QTR Clean Electricity Workshop

Carbon Capture and Storage

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CCS Technology Status

- **Carbon Dioxide Capture and Storage (CCS) is a process consisting of the separation of CO_2 from industrial and energy-related sources, transportation to a storage location, and long-term isolation from the atmosphere.**

- **Three elements of CCS:**
  - *Capture & Compression*– accounts for the majority of the CCS cost due to high capital cost and energy penalties
  - *Transport*- requires infrastructure, pipeline, right of ways, limited by the economics of transport distance.
  - *Storage*- safety, permanence, liability, land and mineral access rights for geologic storage.

- **Technologies exist for all three components.**

- **Current demonstrations focus on proving integrated operation and safe and effective long-term storage at scale.**

- **R&D focus is on developing advanced technologies to improve cost competitiveness.**

President's CCS Task Force: *Key Findings*

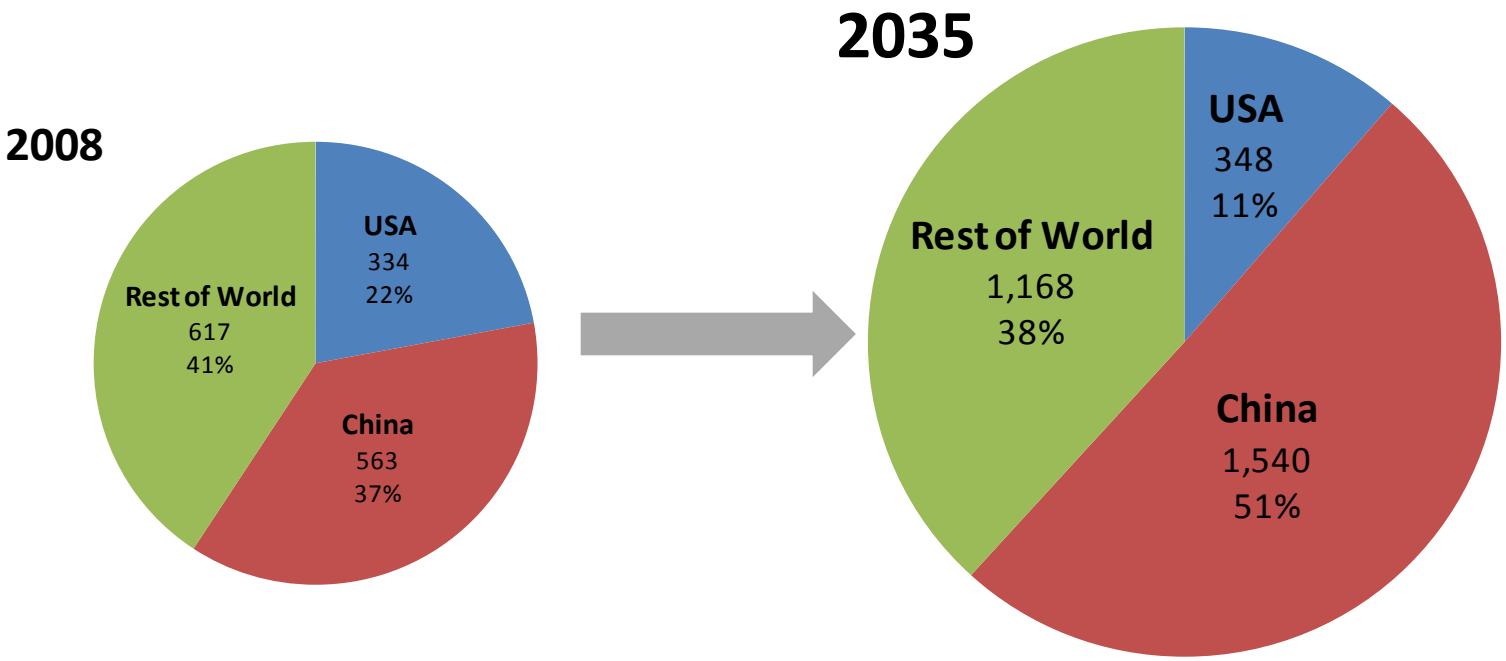
- There are no insurmountable technological, legal, institutional, or other barriers that prevent CCS from playing a role in reducing GHG emissions.

- Lack of a carbon price is the key barrier to commercial deployment of CCS.

- Existing Federal programs are being used to deploy 5-10 large-scale integrated CCS projects to be on-line by 2016. However, early CCS projects face challenges including the cost and performance of current generation technology.

- Federal agencies can use existing authorities and programs to begin addressing barriers for these (and other) early CCS projects while ensuring protection of public health and the environment.
  - Supporting technology development
  - Providing legal and regulatory clarity
  - Supporting regulatory implementation
  - Addressing long-term liability and stewardship
  - Developing tools for public engagement and outreach

