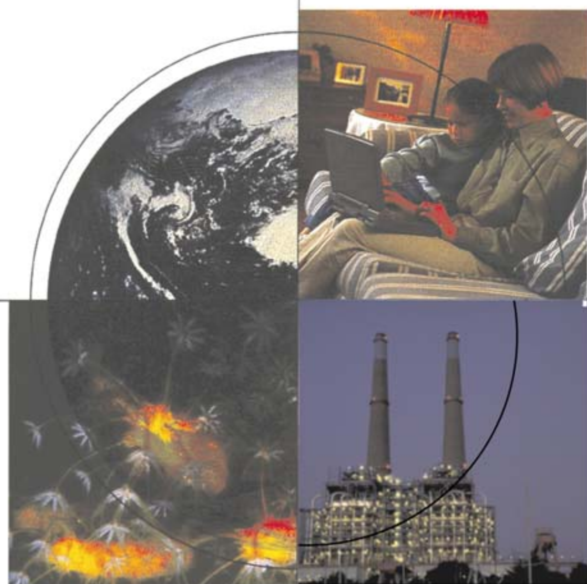
U.S. Economic Benefits of Carbon Capture and Sequestration Given Various Future Energy Scenarios



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First National Conference on Carbon Sequestration
May 14-17, 2001
Washington, DC

Overview

Is the Game Worth the Candle?

Analysis objective: Assess the value of a National investment in carbon sequestration R&D

- Develop a *pathway to stabilization* scenario for U.S. GHG emissions over the next 50 years
- Define and quantify the role for carbon sequestration
  - Mid term, opportunities for emissions reduction with collateral energy supply and economic benefits
  - Long term, options with large capacity to provide deep emissions reductions
- Provide insights for policy and technology development

DOE Carbon Sequestration R&D Program

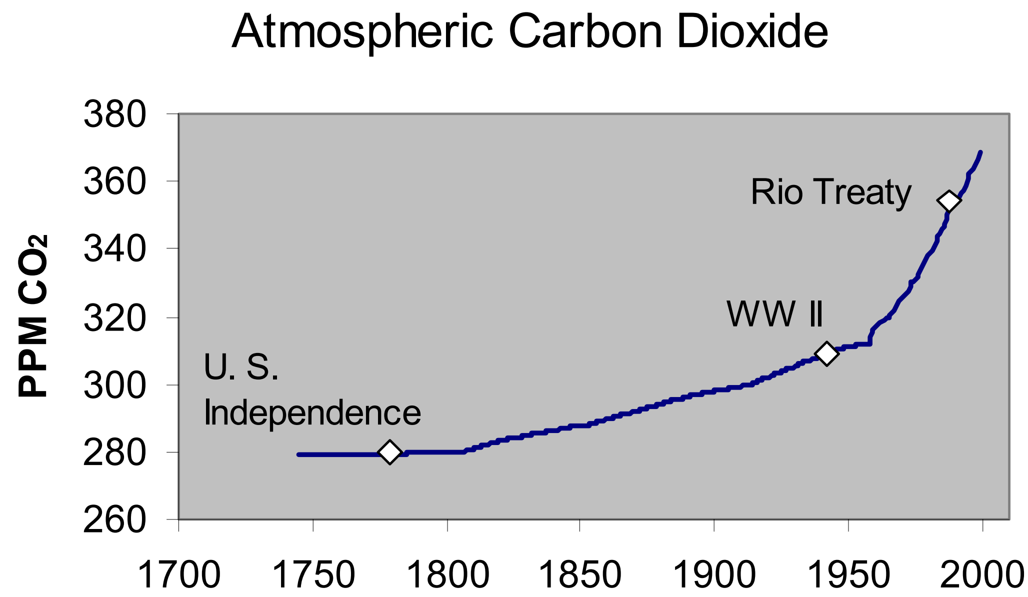
- Program Goals
  - Reduce the cost of carbon sequestration such that it increases the cost of energy services by less than 5%
  - Obtain improved scientific understanding to ensure the environmental acceptability of CO_2 storage
  - Develop technologies to reduce non-CO_2 GHGs

- The strategy is to develop technology partnering with industry, academia, and international groups

The Basis for GHG Emissions Reduction

1992 Rio Treaty

"Stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"

