MRCSP
MIDWEST REGIONAL
CARBON SEQUESTRATION
PARTNERSHIP

Carbon Capture

Efficiencies, technologies, trends

Battelle
Neeraj Gupta and
Joel R. Sminchak

Maryland Energy Administration Carbon Sequestration Workshop
November 19-20, 2019
Maritime Institute, Linthicum, Maryland

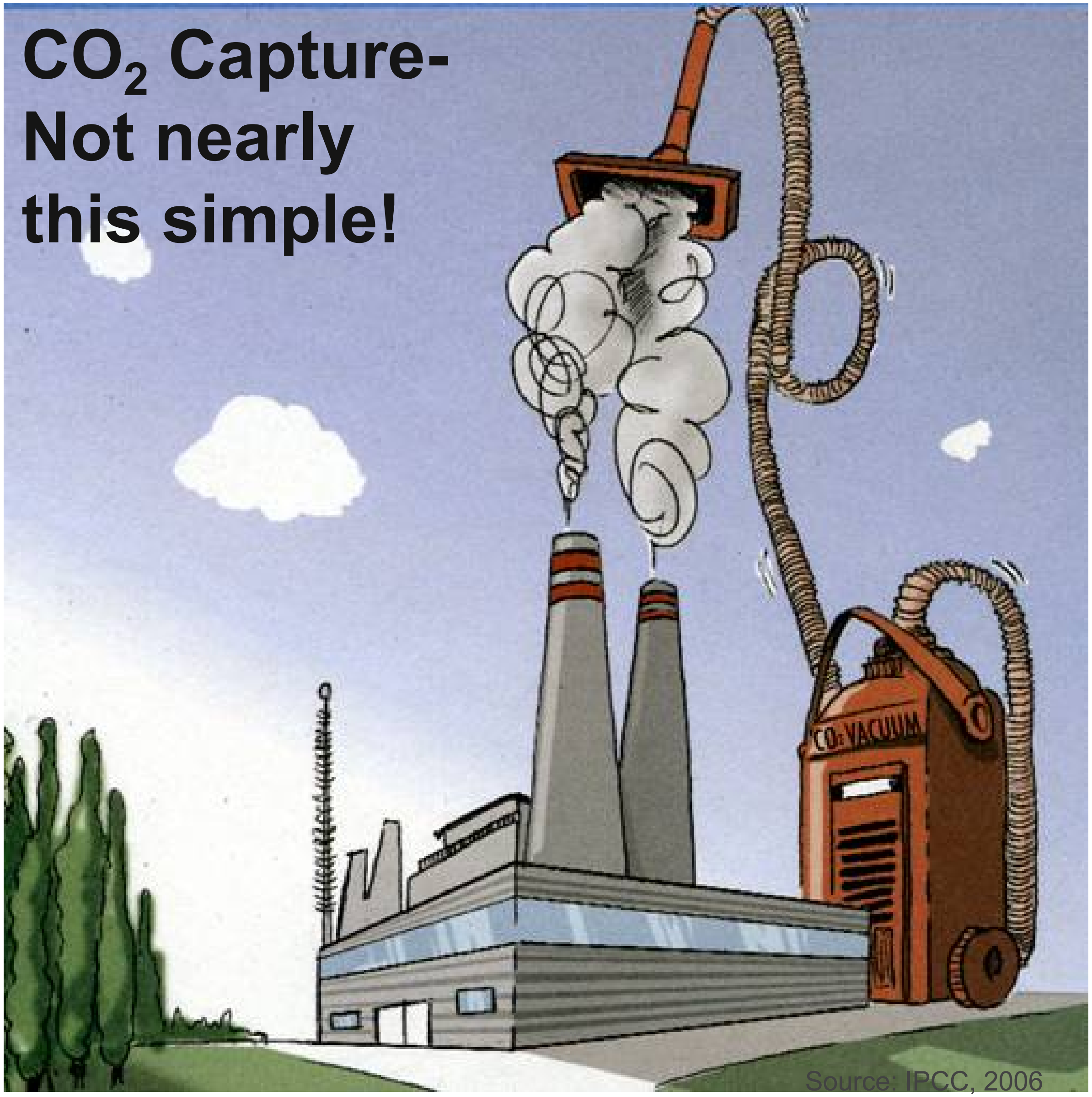
BATTELLE

Disclaimer

- Battelle does not engage in research for advertising, sales promotion, or endorsement of our clients' interests including raising investment capital or recommending investments decisions, or other publicity purposes, or for any use in litigation.
- Battelle endeavors at all times to produce work of the highest quality, consistent with our contract commitments. However, because of the research and/or experimental nature of this work the client undertakes the sole responsibility for the consequence of any use or misuse of, or inability to use, any information, apparatus, process or result obtained from Battelle, and Battelle, its employees, officers, or Trustees have no legal liability for the accuracy, adequacy, or efficacy thereof.

