

Decarbonized Power, Energy for the Future: Clean Coal, CO₂ Sequestration, and the EOR Prize in the Gulf Coast and Permian Basin

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Acknowledgments

Gulf Coast Carbon Center



KINDER MORGAN



Schlumberger



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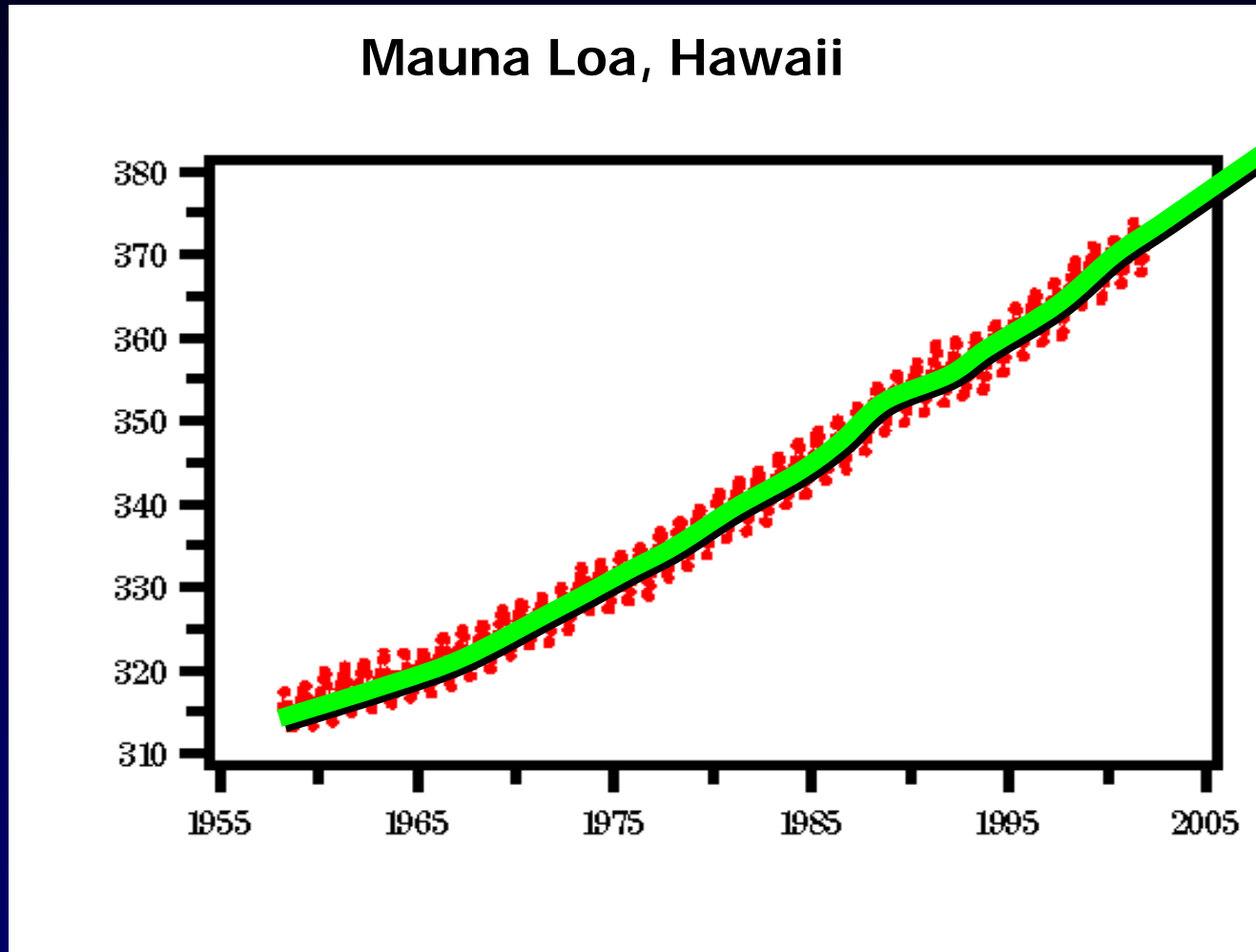
Outline

- **CO₂ Sources and Sinks**
- **Coal Resources, Economy, and Impact**
- **Clean Coal and Decarbonized Energy**
- **CO₂ Stacked Storage**
- **CO₂ EOR: Gulf Coast and Permian Basin**



Recent increases in Global CO₂

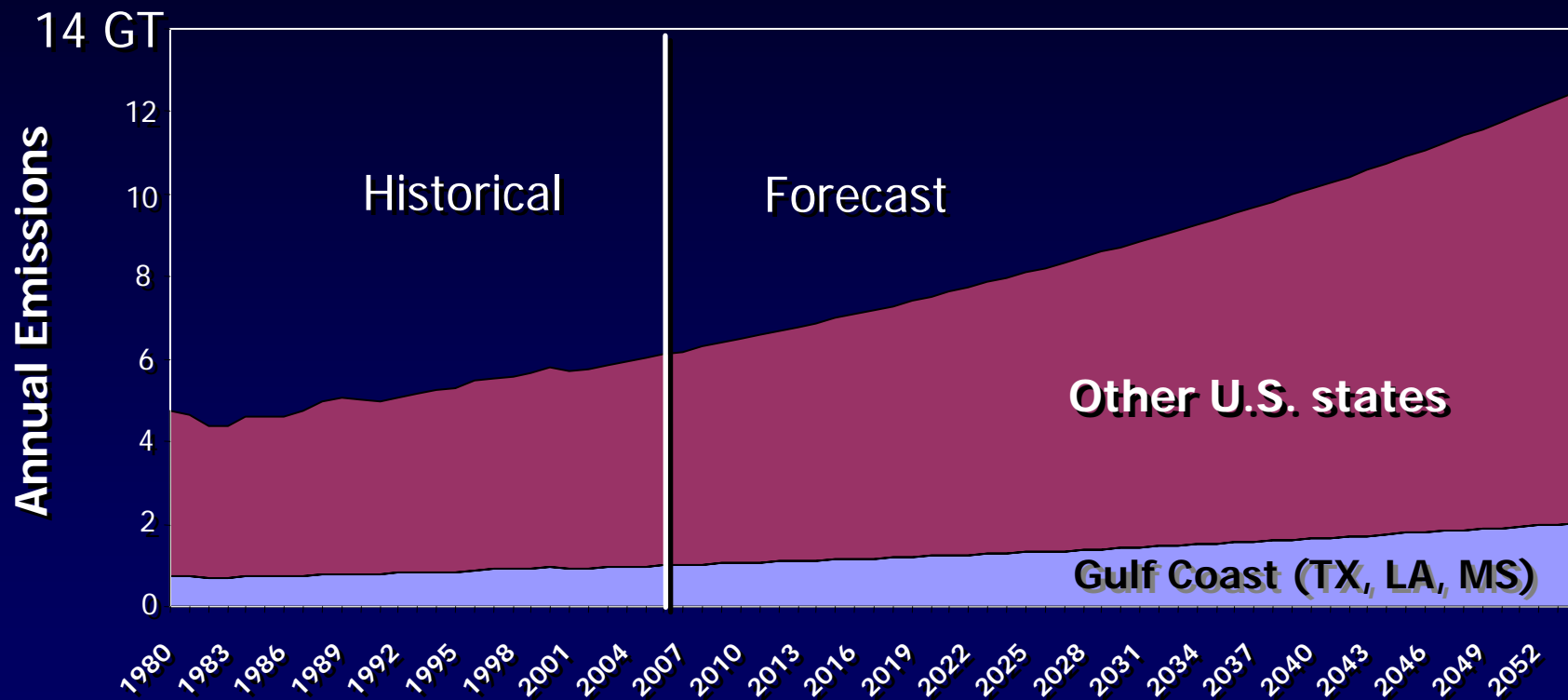
CO₂ Concentration (ppm)



Source: Dave Keeling and Tim Whorf (Scripps Institute)

Anthropogenic CO₂

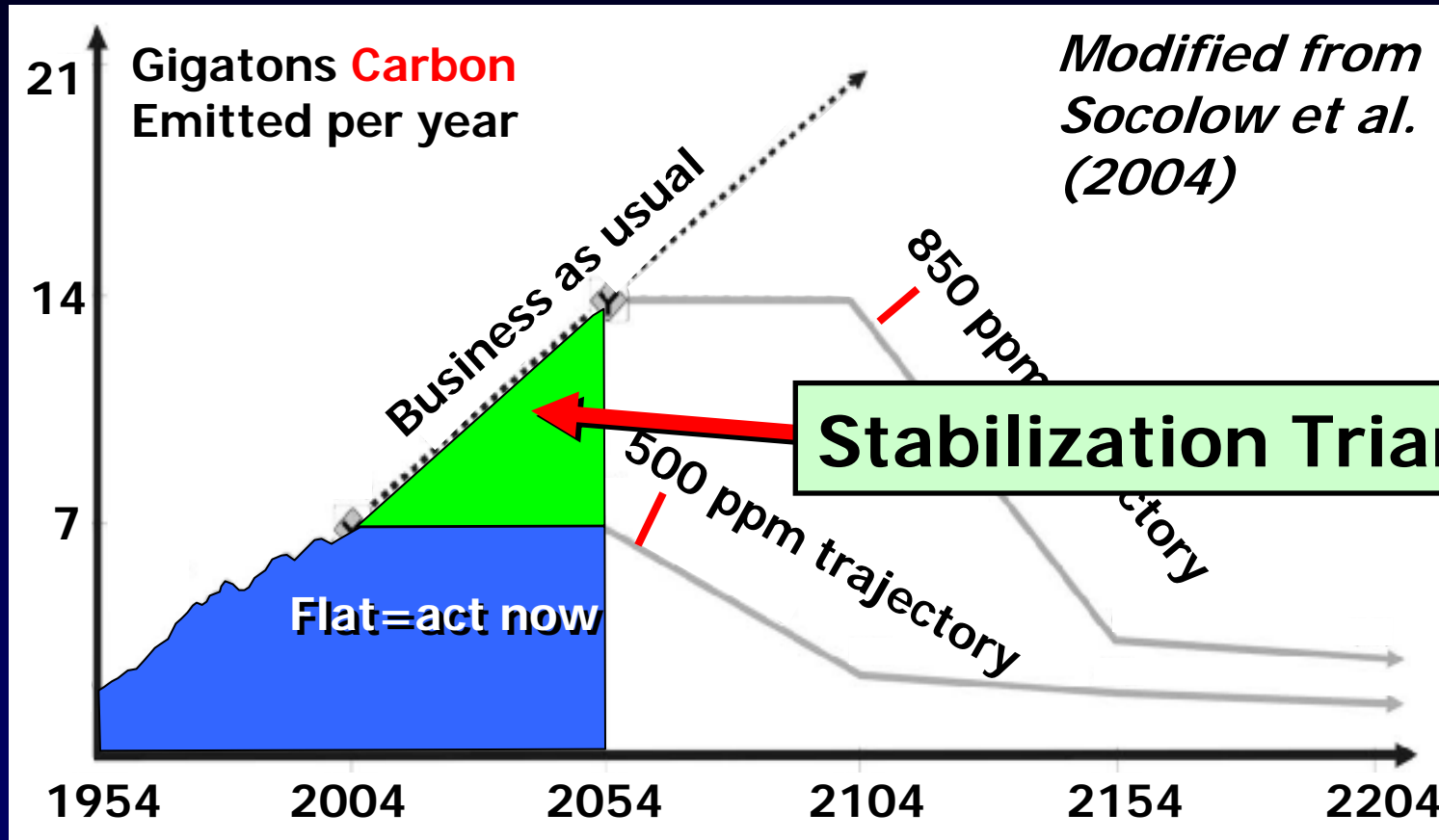
The Gulf Coast "Wedge"



