University of Mississippi Chemical Engineering Climate Change Course
April 15-16, 2009

IGCC and CO_2 Capture Research at the PSDF

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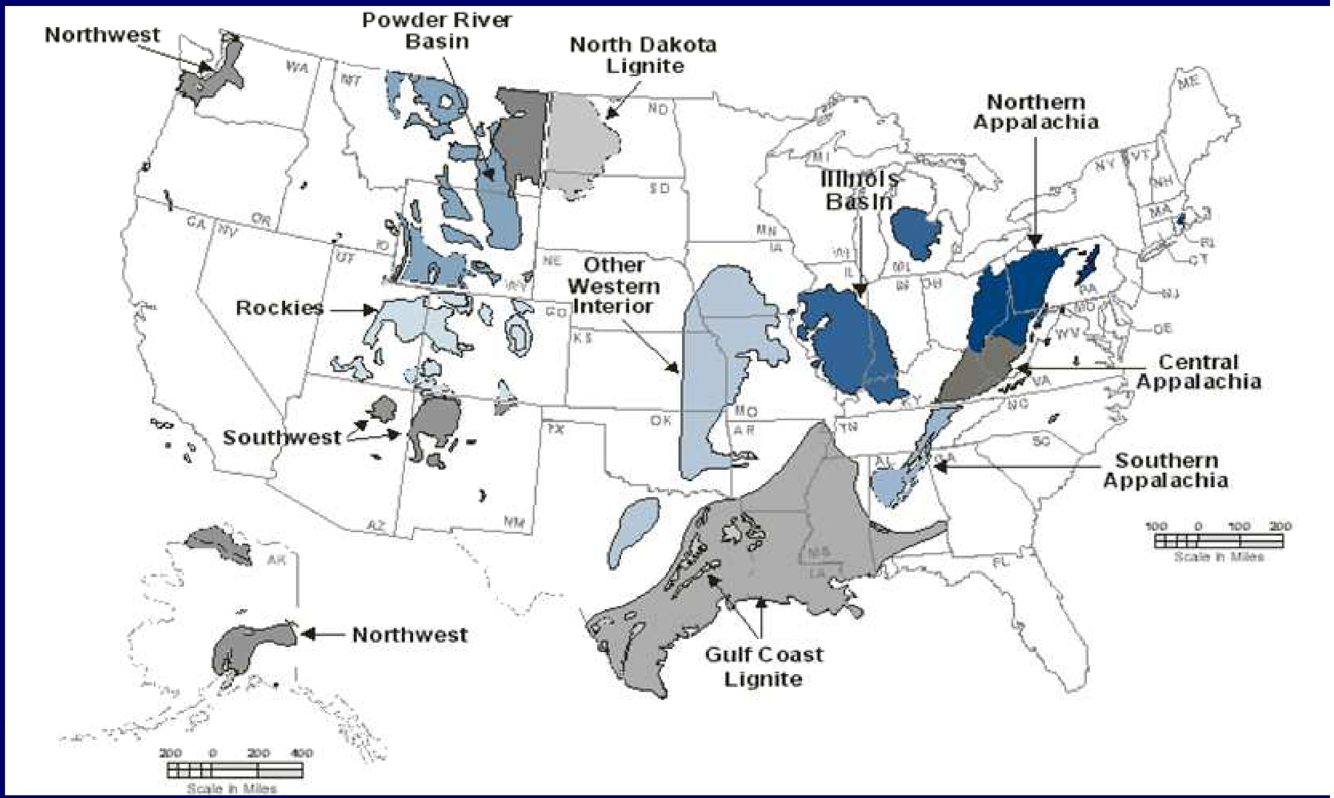
Coal: America's Most Abundant Fuel and Strategically Important

U.S. has a well-known, readily available supply of coal

– 250+ years of coal reserves

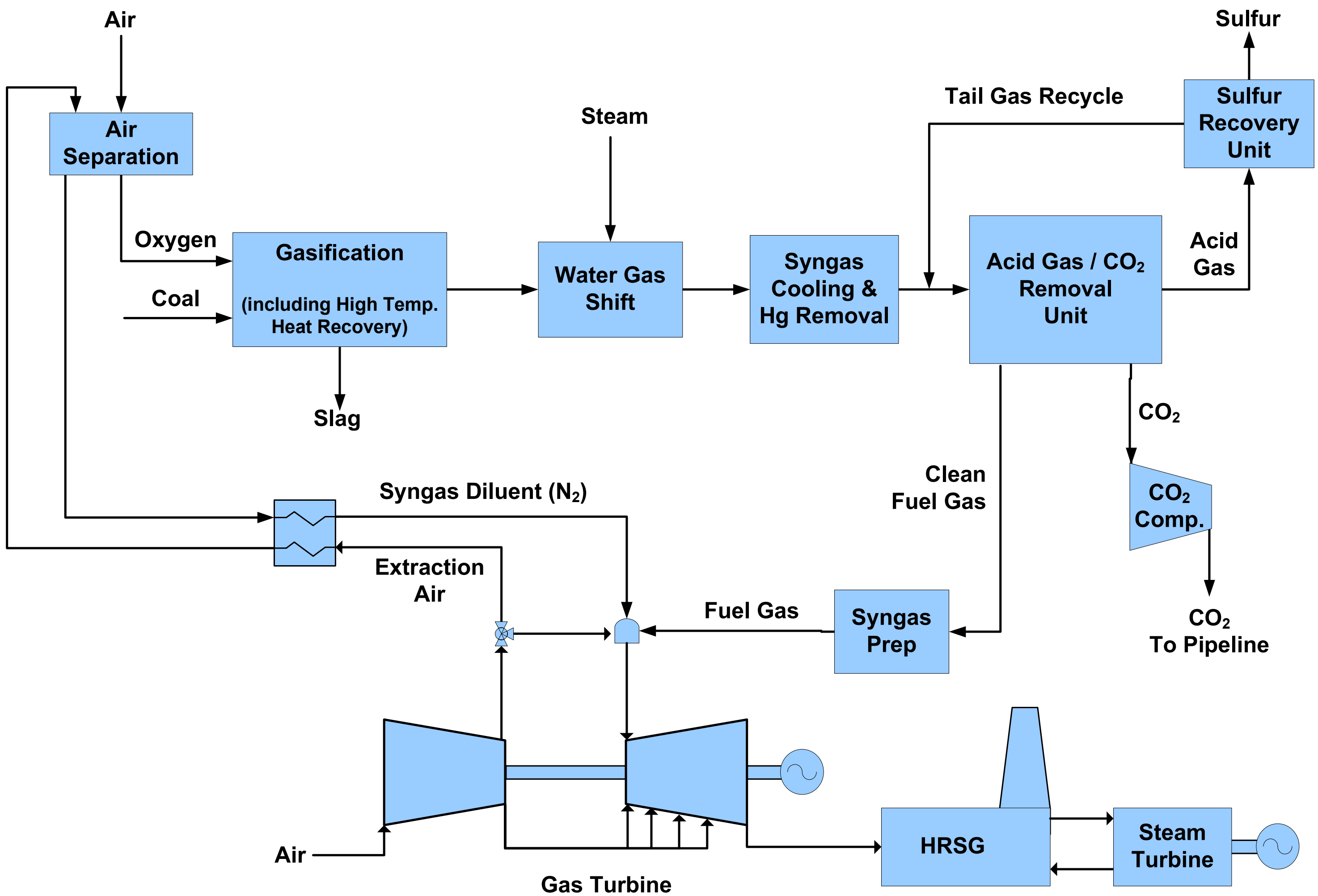
– Limited natural gas availability

– Need to utilize coal reserves more efficiently



Courtesy of Robert Wayland, PhD, EPA OAR

IGCC Simplified Flowsheet



Taken from: "Critical Technology Needs for IGCC" presented by Ron Schoff at the CURC-EPRI Annual Meeting, April 10, 2008.

