

REINHOLD ENVIRONMENTAL Ltd.



## **2019 NO<sub>x</sub>-Combustion-CCR Round Table Presentation**

February 11 & 12, 2019, in Salt Lake City, Utah / Hosted by PacifiCorp


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# Combustion-related Issues in the Retrofit of a Pulverized Coal Fired Boiler Utilizing Oxy-coal Technology



Kevin Davis  
Senior Principal and Co-President



NOx-Combustion-CCR Round Table  
Hosted by   
Marriott Downtown at City Creek, Salt Lake City, UT  
February 11-12, 2019



# Reaction Engineering International

*Privately held consulting firm  
recognized for independent  
analysis and evaluations involving  
a range of industrial combustion  
applications*



- Technical focus on multi-phase, chemically reacting flows
- Serving the utility industry since 1990
- Affiliates in Asia and Europe
- Established capabilities include advanced modeling, process evaluation and testing



# CCUS

- Carbon Capture, Utilization, and Storage (CCUS) refers to methods and technologies for capture of CO<sub>2</sub> from flue gas while utilizing it in a manner resulting in safe and permanent storage
- Two large demonstrations have been undertaken at coal power plants in North America during the last decade:
  - SaskPower's Boundary Dam Power Station
  - NRG's Parish Generating Station



# Petra Nova

- Partnership including NRG and JX Nippon Oil&Gas
- Commercial operation commenced December 29, 2016 on budget and on schedule
- 240 MW equivalent slipstream from Parish Unit 8
- CO<sub>2</sub> used to enhance oil recovery in West Ranch oil field
- Project cost ~\$1 billion; Substantial contributions from DOE and Japanese government; tax incentives from state of Texas; IRS Section 45Q tax credits



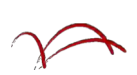
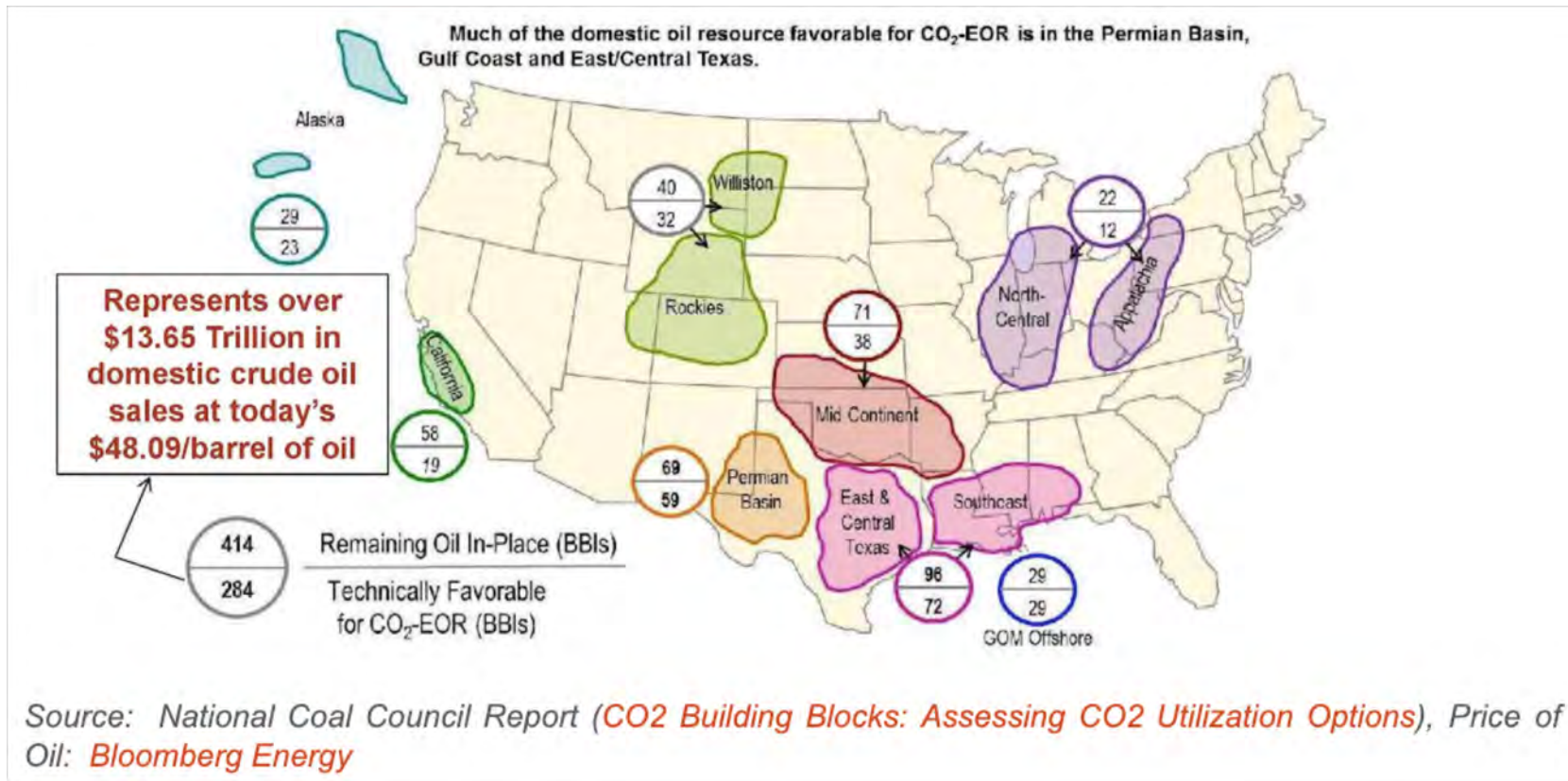
# IRS Section 45Q Tax Credit