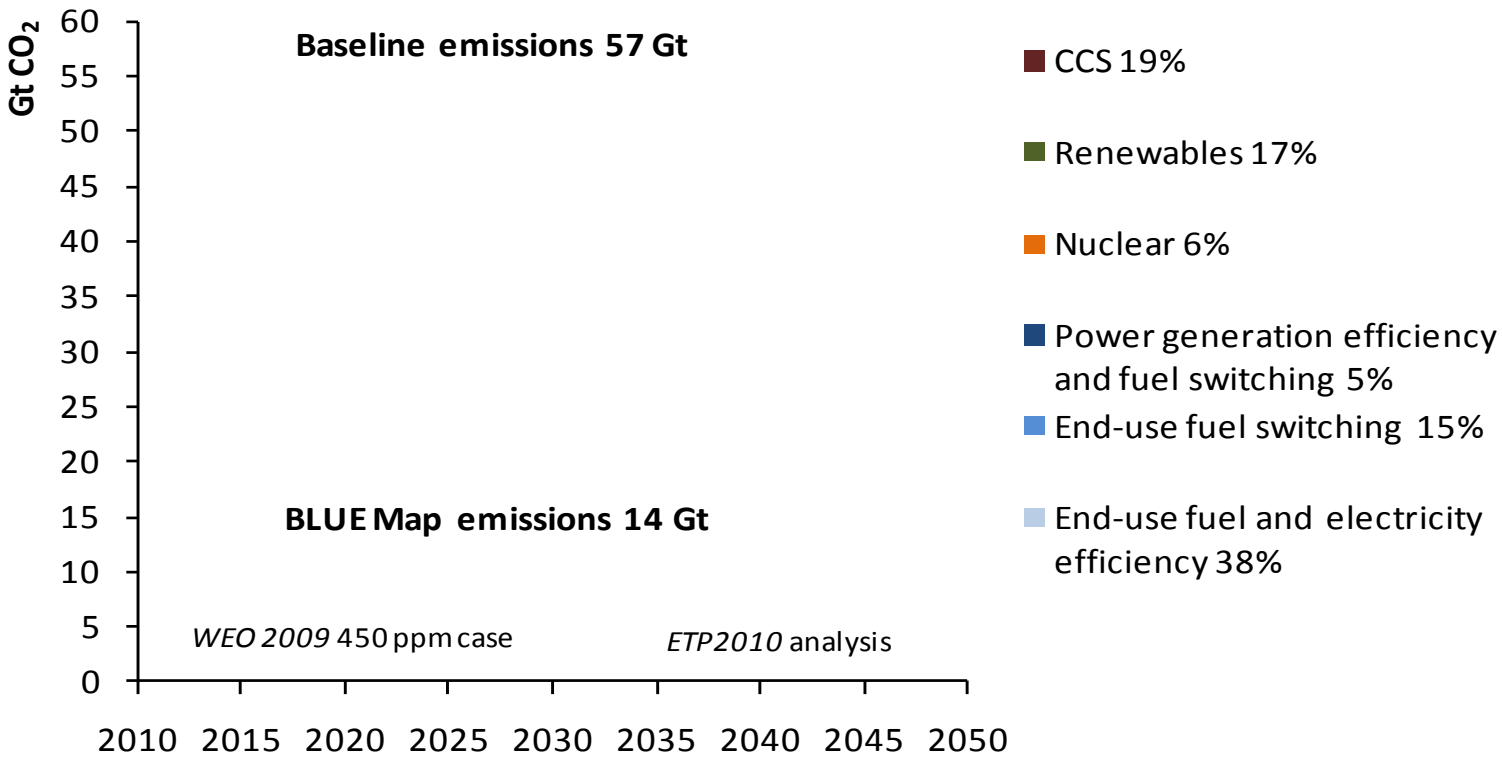
Coal Generation Capacity (GWe)
2010 IEA World Energy Outlook



Total: 1,514

Total: 3,056

IEA Energy Technology Perspectives 2010: Key technologies for reducing global CO_2 emissions

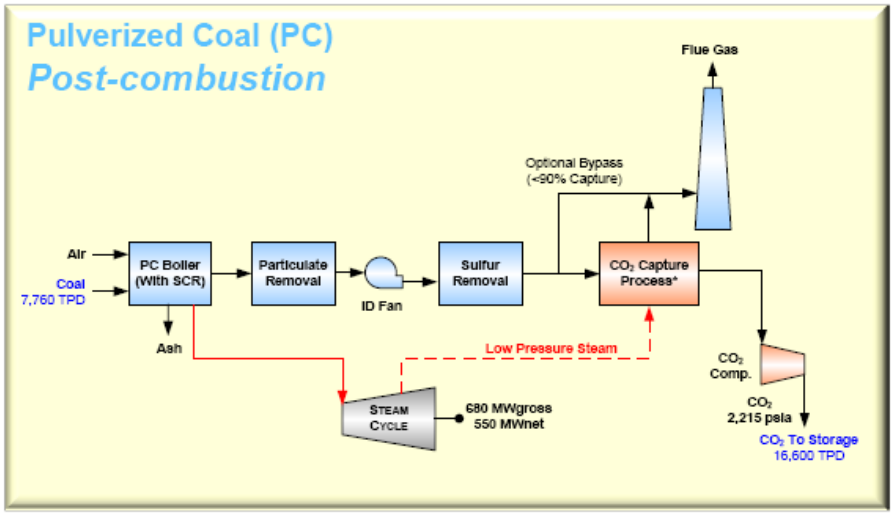


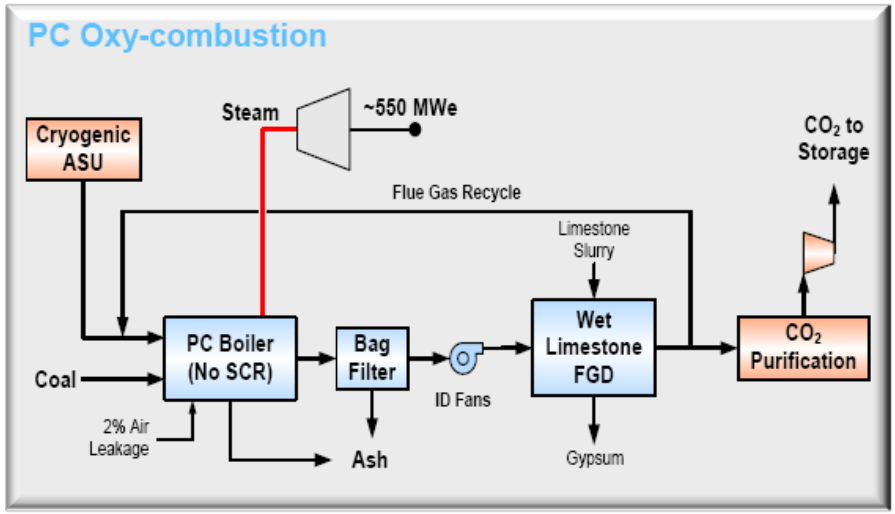
A wide range of technologies will be necessary to reduce energy-related CO_2 emissions substantially.

