

Technological Options to Address Global Climate Change



*First National Conference
on Carbon Sequestration*

May 14-17, 2001

Rita A. Bajura, Director
National Energy Technology Laboratory



The Climate Change Debate



A lot of hot air?
Skeptics unsure it's a real problem

By Tom Corcoran
 Cassidy Crowley

(COW) —
 Valencia
 Dinosaur, a
 Eocene, almost
 more for a living
 Is the a failure?
 Hypo.

"I don't see any
 real global warming," she says. "I haven't noticed any real change
 in the temperatures."

But we have many concerns along the Florida coast in the
 21st. There have been predictions that global warming would
 mean rising seas that would cause large portions of the Florida
 coast.

But Martin Castro, who still resides in South Florida, is
 both) and any signs that have begun any concerned about

What Global Warming?
 As the world heats up, the public sleepily goes wild

from the m...

EDITORIAL

An Unfortunate U-Turn on Carbon

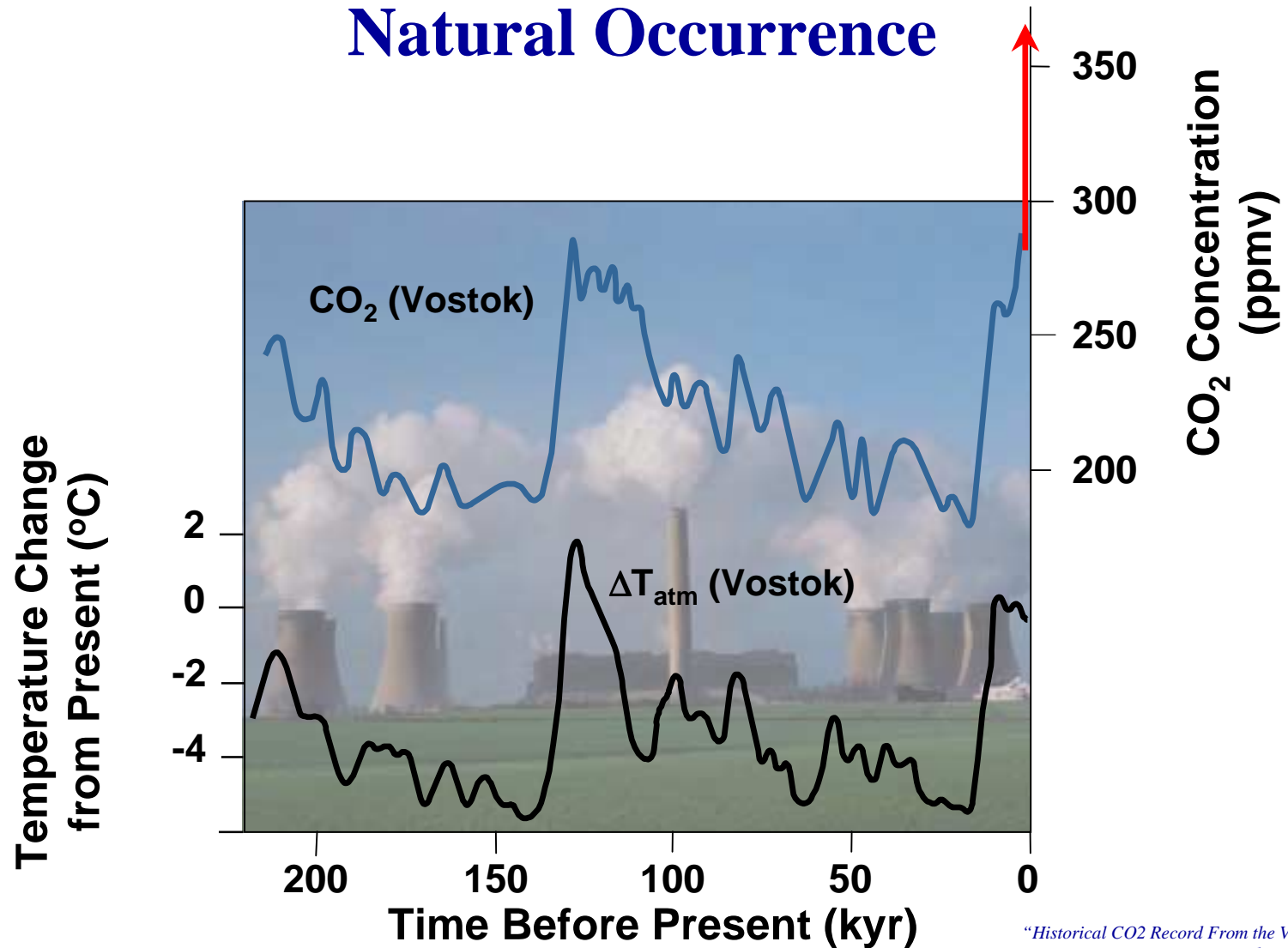
Editorial text discussing carbon emissions and policy.

CLIMATE CHANGE IN THE CABINET ROOM

<p>BELIEVERS EPA chief Christie Whitman and Treasury Secretary Paul O'Neill write to the President urging action on global warming. Both were reappointed, and Whitman had to defend Bush's position publicly.</p>	<p>SKEPTICS Energy Secretary Spencer Abraham and Vice President Dick Cheney are worried more about the economy than the climate. Cheney's energy task force is working on a plan to speed more drilling for fossil fuel.</p>
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CO₂ Concentrations Beyond Range of Natural Occurrence



"Historical CO₂ Record From the Vostok Ice Core"

J.M. Barnolo et al, August 1999

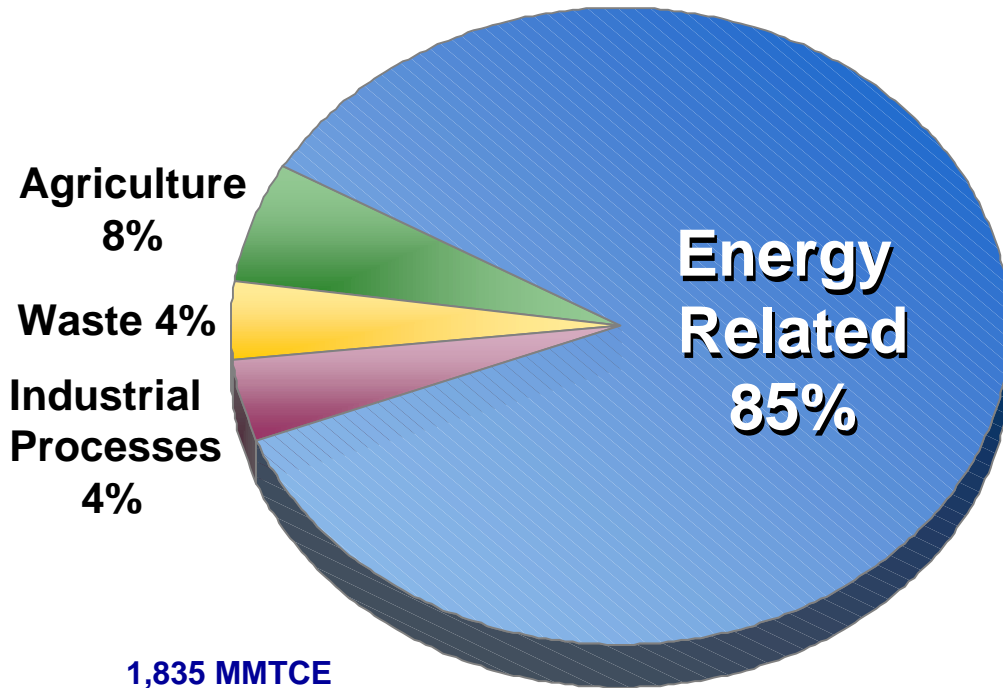
www.cdiac.esd.ornl.gov/trends/co2/vostok.icecore.co2