Data from CDIAC and EIA websites

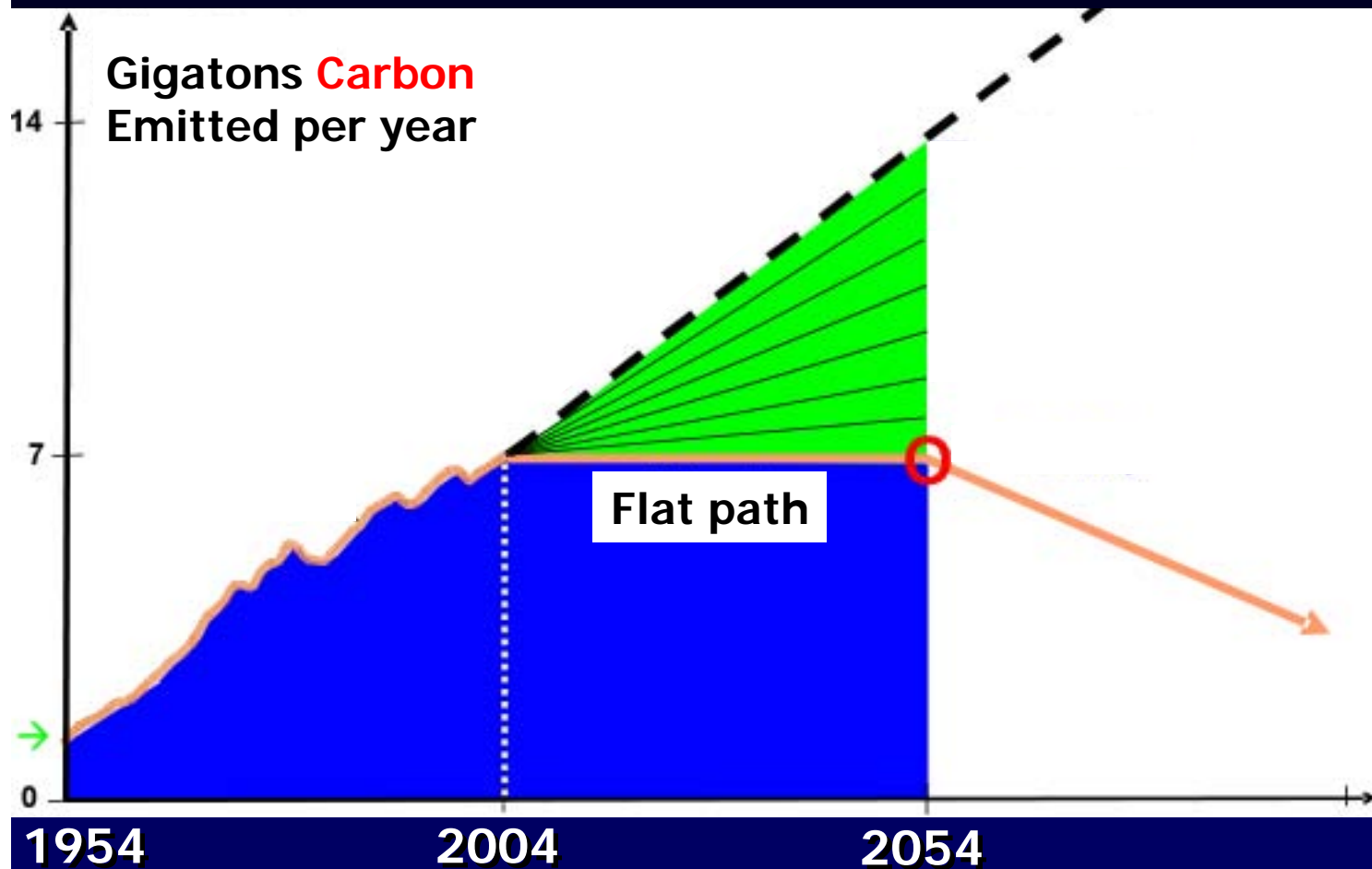


CO₂ Atmospheric Stabilization at $\leq 2x$ Pre-Industrial Level



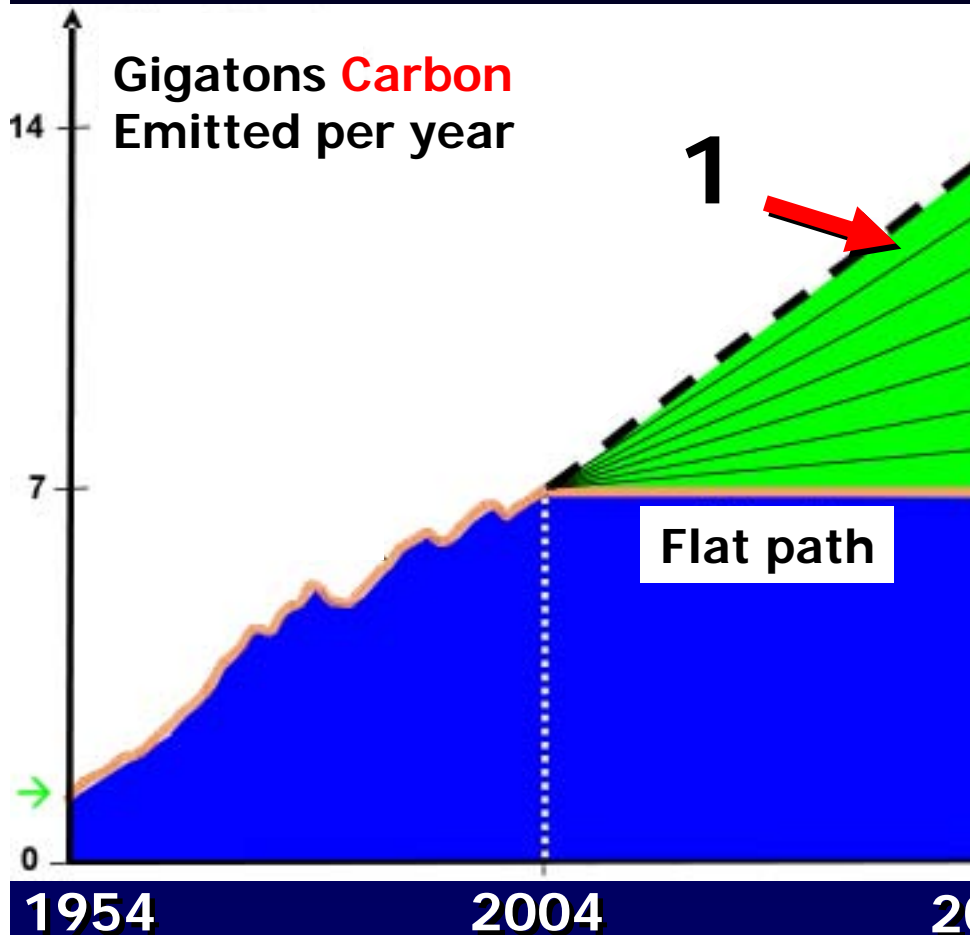
500 ppm trajectory: Avoid 175 Gt of Carbon emissions

Stabilization Triangle and "Wedges"



*Modified from
Socolow et al. (2004)*

Stabilization Triangle and "Wedges"



**Wedge #1:
Energy Efficiency**

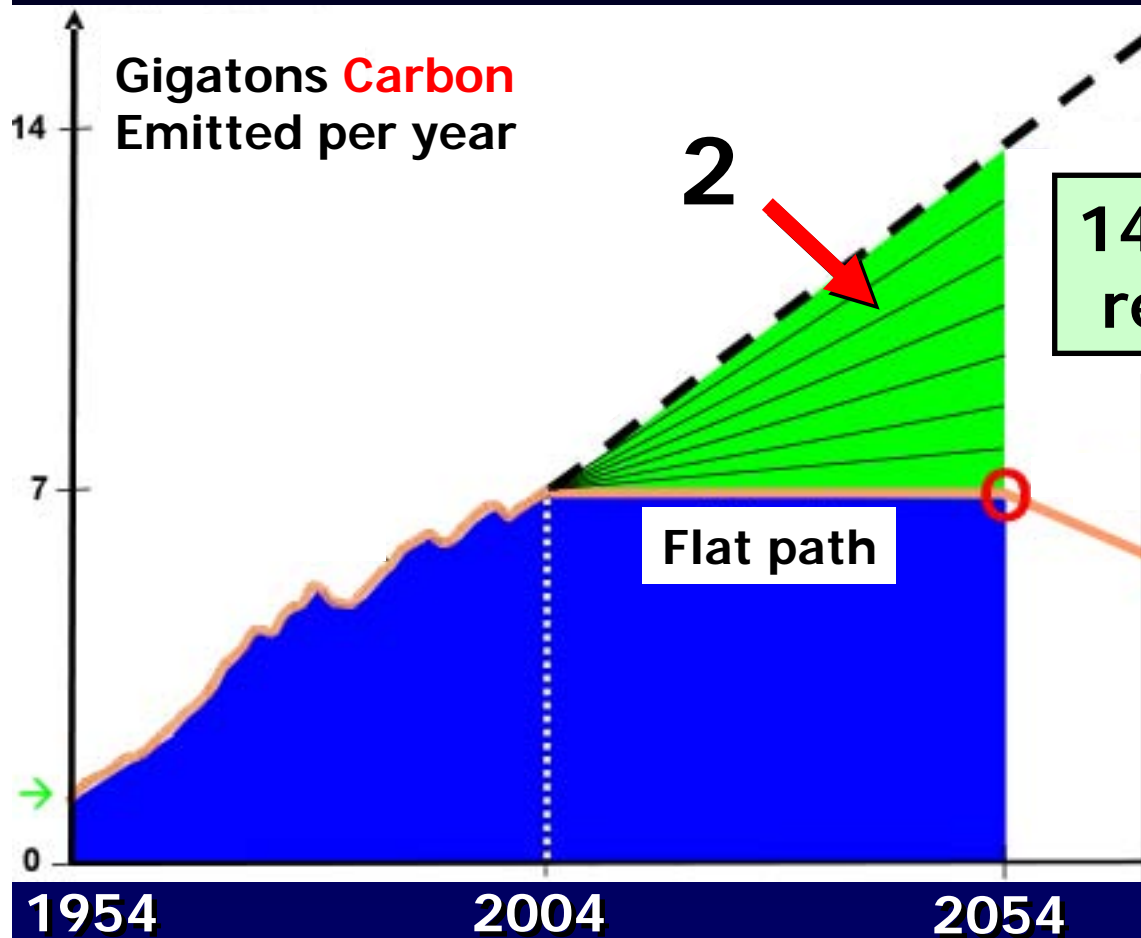
2 billion cars with
fuel economy of 60 mpg



*Modified from
Socolow et al. (2004)*

American Roadster™

Stabilization Triangle and "Wedges"



**Wedge #2:
Fuel Shift**

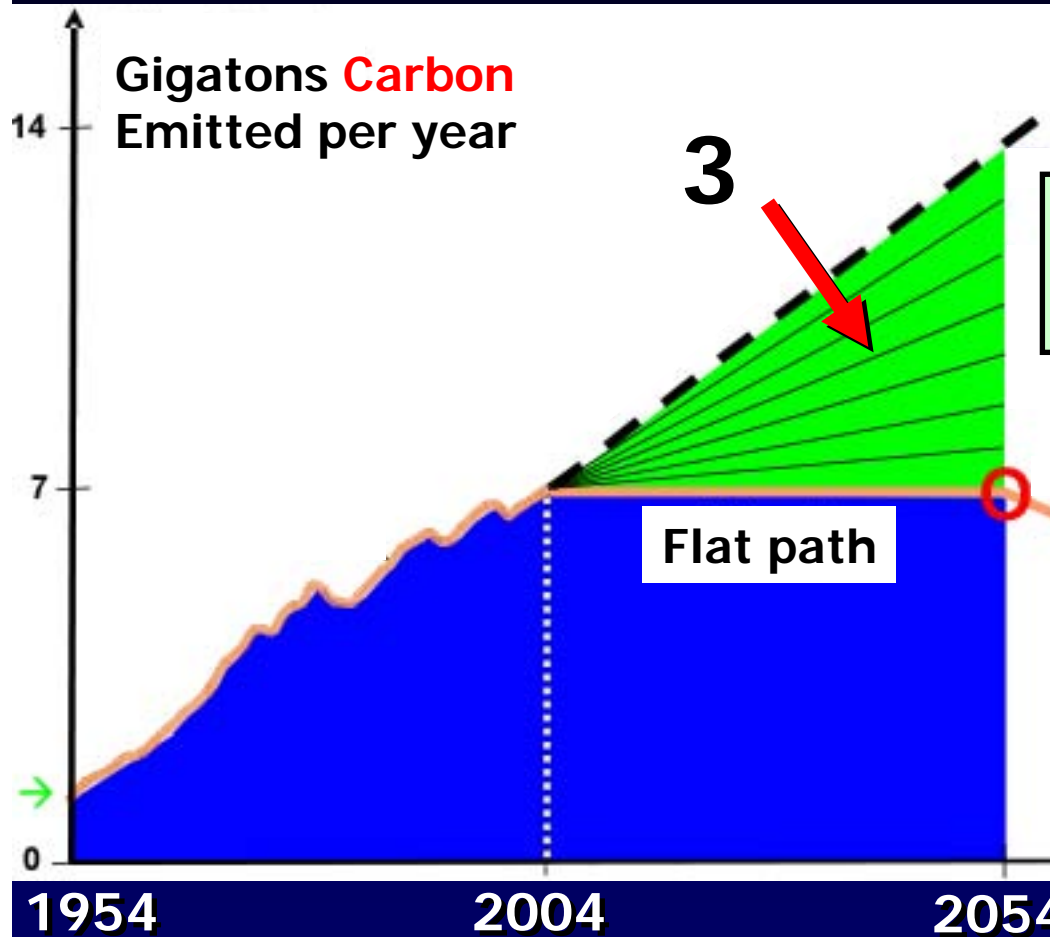
1400, 1-GW coal plants
replaced by gas plants



*Modified from
Socolow et al. (2004)*

New York Power Authority

Stabilization Triangle and "Wedges"



**Wedge #3:
CCS**

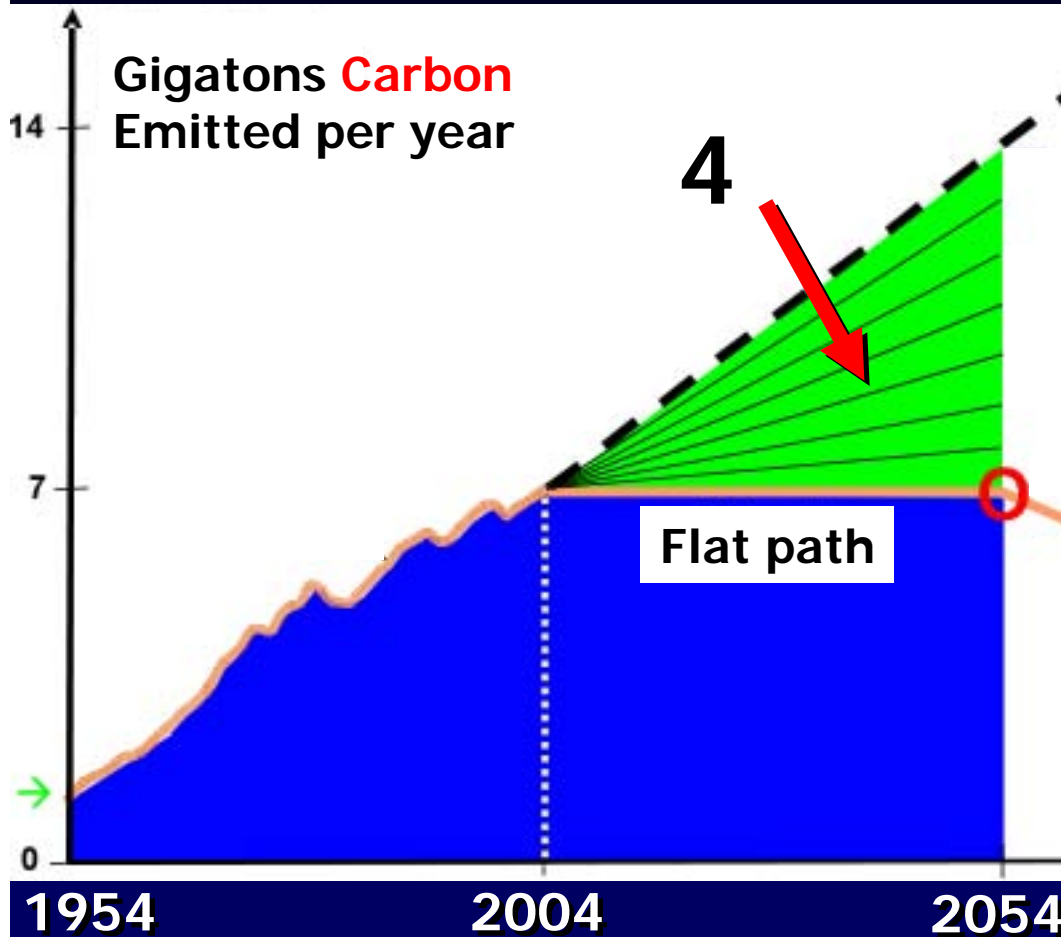
CO₂ Capture/Storage
At 800 1-GW coal plants



*Modified from
Socolow et al. (2004)*

Wabash River IGCC Power Plant

Stabilization Triangle and "Wedges"



**Wedge #4:
Nuclear Fission**

700 1-GW plants
(2x current)

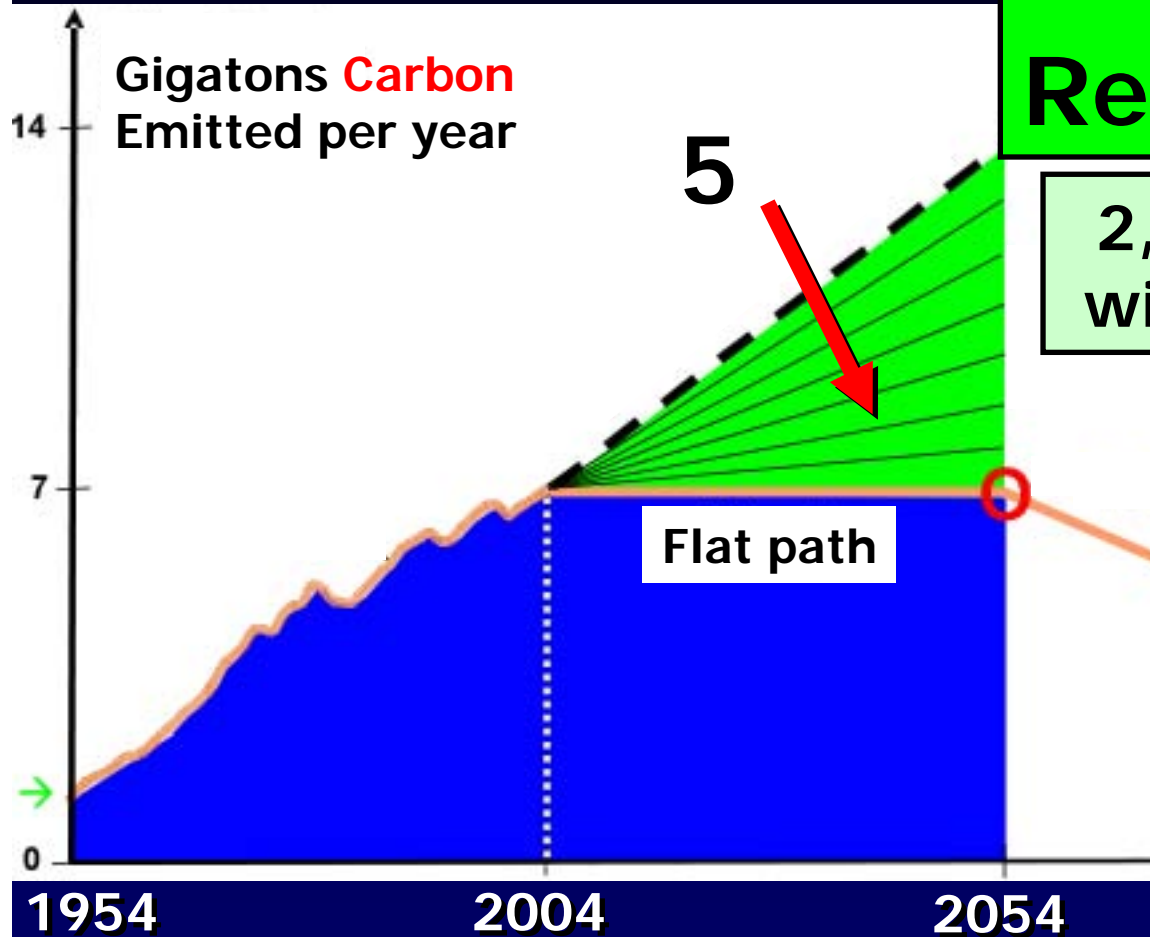


*Modified from
Socolow et al. (2004)*

Nuclear Energy Institute

Stabilization Triangle and "Wedges"