Outline

1. Types of CO_2 Sources
2. CO_2 Capture Technologies
3. Newer CO_2 Capture Technologies



MRCSP in Maryland

MRCSP Annual Partners Meeting
Day 1 Agenda

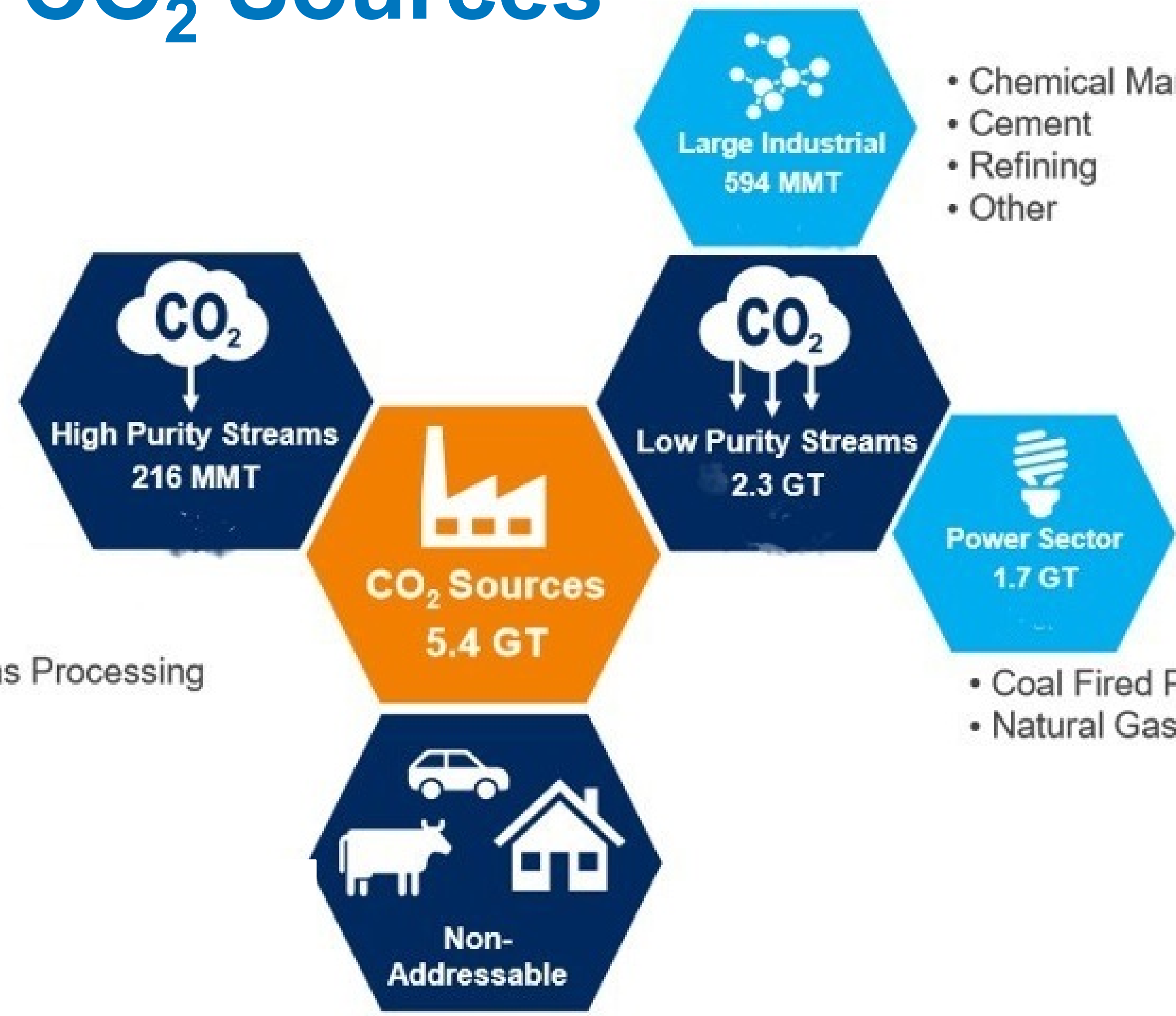
Wednesday, November 14, 2018

Historic Inns of Annapolis
58 State Circle
Annapolis, MD 21401

MRCSP
MIDWEST REGIONAL
CARBON SEQUESTRATION
PARTNERSHIP

BATTELLE

Types of CO_2 Sources



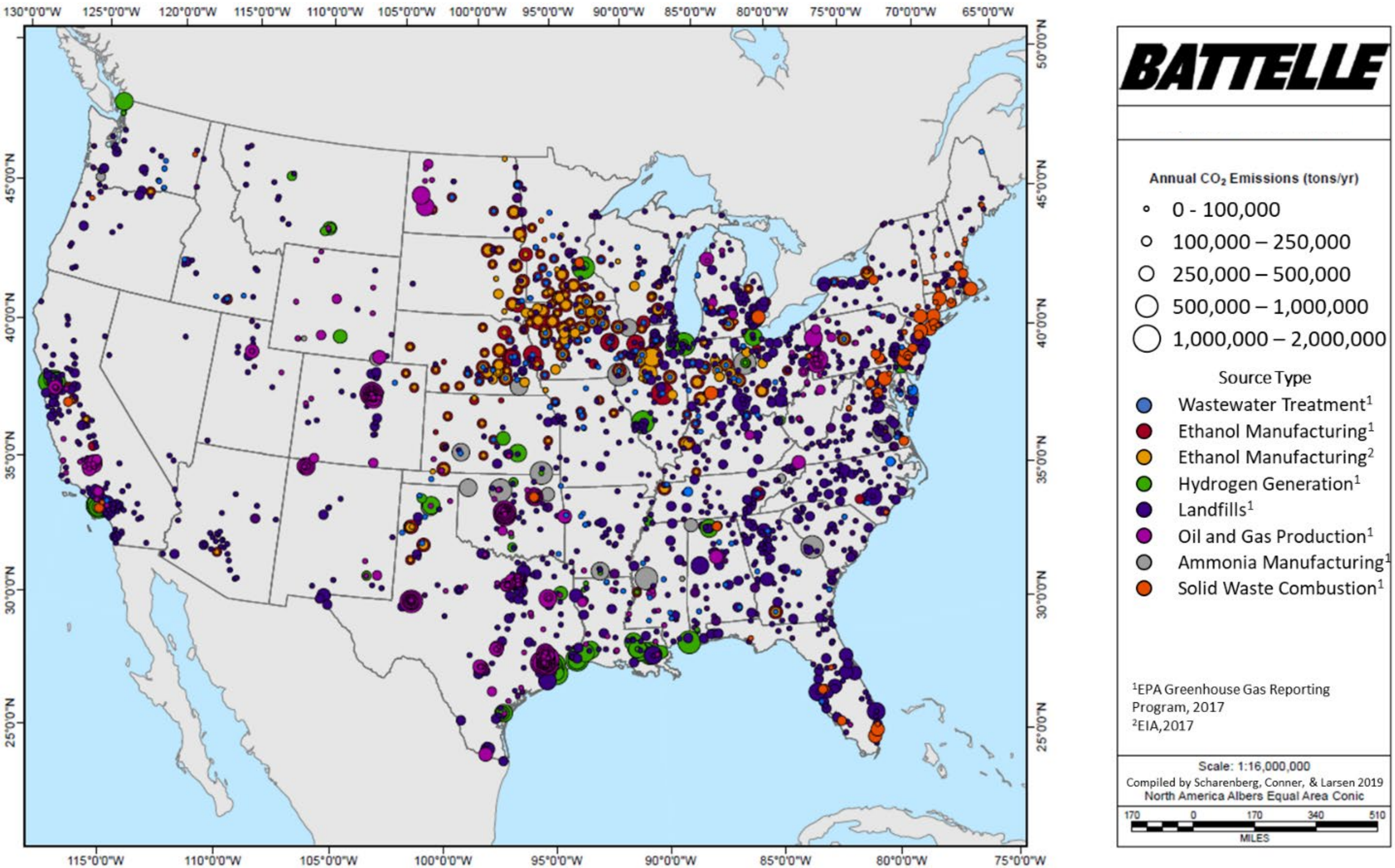
- Chemical Manufacturing
- Cement
- Refining
- Other

