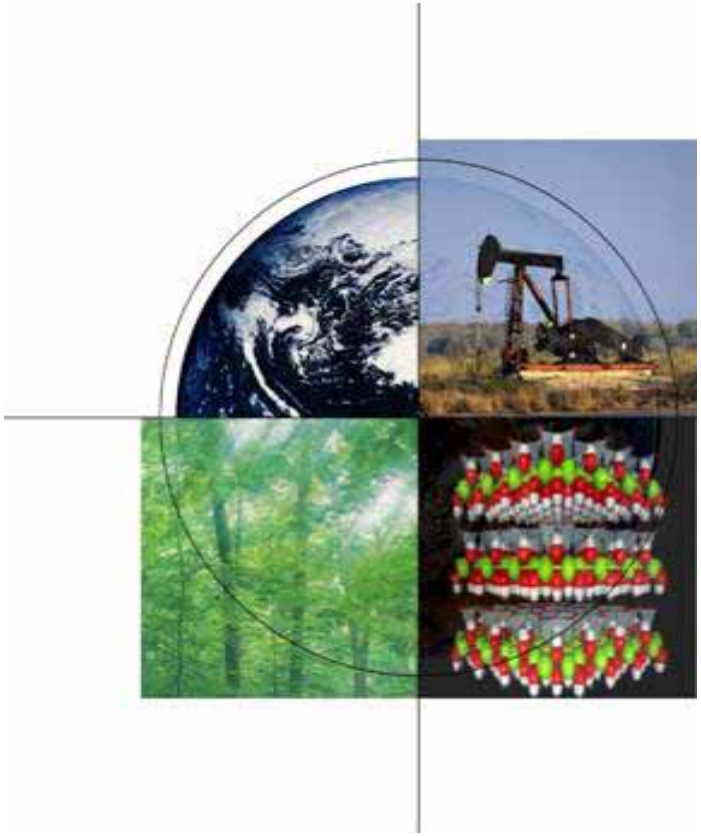
DOE/Fossil Energy
Carbon Sequestration Program



Briefing to

President's Council of Advisors on Science and Technology

September 20, 2005

Jay Braitsch – DOE/Fossil Energy

Technological Carbon Management Options

Reduce Carbon Intensity

- Renewables
- Nuclear
- Fuel Switching

Improve Efficiency

- Demand Side
- Supply Side

Sequester Carbon

- Capture & Store
- Enhance Natural Sinks

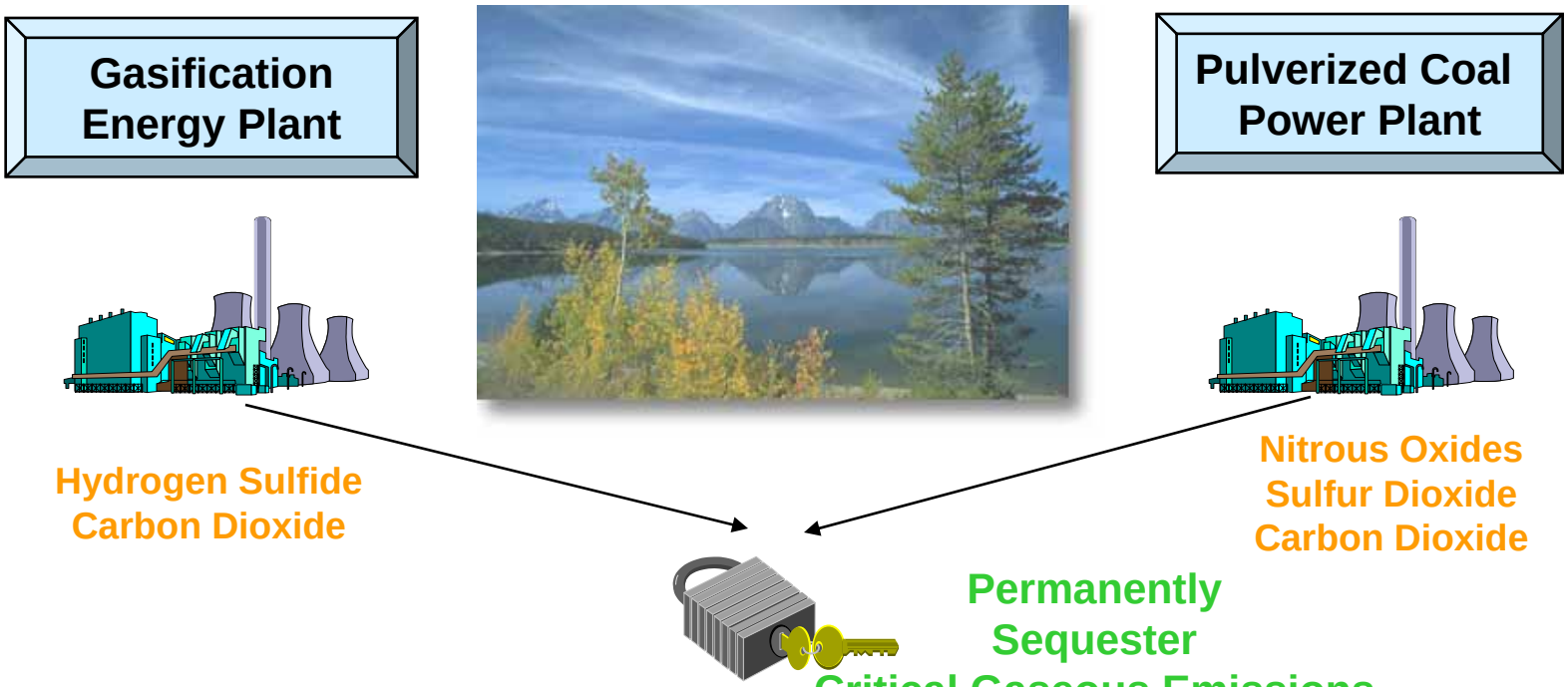
All options needed to:

- Affordably meet energy demand
- Address environmental objectives

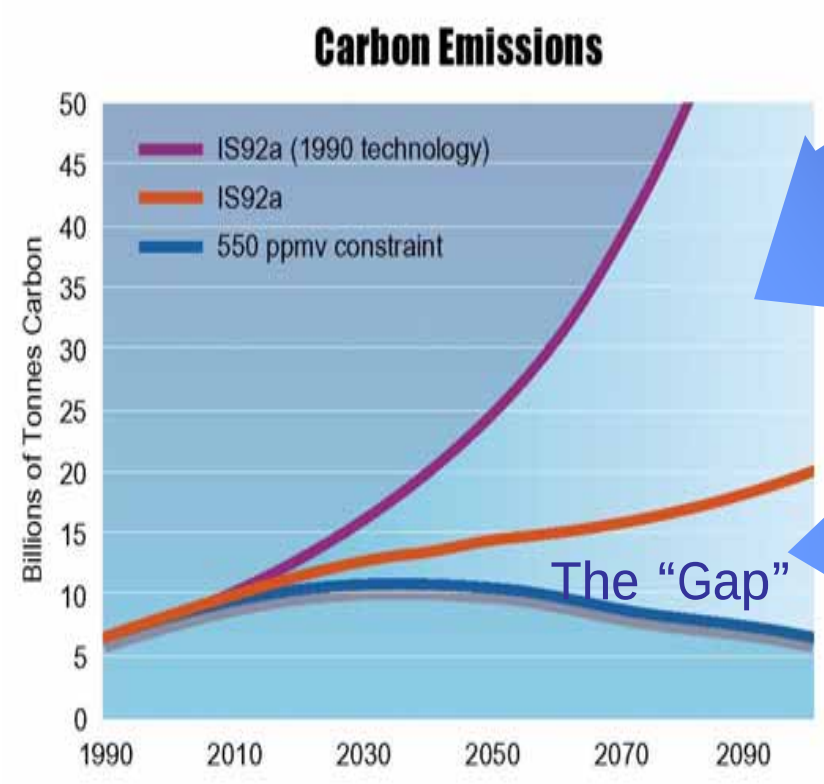
Sequestration - Not Necessarily Just About CO_2

(Near Zero Emissions Concept)

- Sequester traditional pollutants & CO_2
- Avoid costs, energy & complexity of controlling traditional pollutants
- Provide major cost & energy offsets for CO_2 capture & sequestration
- Substantially reduce footprint and complexity of plants



