Oxy-combustion Applied to Coal-fired Power Plants

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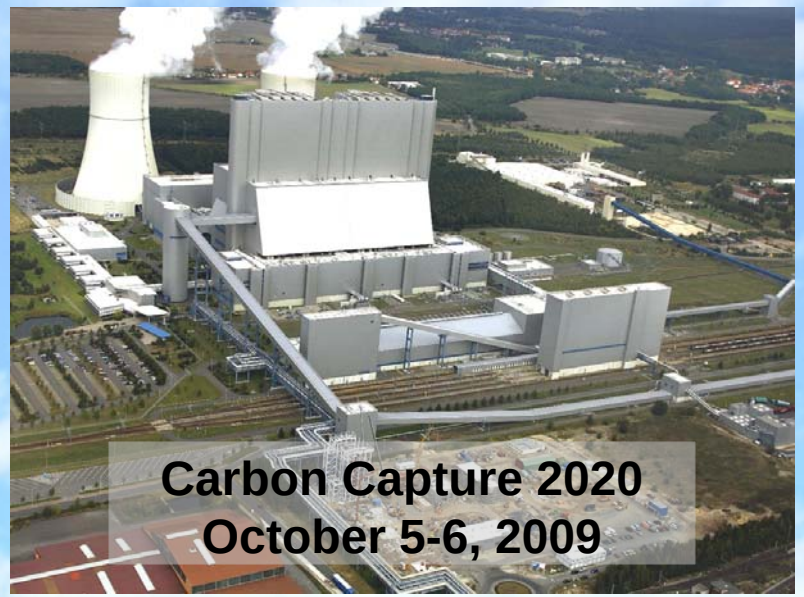


Carbon Capture 2020
October 5-6, 2009

Presentation Overview

- Oxy-combustion Concept
- Benefits and Challenges
- R&D Needs
- Ongoing R&D Programs
- Combustion Modeling
- Summary

Carbon Capture Options for Coal-Fired Power Generation

- **Pre-Combustion Control**
  - **IGCC – syngas from gasification of coal**
- **Post-Combustion Control**
  - **CO_2 capture from flue gas by sorbents, solvents, membranes**
- **Chemical Looping**
  - **Oxidation of fuel by a metal oxide**
- **Oxy-Combustion**
  - **Combustion air replaced with oxygen and recycled flue gas**

Each of these produce an enriched CO_2 stream for sequestration

History of Oxy-fuel Combustion Applications

(Adapted from Kobayashi, 2005)