- Ammonia
- Natural Gas Processing
- Other

- Coal Fired Power
- Natural Gas Fired Power

- Transportation
- Agriculture
- Residential/Commercial

Types of CO_2 Sources



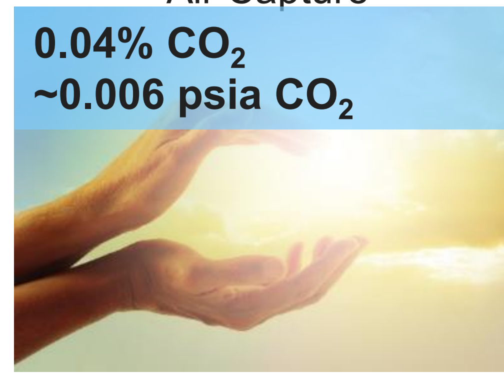
BATTELLE

Types of CO_2 Sources

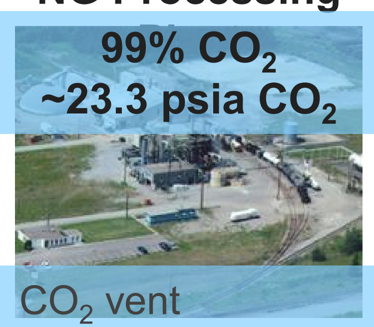
Coal Power Plant

Gas Power Plant

Air Capture



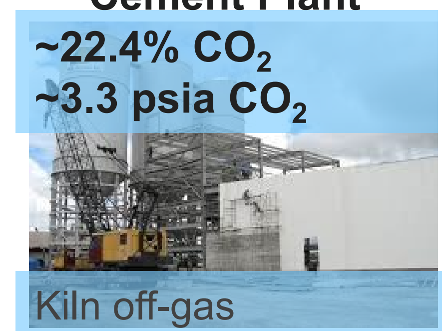
NG Processing



Ammonia Plant

Ethanol Plant

Cement Plant

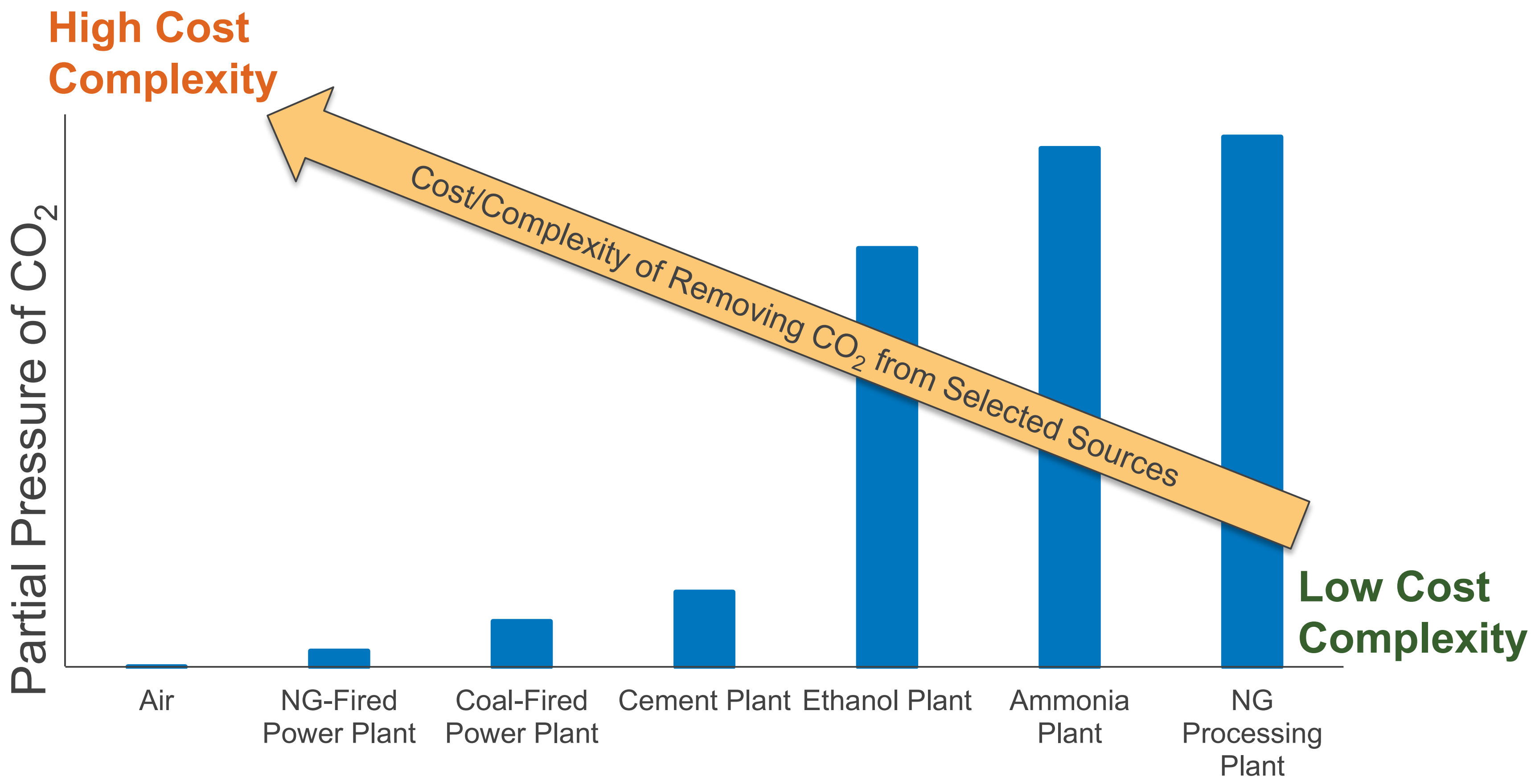


U.S. DEPARTMENT OF ENERGY

Cost of Capturing CO_2 from Industrial Sources, January 10, 2014, DOE/NETL-2013/1602

BATTELLE

Types of CO_2 Sources



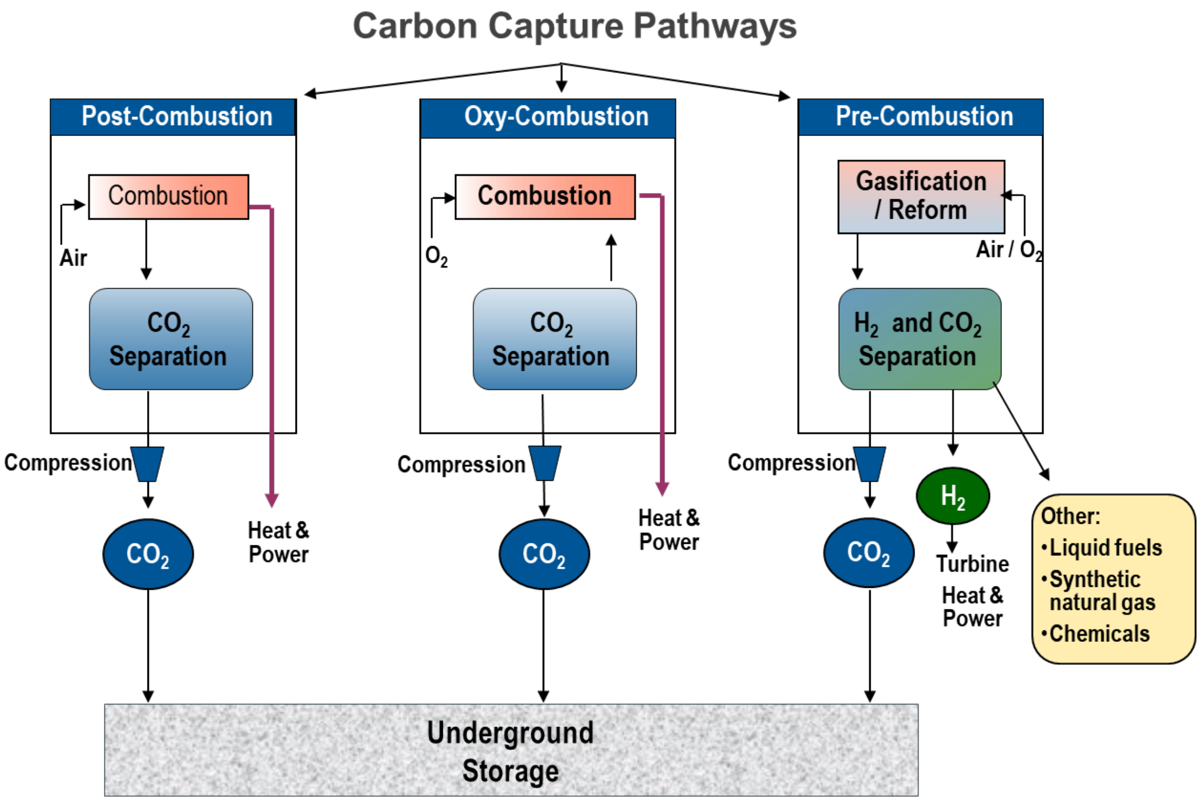
U.S. DEPARTMENT OF ENERGY

Cost of Capturing CO_2 from Industrial Sources, January 10, 2014, DOE/NETL-2013/1602

BATTELLE

CO_2 Capture Technologies

Coal-Fired Power Plants



Other

Direct Air Capture

Gas Processing

Ethanol Plants

Refineries

Chemical Plants

Petrochemical Plants

Cement Plants

Natural Gas Power Plants

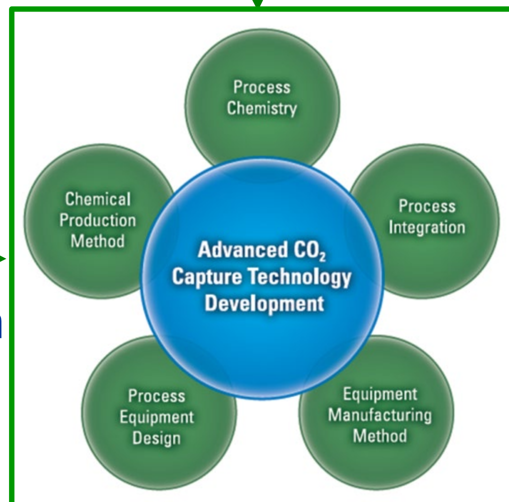
CO_2 Capture Technologies

Pre-Combustion

- *Solvents*
- *Sorbents*
- *Membranes*
- *Hybrid processes*
- *Water-gas shift reactor*

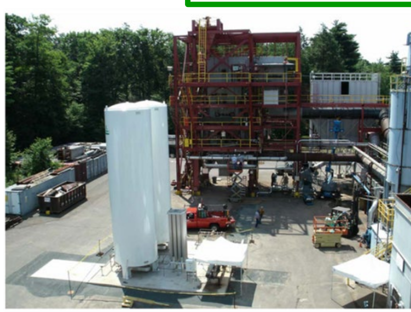
Post-Combustion

- *Solvents*
- *Sorbents*
- *Membranes*
- *Hybrid processes*



Advanced Combustion

- *Atmospheric oxy-combustion*
- *Pressurized oxy-combustion*
- *Oxygen transport membrane*
- *Chemical looping*



Advanced Compression

- *Intra-stage cooling*
- *Cryogenic pumping*
- *Supersonic shock wave compression*

Source: Dr. S. Vora, U.S. DOE/NETL 2013 Capture Technology Meeting

CO_2 Capture Technologies

Energy penalty- capture technologies increase both capital costs and energy use.