Achieving this Reference Case Will Not Necessarily Be Easy



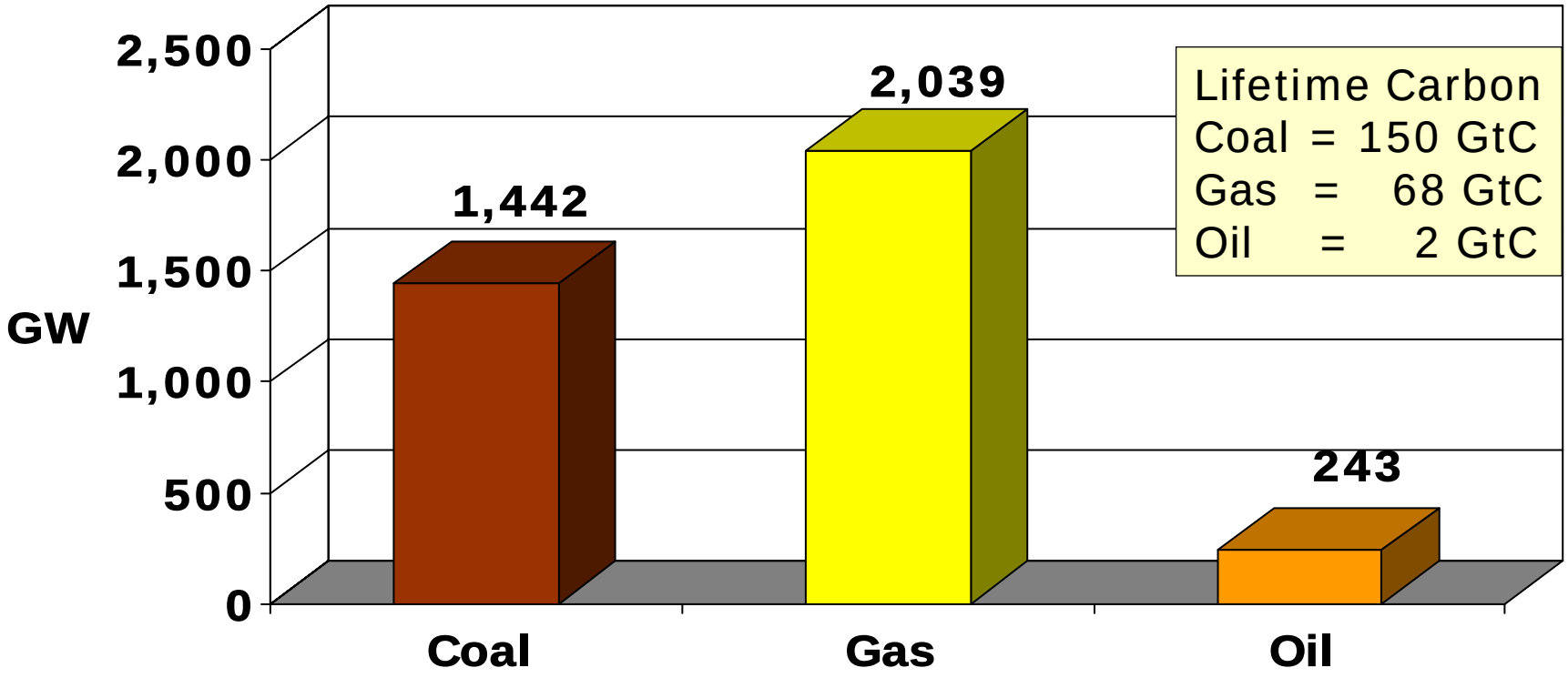
<u>Assumed</u> Advances In

- Fossil Fuels
- Energy intensity
- Nuclear
- Renewables

Gap technologies

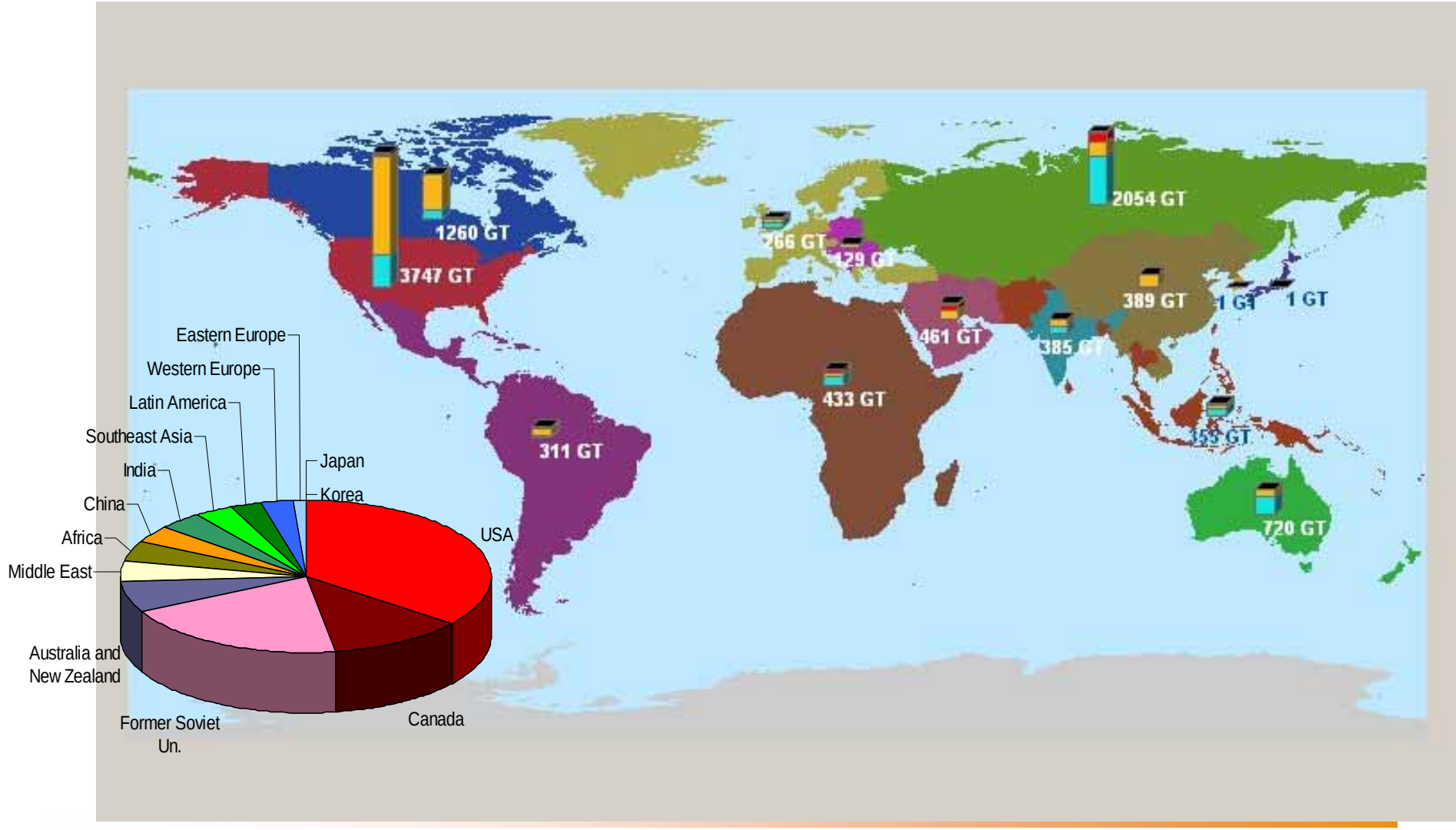
- Carbon capture & storage
  - Adv. fossil
- H2 and Adv. Transportation
- Biotechnologies
  - Soils, Bioenergy, adv. Biological energy

New Electric Generation Plants 2000-2030

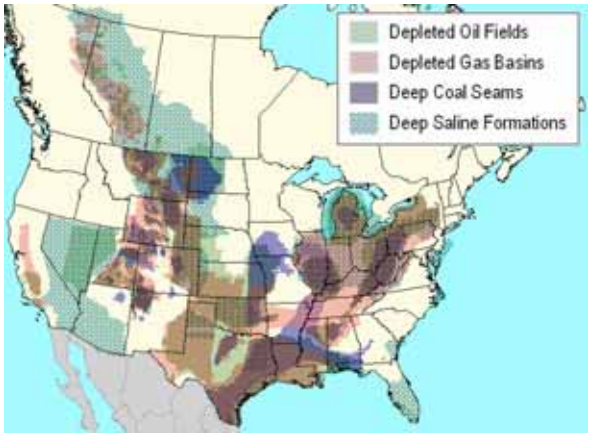


Data Source: IEA, WEO2002
Slide courtesy of Natural Resources Defense Council

Global CO_2 Storage Capacity: Now

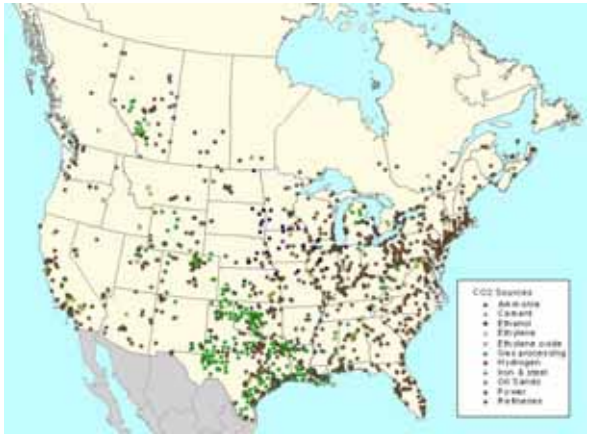


North America: An Abundance of CO_2 Storage Potential and a Large Potential User Market for CCS Technologies



3,800+ $GtCO_2$ Capacity within 330 US and Canadian Candidate Geologic CO_2 Storage Reservoirs

- 3,730 $GtCO_2$ in deep saline formations (DSF)
- 65 $GtCO_2$ in deep unmineable coal seams with potential for enhanced coalbed methane (ECBM) recovery
- 40 $GtCO_2$ in depleted gas fields
- 13 $GtCO_2$ in depleted oil fields with potential for enhanced oil recovery (EOR)



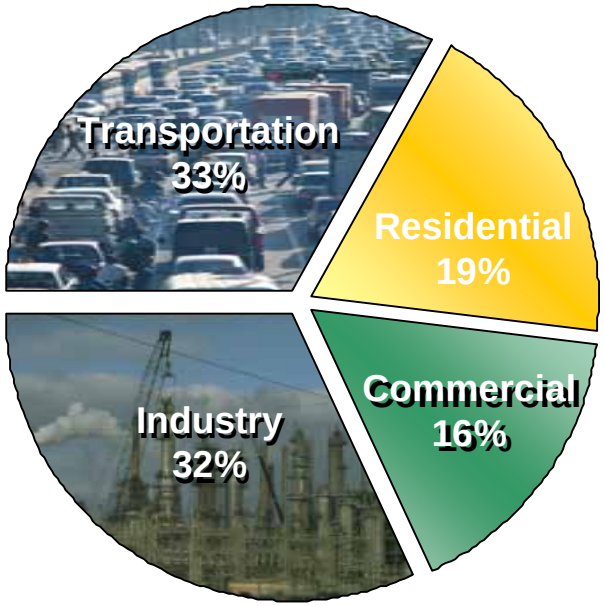
2,082 Large Sources (100+ $ktCO_2/yr$) with Total Annual Emissions = 3,800 $MtCO_2/yr$

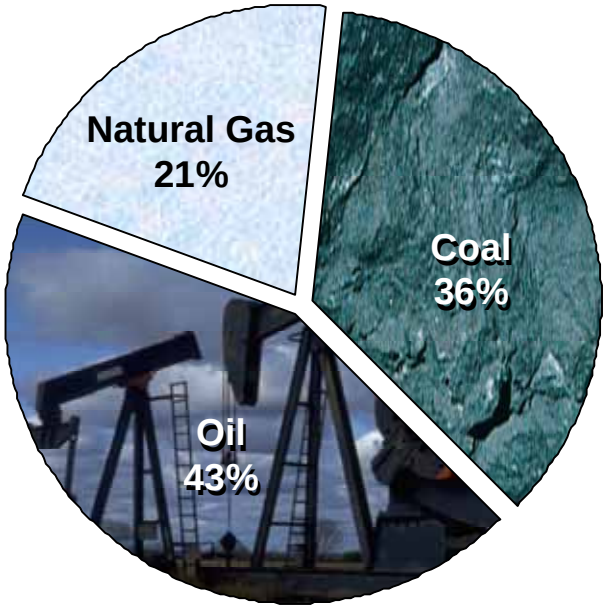
- 1,185 electric power plants
- 447 natural gas processing facilities
- 154 petroleum refineries
- 53 iron & steel foundries
- 124 cement kilns
- 43 ethylene plants
- 9 oil sands production areas
- 40 hydrogen production
- 25 ammonia refineries
- 47 ethanol production plants
- 8 ethylene oxide plants

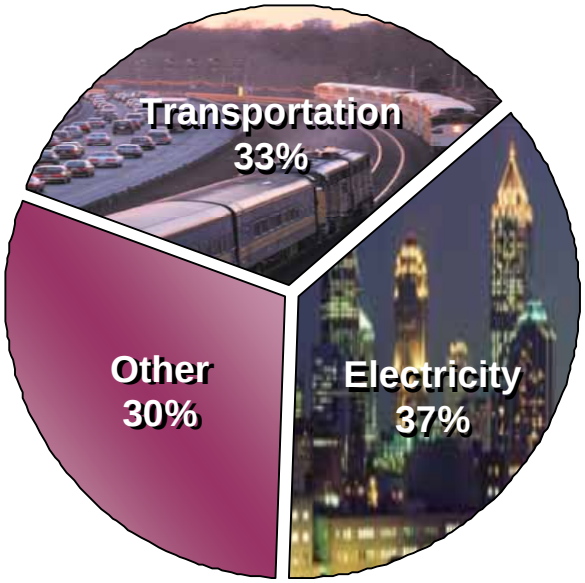
Program Focuses on Coal & Electricity

United States Carbon Dioxide Emissions

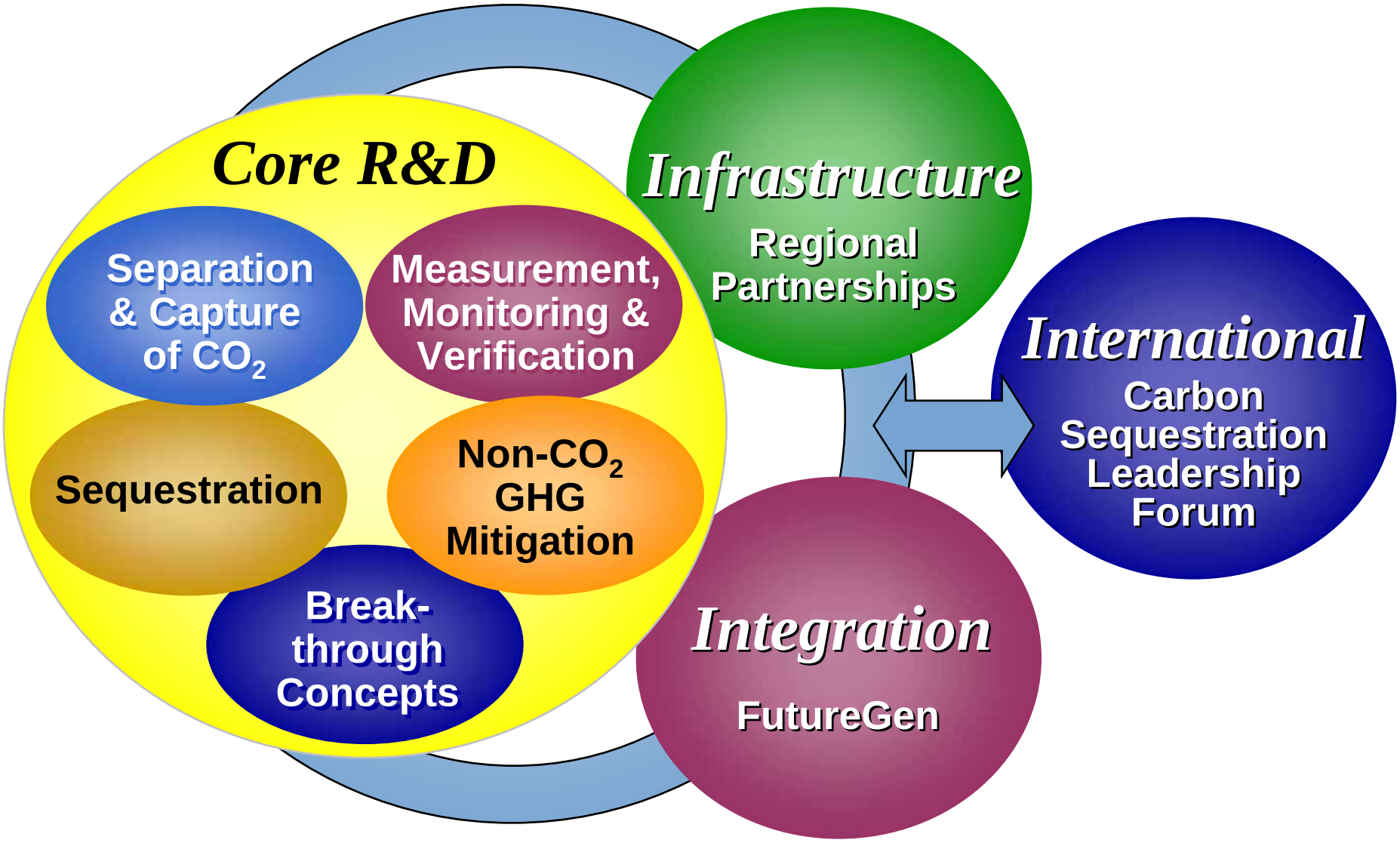
(By Source & Sector)



