National Carbon Capture Center

FE002256

Frank Morton

DOE NCCC

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15 - 19, 2022

National Carbon Capture Center

- **Sponsors:** U.S. Department of Energy and its National Energy Technology Laboratory
  - DOE's primary carbon capture research facility since 2009
- **Partners:** Electric Power Research Institute, power/energy industry leaders
- **Managed/operated by:** Southern Company
- **Location:** Wilsonville, Alabama
- **Infrastructure:** Real-world power plant operating conditions – coal and natural gas
- **Expertise:** Technical staff for design, installation, testing support and analysis
- **International collaboration:** Co-founder of International Test Center Network

Test Centers – Evolving Goals

- Cost-effective host site for moving carbon capture development from lab to industrial setting
- Knowledge sharing of public information
- Contribute to partnerships for commercial technology development
- Support deployment
  - Provide scale-up information
  - Cost-effective testing of novel ideas to improve commercial process
- Support net-negative carbon goals
  - Support transition: fossil fuel use to low- or zero-carbon options (flexible operation, high capture rate)
  - CO_2 utilization and direct air capture at the NCCC

NCCC

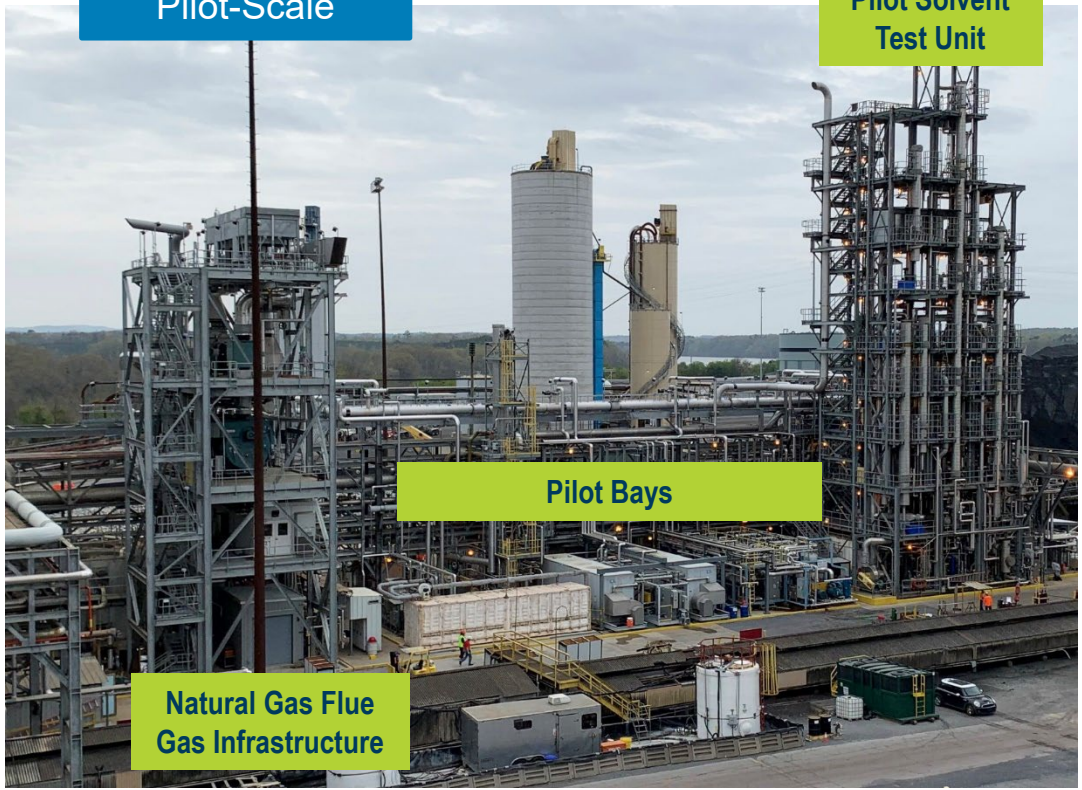
Pilot-Scale

Bench-Scale

Lab-Scale

Test Bays and Equipment

Pilot-Scale



Slipstream Solvent Test Unit

Bench-Scale Area

Lab-Scale Test Unit

Major Accomplishments and Scope

- 129,000+ hours of testing since 2009
- 70+ technologies / developers from 7 countries
- Continuous expansion – alternative regeneration, gas injection, analytical support
- Flexibility for testing at multiple scales & on-site scale-ups
- Accelerated technology development
  - 16+ technologies in queue to test
  - Multiple technologies progressed to FEED studies
  - 8 technologies scaled up (or ready) to 10+ MW
  - CO_2 concrete technology announced commercialization

