US DOE Activities – Overview to the Support of Oxyfuel Combustion Development

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September 11, 2013
Advanced Combustion Systems Program

**Approach:** Combustion of fossil fuels in oxygen, rather than air, presents opportunity to simplify CO\(_2\) capture in power plant applications.

**Why Oxy-fuel Combustion?**

- Flue gas has a high concentration of CO\(_2\), with only water and trace contaminants from the fuel...
  - *Eliminates cost and energy requirements of a large post-combustion CO\(_2\) capture system, simplifying preparation of CO\(_2\) for storage or beneficial use.*

- In pressurized oxy-combustion, the mass and volume of flue gas are reduced, latent heat is recoverable, and heat transfer rates are increased...
  - Reduces heat lost in flue gas...*increases efficiency.*
  - Reduces equipment size...*decreases capital costs.*

- In chemical looping, oxygen is separated from air in the process, *eliminating the need for oxygen production*...
  - *Reduces system cost and parasitic energy demand.*
Advanced Combustion Program Overview

**ADVANCED ENERGY SYSTEMS**

**TECHNOLOGY AREAS**
- Gasification Systems
- Advanced Combustion Systems
- Advanced Turbines
- Solid Oxide Fuel Cells

**KEY TECHNOLOGIES**
- Oxy-Combustion
- Chemical Looping Combustion
- Advanced Materials

**RESEARCH FOCUS**
- Atmospheric Pressure Oxy-Combustion
- Pressurized Oxy-Combustion
- O₂ Membrane Advanced Power System
- Chemical Looping Combustion
- A-USC Oxy-Combustion Materials
- Integrated High-Temperature/Pressure Combustion System Materials

[Image: FOSSILENERGYGOV]
Advanced Combustion Systems Program Projects

**Oxy-combustion**
- **Design/Laboratory Testing**
  - 5 Projects
  - (Pressurized Oxy)
- **SwRI**
  - (incl SCO2 Cycle)
- **Pratt & Whitney**
  - (Aerojet) Rocketdyne
- **Unity Power Alliance**
- **Gas Technology Inst.**
- **Washington University**

**Chemical Looping**
- **Design/Laboratory Testing**
  - 3 Projects
- **University of Kentucky**
- **Alstom Power, Inc.**
- **Babcock & Wilcox**
  - (Ohio State)

**Advanced Materials**
- **Laboratory/Bench Scale**
  - 12 Projects
- **Energy Industries of Ohio**
  - (2)
- **Idaho National Lab**
  - (1)
- **Pacific Northwest National Lab**
  - (2)
- **Ames National Lab**
  - (1)
- **Oak Ridge National Lab**
  - (6)
- **NETL - ORD Projects**

**Lab/Bench/Pilot Scale**
- < 0.5 Mwe & 1.2 MWe
- **Reaction Engineering Intl**

**Pilot Scale**
- 0.5 – 5 MWe
- **Alstom Oxy-comb** – 5 MWe
- **Praxair OTM** – 1 MWe

- **3 Projects**
- **University of Kentucky**
- **Alstom Power, Inc.**
- **Babcock & Wilcox**
  - (Ohio State)

- **Ohio State**

- **5 Projects**
- **Pratt & Whitney**
  - (Aerojet) Rocketdyne
- **Unity Power Alliance**
- **Gas Technology Inst.**
- **Washington University**
**Pressurized Oxy-Combustion**

**Key Advantages**

General
- Nearly 100% CO₂ Capture
- Smaller footprint and O₂ demand (ASU)
- Lower fuel use and water demand, and less solid waste
- Supports SCO₂ Cycles and Direct Power Extraction

Boiler-specific
- Improved heat transfer rate
- Compact
- No air in-leakage

**R&D Challenges**

Pressurized Combustor Design
- Boiler configuration/type
- Combustion characteristics
- Pressure containment
- Advanced materials
- Heat transfer
- Thermal Integration
- Fuel feed
- Fuel conditioning
- Gas cleaning
- Flue gas recycle

**System/Process Design**
- Gas cleaning
- Thermal integration
- Advanced materials
- Process optimization
Pressurized Oxy-Combustion

↓ Capture >$15/tonne
↓ COE >10%
↑ Efficiency 3-5 percentage points

Potential High-Value Pathway: Not in Current Program
Supports Direct Power Extraction

Current Projects
- Gas Technology Institute Molten Bed Combustion
- Pratt and Whitney (Aerojet) Rocketdyne Pressurized Fluidized Bed
- Southwest Research Institute Oxy with SCO2/Cryogenic Compression
- Unity Power Alliance Flameless Reactor
- Washington University Staged High Pressure System