1

High Temp Applications 1940-1950s

Welding
Cutting
Flame Polishing

2

Productivity Enhancement O_2 enrichment 1960-1970s

Glass
Aluminum
Cement

3

Fuel Savings Full Oxy-fuel Combustion 1980s

Incineration
Steel
Copper

4

NOx Reduction 1990-2000s

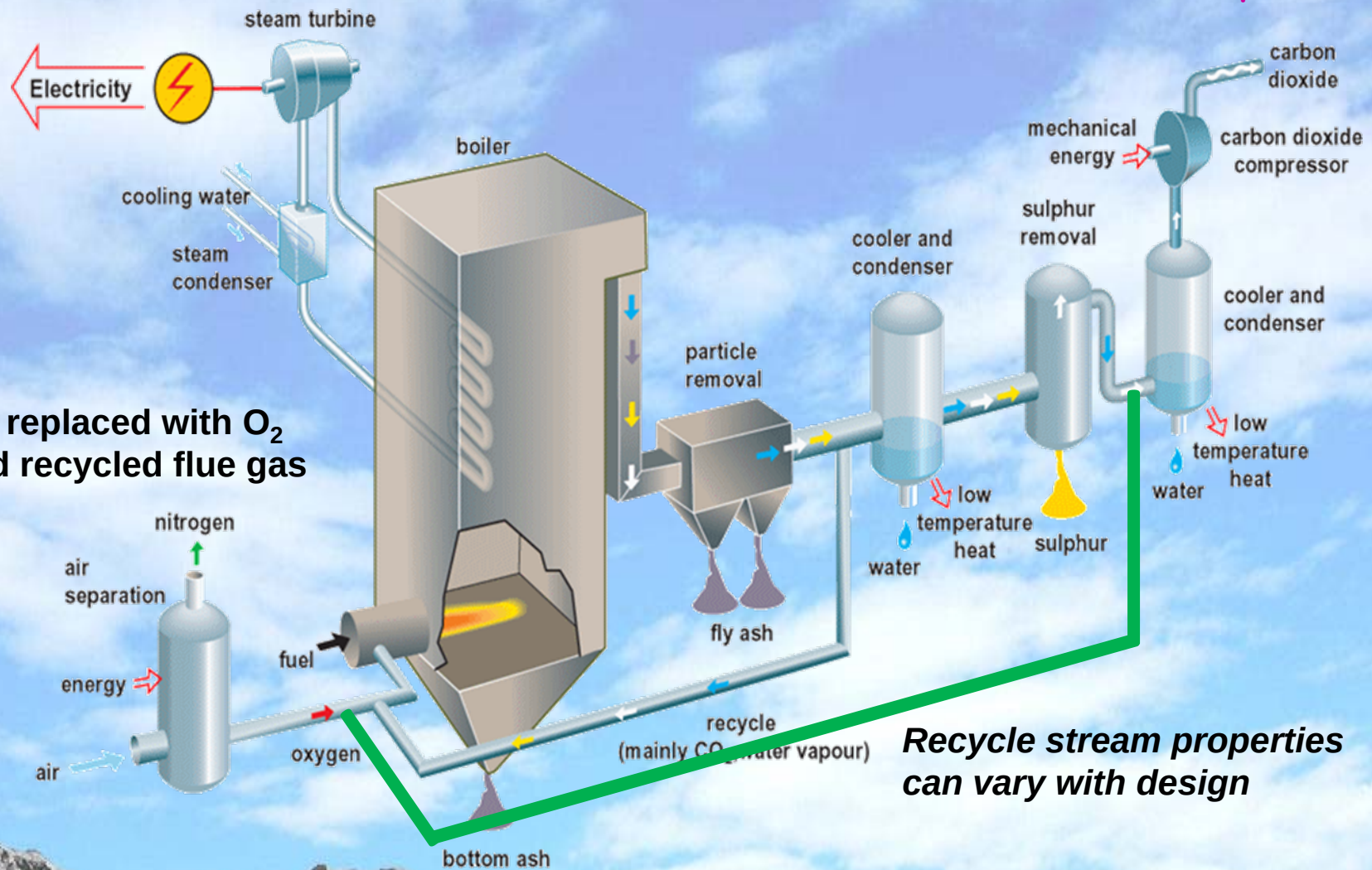
Glass Melting
(30% of US capacity)
Coal-fired boilers

5

CO_2 Reduction 2010s

Power Generation
CO_2 sequestration
(IGCC, Oxy-boilers)

Oxy-Coal Power Plant Overview

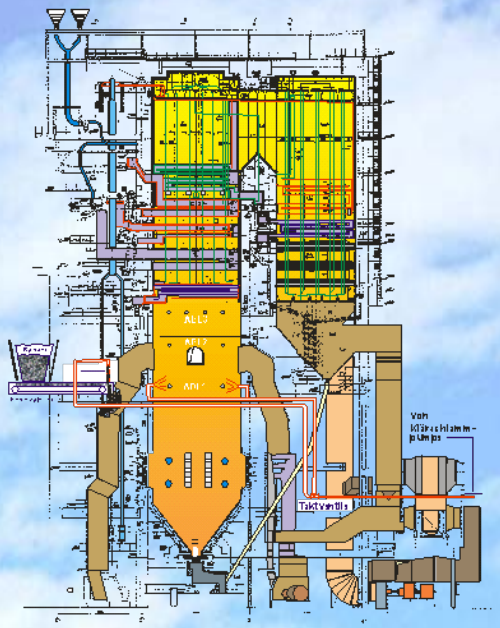


Air replaced with O_2 and recycled flue gas

Recycle stream properties can vary with design

Oxy-Combustion Advantages

- Potential for high CO_2 recovery
- Applicable to new or existing plants
  - New - more compact design
  - Existing - familiar design and operation
  - Applicable to CFB as well as PC plants
- Trace pollutant benefits
  - Lower NOx, more oxidized Hg
  - May not need to clean flue gas as thoroughly for sequestration as for air-fired units