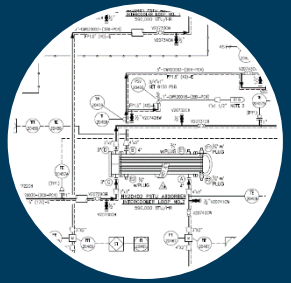
Reduced cost of CO_2 capture from fossil generation by 40%

Oct. 1, 2020 – 5-Year Agreement Renewal / $140 Million
Expanding scope to CO_2 capture for natural gas power, CO_2 utilization, direct air capture

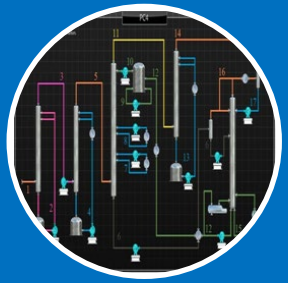
Project Development and Implementation

Safety First

Contract
- Screening
- NDA/TCA
- Onboarding



Project Scope
- Process
- Modification
- Integration



Design
- Mechanical
- Instrument
- Control
- Electrical
- Civil

Construction
- Foundation
- Flue Gas
- Utilities
- Installation
- Interconnection

O&M
- Operate
- Test Support
- Analysis
- Troubleshoot
- Repair

CO_2 Utilization Technology Development

- CO_2 conversion to biomass via agriculture/aquaculture
- Synthesis of fuels and organic chemicals
- Conversion of CO_2 to inorganic products, i.e., construction materials
- Synthesis of inorganic materials and chemicals

Preferred host site for DOE funding opportunities

Southern Research	CarbonBuilt / UCLA (Carbon XPRIZE Winner)	Helios-NRG
Ethylene production using coal-fired flue gas	CO_2 mineralization to produce concrete	Algae technology to utilize CO_2 for value-added products

NCCC International Collaboration

Co-founder of International Test Center Network

Share knowledge (safety, test execution, technology screening, funding, analytical techniques, data analysis, construction, operation) among member facilities

- Support DOE's goal of international cooperation
- Broad effort in China, India, Middle East, Korea, Japan, EU, Australia, Canada, Norway
- Multiple levels of involvement
  - Partners, developers, network members, consulting services, workshops
- Ease of collaboration as IP is not shared

Developing technologies for an international market will make them more robust and more valuable

Conclusions

- **DOE has expanded the NCCC scope to include utilization**
  - **Wide range of test sizes will fit, very small to 1 MW**
- **The NCCC wants to discuss the details of your testing requirements to determine if our site fits your needs**
- **The NCCC collaborates with many test sites**

fcmorton@southernco.com
nationalcarboncapturecenter.com

Questions

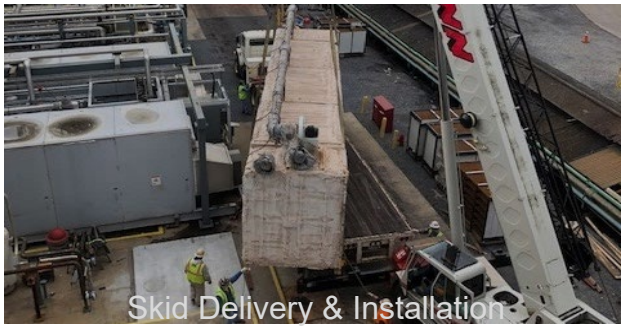
Supplemental Slides

CarbonBuilt Reversa™ Pilot Demonstration Winter 2021

- Demonstrate robustness with respect to flue gas CO_2 concentration (coal/natural gas) and environmental conditions
- Block production and “semi-curing” (to gain sufficient strength for transportation) at Blair Block in Childersburg, AL

- Truck transportation of palletized concrete blocks to NCCC
- Loading of concrete blocks into the carbonation chamber
- Applying Reversa™ technology processing (18 hours)
- Unloading, palletizing and testing of Reversa™ blocks


Direct Use of Coal & Natural Gas Flue Gas


Skid Delivery & Installation


Loading into Carbonation Chamber


Ready For Carbonation


Carbonation Underway


~5,000 Blocks Produced (ASTM C90)

Carbon Utilization R&D Program Objectives

- Reduce CAPEX and OPEX of known technologies
  - Improve process integration with host site
  - More efficient CO_2 conversion vs. conventional manufacturing approaches
- Identify technology opportunities and testing
  - CO_2 conversion to biomass via agriculture /aquaculture
  - Synthesis of fuels and organic chemicals
  - Conversion of CO_2 to inorganic products
  - CO_2 as working fluid for EOR, as solvents / refrigerants
- Leverage preferred DOE host site designation
  - Cooperative agreements / FOA inclusion
  - Investigate options for pairing technologies (natural systems, customers, etc.)

