"Carbon Capture Research at Power Systems Development Facility"

Larry Monroe, Southern Company
Manager, Eng. Science and Tech.

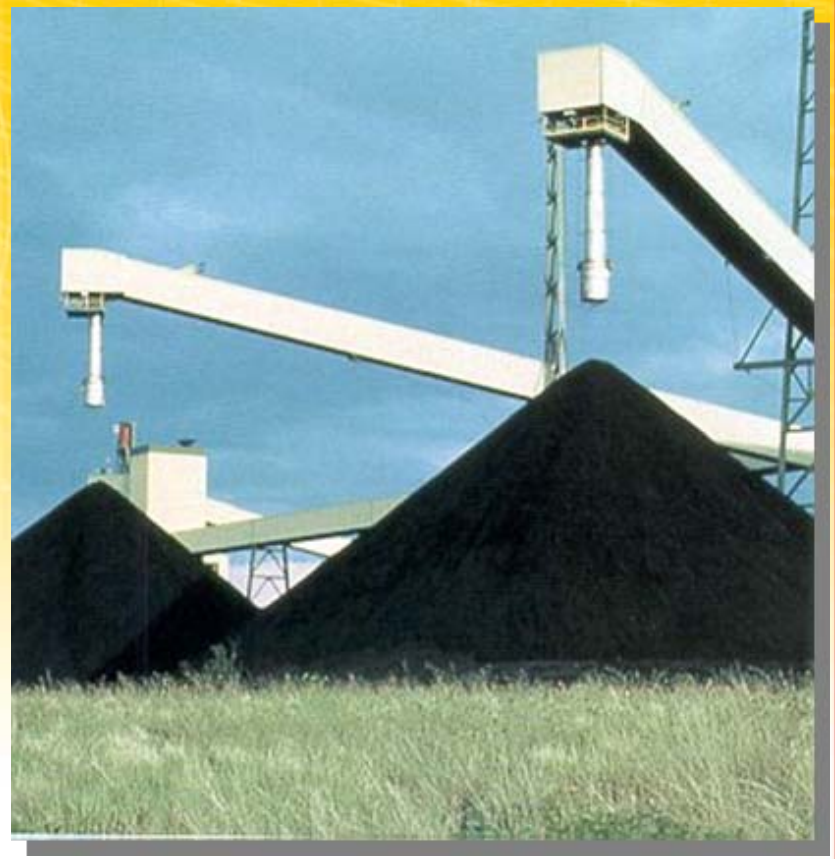
Mike Mosser, NETL Project Manager

NETL CO_2 Capture Technology for Existing Plants R&D Meeting
March 25, 2009

Southern Company Generation

Outline

- Introduction
- PSDF
- Utility industry technology development
- Post-Combustion Carbon Capture Center (PC4)
- Summary



Southern Company (NYSE:SO)

2007 Financial Performance:

- **Revenues: $15.4 billion**
- **Net income: $1.73 billion**
- **Assets: $43.0 billion; 42,000 MW; 287 units**
- **1 of top 3 electric utilities in the U.S.**

Core service area

- **120,000 sq.miles**
- **4.3 million customers, 12 million people**

Table 2. Top 50 Emitting Power Plants for CO_2 By Tons CO_2 (2006)

Rank (Tons)	Facility Name	Facility Owner	State	CO2 Tons	Rank (lbs/MWh)
1	Scherer	Southern/Georgia Power	GA	25,298,498.73	118
2	James H Miller Jr.	Southern/Alabama Power	AL	23,466,022.08	126
3	Bowen	Georgia Power	GA	22,756,191.48	201
4	Gibson	PSI Energy	IN	21,447,979.54	232
5	Martin Lake	TXU	TX	21,301,393.26	44
6	W A Parish	NRG Energy	TX	21,076,082.00	166
7	Rockport	American Electric Power	IN	20,181,544.90	208
8	Navajo	Salt River Project	AZ	20,071,580.51	75
9	Cumberland	Tennessee Valley	TN	19,049,067.53	194
10	John E Amos	Appalachian Power	WV	18,798,260.98	240
11	Monticello	TXU	TX	18,268,348.39	37
12	Colstrip	PP&L Montana	MT	18,240,485.45	26
13	Sherburne County	Northern States Power	MN	18,003,647.95	2
14	Labadie	Ameren- Union Electric	MO	17,458,154.23	236
15	Monroe	Detroit Edison	MI	[illegible]	223
16	Bruce Mansfield	First Energy Company	PA	17,375,622.88	243
17	Gen J M Gavin	Ohio Power	OH	16,997,448.75	189
18	Four Corners	[illegible]	NM	[illegible]	[illegible]
19	Jeffrey Energy	[illegible]	KS	[illegible]	[illegible]
20	Intermountain	Los Angeles (City of)	UT	16,035,530.05	104
21	Crystal River	Progress Energy Florida	FL	16,026,757.78	268
22	[illegible]	[illegible]	WY	[illegible]	[illegible]
23	[illegible]	[illegible]	OH	[illegible]	[illegible]
24	Paradise	[illegible]	KY	[illegible]	[illegible]
25	[illegible]	[illegible]	WY	[illegible]	[illegible]
26	Roxboro	Progress Energy	NC	[illegible]	[illegible]
27	[illegible]	[illegible]	LA	[illegible]	[illegible]
28	Belews Creek	Duke Energy Corp	NC	[illegible]	[illegible]
29	Conemaugh	Reliant Energy NE	PA	[illegible]	[illegible]
30	J M Stuart	Dayton Power & Light	OH	[illegible]	[illegible]
31	[illegible]	[illegible]	GA	[illegible]	[illegible]
32	Harrison Power	Allegheny Energy	WV	13,450,027.47	219
33	Baldwin Energy	Dynegy Midwest	IL	13,250,175.41	159
34	Limestone	NRG Texas	TX	13,055,769.41	184
35	San Juan	Public Service Co of NM	NM	13,054,091.35	160
36	Ghent	Kentucky Utilities Co	KY	12,933,317.73	150
37	Petersburg	Indianapolis Power & Light	IN	12,826,618.08	77
38	Independence	Entergy Arkansas	AR	12,485,093.55	67
39	Mount Storm	Dominion Virginia Power	WV	12,464,709.03	154
40	Barry	Southern/Alabama Power	AL	12,449,918.39	259
41	E C Gaston	Southern/Alabama Power	AL	12,345,694.83	124
42	Keystone	Reliant Energy NE	PA	12,271,116.40	226
43	Homer City	Midwest Generations	PA	11,970,801.97	218
44	R M Schahfer	Northern Indiana	IN	11,850,737.46	31
45	Big Bend	Tampa Electric Company	FL	11,760,766.40	21
46	Marshall	Duke Energy Corp	NC	11,425,787.60	257
47	Craig	Tri-State G & T Assn Inc	CO	11,322,684.57	66
48	Gerald Gentleman	Nebraska Public Power	NE	11,192,809.15	50
49	Sam Seymour	Lower CO River	TX	11,191,253.23	96
50	Coal Creek	Great River Energy	ND	11,094,477.64	7
Total				781,850,370.49 tons	