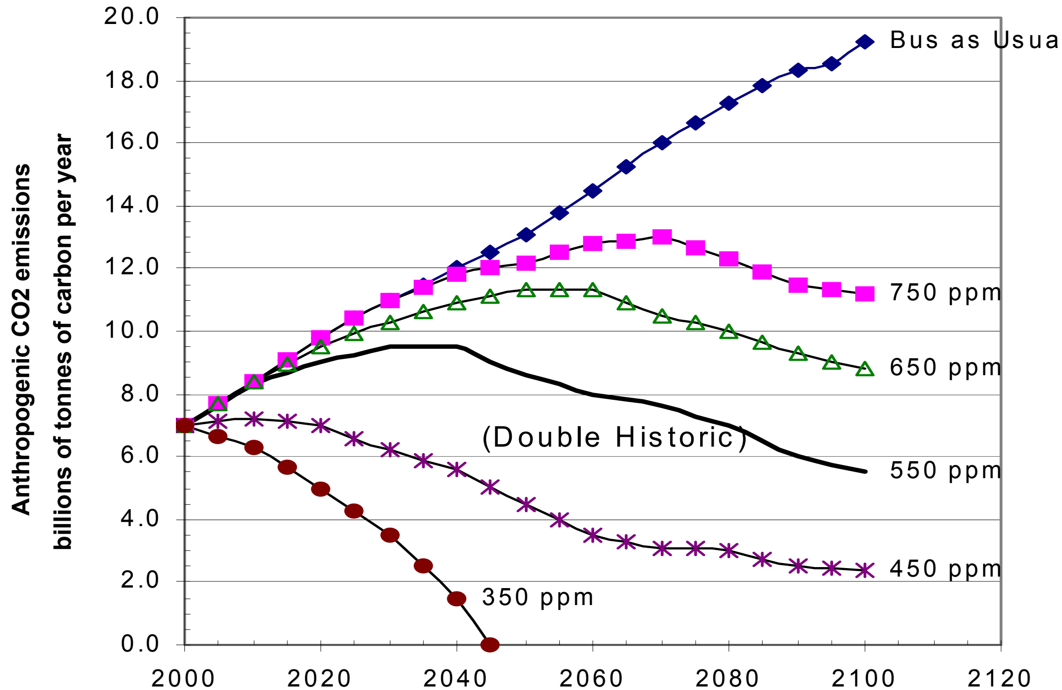


Reference point. In 1999 the concentration of CO_2 increased by roughly 2 ppm.

Atmospheric Stabilization

Future GHG Emissions Scenarios

- Stabilization scenarios allow several decades for technology development
- In the long term, all scenarios require deep reductions in carbon emissions



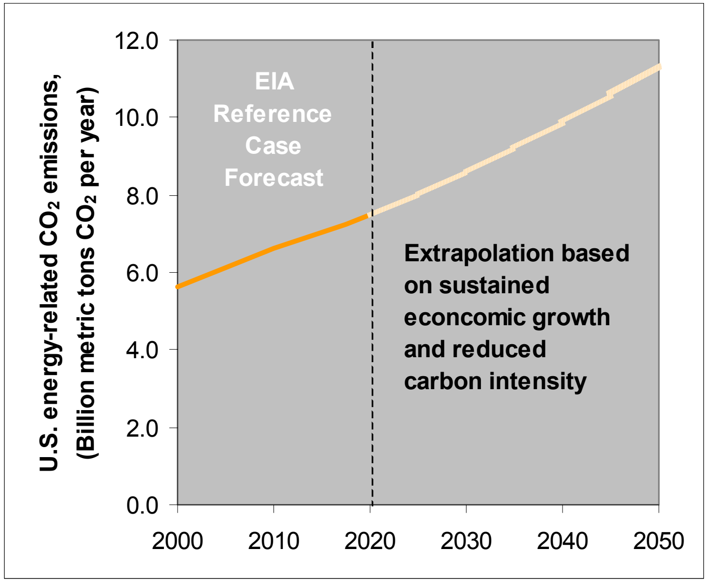
Source: *Nature*, Volume 379, January 18, 1996, pp. 240-243