IGCC and Gasification Background

- Coal gasification first used for streetlights in 1792.
- Late 1800's widely used for lighting and industrial applications in Europe and US.
- By the 1920's there were over 1200 gas plants operating in the US. Post WW II discoveries of natural gas led to demise of these plants.
- Widespread use in South Africa during apartheid for liquid fuel production.
- Renewed interest and development in the 70's due to oil embargo and concerns over natural gas reserves.
- Today's high natural gas prices and stringent environmental regulations focused interest on IGCC.

From: "Tampa Electric's IGCC Plant" presented by B.T. Burrows at the 11th Annual FDEP Central District Power Generation Conference, July 26, 2007

Gasification Worldwide

- 117 operating plants, 385 gasifiers
- Feedstocks:

Feedstocks:	Coal	49%
	Oil	37%
	Nat Gas, PetCoke, Biomass, waste	14%

- Products:

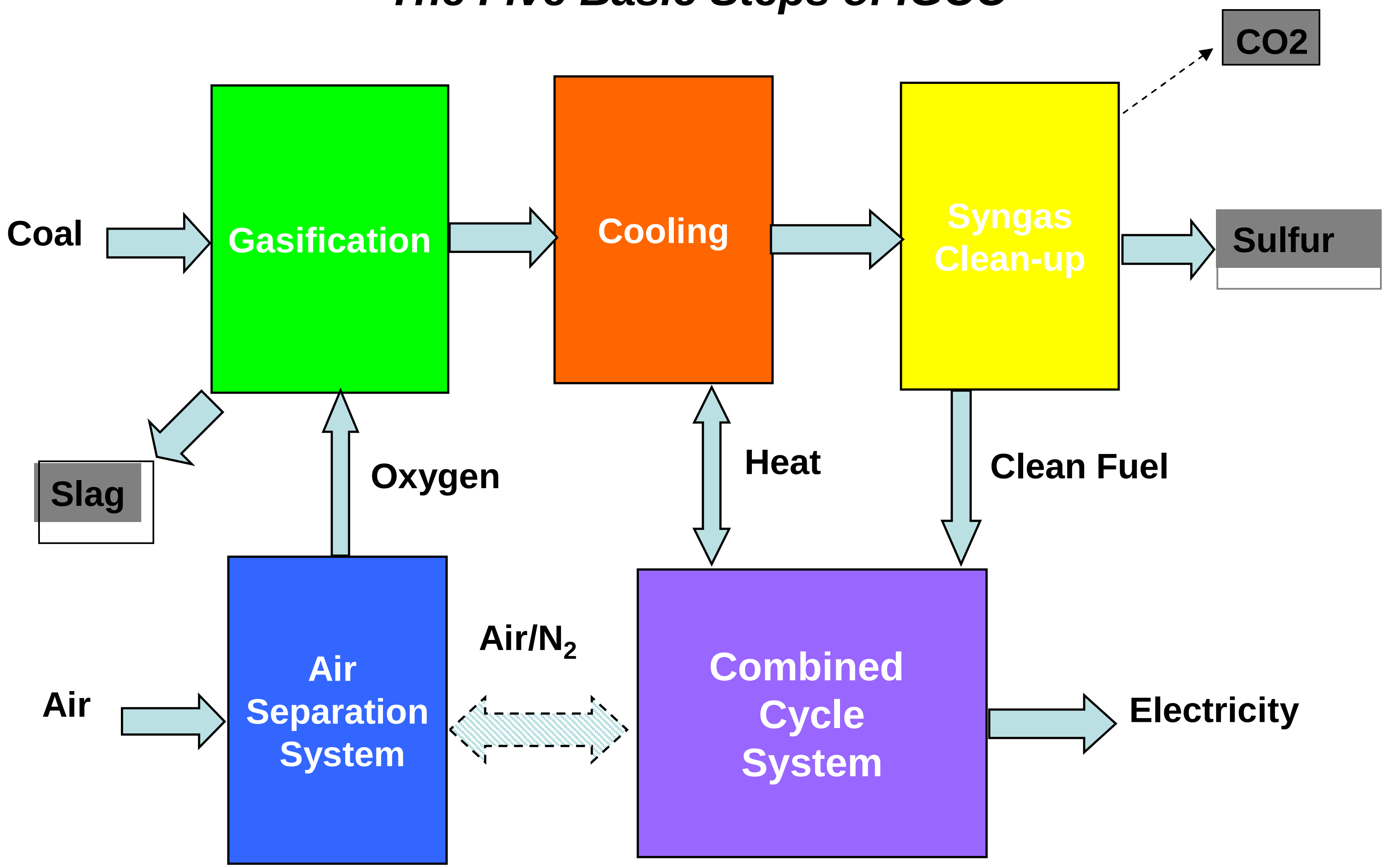
Products:	Chemicals	37%
	Liquid fuels	36%
	Power	19%
	Gas fuels	8%

- Over 20 Combustion turbines firing syngas
- Solids IGCC's

Solids IGCC's	Nuon Power, Netherlands,	253 MW	1993
	Wabash River, Indiana,	262 MW	1995
	Polk, Mulberry FL	250 MW	1996
	Puertollano, Spain	330 MW	1997

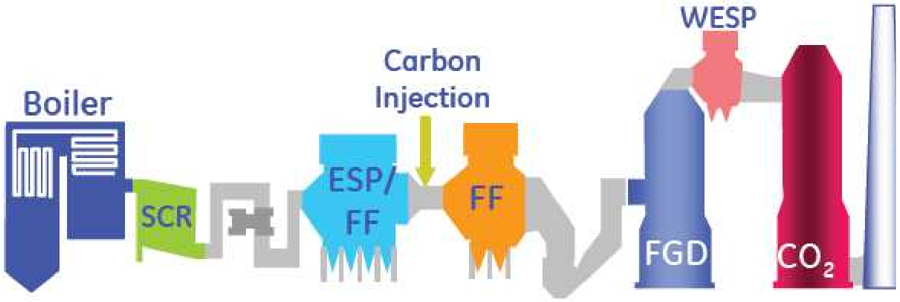
From: "Tampa Electric's IGCC Plant" presented by B.T. Burrows at the 11th Annual FDEP Central District Power Generation Conference, July 26, 2007

The Five Basic Steps of IGCC



From: “Tampa Electric’s IGCC Plant” presented by B.T. Burrows at the 11th Annual FDEP Central District Power Generation Conference, July 26, 2007