Recent/Upcoming Projects at NCCC

✓ CO_2 mineralization to produce concrete

✓ Ethylene production using coal-fired flue gas

✓ Algae technology to utilize CO_2 for value-added products

Developers Testing July 2022

GTI Energy ROTA-CAP™ Solvent Process

GTI Energy's DOE-sponsored project features the ROTA-CAP™ process that uses rotating packed bed gas-liquid contacting devices to replace conventional packed bed columns for CO_2 absorption and regeneration, a process designed to provide a significant reduction in equipment footprint. The process developed by GTI and Carbon Clean also uses an advanced solvent from Carbon Clean that was previously tested at the National Carbon Capture Center's Pilot Solvent Test Unit (PSTU); the next phase is occurring in a ROTA-CAP™ skid installed in the center's bench-scale area.

Susteon Ionic Liquid Catalyst

Susteon, in partnership with the University of Wyoming, is developing a novel ionic liquid that has the potential to increase CO_2 absorption and desorption rates by several orders of magnitude in amine solvents. The catalytic effect of the liquid has been tested at lab-scale and bench-scale as an additive in monoethanolamine (MEA) solvent, resulting in a significant increase in the CO_2 absorption rate of the MEA solvent and order-of-magnitude increase in the desorption rate at temperatures as low as 85°C. In collaboration with DOE, Susteon is demonstrating this ionic liquid catalyst with MEA using the National Carbon Capture Center's PSTU at 0.5-MW scale..

Helios-NRG LLC Algae Technology for CO_2 Capture and Utilization

Helios-NRG is developing technology to capture CO_2 from flue gas using a novel algae culture system and subsequently utilize the algae for revenue-generating products to offset the cost of capture. High capture efficiency and high biomass productivity are a hallmark of the algae growth portion of the technology and will be the focus of an outdoor test program using on-site flue gas from a fossil-fueled power plant at the National Carbon Capture Center.

Carbon Capture Developers Scheduled 2022-2023

Carbon America FrostCC Process
Carbon America is developing the FrostCC cryogenic process to remove CO_2 from industrial flue gases. The process compresses and expands the flue gas stream with recuperative heat integration, frosting the CO_2 and other pollutants out of the emitted gas. The project is being demonstrated at pilot-scale over several test campaigns at NCCC.

Cormetech Monolithic Sorbent Module
Cormetech is pursuing a technology for point-source CO_2 capture. The process uses a monolithic amine contactor for CO_2 capture followed by steam-mediated thermal desorption and CO_2 collection. Key to enhancing scalability to large natural gas combined-cycle power plants is the focus on lower-cost scaling approaches. Cormetech will demonstrate the technology at bench-scale using the NCCC's natural gas testing system.

Electric Power Research Institute (EPRI) Water-lean Solvent
In collaboration with Pacific Northwest National Laboratory and RTI, EPRI is working to test a water-lean solvent expected to operate with lower energy requirements and better resistance to degradation than current benchmark solvents. The center's PSTU will test the solvent with both natural gas- and coal-derived flue gas to support further scale-up.

GTI Energy Graphene Oxide-based Membrane
GTI Energy and team members are demonstrating a graphene oxide-based membrane process, called GO^2. This technology integrates high-selectivity and high-flux membranes in a two-stage configuration for optimal performance. Testing is utilizing the NCCC's Lab-scale Test Unit (LSTU).

GTI Energy Membrane Contactor
GTI Energy's hollow fiber membrane contactor technology combines features of both absorption and membrane processes to provide a cost-effective solution for CO_2 capture from flue gases. After bench-scale testing at another location, GTI is advancing the technology with a pilot-scale, 0.5-megawatt process installed at the NCCC. The project team includes GTI, Air Liquide Advanced Separations and Trimeric Corporation.

GTI Energy ROTA-CAP™ Solvent Process
GTI Energy's project features the ROTA-CAP™ uses rotating packed bed gas-liquid contacting devices to replace conventional packed bed columns for CO_2 absorption and regeneration, a process designed to provide a significant reduction in equipment footprint. The process developed by GTI and Carbon Clean also uses an advanced solvent from Carbon Clean previously tested at the NCCC's Pilot Solvent Test Unit (PSTU); the next phase is occurring in a ROTA-CAP™ skid installed in the center's bench-scale area.