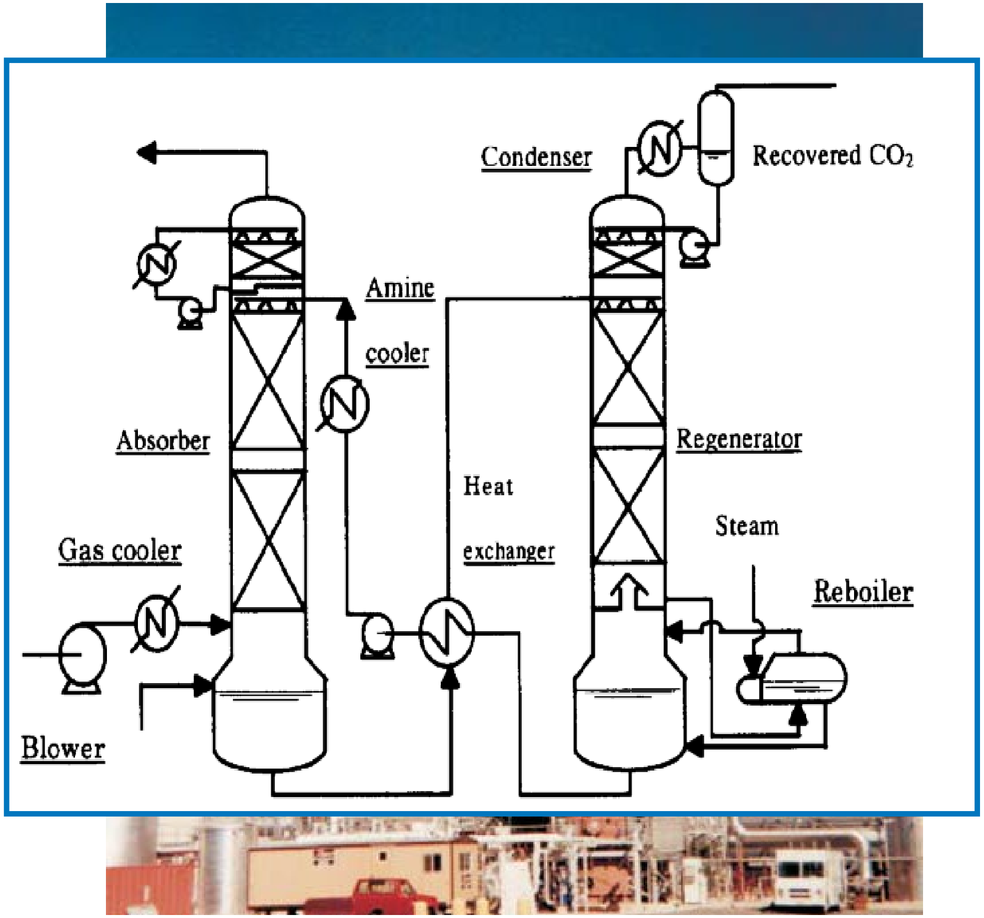
Technology	Net Plant Efficiency	
	Without Capture	With 90% Capture
Pulverized Coal Post Combustion		
• 1950-1980s Boiler Fleet	32-35%	22-25%
• Current Supercritical Units	38-40%	27-28%
• Ultra Super Critical Target	45-48%	31-33%
Oxy-Combustion	--	28-33%
Integrated Gasification Combined Cycle, IGGC	38-44%	31-35%

Post-Combustion Capture

<u>Post-combustion advantages</u>:
- Back-end retrofit
- Slip-stream (0 to 90% capture)

<u>Amine scrubbing Advantages</u>:
- Proven Technology (Petroleum refining, NG purification)
- Chemical solvent → High loadings at low CO_2 partial pressure
- Relatively cheap chemical ($2-3/lb)

<u>Key Challenges</u>:
- Dilute flue gas (12-15 volume %)
- 2-3 MM acfm for a 500-600 Mwe plant
- ~50% currently scrubbed for SOx/NOx
- Increased cooling requirements



AES Warrior Run Power Plant, Cumberland, MD post-combustion amine capture 150-300 tons/day

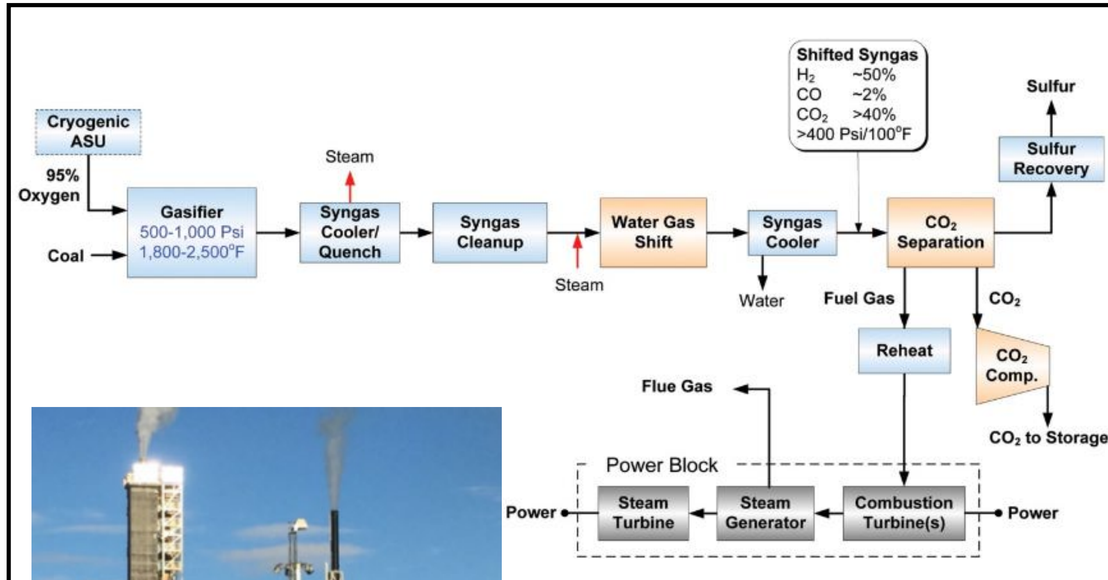
BATTELLE

Pre-Combustion Capture

Pre-combustion advantages:
- Easier removal
- More efficient
- Proven Technology (fertilizers, gaseous fuel, power production)
- Relatively more expensive ($60/ton)

Key Challenges:
- High pressure/temperature system
- Separation technology

Future Work:
- Emphasis on improving separation technology to reduce cost to $30/ton
  - Sorbents, membranes, etc




Carbon Clean Solutions, Ltd.

BATTELLE

Oxyfuel Combustion

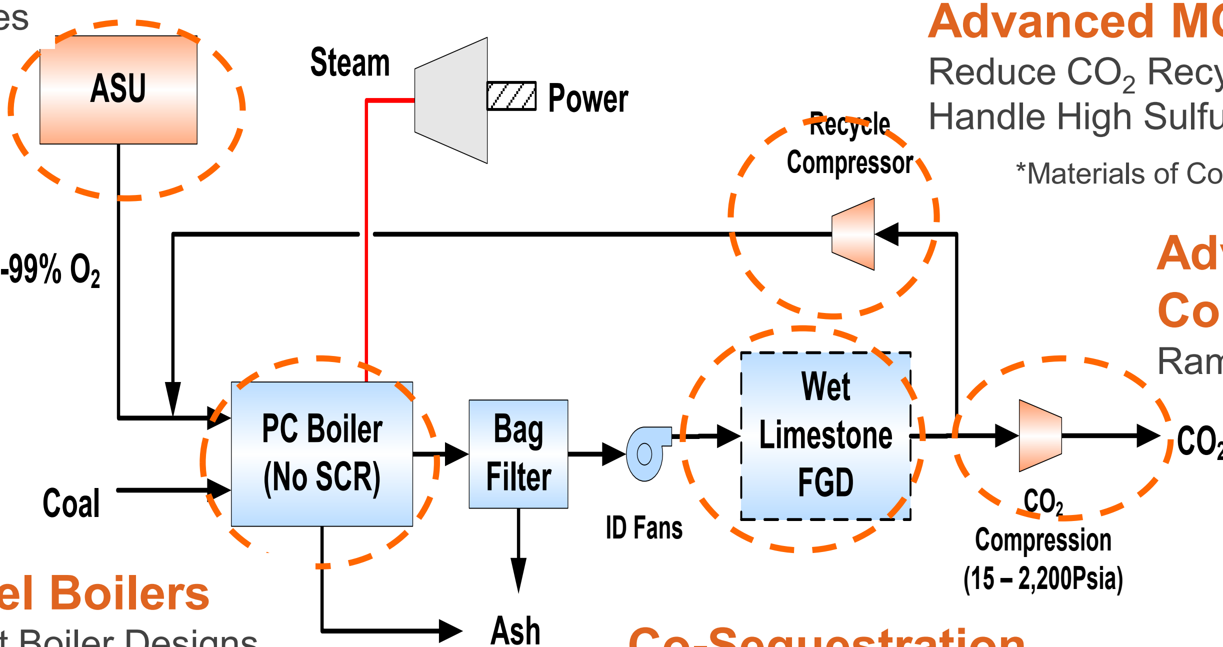
Coal + O_2 → CO_2 + H_2O

Cheap Oxygen
Oxygen Membranes

Advanced MOC*
Reduce CO_2 Recycle
Handle High Sulfur Con.