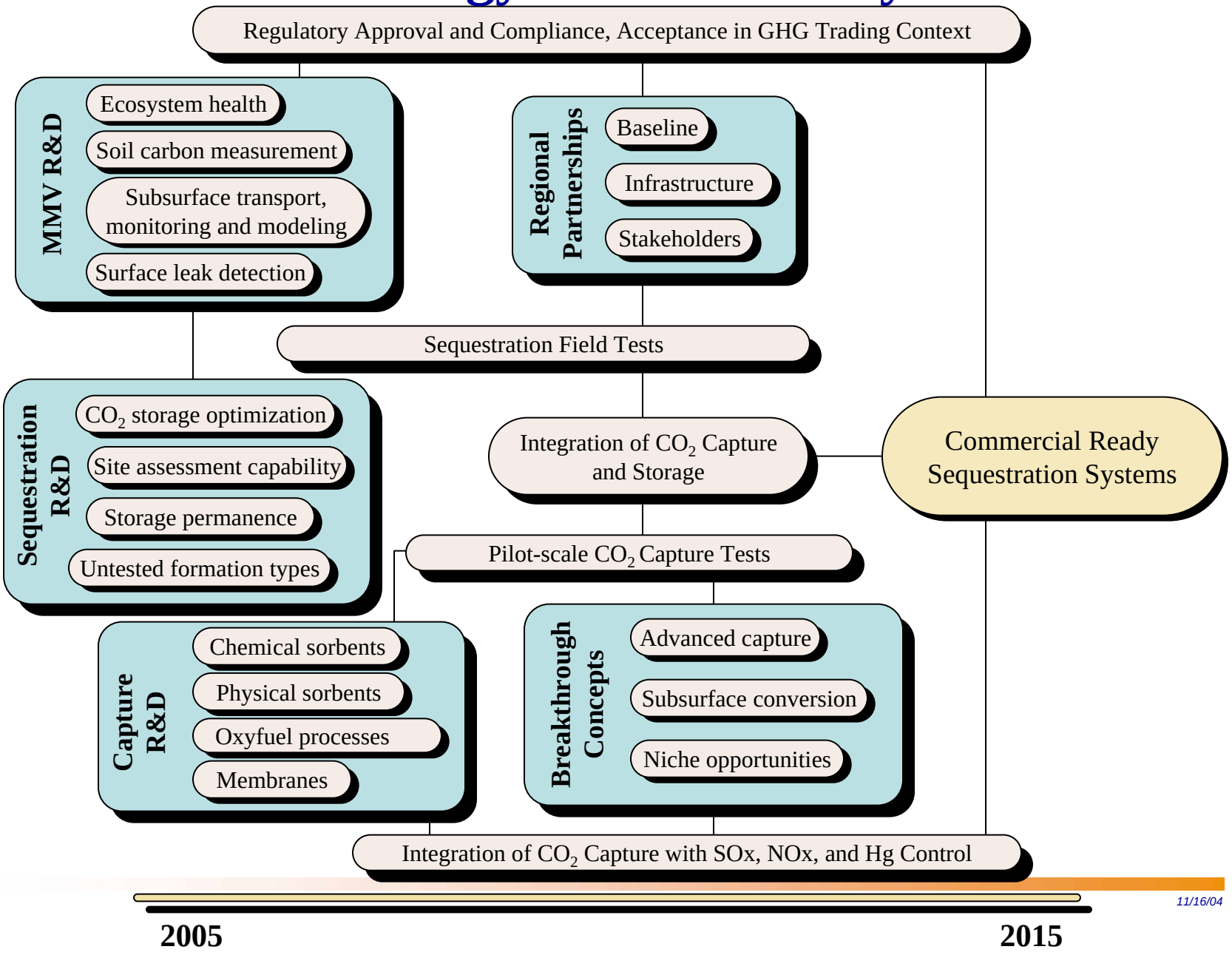




U.S. DOE/ Fossil Energy Program Organization

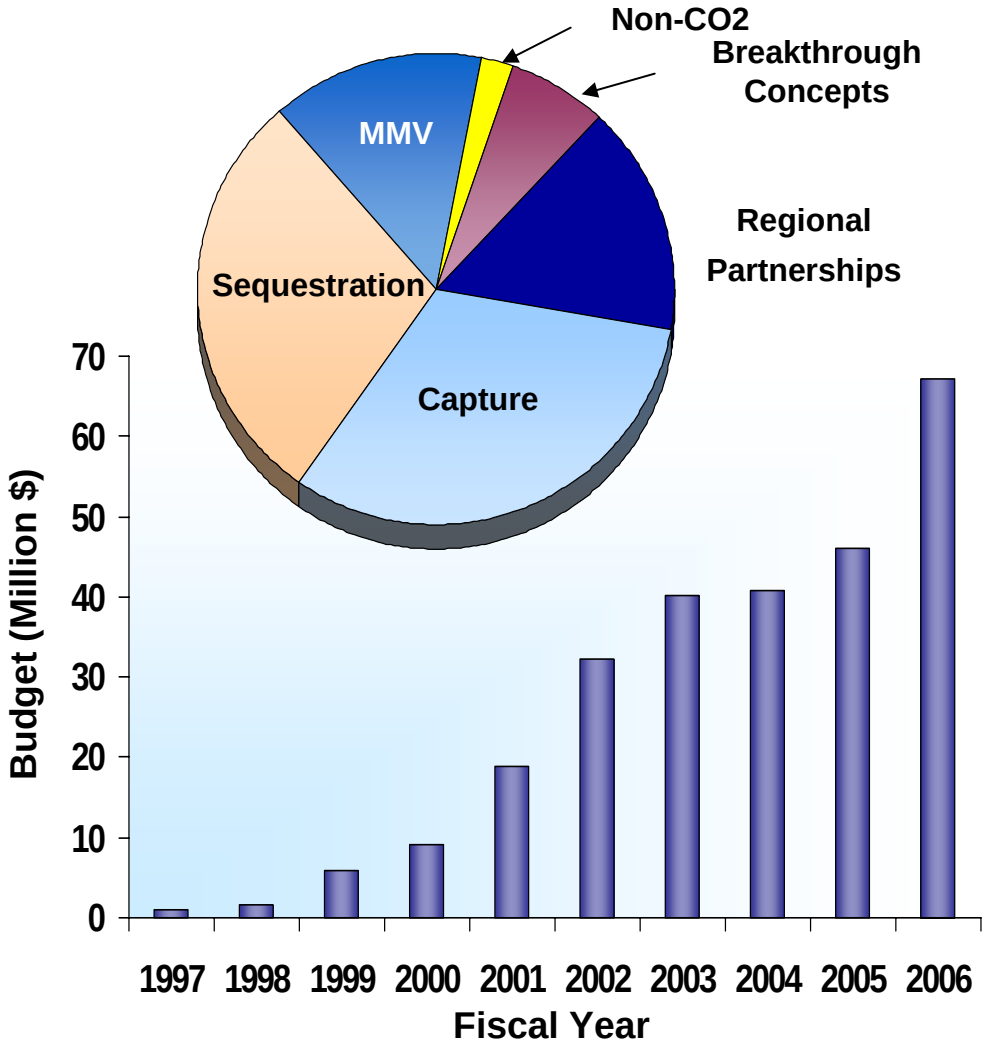


Technology R&D Pathways

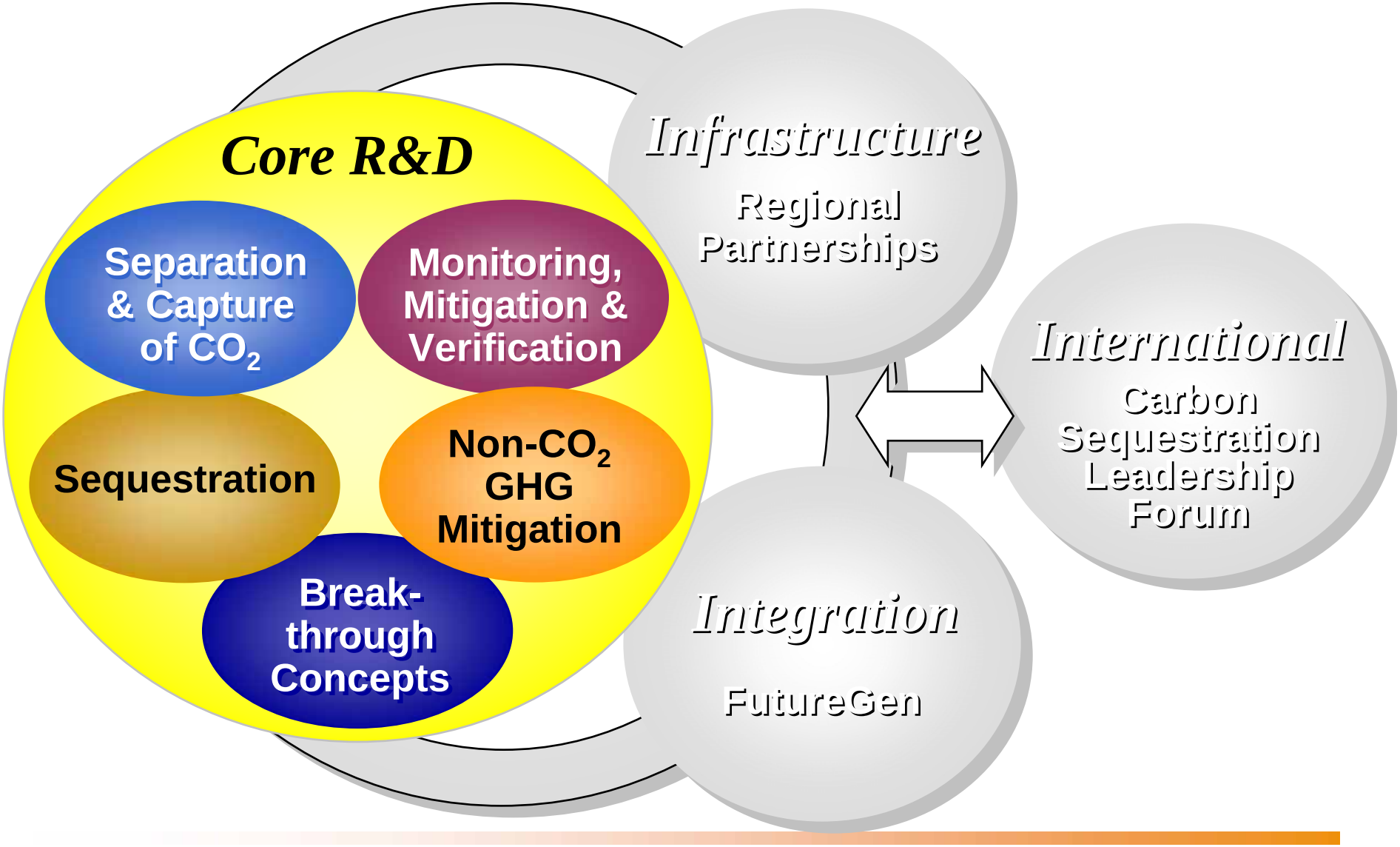


Sequestration: A Dynamic Program Portfolio Overview – FY2005

- **Diverse research portfolio**
  - ~ 60 R&D Projects
  - IEA & CCP consortia
- **Strong industry support**
  - ~ 36% cost share
- **Federal Investment to Date ~ $200 Million**
- **Administration Priority**
  - ~ 50% increase in 2006 budget request
  - House $50 MM
  - Senate $74.2MM