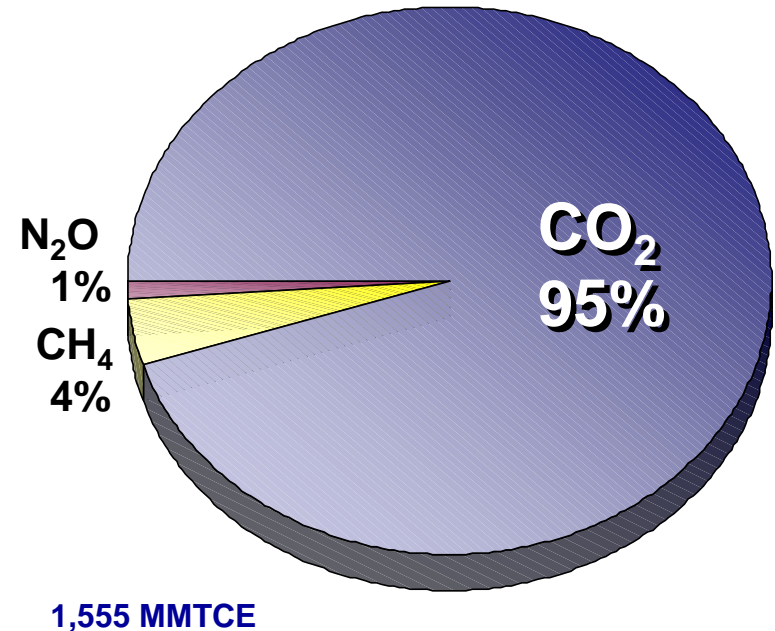
Energy Is Major Contributor

U.S. Anthropogenic Greenhouse Gas Emissions

*85% of Emissions
Energy Related*

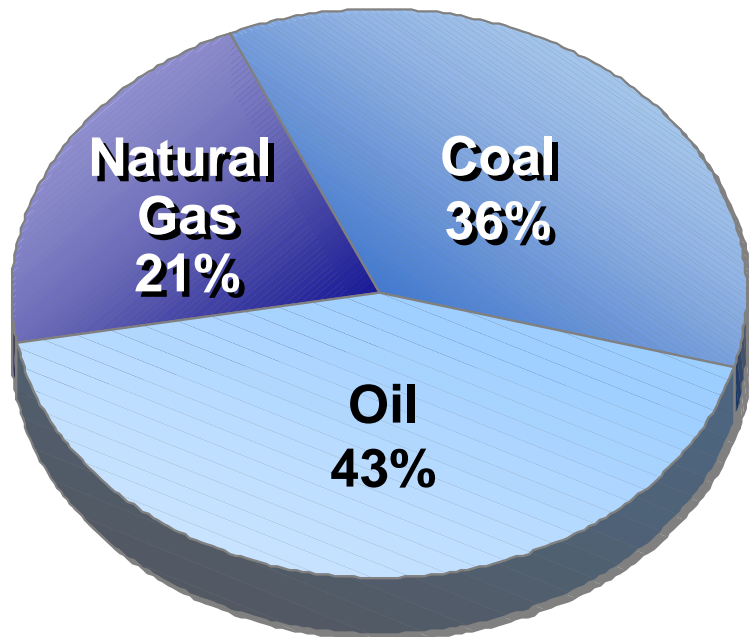


*CO₂ Dominates Energy-
Related Emissions*

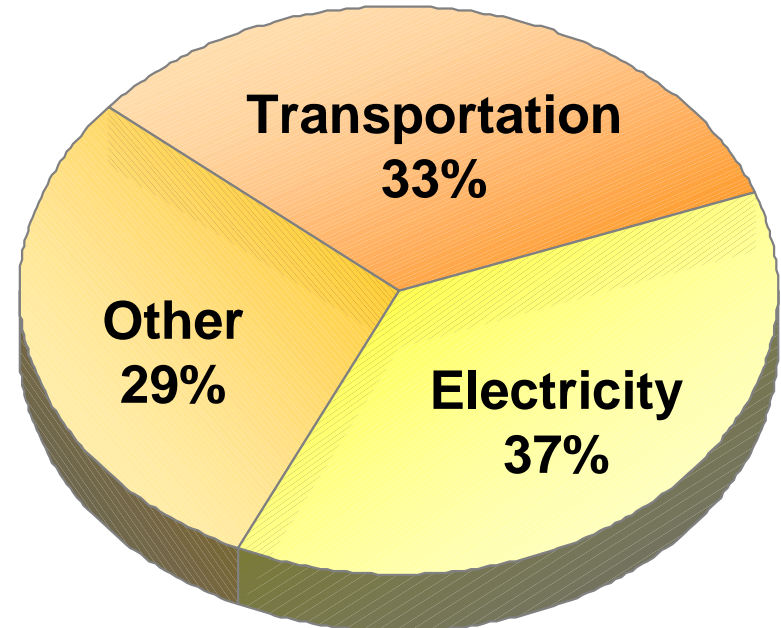


All Fossil-Based Sources and Uses Contribute *1999 U.S. CO₂ Emissions From Energy*