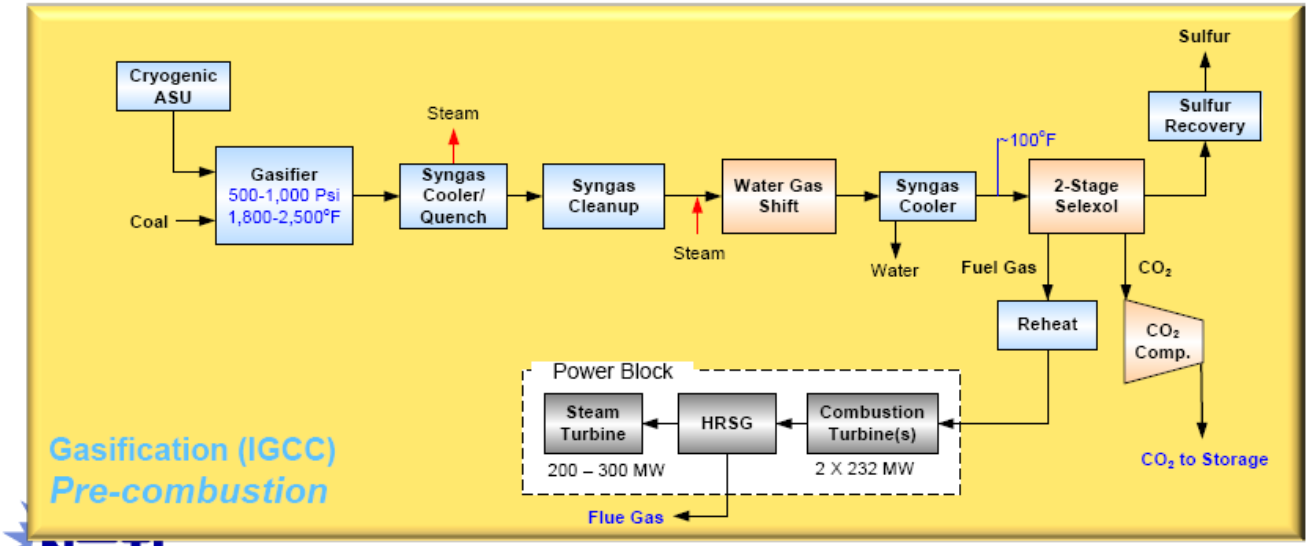
Scope of QTR CCS Assessment

- **Focus is primarily on CO_2 capture from existing and new coal power plants and storage in geologic formations. However, all of storage and most of capture options are applicable to natural gas CCS.**
- **Biomass feedstocks are not considered here due to limited information, although CCS could yield benefits when applied to biomass combustion or gasification since it is a "CO_2 air capture" option.**
- **Beneficial uses of CO_2 other than enhanced oil recovery (EOR), e.g., using CO_2 to produce fuels or building products, are not considered. It is unclear at this stage if these non-EOR uses are more than niche applications.**

CO_2 Capture Applications







Technologies also applicable to:

- Industrial sources (cement, refinery, chemical…)
- NGCC power plants

2nd Generation Capture Technologies

- IGCC (pre-combustion capture)
  - 90% capture with potential for *no increase in COE*
  - 4 to 5 percentage points higher in efficiency than today's plants with capture
  - Feedstock/product flexibility (coal, biomass, or opportunity fuels to produce power, liquid fuels, chemicals)
- Post-Combustion Capture
  - COE penalty for CCS reduced from +80% (1st Generation) to +35%
  - 90% capture efficiency
  - Parasitic energy reduced (from 30% to ~15%)
  - Applicable to new plants, retrofits, natural gas, & industrial power
- Oxy-Combustion
  - Increase in COE for CCS cut from +80% (1st Generation) to +35%
  - +99% capture potential
  - Parasitic energy reduced (from 30% to ~15%)
  - Applicable to new and existing power plants
  - Co-sequestration opportunities

Example Technologies

ITM Oxygen
Warm gas cleanup
Hydrogen turbine
Solid coal feed pump
Ramgen CO2 compressor

Advanced Solvents (Ionic liquids, phase change solvents, etc.)
CO_2 membranes
Solid sorbents
USC boiler materials
Ramgen CO2 compressor

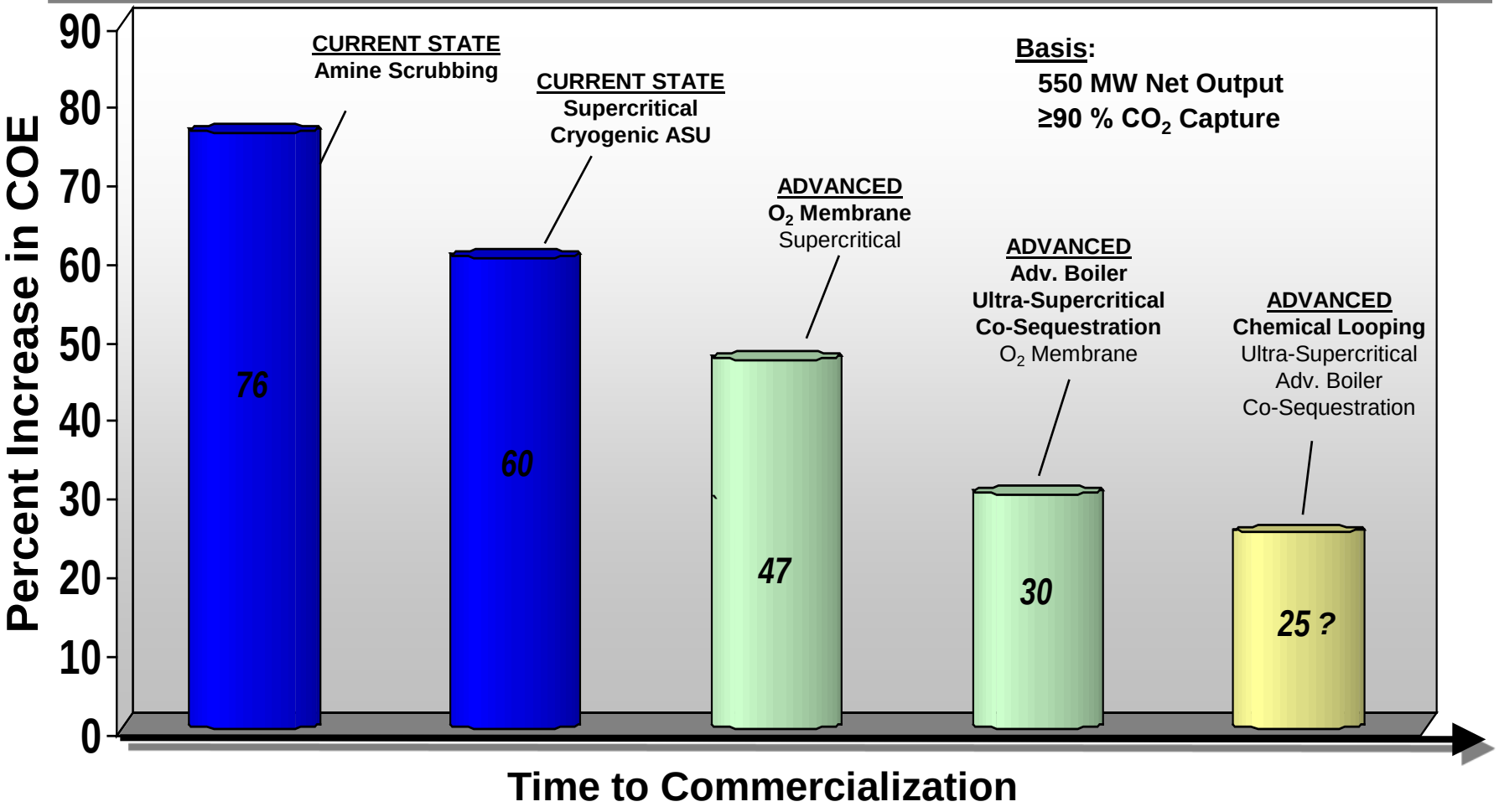
Advanced Oxyfuel Boilers
ITM oxygen
CO_2 purification
USC boiler materials
Ramgen CO2 compressor
Chemical looping