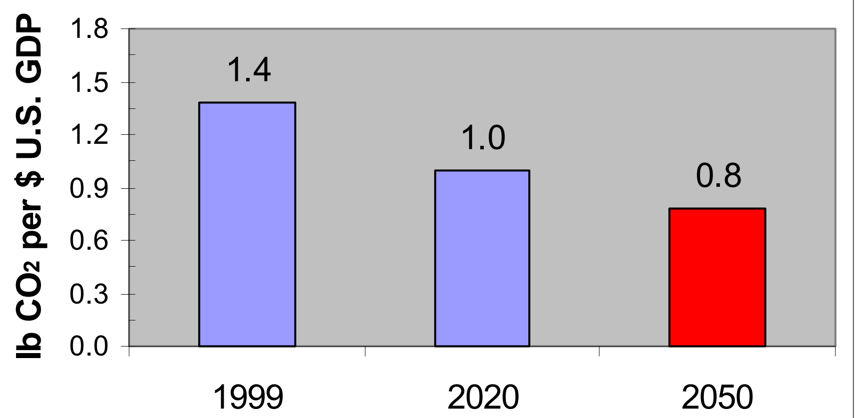
Reference Point: "We must stress that, even from the narrow perspective of a cost-effectiveness analysis, our results should not be misinterpreted as a "do nothing" or "wait and see" policy." text from the 1996 WRE article in *Nature*

U.S. GHG Emissions Scenario, 2000-2050

Carbon Emissions from Energy

- CO_2 from energy based on the AEO 2001 reference case forecast, 2020 (U.S. EIA)
  - GDP grows 3% per year
  - CO_2 emissions per unit of economic activity decrease 1.4% per year
- Extrapolate AEO 2001 reference case to 2050
  - 2.2 % annual GDP growth
  - 0.8 % decrease in carbon emissions per unit GDP
  - Net 1.4% growth in carbon emissions per year



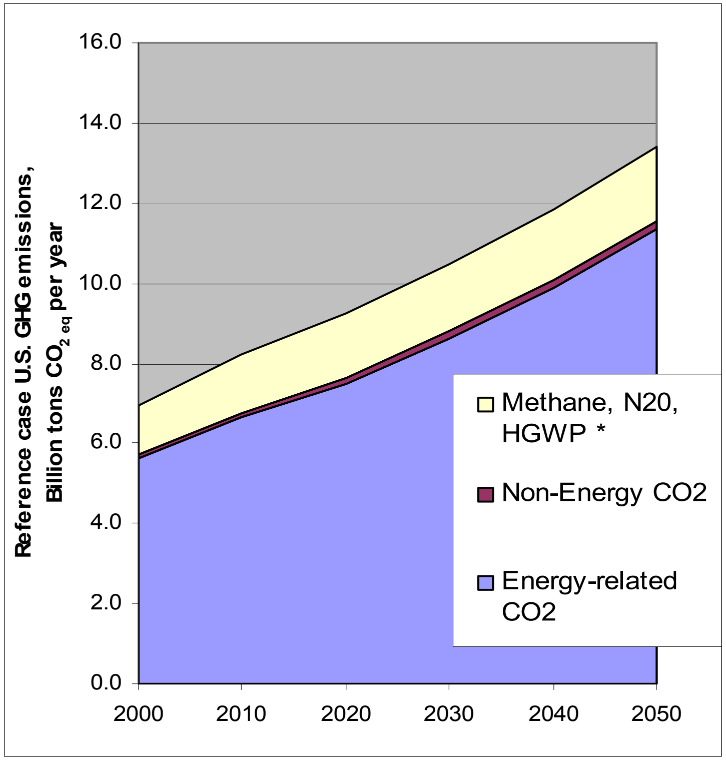


Source: 2000, 2020 AEO 2001; 2050 AEO 2001 extrapolated, 0.8% annual decrease in GHG intensity of GDP

U.S. GHG Emissions Scenario, 2000-2050

Total U.S. GHG Emissions

- Total GHG is the sum of:
  - energy-related CO_2
  - non-energy CO_2 and
  - non-CO_2 GHG*
- Between 2000 and 2050, total U.S. GHG emissions increase from 7 to 13 billion tons $CO_{2\ eq}$ per year