Fuel Sources



End Uses

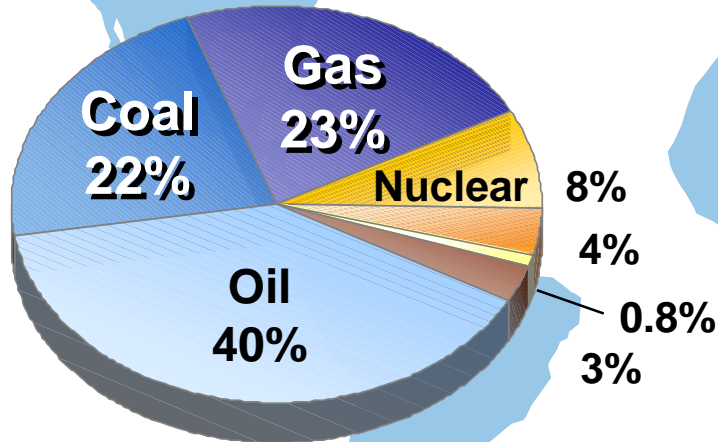


U.S. and World Economies Based on Fossil Fuels

United States

85% Fossil Energy

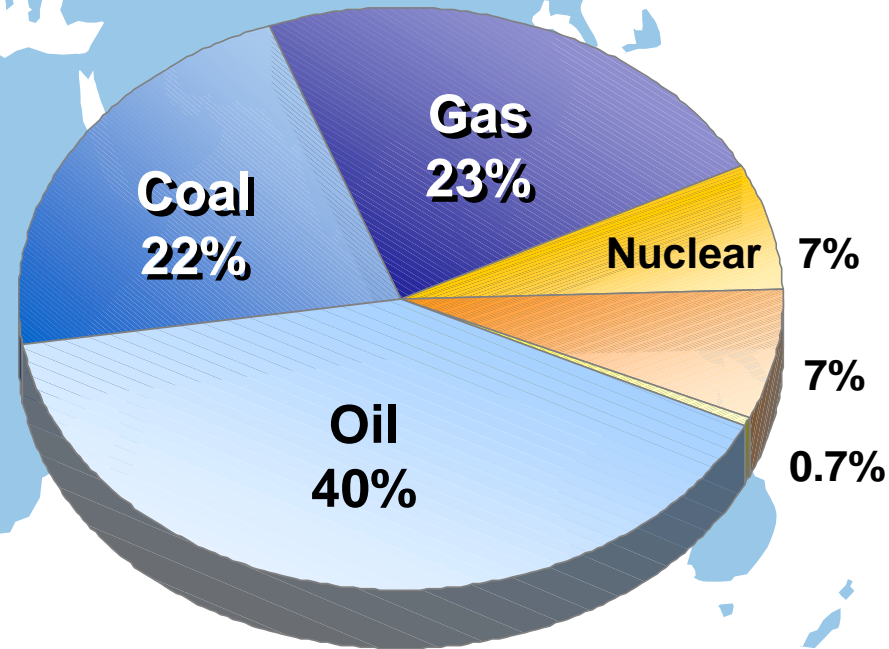
96 Qbtu / yr



World

85% Fossil Energy

382 Qbtu / yr



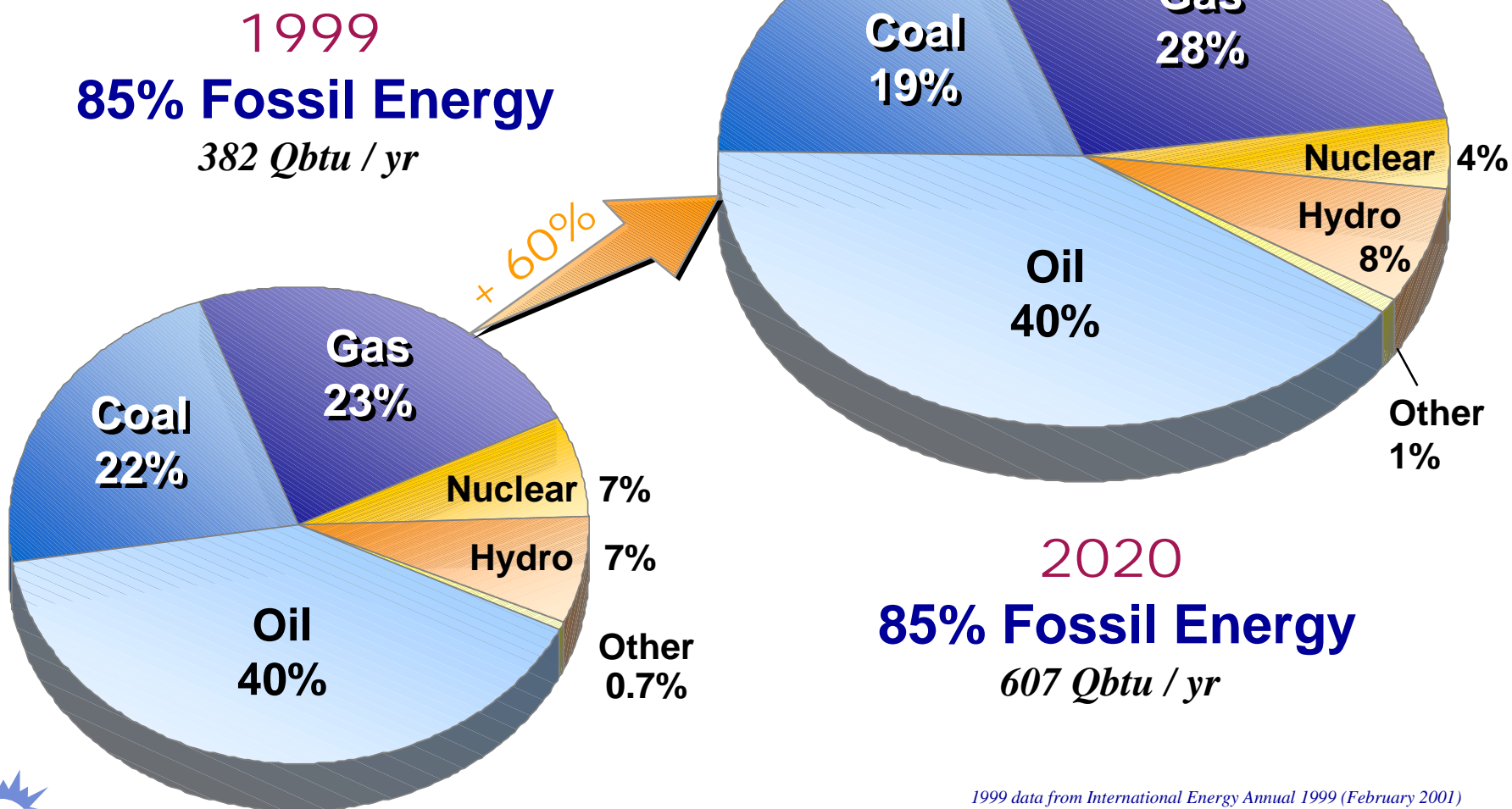
World data from International Energy Annual 1999 (February 2001)

U.S. data from Renewable Energy Annual 2000 (March 2001)