* Demonstrations not funded under Advanced Combustion Program
# Chemical Looping Combustion

## Key Advantages
- Oxy-firing without ASU
- High CO₂ concentration exhaust
- Potential for high-efficiency
  - >45%
  - Supports SCO₂ Cycles
- Capture without additional external energy (eliminates thermodynamic penalty)
- Reduced equipment size (fast chemical reactions) lowers capital cost
- Uses conventional material of construction and fabrication techniques

## R&D Challenges

### Oxygen Carrier
- Composition
- Density
- Reaction kinetics
- Oxygen carrying capacity
- Fluidization properties
- Attrition
- Agglomeration
- Sintering
- Degradation

### Solids Circulation
- Dilute pneumatic
- Dense pneumatic
- Mechanical
- Flow control
- Mechanical valves
- Non-mechanical valves
- Uncontrolled

### System/Process Design
- Gas cleaning
- Process optimization
- Thermal integration

### Reactor Design
- Gas cleaning
- Process optimization
- Thermal integration

### R&D Challenges
- Solids Circulation
- System/Process Design
- Reactor Design
Chemical Looping Combustion

- Capture >$15/tonne
- COE >10%
- Efficiency 3-5 percentage points

2012 Project Awards
10+ MWe Pilot

Current Projects
- Alstom Power Calcium-Based Chemical Looping
- Babcock and Wilcox/Ohio State Coal Direct Chemical Looping
- University of Kentucky Pressurized Chemical Looping

* Demonstrations not funded under Advanced Combustion Program
Chemical Looping R&D is Advancing Worldwide

U.S. Chemical Looping

Design/Laboratory Testing
- University of Kentucky
- Alstom Power, Inc.
- Babcock & Wilcox (Ohio State)

Laboratory/Bench Scale
- Ohio State – 25 kWth

Pilot-Scale
- Alstom Power – 3 MWth

Worldwide Chemical Looping

PDU-Scale
- FRC-UBC Canada – 50 kWth
- ITRI Taiwan – 30 kWth
- Southeast University China – 10 kWth
- Vienna UT Austria – 120 kWth
- Chalmers Sweden – 100 kWth
- KIER Korea – 50 kWth
- BIGCO2 – SINTEF Norway – 100 kWth
- CSIC Zargoza Spain – 10 kWth

Pilot-Scale
- TU Darmstadt Germany – 1 MWth
Advanced Materials and Concepts

Key Technology

Advanced Materials and Concepts

ACS Program Contribution to Overall Goal

2010

Cost and efficiency improvements associated with A-USC Boiler Conditions and Supercritical CO₂ Power Cycle

A-USC Oxy-Combustion Materials Testing/Modeling

Integrated High-Temperature/Pressure Combustion System Materials

Alloy Development/Advanced Concepts

Current Projects

Energy Industries of Ohio (2 projects)

Idaho National Lab

Pacific Northwest National Lab (2 projects)

Ames National Lab

Oak Ridge National Lab (6 projects)

NETL - ORD

Direct Power Extraction (DPE)

\[ P_{\text{out}} \propto \sigma u^2 B^2 \]

where \( B \) is applied magnetic field

\( \sigma \) is gas/plasma conductivity

\( u \) is gas/plasma velocity

Advanced Ultra-Supercritical Boiler Conditions

- Temperature: 1400°F
- Pressure: 5000 psig
- Efficiency Improvement: 3 percentage points
- Cost Reduction: $2/tonne

Supercritical CO₂ Power Cycle

- Efficiency Improvement: 4 percentage points
- Cost Reduction: $9/tonne
Program Accomplishments

Integrating advances from fundamental research through bench- and pilot-scale technology development

Pilot-Scale Tests
- Alstom 5-MWe Oxy-Combustion Pilot
- Alstom 1-MWe CLC Pilot
- NETL-ORD CLC Reactor
- OSU CDLC 25-kWth Reactor
- Jupiter Oxygen 5-MWe Oxy-Combustion Pilot
- B&W 30-MWth Oxy-Combustion Burner Testing

Simulation & Modeling
- NETL-ORD ICMI CLC
- University of Utah Reaction Engineering

Flue Gas Purification Systems
- Air Products PDU
- Praxair PDU

Boiler & Burner Development
- Southern Research Institute
- Reaction Engineering International

Materials
- Foster Wheeler
- NETL-ORD
Thank You

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