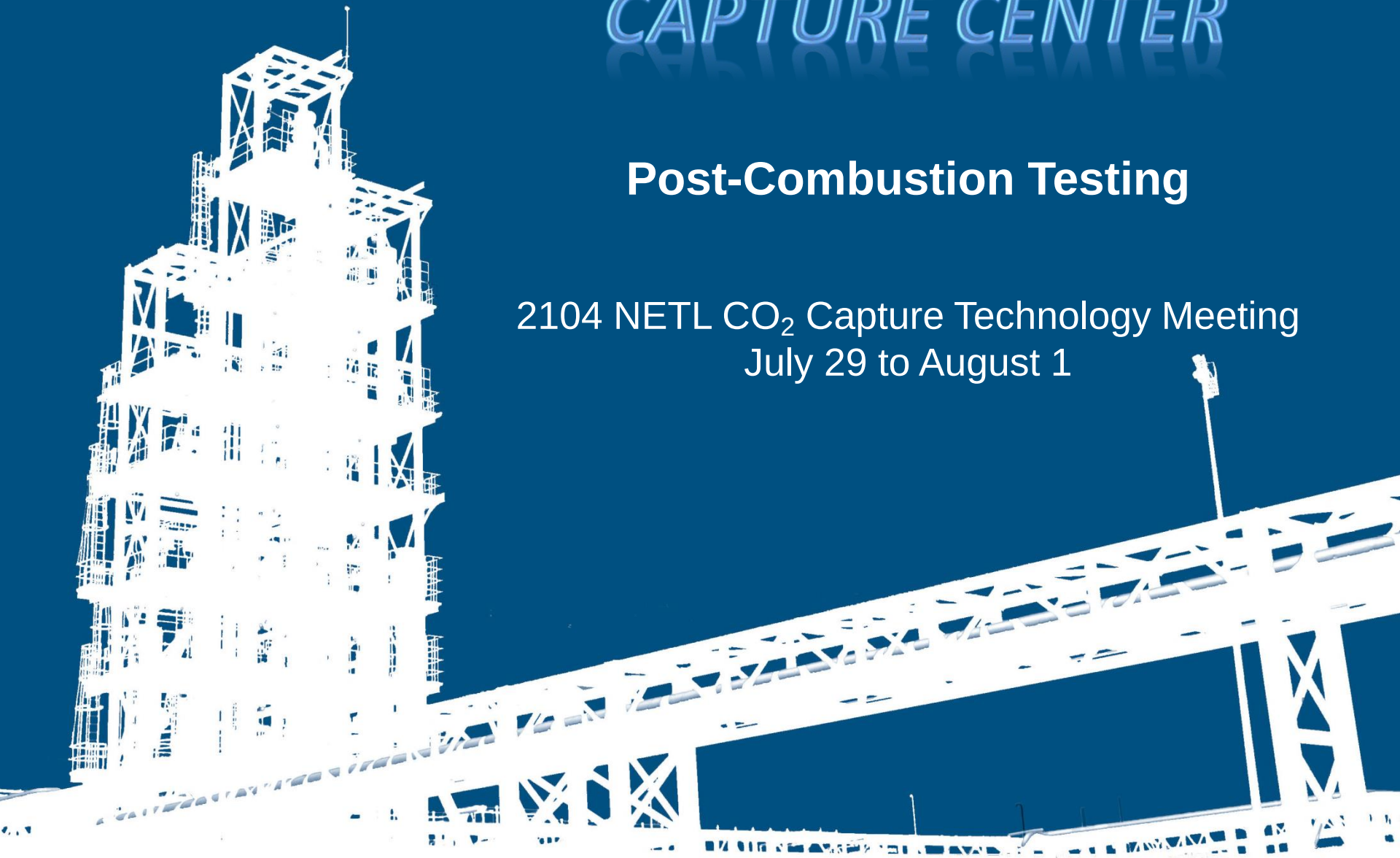
NATIONAL CARBON CAPTURE CENTER



Post-Combustion Testing

2104 NETL CO_2 Capture Technology Meeting
July 29 to August 1

U.S. Department of Energy

National Carbon Capture Center

at the Power Systems Development Facility

Managed by Southern Company Services, Inc.