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Power Systems Development Facility

Overview

The Power System Development Facility (PSDF) is a key national asset for ensuring continued, cost-effective, environmentally acceptable energy production from coal. It is a joint effort of the DOE National Energy Technology Laboratory and several of the world's leading energy technology and supply companies. Current participants include Southern Company, Electric Power Research Institute, KBR, Siemens Power Generation, Burlington Northern Santa Fe Railway, Lignite Energy Council, and Peabody Energy.

DOE conceived the PSDF as the premier advanced coal power generation R&D facility of the world, and work there thus far has fulfilled this expectation. DOE's vision is that: "The Wilsonville PSDF will serve as the proving ground for many new Advanced Power Systems. The Wilsonville PSDF gives U.S. industry the world's most cost-effective flexible test center for testing tomorrow's coal-based power-generating equipment. Capable of operating at pilot to near-demonstration scales, the facility is large enough to give industry real-life data, yet small enough to be cost-effective and adaptable to a variety of industry needs." A key feature of the PSDF is its ability to test new systems at an integrated, semi-commercial scale. Integrated operation allows understanding of the effects of system interactions that are typically missed in nonintegrated pilot-scale testing. This significantly advances commercial development of the proposed technology. The semi-commercial scale at the PSDF also allows the maintenance, safety, and reliability issues of a technology to be investigated at a fraction of the cost of testing at commercial scale.

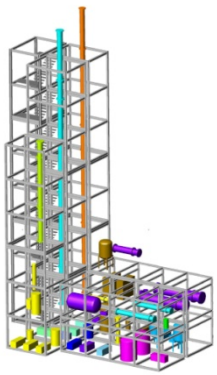
PSDF Accomplishments

The PSDF has developed testing and technology transfer relationships with many vendors to ensure that test results and improvements developed at the PSDF are incorporated into future plants. Major subsystems tested and some highlights of the test program at the PSDF include:

- ***Transport Reactor:*** The Transport Reactor has operated successfully as a pressurized combustor and as a gasifier in both oxygen- and air-blown modes. Several types of coals have been tested in gasification operation including subbituminous, bituminous, and lignite coals. The Transport Gasifier is projected to be the lowest capital cost coal-based power generation option, while providing the lowest cost of electricity and excellent environmental performance.
- ***Advanced Particulate Control:*** Advanced hot gas particulate filtration with more than 30 different filter elements types has been tested. Material property testing on filter elements is routinely conducted to assess their suitability for long-term operation. Cooperative work with filter vendors has advanced the technology and aided in identifying commercially suitable materials and designs.
- ***Filter Failsafe Device:*** To enhance filter system reliability and protect downstream components, "failsafe" devices that reliably seal off failed filter elements have been successfully developed.
- ***Coal Feed and Ash Removal Systems:*** Reliable operation of the coal feed system and the ash removal systems has been achieved. Modifications developed at the PSDF and shared with the equipment supplier allow current coal feed equipment to perform in a commercially acceptable manner. Innovative, continuous processes for course ash removal from the gasifier and fine ash removal from the particulate filter system were developed at the PSDF and implemented with remarkable results.
- ***Syngas Cooler:*** Syngas cooler operation is now routine and reliable. Material testing has aided in the selection of cooler inlet erosion inhibiter material with excellent, long-term performance.
- ***Syngas Cleanup:*** A slip-stream syngas cleanup train was constructed and has proven capable of meeting stringent syngas decontamination requirements. This module provides an ultra-clean slip stream, and is now available for testing a wide variety of technologies

Goals of PSDF CO_2 Capture Development Program

- Offer a unique flexible testing facility where processes can be tested on coal derived gas at various scales
- Serve as a technology development facilitator by providing facilities for the scale-up from bench-top to engineering-scale
- Solicit and incorporate activities and projects from a wide variety of participants and partners. Find "Best-in-class" Technology.
- Deliver innovation through a cross-cutting, collaborative project portfolio that provides an accelerated pathway to cost-effective CO_2 capture technology for coal fueled power production



PSDF links DOE's Coal Power R&D Program to the Commercial Market

CCPI Technology Demonstrations

Core R&D Technology Development Activities*

PSDF Component Testing & Evaluation

Clean Coal Technology Commercial Market

Facilitate / Accelerate Technology Development

* *Carbon Sequestration Roadmap*
- *Post-Combustion*
  - *Chemical / Physical Solvents*
  - *Chemical / Physical Sorbents*
  - *CO2 / H2 Membranes*
- *Pre-Combustion*
  - *Chemical / Physical Solvents*
  - *Metal Organic Frameworks*
  - *Membranes*

* *Gas Clean-up*
  - *Mercury Sorbents*

* *Advanced Generation*
  - *Fuel Cells*
  - *Biomass Gasification*

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CO_2 Capture effort is similar to other major technology programs (e.g. SCR)...

Concept 1986	Proposal 1987	Pilot Plant Design, Construction and Operation at Plant Crist 1990- 1996	First Commercial SCR Unit SEI's Birchwood Plant 1998	Commercial SCR Deployment, 2001 - present

SCRs

10,110 MW

Bowen 1-4, Gaston 5, Gorgas 10, Miller 1-4, Hammond 4, Wansley 1, 2, Crist 7

1,518 MW

Barry 5, Scherer 3

1,600+ MW

Scherer 1,2

Clean Coal Technology Demonstration Program
Environmental Control Devices
NO_x Control Technologies

Demonstration of Selective Catalytic Reduction Technology for the Control of NO_x Emissions from High-Sulfur, Coal-Fired Boilers

Project completed

Participant
Southern Company Services, Inc.

