Carbon Capture Technology

Strategies

ARPA-E Carbon Capture and Conversion Workshop
Howard Herzog
MIT
October 29, 2009

Howard Herzog / MIT Energy Initiative
Today’s Technology

- Amines, primarily Monoethanolamine (MEA)
- Invented in 1930
- Hundreds of processes in operation
  - Most industrial gas clean-up (natural gas, hydrogen, etc.)
- Experience on power plant exhaust about 20
  - Largest size about 1,000 tonnes per day (tpd)
    » 1,000 tpd equivalent to 50 MW coal-fired power plant
  - More experience on gas than coal

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CO₂ Capture at a Power Plant

Source: ABB Lummus
Poteau, OK – 200 tpd

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Challenges for Today’s Technology

- **Costs for GHG mitigation**
  - Starts at $60-65 per tonne CO₂ avoided (4¢/kWh) for coal
  - Add first mover costs
  - Add premium for retrofits

- **Large contributor to cost is parasitic energy load**
  - ~25% loss of output for a power plant capturing 90% of CO₂ in exhaust gas

- **Critical challenge for PCC** – reducing the parasitic energy load

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Improving CO$_2$ Capture Technology

- Two primary approaches
  - Improved PCC technology
    - Improved solvents
    - Improved process design
  - Change process to make capture easier
    - Oxy-combustion
    - Pre-combustion

Post-Combustion Capture is critical technology for:
(1) Existing coal-fired power plants
(2) Existing and new gas-fired power plants
Post-Combustion Capture Technology Options

- MEA
- Improved Amines
  - Mixed amines
  - Hindered amines
  - Additives (e.g., piperazine)
- Other solvents (e.g., ammonia)
- Adsorption or membranes
- Other options
  - Biomimetic approaches (e.g., carbonic anhydrase)
  - Microalgae
  - Cryogenics/ phase separation
- Structured and Responsive Materials
Structured and Responsive Materials

- Opportunities for advanced technologies
  - Greater reliance on entropic rather than enthalpic interactions
  - Minimization of large thermal swings for regeneration
    - Stimuli-responsive materials to modify separation environment
    - Use of non-thermal regeneration methods (e.g., electric swing)

Courtesy Alan Hatton
Examples of Structured and Responsive Materials

- **Adsorbents**
  - Metal-Organic Frameworks (MOFs)
  - Zeolitic Imidazolate Frameworks (ZIFs)
  - Functionalized Fibrous Matrices
  - Poly(Ionic Liquids)

- **Absorbents**
  - CO$_2$ Hydrates
  - Ionic Liquids
  - Liquid Crystals

Courtesy Alan Hatton
Oxy-combustion 30 MWth Pilot Plant

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Oxygen Production

• Today
  ▪ Cryogenic Air Separation Unit (ASU)
  ▪ Largest size – 4,000 tpd

• Improved ASUs
  ▪ Oxygen purity (95-97%)
  ▪ Pressure (1.3-1.7 bar)
  ▪ Low power
  ▪ Large scale

• Ionic Transport Membranes
  ▪ Current scale = 5 tpd
  ▪ Stand-alone (heat and temperature recovery)
  ▪ Integrate in process (reduce \( \text{O}_2 \) partial pressure on permeate side)
Oxy-Boilers

- **Synthetic Air**
  - Requires flue gas recycle
  - First tested in mid-1980s
  - No changes to water/steam system
  - Minimum changes to boiler
  - Air enleakage an issue for retrofits

- **Oxy-Burners**
  - Used in glass, metals, cement, waste treatment

- **Oxy-boilers**
  - Eliminate external recycle
  - Higher efficiency
  - Pressurized operation?
CO₂ Purification

- **Flue Gas**
  - 60-70% CO₂ (Air enleakage biggest unknown)
  - Particulate matter must be removed
  - Non-condensibles and water removed during compression

- **Criteria pollutant control**
  - Co-sequester
  - Modify current equipment
  - Remove during compression as acids

- **High recovery, high purity systems**
  - Distillation
  - Membranes
## RD&D Pipeline for a 8-10 Year RD&D PCC Program

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<tr>
<th>Stage</th>
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<th>Notes</th>
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<td>Exploratory (~$1 MM each)</td>
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<td>Proof of Concept (~$10 MM each)</td>
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<td>Pilot Plants (~$50 MM each)</td>
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<td>Demonstrations (~$1,000 MM each)</td>
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Commercial Technologies

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Closing Thoughts

- Allow room for people to explore
- Avoid stove-piping
- Understand lifecycle considerations
- Create a transition from ARPA-E to other programs as technology advances
- Don’t forget fundamental principals
Obama visit to MIT
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Howard Herzog / MIT Energy Initiative
Contact Information

Howard Herzog
Massachusetts Institute of Technology (MIT)
Energy Initiative
Room E19-370L
Cambridge, MA 02139
Phone: 617-253-0688
E-mail: hjherzog@mit.edu
Web Site: sequestration.mit.edu