Performance Period for DE-FE0022596: 5/01/2014 to 04/30/2019

DOE funding $150M with $38M industrial cost share

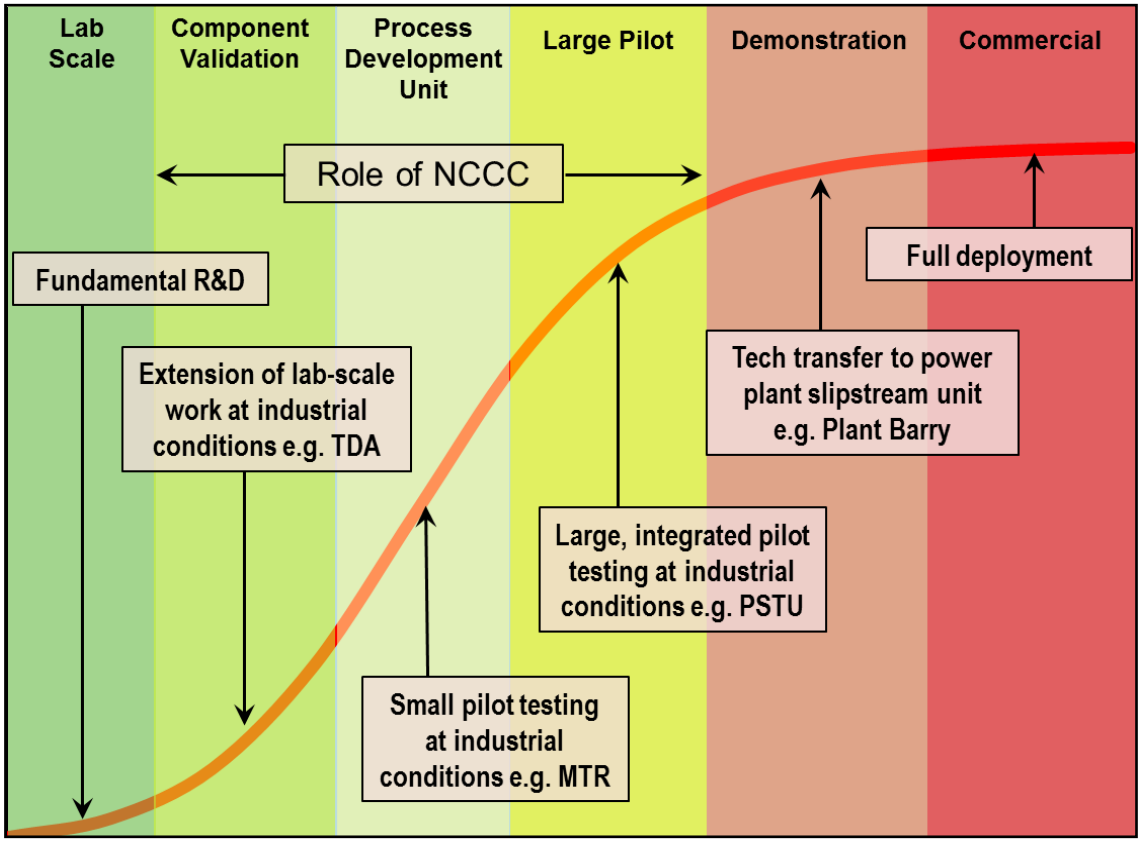
DOE Project Manager Mike Mosser

Role of NCCC in CO_2 Capture Technology Development

First-class facilities to test developer's technologies for extended periods under commercially representative conditions with coal-derived flue gas and syngas. Simultaneous testing at a range of sizes to accelerate development of cost-effective technologies.