DOE CCS RD&D Electricity Cost (COE) Estimates

	COE Increase vs Current SCPC Plants w/o CCS		
New Coal Plant Type with CCS	**Generation 1**	**Generation 2**	**Transformational**
Super Critical Pulverized Coal (SCPC)	$48/MWh (81%)	$21/MWh (35%)	TBD (<5%)
Oxy-Combustion	$37/MWh (63%)	$21/MWh (35%)	
Integrated Gasification Combined Cycle	$47/MWh (79%)	$13/MWh (22%)	
Integrated Gasification Fuel Cell	n/a	$14/MWh (23%)	<$3/MWh (<5%)
	COE Increase vs Current NGCC Plants w/o CCS		
New Gas Plant Type with CCS	**Generation 1**	**Generation 2**	**Transformational**
Natural Gas Combined Cycle	$22/MWh (38%)	TBD	TBD

Pathway to Meeting DOE Goals

Percent Increases in COE over SOTA PC Plant w/o Capture

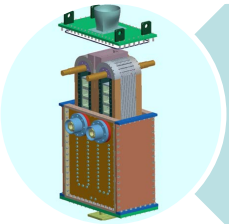


Reference: Advancing Oxycombustion Technology for Bituminous Coal Power Plants: An R&D Guide, NETL 2010

Advanced Gasification Technologies

Ion Transport Membranes – ITM (APCI)

- Operating full-scale modules – 5 TPD unit
- Detailed design/construction of 150 TPD unit in progress – *commissioning scheduled 1Q FY 2011*
- 2,000 TPD unit planned for 2014

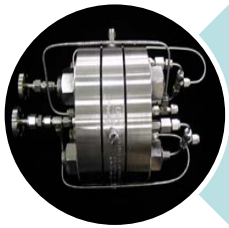


Linear Extrusion Coal Feed Pump (PWR)

- Detailed design of 600 TPD pump in progress
- Commissioning scheduled 4Q 2010

High Temperature Gas Cleaning (RTI)

- 50 MWe transport desulfurizer at TECO with option for integrated high temperature CO_2 capture
- Commissioning scheduled 1Q FY 2012



Hydrogen/Carbon Dioxide Membrane (Eltron)

- Eastman Chemical – Development partner
- Current testing at 1.5 lb/d H_2
- Scale-up 12 lb/d – 2010; 220 lb/d – 2011/12

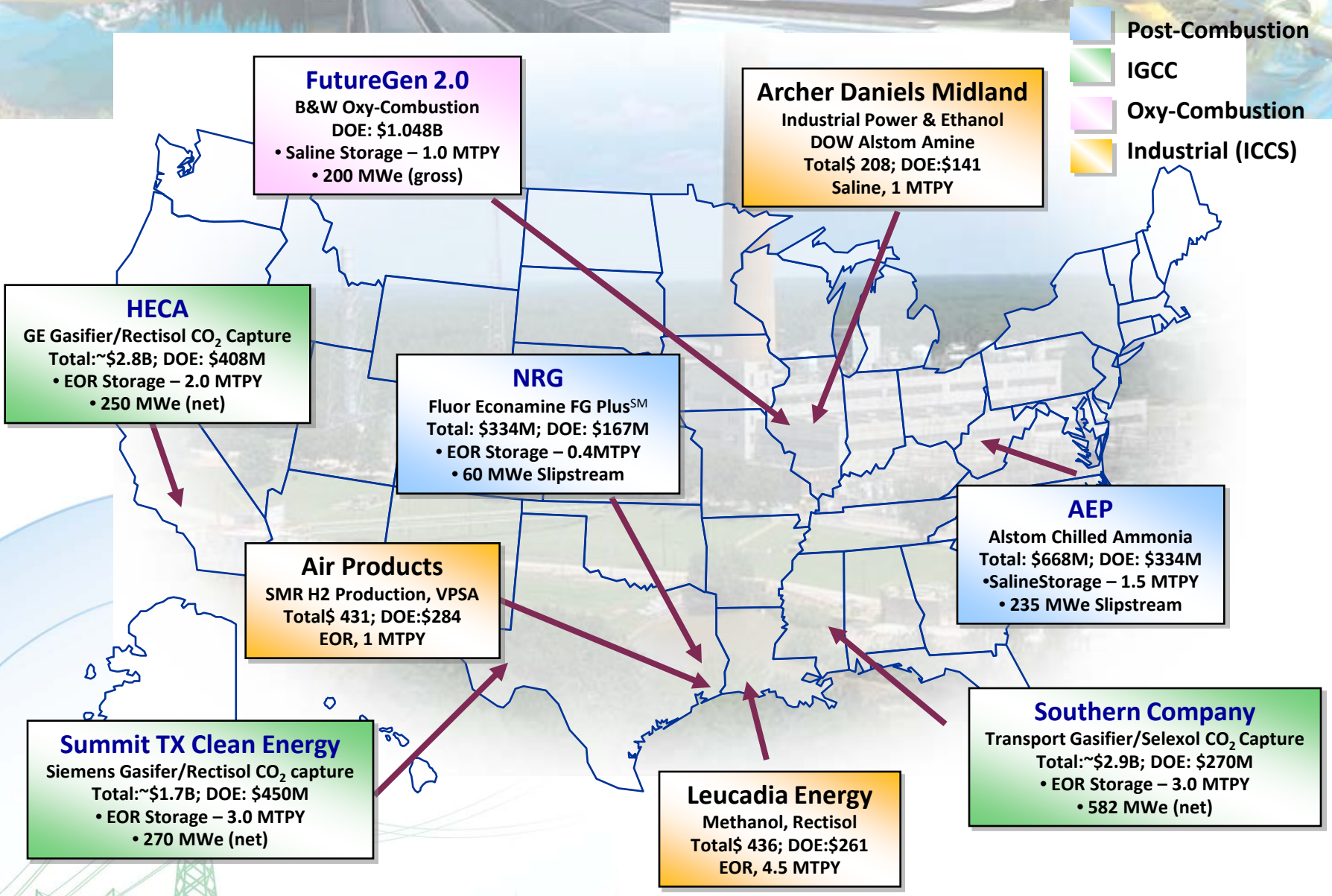
Worldwide CCS Large Scale Integration Projects by Technology and Industry