Comparison of IGCC to Conventional Power Plant



IGCC

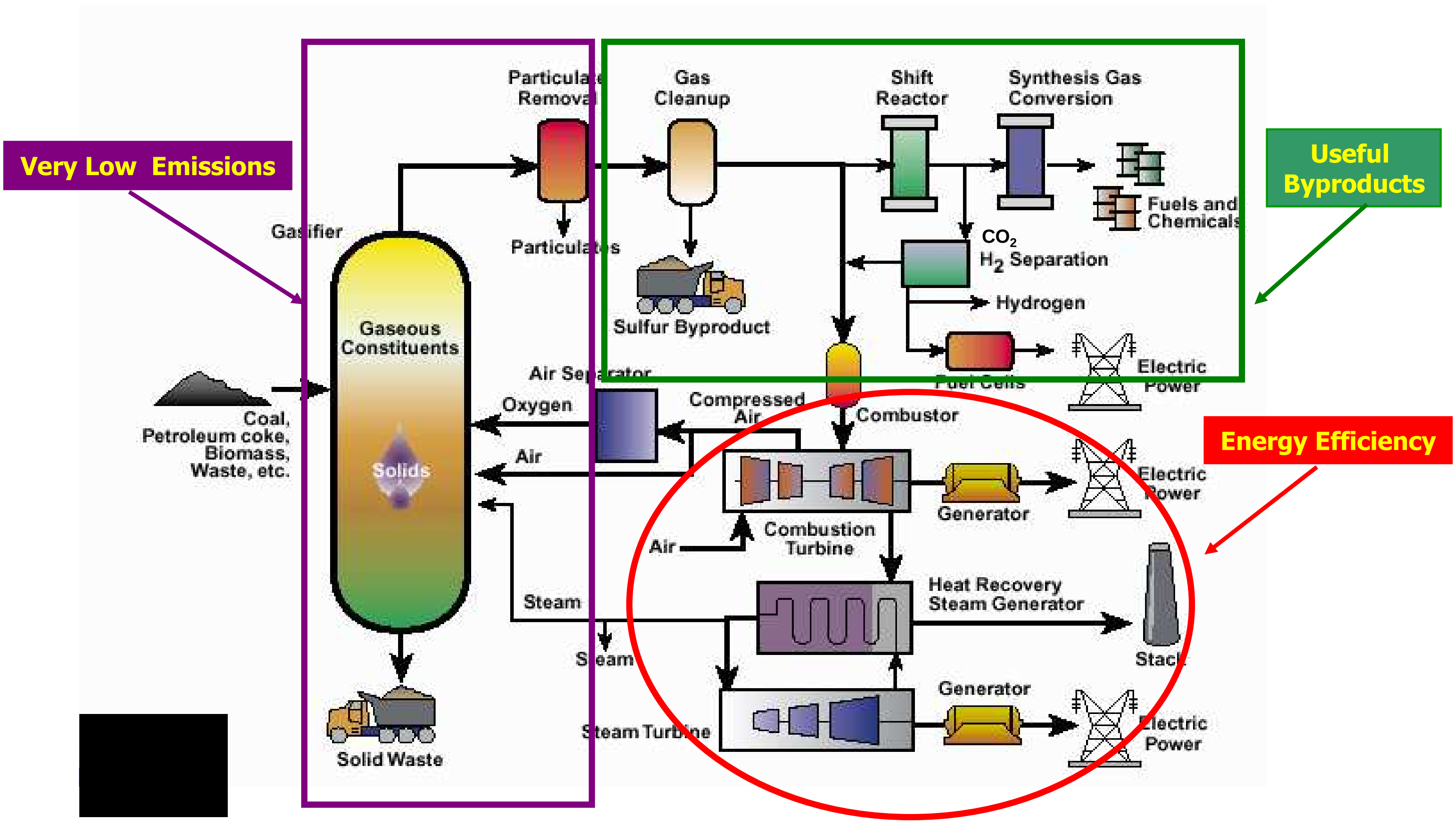
- Gasification cleans the coal before it is burned.
- High pressure & low volume provide favorable economics of pollutant removal
- The IGCC Cleaner Coal option increases fuel diversity, reduces emissions, and increases siting and permitting flexibility.

Pulverized Coal

- Pollutants are removed after the coal is burned.
- The gas volume treated is 100 times the gas volume of an IGCC plant.
- Criteria & HAPS emissions are higher than an average IGCC plant
- Combustion produces large quantities of waste and consumes more water than IGCC

Taken from: "IGCC Cleaner Coal – Ready for Carbon Capture" presented by GE Energy at the UBS 2007 Climate Change Conference, May 14, 2007.

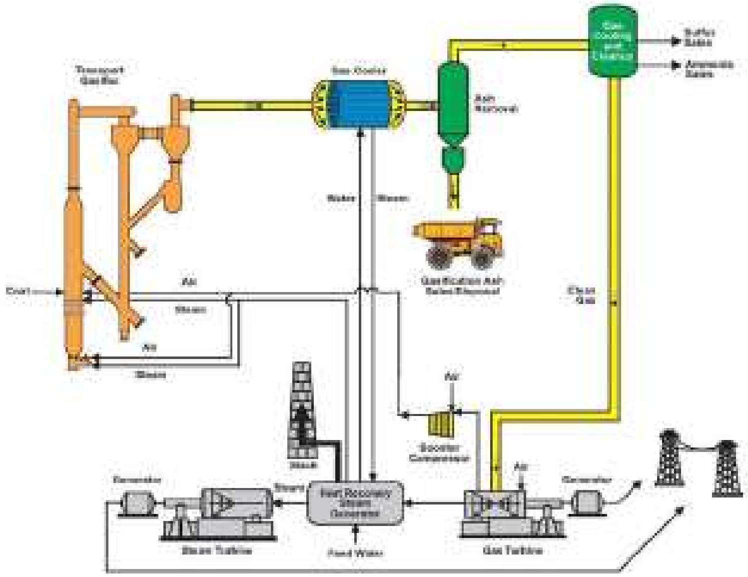
PolyGen: IGCC with Chemicals Production



Courtesy: DOE/NETL

IGCC Generates More Electricity per Ton of Coal

- **IGCC plants use two power cycles, generating electricity more efficiently**
  - Coal is heated in a specialized process to release syngas which is used to generate electricity in a turbine
  - Then exhaust gas from the turbine is used to heat water, which produces steam to generate additional electricity
- **With two power cycles, the amount of electricity generated from a ton of coal is increased**



