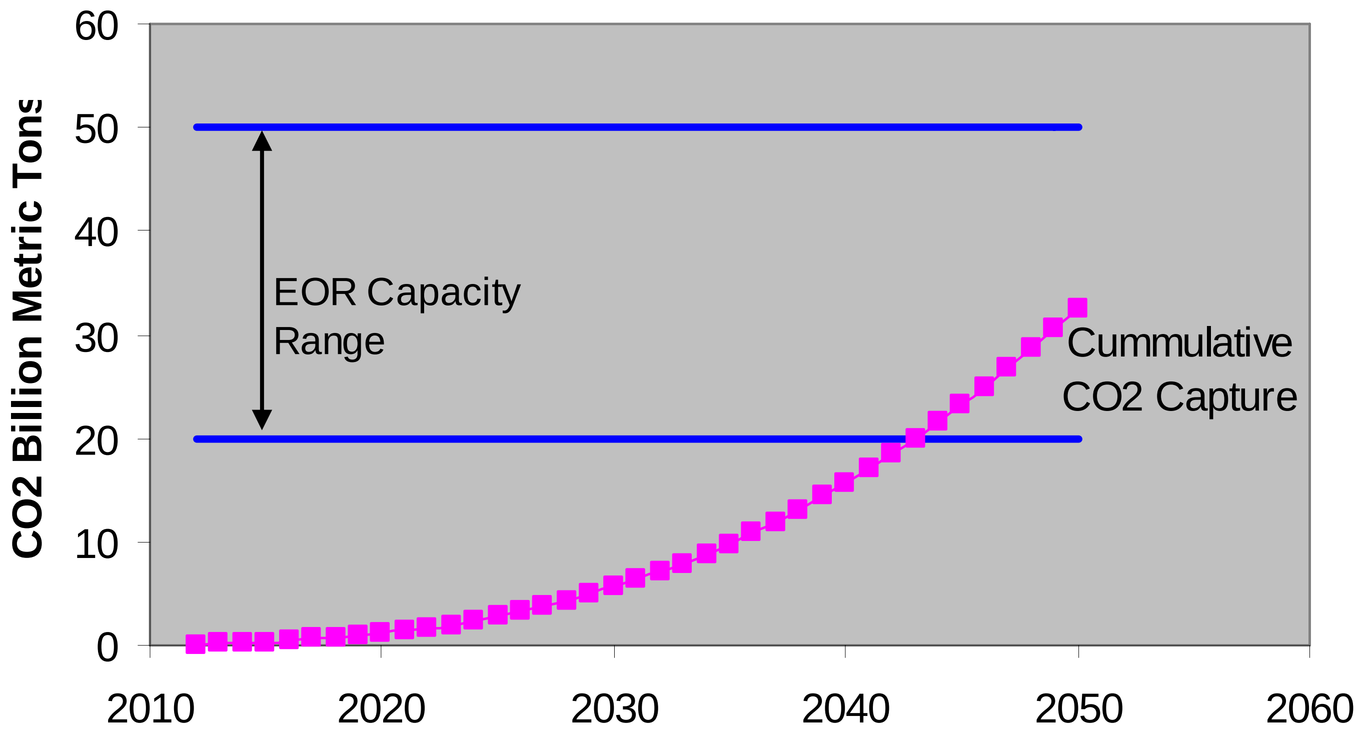
CO2 Captured Under the U.S. Atmospheric Stabilization Scenario



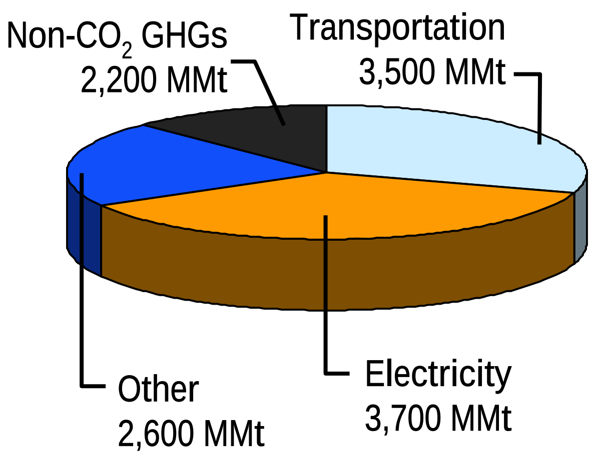
*Industrial vents include natural gas processing, steam reforming, cement mfr, and coal-derived liquids