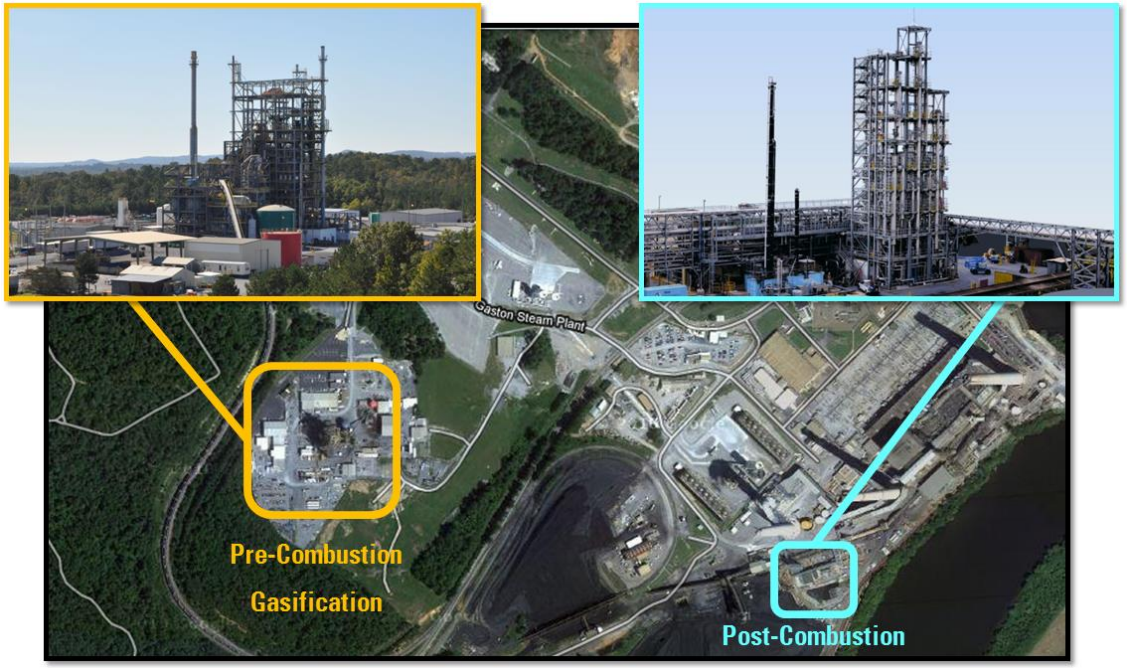
- Supports transition from lab to commercial environment.
- Full support for testing of developer's technology.
- Experienced operators and maintenance staff.
- Comprehensive data collection and analysis capability.
- Local access to advanced analytical techniques.
- Flexible facilities for scale-up from bench- to pilot-scale.

Testing support to advance developer's technologies is top priority.