NETL

Benefits Presentation: Southern Company CCPI 2 – D. Revay Madden, 321, 05/2007

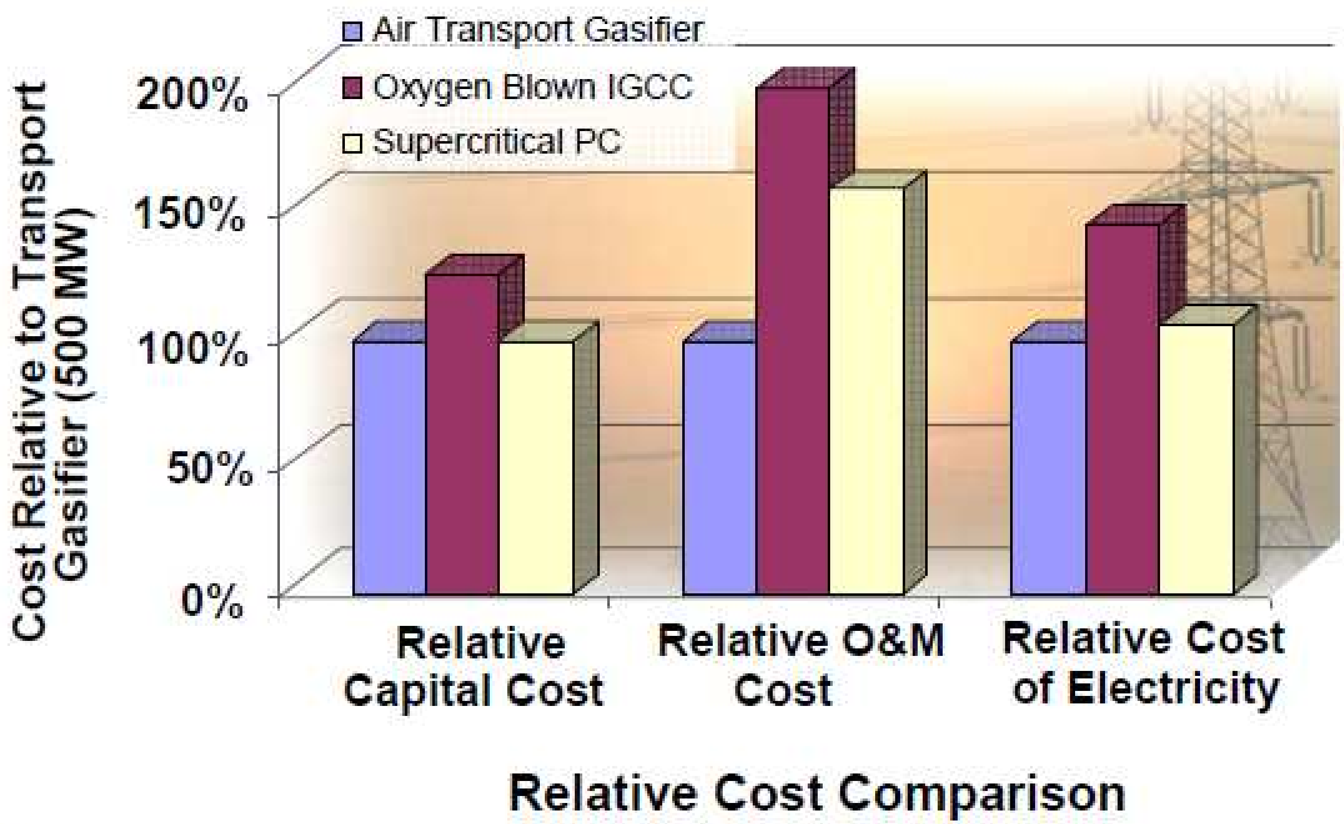
Two Options for IGCC: Oxygen vs Air-Blown

- **Coal gas is produced with O_2 in some IGCC plants**
- **O_2 plants:**
  - Are expensive to build
  - Require high levels of electricity to operate
  - Reduce electricity available for sale to consumers
- **Southern Company's air-blown IGCC system uses O_2 from the air to produce syngas, increasing the overall efficiency of the plant**
  - Process does not require a costly O_2 plant

NETL

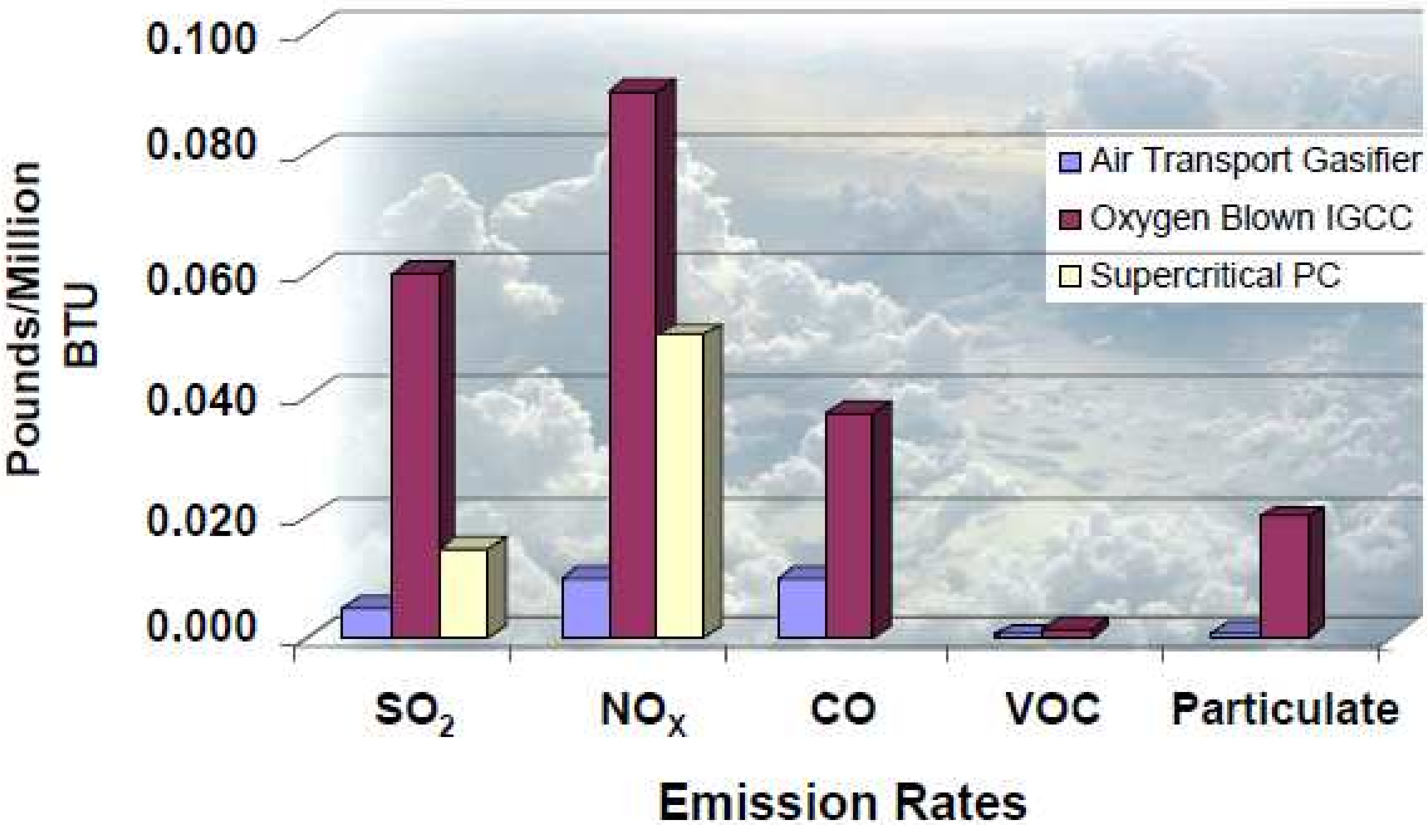
Benefits Presentation: Southern Company CCPI.2 – D. Rasey Madden, 321, 05/2007