U.S. DOE/ Fossil Energy Program Organization



Separation & Capture R&D

Technology Goals

- 2007 have two technologies < 20% increase in Cost of Energy
- 2012 developed two technologies < 10% increase Cost of Energy

Issue

- Demonstrating technology is costly

Pathways

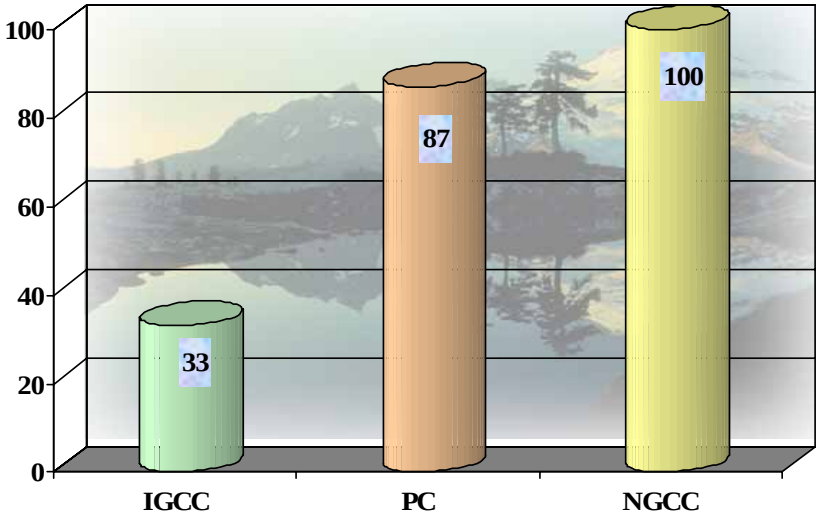
- Pre-combustion capture
- Post-combustion capture
- Oxygen-fired combustion
  - Chemical looping
- Optimized engineering

Current "Best Case" Technologies Costly

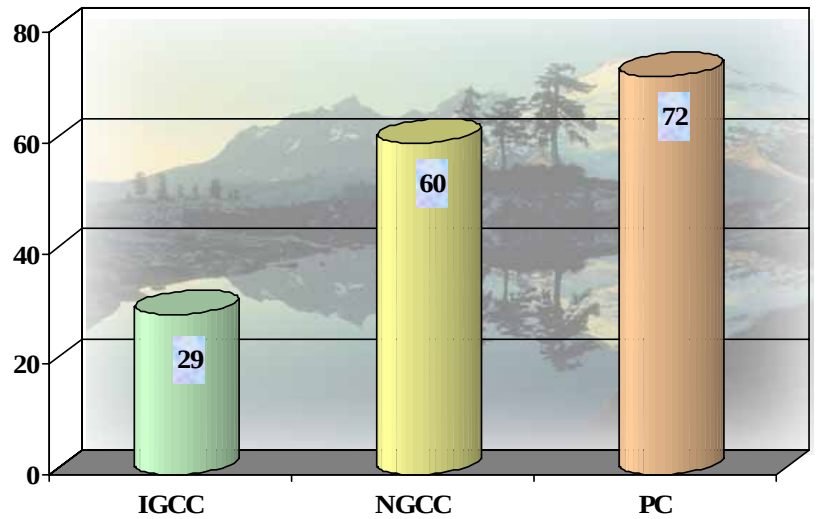
Using State-of-the-Art Scrubbing Technologies

- **5 to 30% Parasitic energy loss**
- **30 to 100% Increase in capital cost**
- **25 to 100% Increase in cost of electricity**

Effect of CO_2 Capture on Capital Cost
(% Increase Resulting From CO_2 Capture)

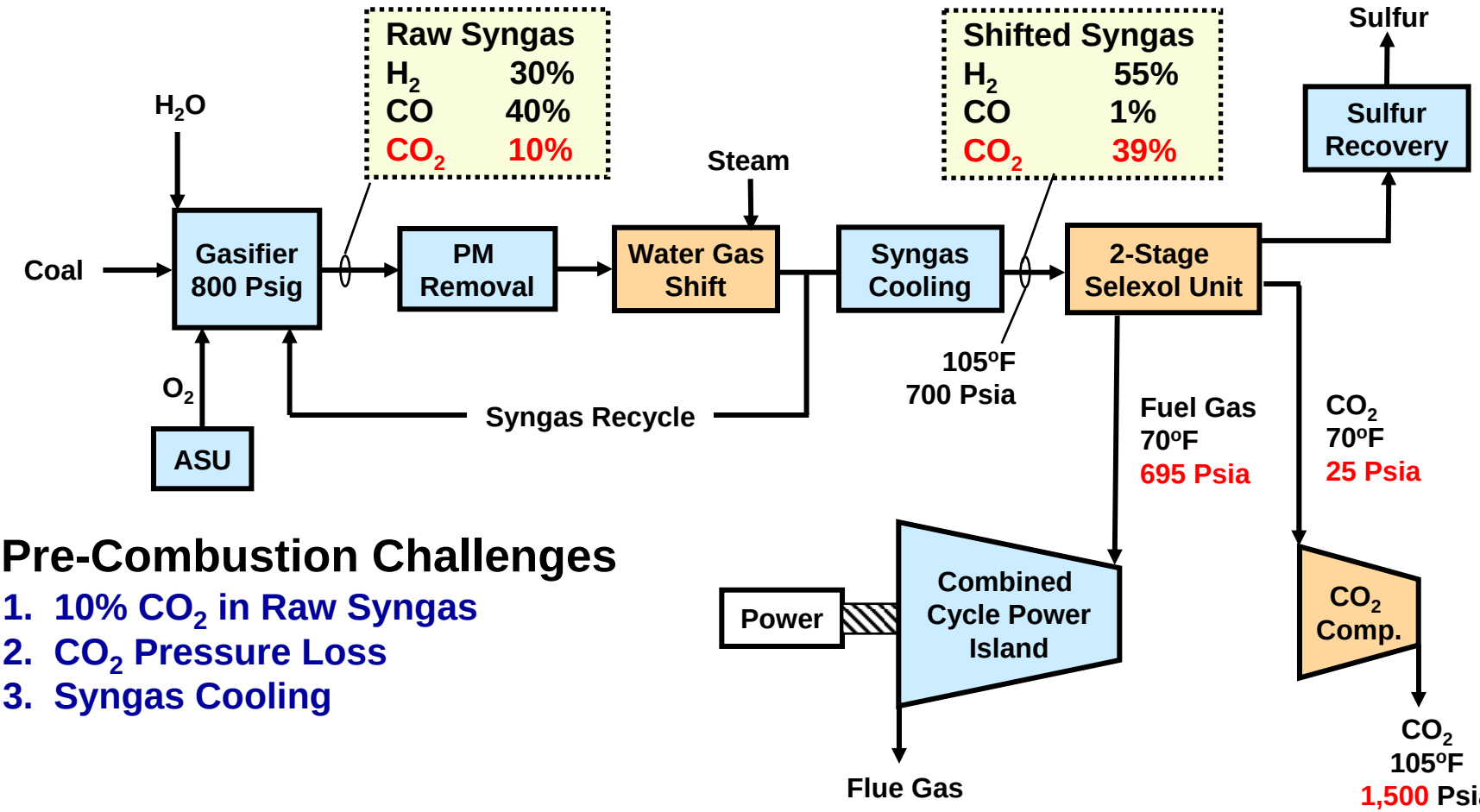


Effect of CO_2 Capture on Cost of Electricity
(% Increase Resulting From CO_2 Capture)



Pre-Combustion Challenges

IGCC Power Plant with CO_2 Scrubbing



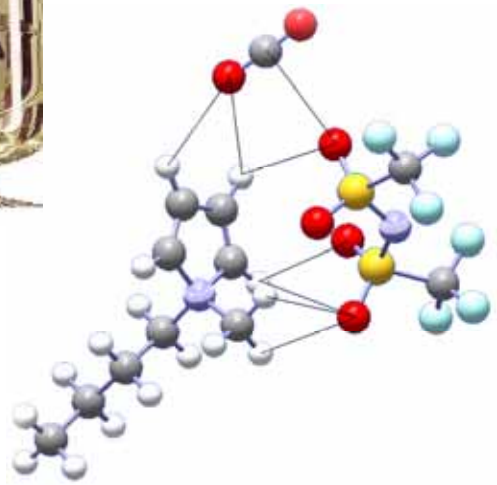
Pre-Combustion Challenges

1. 10% CO_2 in Raw Syngas
2. CO_2 Pressure Loss
3. Syngas Cooling

Source: *Evaluation of Innovative Fossil Fuel Power Plants with CO2 Removal*, DOE/EPRI, 1000316

Ionic Liquids as Novel Absorbents

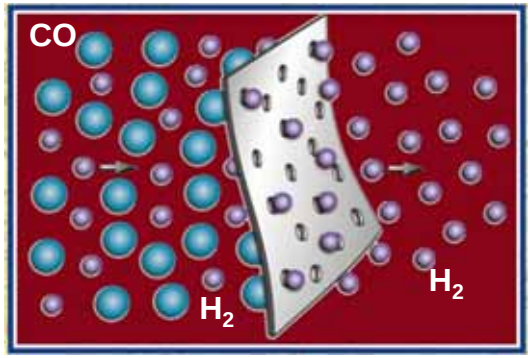
- **Ionic liquids (ILs): salts that are liquid at room temperature**
  - Discovered ~ 12 years ago
  - Will *never* evaporate
  - Can absorb large amounts of CO_2
- **Basic research stage**
  - Select best compounds
  - Feasibility of use for CO_2 capture from post combustion plants
- **Possible uses**
  - Liquid absorbents to replace amines
  - Supported liquid membranes (with NETL)

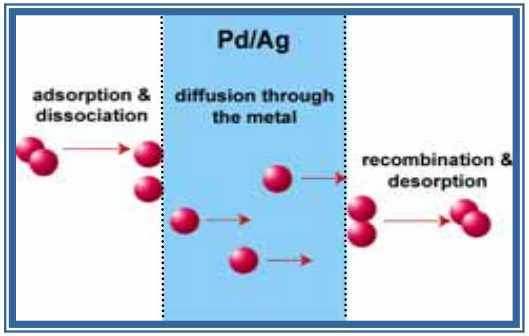


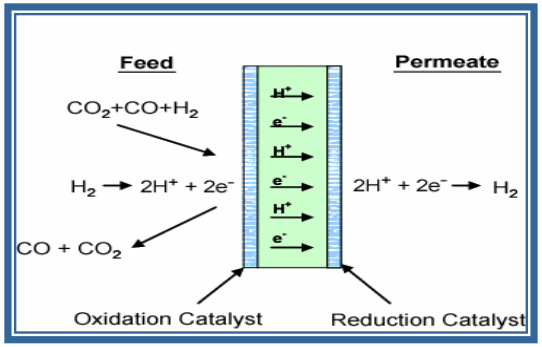
Participants: University of Notre Dame

DOE Focus on Membrane-Based Hydrogen Separation Methods

- **Micro Porous**
- **Dense Metallic**
- **Dense Ceramic (ITM)**
  - Pure Ceramic ITMs
  - Cermet ITMs







Sequestration/Storage R&D

Technology Goals

- 2012 – predict CO2 storage capacity with +/- 30% accuracy
- Develop best practice reservoir management strategies that maximize CO_2 trapping

Issues

- Health, safety, and environmental risks
- Uncertain regulatory framework
- Site selection

Pathways

- Field experiments / demos
- Protocols for identifying amenable storage sites
- Capacity evaluation studies
- Underlying science