			GEOGRAPHIES							
			NORTH AMERICA	EUROPE	CHINA	AUSTRALIA	OTHER ASIA	MIDDLE EAST	AFRICA	TOTAL
Industry and Capture	Power	Power, pre-combustion	9	5	2	1		1		18
		Power, post-combustion	6	9		1	1			17
		Power, oxyfuel	2	2						4
		Power, other or to be determined			1	1	1			3
	Other	Iron & steel		1				1		2
		Cement	1							1
		Other industries	21	4	2	4		1	1	33
Transport	Pipeline	Pipeline point-to-point onshore	12	7	2	3			1	25
		Pipeline point-to-point offshore	1	5	2					8
		Pipeline point-to-point, not specified on/offshore				1				1
		Pipeline network	18	4		3		2		27
		Pipeline, not specified as point-to-point or network	7	1						8
		Ship		1			2			3
		Cross border CO_2 transport	1	1						2
		Combination/not specified	1	2	1					4
Storage		Deep saline formations	6	11	2	4	2		1	26
		Depleted oil and gas reservoirs		6	1	1				8
		Other geological storage or detail to be determined	1	2		1				4
		Gas field for enhanced gas recovery (EGR)								0
		Oil field for enhanced oil recovery (EOR)	28	1	1			2		32
		Other, combination or to be determined	4	1	1	1				7

Key:
No projects | 1 - 2 projects | 3 - 10 projects | > 10 projects

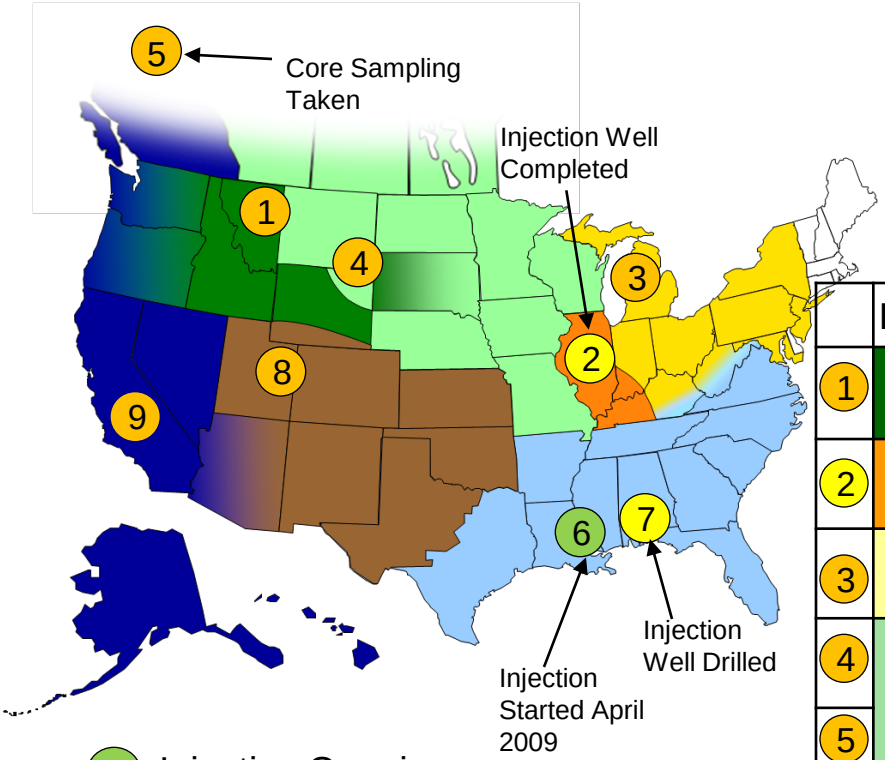
Source: Global CCS Institute. "The Global Status of CCS 2010"

Major CCS Demonstration Projects



RCSP Phase III: Development Phase

Large-Scale Geologic Tests



- Injection Ongoing
- 2011 Injection Scheduled
- Injection Scheduled 2012-2015

Note: Some locations presented on map may differ from final injection location

- ✓ *Nine large-volume tests*
- ✓ *One injection commenced April 2009*
- ✓ *Remaining injections scheduled 2011-2015*

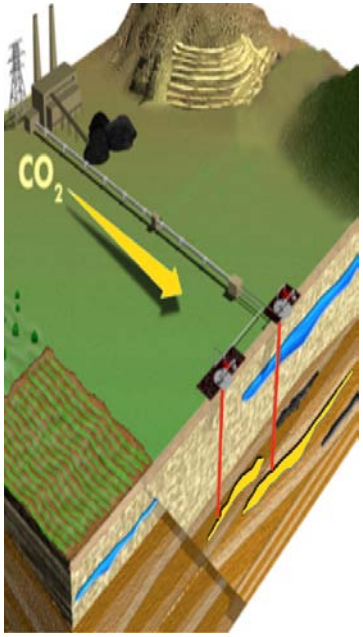
	Partnership	Geologic Province	Type
1	Big Sky	Nugget Sandstone	Saline
2	MGSC	Illinois Basin- Mt. Simon Sandstone	Saline
3	MRCSP	Michigan Basin- St. Peter Sandstone	Saline
4	PCOR	Powder River Basin- Bell Creek Field	Oil Bearing
5		Horn River Basin- Carbonates	Saline
6	SECARB	Gulf Coast – Cranfield Field- Tuscaloosa Formation	Saline
7		Gulf Coast – Paluxy Formation	
8	SWP	Regional Jurassic & Older Formations	Saline
9	WESTCARB	Central Valley	Saline

Accelerating Technology Thru Simulation

Utilize Synergies of Science National Laboratories

Carbon Capture Simulation Initiative (CCSI)

National Risk Assessment Partnership (NRAP)



Identify promising concepts → Develop optimal designs → Quantify technical risk in scale up

Accelerate learning during development & deployment

Thank You

For more information

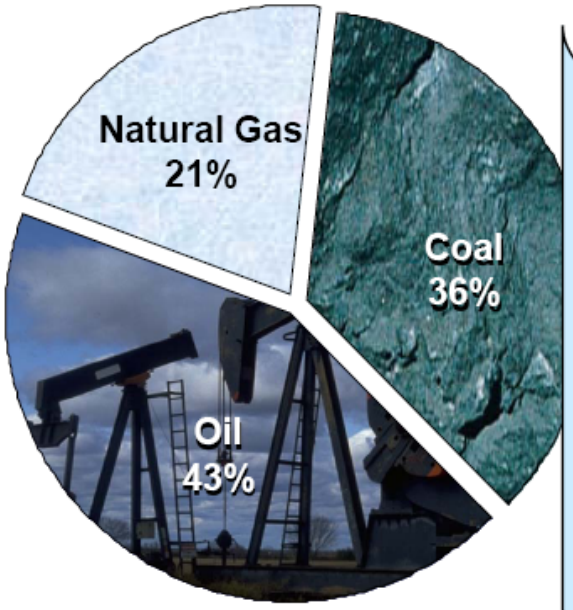
www.fe.doe.gov

www.netl.doe.gov

CCS – It's Not Just About Coal !!!