* Reported in 100 year CO_2 equivalents

Policy Dilemma

- How to sustain economic growth yet make progress toward the long-term goal of atmospheric stabilization?
- Unrealistic to assume that technology progress will occur in the absence of significant R&D investment and economic incentives
- Effective policy will find a balance

U.S. GHG Emissions Scenario, 2000-2050

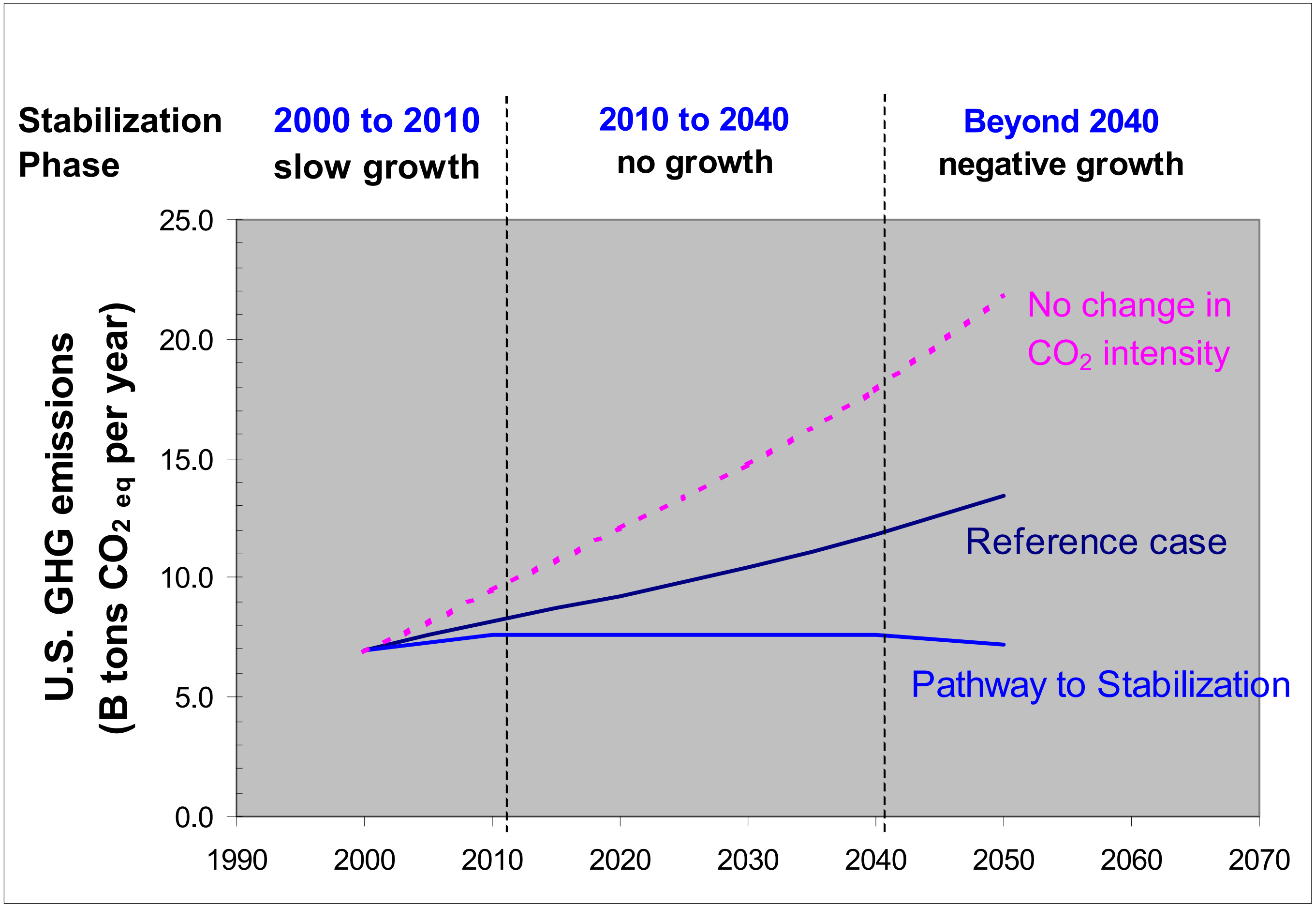
Pathway to Stabilization

- 2000 to 2010 rate of growth in GHG emissions half of reference case
- 2010 to 2040 rate of growth in GHG emissions held to zero, consistent with sequestration R&D program plan goal
- Beyond 2040 GHG emissions reduced as a part of a global strategy toward atmospheric stabilization (550 ppm)
- Guiding principles
  - Market incentives drive significant near-term action
  - Orderly capital stock turnover to reduce cost