Wedge #5: Renewable Power



2,000,000 1-MW-peak
windmills (50x current)



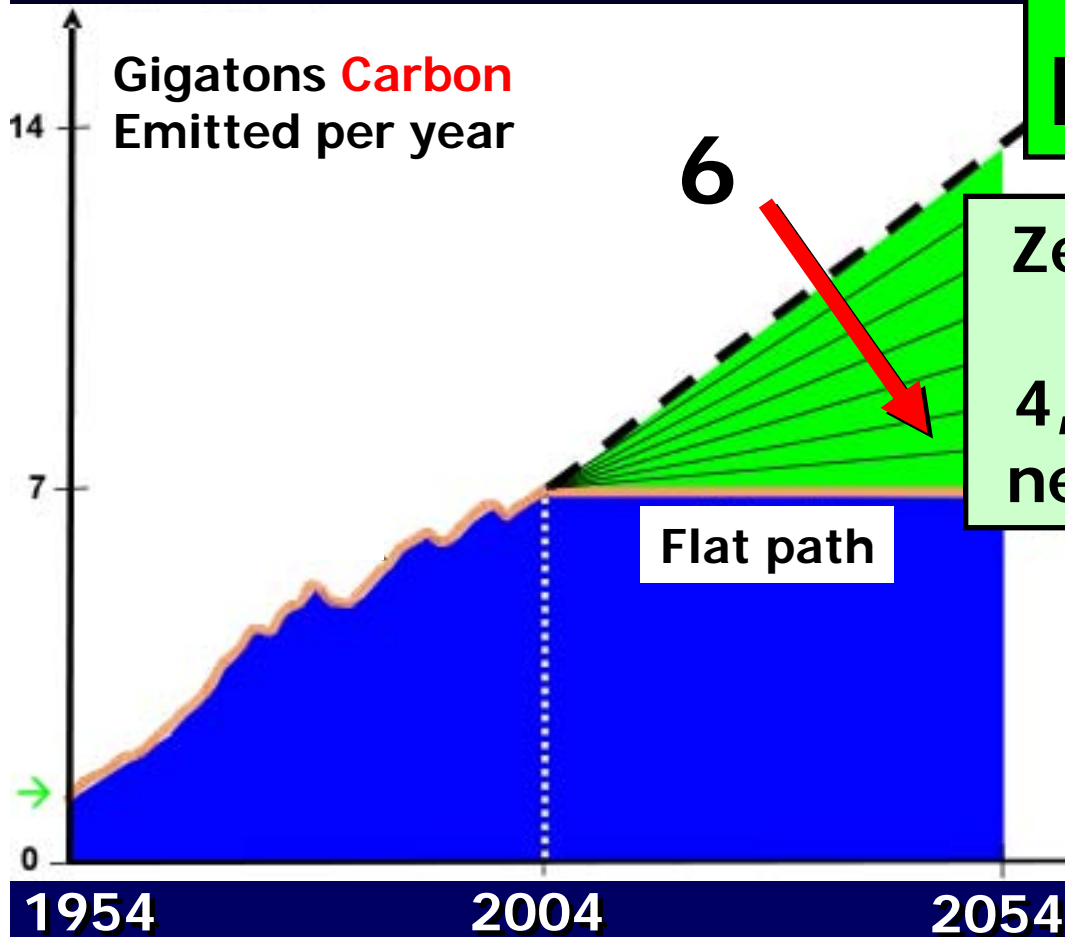
*Modified from
Socolow et al. (2004)*

Danish Wind Energy Association

Stabilization Triangle and "Wedges"

Modified from
Socolow et al. (2004)

Wedge #6: Forests and Soils



Zero deforestation by 2054
Instead of 0.5GtC/yr;
4,000,000 ha (40,000 km²)
new trees (temperate zone)

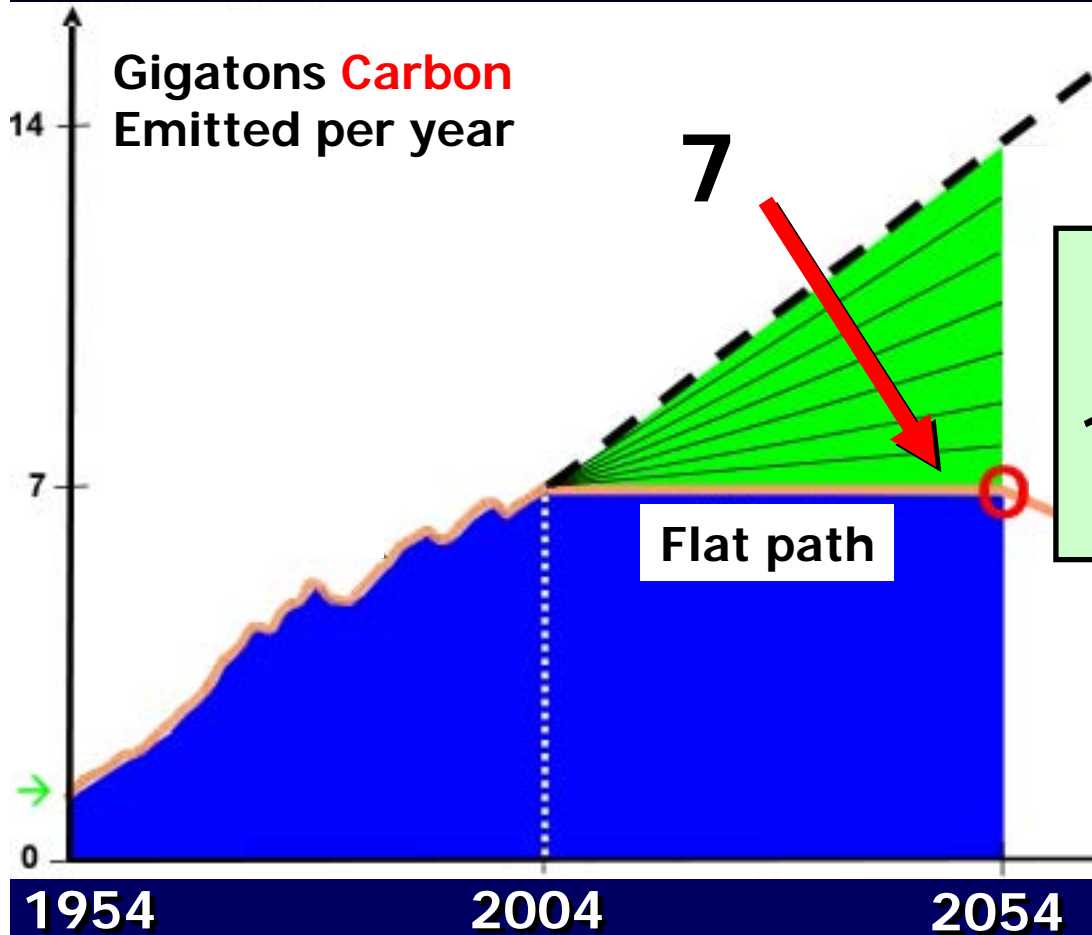


SUNY Stonybrook

Stabilization Triangle and "Wedges"

Modified from
Socolow et al. (2004)

**Wedge #7:
Biomass Fuel**

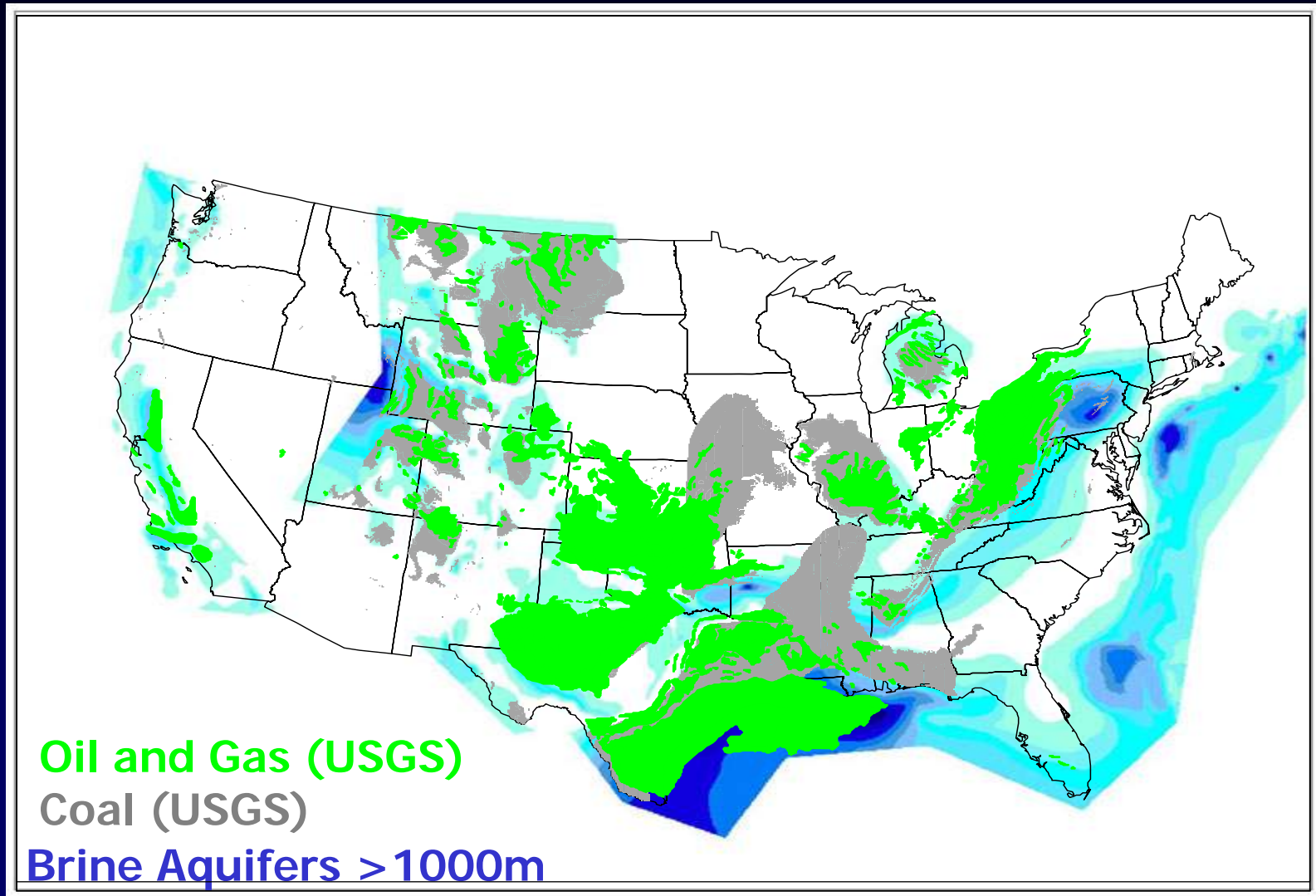


150x Brazil or US ethanol program;
150 million ha cropland
(1,500,000 km²)



Union of Concerned Scientists

U.S. CO₂ Sources and Sinks



Data Compilation: BEG Gulf Coast Carbon Center

US CO₂ Sources and Sinks

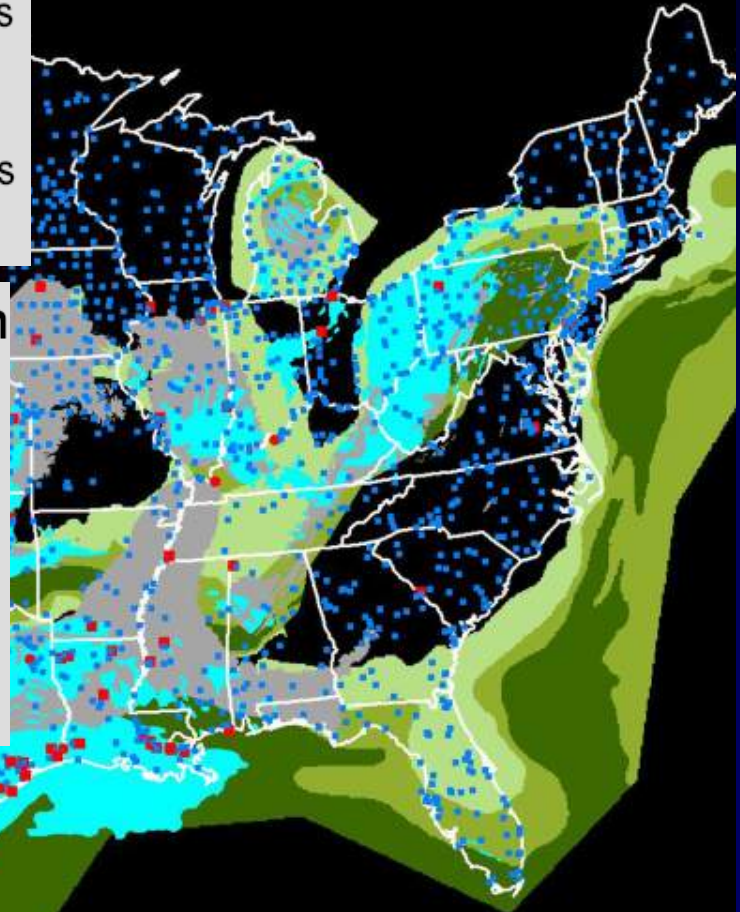
2,082 Large Sources (100+ ktCO₂/yr)
with Total Annual Emissions = 3,800 MtCO₂/yr

- 1,185 electric power plants
- 447 natural gas processing facilities
- 154 petroleum refineries
- 53 iron & steel foundries
- 124 cement kilns
- 43 ethylene plants
- 9 oil sands production areas
- 40 hydrogen production
- 25 ammonia refineries
- 47 ethanol production plants
- 8 ethylene oxide plants

3,800+ GtCO₂ Capacity within 330 US and Canadian
Candidate Geologic CO₂ Storage Reservoirs