West Virginia Field Test

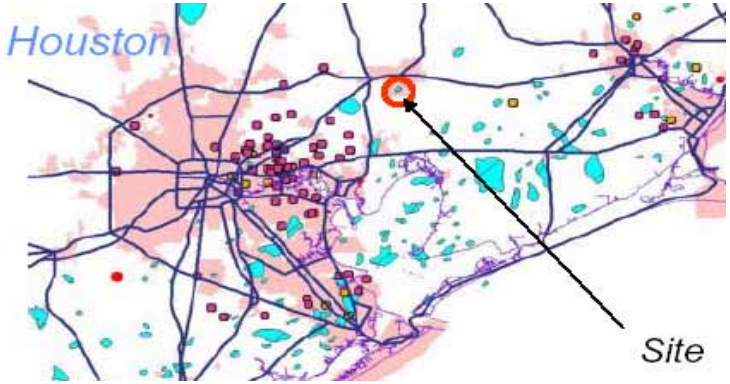
Saline Aquifer – Mt. Simon Sandstone

- **Completed new well to 9172 ft in New Haven, West Virginia**
- **Characterizing formation using seismic, logging and reservoir modeling techniques**
- **Developing comprehensive monitoring plan**
- **Investigating injectivity, safety, capacity & permanence**
- **No current plans for CO_2 injection**

Participants: Battelle, AEP, PNNL, BP, OCDO, Schlumberger, OGS, WVU

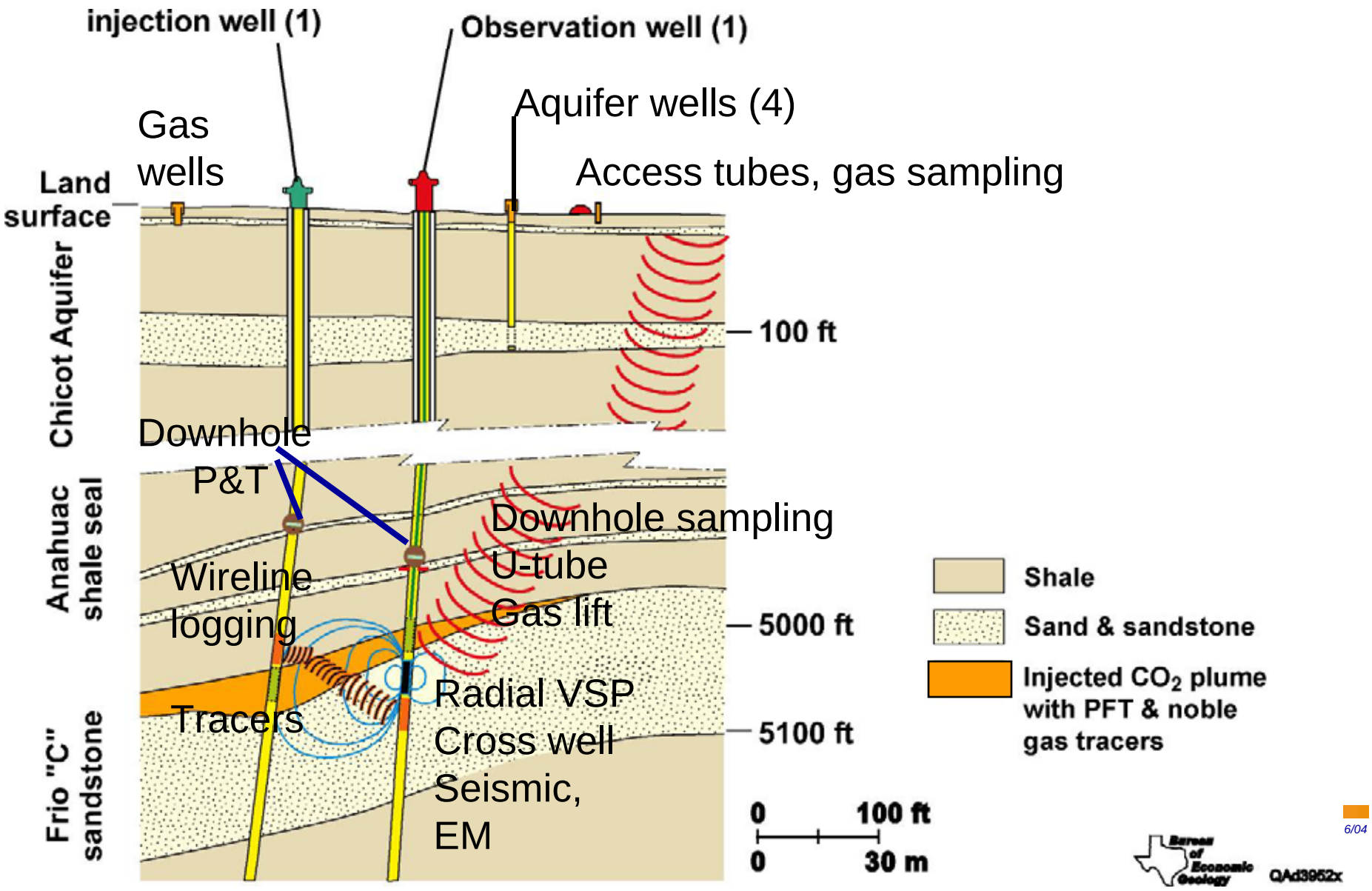
Texas Field Test
Saline Aquifer – Frio Formation

- **Drilling new well by year's end at depth ~5000 ft near Houston, Texas**
- **Characterizing formation using seismic, logging and reservoir modeling techniques**
- **Investigating injectivity, safety, capacity & permanence**
- **Plan to inject 3000 tons CO_2 & extensively monitor**



Participants: Texas BEG, TARC, BP, Schlumberger, Sandia, LBNL, LLNL,ORNL, NETL

Model of Frio (Texas)
Brine Pilot Site With Monitoring



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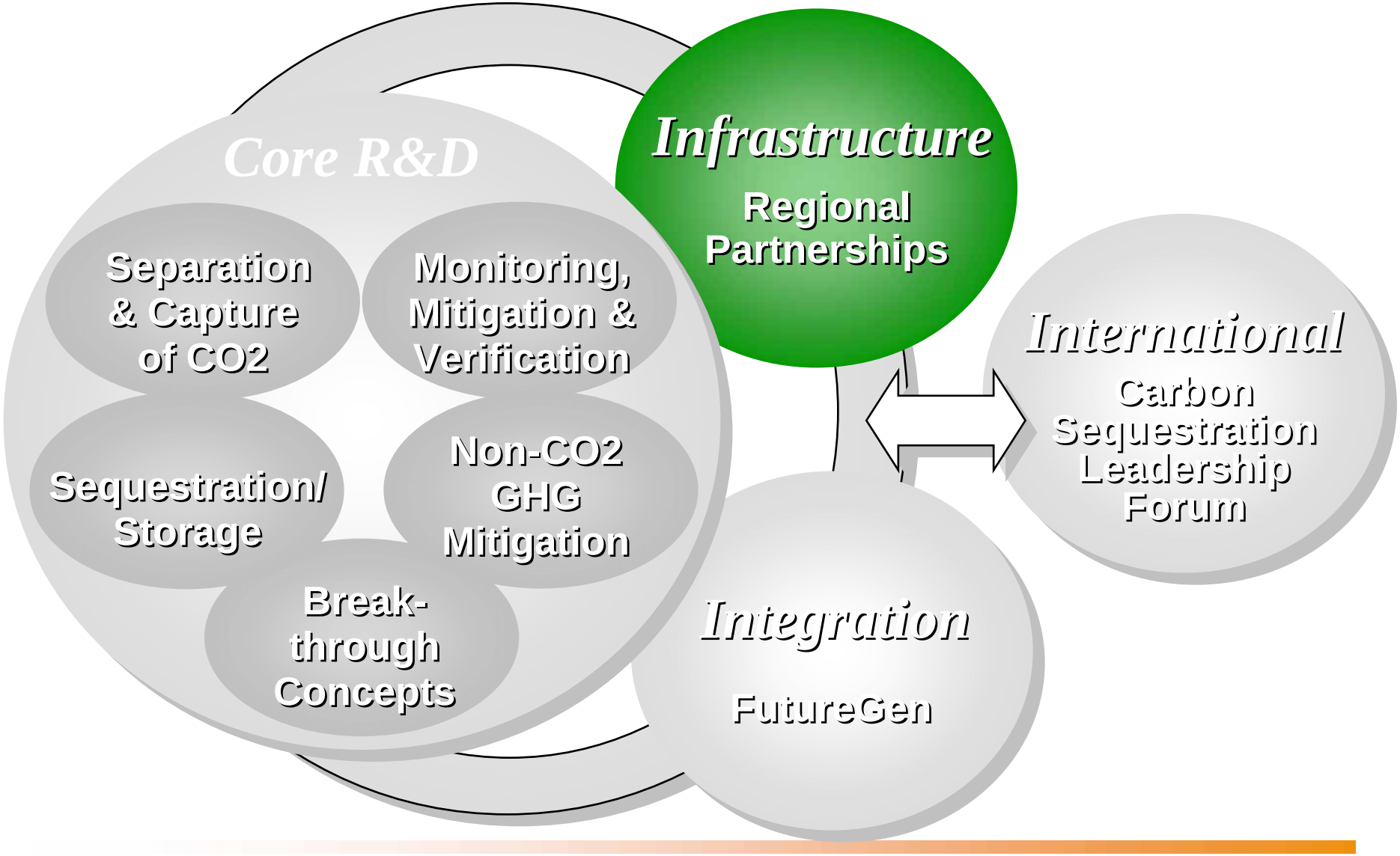
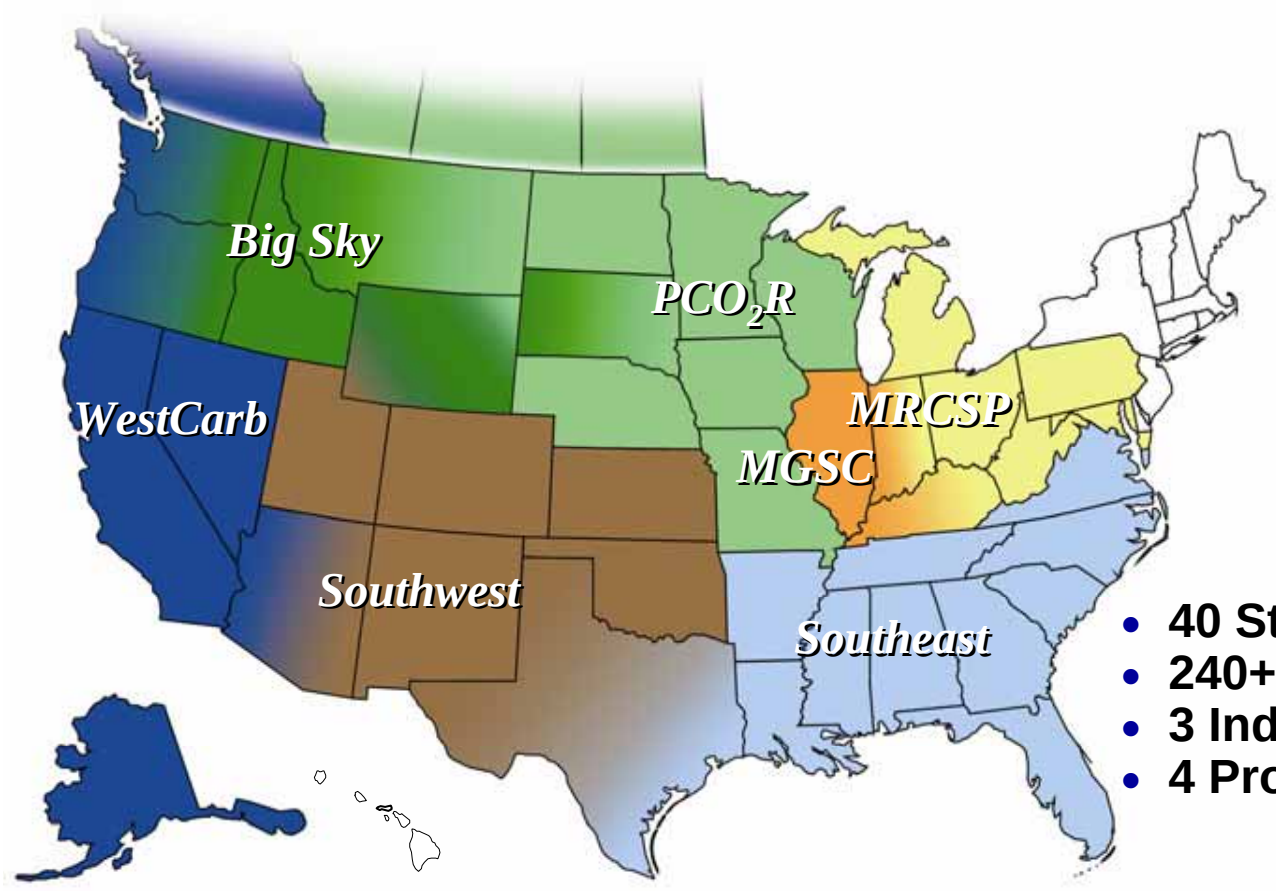


Seven Regional Partnerships

Developing the Infrastructure for National Deployment of Carbon Sequestration Technologies



- **40 States**
- **240+ Organizations**
- **3 Indian Nations**
- **4 Provinces**

Regional Carbon Sequestration Partnerships

Developing Infrastructure for Wide Scale Deployment

- Baseline region for sources and sinks
- Address regulatory, environmental, outreach issues
- Establish monitoring and verification protocols
- Validating sequestration technology & infrastructure
  - Phase 1 - design
  - Phase 2 - testing
- Determine benefits of sequestration to region
- Phase II – 4 year effort
  - Total DOE Contribution $100 MM
  - Cost-Sharing $45 MM (31% of total project costs)

Announcement of Phase II Selections

By moving carbon sequestration technology from the laboratory to the field…we are another step closer to significantly reducing greenhouse gas emissions while maintaining the important role coal plays in America's energy mix.