Progression of a Technology with Time

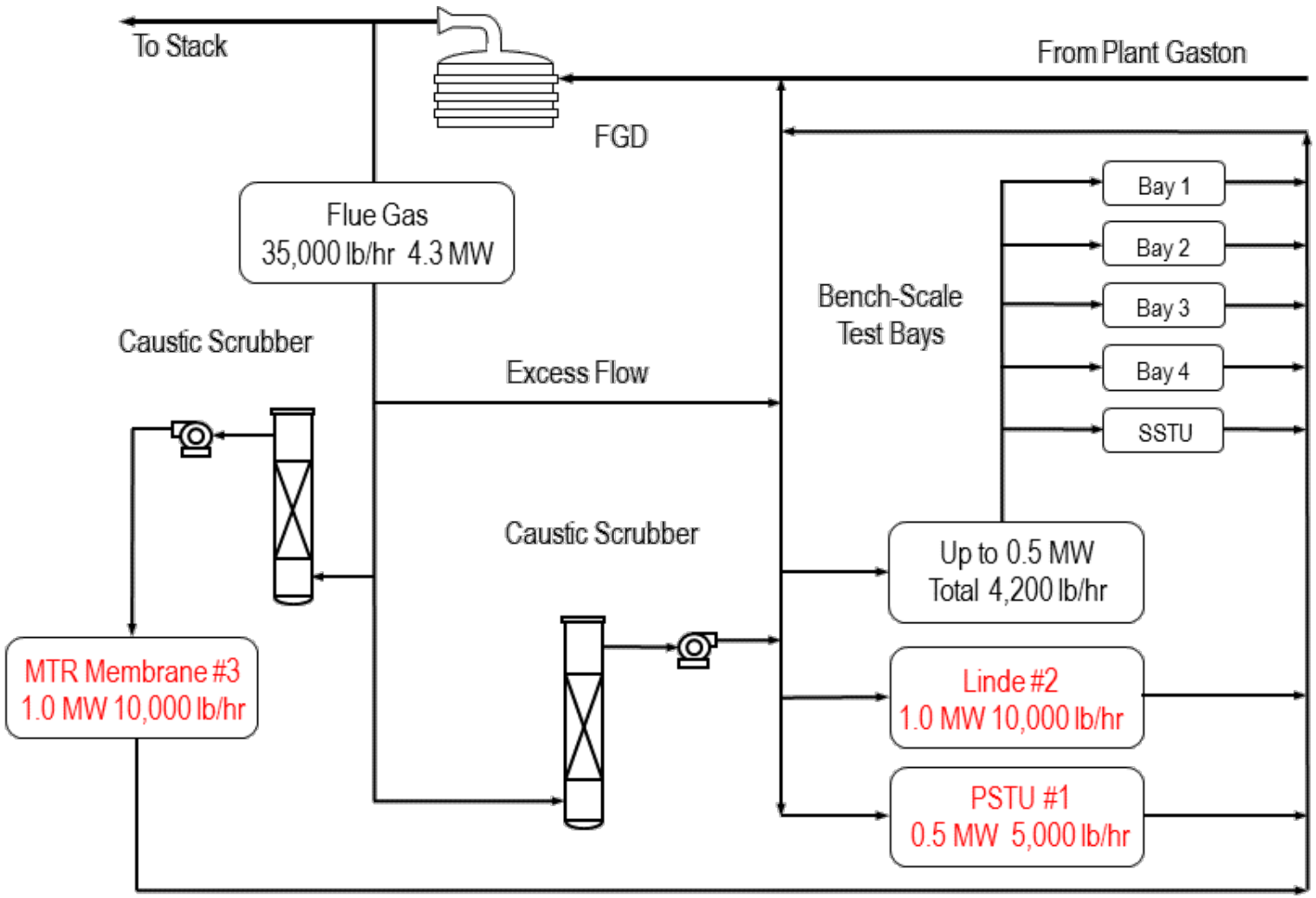
National Carbon Capture Center



- Located in Wilsonville AL, 30 miles S-E of Birmingham.

- Gasification and pre-combustion CO_2 capture testing carried out at Power Systems Development Facility: in service since 1996.
- Post-combustion CO_2 capture testing carried out at Post-Combustion Carbon Capture Center (PC4) located at Alabama Power's Plant Gaston: in service since 2011.
- Base-loaded, 900-MW supercritical unit with SCR and wet FGD firing medium-sulfur bituminous coal providing a commercially representative flue gas slipstream to PC4.