Additional Team Members
Electric Power Research Institute—cofunder
Ontario Hydro—cofunder
Gulf Power Company—host

Location
Pensacola, Escambia County, FL (Gulf Power Company's Plant Crist, Unit No. 5)

Technology
Selective catalytic reduction (SCR)

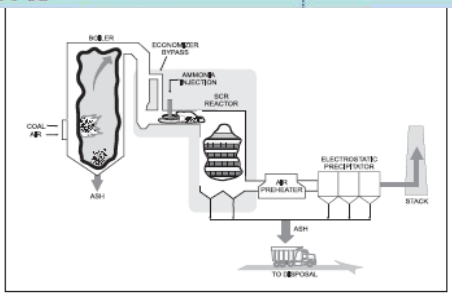
Plant Capacity/Production
8.7-MWe equivalent (three 2.5-MWe and six 0.2-MWe equivalent SCR reactor plants)

Coal
Illinois bituminous, 2.7% sulfur

Project Funding

Total	$23,229,729	100%
DOE	9,405,673	40
Participant	13,823,056	60

Project Objective
To evaluate the performance of commercially available SCR catalysts when applied to operating conditions found in U.S. pulverized coal-fired utility boilers using high-

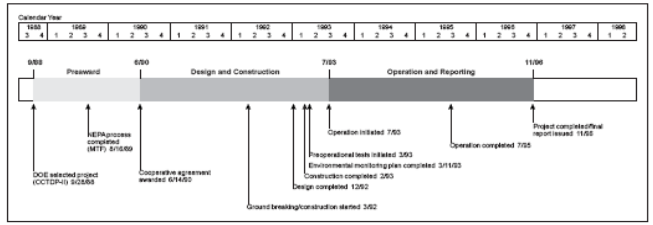


sulfur U.S. coal under various ope
achieving as much as 80% NO_x re

Technology/Project Descriptio

The SCR technology consists of in
boiler flue gas and passing it throu
the NO_x and ammonia react to form
vapor.

In this demonstration project, the S
three 2.5-MWe equivalent SCR rea
nate 5,000-scfm flue gas slipstream
equivalent SCR reactors. These rea
be large enough to produce design
SCR process to be scaled up to com
suppliers (two U.S., two European,
provided eight catalysts with various
compositions for evaluation of proc
nomics of operation during the dem



Results Summary

Environmental

- NO_x reductions of over 80 percent were achieved at an ammonia slip well under the 5 ppm deemed acceptable for commercial operation.
- For most catalysts, flow rates could be increased to 150 percent of design without exceeding the ammonia slip design level of 5 ppm at 80 percent NO_x reduction.
- While catalyst performance increased above 700 °F, the benefit did not outweigh the heat rate penalties.
- Ammonia slip, a sign of catalyst deactivation, went from less than 1 ppm to approximately 3 ppm over the nearly 12,000 hours of operation, thus demonstrating that deactivation in coal-fired units was in line with worldwide experience.
- Long-term testing showed that SO_2 oxidation was within or below the design limits necessary to protect downstream equipment.

Operational

- Fouling of catalysts was controlled by adequate soot-blowing procedures.
- Long-term testing showed that catalyst erosion was not a problem once sootblowing procedures were adopted.
- Air preheater performance was degraded because of ammonia slip and subsequent by-product formation; however, solutions were identified.
- The SCR process did not significantly affect the results of Toxicity Characteristic Leaching Procedure (TCLP) analysis of the fly ash.

Economic

- Levelized costs on a 30-year basis for a 250-MWe unit, with a SCR inlet NO_x concentration of 0.35 lb/10^6 Btu, were 2.39, 2.57, and 2.79 mills/kWh (constant 1998$) for 40, 60, and 80 percent removal efficiency, respectively, which equates to 3,502; 2,500; and 2,036 $/ton (constant 1998$), respectively.

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EPRI Study: Post-Combustion Technologies

Summary

- No breakthrough technologies (~10% energy penalty)
- Process developers continuing to make improvements, but at increasing complexity of process
- Few process developers have power plant knowledge
- Even fewer material scientists and synthesis chemists have process engineering or power plant knowledge
- Breakthroughs likely to require combination of expertise in
  - Power plant
  - Process engineering
  - Materials science and chemistry