Samuel W. Bodman
Secretary of Energy
June 9, 2005

Proposed Field Tests - DRAFT

- **25 Geologic Sequestration Injection Tests**
  - 4 stacked saline/EOR reservoir sequestration tests
  - 6 saline reservoir sequestration tests
  - 6 coal seam sequestration tests with ECBM
  - 8 depleted oil field sequestration tests with EOR
  - 1 depleted gas field sequestration tests with EGR
  - Injecting 1,000-525,000 tons of CO2 over 3.5 years

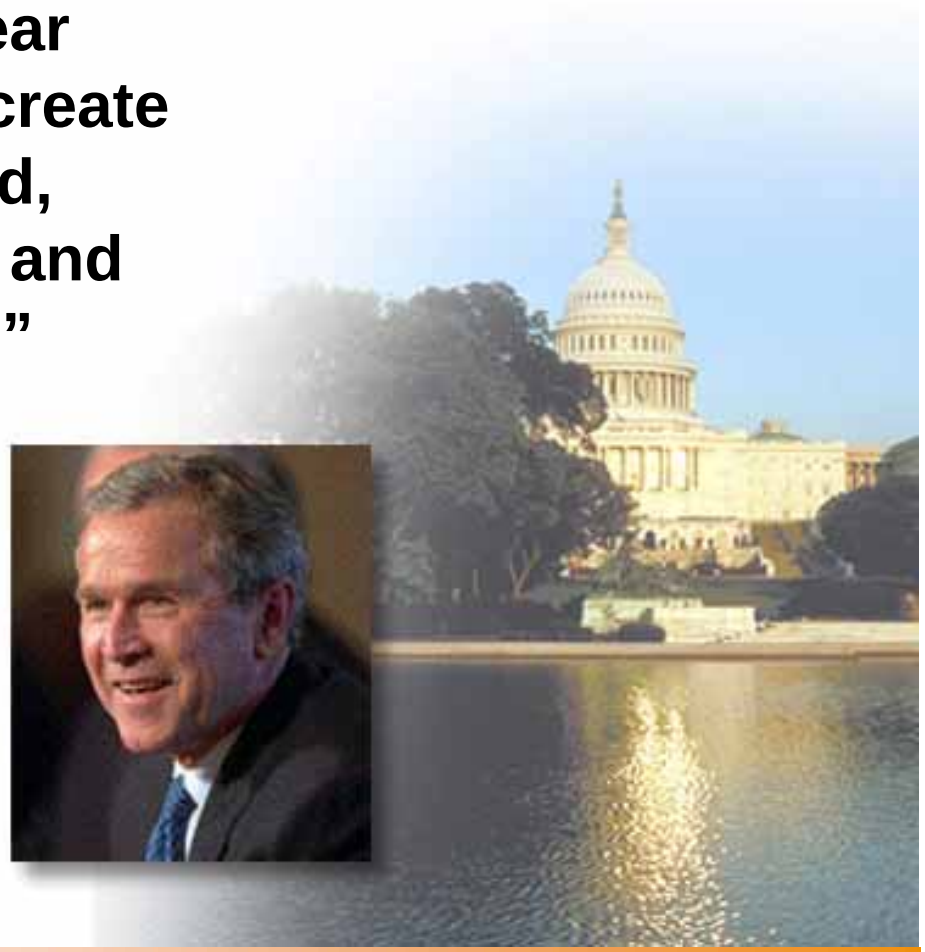
- **10 Terrestrial Indirect Sequestration Tests**
  - 4 Agriculture/Rangeland management
  - 4 Forestry
  - 1 Mineland restoration
  - 1 Wetland/Prairie Restoration

FutureGen

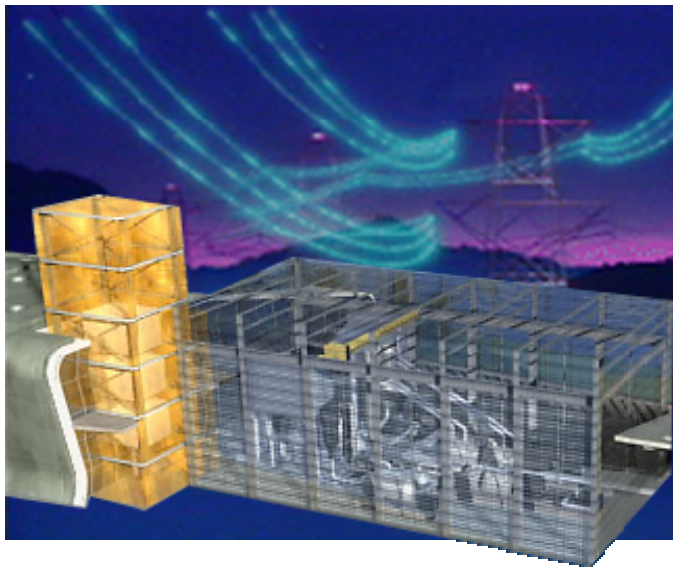
Sequestration & Hydrogen Research Plant

“ . . . the United States will sponsor a $1 billion, 10-year demonstration project to create the world's first coal-based, zero-emissions electricity and hydrogen power plant . . . ”

February 27, 2003



What is the *FutureGen* prototype?



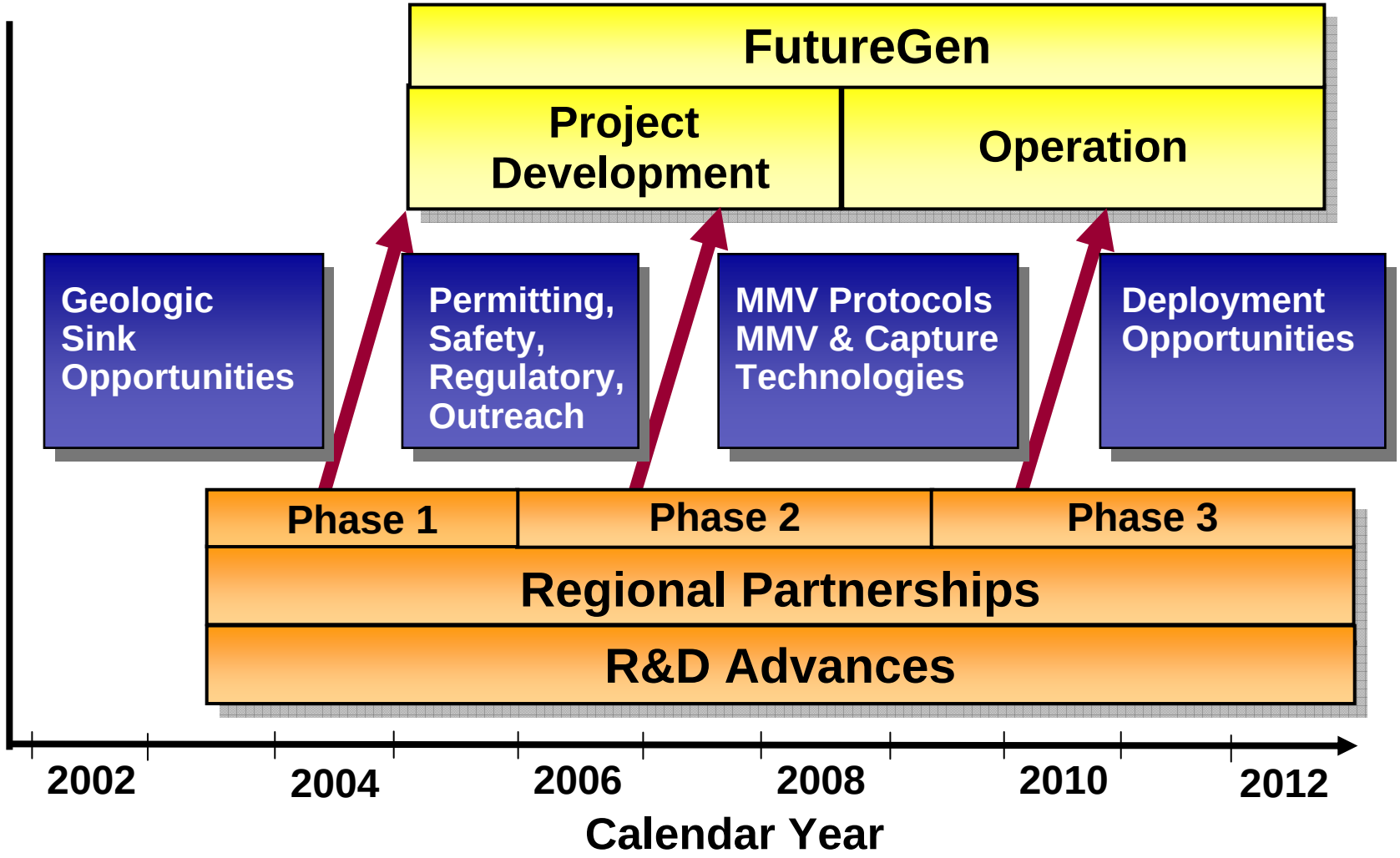
The world's first zero-emission, coal-based power plant to:

- ✓ *Pioneer advanced hydrogen production from coal*
- ✓ *Emit virtually no air pollutants*
- ✓ *Capture and permanently sequester carbon dioxide*
- ✓ *Integrate operations at full-scale – a key step to proving feasibility*

FutureGen **will be a research testing and validation facility for breakthrough technologies that address three key Presidential initiatives:**