Equipment Layout for PC4



Infrastructure recently expanded to meet demand for testing

Pilot-Scale Test Bays at PC4

PC4 Site Preparation October 2010

PC4 June 2014

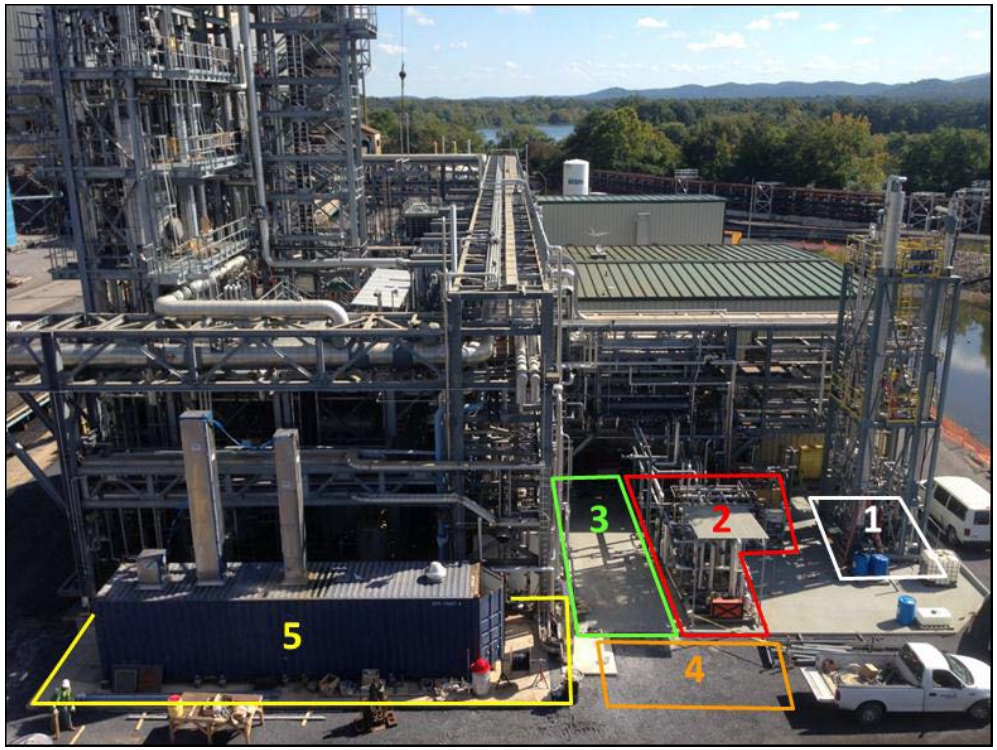
Current Occupants

1. 0.5-MW PSTU (solvent)
2. 1.0-MW Linde (solvent)
3. 1.0-MW MTR (membrane)

Once testing complete, other developers accommodated

Each Bay complete with foundations, services, and gas connections to accept future technologies with limited modification.

Bench-Scale Test Bays at PC4



Current occupants

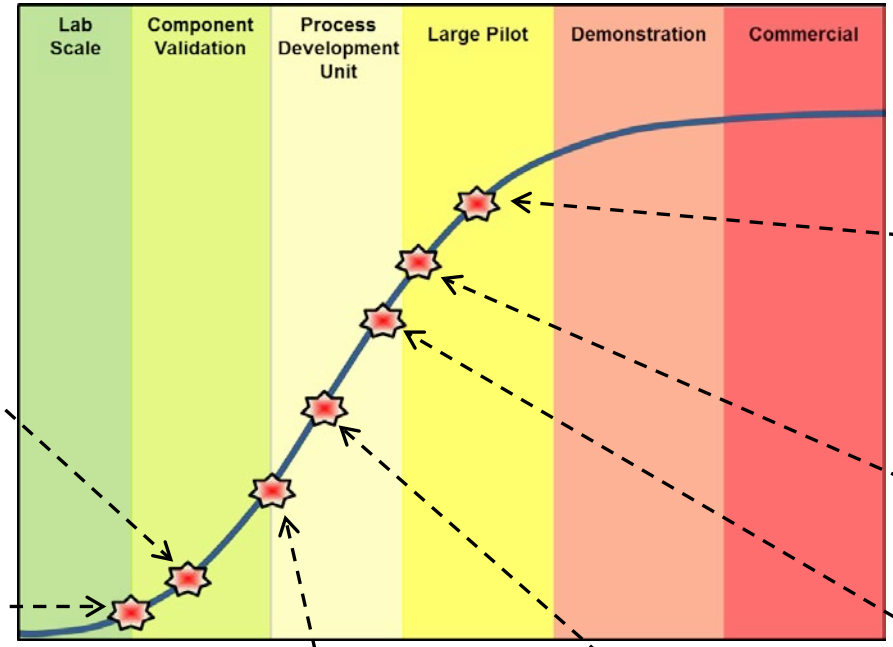
1. Akermin (solvent); to be modified for testing first half 2015 with new solvent.
2. MTR (membrane). Near end of program; provided valuable data to support design of 1-MW unit.
3. SRI International (sorbent): in progress
4. DOE (sorbent): in progress
5. Slipstream Test Unit (SSTU) (solvent): being completed ready for testing first half 2015.