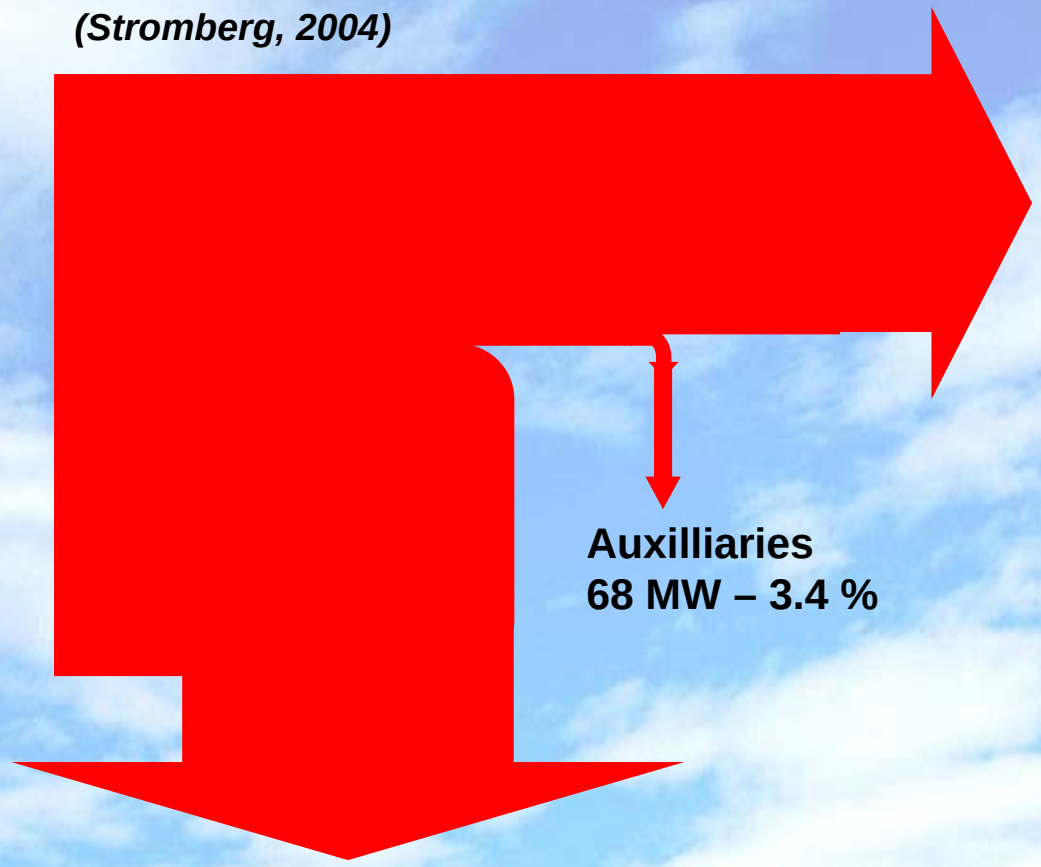
Oxy-Combustion Challenges

- **Higher plant cost**
  - **Equipment (ASU, CO_2 compressor)**
  - **Design (materials, "plumbing")**
- **Lower plant efficiency**
  - **Significant penalties from ASU and CO_2 compression**
- **Technical challenges**
  - **Balance of plant impacts**
  - **Operating availability with new technology**

(Marion, 2009)

Energy Flow Diagram for New PC Plant

(Stromberg, 2004)



Energy input
Fuel
2026 MW
100 %

Net electricity output
865 MW – 42.7 %

Auxilliaries
68 MW – 3.4 %

Cooling
1093 MW – 53.9%

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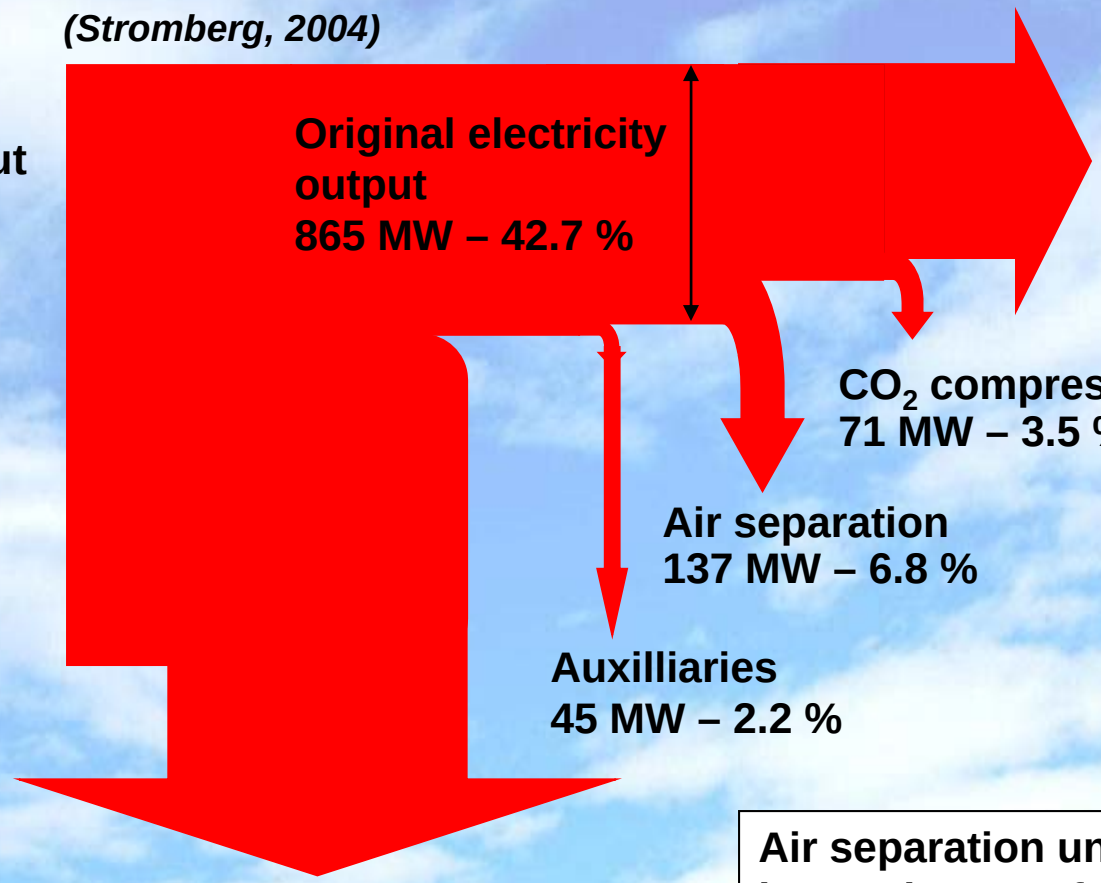
Energy Flow Diagram with Oxy-Combustion