Economics of Oxygen vs Air-Blown IGCC



Benefits Presentation: Southern Company CCPI 2 – D. Revay Madden, 321, 05/2007

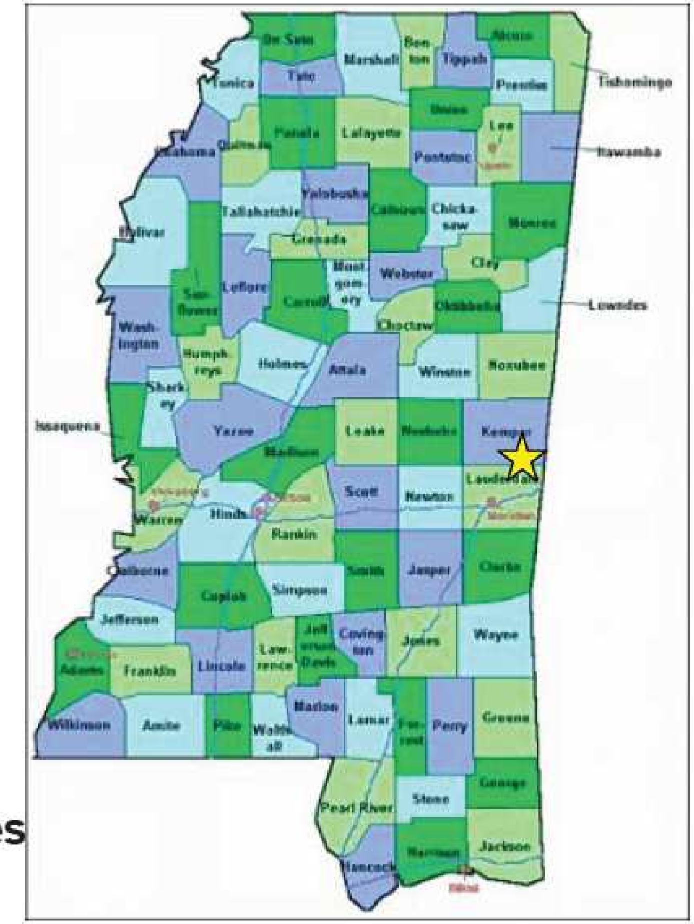
Emissions Comparison: Oxygen vs Air-Blown



Benefits Presentation: Southern Company CCPI 2 – D. Revay Madden, 321, 05/2007

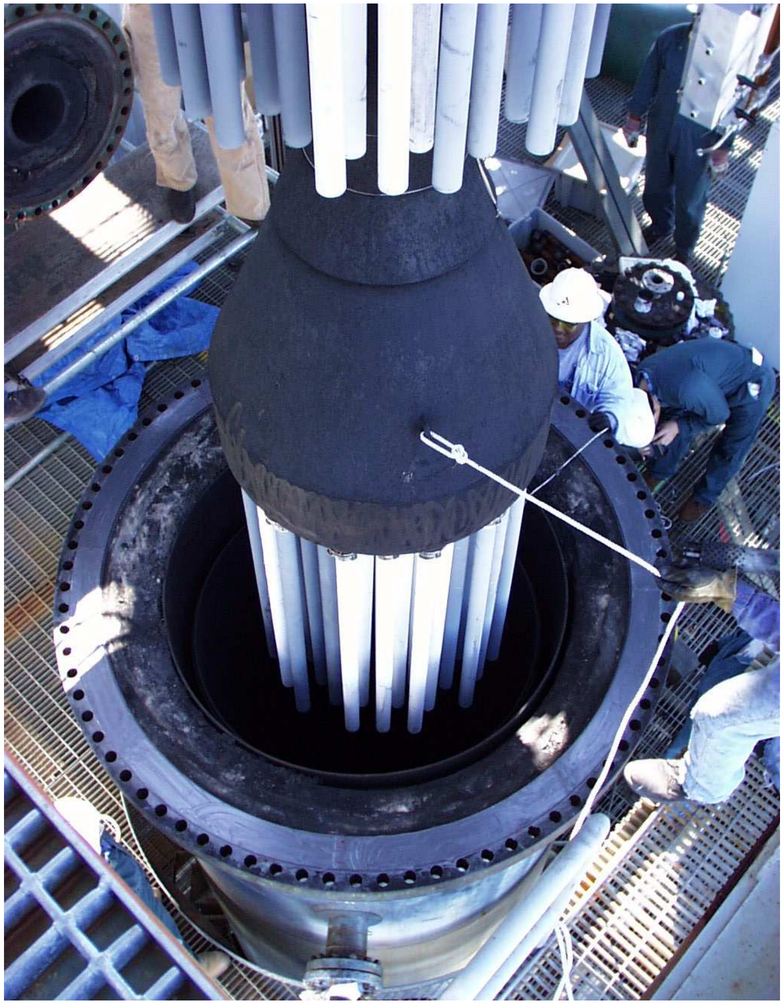
IGCC Demo Plant – Kemper County, Mississippi

- Location
  - Kemper County, MS,
  - ~ 20 miles North of Meridian
  - 1600 Acre Plant Site
- In-Service Date
  - November 2013
- Over $2 billion capital investment
- 513 MW capacity, 65 °F, 75% RH
- 11,225 btu/kwh HHV with 50% CO_2 capture
  - 2x1 Integrated Gasification Combined Cycle (IGCC) using TRIG™
  - Fuel
    - Primary: Mine Mouth Lignite (31,000 Acres Life of Mine)
    - Backup: Natural Gas



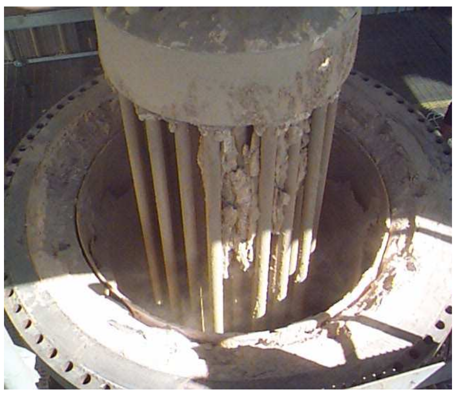

IGCC Research at the
Power Systems Development Facility
Wilsonville, Alabama

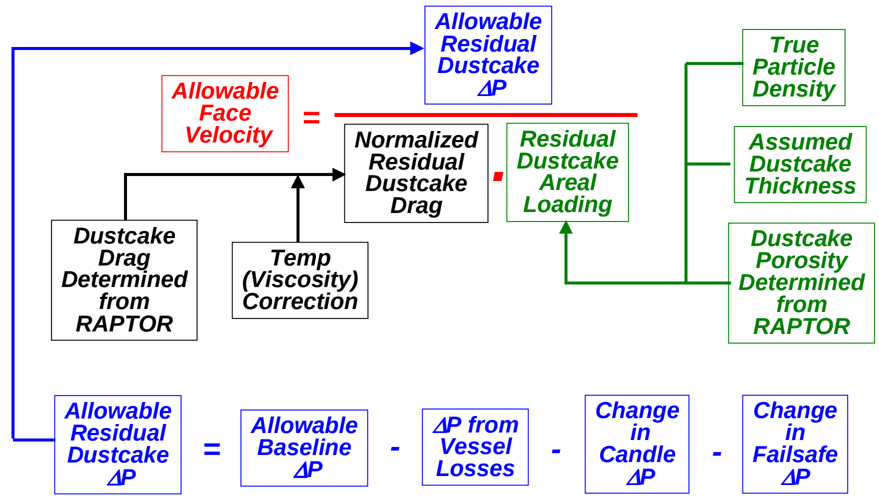
Hot-Gas Filter for Particulate Control



Particulate Removal by Hot-Gas Filtration

Analysis and solution of HGF performance problems (high ΔP, bridging, tar deposition, filter element damage, etc)