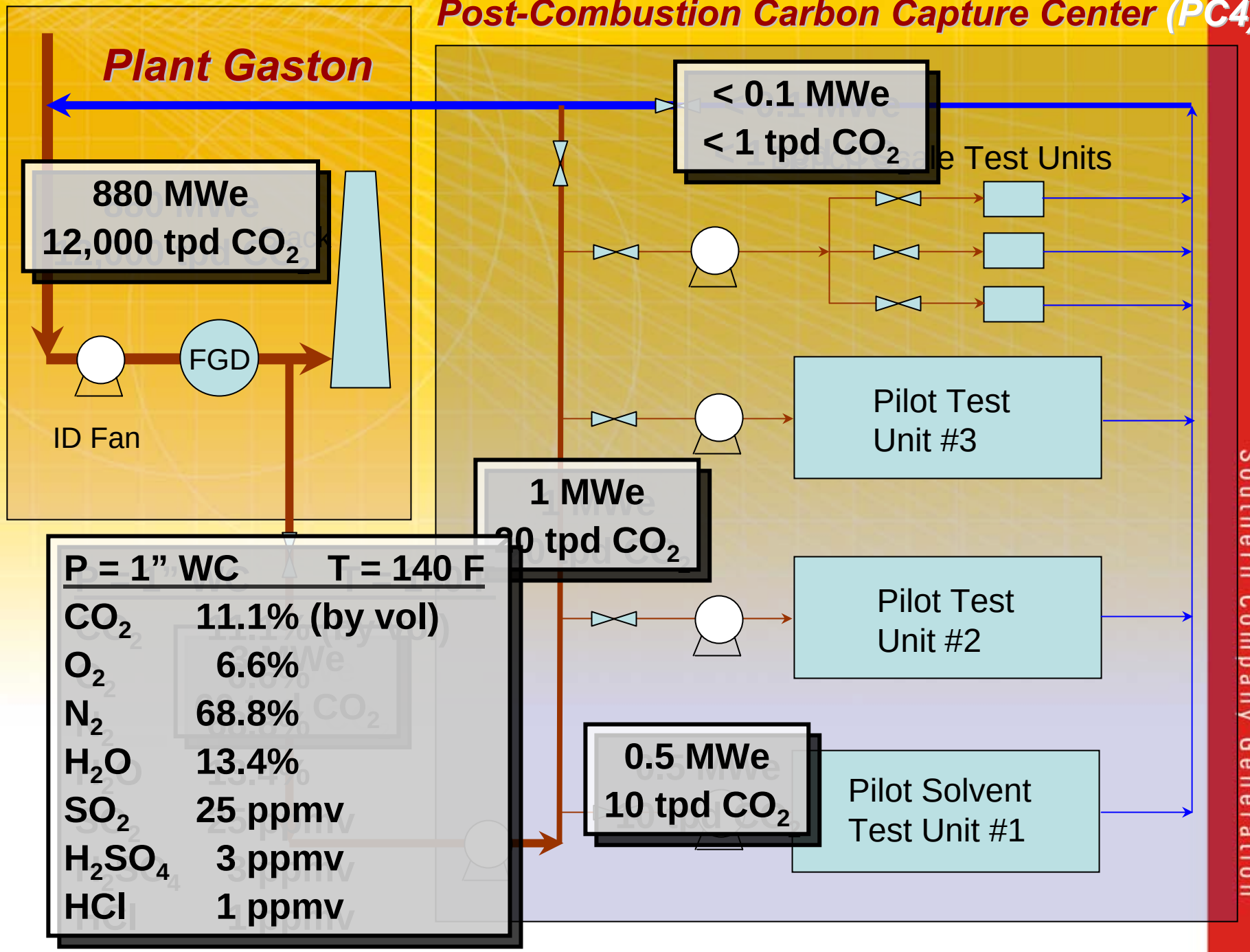
EPRI ELECTRIC POWER RESEARCH INSTITUTE

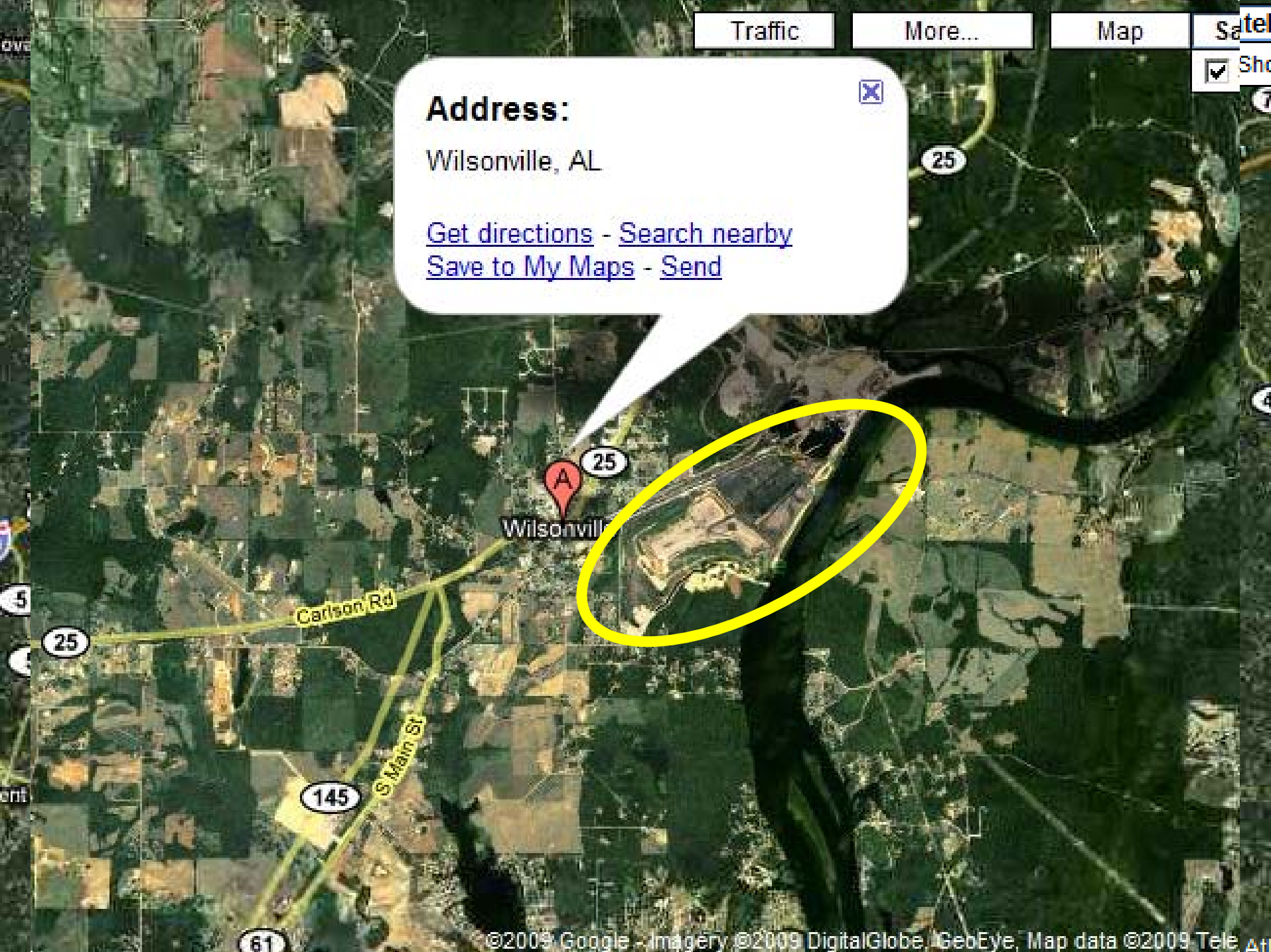
Carbon Capture Technology Development at PSDF

1. Post-combustion (Pulv. Coal)

2. Pre-combustion (IGCC)

Post-Combustion Carbon Capture Center (PC4)

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Alabama Power Plant E.C. Gaston
Wilsonville, Alabama

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E.C.Gaston

Post-Combustion Carbon Capture Center (PC4)