(Stromberg, 2004)



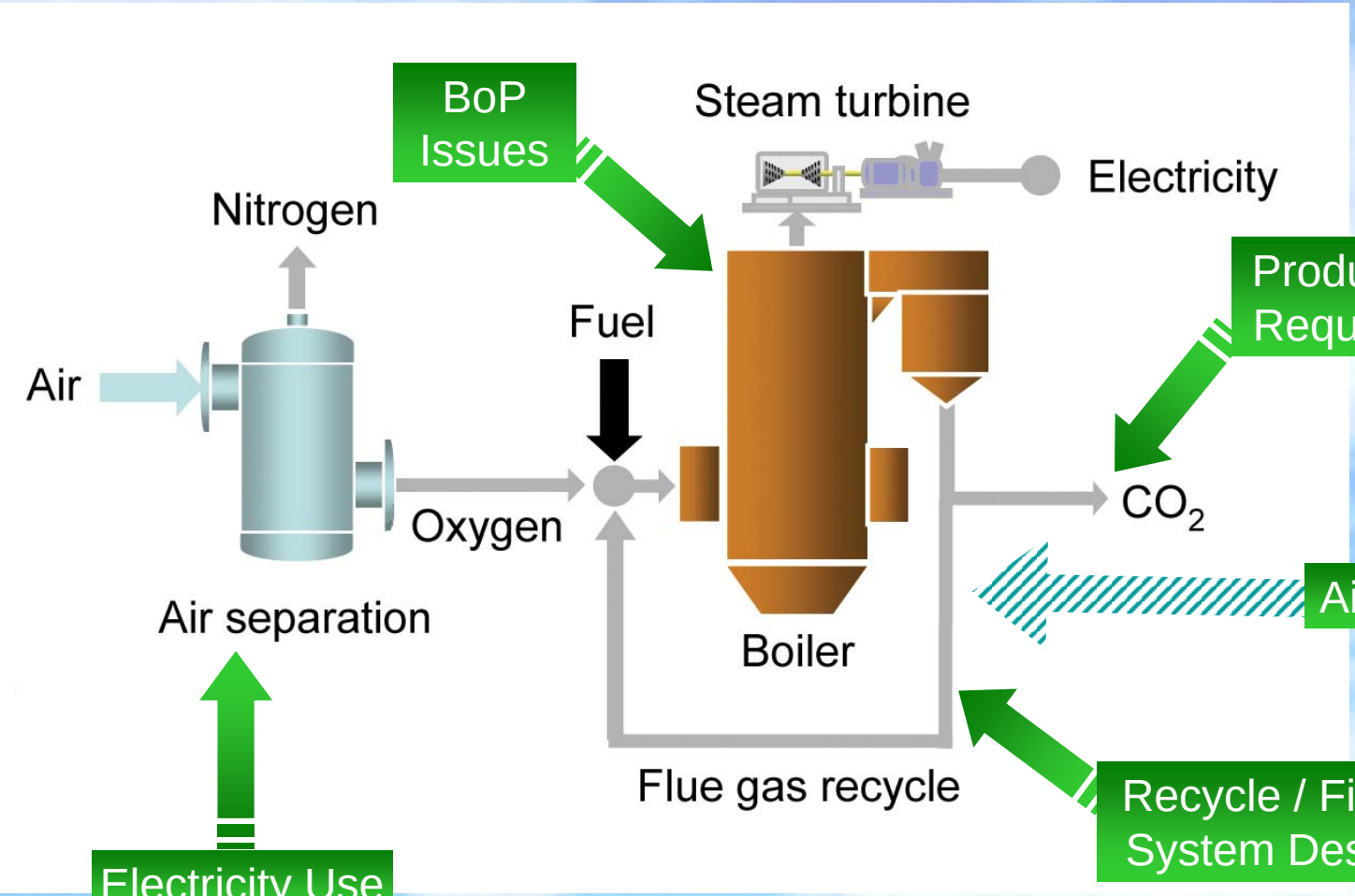
Air separation unit (oxygen supply) is a major cost for process