- ▶ 3,730 GtCO₂ in deep saline formations (DSF)
- ▶ 65 GtCO₂ in deep unmineable coal seams with potential for enhanced coalbed methane (ECBM) recovery
- ▶ 40 GtCO₂ in depleted gas fields
- ▶ 13 GtCO₂ in depleted oil fields with potential for enhanced oil recovery (EOR)

- Oil and Gas (USGS)
- Coal (USGS)
- Brine Aquifer > 1000m



Sources: Gulf Coast Carbon Center
Dooley (2005)



Outline

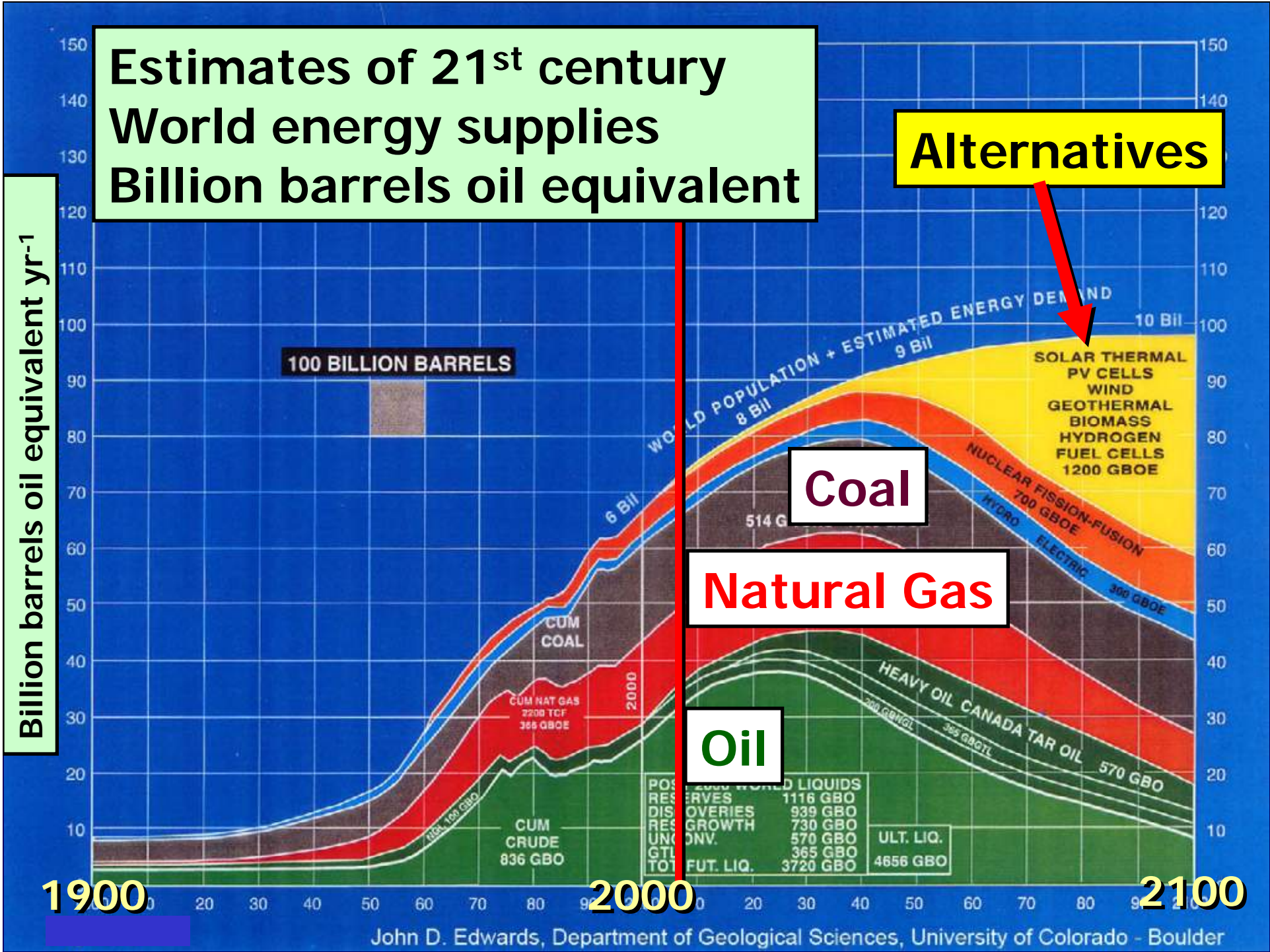
- CO₂ Sources and Sinks
- **Coal Resources and Economic Impact**
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**Estimates of 21st century
World energy supplies
Billion barrels oil equivalent**

Alternatives

Billion barrels oil equivalent yr⁻¹



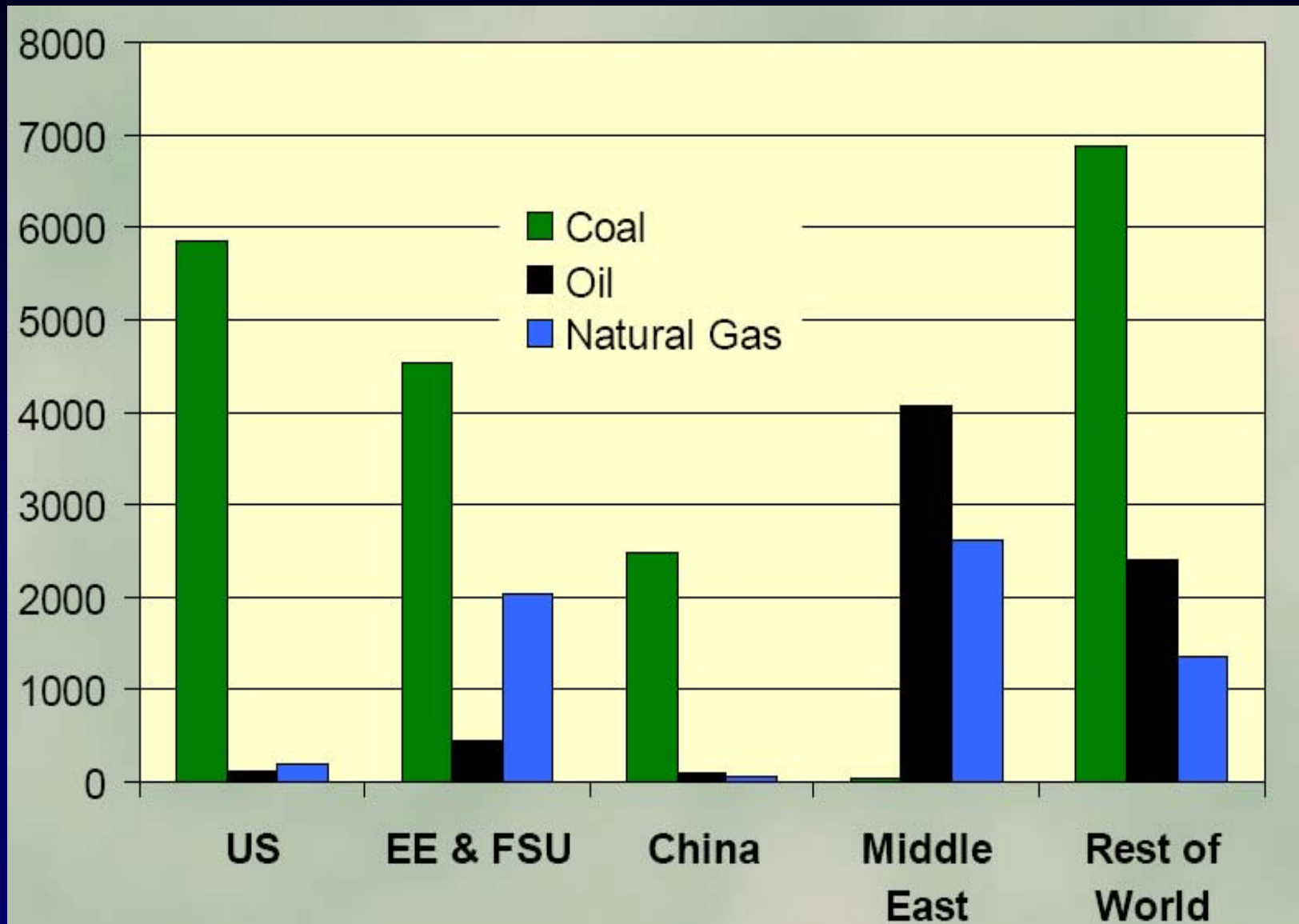
1900

2000

2100

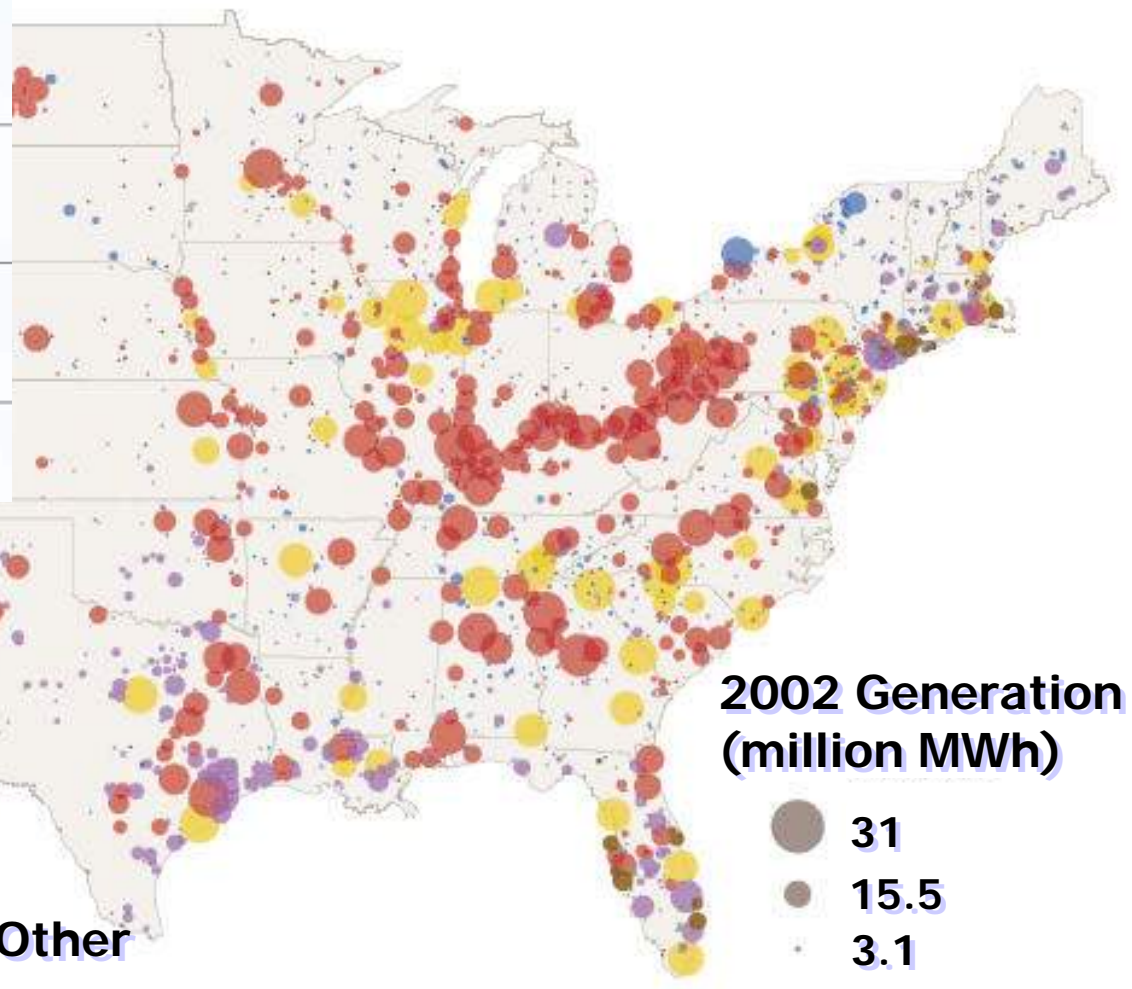
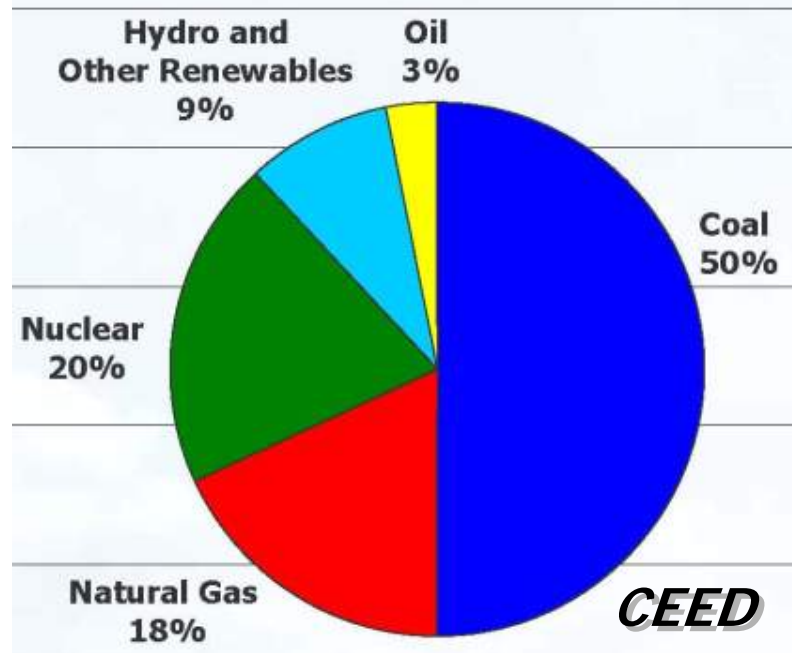
World Energy Fuel Distribution

Quadrillion (10^{15}) Btu



U. S. Energy Fuel Distribution

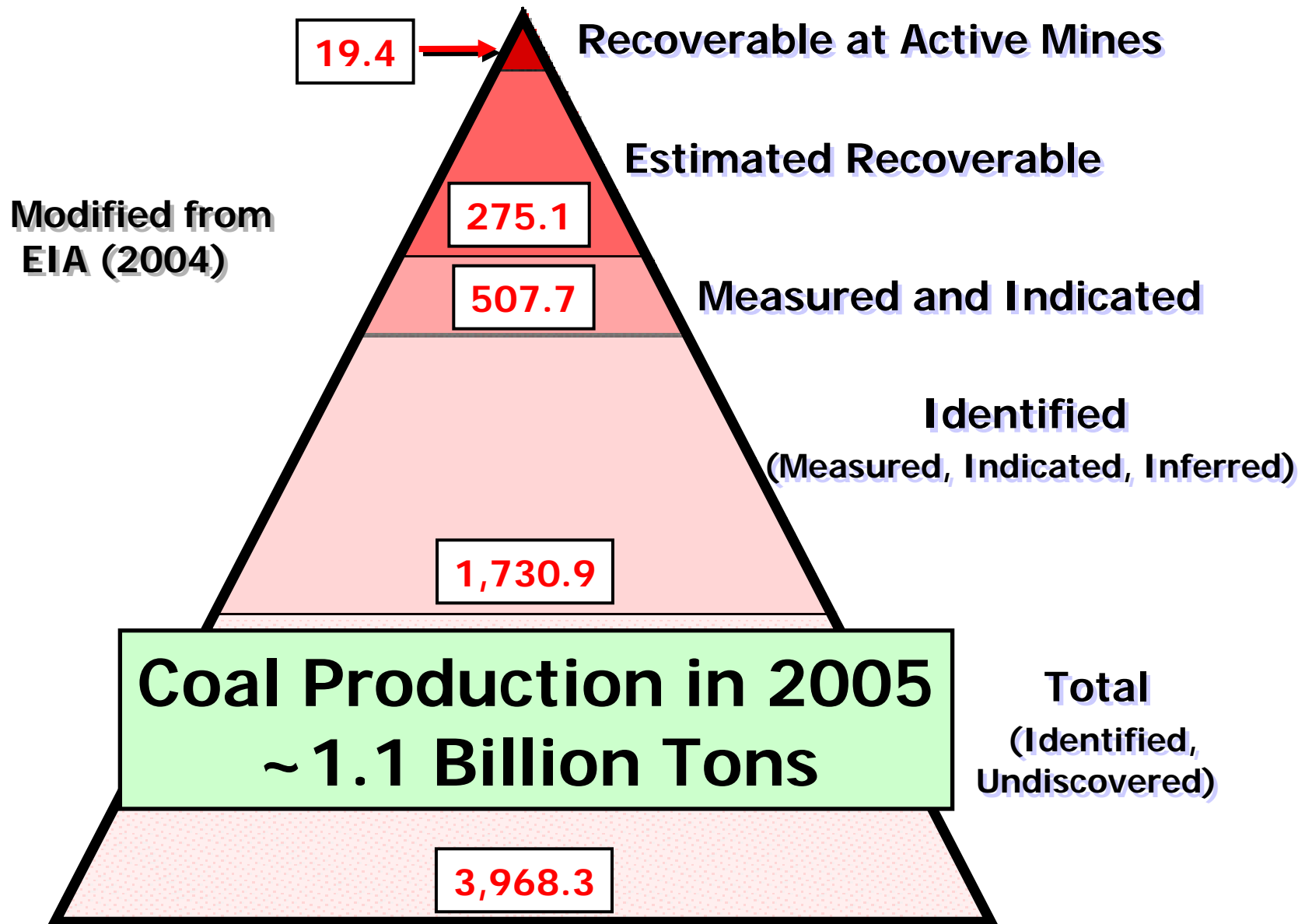
U.S. Electricity Mix (Percentages by Generation)