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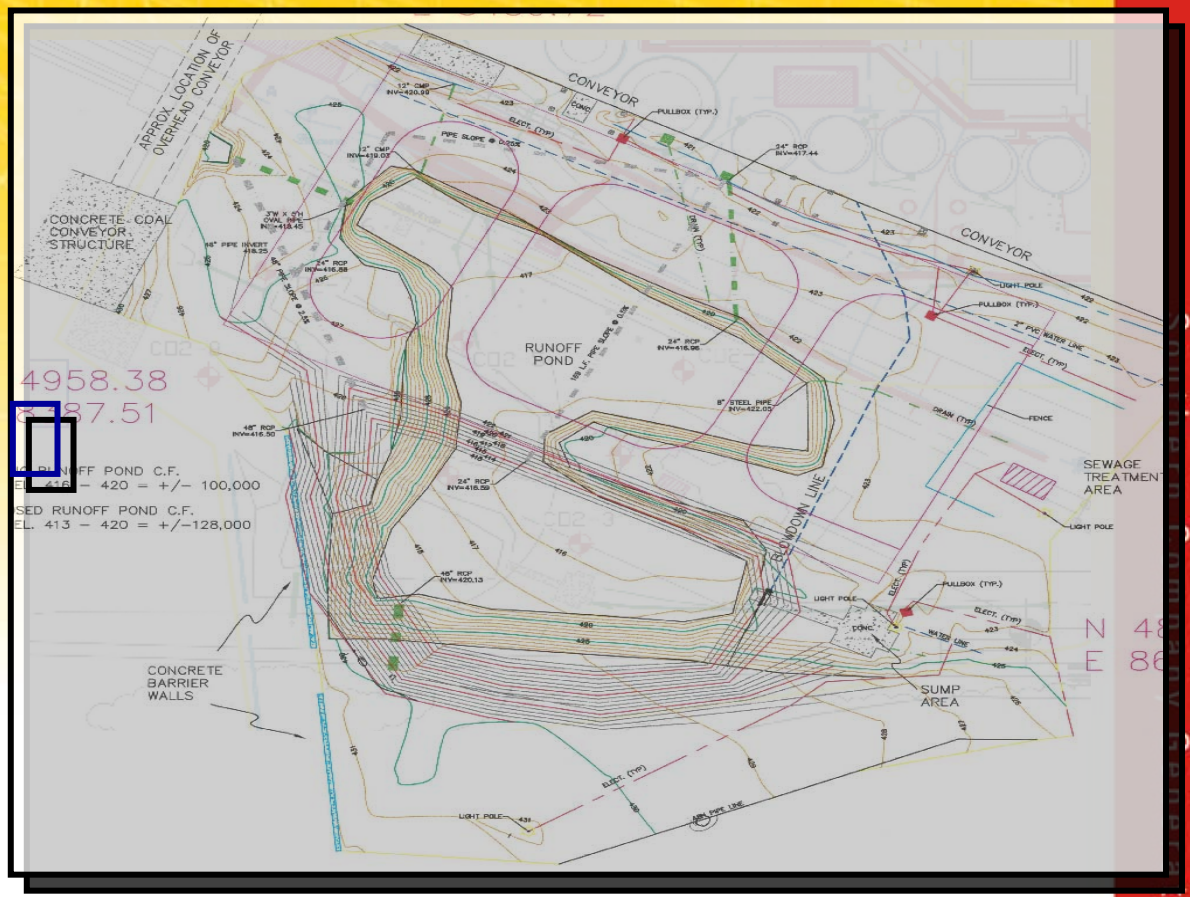
Status of PSDF PC4

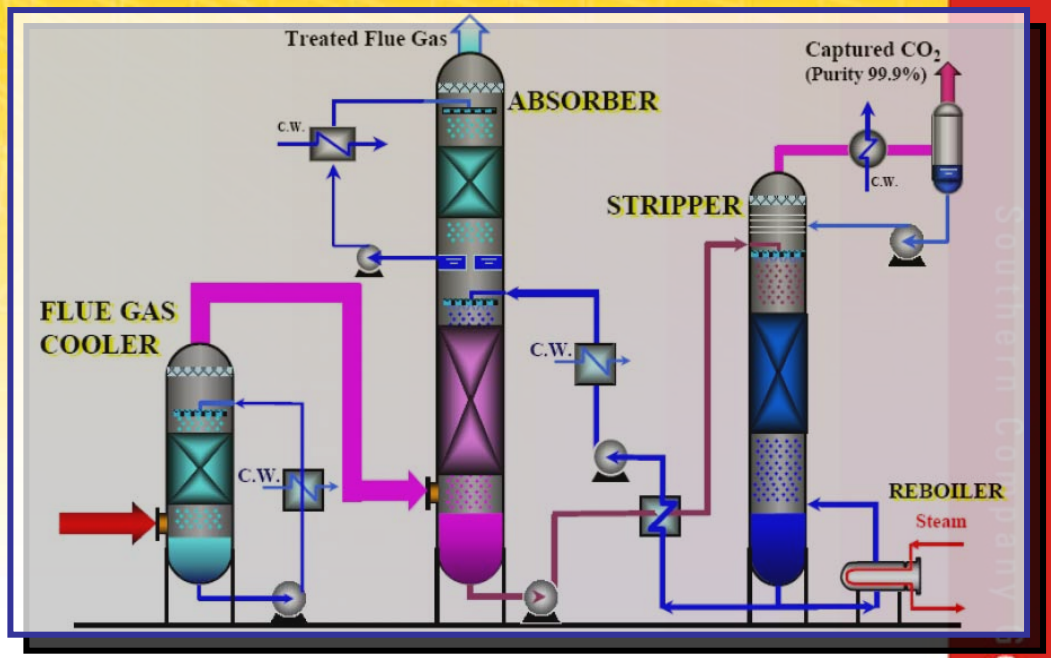
Civil Engineering

- **Initial site surveying & soil sampling completed**
- **Identification and relocation of underground piping & conduit**
- **Site preparation design started, including retention pond**
- **Second survey under way**

