DOE/NETL Existing Plants Program
Post- and Oxy-combustion CO$_2$ Capture

Timothy Fout, Project Manager
Existing Plants Program
U.S. DEPARTMENT OF ENERGY • OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
Innovation for Existing Plants Program with ARRA Projects

Core R&D
- Post-combustion Capture
- Oxy-combustion
- CO₂ Compression
- National Carbon Capture Center
- Water Management
- Air Toxics, Mercury

ARRA: Capture and Compression

Benefits
- Reduced cost of Capture/Comp.
- Reduced energy penalty
- Pilot-plant scale up

Post-Combustion
Laboratory/Bench Scale
- < 0.5 MWe
- Simulated or real flue gas
- 11 Solvents
- 4 Solid Sorbents
- 4 Membranes

Pilot Scale*
- 0.5 – 5 MWe (10 – 100 TPD)
- Coal flue gas
  - Siemens Solvent 2.5 MWe*
  - ADA Sorbent 1 MWe*
  - MTR Membrane 1 MWe*

Oxy-combustion
Laboratory/Bench Scale
- < 0.5 MWe
- 1 Corrosion Testing
- 2 Purification
- 2 Retrofit/Modeling
- 1 Chemical Looping

Pilot Scale
- 0.5 – 5 MWe (10 – 100 TPD)
  - Alstom Oxy-comb. 5 MWe*
  - Jupiter Oxygen 5 MWe
  - Praxair OTM 1 MWe*
  - Alstom CLC 1 MWe

Compression
Pilot Scale
- > 0.5 MWe
  - Ramgen 13,000 hp*
  - SwRI 3,000 hp

National Carbon Capture Center
Pilot Scale
- Up to 1 MWe
  - 0.5 MWe Solvent Test Unit
  - Slipstream Test Header

No active R&D in 2011 and 2012

*ARRA Funded Projects
Advanced CO$_2$ Solvents

Solvent R&D Focus
- High CO$_2$ working capacity
- Optimal regeneration energy
- Low heat capacity
- Fast kinetics
- Thermally and chemically stable
- Non-corrosive, environmentally safe

Solvent Technologies
- Novel high capacity oligomers
- Ionic liquids
- Potassium carbonate
- Phase change solvents
- Bicarbonates/additives
- Amino Acids
- Enzymes

Partners:
1. GE Research Corporation (Polymers)
2. Akermin (Enzymes)
3. Ion Engineering (IL/Amine mixtures)
4. Siemens Energy (Amino Acids)
5. University of Notre Dame (IL)
6. Georgia Tech. (IL)
7. Illinois St. Geological Survey (Carbonate)
8. 3H (Phase change)
9. Lawrence Berkeley Nat. Lab. (Bicarbonate, ILs)
10. NETL (ILs, Phase change, Molecular simulations)

Status:
- 2011: Designing 2.5 MWe slipstream
- 2016: 10 – 25 MWe Pilot Scale
- 2018: Demonstration Scale
CO₂ Solvent Progress: Pilot Scale
Siemens POSTCAP Amino Acid

2.5 MWe Amino Acid Solvent slipstream at TECO’s Big Bend Station
- Amino acid salt (AAS) designed to operate in a conventional absorption/scrubbing system, however lab test showed:
  - Less corrosion than MEA
  - Lower volatility than MEA
  - Lower regeneration than MEA (2.64 GJ/tonne CO₂ vs 4.25)
  - Capacity similar to hindered amine
  - Moderately better than MHI’s hindered amine
- Systems analysis shows 44% increase in COE
- 5000 hours of bench-scale operation

Maturity: Design Phase
Commission in 2013
Complete in 2014

Competitively Selected
ARRA Funded $15 MM
Advanced CO₂ Sorbents

Sorbent R&D Focus
- High CO₂ working capacity + Low Cp
- “Ideal” ΔHrxn
- Fast reaction kinetics
- Durability: Thermal, chemical, mechanical
- Gas/solid systems
  - Low pressure drop, heat management

Partners:
1. University of Akron (amine functionalized metal zeolites)
2. ADA-ES (amine, zeolites, process design)
3. SRI International (Carbon-based)
4. TDA (Alumina)
5. NETL ORD (Supported amines)

Project Types
- Supported amines (silica, clay)
- Metal zeolites
- Carbon-based
- Alumina
- Sorbent systems development

Status
- 2011: Running 1 kW pilot scale and designing 1 MWe Pilot (ADA-ES)
- 2016: 10 – 25 MWe Pilot Scale
- 2020: Demonstration Scale
CO₂ Sorbent Progress: Lab and Pilot-scale

**ADA-ES, Inc.**

- Evaluate performance of 100+ CO₂ capture sorbents at bench-scale using simulated flue gas

- 1 kW pilot-scale slip-stream tests at 3 field-sites:
  - Luminant Martin Lake: Lignite
  - Xcel Energy Sherco: PRB
  - NCCC Alabama Power Gaston: Bituminous

- **Scale-up 1 MWe Pilot Plant — ARRA $15 MM**
  - 2011 Design Phase, Complete in 2015
  - Significant coordination with Carbon Capture Simulation Initiative
Advanced Flue Gas CO$_2$ Membranes

Membrane Advantages
- Simple operation; no chemical reactions, no moving parts
- Tolerance to acid gases & O$_2$
- Compact, modular → small footprint
- Builds on existing technology at similar scale (NG purification)

Membrane Approaches
- Spiral wound
- Hollow fiber
- Cryogenic membrane separation
- Membrane/solvent hybrid

Partners:
1. Membrane Technology Research (MTR)
2. RTI International
3. Air Liquide
4. Gas Technology Institute

Status
Today: 1 Ton/day slipstream (MTR)
2011: 1 MWe Pilot Scale
2015: 5 – 25 MWe Pilot Scale
2018: Demonstration Scale
Post-Combustion CO₂ Membrane Progress

2008
Performance Targets Met
CO₂/N₂ Selectivity ~50
Permeance >1000gpu

2009-2010
Flue Gas Slip-stream Test
1 TPD CO₂, 3 month
APS Cholla Plant

Is it competitive?