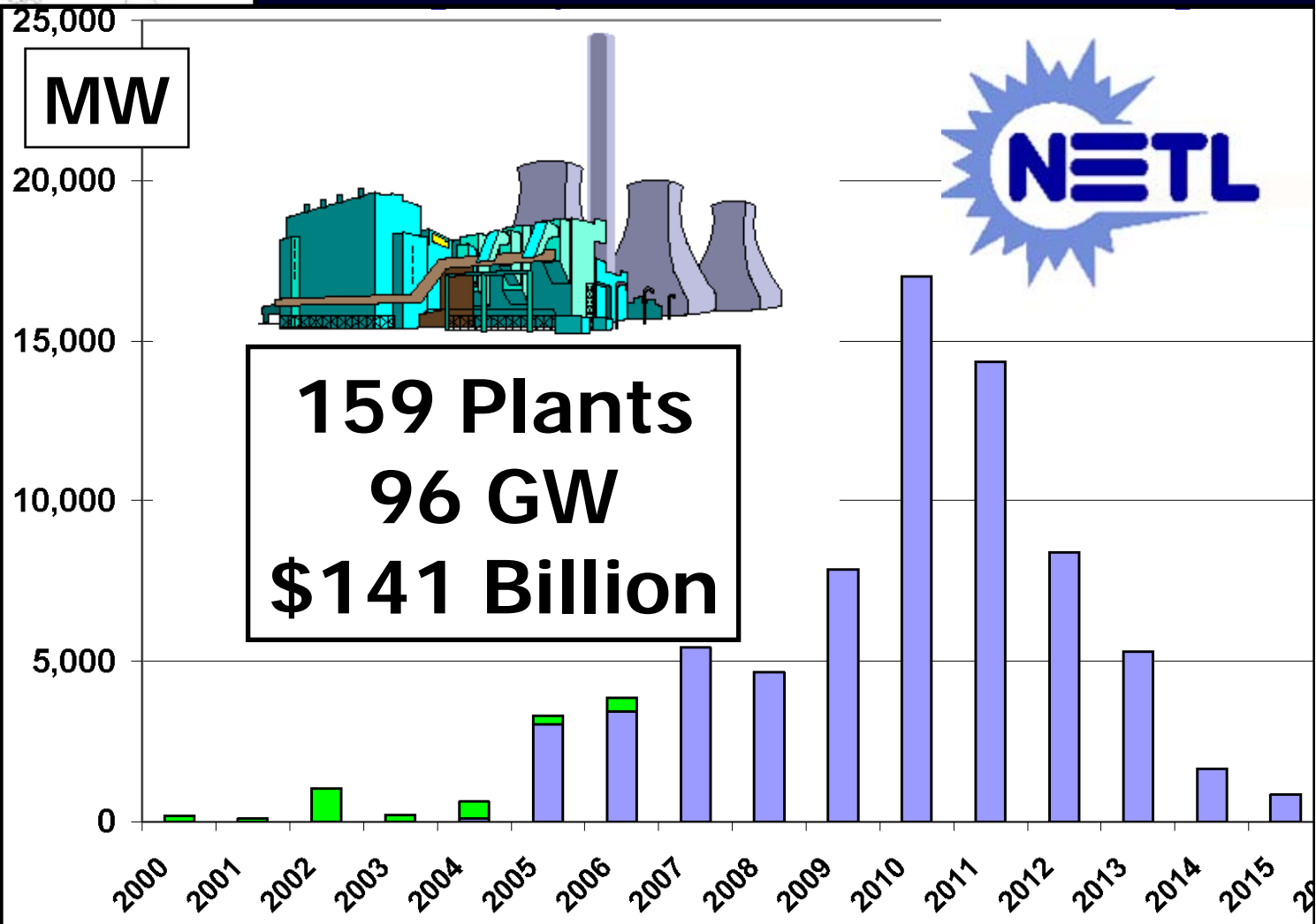
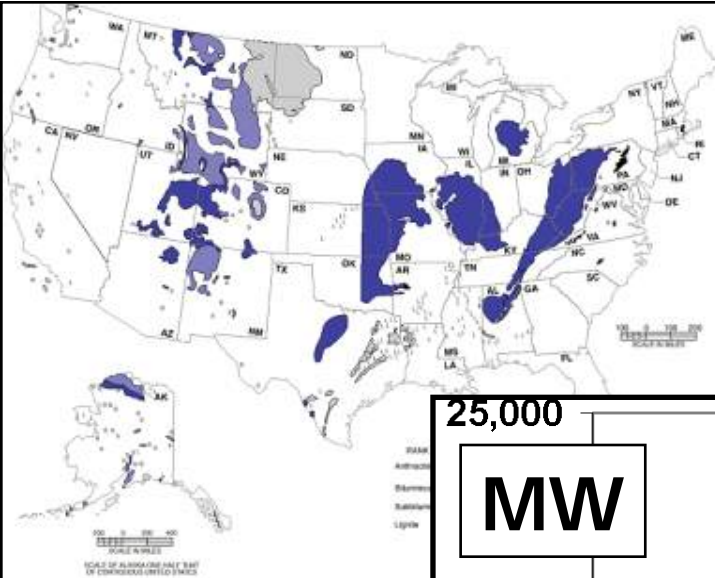
- Coal
- Oil
- Nat. Gas
- Nuclear
- Hydro
- Renewable/Other


Courtesy NRG


U. S. Coal Resources (Billion Tons)



US Coal-Fired Capacity Additions



 Operational

 Proposed

Outline

- CO₂ Sources and Sinks
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Traditional Pulverized Coal Power Generation

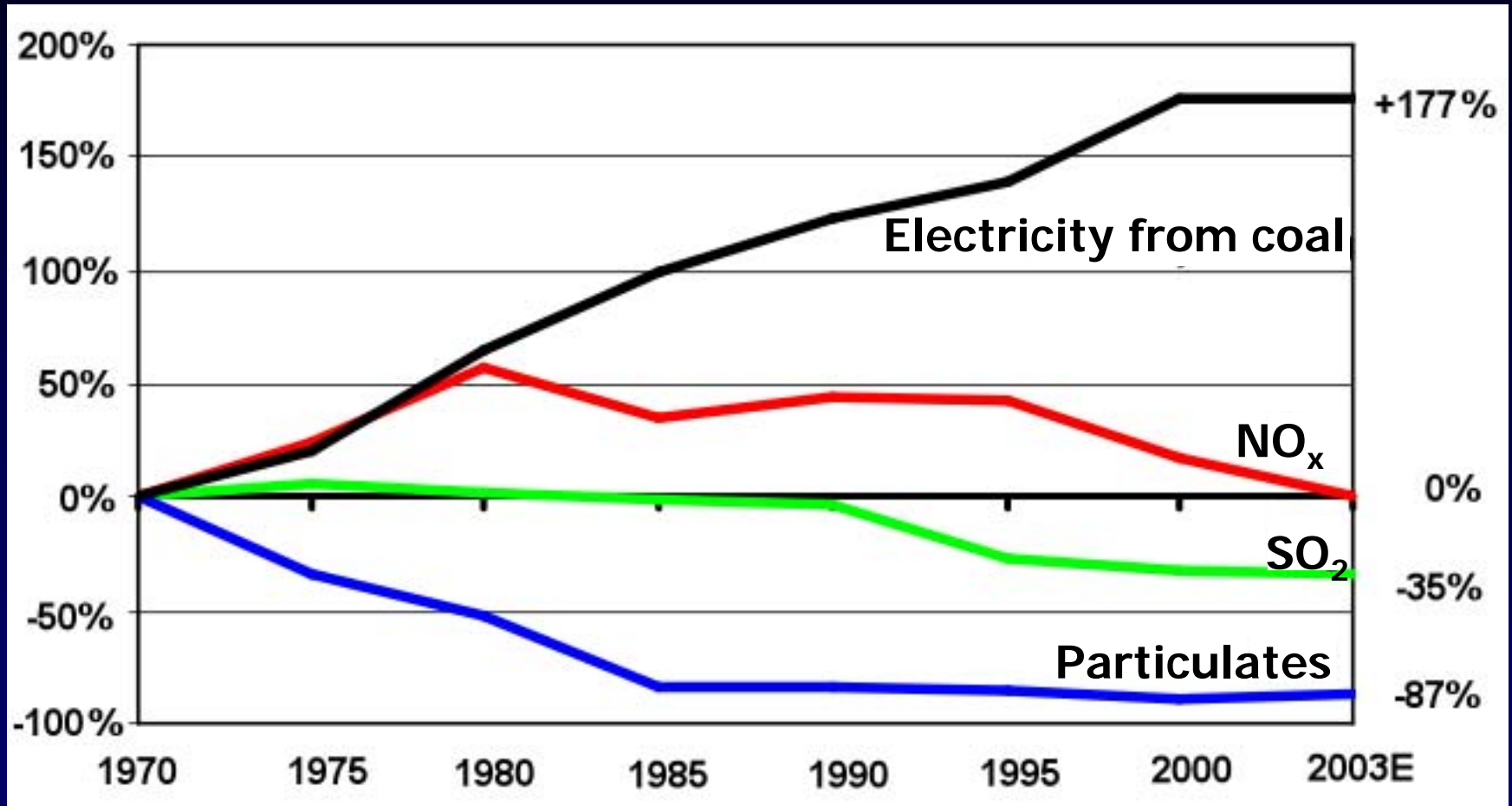


Pollutants (500 MW Plant Yr⁻¹)

- Nitrogen oxides (NO_x): **10,200 tons**
- Sulfur Dioxide (SO₂): **10,000 tons**
- Mercury (Hg): **170 pounds**
- Arsenic (As): **225 pounds**
- Lead (Pb), Cadmium (Cd):
114 pounds, 4 pounds
- Carbon Monoxide (CO): **720 tons**
- Carbon Dioxide (CO₂): **3,700,000 tons**

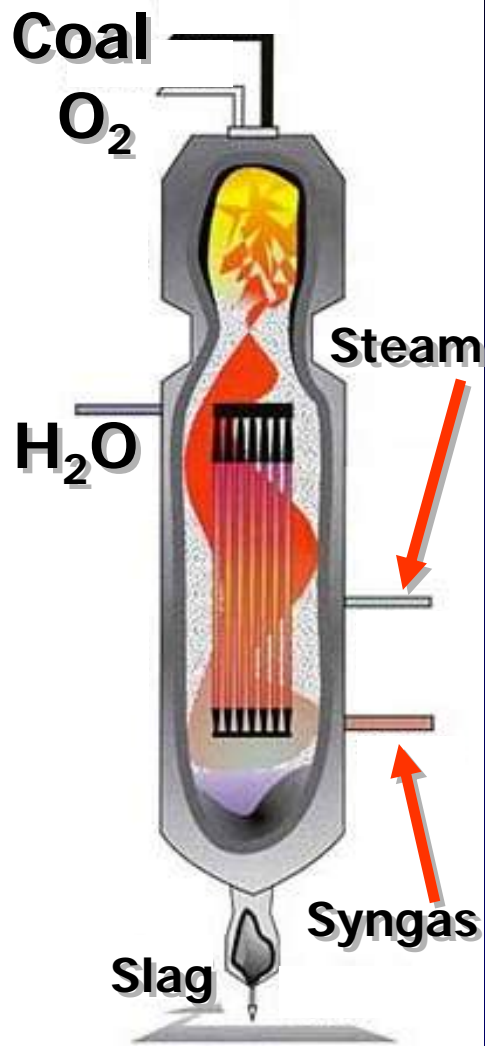
Decline in Emissions US Coal-Fired Plants

% Change since 1970



EIA (2003), EPA (2004)

Clean Coal Power Generation



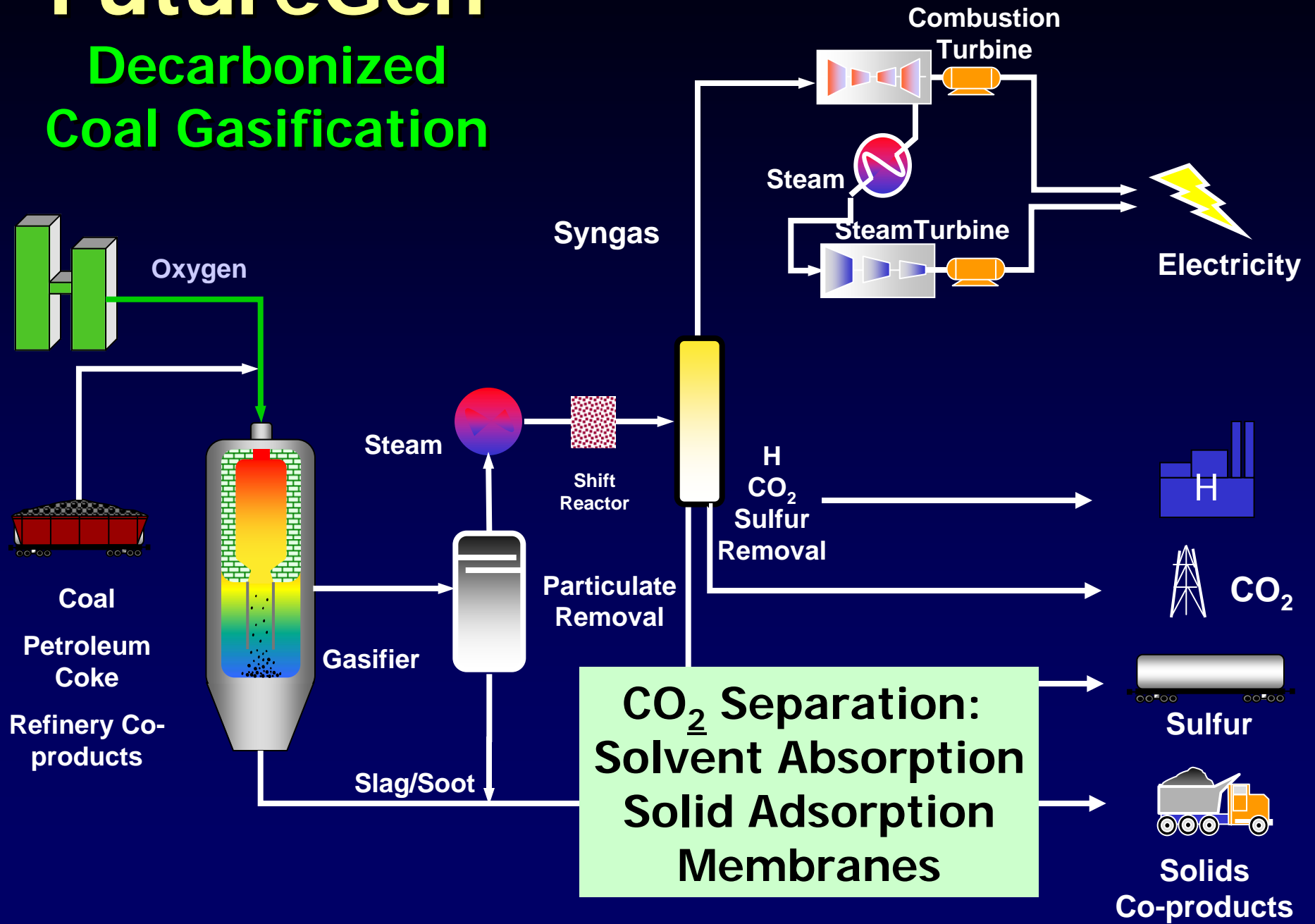
Texaco Gasifier

- Gasification: Injection of heat, air or O_2 into a gasifier under high pressure
- 385 gasifiers worldwide in 2004
- 49% use coal; 36% use petroleum residuals
- Syngas product (mainly CO , H_2)
- Syngas processed to remove contaminants