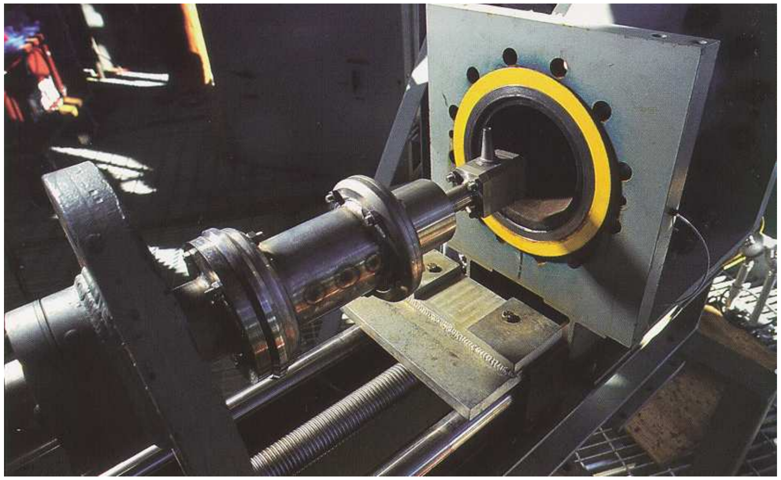




Development and validation of HGF design procedures

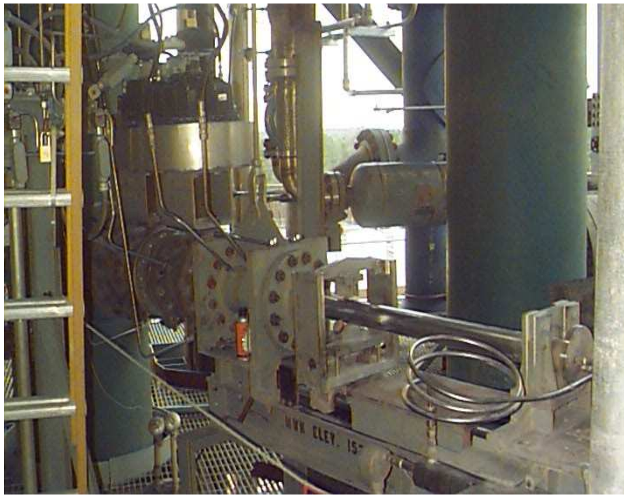
HTHP In-Situ Particulate Sampling System

Close-up view of isolation valves with nitrogen purge and vent lines

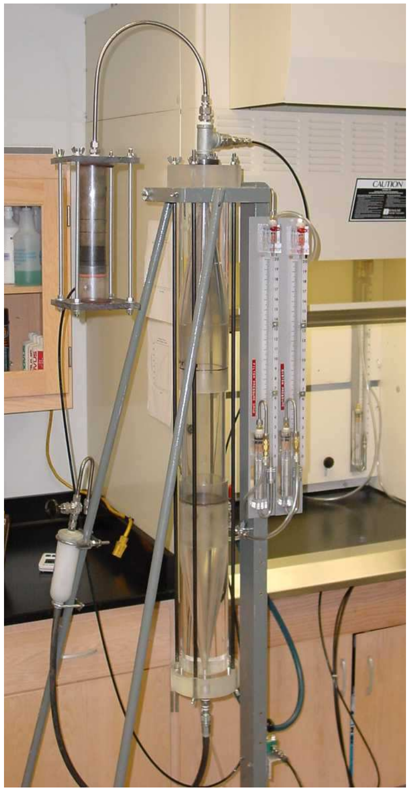


Sampling nozzle, filter holder and alkali getter

Sampling probe inserted through gland seal

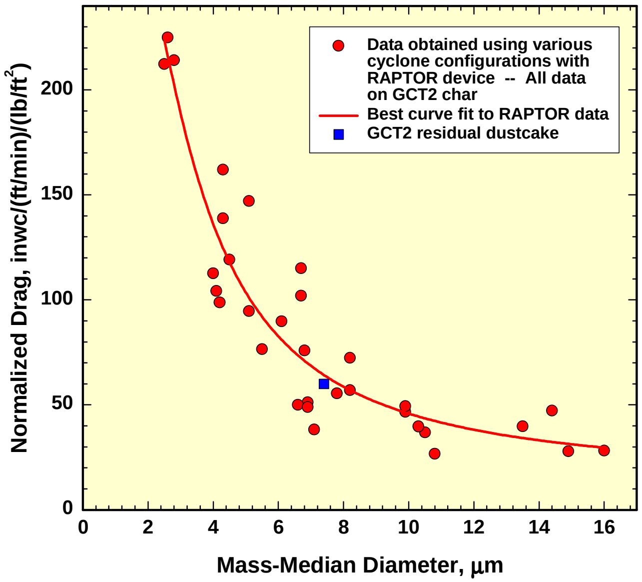


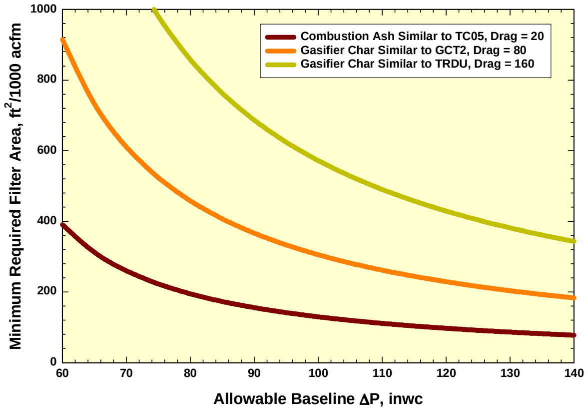
Development of HGF Drag Correlations for System Design



RAPTOR system for measuring dust flow resistance

Validation of RAPTOR with HGF performance data





Use of RAPTOR results in design of new HGF systems

Tar Cracking and Gas Cleanup Testing Area

Medium-Temperature Reactors

(Used for low-temp tar cracking, desulfurization)

Mini-Reactor Operating Parameters for G117RR and G-31

Gasifier operation	**Air Blown**	**Air Blown**
Coal type	**PRB**	**PRB**
Reactor	**RX301**	**RX301**
Reactor size	**1.5”ID x4’ Ht**	**1.5”ID x4’ Ht**
Reactor material	**310SS**	**310SS**
Sorbent manufacturer	**Sud-Chemie**	**Sud-Chemie**
Sorbent	**G-117RR**	**G-31**
Sorbent mass, lb	**0.3**	**0.3-0.5**
Sorbent bed height, in	**5**	**5**
Syngas flow, scfh	**10-12**	**15-20**
Pressure, psig,	**2-10**	**2-10**
Temperature, ^{o}F	**1650**	**1650-1750**
Space velocity, hr^{-1}	**2155**	**1950-3430**
Ammonia inlet, ppm	**2040**	**2250**
Ammonia outlet, ppm	**86**	**6**
Benzene inlet, ppm	**860**	**825**
Benzene outlet, ppm	**210**	**20**
Operating time, hr	**290**	**13 / 300**