New Build vs Retrofit

- **Plant efficiency impacts favor new build (USC)**
  - **Not economical to pay ASU and compressor penalty if plant efficiency is already low (subcritical ~33% before retrofit)**
- **Installed generating capacity favors retrofit**
  - **~1400 coal-fired boilers**
  - **~330,000 MW of installed capacity**
  - **Average age of ~38 years**
  - **~3 *trillion* dollar investment to replace**

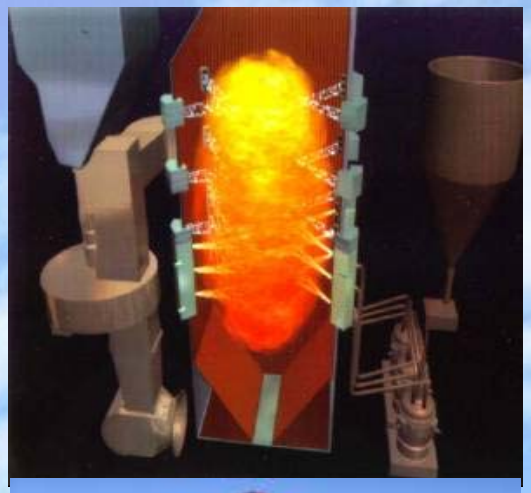
- **Utilities' choice based on individual situation**

Technical Challenges



R&D Focus Areas

- Low-cost oxygen
- CO_2 purification
- New oxy-fuel boilers
  - Advanced materials and burners
  - Compact designs (FG recycle)
  - Corrosion
- Retrofit existing air boilers
  - Air leakage
  - FG recycle / firing system
  - Process control / sensors
  - Balance of plant issues
- Modeling

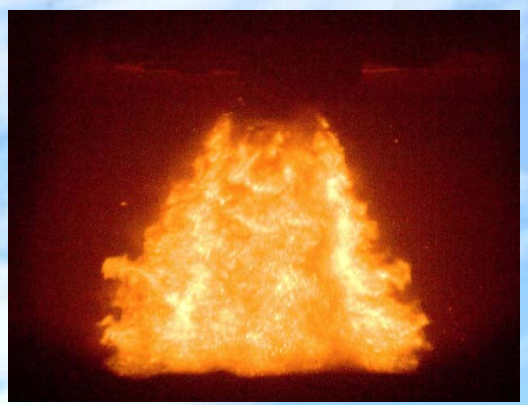


(Fout, 2009)

Balance of Plant / Combustion Issues

- Recycle rate / oxygen concentrations
- Burner aerodynamics / flame behavior
- Pyrolysis and char combustion
- NOx emissions
- Sulfur chemistry
- Radiation
- Slagging, fouling
- Corrosion

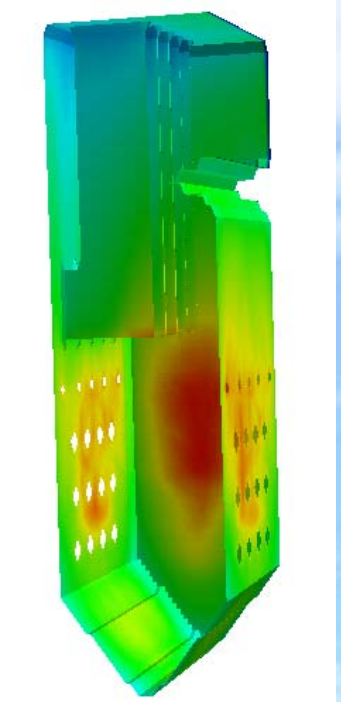
Coal + air
(Chalmers)



Coal + 27% O_2
(Chalmers)

Modeling Oxy-Combustion

- Process models useful, but CFD needed for evaluation of full-scale boilers (scale-up)
- Must account for key mechanisms
  - Flame behavior (temperature, composition, particle reactions)
  - Ash behavior (deposition, slagging, fouling)
  - Heat transfer (flame radiation, surface props)
  - Corrosion
- Must be validated
  - Mechanisms from literature and theory
  - Data from well-controlled experiments