United States CO_2 Emissions

Emissions By Fuel Type



Natural Gas Power Plants

Natural Gas Processing

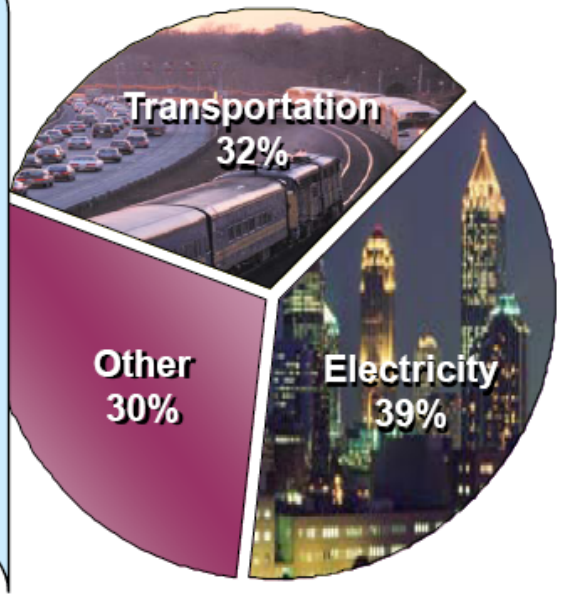
Ethanol Plants

Cement Production

Refineries

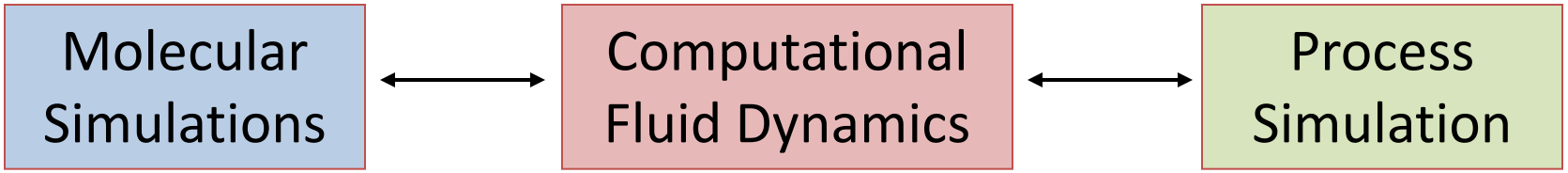
Etc….

Emissions By Sector



Role of Simulation in CCS

Accelerating the Demonstration and Commercialization of Mature Technology



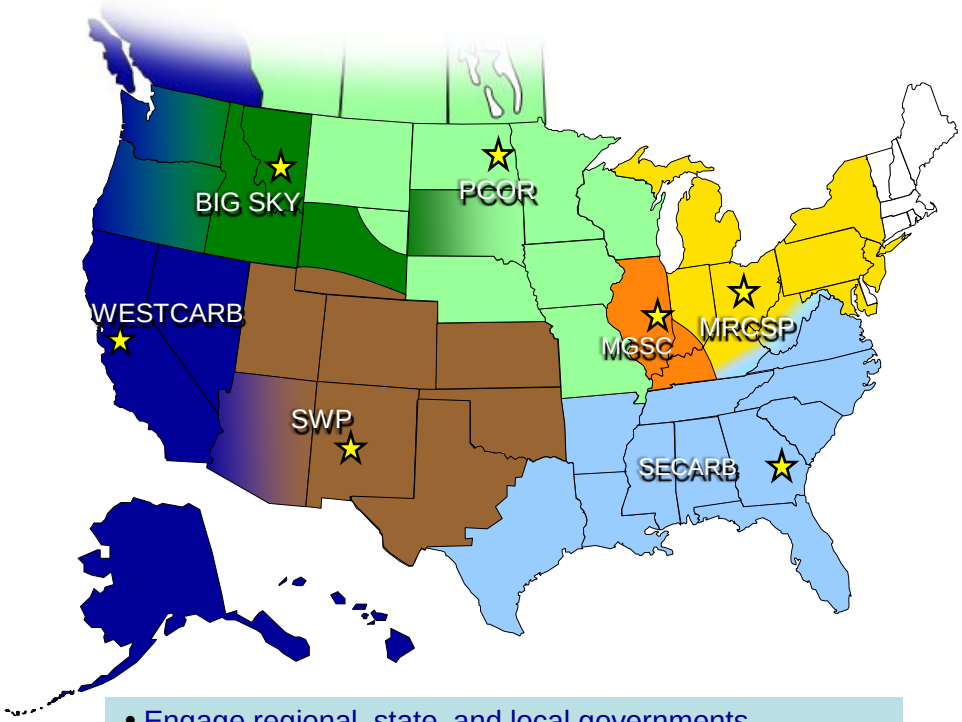
- **Molecular Simulation:**
  - Design and screening of advanced capture materials
  - Physicochemical properties for evaluation and design of bench scale experiments
- **Computational Fluid Dynamics:**
  - Design and performance of CC contacting equipment
  - Set targets for material properties
- **Process Simulation:**
  - Plant design, integration and performance
  - Real time plant simulation for response testing and operator training

Regional Carbon Sequestration Partnerships

Developing the Infrastructure for Wide Scale Deployment

Seven Regional Partnerships

400+ distinct organizations, 43 states, 4 Canadian Provinces



- Engage regional, state, and local governments
- Determine regional sequestration benefits
- Baseline region for sources and sinks
- Establish monitoring and verification protocols
- Address regulatory, environmental, and outreach issues
- Validate sequestration technology and infrastructure

Characterization Phase (2003-2005)

Search of potential storage locations and CO_2 sources	Found potential for 100's of years of storage

Validation Phase (2005-2010)

20 injection tests in saline formations, depleted oil, unmineable coal seams, and basalt