(1) Hydrogen,
(2) Clear Skies, and
(3) Climate Change Technology

Critical Synergys

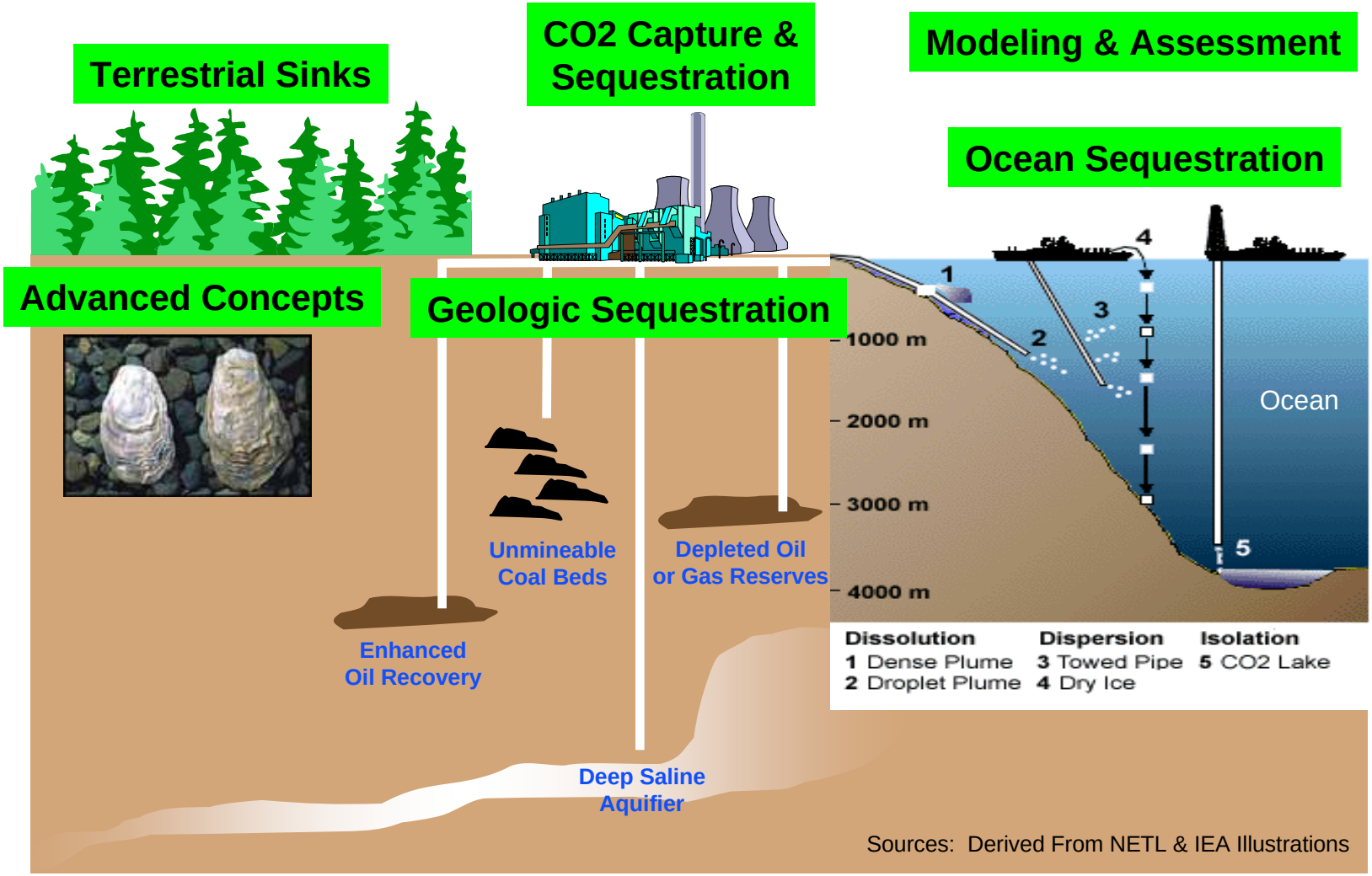


Carbon Sequestration Leadership Forum (CSLF)

- International climate change initiative established by George W. Bush in 2003
- Focus: Development of improved cost-effective technologies for the separation, capture, transport and long-term safe storage of CO2
- Purpose: To make these technologies broadly available internationally; Identify and address wider issues relating to carbon capture and storage, i.e. to promote the appropriate technical, political, and regulatory environments for the development of such technologies
- Membership includes 14 charter members, 5 new members, and 2 applications pending (all members are countries except for the EC)
- Recognition of 10 Collaborative Projects

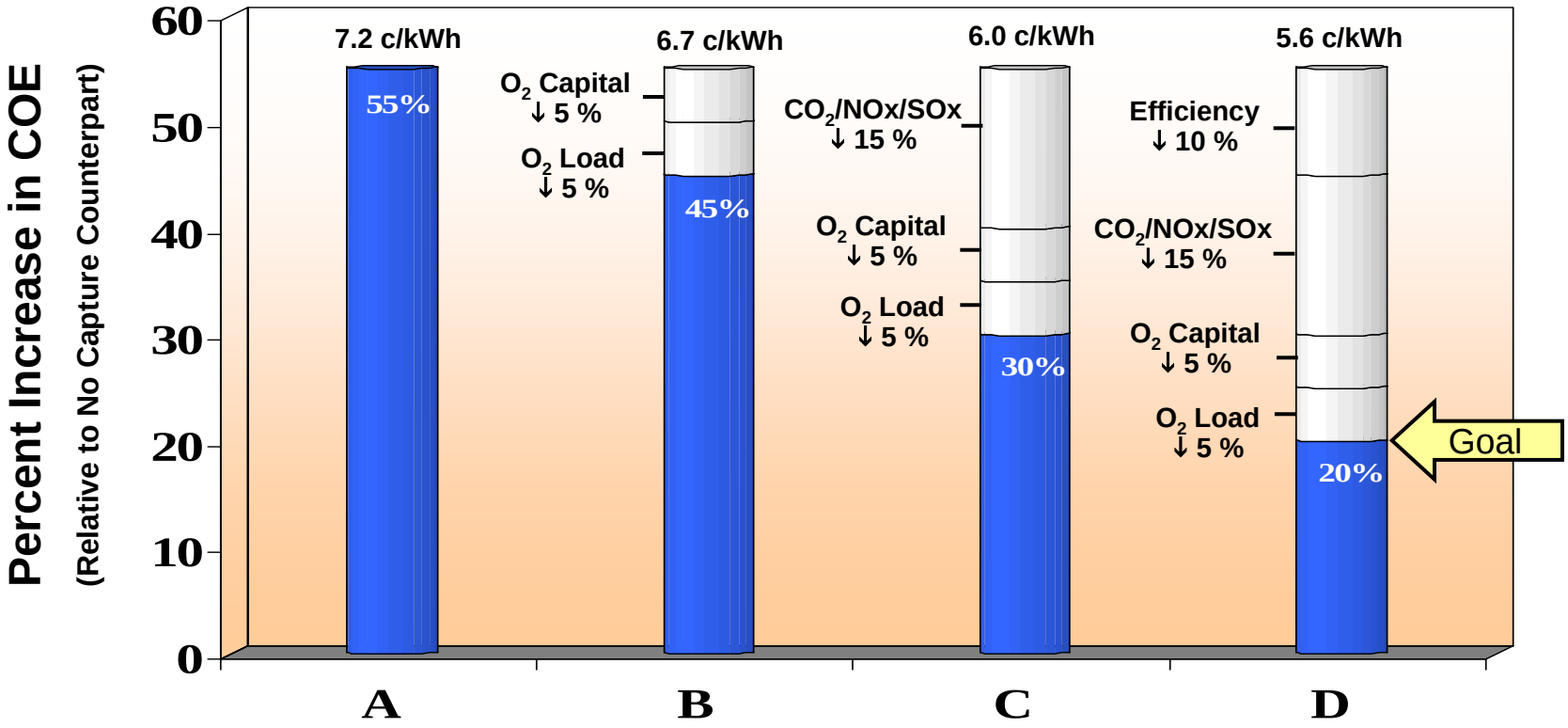
Back-up

Key Research Areas



Sources: Derived From NETL & IEA Illustrations

Advances in Pulverized Coal Applications



Basis:

- No Capture COE 4.6 c/kWh
- 400 MW Net Output
- 90 % CO_2 Capture
- 80% Capacity Factor
- Saline Formation Storage

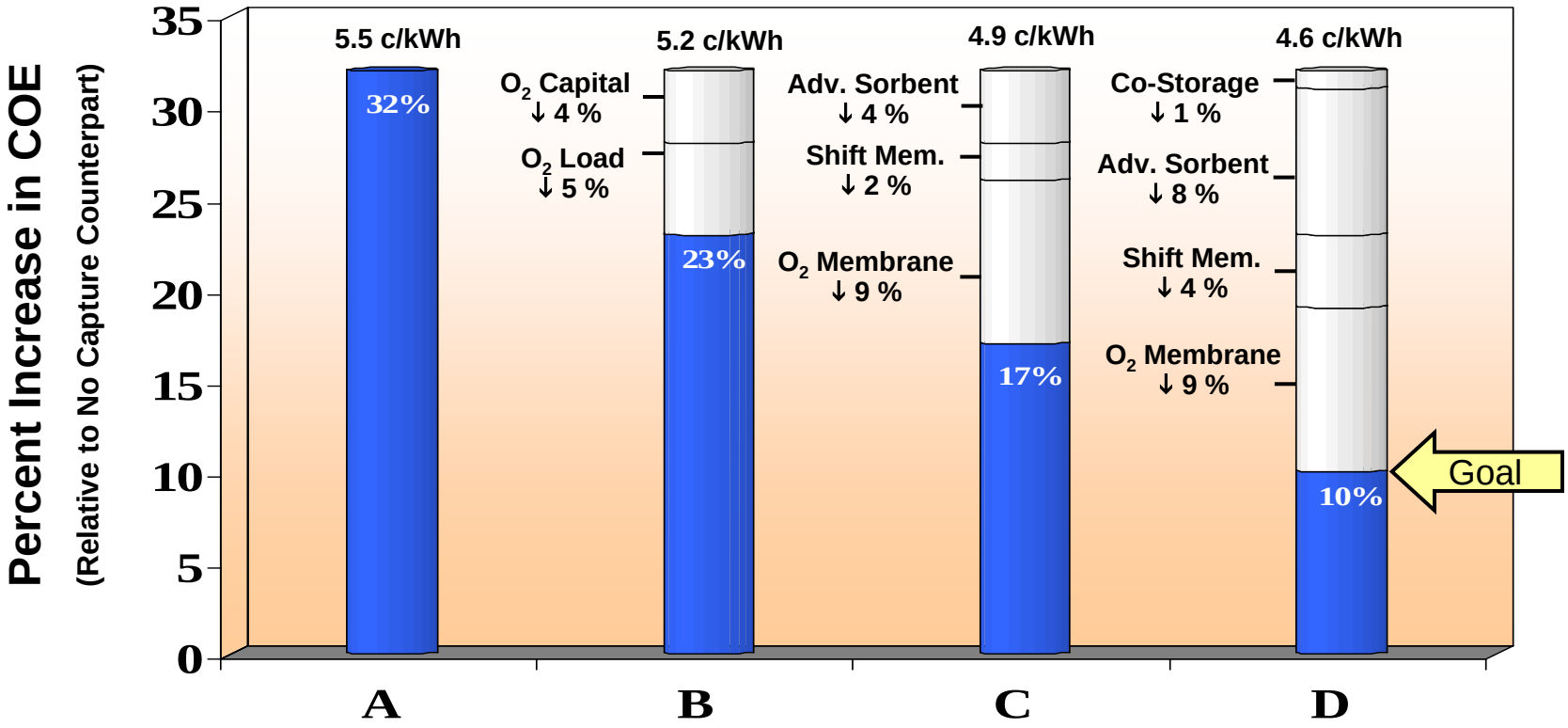
A—Cryogenic Oxygen

B—Oxygen Membrane

C—O_2 Membrane + Co-Storage CO_2

D—Ultra-supercritical + O_2 Membrane + Co-Storage NOx/SOx

Advances in Gasification Applications



Basis:

- No Capture COE 4.2 c/kWh
- 400 MW Net Output
- 90 % CO_2 Capture
- 80% Capacity Factor
- Saline Formation Storage