Desulfurization Sorbents Developed by DOE and Tested at PSDF

Gasifier Operation	**Air / O2 Blown**	**O2 Blown**
Coal Type	**Powder River Basin**	**Powder River Basin**
Reactor	**RX700A**	**RX700B**
Reactor Size	**5.187"ID x5' Ht**	**5.187"ID x5' Ht**
Catalyst	**RVS-1**	**RVSLT-1**
Catalyst Mass, lb	**2**	**2**
Bed Height, in	**2.3**	**2.3**
Syngas flow, lb/hr	**45 - 3**	**12**
Pressure, psig,	**210 - 130**	**135**
Temperature, oF	**550 - 700**	**650**
Space Velocity, hr^{-1}	**24,000 - 1,700**	**6700**
Inlet H2S, ppm	**160 - 620**	**580**

CO_2 Capture with IGCC and Conventional PC Plants

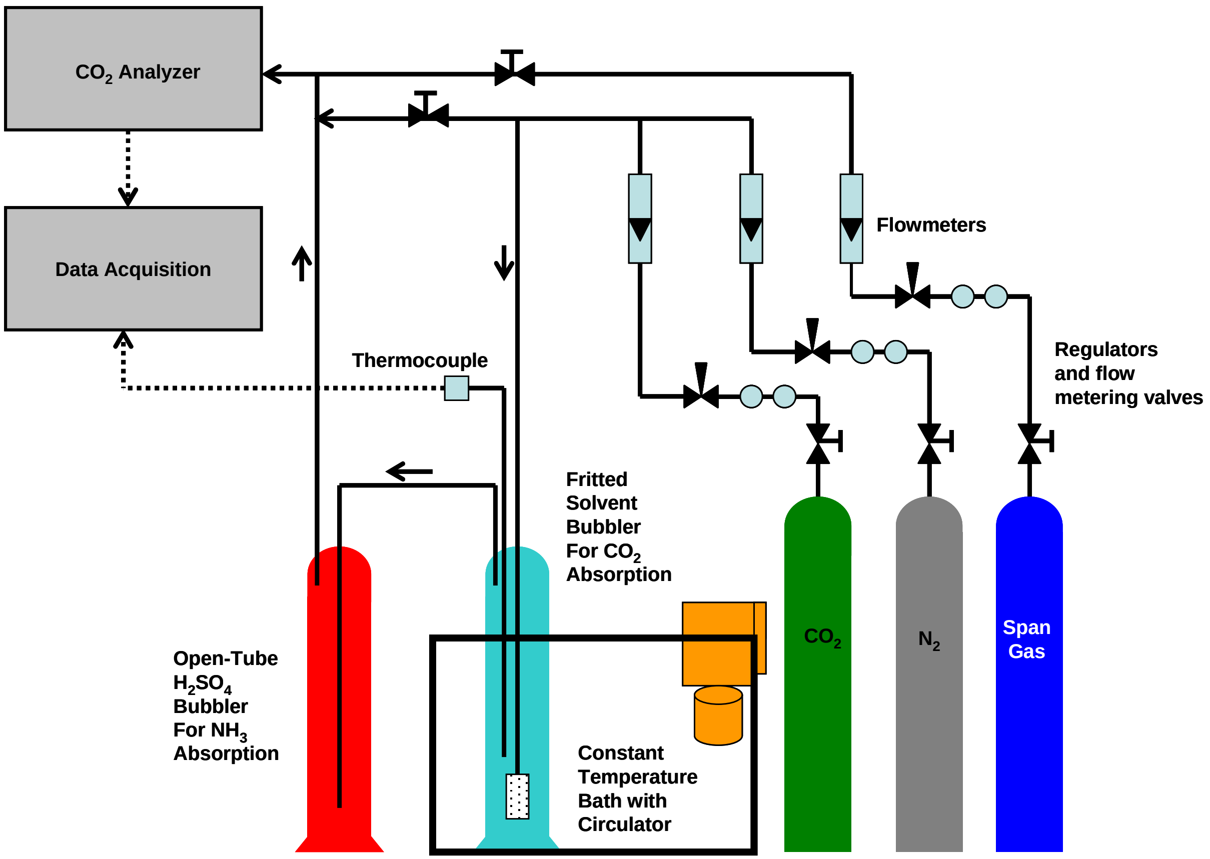
	IGCC Plant	PC Plant*
CO_2 capture (%)	91	90
Unit output derating (%)	14	29
Efficiency Decrease (%)	16.5	40
Capital cost increase (%)	47	73

Source: Environmental Footprints and Costs of Coal-Based Integrated Gasification Combine Cycle and Pulverized Coal Technologies, U.S. Environmental Protection Agency, EPA-430/R-06/006, July 2006

High-Pressure CO_2 Capture Reactor

Approach

- *Begin screening tests with simple lab system.*
- *Identify most promising systems.*
  - *Abs rate & capacity.*
  - *Energy requirements.*
  - *Corrosion.*
  - *Solvent stability.*
- *Maintain steady dialog with other researchers to identify new materials that should be addressed.*

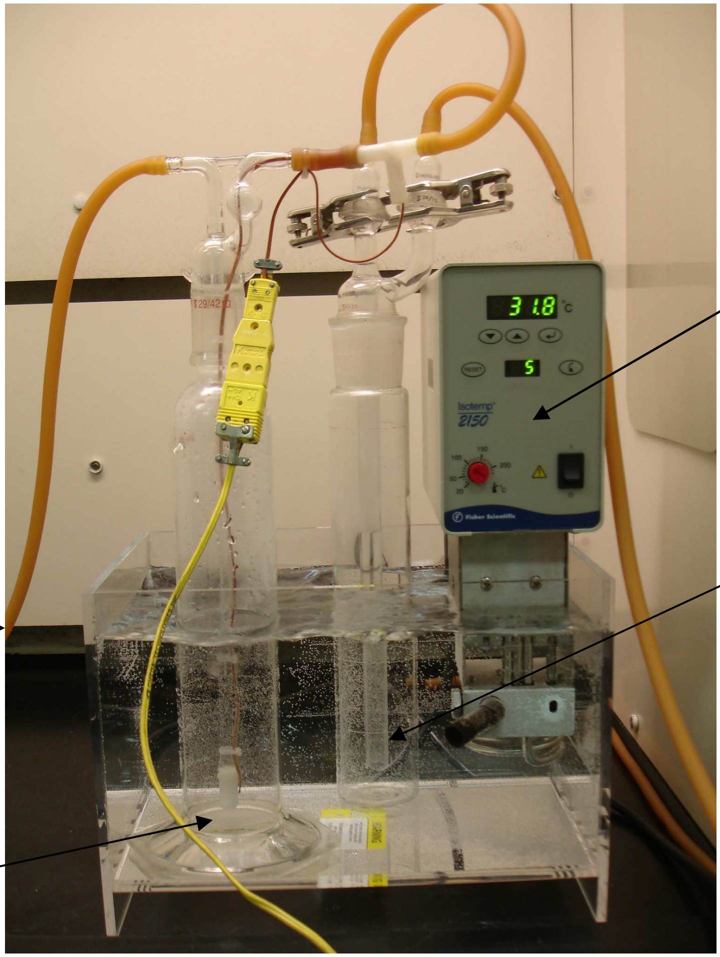


Photograph of Initial Absorber Setup

Gas flow = 1.5 L/min

Liquid volume = 200 mL

Gas residence time ~1 sec



Circulator/heater for constant temperature bath

Open-tube bubbler for absorption of residual NH_3

Inlet gas (CO_2 in N_2)

Exit gas to analyzer

Fritted bubbler for CO_2 absorption

Thermocouple output to data logger

Some Candidate Solvents and Additives

Initially, all of the primary solvents are being compared at a concentration of 1 M, but tests will also be done at other concentrations, including those used commercially. A tentative list of the solvents and additives to be tested is given below. Various combinations of solvents and additives are being tested as appropriate. The lists of solvents and additives are continually updated based in input from other researchers and developers.