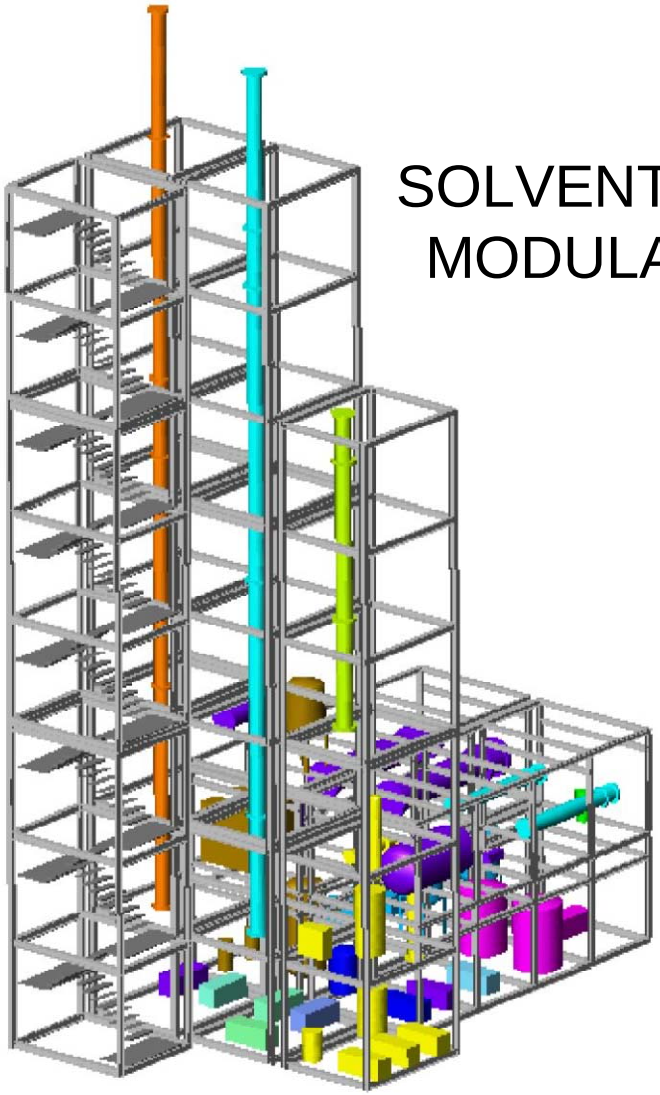


Status of PSDF PC4
Process Engineering

- Infrastructure
  - Heat and Material Balances updated with input from Pilot Solvent Test Unit H&MB
  - Water Requirements finalized (quality, quantity and sources)
- Pilot Solvent Test Unit
  - Heat and Material Balances completed for base case solvent
  - Process Flow Diagram (PFD) complete
  - Equipment sizing of heat exchangers and tanks underway



Pilot Solvent Test Unit Modular Design



SOLVENT TEST UNIT
MODULAR DESIGN

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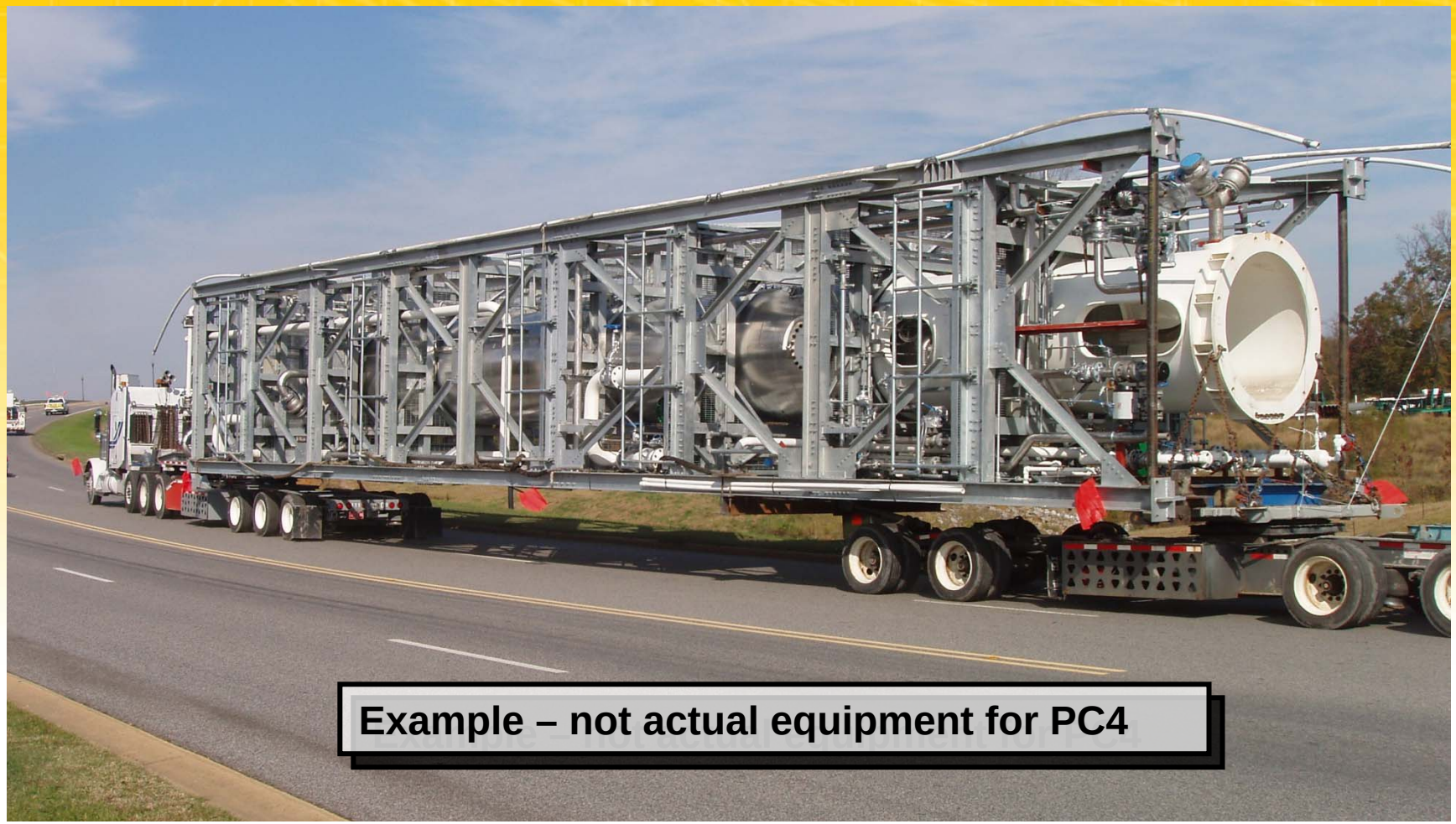
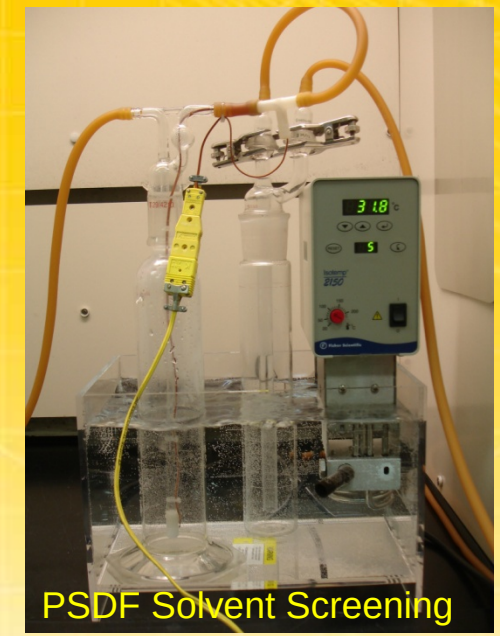
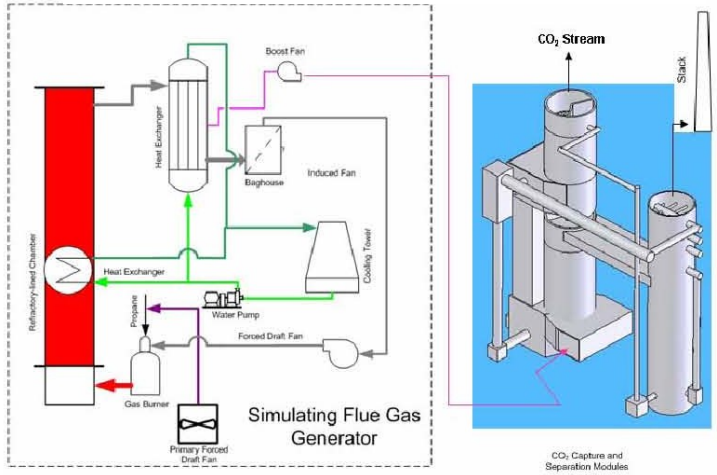
Pilot Solvent Test Unit - Delivery



