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

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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.**

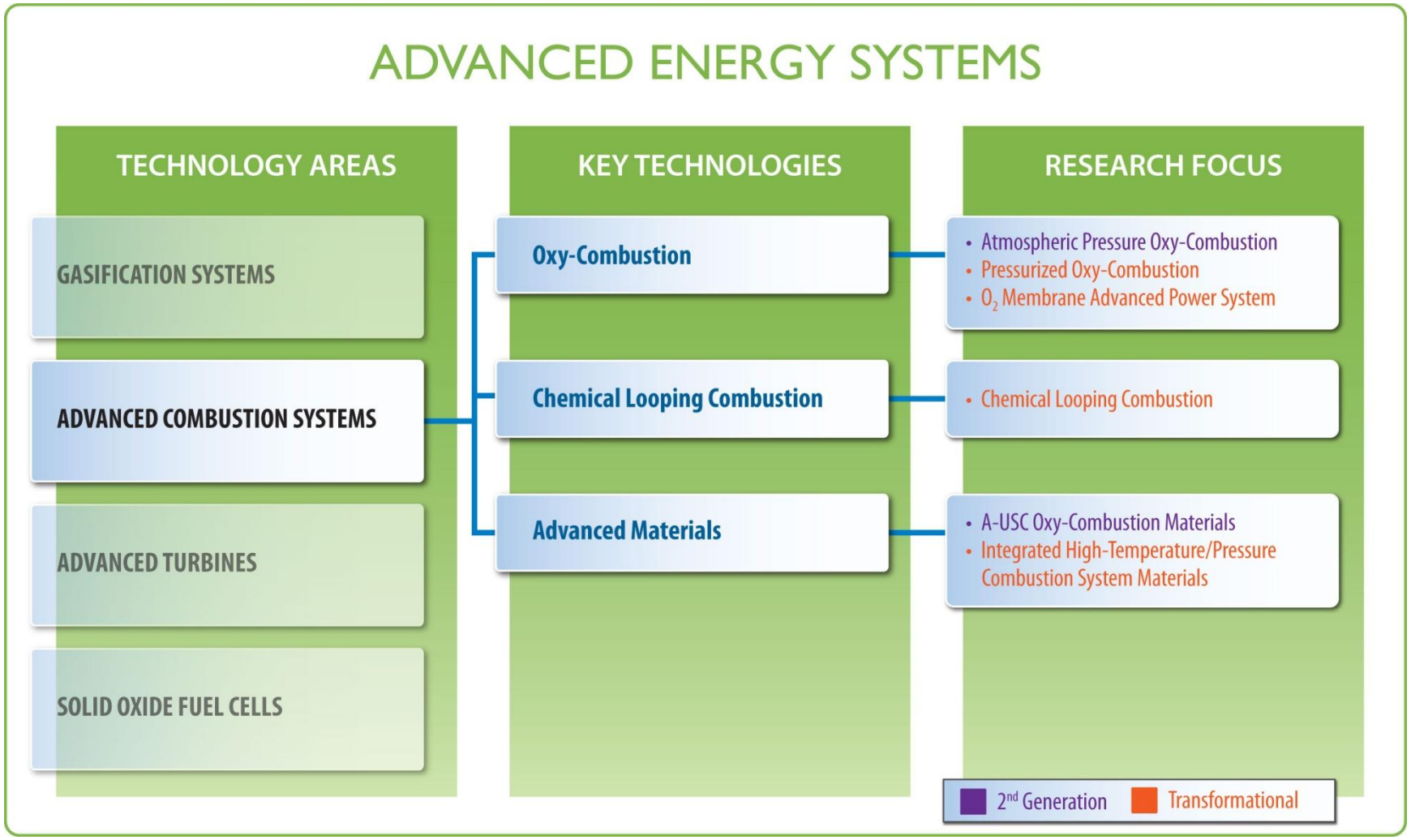
Why Oxy-fuel Combustion?

- 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 Combustion Systems Program Projects

Oxy-combustion

Design/Laboratory Testing

5 Projects

(Pressurized Oxy)

- SwRI (incl SCO_2 Cycle)
- Pratt & Whitney (Aerojet) Rocketdyne
- Unity Power Alliance
- Gas Technology Inst.
- Washington University

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

Chemical Looping

Design/Laboratory Testing

3 Projects

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

Laboratory/Bench Scale

< 0.5 MWe

- 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

Pressurized Oxy-Combustion

Key Advantages

General

- Nearly 100% CO_2 Capture
- Smaller footprint and O_2 demand (ASU)
- Lower fuel use and water demand, and less solid waste
- Supports SCO_2 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