World data does not include non-grid-connected biomass

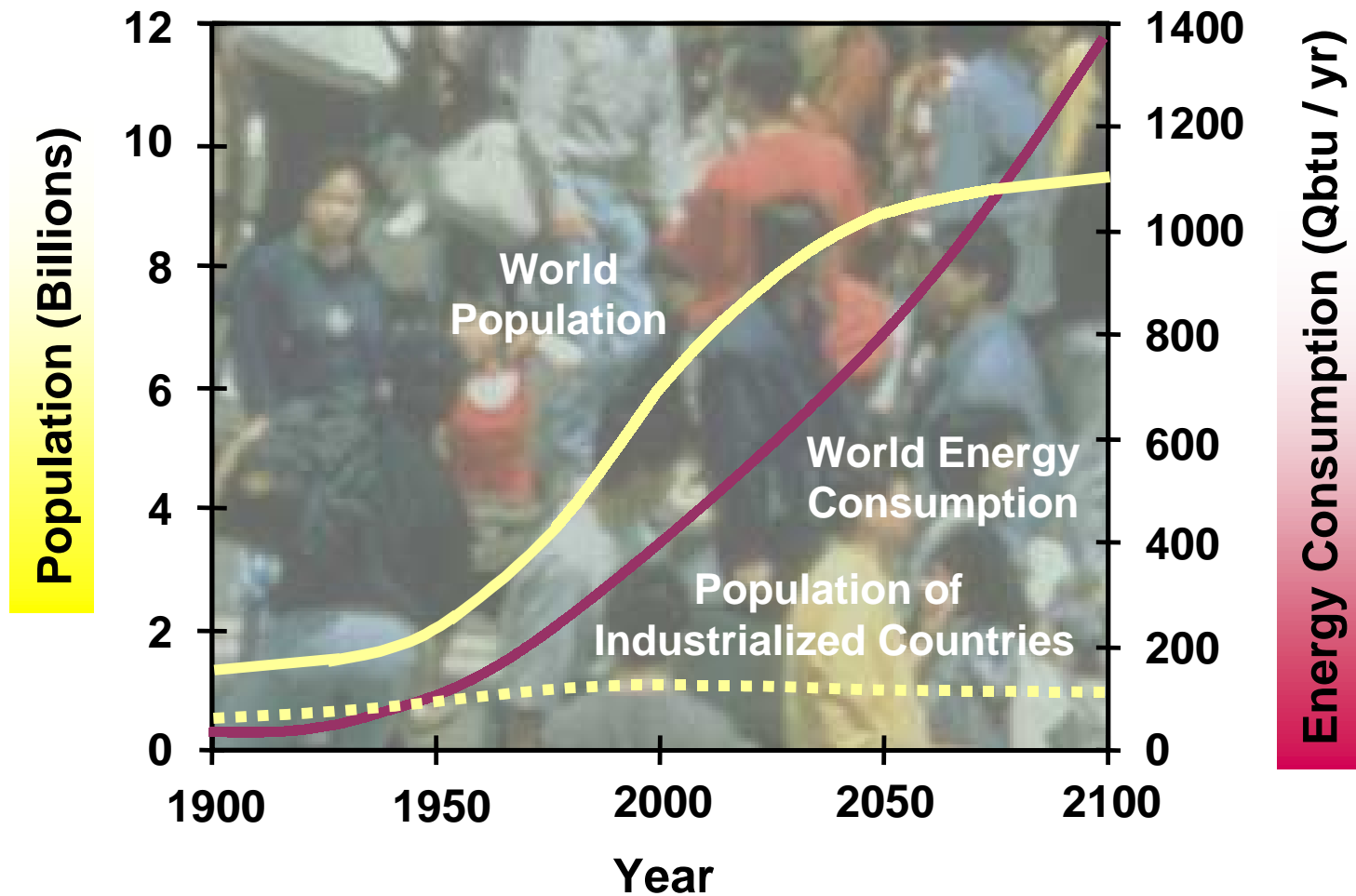


Fossil Fuels Will Continue as Key to World Economy



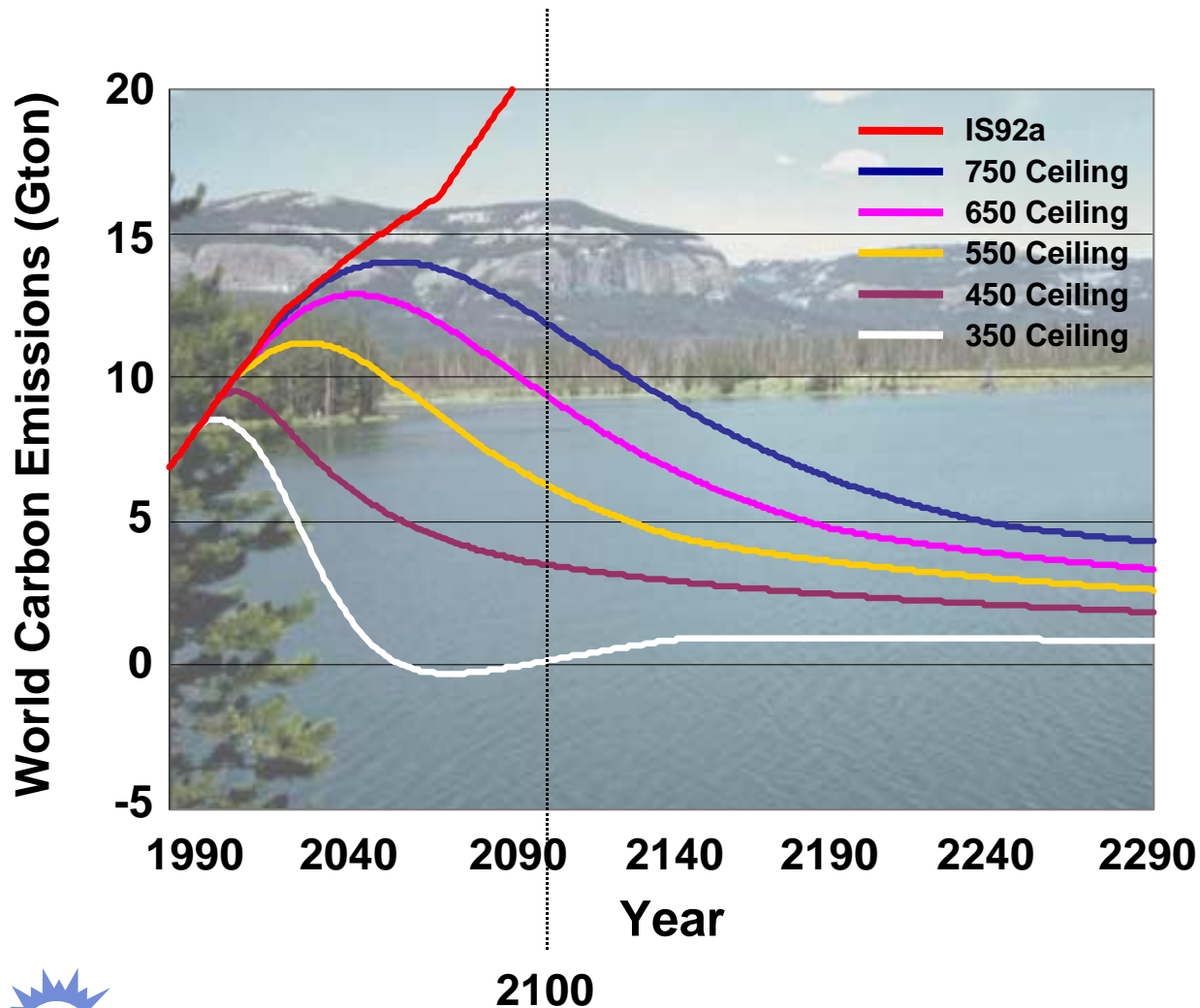
1999 data from International Energy Annual 1999 (February 2001)
2020 data from International Energy Outlook 2001 (March 2001)

World Energy Demand Growing Dramatically



Population Projections: United Nations "Long-Range World Population Projections: Based on the 1998 Revision"
Energy Projections: "Global Energy Perspectives" ITASA / WEC

Scenarios to Stabilize CO₂ Concentrations



**550 ppmv
pathway
requires 60%
reduction from
1990 levels by
2100**



Technological Carbon Management Options

Reduce Carbon Intensity

- Renewables
- Nuclear
- Fuel Switching

Improve Efficiency

- Demand Side
- Supply Side

Sequester Carbon

- Capture & Storage
- Enhance Natural Processes

All options needed to:

- Supply energy demand
- Address environmental objectives



Approaches to Sequester Carbon

Capture and Storage



Unmineable
Coal Seams



Deep Ocean
Injection



Depleted Oil /
Gas Wells,
Saline Reservoirs



Mineral
Carbonation



Iron or Nitrogen
Fertilization of
Ocean

Enhance Natural Processes

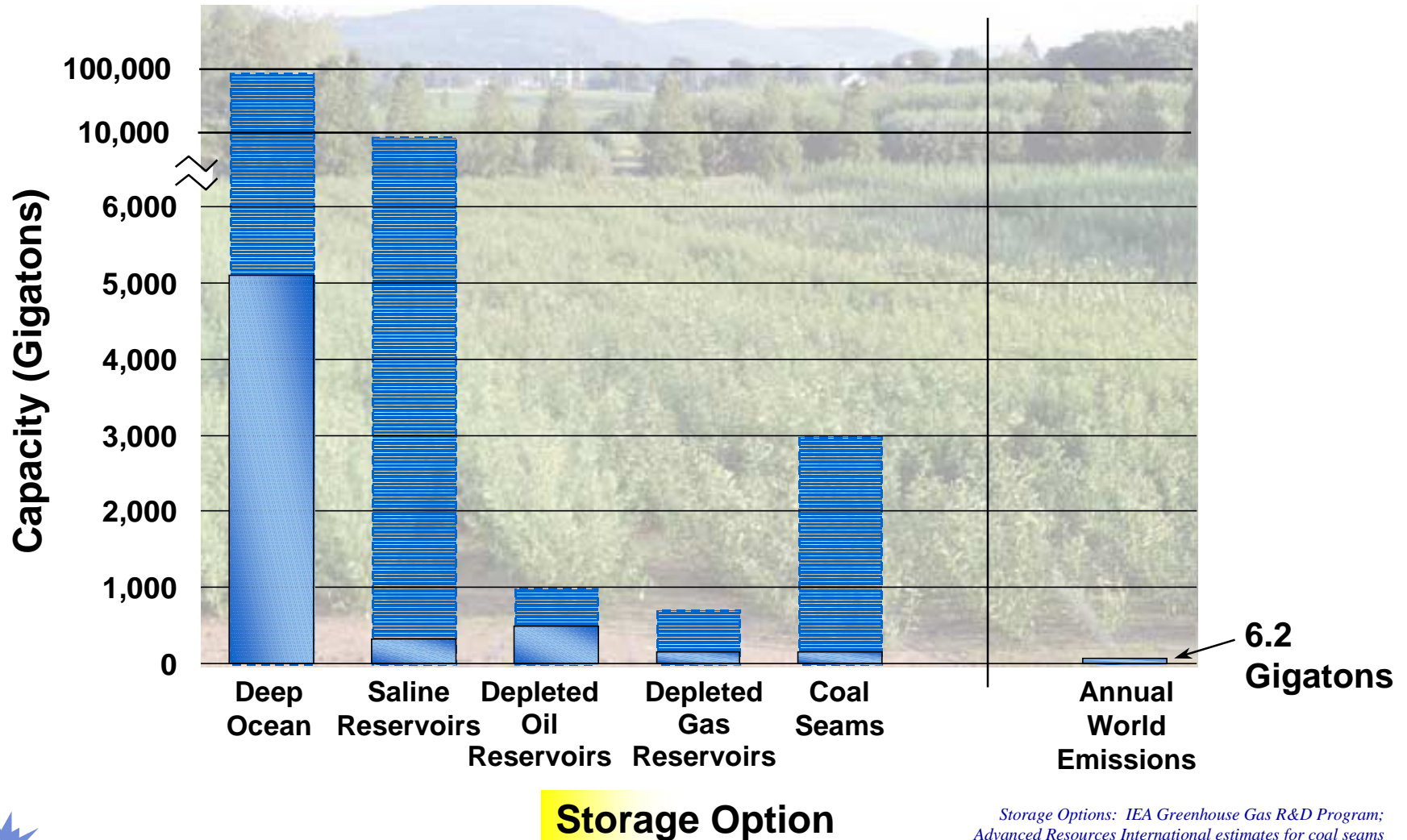


Forestation



Enhanced
Photosynthesis

Large Potential Worldwide Storage Capacity



Storage Options: IEA Greenhouse Gas R&D Program;
Advanced Resources International estimates for coal seams
World Emissions: International Energy Outlook 2000, Table A10

Requirements for Sequestration

- **Environmentally acceptable**
 - No legacy for future generations
 - Respect existing ecosystems
- **Safe**
 - No sudden large-scale CO₂ discharges
- **Verifiable**
 - Ability to verify amount of CO₂ sequestered
- **Economically viable**



DOE's Sequestration Program

Office of Fossil Energy

- Separation and capture
- Terrestrial ecosystems
- Geologic sequestration
- Ocean sequestration
- Conversion and reuse
- Modeling and assessments