*Materials of Construction

Advanced Compression
Ramgen, SwRI

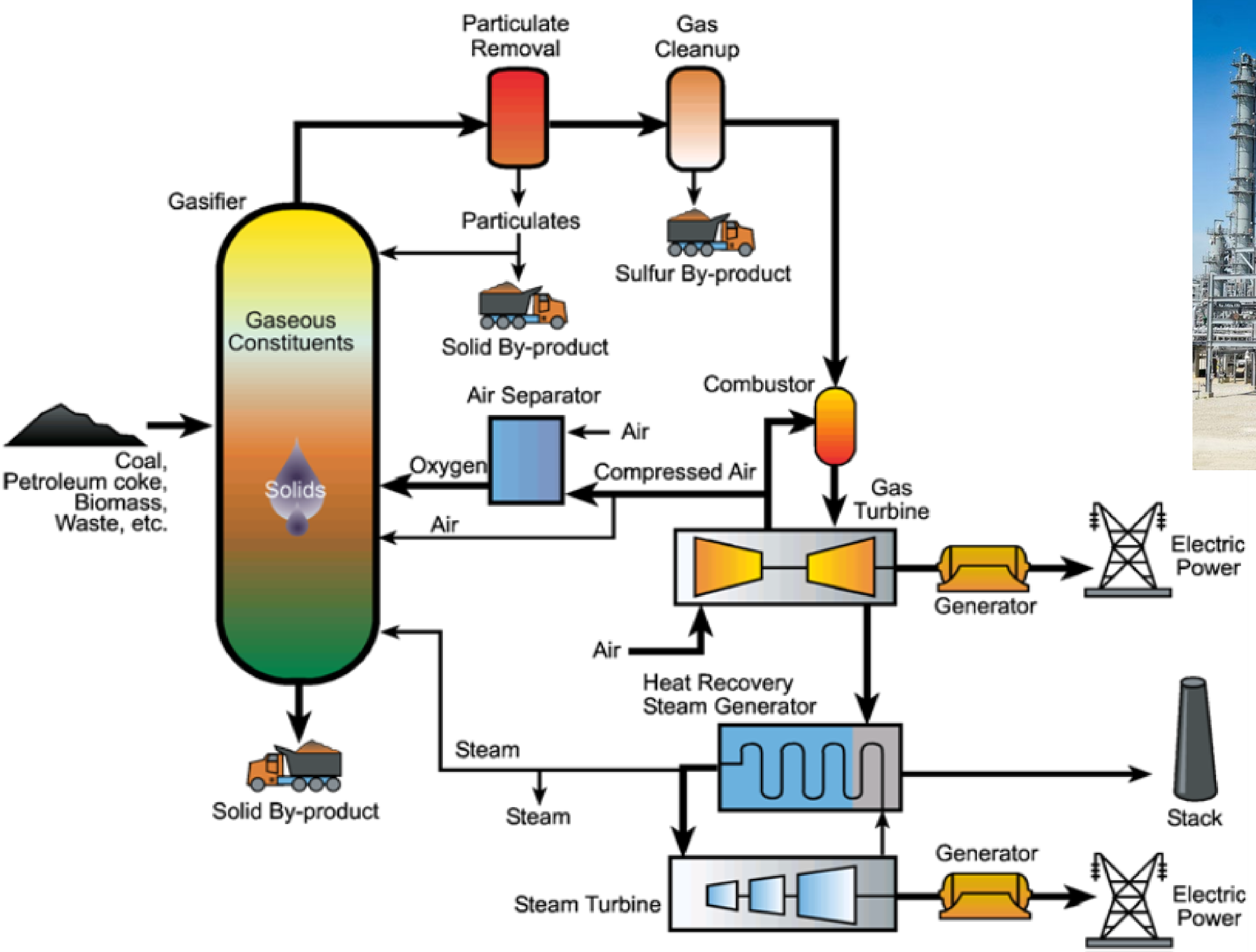


Oxyfuel Boilers
Compact Boiler Designs
Adv. Materials (USC)
Advanced Burners

Co-Sequestration
Multi-pollutant capture

Source: Dr. S. Vora, U.S. DOE/NETL 2012 Capture Technology Meeting

Integrated Gasification Combined Cycle (IGCC)