With Advanced EOR, U.S. Oil Formations Have the Capacity to Accommodate Captured CO_2 Through 2050 and Beyond



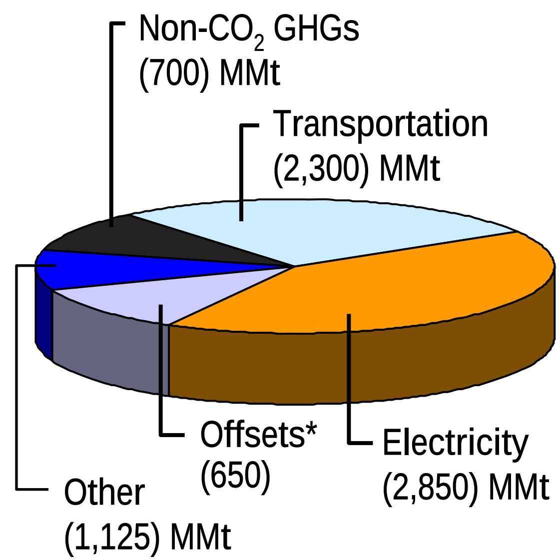
Realizing The Stabilization Of Atmospheric Concentrations Goal!

Reference Case GHG Emissions
<u>Year 2050</u>



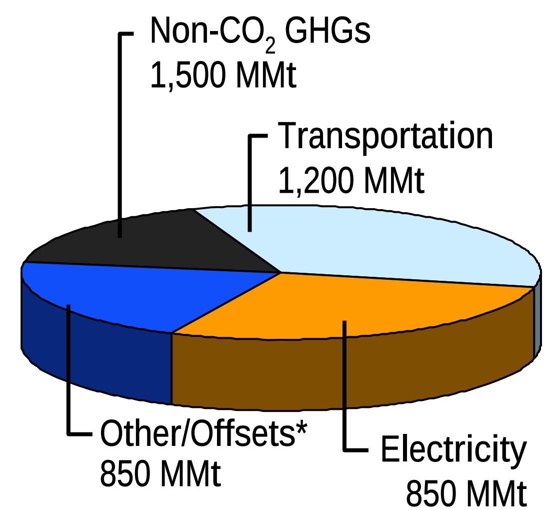
<u>12,000 MMt CO_2</u>

Required Reductions
<u>Year 2050</u>



<u>7,600 MMt CO_2</u>

Atmospheric Stabilization
<u>Year 2050</u>



<u>4,400 MMt CO_2</u>

**Offsets include Enhanced Land Use/Forestry (120/MMt CO_2), Capture of High CO_2 Vents (400 MMt CO_2).*

Checking the Milesposts

	2012		2020		2050	
	Atmospheric Stabilization Case	Reference Case	Atmospheric Stabilization Case	Reference Case	Atmospheric Stabilization Case	Reference Case
GW of pre-1970 power plants retired (cummulative)	35	4	65	7	109	32
CFPPs w/CO2 capture deployed, cumm (avg. 1,000 MW)	3	0	12	0	274	0
Generation from non-hydro renewables as a % of total gen	3.5%	3.1%	4.6%	3.5%	10.0%	6.0%
Efficiency of new coal-fired power plants (no capture)	39%	39%	45%	40%	60%	45%
Efficiency of new NG-fired power plants (no capture)	49%	49%	55%	51%	65%	54%
Average LDV fuel efficiency, mpg	20.5	20.5	25	21.4	50	24.7
No. of ethanol vehicles OTR, millions	13	13	19	16	112	59
No. of H2 vehicles OTR, millions	0	0	0	0	74	0
Total amount of CO2 captured per year, MMmtCO2/yr	41	0	181	0	1962	0
Non CO2 GHG emissions (MMmtCO2eq/yr))	1,423	1,322	1,712	1,470	2,165	1,516
Acres of pastureland forested for carbon storage, millions	33	0	68	0	22	0

Conclusion

- **An aggressive GHG emissions schedule of 4,400 MMmtCO_2 year in 2050 is possible**

- **Optimal approach is a combination of**
  - Numerous little changes, and
  - Several significant themes
    - Accelerated retirement of old coal-fired power plants
    - Improved LDV efficiency
    - Use of terrestrial and non-CO_2 GHG abatement

- **Oil bearing formations have the potential capacity to accommodate captured CO_2 through 2050 and beyond**