- Originally enacted under Energy Improvement and Extension Act of 2008
  - Program is capped at 75 million tons
  - \$10/ton for qualified EOR project, \$20/ton for geological storage
  - Rates are adjusted for inflation in subsequent years.
- Reformed February 2018
  - Cap removed
  - Party performing CO<sub>2</sub> capture no longer required to also handle sequestration
  - Credit claiming period is 12 years
  - \$/ton increased (adjusted for inflation >2026)

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Tertiary injectant/other use	\$12.83	\$15.29	\$17.76	\$20.22	\$22.68	\$25.15	\$27.61	\$30.07	\$32.54	<b>\$35.00</b>
Sequestration only	\$22.66	\$25.70	\$28.74	\$31.77	\$34.81	\$37.85	\$40.89	\$43.92	\$46.96	<b>\$50.00</b>

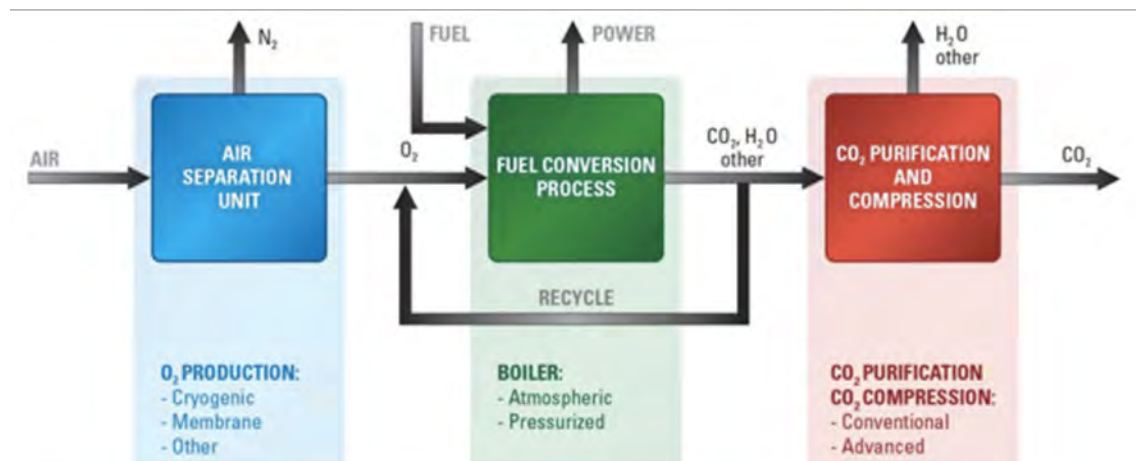


# Regional CO<sub>2</sub>-EOR Potential



# Motivation for Oxy-coal Combustion

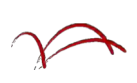
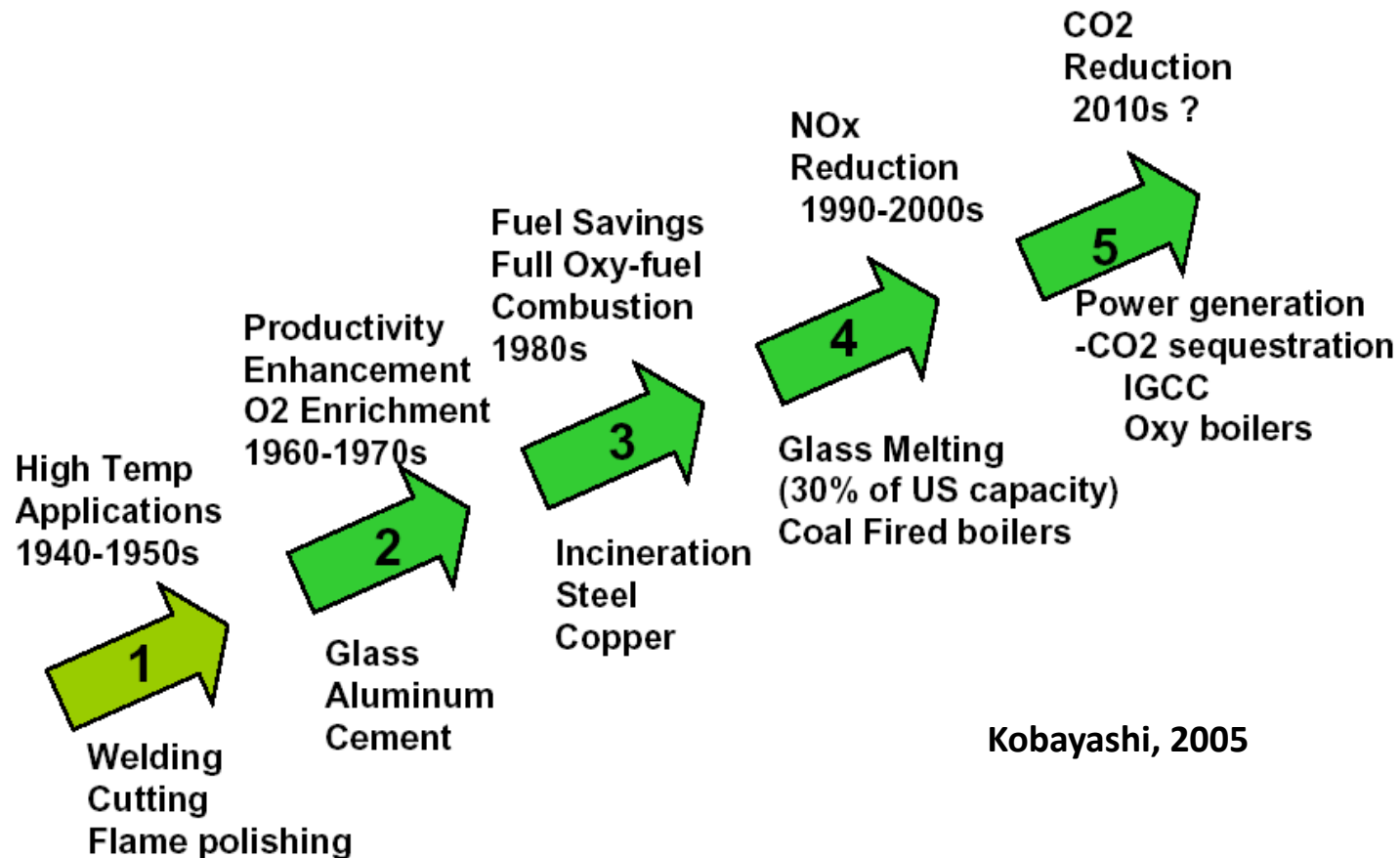
- Utilization of conventional coal conversion technologies in combination with existing CCUS technologies is economically challenging
- Advanced coal conversion systems involving high temperatures and/or pressures can be effectively integrated with state-of-the-art CCUS and offer a more promising approach to continued utilization of a valuable, secure resource by reducing emissions, increasing efficiency, reducing capital and operating costs