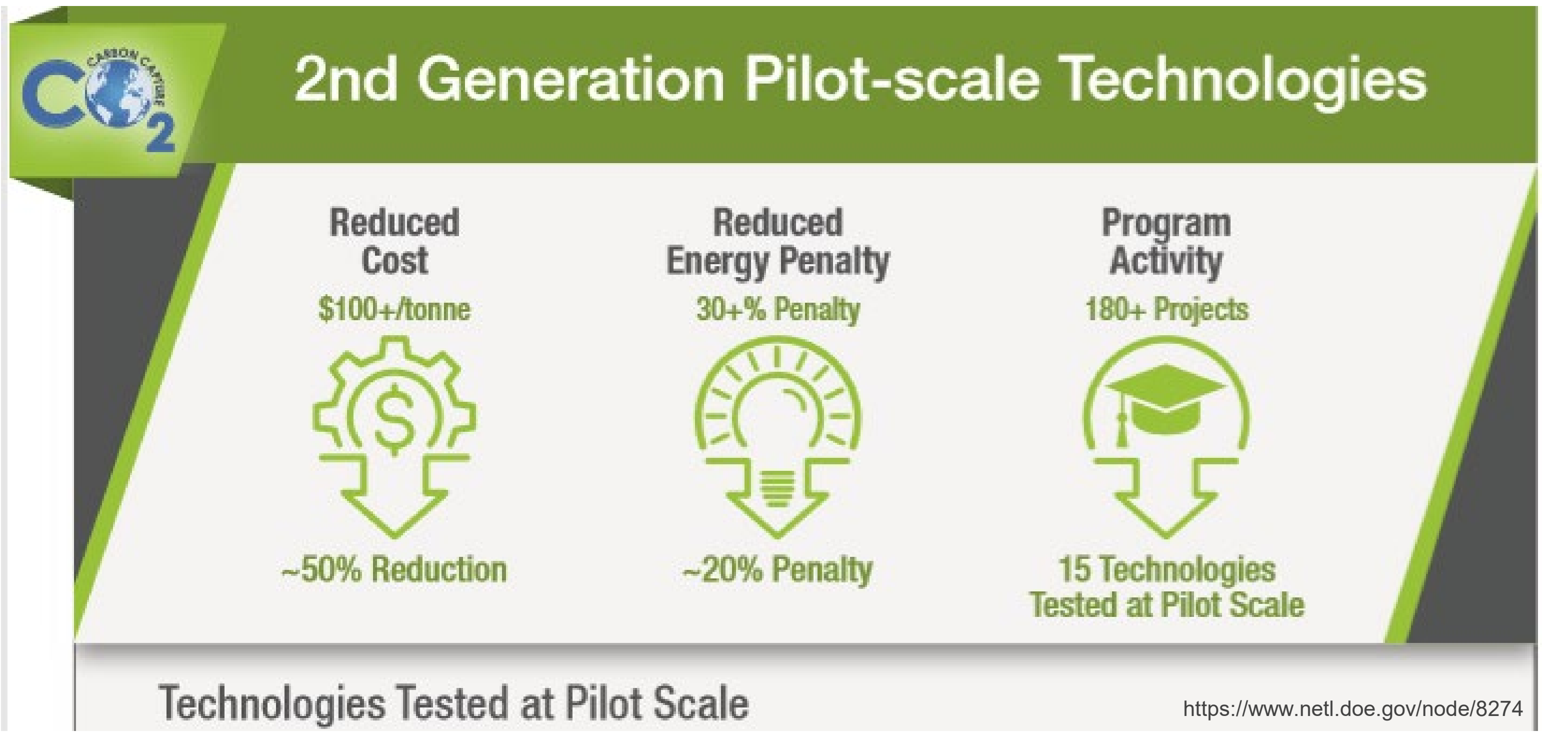


CO_2 Capture - Deployment Barriers for New and Existing Coal Plants

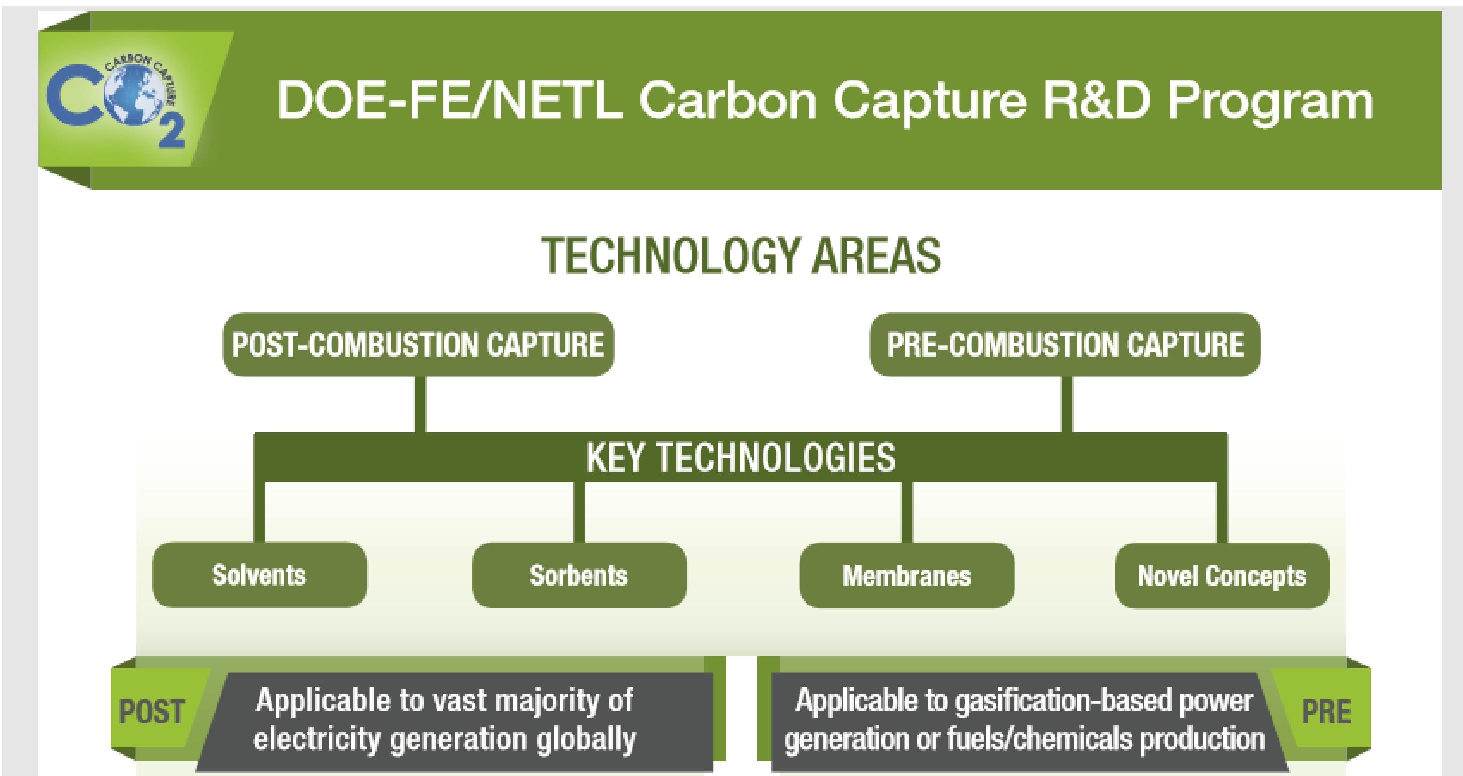
1. Scale-up
   - Current Post Combustion capture ~200 TPD
   - 550 MWe power plant produces 13,000 TPD
2. Energy Penalty
   - 20% to 30% less power output
3. Cost
   - Increase Cost of Electricity by 80%
   - Adds Capital Cost by $1,500 - $2,000/kW
4. Regulatory framework
   - Transport — pipeline network
   - Storage
5. Economies of Scale
   - Land, power, water use, transportation, process components, …