Once testing complete, other developers accommodated

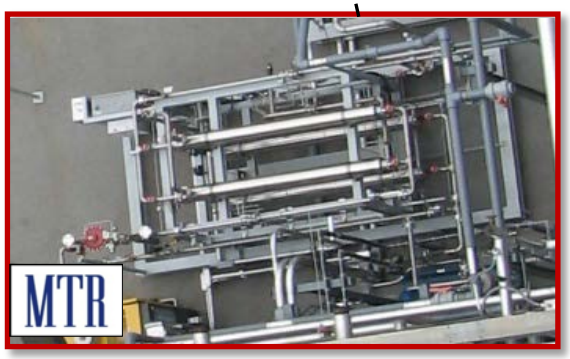
For PC4 test bays, in typical three-month period flue gas available for 1750 hours, allowing a lot of data to be collected in short period of time.

Progression Along Technology Time Line

Enzymes

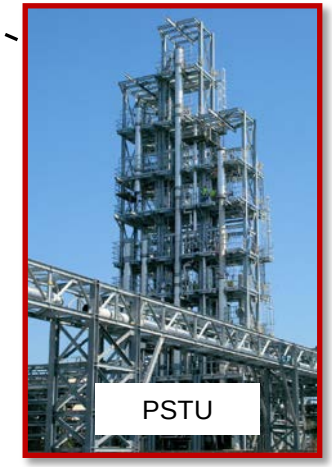


Solvent & membrane



Membranes

Sorbents

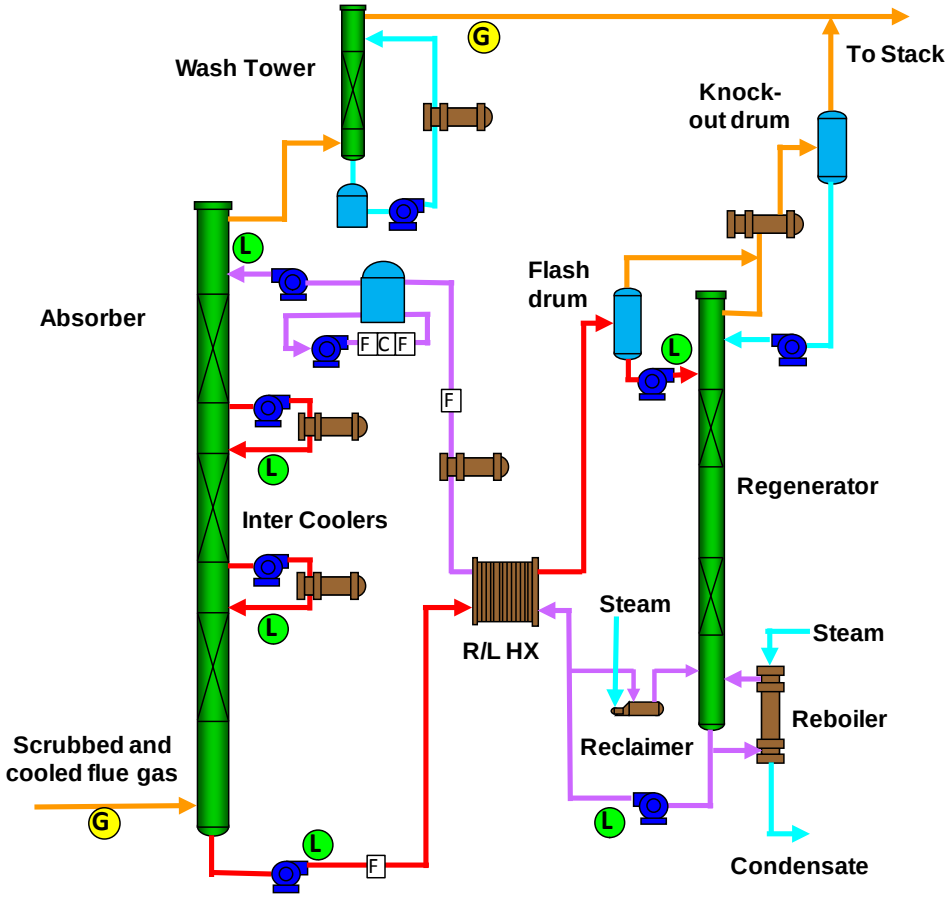


Solvents

Example of Scale-Up Support Provided by NCCC

Data collected and lessons learned on MTR's 500 lb/hr flue gas bench-scale membrane used to support design and equipment selections of 10,000 lb/hr pilot-scale membrane.