FutureGen

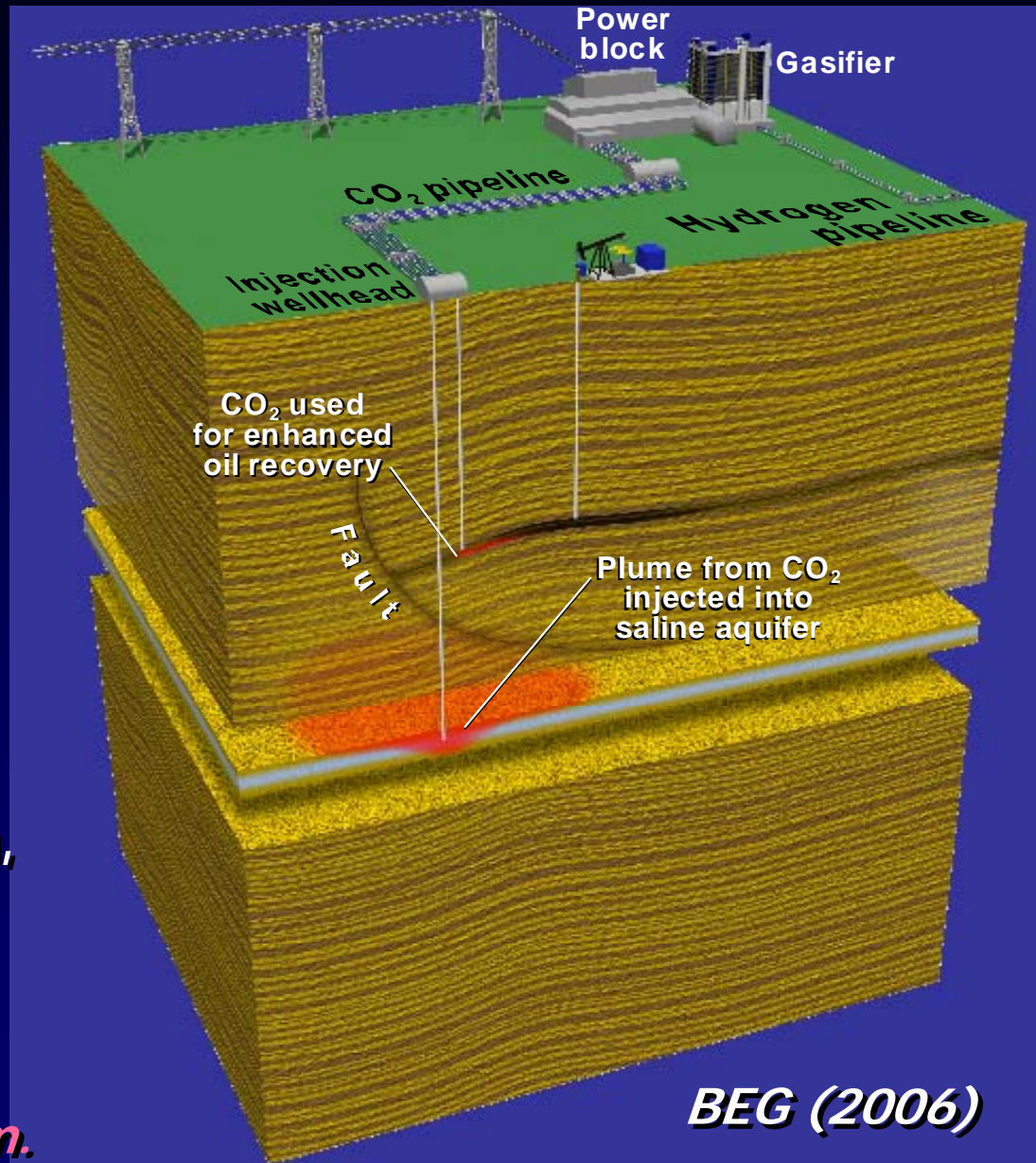
Decarbonized Coal Gasification

Modified from Eastman Chemical



FutureGen

- 275-MW, near-zero-emission gasifier
- Flexible fuel source
- Produces electricity, H₂, >1MMT CO₂ per year
- CO₂, H₂ pipelines
- Sequester ≥90% CO₂
- Protocols for CO₂ measuring, monitoring, and verification
- Stacked storage
 - EOR
 - Deep brine-bearing fm.



Decarbonized Coal Benefits

Environment:

Benefits of capturing and storing CO₂, a major greenhouse gas.

Energy:

CO₂ Enhanced Oil Recovery (EOR), hydrogen.

Economy:

Wellhead value, taxes, infrastructure development, jobs.

Decarbonized Coal: CO₂ Yield and **Costs**

Fruitland Formation, Colorado



1 Ton of coal = 3 Tons of CO₂

<http://cbll.net/articles/coal-question>

Wabash River IGCC Power Plant



**Capture, Transport, Storage:
\$20 to \$25 per metric ton**

**Additional 1-2¢ per kWh
(baseline = 4¢ per kWh)**

Stephens (2005)

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Emissions and Storage

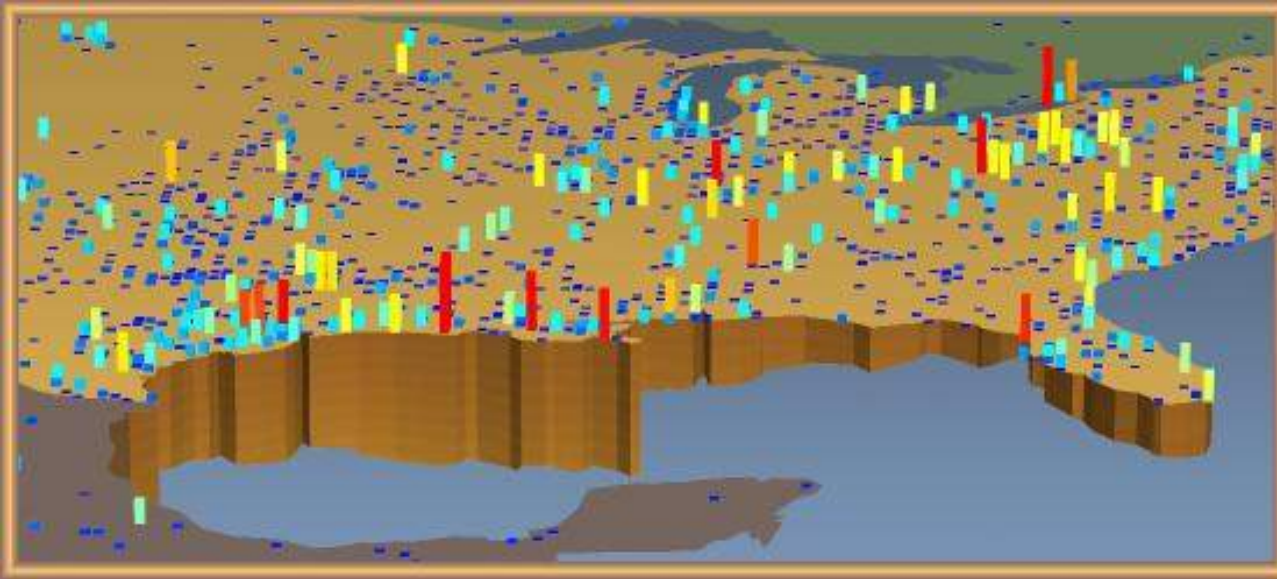
Texas emits ~700 million metric tons annually.

The U. S. emits ~5,700 million metric tons annually.

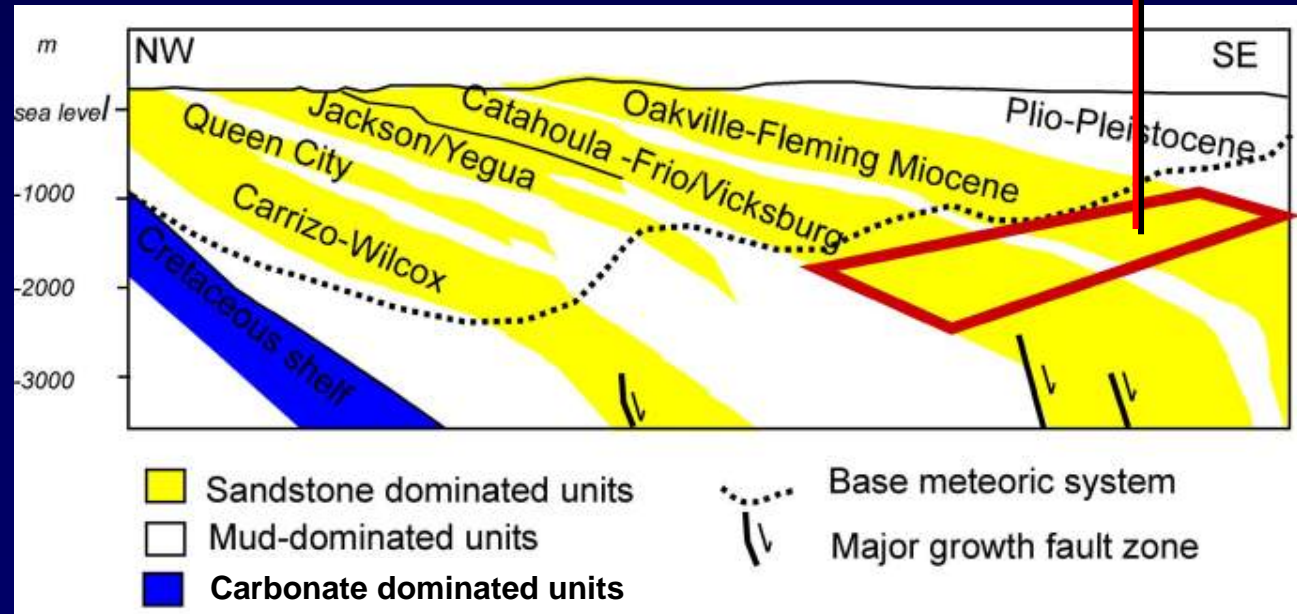
~700 million metric tons of minimum CO₂ storage exists in the Texas Gulf Coast from EOR.

~220 billion metric tons of CO₂ could be stored by filling 1% of the brine volume in sandstones from Alabama to the Mexico border (37,000 km³, 4000-12,000 ft depth).