DOE NETL Oxy-Combustion Projects

Projects

- Adv. Oxygen Production
  - Praxair
- CO_2 Purification
  - Praxair, Air Products
- Boiler Development
  - Alstom, B&W
- Corrosion
  - Foster Wheeler

Projects

- Small Pilot Scale Studies
  - Babcock & Wilcox (B&W)
  - Southern Research Inst.
  - Jupiter Oxygen
  - Reaction Engineering Intl.
  - Alstom Power

For more information:
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www.netl.doe.gov/technologies/coalpower/ewr/co2/OxyCombustion.html

REI's Oxy-Coal Research Program

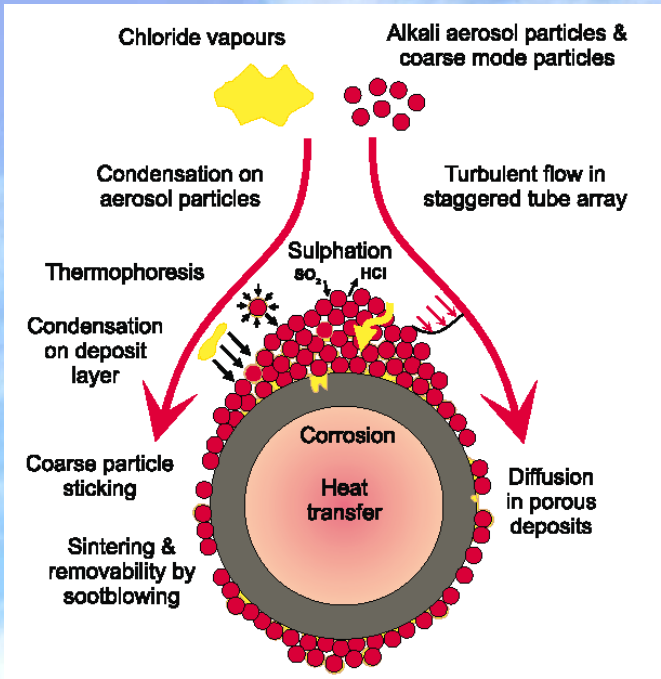
- **Objective:** ***Characterize and predict performance and operational impacts of oxy-combustion retrofit designs on existing coal-fired boilers***
- **Approach: Utilize multi-scale testing and theoretical investigations to develop:**
  - **Fundamental data that describe flame characteristics, corrosion rates, and ash properties during oxy-coal firing**
  - **Validated mechanisms that describe oxy-combustion processes**
  - **Firing system principles that guide oxy-burner design and flue-gas recycle properties**
- **Incorporate validated mechanisms into CFD software to evaluate full-scale oxy-combustion retrofit designs**

Multi-Scale Experiments

- **Bench-Scale Optical Entrained Flow Reactor**
  - Char oxidation kinetics
- **Lab-Scale 100 kW Oxy-Fuel Combustor (OFC)**
  - Ash deposition and characterization (slagging, fouling)
  - Soot evolution
- **Pilot-Scale 1.5 MW Furnace (L1500)**
  - Burner configuration impacts
  - Flame temperature and chemistry
  - Heat flux profiles
  - Corrosion
  - Ash deposition / characterization

Mechanism Development

- **Mechanisms**
  - **Flame: sooting, char oxidation, NOx**
  - **Ash: fouling, slagging,**
  - **Surface: corrosion**
- **Developed from theory and literature**
- **Validated from experimental data**
- **Correlation format**
- **Can be incorporated in CFD codes or process models**



Corrosion Process presented at "Biomass Co-firing", European Bioenergy Networks, VTT Processes, March 2003