U.S. GHG Emissions Scenario, 2000-2050

The gap between reference and stabilization path

Over time, a large difference arises between steadily increasing GHG emissions and the absolute global emissions targets associated with atmospheric stabilization



U.S. GHG Emissions Forecast, 2000-2050

Filling the Gap

GHG emissions reduction requirements million metric tons of $CO_{2\ eq}$ per yr*	2020	2050
GHG emissions reduction need (delta between reference case and pathway to stabilization)	1,700	6,200
Reduction from Non-CO_2 GHGs	150	180
Reduction from low-tech forestry (LTF) and agricultural practices	450	650
Remaining requirements for sequestration and other options	*1,100*	*5,400*

Reference point

In the AEO 2001 reference case scenario, by 2020 improved efficiency and the use of renewables and other low-carbon fuels effectively lowers GHG emissions by 2,900 million tons $CO_{2\ eq}$ per year.

2,900 millions tons of CO_{2eq} is equal to 42% of current US GHG emissions.

** Divide billion metric tons of $CO_{2\ eq}$ by 3.67 to get weight of carbon*

Mid-term options with low-cost potential

- There are also advanced terrestrial applications that require R&D but have the potential to provide low net cost GHG emissions reductions in the mid term
- There exist a significant number of CO_2 emissions sources amenable to capture – they will be used first to supply value-added geologic sequestration
  - Natural gas processing
  - Petroleum refineries
  - Fertilizer manufacture
  - Gasification-based power generation
  - Gasification-based industrial processes

Storage in geologic formations with resource recovery

- Formations with potential for value-added resource recovery include:
  - depleted oil fields
  - unmineable coal seams
  - depleted gas fields
  - unconventional gas fields

- Market incentives for CO_2 emissions reduction and enhanced resource recovery both provide revenue-generating C-business model.

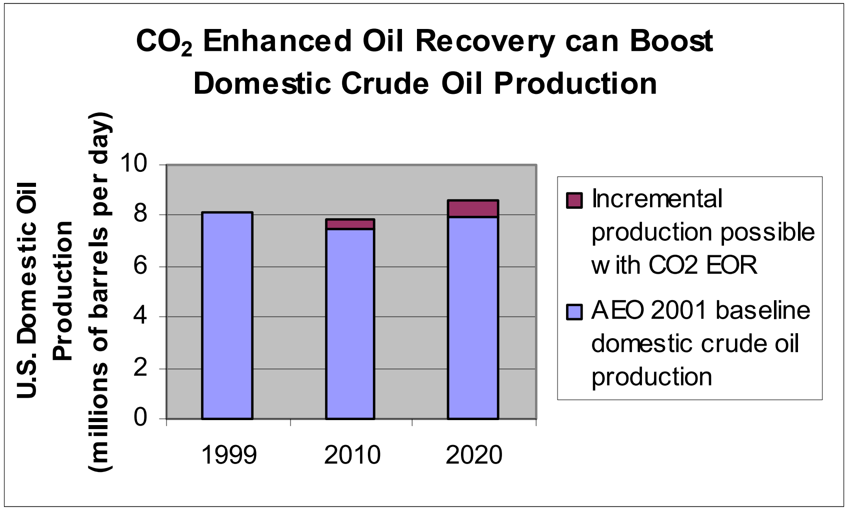
Reference point

In 1999, 30 million tons of CO_2 were used in enhanced oil recovery operations in the United States, 7 from industrial sources

National Benefits of Carbon Sequestration R&D

Storage in geologic formations with resource recovery

- Analysis conducted by Advanced Resources International (ARI) shows that by 2020 CO_2 EOR and ECBM could provide:
  - 200 MM tons $CO_{2\ eq}$ per year reduction in GHG emissions by 2020
  - 260 million barrels per year incremental domestic crude oil production
  - 1.1 tcf per year incremental domestic natural gas production
  - 8.3 billion dollars per year reduction in the U.S. trade deficit