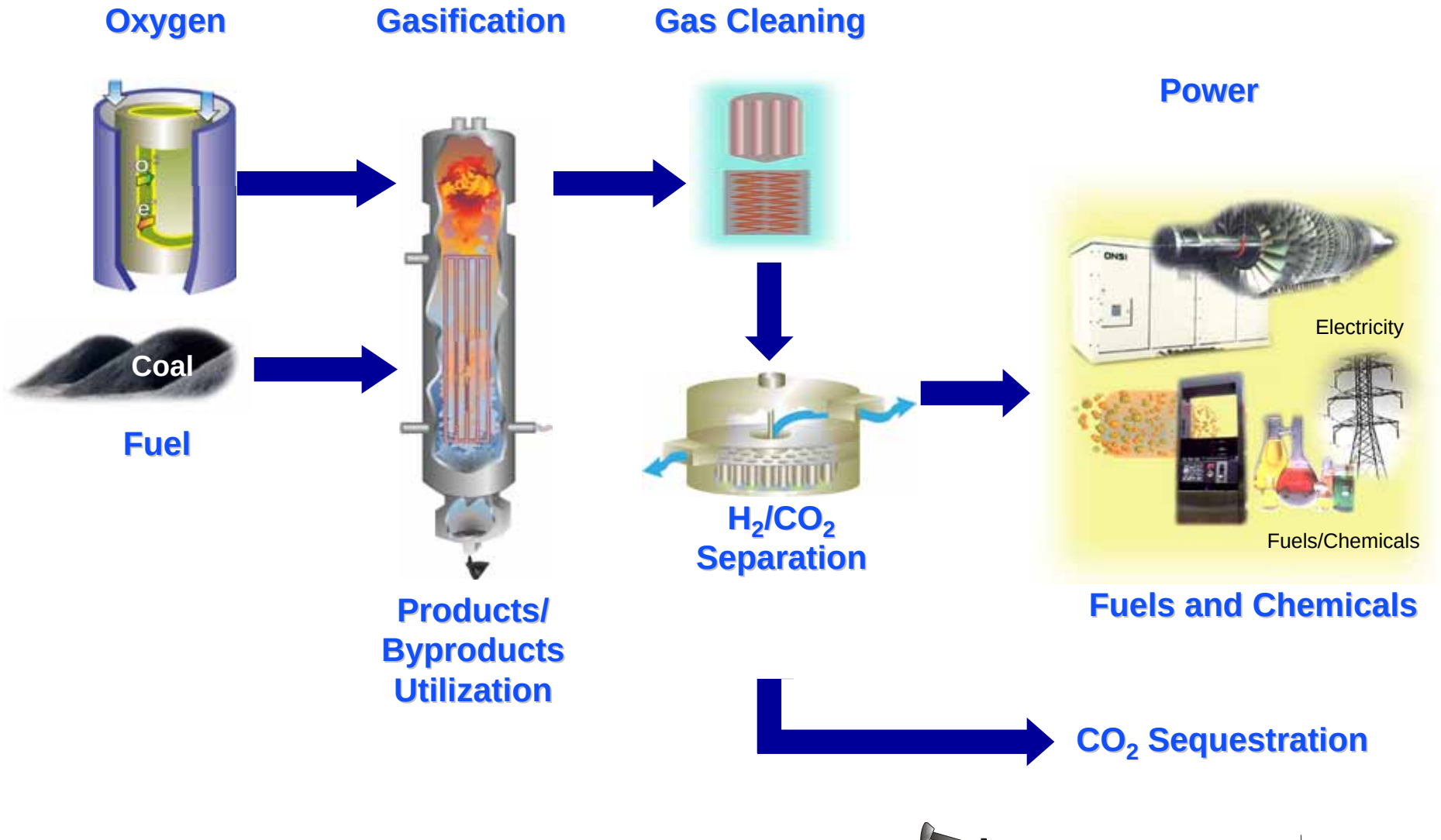
A—Current Scrubbing

B—Oxygen Membrane

C—O_2 Membrane + WGS Membrane + Adv. Sorbent

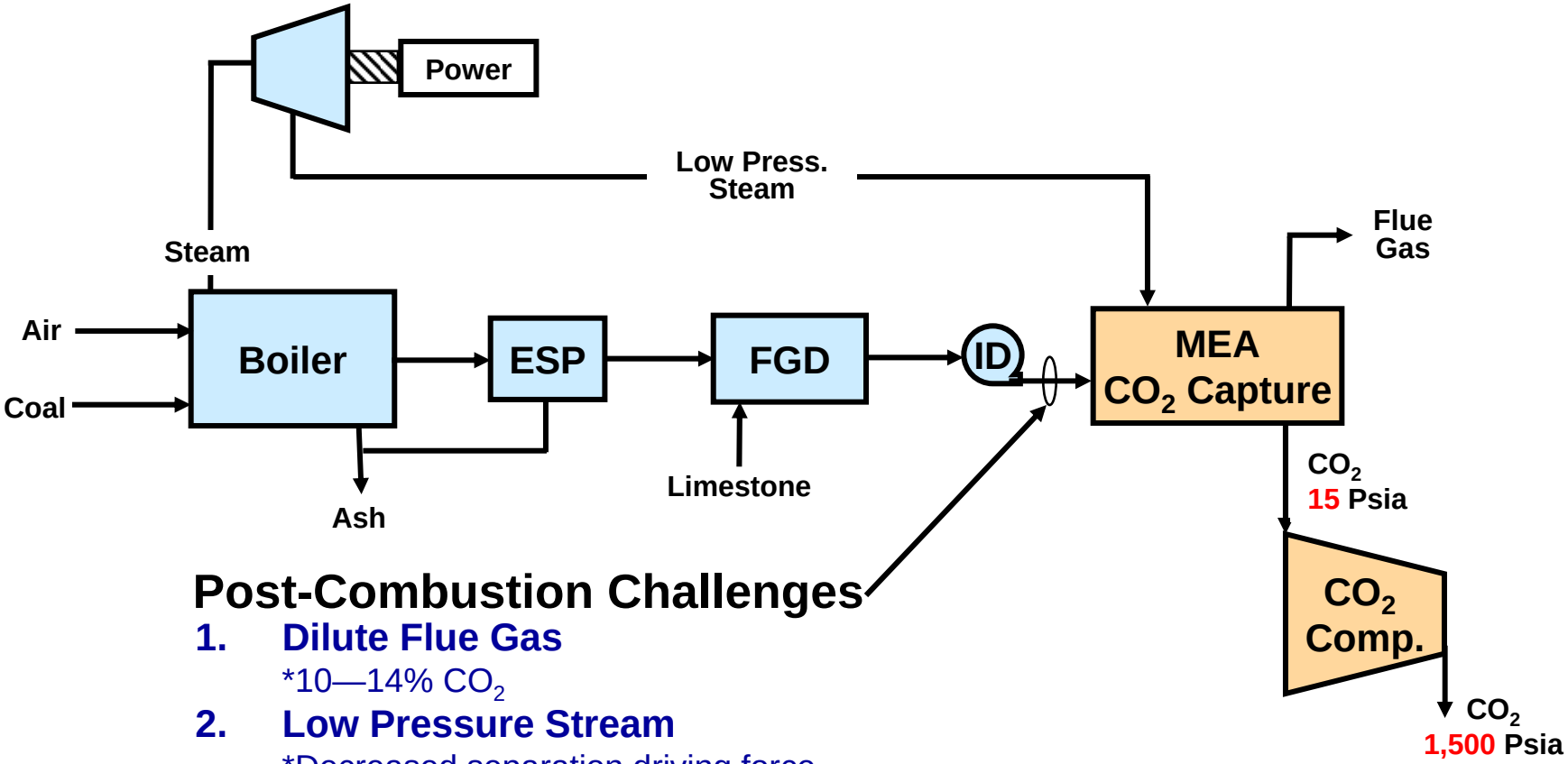
D—O_2 Membrane + WGS Membrane + Adv. Sorbent + Co-Storage H_2S/CO_2

"Near-Zero" Emissions Systems



Post-Combustion Challenges

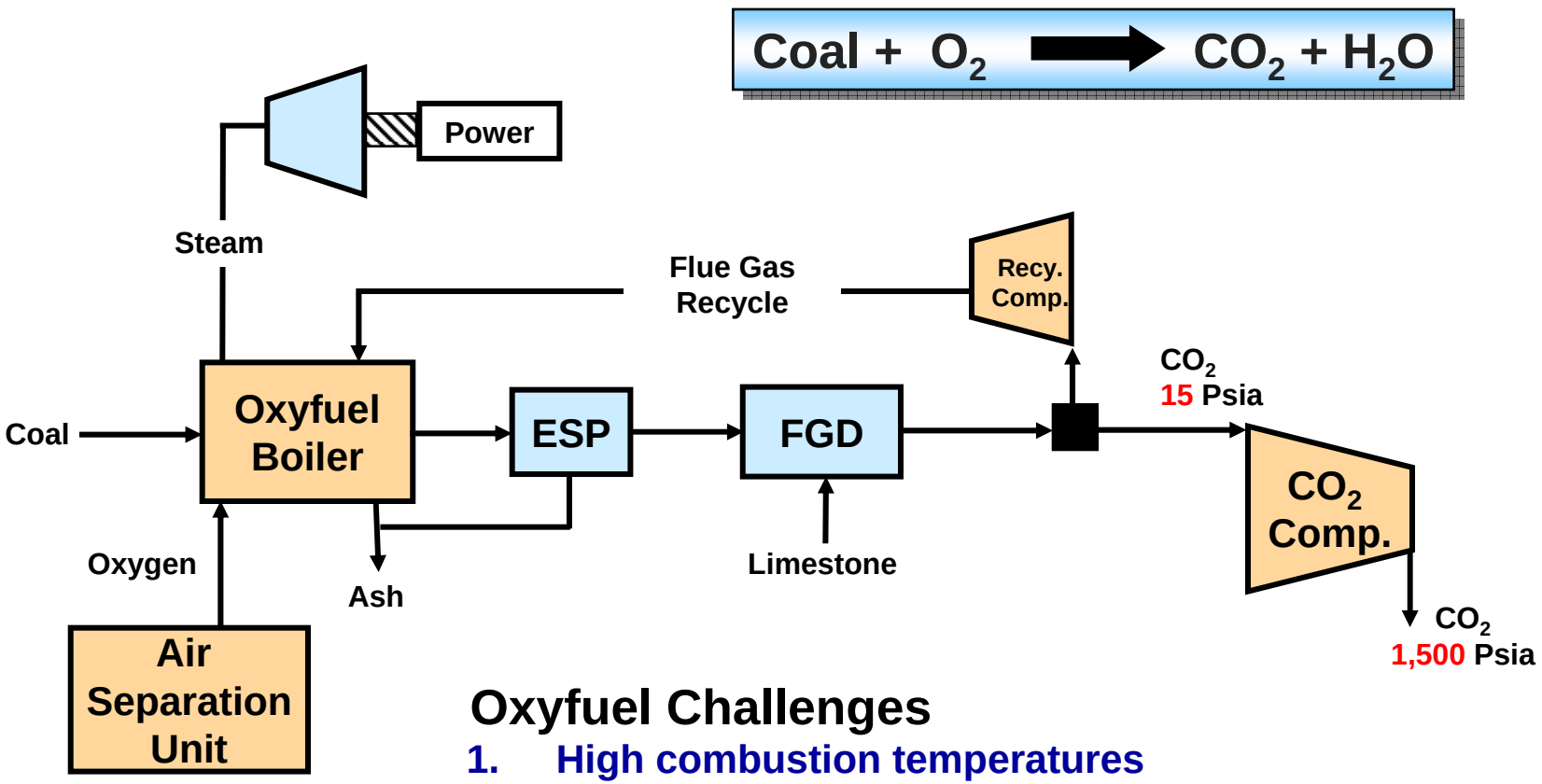
Pulverized Coal Power Plant with CO_2 Scrubbing



Post-Combustion Challenges

1. **Dilute Flue Gas**
   *10—14% CO_2
2. **Low Pressure Stream**
   *Decreased separation driving force
3. **Contaminants**
   *SO_2, Particulates, etc.
4. **Large Parasitic Load (regeneration steam)**

Oxy-fuel Combustion Challenges



Oxyfuel Challenges

1. **High combustion temperatures**
   - *Boiler materials of construction issues
   - *Requires large amounts of flue gas recycle
2. **Cryogenic oxygen production is expensive and energy intensive**
   - *Opportunity for oxygen membranes

Phase I Partnerships At-a-Glance

	**California Energy Commission** http://www.westcarb.org/	• Region has identified candidate enhanced coal bed methane and enhanced oil recovery projects • Detailed assessment of forestation opportunities in storage, fire management, and biofuel
	**New Mexico Institute of Mining and Technology** http://www.southwestcarbonpartnership.org/	• Resource-rich region with two CO_2 pipelines • Identified seven candidate sites for field testing • Conducted web-based "town hall" meetings
	**Montana State University** http://www.bigskyco2.org/	• Mineralization in basalt formations large potential • Focus on agriculture and forestry accounting management and accounting protocols • Close interaction with state governments
	**University of North Dakota, Energy & Environmental Research Center** http://www.undeerc.org/pcor/	• Region rich in value-added geologic sequestration options • Wetland restoration unique opportunity • Half-hour sequestration documentary aired on prairie public television
	**University of Illinois, Illinois State Geological Survey** http://www.sequestration.org/	• Efforts centered on a CO_2 pipeline "fairway" and a focused region • Link to agriculture interests through ethanol
	**Battelle Memorial Institute** http://198.87.0.58/default.aspx	• Strong analysis and cost-supply curves for CO_2 sequestration • Interactive website as outreach tool • 21% of U.S. CO2 emissions in the region
	**Southern States Energy Board** http://www.secarbon.org/	• Electricity supply industry and governor-level political participation • Carbon offset program, a web-based portal for advertising sequestration opportunities

CSLF Key Decisions taken at Melbourne Ministerial September 2004

- **Recognition of 10 Collaborative Projects**
  - ARC Enhanced Coal-Bed Methane Recovery
  - CASTOR
  - CANMET Oxyfuel Combustion for CO2 Capture
  - CO2 Capture Project (Phase 2)
  - CO2 Separation from Pressurized Gas Streams
  - CO2STORE
  - CO2SINK
  - Frio Project
  - ITC CO2 Capture with Chemical Solvents
  - Weyburn II CO2 Storage Project