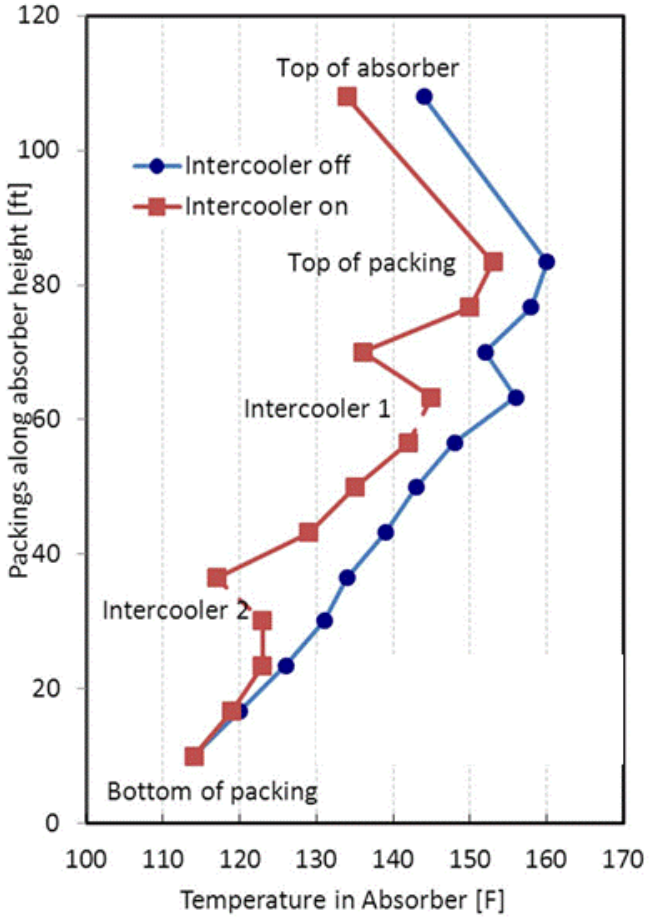
Pilot Solvent Test Unit



- Solvents from six developers, plus MEA, tested some with diluted coal-derived flue gas to mimic NGCC flue gas
  - High quality data collected with mass balance closures better than ±3 percent
  - Monoethanolamine (MEA) heat of regeneration with 7°F approach temperature ~1550 Btu/lb
  - Solvent tested with heat of regeneration as low as ~900 Btu/lb, 40 percent lower.
  - Lower values possible with improved heat integration (CCSI modeling)
  - Close to achieving Clean Coal Research Program 2020-2025 objective of lowering cost of CO_2 capture to $40/tonne.