There is more value-added capacity beyond ARI's initial estimate

ARI considered only EOR and ECBM sites most amenable to CO_2 storage. Deployments in 2010 and 2020 based on 25$/bbl crude oil market price and 3 $/Mscf natural gas market price, and 5-10 $/ton CO_2 cost. EOR 10,000 scf CO_2 per bbl; ECBM 3 scf CO_2 per scf methane

Advanced technology is needed for longer-term deep emissions reduction

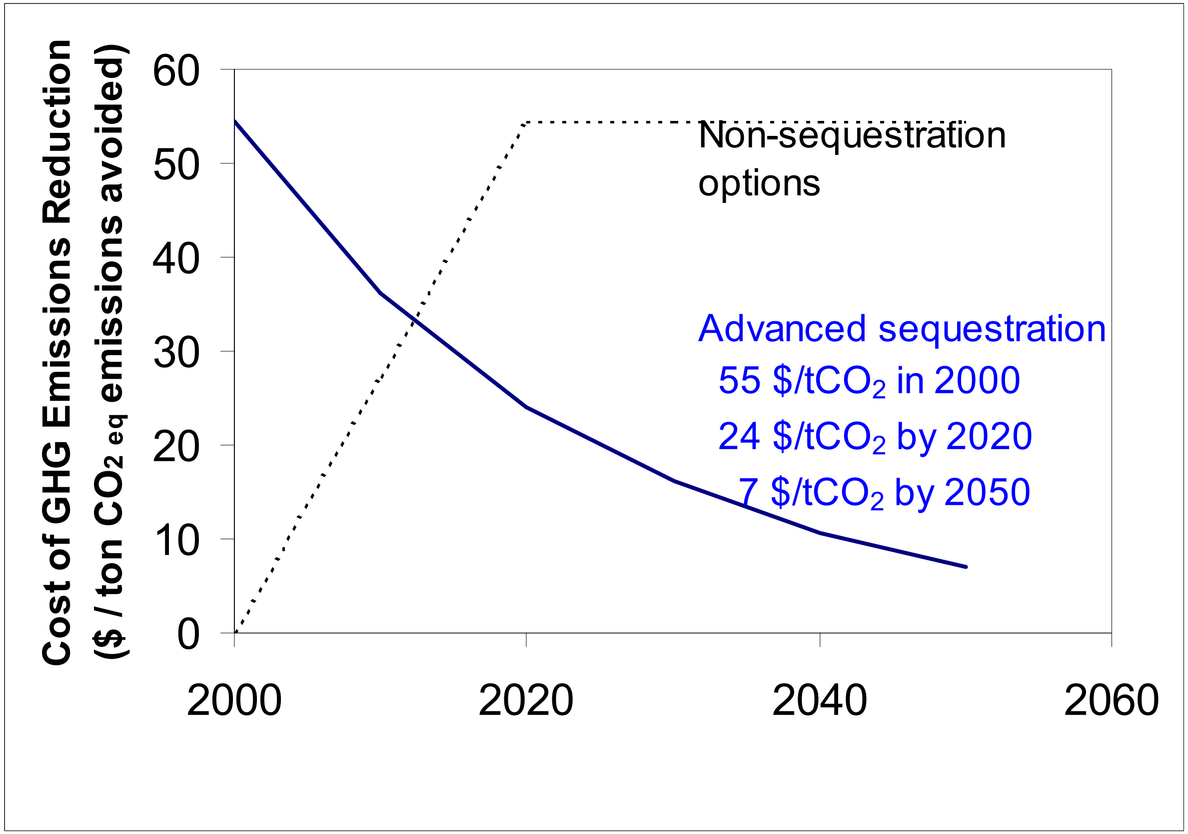
GHG emissions (billion tons $CO_{2\ eq}$ per year)	**2020**	**2050**
GHG emissions reduction need (delta between reference case and pathway to stabilization)	1,700	6,200
Reduction from Non-CO_2 GHGs	150	0.18
Reduction from forestry and agricultural practices	450	650
Mid-term carbon sequestration with collateral benefits	*200*	*330*
Remaining emissions reduction requirements	**900**	**5,040**