SE US Potential For Stacked Storage



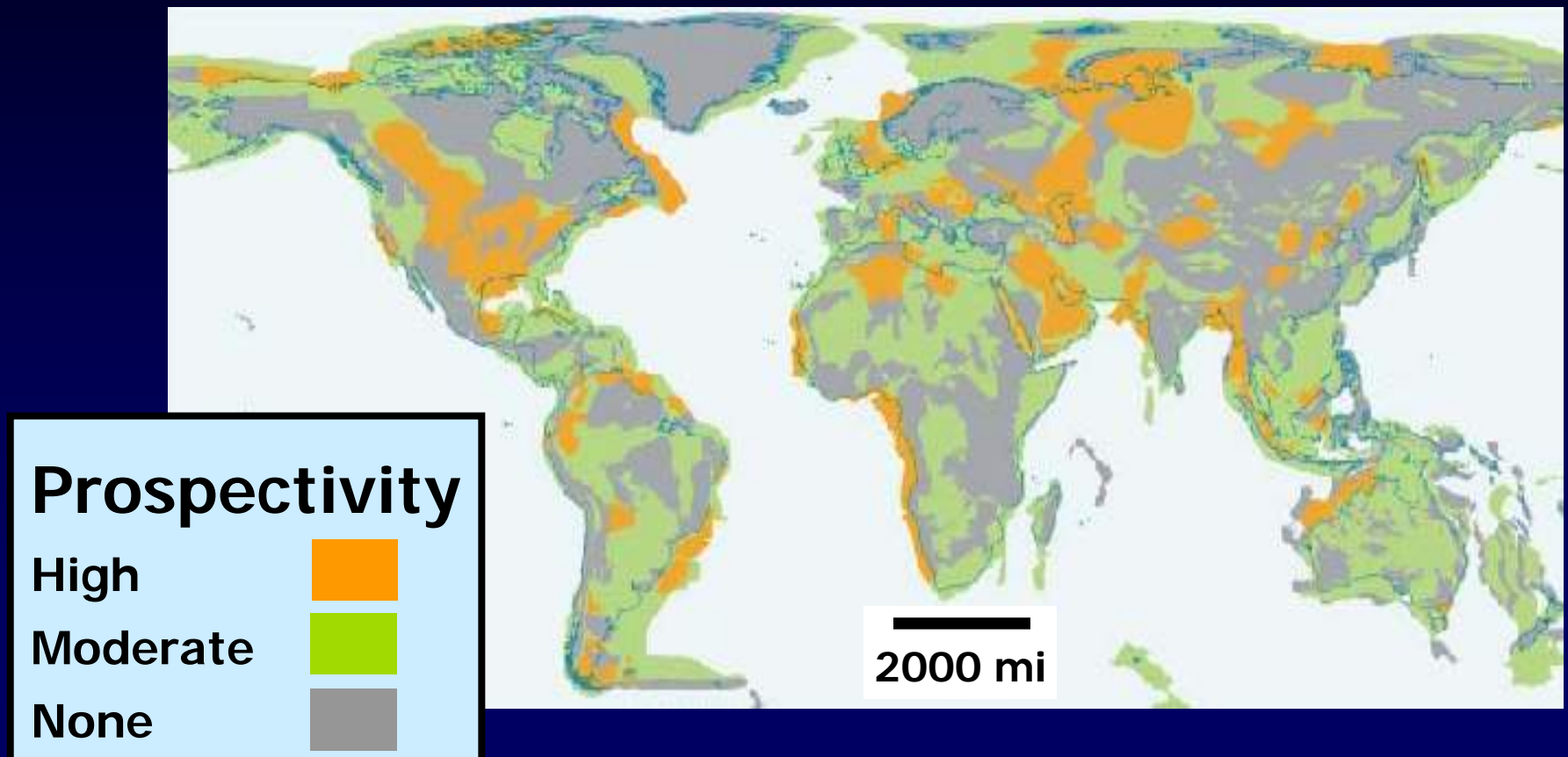
Potential
Frio Injection Zone



*Galloway
and others, 1982*

Worldwide CO₂ Storage Potential

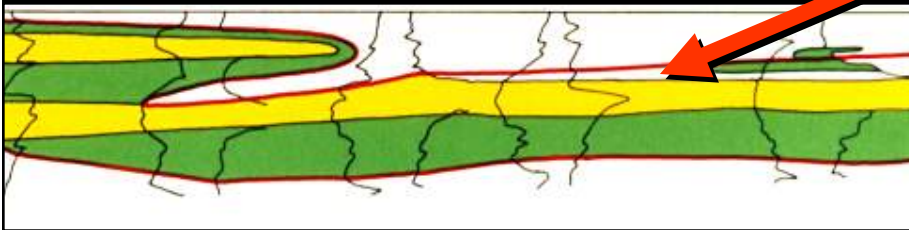
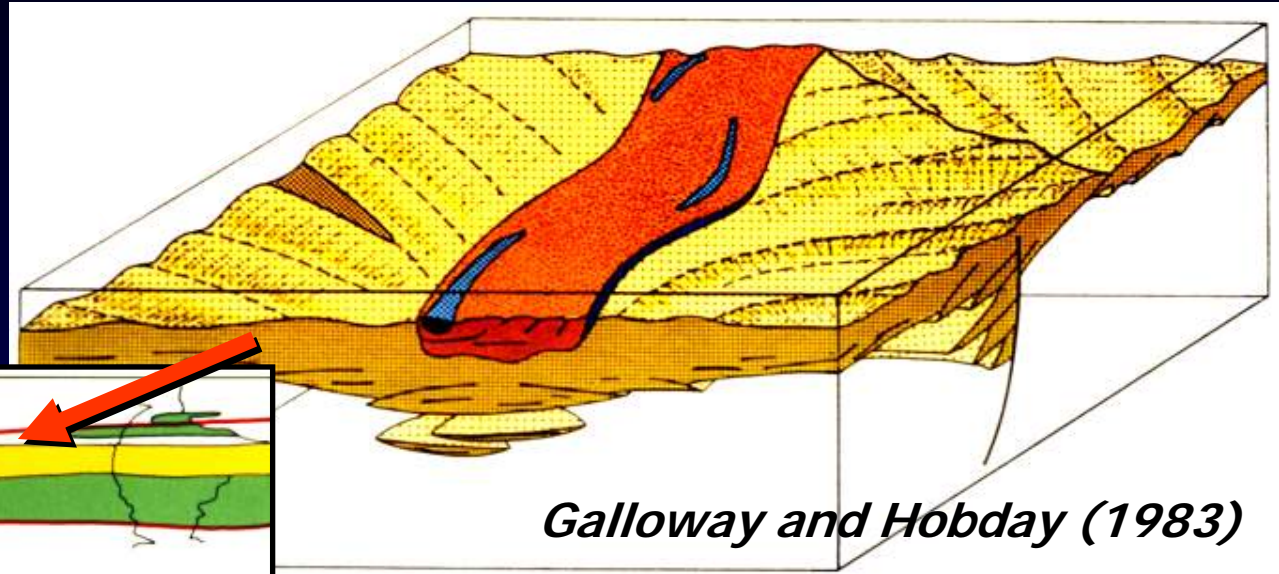
Deep Brine Aquifers: 2,200-10,000 Gt
Depleted Oil and Gas Fields: 740-1,850 Gt



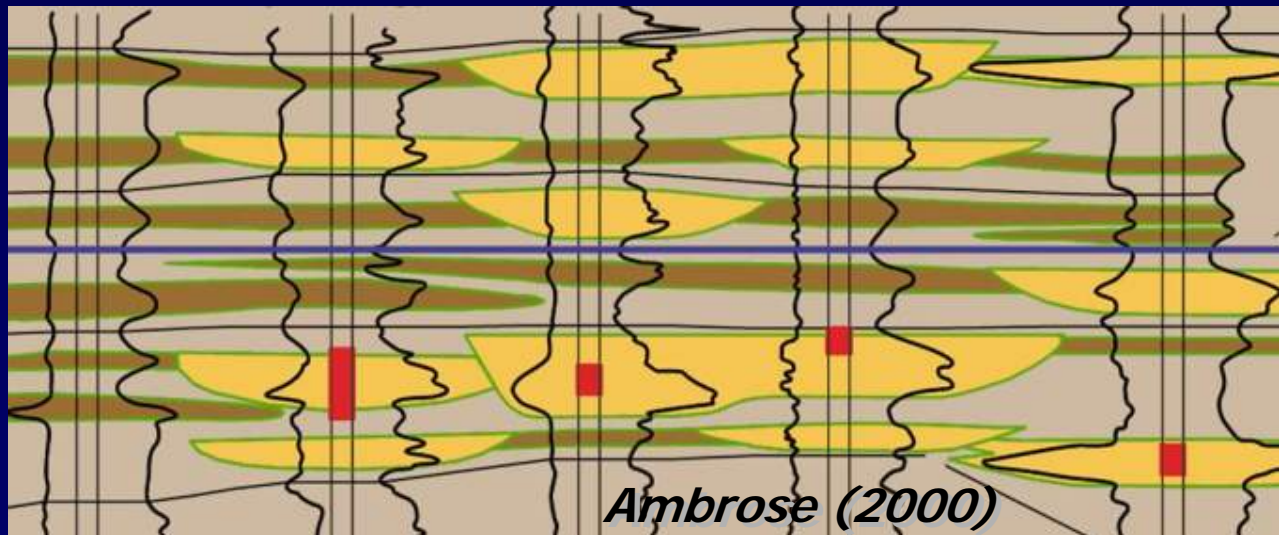
Bradshaw and Dance, 2004
Parson and Keith, 1998

CO₂ Storage Capacity vs. Effectiveness

Homogeneous
Wave-dominated
delta



Heterogeneous
Middle Frio Fm.
Stratton field



Outline

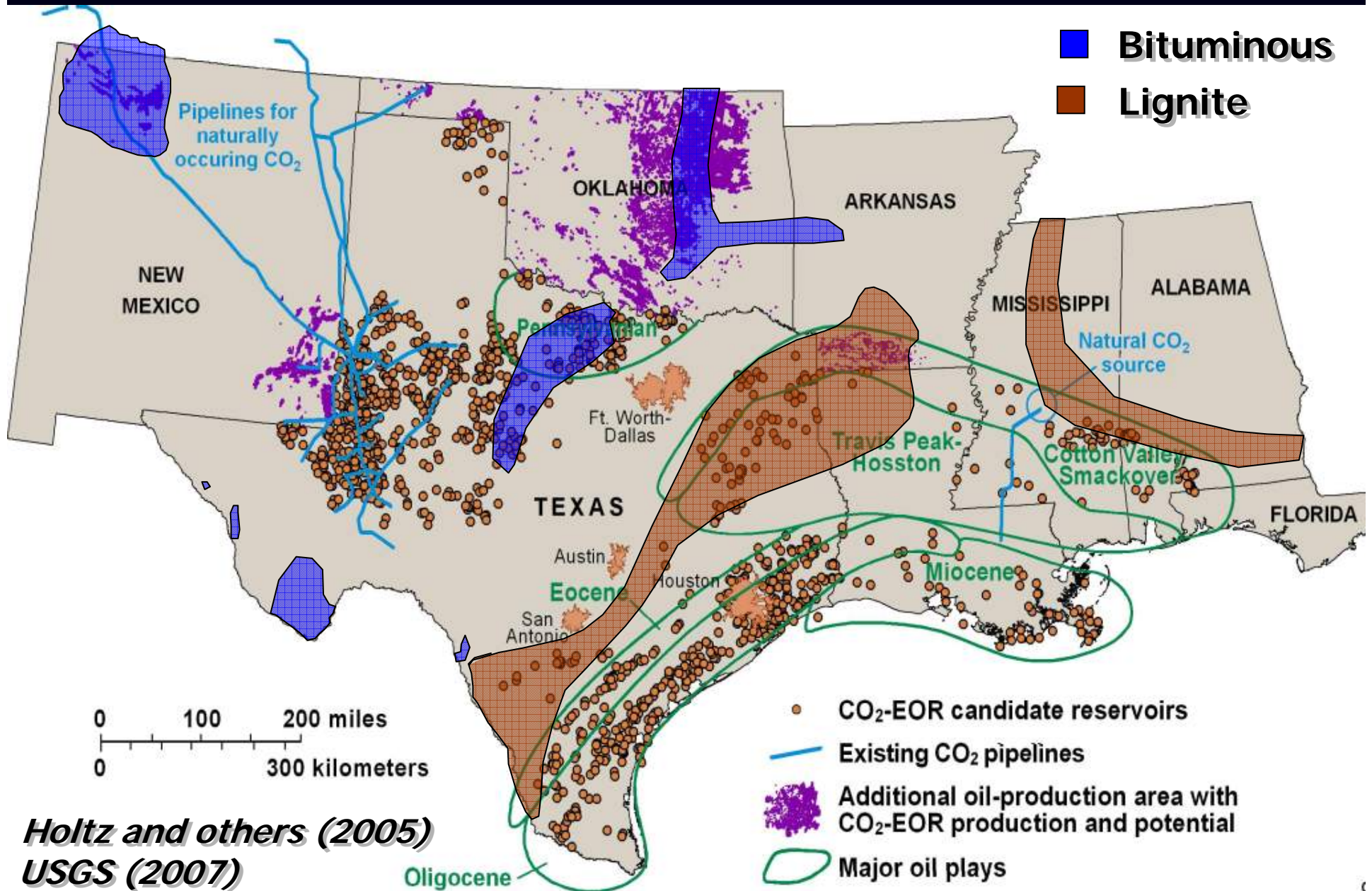
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United States CO₂ EOR

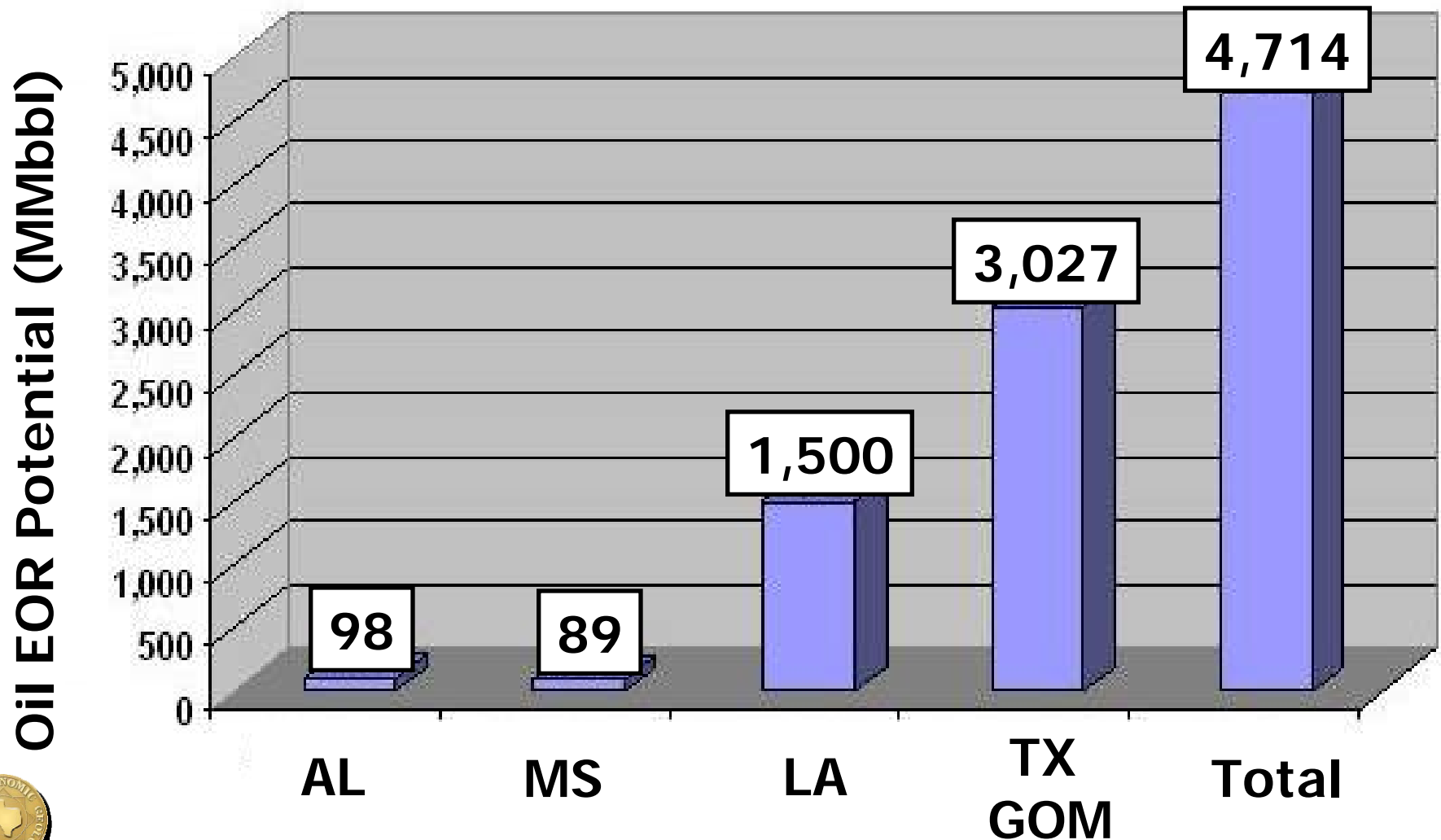
- 2 Bcf/day (~35 MMTY) of CO₂ currently injected for EOR, largely in the Permian Basin.
- Annual US oil consumption is ~7 BSTB and annual oil production is ~3.2 BSTB.
- Current US CO₂ EOR production is ~206 MBOPD, 7.5 MMBOPY: 4% of US production
66 active projects, 50 in the Permian Basin.