Membrane Technology & Research (MTR) Bench-scale Membrane
MTR, in partnership with the State University of New York (SUNY) at Buffalo, is performing bench-scale testing of composite membranes expected to reduce the cost of CO_2 capture. In previous projects at the NCCC, MTR developed the high-performance Polaris™ membrane, advanced low-pressure-drop modules and a patented selective recycle membrane design. The current project utilizes novel isoporous supports that have high surface porosity and enhanced membrane permeance.

Carbon Capture Developers Scheduled 2022-2023 (continued)

National Energy Technology Laboratory (NETL) Membrane Materials
NETL aims to reduce the cost of post-combustion CO_2 capture by creating transformational membrane materials that are highly permeable and selective for CO_2. NETL developed an automated bench-scale test skid at the NCCC to support the evaluation of novel materials at Technology Readiness Level 3 or 4. The skid can house flat sheet or hollow fiber membrane materials, and the small area required makes it uniquely accessible for developing materials.

Ohio State University Bench-scale Membrane
In partnership with DOE and American Electric Power, OSU has been advancing a cost-effective design and manufacturing process for a novel transformational membrane for CO_2 separation from flue gas. The membrane consists of a thin amine-containing selective layer supported by a porous polymer substrate that can be made in a continuous manufacturing process. OSU's testing at the NCCC is being used to incorporate design improvements at bench scale.

Precision Combustion Inc. (PCI) Microlith® Sorbent
PCI is developing a modular post-combustion CO_2 capture system utilizing metal-organic framework nanosorbents supported on a Microlith® mesh substrate. The system design enables low pressure drop, high volumetric utilization and high mass transfer and is suitable for rapid heat transfer and low-temperature regeneration operating modes. PCI operates their sorbent test skid at the NCCC's LSTU.

SUNY Buffalo Bench-scale Sorbent
This future project will demonstrate a sorbent having a molecular layer coating that is tailor-made to be size-sieving. The process will use pressure swing adsorption for CO_2 capture. The project team includes RPI/SUNY Buffalo, GTI Energy, Trimeric Corporation and the University of South Carolina.

SUNY Buffalo Bench-scale Membrane
SUNY Buffalo, along with a team that includes RPI, MTR, Caltech and Trimeric Corporation, is developing novel metal-organic, polyhedral-based membranes with high permeance and selectivity and with ease of manufacturing. These membranes will demonstrate their performance at NCCC in the LSTU in the future.

Susteon Ionic Liquid Catalyst
Susteon, in partnership with the University of Wyoming, is developing a novel ionic liquid that has the potential to increase CO_2 absorption and desorption rates by several orders of magnitude in amine solvents. The catalytic effect of the liquid has been tested at lab-scale and bench-scale as an additive in monoethanolamine (MEA) solvent, resulting in a significant increase in the CO_2 absorption rate of the MEA solvent and order-of-magnitude increase in the desorption rate at temperatures as low as 85°C. In collaboration with DOE, Susteon is demonstrating this ionic liquid catalyst with MEA using the NCCC's PSTU at 0.5-MW scale.

University of Texas at Austin (UT-Austin) PZAS™ Process
UT-Austin is developing the PZAS process, a solvent-based technology that uses aqueous piperazine with an advanced flash stripper. UT-Austin has completed two successful campaigns of PZAS at the NCCC. A future campaign, supported by DOE, EU LAUNCH and private companies, will use natural gas flue gas to study solvent oxidation.

Carbon Utilization & Direct Air Capture Developers Scheduled 2022-2023

Helios-NRG LLC Algae Technology for CO_2 Capture and Utilization

Helios-NRG is developing technology to capture CO_2 from flue gas using a novel algae culture system and subsequently utilize the algae for revenue-generating products to offset the cost of capture. High CO_2 capture efficiency and high biomass productivity are a hallmark of the algae growth portion of the technology and will be the focus of an outdoor test program using on-site flue gas from a fossil-fueled power plant at the NCCC.

CarbonBuilt Reversa™ Process

The University of California, Los Angeles will return to the NCCC for the second phase of a project featuring the Reversa™ CO_2 mineralization process. First tested at the site in 2021, the process uses CO_2 in flue gas, and coal combustion residuals to produce low-carbon concrete. The CarbonBuilt technology was a grand prize winner in the prestigious NRG COSIA Carbon XPRIZE competition.