**Research
coordination**

Office of Science

- Geologic sequestration
- Enhanced carbon sequestration in terrestrial ecosystems (CSiTE)
- Ocean carbon sequestration (DOCS)
- Sequencing genomes of microorganisms
- Advanced chemical and biological processes

Applied R&D

Basic Science



Agencies Conducting Sequestration-Related Research

USGS

Geologic sequestration research

NASA

Space-based studies of earth as integrated system

EPA

Inventory of greenhouse gases

OSM

Carbon sequestration on abandoned mine sites

NOAA

Atmospheric and oceanic global observations



USAID

Tropical reforestation in developing countries

NSF

Science of CO₂ and N₂ cycles in oceans

USDA

Terrestrial sequestration, soil carbon database, sequestration models

Forest Service

Management practices to increase carbon sequestration



Office of Fossil Energy's Sequestration Program

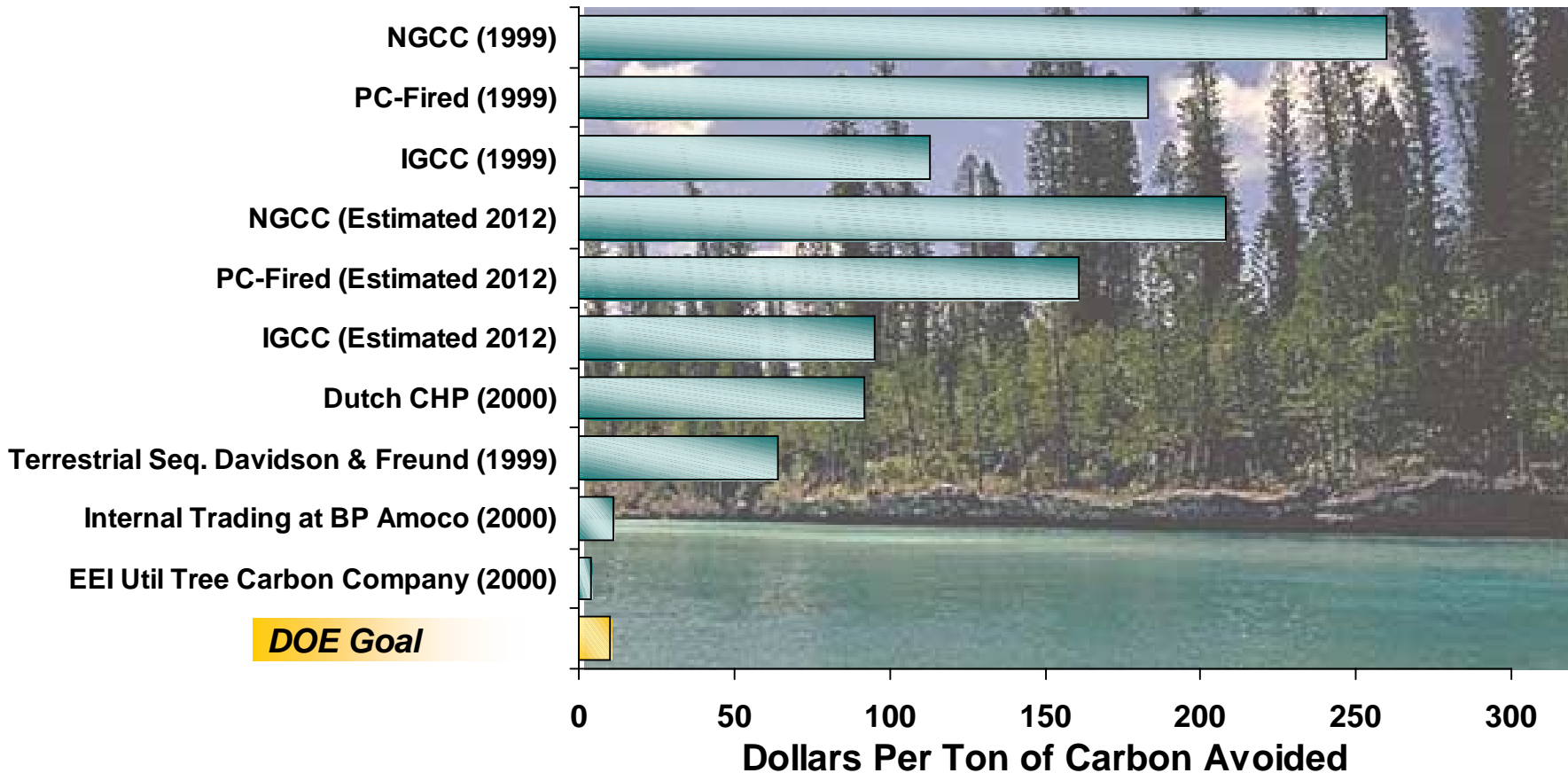
Number of Projects by Research Area

- 15** Separation and capture
- 3** Terrestrial ecosystems
- 17** Geological sequestration
- 7** Ocean sequestration
- 9** Conversion and reuse
- 7** Modeling and assessments



DOE Cost Goal for Sequestration

Net Costs



Long Term Cost Goal Is \$10 Per Ton of Carbon Avoided



Dollar figures are for year cited & are not adjusted to a constant year dollar

Designs for Carbon Sequestration

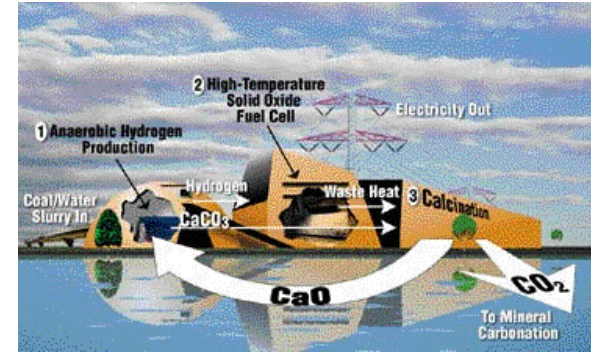
Advanced Energy Plants



**Coal Gasification
With Water Gas
Shift to H₂ and CO₂**



**Pressurized Combustion
Using Pure O₂**



**Coal Gasification With
CaCO₃ Intermediate to
Produce H₂ and CO₂**

Producing a Concentrated Stream of CO₂ at High Pressure

- *Improves Sequestration Economics*
- *Reduces Energy Penalty*

Energy Production → Geological Sinks

Export Header Export Cumulativez View Monthly Shallow EUR Deep EUR Decline Curve Close

Production Records for Selected Wells

API # 34007218470000

Operator: RANGE OPERATING COMPANY Well #: X Coord: 2469540.47
Operator Well #: Lease: Y Coord: 713754.82
County #: ASHTABULA Township: NEW LYME Section: 8 Other Sub:
Date Plugged: Date Issued: Lot: Fraction:
Date Completed: Producing Formation: RSRN Field ID: 0
1st Year Production Indicated: 1982 Producing Formation 2:
Well Comment:

Yearly Production for Well

Year	Oil (bbl)	Gas (mcf)	Water (bbl)	Source
1982	673	512068	0	LOWE
1983	155	157457	0	LOWE
1984	0	52999	0	LOWE
1985	148	20772	0	LOWE
1986	0	8916	0	LOWE
1987	0	4876	0	LOWE
1988	94	3413	0	LOWE
1989	0	3793	0	LOWE