A wide range of Solvents and Additives will be explored



Univ of Kentucky Solvent Screening



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

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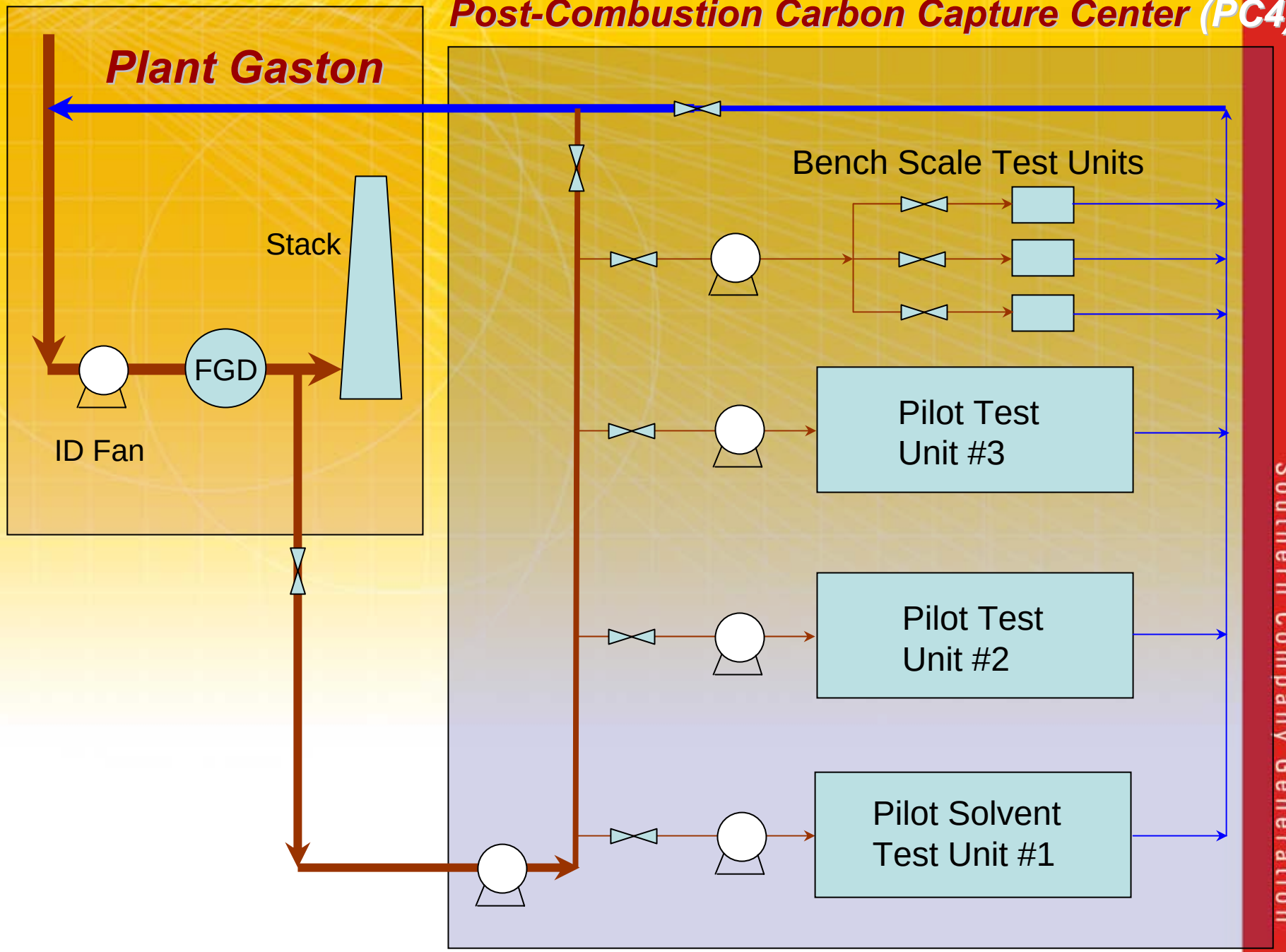
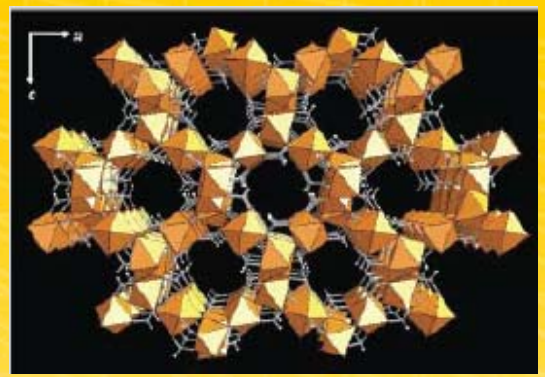
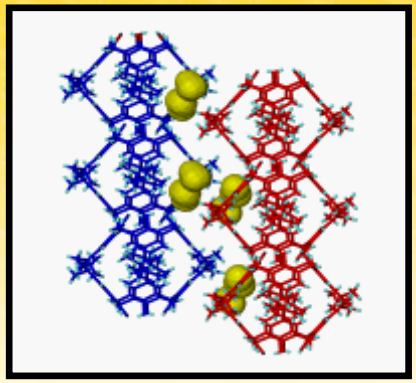
Post-Combustion Carbon Capture Center (PC4)