Source: Dr. S. Vora, U.S. DOE/NETL 2012 Capture Technology Meeting

CO_2 Capture - Deployment Barriers for New and Existing Coal Plants

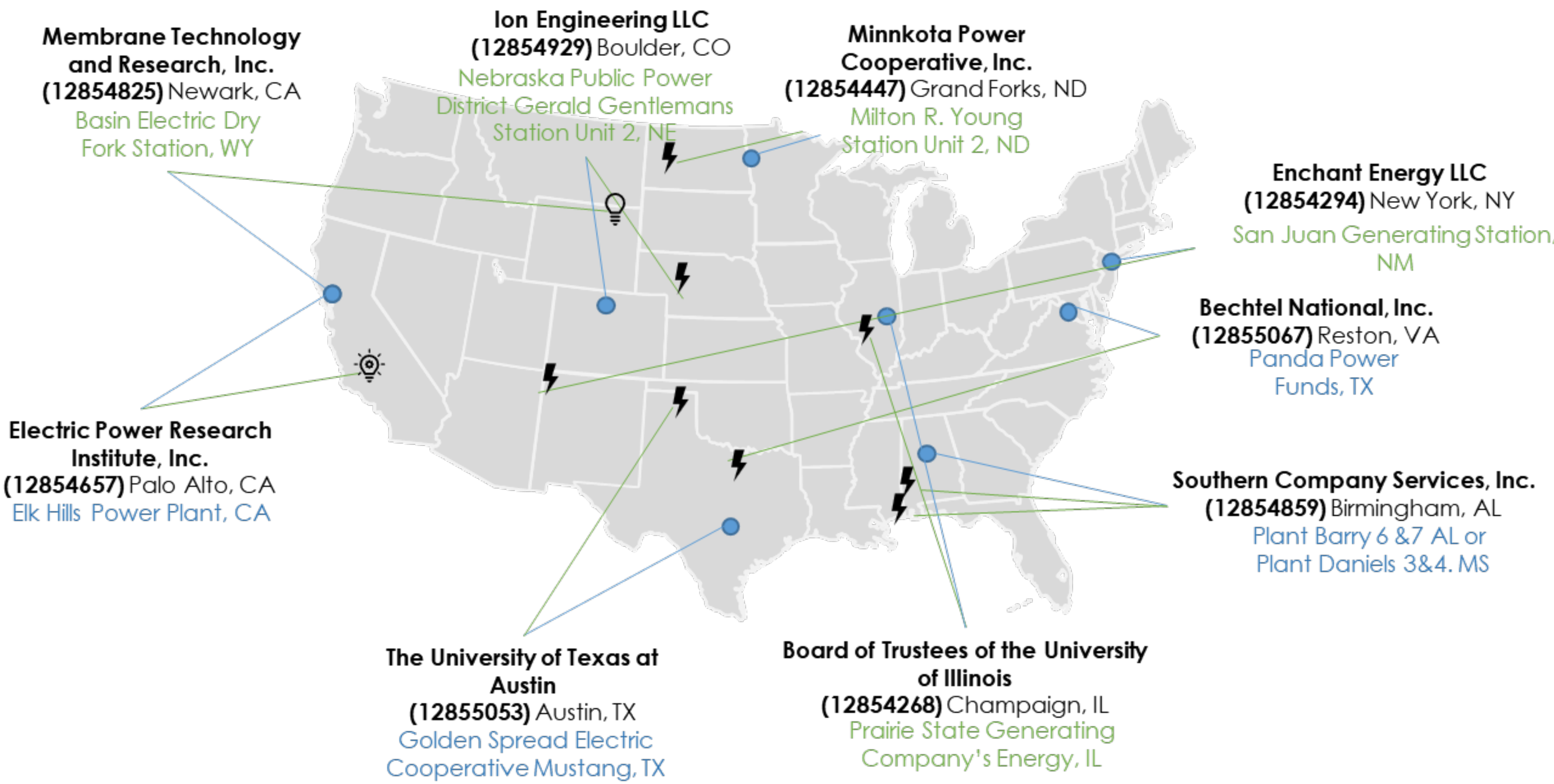


CO_2 Capture - Deployment Barriers for New and Existing Coal Plants



https://www.netl.doe.gov/node/8274

DOE-NETL Projects



Applicant Locations and Host Sites

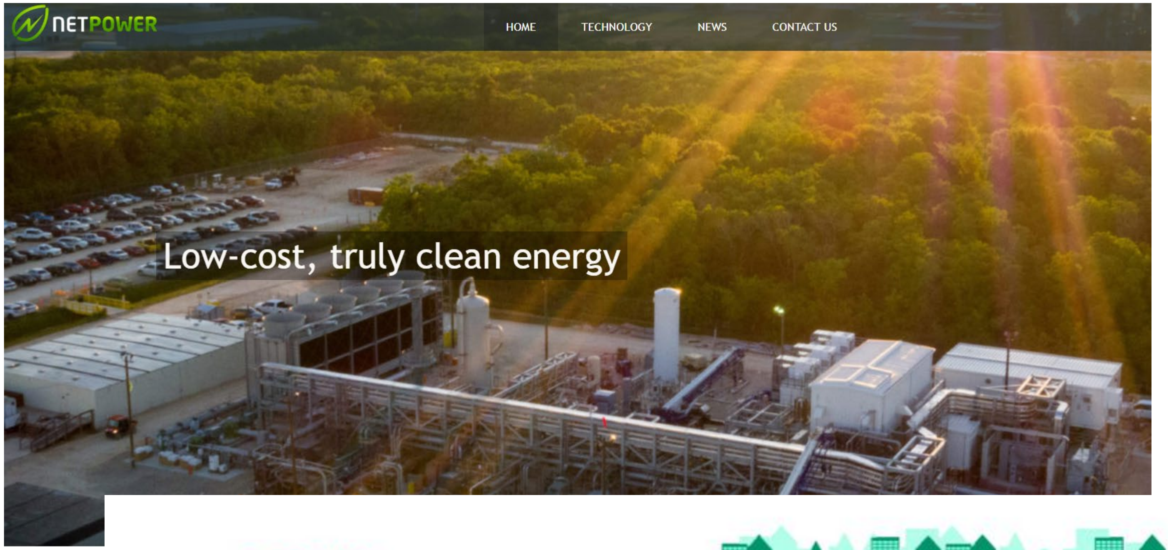
BATTELLE

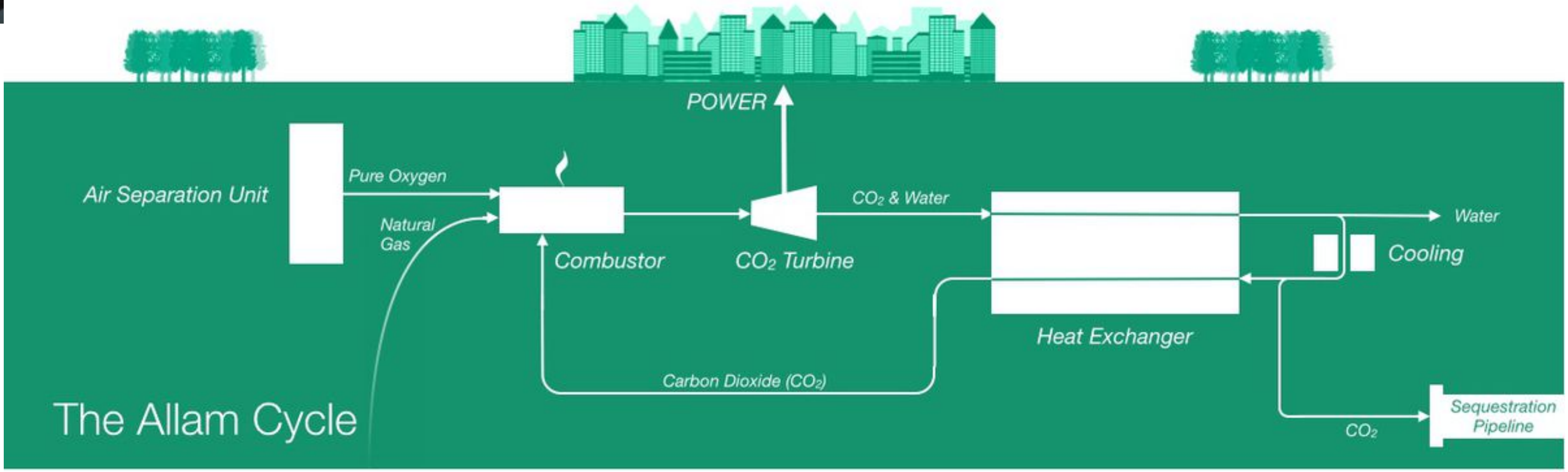
Newer CO_2 Capture Technologies being researched

- Post-combustion capture
  - Calcium looping – provides own source of power hence efficient and least cost
  - Membranes (alternative post-combustion capture solution)
  - Advanced solvents (engineered enzymes)
- Pre-combustion capture
  - Membranes
- Oxyfuel
  - Allam Cycle – promises high efficiencies with lower costs with coal syngas; NET Power testing natural-gas based version in TX.
  - Pressurized oxyfuel (tested at small pilot scales)
- Chemical looping

Lockwood, 2017

Allam Cycle Capture





https://www.netpower.com/technology/

NETPOWER 25 MW pilot in LaPorte, Texas

- Natural Gas
- Oxygen fired
- Supercritical
- CO_2 Turbine
- Recuperative

BATTELLE

Newer CO_2 Capture Technologies being researched

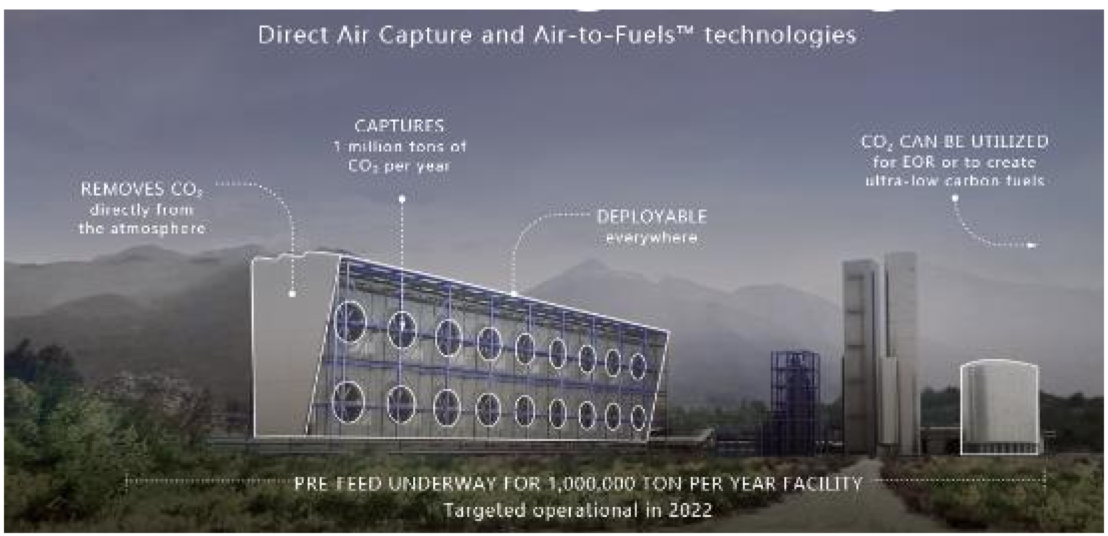
WIRED

A Power Plant in Iceland Has Turned Its CO_2 Into Stone

CO_2 Mineralization in Basalt Flows

https://www.wired.com/2016/06/iceland-pumped-co2-underground/

Direct Air Capture (DAC)



https://www.oxy.com/News/Pages/Article.aspx?Article=6095.html

BATTELLE

Newer CO_2 Capture Technologies being researched

- Numerous technologies being tested at pilot or lab scale.

2019 PROCEEDINGS - ADDRESSING THE NATION'S ENERGY NEEDS THROUGH TECHNOLOGY INNOVATION – 2019 CARBON CAPTURE, UTILIZATION, STORAGE, AND OIL AND GAS TECHNOLOGIES INTEGRATED REVIEW MEETING - CAPTURE AND UTILIZATION SESSIONS