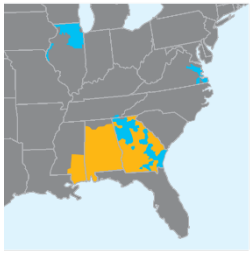
InnoSepra Sorbent Process

With support from the Small Business Innovation Research program, InnoSepra is advancing a direct air capture (DAC) process using sorbent materials with exceptionally high CO_2 capacities and low regeneration energy requirements. The project team will optimize the material/process combinations and evaluate effectiveness for DAC under different process conditions during small bench-scale testing at the NCCC.

Southern States Energy Board (SSEB) CO_2 Capture

SSEB and AirCapture LLC are leading a team to scale up and demonstrate a hybrid DAC/point-source CO_2 capture system. The technology features solid-amine adsorbents to produce a CO_2 of at least 95% purity using low-grade waste heat, which is often available in a power plant setting. The technology will be field-tested at the NCCC after construction and testing by AirCapture. Other participants include Global Thermostat, Synapse Development Group, Crescent Resource Innovation and Southern Company. The project is funded by the U.S. Department of Energy and partners.

Providing Clean, Cafe, Reliable, Affordable Energy and Customized solutions

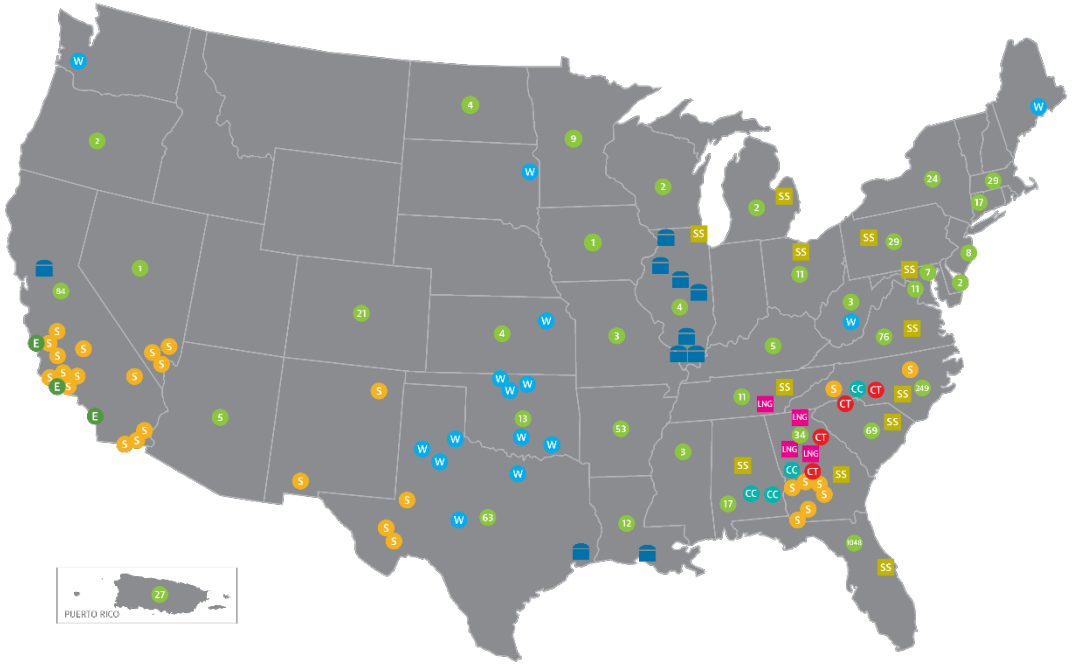


Service territories

- Electric
- Gas

Gas pipelines

- Southern Natural Gas
- Southern Company Gas
- Pipeline projects



Southern Power

- Combined-cycle facility
- Peaking facility
- Solar facility
- Wind facility
- Energy storage

Southern Company Gas

- LNG facilities
- SouthStar
- Natural gas storage

PowerSecure

- Owned and/or managed sites per state

Southern Company

Capabilities in **50 States**

7 Electric & Natural Gas Utilities

9 Million Customers

Approximately **28,000** Employees

Approximately **42,000 MW** of Generating Capacity

Southern Company's Net-Zero Commitment

Our energy strategy includes the continued development of a diverse portfolio of resources, driven by RD&D, to serve customers and communities with a focus on reducing greenhouse gas emissions

GHG Emissions Reduction Goals

2007

Baseline

2020

Reduced[1] 52%

2030

50% Reduction Goal

2050

Net-Zero Goal

[1] The reduction in GHG emissions from 2019 to 2020 was primarily driven by milder weather, decreased customer energy usage resulting from the COVID-19 pandemic, and the continued transition to lower- and non-emitting resources. Expect to achieve sustainable reduction of at least 50% in 2025, if not earlier.

Southern Company