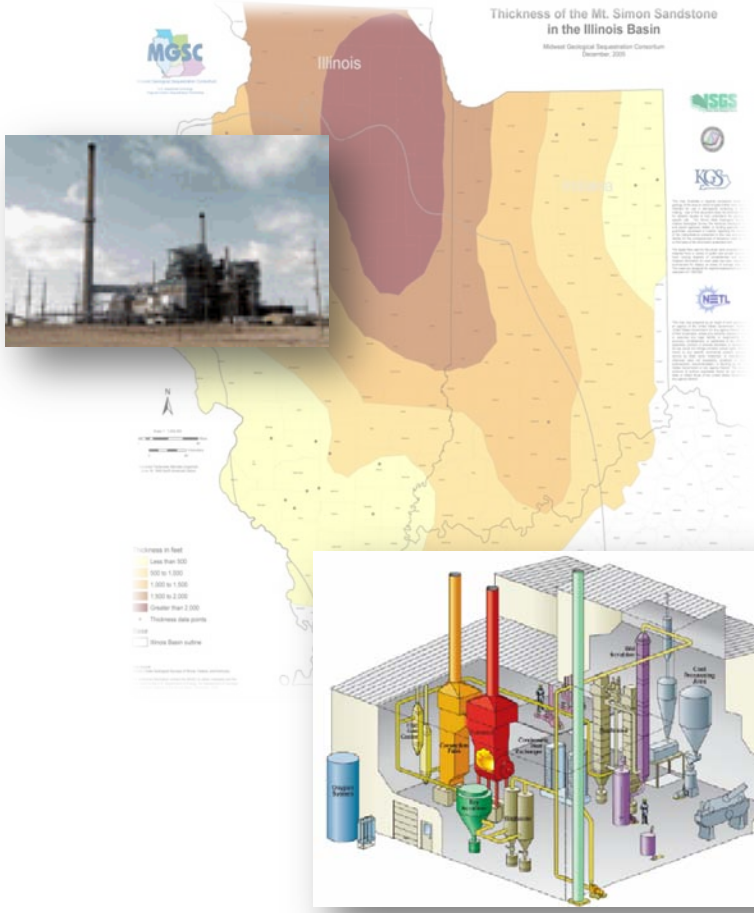
Development Phase (2008-2017+)

9 large scale injections (over 1 million tons each)	Commercial scale understanding	Regulatory, liability, ownership issues

FutureGen 2.0

Large-Scale Oxy-Combustion Integrated with CCS

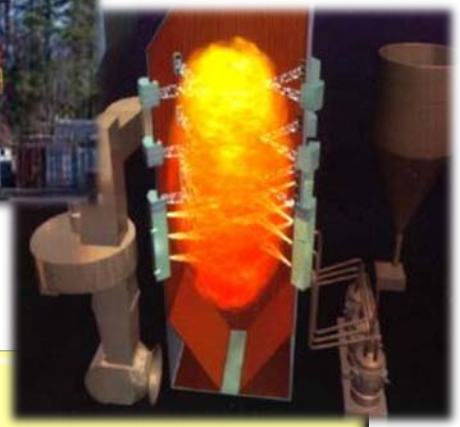
- Repower Unit 4 of Ameren's Meredosia, IL power station with coal-fueled oxy-combustion technology
- Utilize existing 202 MWe steam turbine & plant infrastructure
- Pipeline & Store CO_2 in Mt. Simon Saline Formation
- Craft Training and Research, and Visitor Centers to be Co-located at Injection Site



Pulverized Coal Oxy-combustion

Advantages

- 1st generation plants can utilize existing technologies (e.g. boiler, cryogenic ASU)
- Existing technologies show slight economic advantage over scrubbing
- Applicable to new and existing PC power plants
- Plant vs. unit operation—multiple cost reduction opportunities
- Co-sequestration options



Challenges

- Existing cryogenic ASUs are capital and energy intensive
- Excess O_2 and inerts (N_2, Ar) ↑ CO_2 purification cost
- Existing boiler air infiltration
- Corrosion and process control

R&D Focus

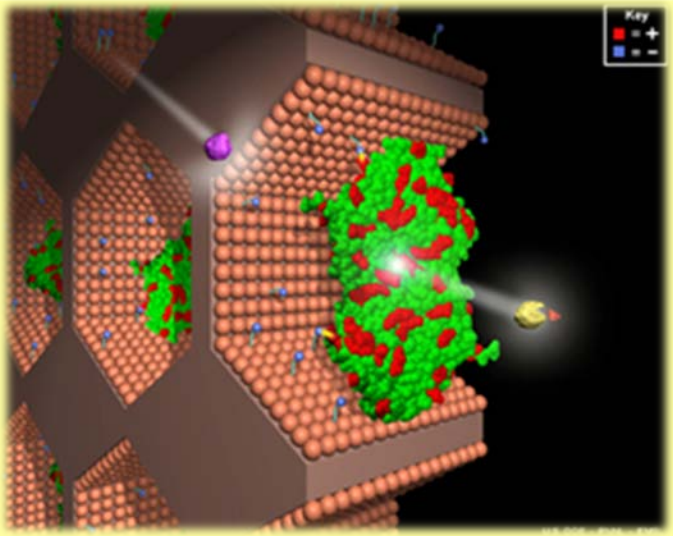
- New oxyfuel boilers
  - Advanced materials and burners
  - Corrosion
- Retrofit existing air boilers
  - Air leakage, heat transfer, corrosion
  - Process control
- Low-cost oxygen
- CO_2 purification
- Co-capture (CO_2 + SOx, NOx, O_2)

Partners (11 projects): ***Praxair, Air Products, Jupiter, Alstom, B&W, Foster Wheeler, REI, Southern Research***

Advanced Solvents

R&D Focus

- High CO_2 loading capacity
- Minimize regeneration energy
- Fast reaction kinetics
- Non-corrosive
  - Low cost materials of construction
- No solvent degradation
- Low cost



Project Types

- Ionic liquids
- Novel high capacity oligomers
- Potassium carbonate/enzymes
- CO_2 capture additives

Partners (5 Projects)

- **University of Notre Dame**
- **Georgia Tech.**
- **Illinois St. Geological Survey**
- **GE Research Corporation**
- **Lawrence Berkeley Nat. Lab**

Solid Sorbents

Advantages

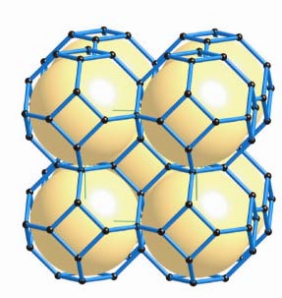
- Low regeneration energy (no water, low heat capacity, low heat of reaction)
- High equilibrium capacity—high surface area
- Fast kinetics

Challenges

- System design
  - Pressure drop
  - Heat integration
  - Solid transport
- Durability (attrition, chemical stability)