1 Mwe Slipstream Pilot
• ARRA Funded $15 MM
• Design 2011-2012
• Commission 2014
• Complete 2015

2010
Systems Analyses
Energy Penalty 20%
COE Penalty ↓ from 85% to 50%

Pulverized Coal Oxyfuel Combustion
Technology Opportunities

Cheap Oxygen
Oxygen Membranes

Coal + O₂ → CO₂ + H₂O

Advanced MOC*
Reduce CO₂ Recycle
Handle High Sulfur Con.

ASU

95-99% O₂

PC Boiler (No SCR)

Steam

Power

Bag Filter

Wet Limestone FGD

Recycle

Compressor

(15 – 2,200Psia)

CO₂

Ash

Coal

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

Co-Sequestration
Multi-pollutant capture
Pulverized Coal Oxy-combustion

Challenges
- Cryogenic ASUs are capital and energy intensive
- Existing boiler air infiltration
- Corrosion and process control
- Excess O₂ and inerts (N₂, Ar) ↑ CO₂ purification cost

Oxycombustion R&D Focus
- New oxyfuel boilers
  - Advanced materials and burners
  - Corrosion
- Retrofit existing air boilers
  - Air leakage, heat transfer, corrosion
  - Process control
- Low-cost oxygen
- CO₂ purification
- Co-capture (CO₂ + SOx, NOx, O₂)

Partners:
1. Praxair (O₂ Membrane, CO₂ Purification)
2. Jupiter Oxygen (Burners)
3. Alstom (Pilot plant)
4. Foster Wheeler (Corrosion)
5. Reaction Engineering Int. (Retrofit)
6. Southern Research Institute (Retrofit)
7. NETL ORD (Modeling, CO₂ Purification)

Status
Today: 5 MWe T-fired pilot (Alstom)
5 MWe burner pilot (Jupiter)
by 2015: 1st Gen (Cryogenic) demo.
2020: 2nd Gen demonstration*

PC Oxycombustion Progress

Tangential-Fired Boiler Oxycombustion:
- Continue pilot testing in 2011
- 5 MWe scale with CO₂ recycle
- 3 coal types (Bit, sub-bit and lignite)
- Test matrix to assess: furnace staging, excess oxygen, air-leakage, reduced loads, variable recycle rates, various nozzle tips
- Process control—balancing boiler pressure with CO₂ recycle
- Engineering scale-up design to 250 MWe

CO₂ Purification Slip-Stream Test:
- 2-stage compression/purification
- Removes SOx, NOx, O₂, & Inerts

Alstom Power

Air Products

Flue Gas
Oxycombustion: Chemical Looping

Chemical Looping Advantages:
- Oxy-combustion without an O₂ plant
- Potential lowest cost option for near-zero emission coal power plant <20% COE penalty
- New and existing PC power plant designs

Key Challenges
- Solids transport
- Heat Integration

Key Partners (2 projects): Alstom Power (Limestone Based), Ohio State (Metal Oxide)

Status
2011 Alstom Pilot test (1 MWe)
- 1000 lb/hr coal flow
- 1st Integrated operation
- 1st Autothermal Operation

Oxy-Firing without Oxygen Plant
- Solid Oxygen Carrier circulates between Oxidizer and Reducer
- Oxygen Carrier: Carries Oxygen, Heat and Fuel Energy
- Carrier picks up O₂ in the Oxidizer, leaves N₂ behind
- Carrier Burns the Fuel in the Reducer
- Heat produces Steam for Power

Air Reactor (Oxidizer)
CaS + 2O₂ \rightarrow CaSO₄ + Heat

Air Reactor Oxidizer

CaS + O₂ \rightarrow CaSO₄

Air

CaS

Fuel Reactor (Reducer)
CaSO₄ + 2C + Heat \rightarrow 2CO₂ + CaS
CaSO₄ + 4H₂ + Heat \rightarrow 4H₂O + CaS

Fuel

CO₂ + H₂O

Fuel Reactor Reducer

Ox

CaSO₄

2000°F

Red

1700°F

MB HX

Air Reactor Oxidizer

O₂

N₂ + O₂

Steam

CaS

Oxidizer and Reducer

Solid Oxygen Carrier

Fuel

Steam for Power
Advanced CO₂ Compression

**R&D Focus**
- Reduce capital costs
- Increase efficiency
- Integration with CO₂ capture process
- Modeling
- Heat recovery
- Reduced footprint

**Projects:**
- Ramgen & Dresser Rand Shockwave Compression
  - $30 MM DOE funded via ARRA
  - 13,000 hp demonstration test in 2012
- Southwest Research Institute (SwRI) – Initiated phase 3 pilot project combining ‘isothermal’ compression to 250 Psi followed by pumping to 2200 psi.
National Carbon Capture Center at the Power Systems Development Facility (PSDF)
Managed by Southern Company Services, Inc

Goal
Develop technologies under realistic conditions that will reduce the cost of advanced coal-fueled power plants with CO₂ capture.
For More Information About the NETL Existing Plants Program

- NETL website: www.netl.doe.gov
- Office of Fossil Energy website: www.fe.doe.gov

Reference Shelf
- Annual CO₂ Capture Meeting

Tim Fout
Project Manager,
Innovation for Existing Plants
National Energy Technology Laboratory
U. S. Department of Energy
(Tel) 304 285-1341
timothy.fout@netl.doe.gov