Initial Production for Well

	GAS	OIL
IP Natural	2000	10
IP After Treatment	0	0

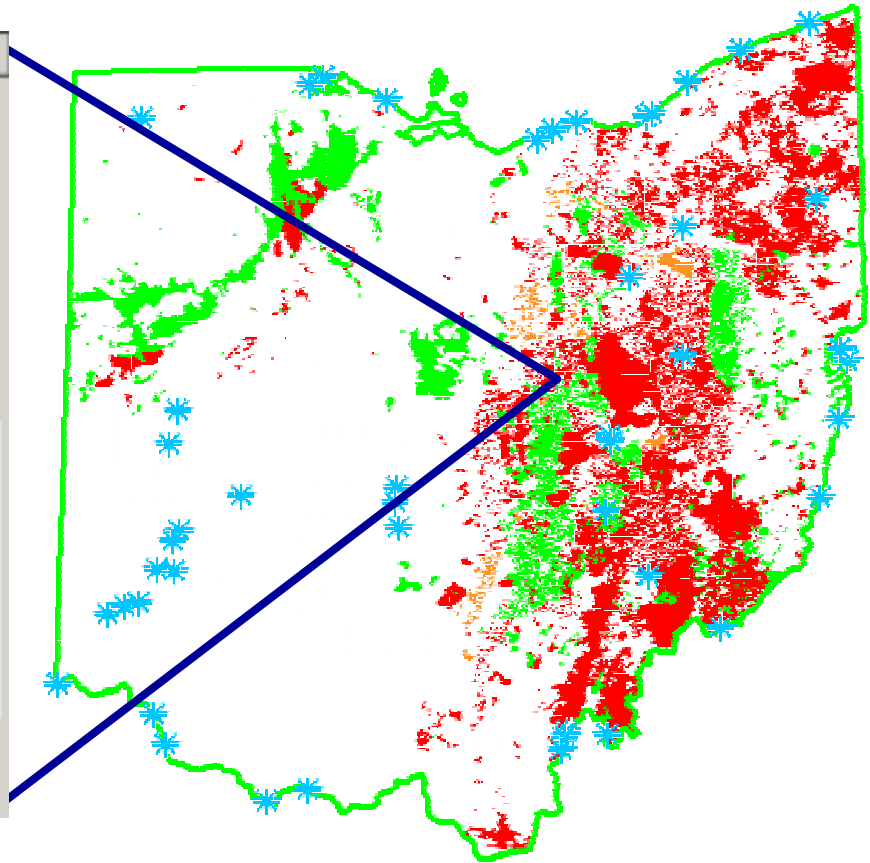
PRESSURE

Initial Pressure: 0
Last Pressure:
Year Last Pressure:

Record: 1 of 12

Cumulative Production for Well

Oil (BBL)	Gas (MCF)	Water (BBL)
1070	769767	0



Midcontinent Interactive Digital Carbon Atlas and Relational DataBase

www.midcarb.org



Geologic Sequestration in a Depleted Oil Reservoir

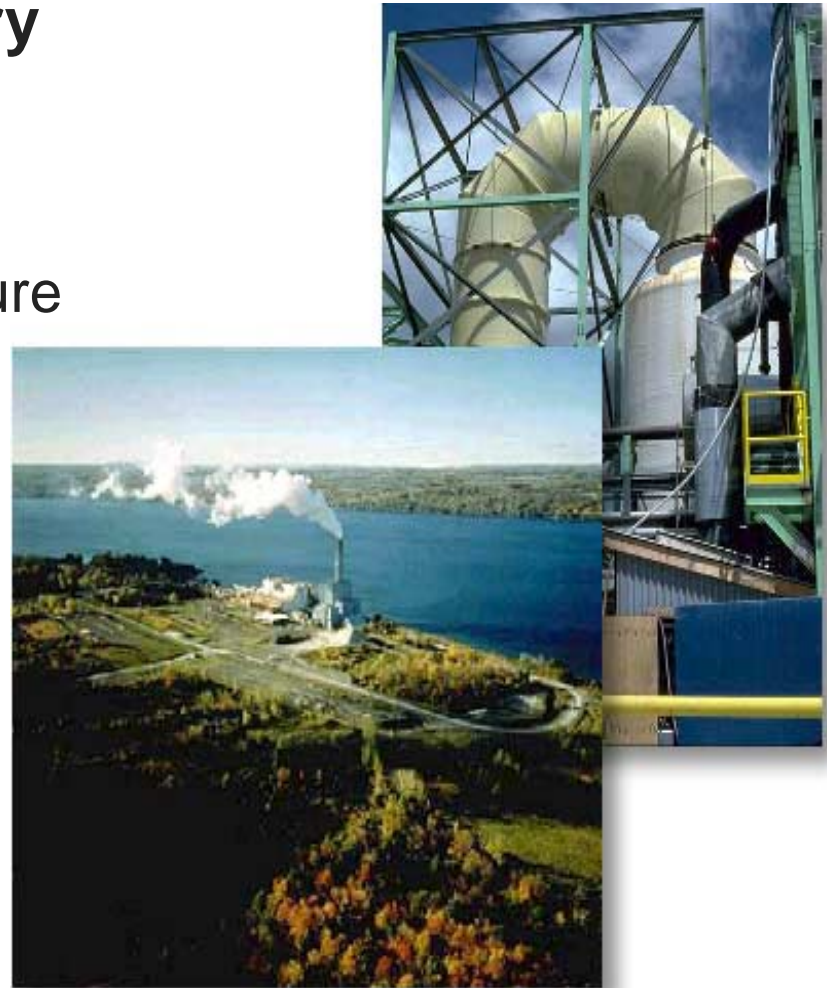
First U.S. Depleted Reservoir Storage Project

- **Inject CO₂ and monitor its movement**
- **Location**
 - Oil reservoir near Roswell, New Mexico
- **Partners**
 - Pecos Petroleum
 - Strata Production
 - New Mexico Tech U.
 - Sandia
 - LANL
 - NETL



CO₂ Separation from Flue Gas

- Use sodium carbonate, a dry regenerable sorbent
- Benefits
 - Capable of 100% CO₂ capture
 - \$15/ton carbon at 25-50% capture
- Team members
 - Research Triangle Institute
 - Church and Dwight, Inc.



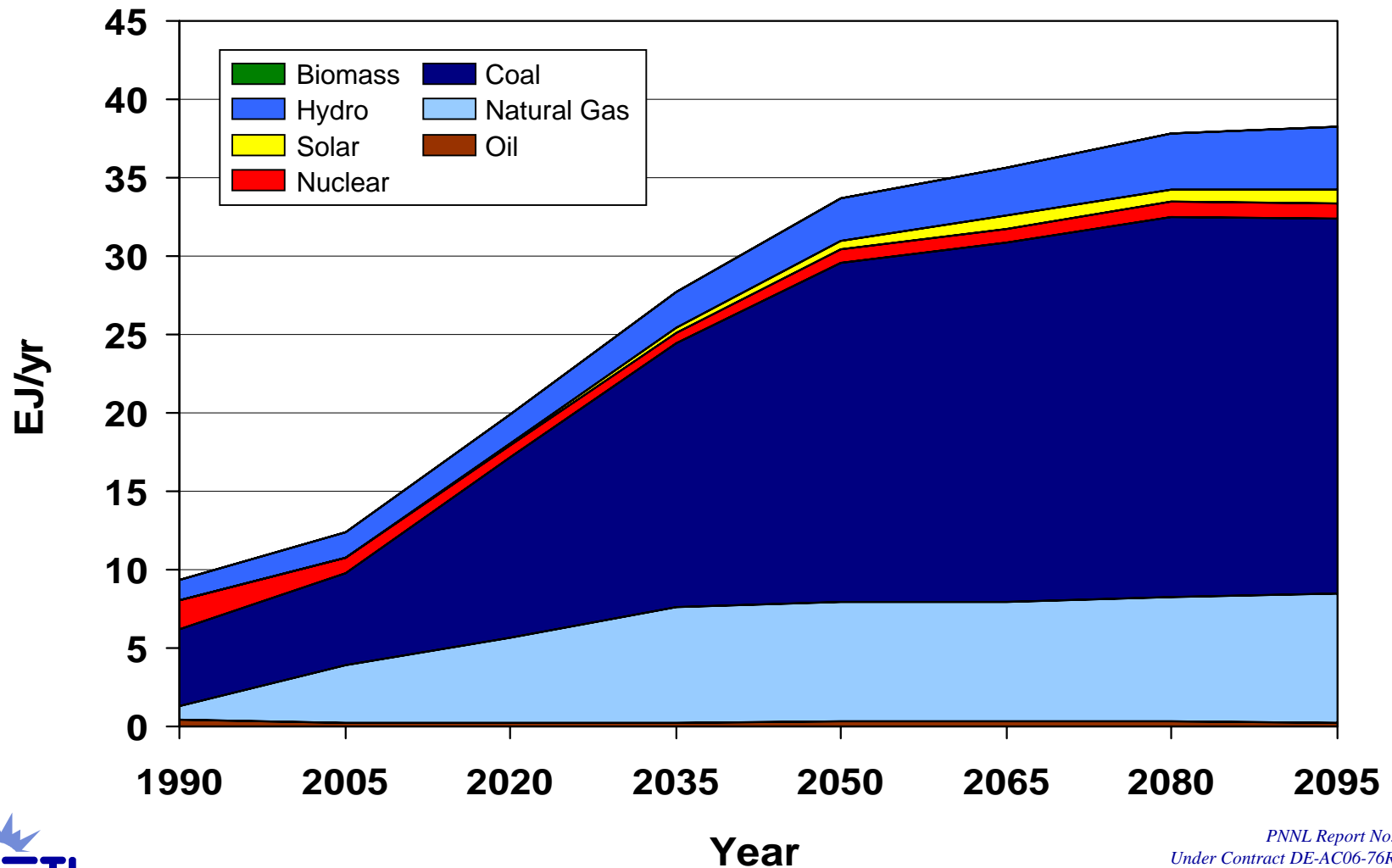
Terrestrial Sequestration at a Power Plant