Reference point

200 million tons of CO_2 is roughly equivalent to the annual CO_2 emissions from 100 coal-fired power plants

R&D for advanced sequestration

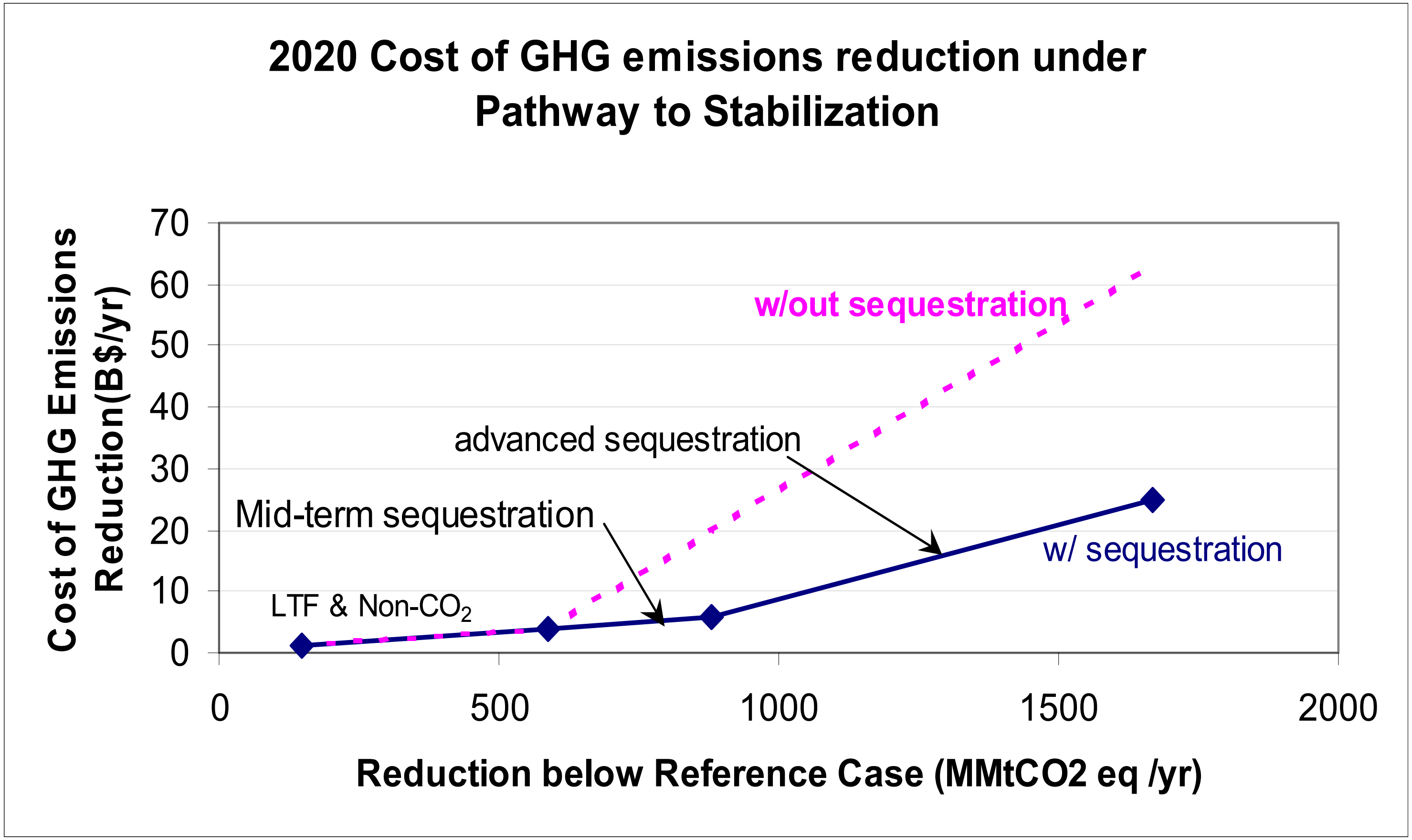
- Eventually all the low-hanging fruit will be picked
- Sustained R&D to lower the cost of advanced options
  - Capture & separation
  - Conversion and reuse
  - Storage without enhanced resource recovery



Quotable: "You soon run into cars and coal" *German official on the difficulties his country is having in reducing GHG emissions*

National Benefits of Carbon Sequestration R&D

Reference Case Economic Benefits



Reference point: Based on the reference case projection in the AEO 2001: In 2020 the U.S. will spend roughly 600 billion dollars on oil imports.