2010 | 2020 | 2030

↓ Capture >$15/tonne

↓ COE >10 %

↑Efficiency 3-5 percentage points

Pressurized Oxy-Combustion

Design/Lab Tests

Pilot Scale

10+ MWe Pilot

Demo. *

Downselect

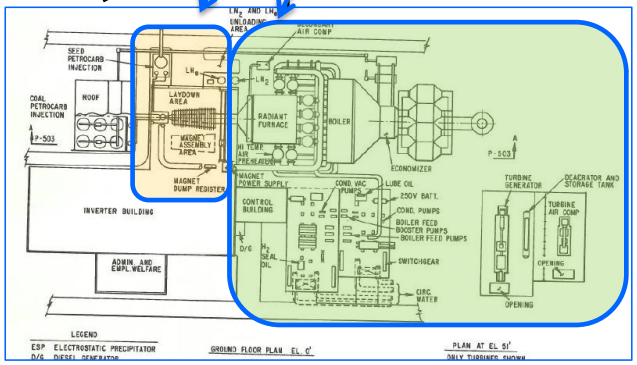
Current Projects
Gas Technology Institute Molten Bed Combustion
Pratt and Whitney (Aerojet) Rocketdyne Pressurized Fluidized Bed
Southwest Research Institute Oxy with SCO2/Cryogenic Compression
Unity Power Alliance Flameless Reactor
Washington University Staged High Pressure System

Potential High-Value Pathway: Not in Current Program

Supports Direct Power Extraction

Added MHD power

Existing powerplant



** Demonstrations not funded under Advanced Combustion Program*

Chemical Looping Combustion

Key Advantages

- Oxy-firing without ASU
- High CO_2 concentration exhaust
- Potential for high-efficiency
  - >45%
  - Supports SCO_2 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

Reactor Design

- Gas cleaning
- Process optimization
- Thermal integration

Solids Circulation

- Dilute pneumatic
- Dense pneumatic
- Mechanical
- Flow control
- Mechanical valves
- Non-mechanical valves
- Uncontrolled

System/Process Design

- Gas cleaning
- Process optimization
- Thermal integration
- Heat transfer strategy

Chemical Looping Combustion

2010 | 2020 | 2030

↓ Capture >$15/tonne

↓ COE >10 %

↑Efficiency 3-5 percentage points

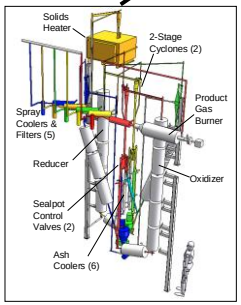
Research/Lab Testing

Pilot-Scale

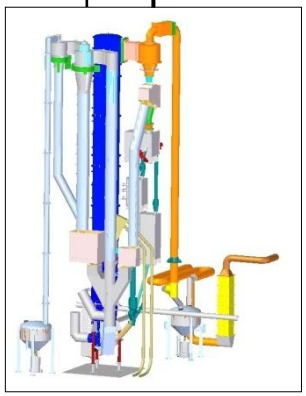
10+ MWe Pilot

Demo. *

2012 Project Awards



Alstom 65 kWth (2008)



Alstom 1 MWe (2011)

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

Pilot-Scale

- TU Darmstadt Germany – 1 MWth

Advanced Materials and Concepts

Key Technology	ACS Program Contribution to Overall Goal	2010	2020	2030	2040
Advanced Materials and Concepts	Cost and efficiency improvements associated with A-USC Boiler Conditions and Supercritical CO_2 Power Cycle	A-USC Oxy-Combustion Materials: Testing/Modeling			
		Integrated High-Temperature/Pressure Combustion System Materials: Alloy Development/Advanced Concepts			

Advanced Ultra-Supercritical Boiler Conditions

- **Temperature:** 1400^0F
- **Pressure:** 5000 psig
- **Efficiency Improvement:** 3 percentage points
- **Cost Reduction:** $2/tonne

Direct Power Extraction (DPE)

$P_{out} \propto \sigma u^2 B^2$

where B is applied magnetic field
σ is gas/plasma conductivity
u is gas/plasma velocity

Supercritical CO_2 Power Cycle

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

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

Program Accomplishments

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

Pilot-Scale Tests

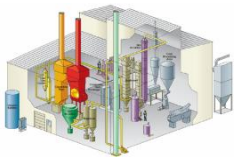
Alstom 5-MWe Oxy-Combustion Pilot

Alstom 1-MWe CLC Pilot

NETL-ORD CLC Reactor

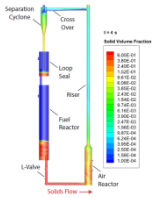
OSU CDLC 25-kWth Reactor

Jupiter Oxygen 5-MWe Oxy-Combustion Pilot

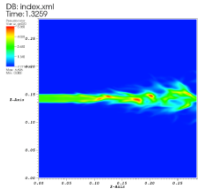


B&W 30-MWth Oxy-Combustion Burner Testing

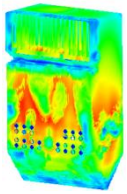
Simulation & Modeling



NETL-ORD ICMI CLC



University of Utah



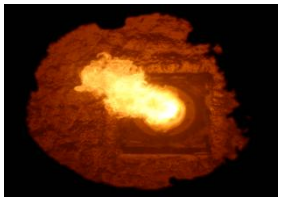
Reaction Engineering

Flue Gas Purification Systems

Air Products PDU

Praxair PDU

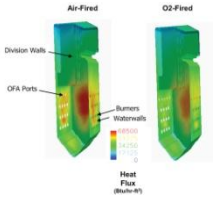
Boiler & Burner Development



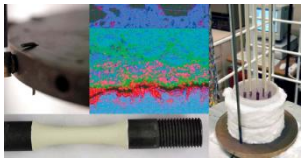
Southern Research Institute

Reaction Engineering International

Materials



Foster Wheeler



NETL-ORD

Thank You

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