Miscible CO₂-EOR Potential: 4.7 BBbl in Gulf Coast

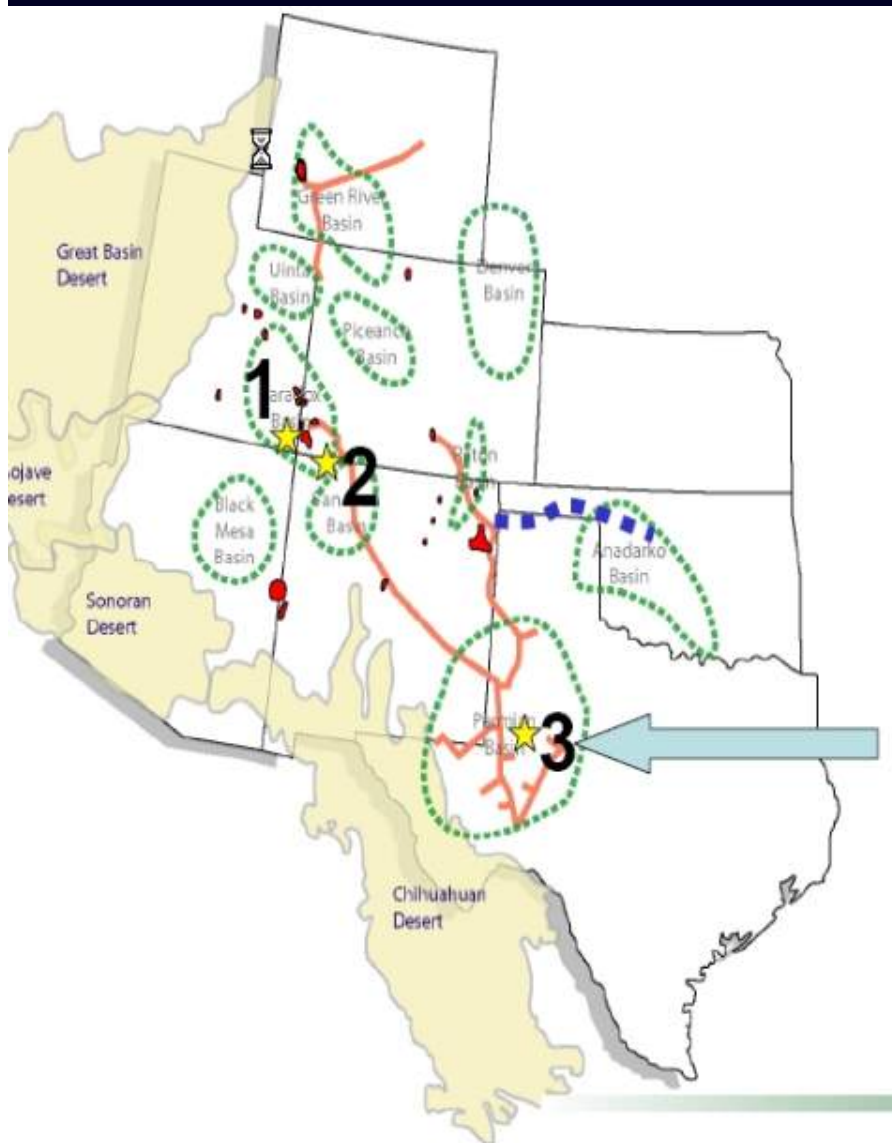


Miscible CO₂ EOR Resource Potential in the Gulf Coast

Holtz and others (2005)



DOE Southwest Partnership Phase 2 Pilot Sites



Objectives

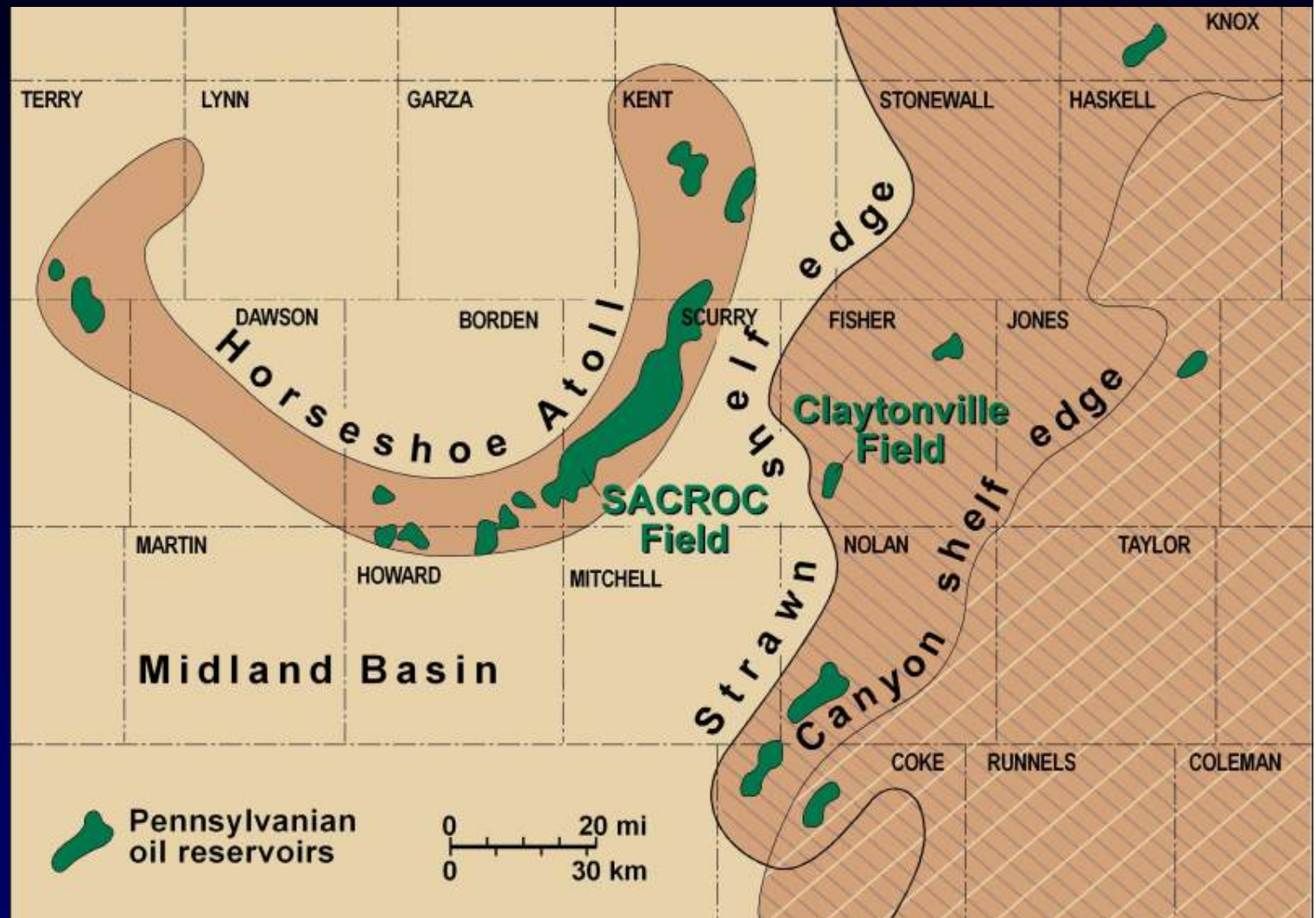
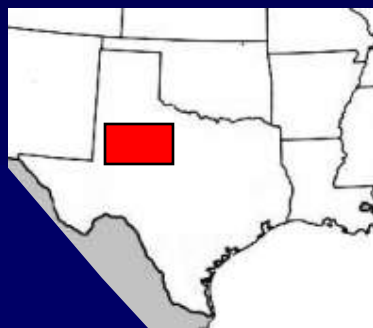
SACROC

- *Long-term CO₂ injection*

Claytonville Field

- *Baseline CO₂ monitoring*
- *Reservoir Characterization*
- *3-D Seismic Data, VSP*
- *Groundwater Analysis*

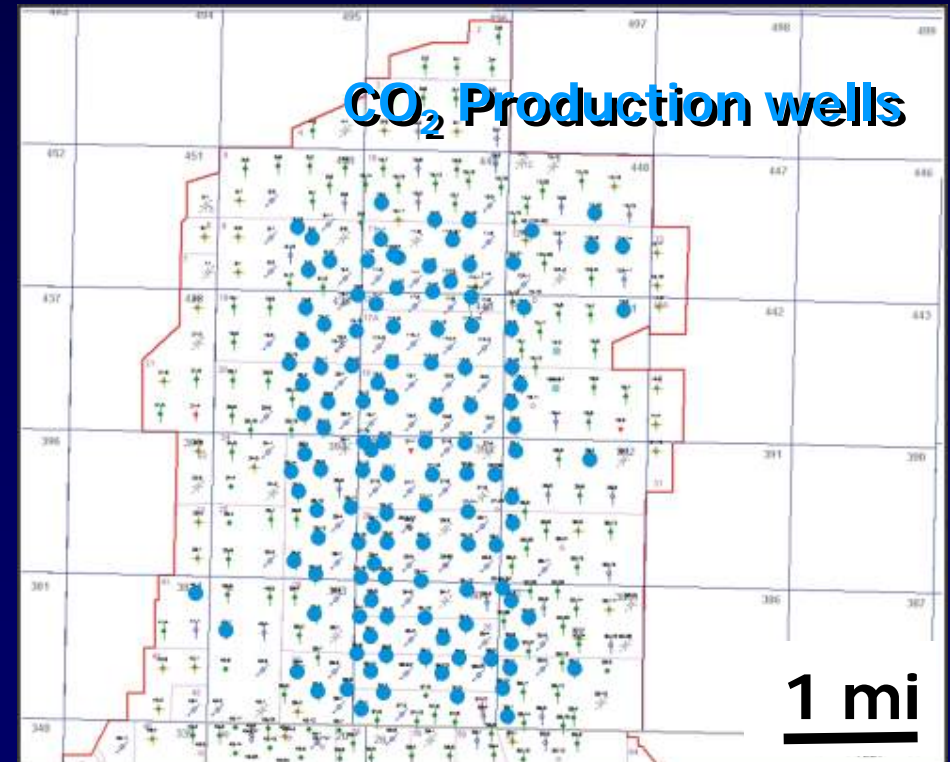
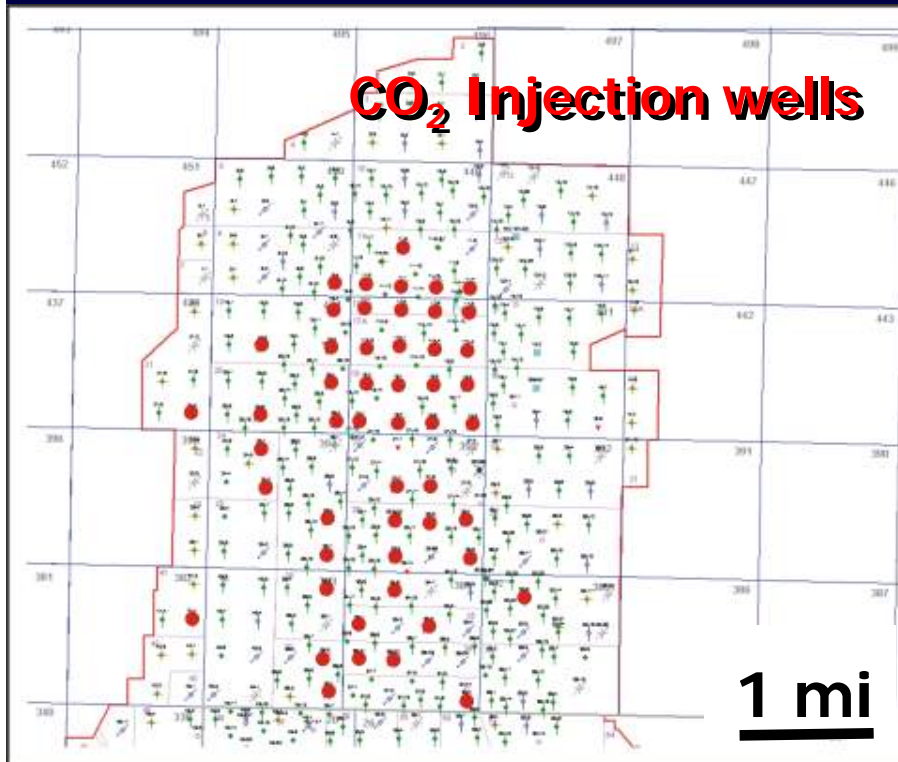
SACROC* and Claytonville Field



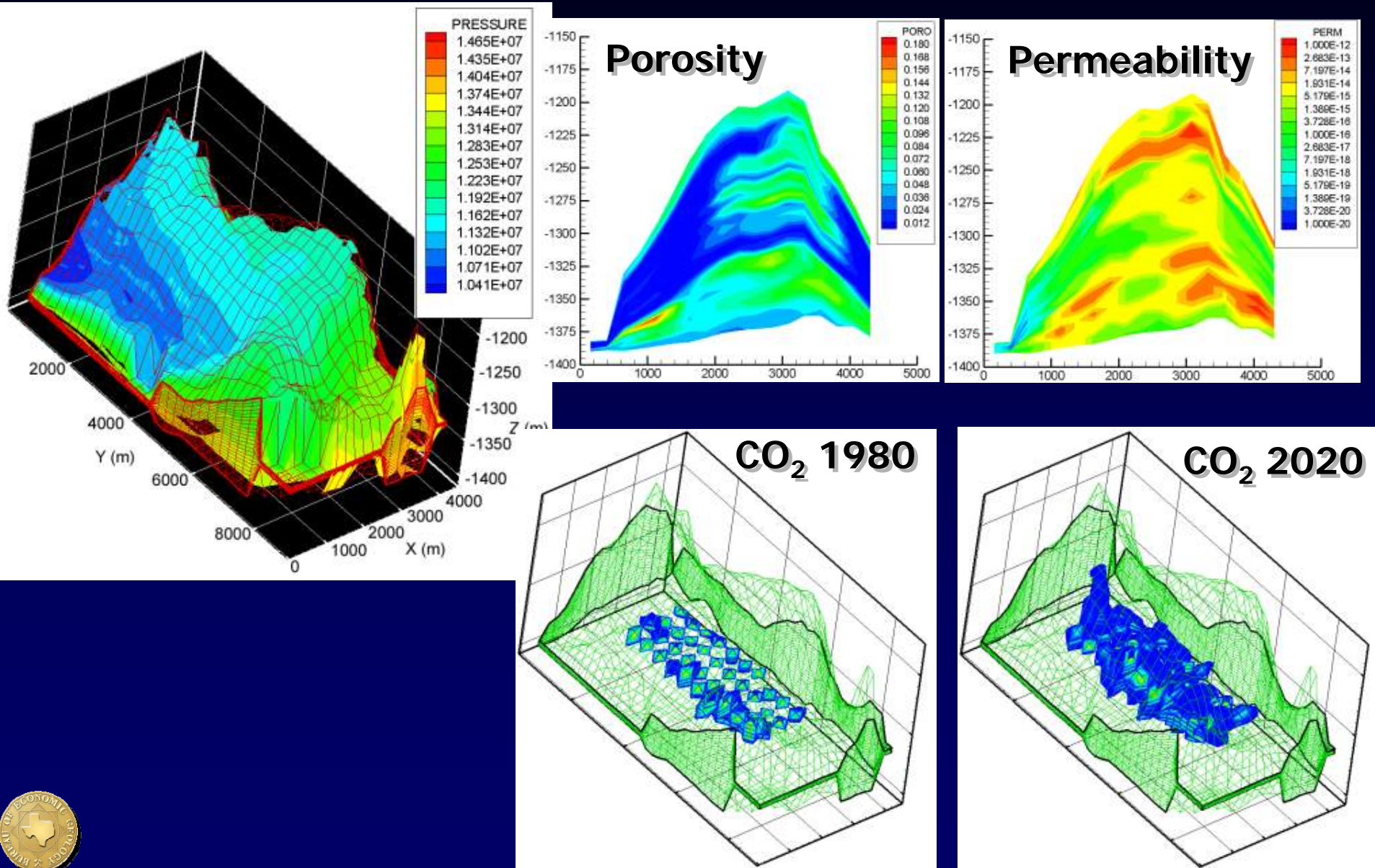
Modified from Galloway and others (1983)

SACROC CO₂ Injection and Production

- **13 million tons** of CO₂ injected in 51 wells
- **6 million tons** of CO₂ produced in 119 wells
- **EUR 57%** of 2.16 Bbbl OOIP (Kelly-Snyder Field)



Spatial distribution of Reservoir Properties and CO₂



Summary

Total US coal resource: 3,968 Billion Tons

Clean coal benefits: Hydrogen, Reduced CO₂, EOR

Wide variety of miscible CO₂-EOR plays in Gulf Coast and Permian Basin