- MEA data supporting DOE's CO_2 Capture Simulation Initiative (CCSI) modeling activity
- Investigation of performance aspects of value to end users: solvent emissions, ash accumulation, instrumentation testing.

Wide Range of Data Collected



Operation with intercoolers raised capture efficiency 6 percentage points (90 to 96%)

- PSTU can gather solvent density, viscosity, and specific heat data for a range of CO_2 loadings to validate and/or expand physical property database.

- Coupons installed throughout the PSTU to assess how corrosion rates of different materials vary with location.

Issues Revealed by PC4 Testing

- MEA emissions from the PSTU as high as 500 ppmv (5.7 lb/hr)
  - Emissions predicted to be less than 3 ppmv
  - SO_3 aerosol present in flue gas leaving Gaston FGD responsible
  - All amine solvents had similar experience but not potassium carbonate
  - Increases solvent make up rate, may infringe emission limits
  - Cost effective approaches to reduce amine emissions from absorber required.
- Although flue gas low in metals content, they accumulate in solvent
  - Selenium exceeds RCRA limit: rate of accumulation will be reduced for plants meeting new Mercury and Air Toxics Standards
  - Anions (sulfate, nitrate, and chloride) also present in addition to solvent degradation products (e.g. aldehydes and ammonia)
  - Economic cleanup for optimal solvent and plant performance required.
- SO_3 (present as ammonium sulfate/bisulfite) resulted in deposits forming in outlet of 0.05-MW MTR flue gas compressor.
  - Resulted in changes to 1-MW membrane design

Results emphasize benefits of testing with commercially representative flue gases

Tests Completed or Planned at PC4 Pilot Bays

PSTU	Pilot Bays 2 & 3
Completed or in progress	
MEA Baseline	Aker Clean Carbon
Babcock & Wilcox Opticap	Linde solvent (*)
MEA solvent carry over	MTR membrane (*)
Hitachi H3-1	
Cansolv 201 (12% CO_2)	
Chiyoda T-3	
Cansolv 201 (4% CO_2)	
Clean Carbon Solutions	
Cansolv 103	
Planned (not necessarily confirmed)	
Univ. Texas Austin (*)	Air Liquide membrane (*)
MEA Sampling Techniques	SRI sorbent (*)
GE Global Research (*)	

(*) presenting at this meeting

Tests Completed or Planned at PC4 Bench-Scale Bays

Completed or in progress
Codexis enzyme
MTR membrane (*)
Akermin enzyme (*)
SRI sorbent (*)
NETL sorbent (*)
Planned (not necessarily confirmed)
Carbon Capture Scientific (*)
Sustainable Energy Solutions
Akermin Advanced Process (*)
TDA Research sorbent (*)
SSTU for novel solvents

(*) presenting at this meeting

Closing Comments

- 17 test campaigns completed or in progress at PC4 with over 24,000 data collection hours using 50 to 10,000 lb/hr of flue gas
  - In service just over three years: cost-effective testing and data collection
  - Supporting scale up from bench- to pilot-scale, advancing technologies along the developmental time line
  - Several other developers are scheduled to test their technologies.
- An advanced solvent has been tested on the PSTU with a regeneration energy 40% lower than that of 30-wt% MEA
  - Close to achieving Clean Coal Research Program 2020-2025 objective of lowering cost of CO_2 capture to $40/tonne.
- Need to continue identifying improved technologies that lower the cost of CO_2 capture and satisfy Clean Coal Research Program 2030-2035 objectives
  - NCCC will continue to support developers in advancing commercialization of their technologies in pursuit of this goal.