Program Approach

Identify mechanisms and correlations

Design oxy-research burner

Conduct bench-scale, lab-scale and pilot-scale tests

Validate and update mechanisms / correlations

Update firing system design principles

Implement sub-models in CFD code

Scale-up firing system design

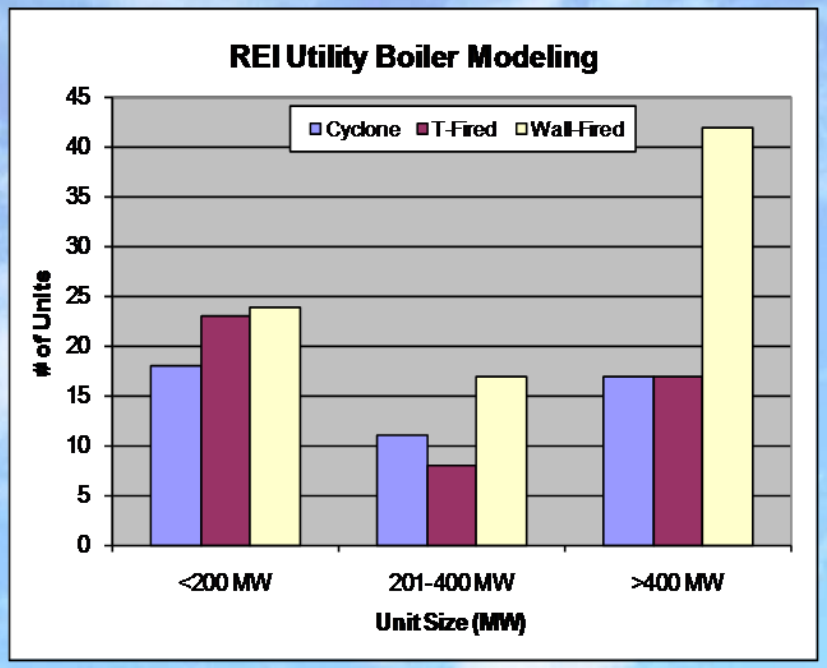
Use CFD to assess full-scale retrofit design

Design and optimization guidelines:

- Match air-fired heat duties
- Maximize combustion efficiency
- Minimize surface impacts (corrosion, slagging, fouling)
- Minimize trace pollutant emissions

REI Boiler Model

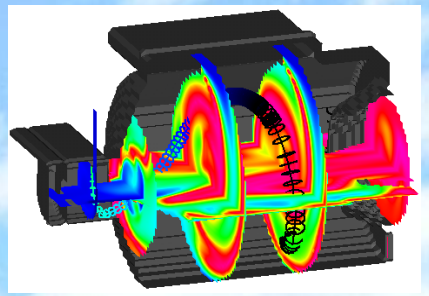
- Coal combustion code has 20+ years development and application

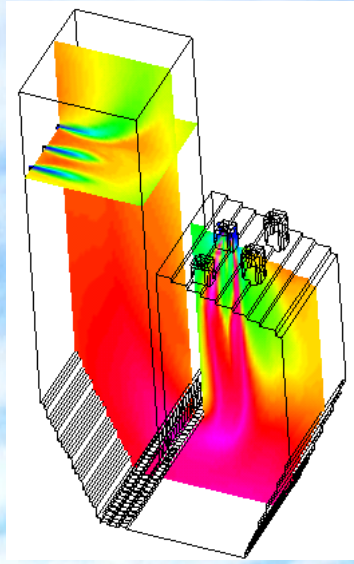


- 190+ utility boilers modeled (~75,000 MW Capacity)
  - Wall, t-fired, cyclone, turbo,
  - Coal, biomass, petcoke, tires, blends, oil, gas
- Stokers, fluidized beds, gasifiers
- Emission reduction
- Operational impacts
- Concept design