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

Capture and Utilization Sessions

Proceedings | Monday | Tuesday | Wednesday | Thursday | Friday

Monday

CAPTURE – LAB/BENCH-SCALE RESEARCH

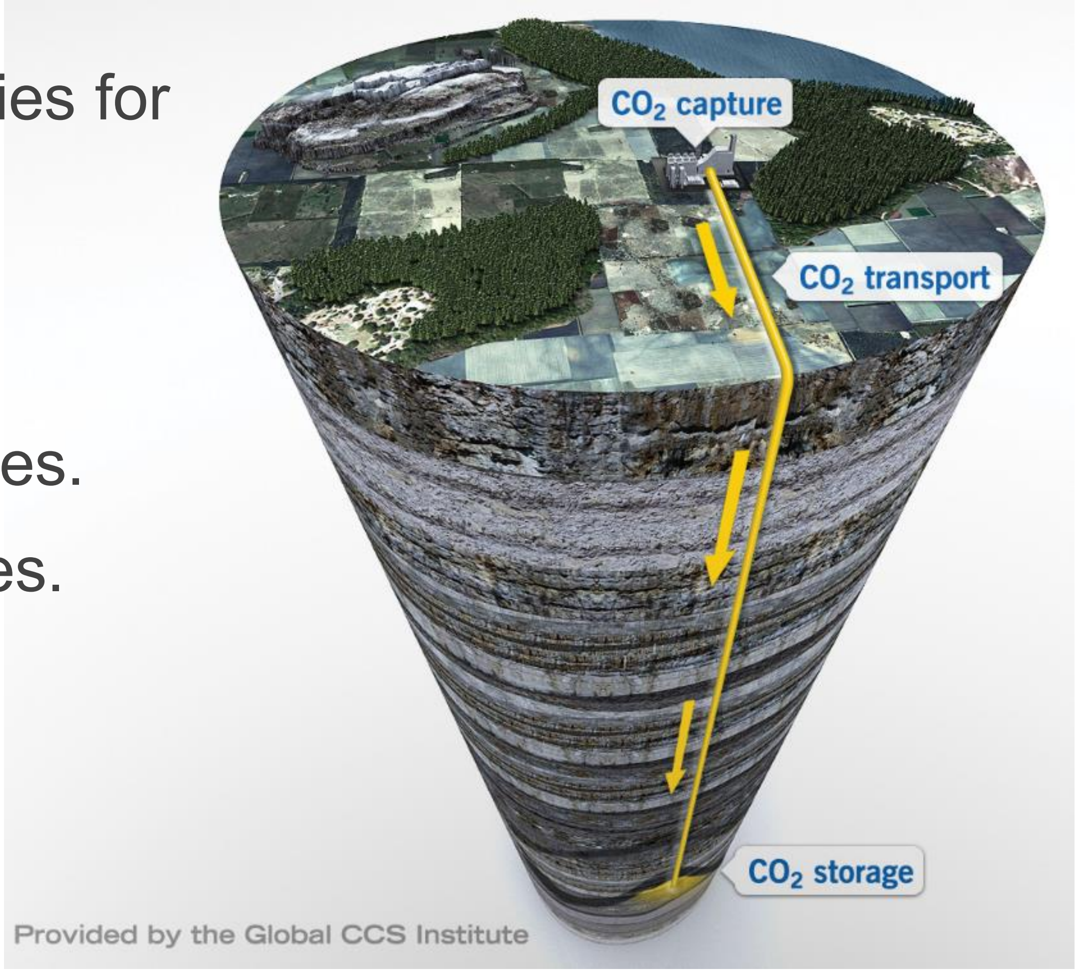
- Bench-Scale Testing of Next-Generation Hollow-Fiber Membrane Modules (FE0026422)
  Shilu Fu, American Air Liquide Inc.
- Energy-Efficient GO-PEEK Hybrid Membrane Process for Post-Combustion Carbon Dioxide Capture (FE0026383)
  Shiguang Li, Gas Technology Institute
- Novel Process That Achieves 10 MOL/KG Sorbent Swing Capacity in a Rapidly Cycled Pressure Swing Adsorption Process (FE0026433)
  Ryan Lively, Georgia Institute of Technology
- Cryogenic Carbon Capture Development (FE0028697)
  Larry Baxter, Sustainable Energy Solutions
- Electrochemically Mediated Amine Regeneration in CO_2 Scrubbing Processes (FE0026489)
  T. Alan Hatton, Massachusetts Institute of Technology
- Rapid Design and Testing of Novel Gas-Liquid Contacting Devices for Post-Combustion CO_2 Capture Via 3D Printing: Modular Adaptive Packing (FE0031530)
  Erik Meuleman, ION Engineering LLC
- Development and Bench-Scale Testing of a Novel Biphasic Solvent-Enabled Absorption Process for Post- Combustion Carbon Capture (FE0031600)
  Yongqi Lu, University of Illinois at Urbana-Champaign
- A Process with Decoupled Absorber Kinetics and Solvent Regeneration through Membrane Dewatering and In-Column Heat Transfer (FE0031604)
  James Landon, University of Kentucky
- Universal Solvent Viscosity Reduction Via Hydrogen Bonding Disruptors (FE0031629)
  Xu Zhou, Liquid Ion Solutions LLC
- ROTA-CAP: An Intensified Carbon Capture System Using Rotating Packed Beds (FE0031630)
  Osman Akpolat, Gas Technology Institute
- Mixed Salt-Based Transformational Solvent Technology for CO_2 Capture (FE0031597)
  Palitha Jayaweera, SRI International
- Development of Self-Assembly Isoporous Membranes (FE0031596)
  Hans Wijmans, Membrane Technology and Research Inc.
- Bench-Scale Development of a Transformational Graphene Oxide-Based Membrane Process for Post- Combustion CO_2 Capture (FE0031598)
  Shiguang Li, Gas Technology Institute
- Flue Gas Aerosol Pretreatment Technologies to Minimize PCC Solvent Losses (FE0031592)
  Devin Bostick, Linde Gas North America LLC
- Development of Carbon Molecular Sieves Hollow Fiber Membranes Based on Polybenzimidazole Doped with Polyprotic Acids with Superior H_2/CO_2 Separation Properties (FE0031636)
  Haiqing Lin, University at Buffalo, SUNY
- Emissions Mitigation Technology for Advanced Water-Lean Solvent-Based CO_2 Capture Processes (FE0031660)
  Jak Tanthana, Research Triangle Institute
- Syngas Purification Using High-Pressure CO_2BOL Solvents with Pressure Swing Regeneration (FWP-72564)
  Philip Koech, Pacific Northwest National Laboratory (PNNL)

CO_2 UTILIZATION - NEW RESEARCH PROJECTS LIGHTNING ROUND

- Unique Nanotechnology Converts Carbon Dioxide to Valuable Products (FE0031707)
  Bingyun Li and Trina Karolchik Wafle, West Virginia University
- Novel Modular Electrocatalytic Processing for Simultaneous Conversion of Carbon Dioxide and Wet Shale Gas Into Valuable Products (FE0031709)
  Jason Trembly, Ohio University
- An Intensified Electro-Catalytic Process for Production of Formic Acid (FE0031720)
  Jesse Thompson, University of Kentucky Center for Applied Energy Research
- CO_2 and Renewable Electricity into Chemicals: Formic Acid Production from Coal Flue Gas (FE0031706)
  Hongzhou Yang, Dioxide Materials Inc.
- Selective and Efficient Electrochemical Production of Neat Formic Acid from Carbon Dioxide Using Novel Platinum Group Metals-Free Catalysts (FE0031704)
  Syed Mubeen Jawahar Hussaini, The University of Iowa
- CO_2 to Fuels Through Novel Electrochemical Catalysis (FE0031716)
  Zehua Pan, Colorado School of Mines
- Design of Transition-Metal/Zeolite Catalysts for Direct Conversion of Coal-Derived Carbon Dioxide to Aromatics (FE0031719)
  Chris Jones, Georgia Institute of Technology
- Electrochemical Conversion of CO_2 from Coal into Fuels and Chemicals Using a Modified Pem Electrolyzer (FE0031712)
  Etosha Cave, Opus 12 Inc.
- Novel Process for CO_2 Conversion to Fuel (FE0031714)
  Gokhan Alptekin, TDA Research Inc.
- Sustainable Conversion of Carbon Dioxide and Shale Gas to Green Acetic Acid Via a Thermochemical Cyclic Redox Scheme (FE0031703)
  Fanxing Li, North Carolina State University
- Synthetic Calcium Carbonate Production by Carbon Dioxide Mineralization of Industrial Waste Brines (FE0031705)
  Bu Wang, University of Wisconsin - Madison
- A Scalable Process for Upcycling Carbon Dioxide and Coal Combustion Residues Into Construction Products (FE0031718)
  Gabriel Falzone, University of California - Los Angeles
- Field-Scale Testing of the Thermocatalytic Ethylene Production Process Using Ethane and Actual Coal- Fired Flue Gas CO_2 (FE0031713)
  Amit Goyal, Southern Research Institute
- Beneficial Use of CO_2 from Coal-Fired Power Plants for Production of Animal Feeds (FE0031717)
  Tryg Lundquist, MicroBio Engineering
- Novel Algae Technology to Utilize CO_2 for Value-Added Products (FE0031710)
  Fred Harrington, Helios-NRG LLC

Moving Forward

- Best capture technologies for Maryland?
- Source-sink matching.
- Economic ranking of technologies and sources.
- Feasibility, FEED studies.
- Policy support.



Provided by the Global CCS Institute

MRCSP
MIDWEST REGIONAL
CARBON SEQUESTRATION
PARTNERSHIP

BATTELLE