Solvents

Monoethanolamine
Diethanolamine
Methyl-Diethanolamine
Triethanolamine
Diglycolamine
Diisopropanolamine
Methyl-Monoethanolamine
Morpholine
Ammonium Hydroxide
Dimethyl Ether Polyethylene Glycol
Sodium Hydroxide
Piperazine
Potassium Carbonate
N-formylmorpholine

Solvents (continued)

N-acetylmorpholine
Sodium Glycinate
Potassium Glycinate
Potassium Taurate
Potassium Sarcosinate
Diaza-Bicyclo-Undecene
Other Sterically-Hindered Amines
Other Amino Acid Salts
Other Nitrogen-Containing Solvents
Other Nitrogen-Free Solvents
Diaza-Bicyclo-Undecene-1-Hexanol
Other Amidine-Alcohol Systems
Guanadine-Alcohol Systems
Perfluoro-Perhydro-Benzyltetralin

Additives

Piperazine
Guanadine Hydrochloride
Monoethanolamine
Ammonium Chloride
Sodium Chlorides
Other Chloride Salts
Chloroform
Carbon Tetrachloride
Dimethyl Sulfoxide
Isopropanol
Acetone
Ammonium Sulfate
Ammonium Bisulfate
Diethanolamine

Additives (continued)

Methyl Diethanolamine
Triethanolamine
Diaza-Bicyclo-Undecene
Other Sterically-Hindered Amines
Sodium Glycinate
Potassium Glycinate
Potassium Taurate
Potassium Sarcosinate
Other Amino Acid Salts
Other Chlorinated Hydrocarbons
N-formylmorpholine
N-acetylmorpholine
Hexanol
Other Alcohols

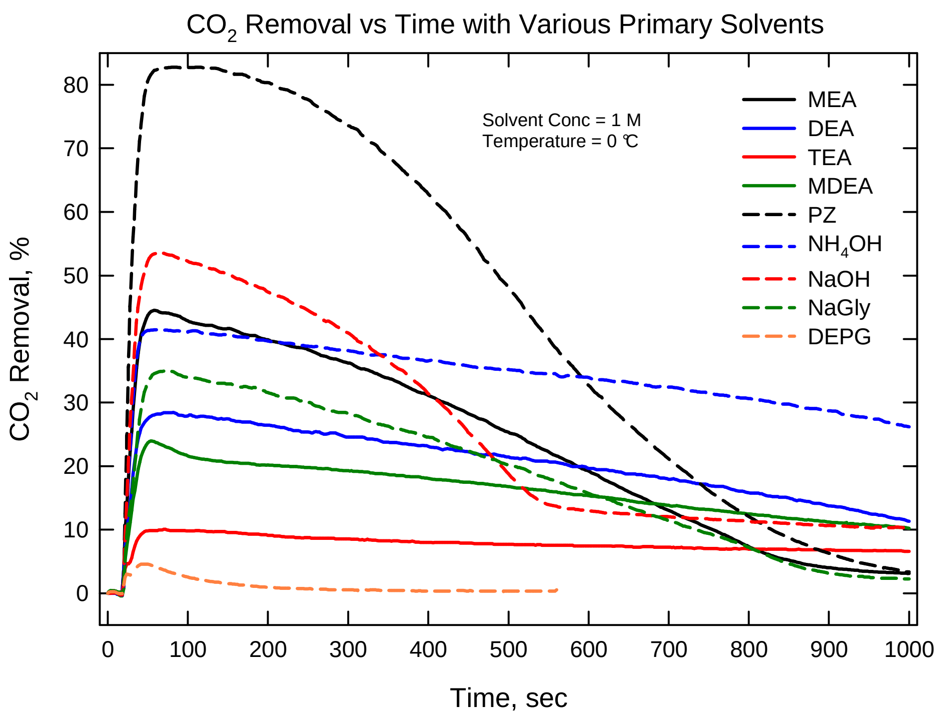
Derived from literature and discussions with other researchers and process developers.

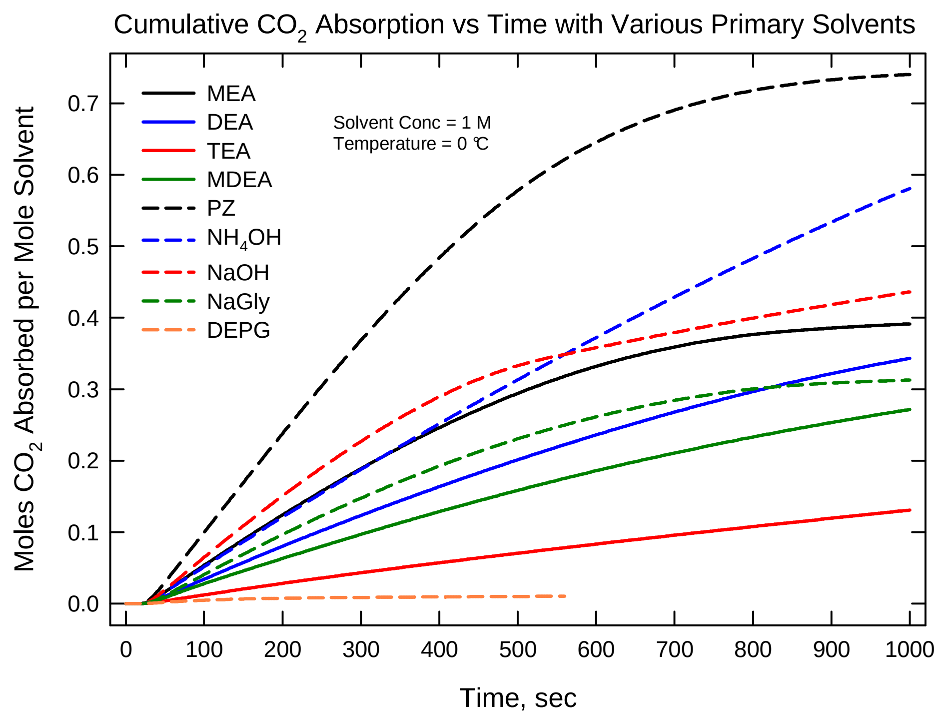
Primary purpose of additives to enhance reaction rate.

Some additives selected to simulate effects of dual capture of CO_2 and SO_2.

List is being updated continually based on input from many sources.

Example 1 - CO_2 Removal Results Obtained with “Standard” Materials





Note: These initial results were obtained with low-concentration (1-M) solvents for comparison of absorption rate and capacity with gas residence time of ~1 sec. These measurements were made before the constant-temperature bath was available, so an ice-bath was used as a convenient means of providing a constant temperature (0℃). Future tests will be done at various temperatures representative of scrubber operation. Note that over time interval studied absorption curves show asymptotic approach to saturation for all solvents except NH_4OH.