R&D Focus

- **High CO_2 loading capacity**
- **Minimize regeneration energy**
- **Fast reaction kinetics**
- **Durable**
  - Thermally & chemically stable
- **Gas/solid systems**
  - Low pressure drop, heat management



Project Types

- Sorbent systems development
- Carbonates
- Metal organic frameworks
- Metal zeolites

Partners (6 Projects): ***RTI, UOP, University of Akron, ADA, SRI, TDA***

CO_2 Membranes

Advantages

- Simple operation; no chemical reactions, no moving parts
- Tolerance to high levels of wet acid gases; inert to oxygen
- Compact and modular with a small footprint
- Relatively low energy use; no additional water used (recovers water from flue gas)
- Builds on existing, low-cost technology already used at a similar scale

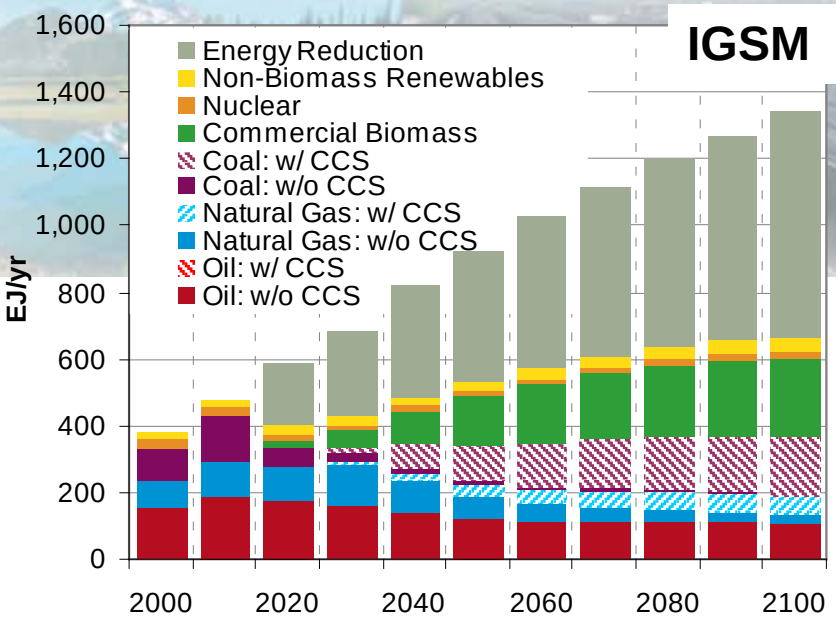
Challenges

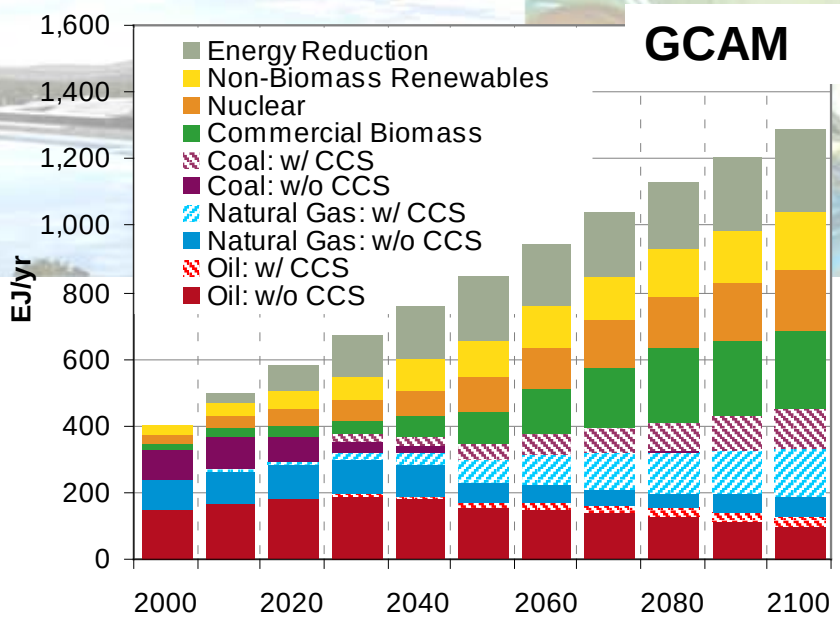
- Low flue gas CO_2 partial pressure
- Particulate matter and potential impact on membrane life
- Energy losses due to feed and permeate side pressure drops
- Cost reduction and device scale-up
- Power plant integration (e.g. sweep gas)
- Lack of power industry operating experience

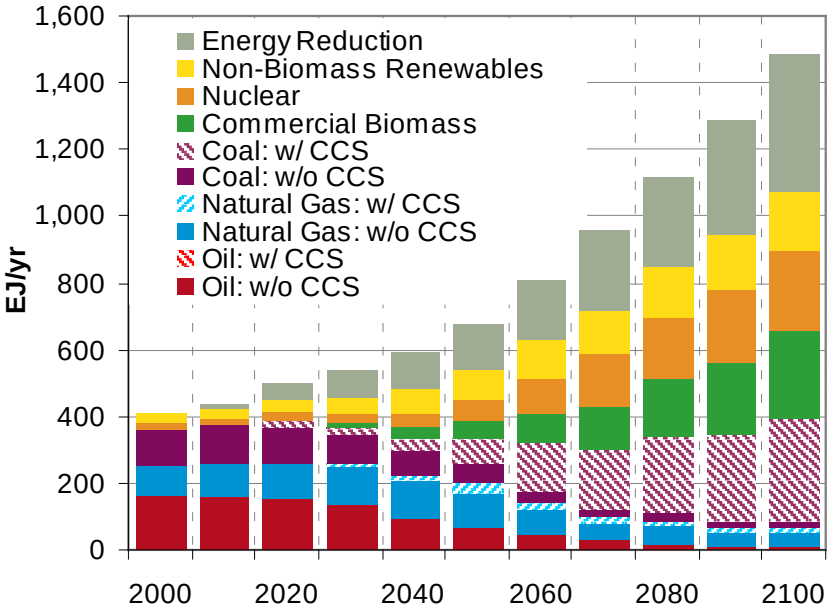
R&D Focus

- High CO_2/N_2 selectivity & permeability
- Durability
  - Chemically (SO_2), thermally
  - Physically
- Membrane systems
  - Process design critical
- Low cost
  - Capital and energy penalty

Partners: ***MTR, RTI***







MERGE

Primary Energy from the CCSP Scenarios (≈ 450 ppmv CO_2)

These models show CCS meeting roughly 1/3 of total energy demand by 2100

Source: PNNL