- Amend coal mine spoil land near Paradise Power Plant in KY using FGD solids
- Multiple benefits
 - Sequester carbon
 - Improve soil quality
 - Integrated assessment
- Partners
 - TVA
 - EPRI
 - NETL



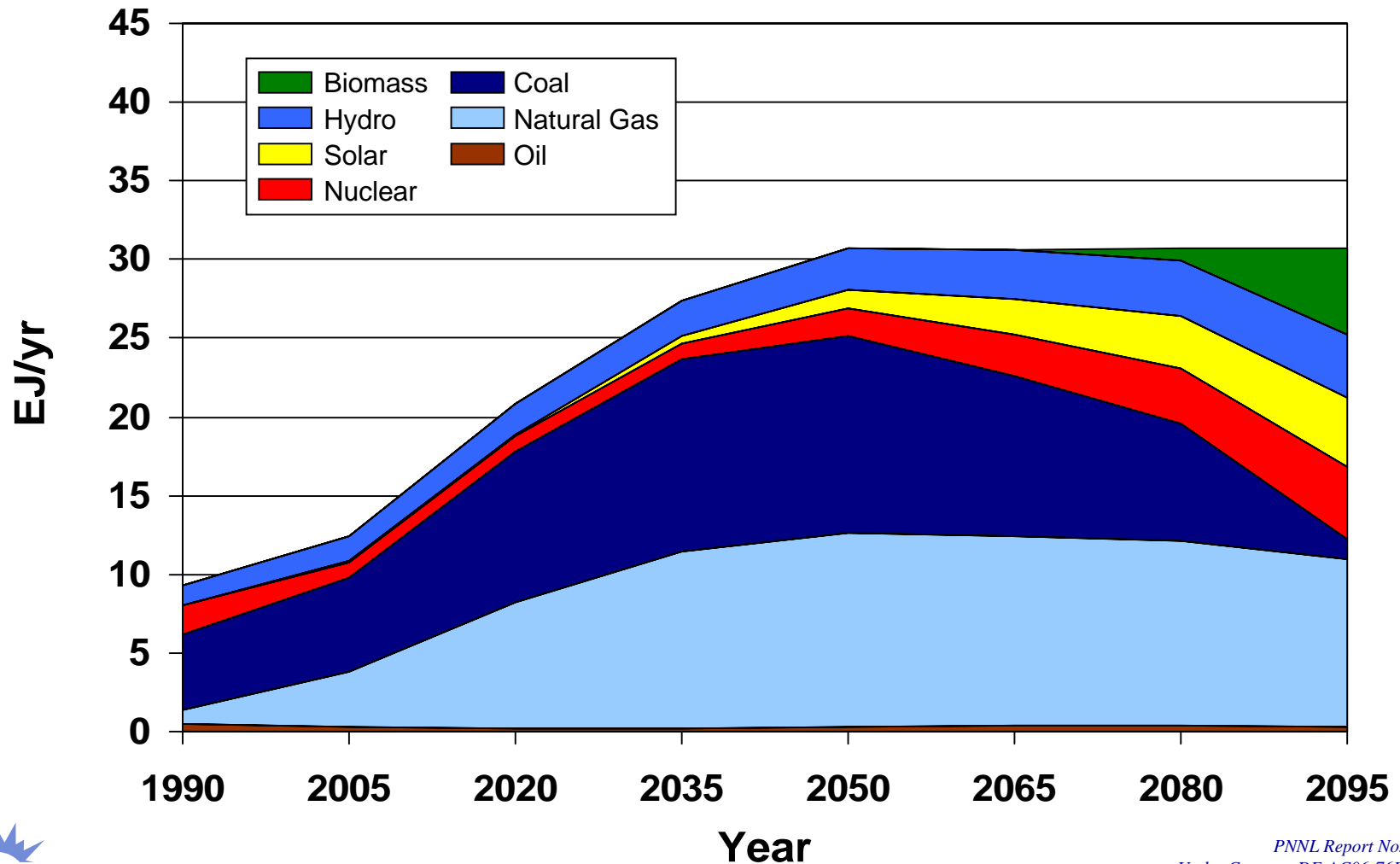
A Reference Case Scenario

U.S. Electricity Generation



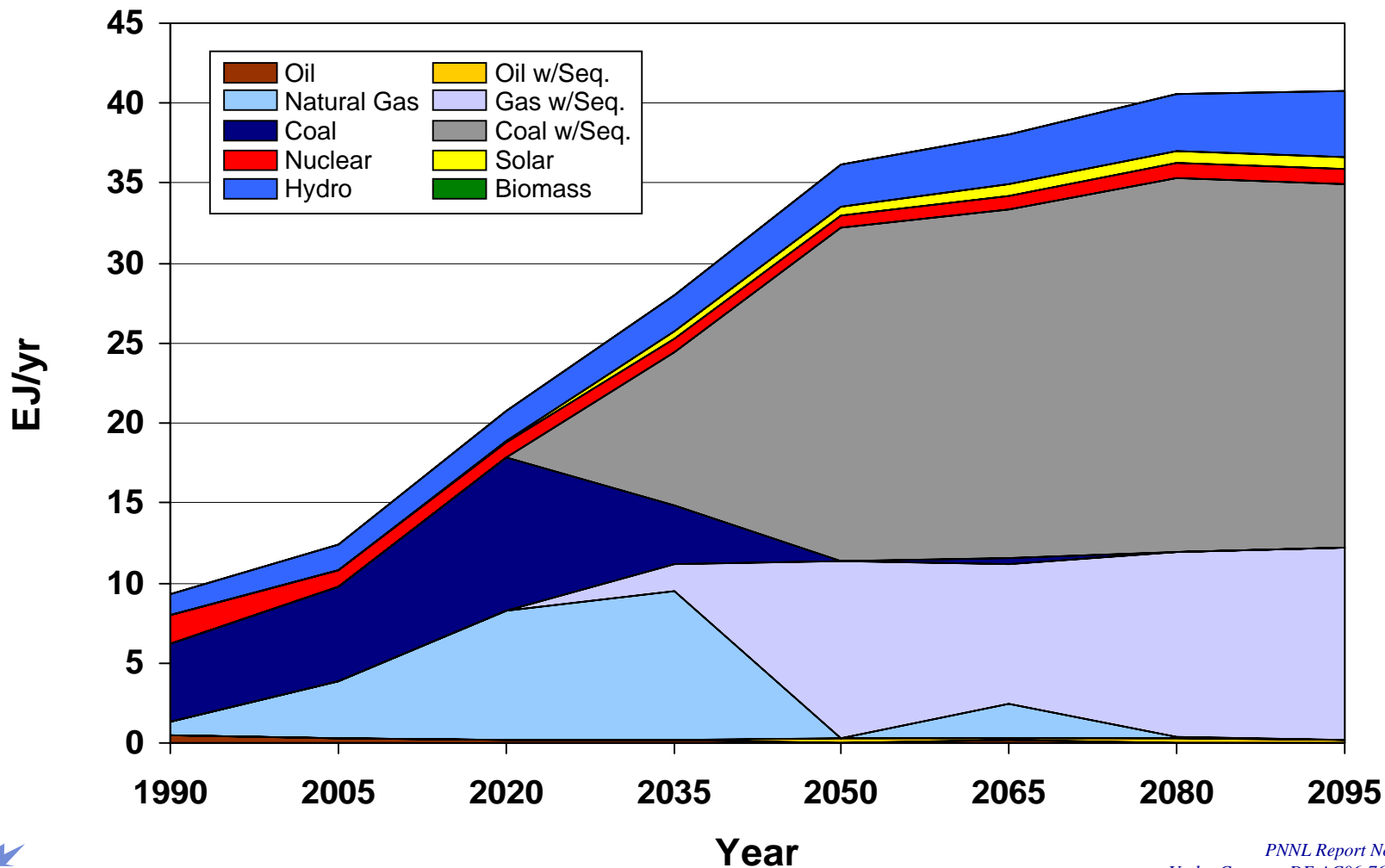
Case Without Carbon Sequestration

U.S. Electricity Generation- 550 ppmv



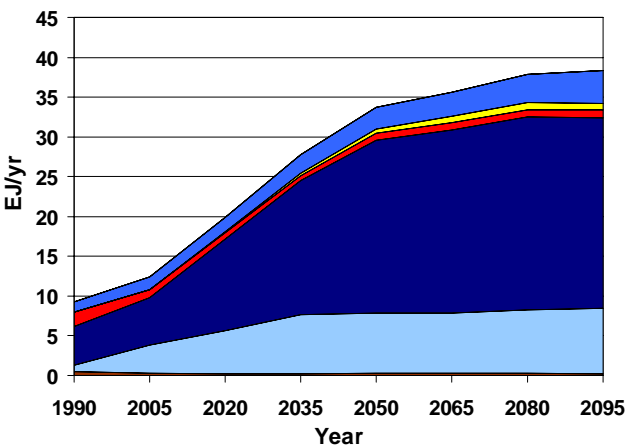
Sequestration / High-Efficiency Generation