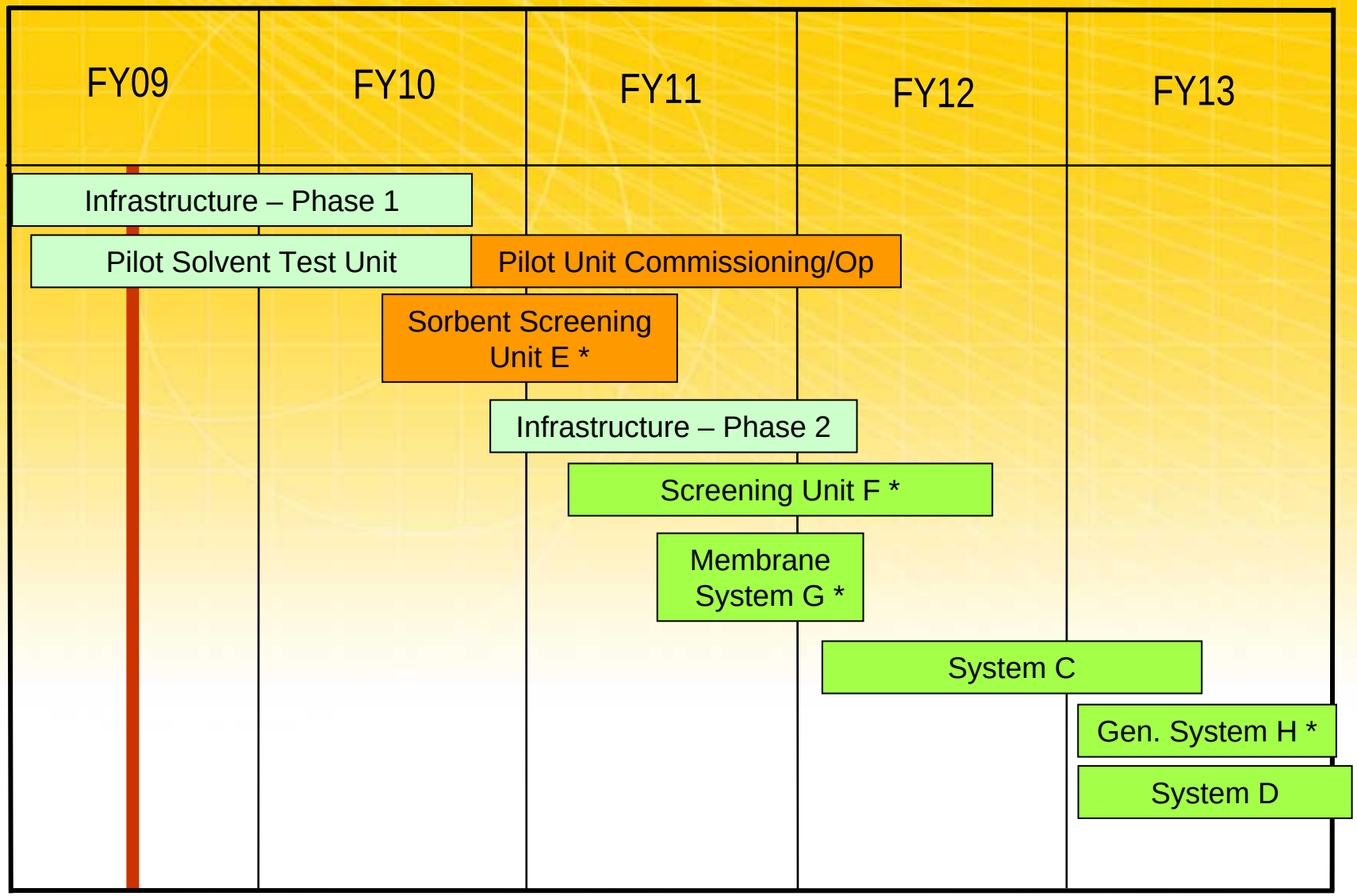
ADA Sorbent Screening

- **ADA focus: Assess the viability and accelerate development of solid-sorbent based capture technology PC plants**
- **Sorbent screening with EPRI and DOE funding. Successful bench scale testing and designing pilot scale.**
- **PSDF designed contactor for pilot plant.**
- **Will test at PC plants before moving to PC4 in 2010.**





Post-Combustion (PC_4) Schedule



**** Bench scale, ≤ 1000 pph flue gas***

Summary Carbon Capture Research at PSDF

- PSFD is a unique test bed for technology development
  - Combines knowledge of power plants with process engineering
  - Operations mindset enables utilities to be informed buyers
  - Multiple supplier options for utilities
- Syngas and flue gas available at same site
- Leverage assets – existing infrastructure and staff, DOE Fossil Energy Program
- Accelerate CO_2 capture technology commercialization