National Benefits of Carbon Sequestration R&D

Reference Case Economic Benefits

	2020	**2050**
Value-added geologic sequestration		
Rate of sequestration, $MMtCO_{2\ eq}$/yr	200	330
Annual savings, Billions of US$/yr	14	23
Advanced capture and sequestration		
Rate of sequestration, $MMtCO_{2\ eq}$ /yr	900	5,040
Annual savings, Billions of US$/yr	24	232
Cumulative benefits		
Billions of US$	170	4,000

Sensitivity Analysis

- Less aggressive stabilization scenario
  - U.S. GHG emissions grow at half of the reference case through 2020 instead of 2010 in the reference case
  - Zero emissions growth post 2020
  - Reduction below 2020 level begin in 2040.
- Effects on Sequestration R&D benefits
  - Mid-term sequestration options are still fully applied
  - Need for advanced sequestration in 2020 is reduced from 900 to 300 million tons of CO_2 per year

Cumulative R&D benefits (Billions of dollars)		
	Through 2020	Through 2050
50% of ref case growth through 2010	170	4,000
50% of ref case growth through 2020	120	3,300

Key Insights

- A transparent modeling analysis can demonstrate the large economic benefits of sequestration R&D
- Progress toward atmospheric stabilization will require large reductions in GHG emissions over the next 50 years
- Potentially there are pathways toward atmospheric stabilization that are economically viable, environmentally responsible, and provide energy supply benefits along the way
- Achieving the potential of these pathways will require sustained public/private R&D combined with market-based performance incentives

Key Insights (cont.)

- In the mid term, carbon sequestration offers low-cost options for emissions reduction that provide collateral energy supply and economic benefits
- In the longer term, carbon sequestration options can provide capacity for deep GHG emissions reductions

For More Information

Please visit our web sites:

Fossil Energy HQ:

http://www.fe.doe.gov/coal_power/sequestration/index.shtml

National Energy Technology Laboratories:

http://www.netl.doe.gov/products/sequestration

International Energy Agency Greenhouse Gas (IEAGHG) R&D Programme:

http://www.ieagreen.org.uk/

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Pace of Technology Progress

- Assume R&D will reduce the cost of carbon sequestration for broad applications by 4% per year
- Rate is consistent with technology progress assumptions in other studies
  - NPC natural gas study used 4% annual cost reductions for deepwater platforms and 3.5% cost reductions for D&C cost (Fast Technology Advance Case)
  - EIA uses 3% annual cost reductions for offshore drilling and 4% to 8% annual improvements in new field discoveries (Rapid Technology Progress Case)

Current sequestration cost

- The current CO_2 capture and sequestration cost of $200/tC was established as follows:

	$/tC avoided
Capture[1]	90[2] – 170[3]
Transportation	20[4] – 50[5]
Sequestration[6]	50 -100
Total	160 – 320

[1] Costs of capture include pressuring CO2 to 110 to 150 bar for transmission

[2] Retrofit pulverized coal with O2 and recycle CO2 (Simbeck and McDonald, 2000)

[3] New Pulverized coal with post-combustion capture (Edmunds, Freund, and Dooley, 2000)

[4] Short distance gathering and transportation at $0.25 per Mcf of CO2

[5] Long distance, high volume transportation at $0.75 per Mcf of CO2

[6] Geologic sequestration in depleted oil and gas fields plus enhanced CBM (Stevens and Kuuskraa, 2000)

Benefits Calculation Method

- Method
  - If \$seq > \$other options, then no benefit
  - If \$seq < \$other options, then benefit = (\$other - \$seq)*quantity

- Assume cost of other options is zero today and increases with increased demand for emissions reduction. Cost levels out at \$200 per tC in 2020

- Sequestration cost. Value-added geologic averages \$25/mt; broad based starts at \$200 per ton and decreases to 33 \$/mtC by 2050.