U.S. Electricity Generation - 550 ppmv

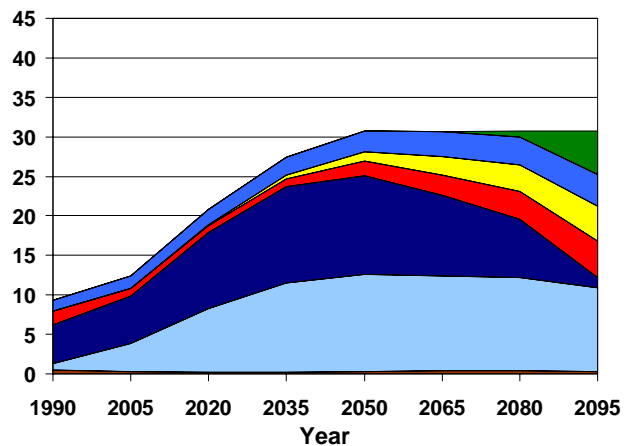


The Benefit of Sequestration

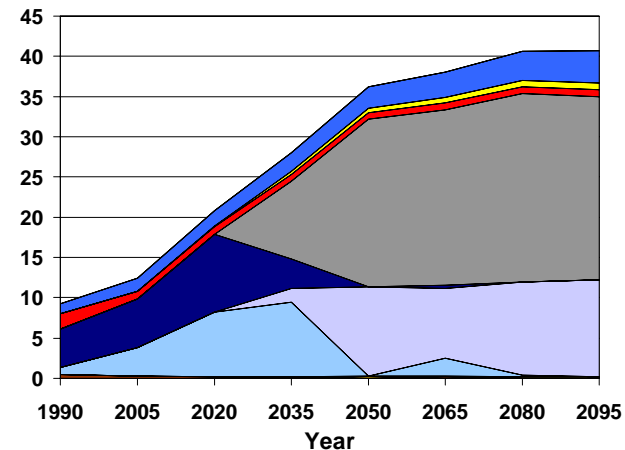
Reference Case



No Sequestration



Sequestration Option



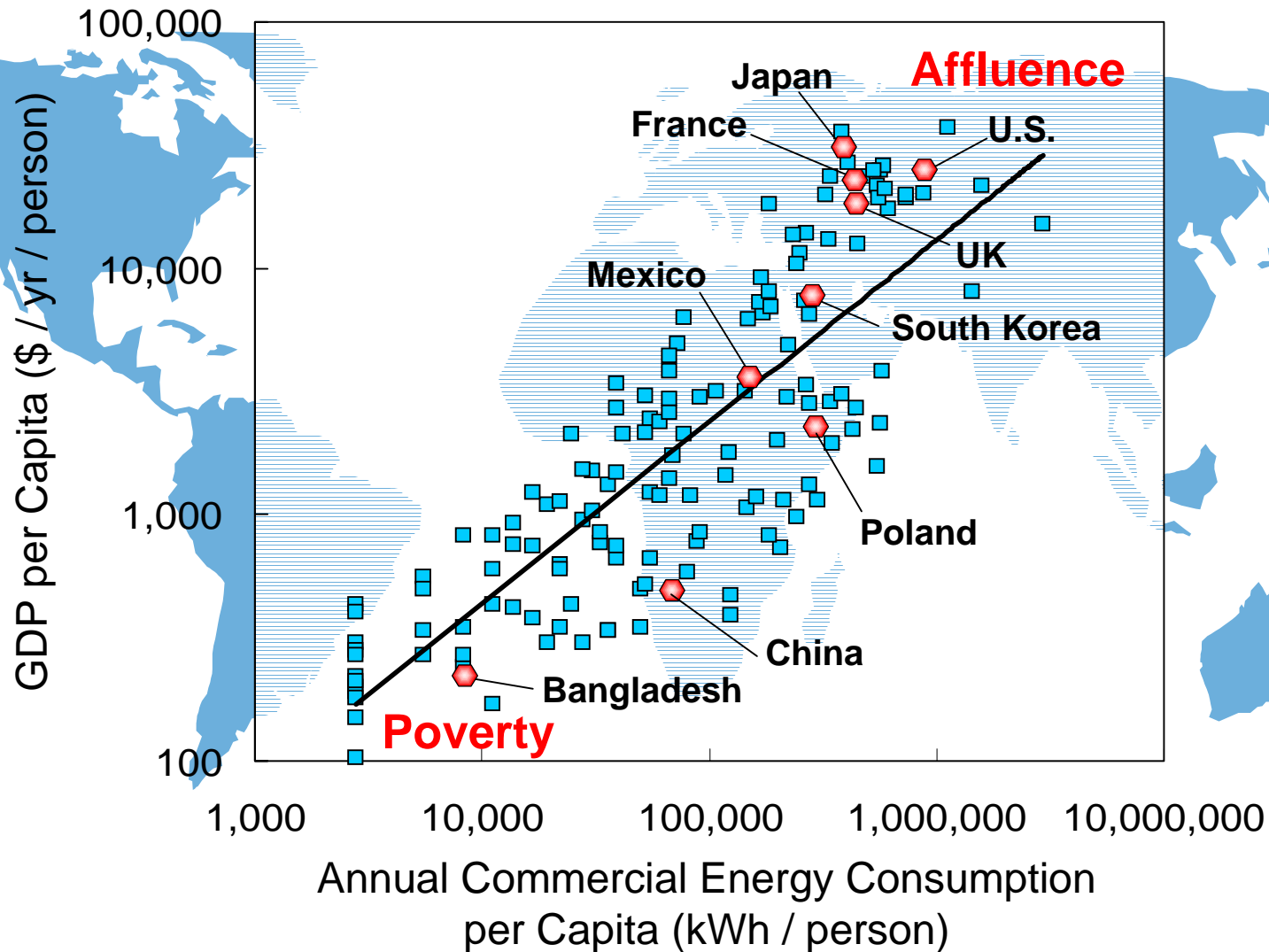
- Miss environmental target

- Meet 550 ppmv target

- Meet 550 ppmv target
- Save U.S. \$215 billion
- World Wide Saving \geq \$1 Trillion



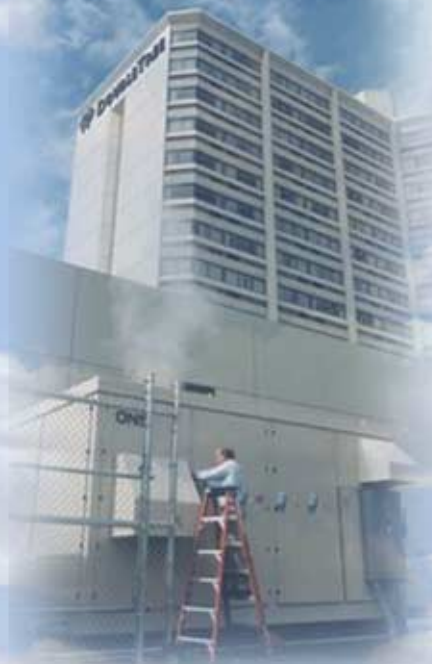
The World Needs Affordable Energy



Focus on All Technological Options to Address Climate Change



**Reduce
Carbon Intensity**



**Improve
Efficiency**



**Sequester
Carbon**