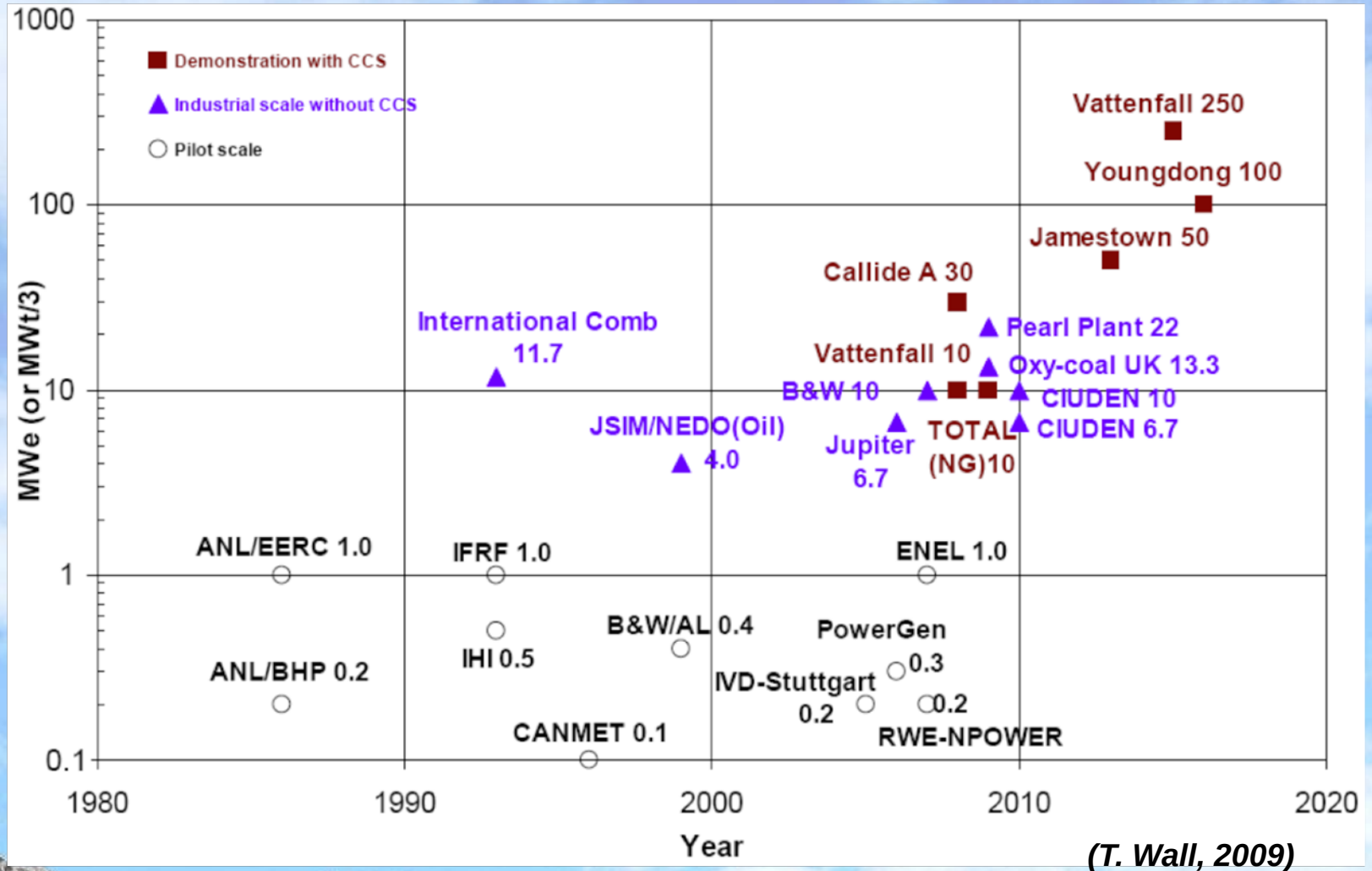
REI Modeling Guidelines

- **Successful Combustion Modeling Requires:**
  - **Capable combustion simulation tools**
  - **Capable modelers who understand**
    - **Physical combustion process**
    - **Numerical simulation process**
- **Accuracy based on:**
  - **Inputs**
  - **Numerics**
  - **Understanding of results**





Scale-Up Over Time



(T. Wall, 2009)

Pilot and Demonstration Plants

No	Demo/Pilot plant name	Scale (Demo/ Pilot plant	MW_e	New Retrofit	Start up	Main Fuel	Electricity generation (Yes/No)	CO_2 Compression (Yes/No)	CO_2 use/Seq	CO_2 purity	Gas clean up
1	Vattenfall pilot plant, Germany	P (PC)	10	N	2008	Coal	N	Y	Y (partial by truck)	99,90%	ESP, FGD
2	Babcock&Wilcox pilot plant, USA	P	10	R	2008	Coal	N		N	70% dry	SCR FF
3	Doosan Babcock, UK	P	30	NA	2008	Coal	N		N		
4	ALSTOM, Windsor, USA	P	5	R	2009	Coal	N	N	N		FF, NID
5	Jupiter Pearl plant, USA	P	22	R	2009	Coal	N	N			
6	Callide (CS Energy, Australia)	P	30	R	2010	Coal	Y	Y	N		FF
7	CIUDEN, Spain	P (PC/CFB)	10	N	2010	Coal		Y	N		SCR FF
8	Jamestown/ Praxair Plant, USA	CFB	50	N	2013	Coal	N	N			
9	Jänschwalde	D	250	N	2015	Coal	Y	Y	Y		SCR, ESP, FGD
10	Youngdong, South Korea	D	100	R	2016	Coal	Y		Y		

(G. Scheffnecht, 2009)

Summary

- **Oxy-coal combustion is a CCS technology applicable to new and existing utility boilers**
  - **Can achieve 90% CO_2 recovery**
  - **Need to reduce costs / improve efficiency**
  - **Need experience with fully operating plants**
- **Boiler impacts may include**
  - **Flame properties, heat transfer, slagging, fouling, corrosion**
- **Validated modeling tools are necessary for the design and scale-up of oxy-coal technology**
- **Several on-going R&D projects and pilot-scale demos to prove concept, test impacts and gain experience**

Acknowledgements

- REI oxy-combustion program supported by the Department of Energy under Award Number DE-NT0005288, Timothy Fout Program Manager