<http://www.netl.doe.gov/research/coal/energy-systems/advanced-combustion/oxy-combustion>

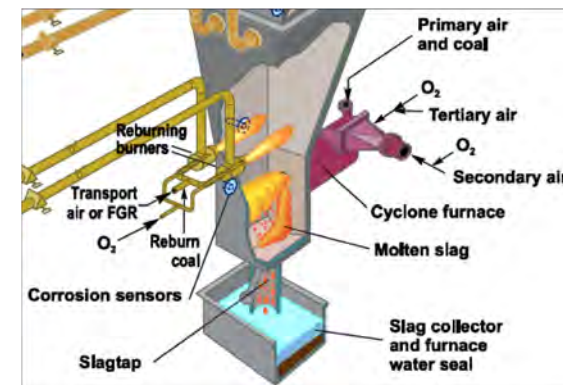
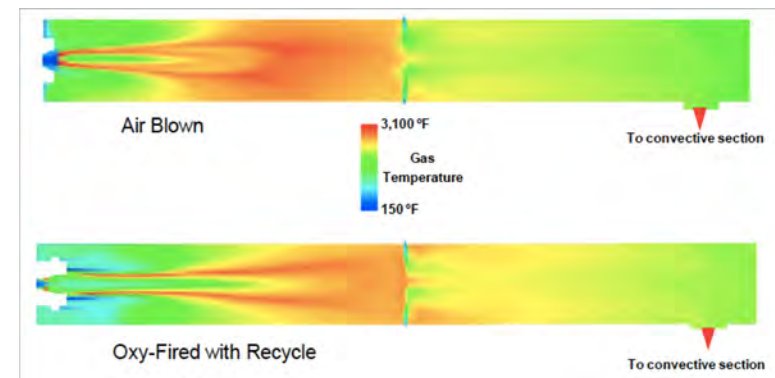


# Oxy-fuel Combustion Developments



# Selected Past REI Activity in Oxy-coal Applications

- Enhanced and targeted oxygen injection for NO<sub>x</sub> control in utility and industrial boilers and cement kilns (with Praxair)
- Optimization of oxygen-fired IGCC
- Development and validation of pyrolysis and oxidation models for oxygen firing with FGR
- Real-time corrosion monitoring in oxy-coal fired pilot-scale testing
- Oxy-combustion impacts during retrofit (with Univ of Utah and Praxair)
- CO<sub>2</sub> for EOR/ECBM (with Plasma/JOC)
- Optimization of oxy-coal burner design for a package boiler (with JOC)
- High flame temperature modular boiler concept development (with JOC)

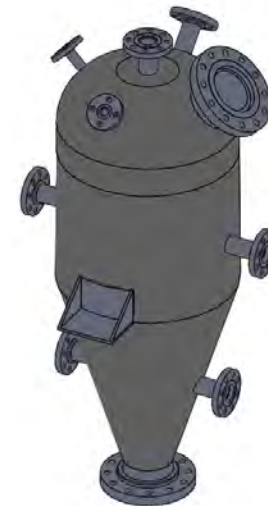
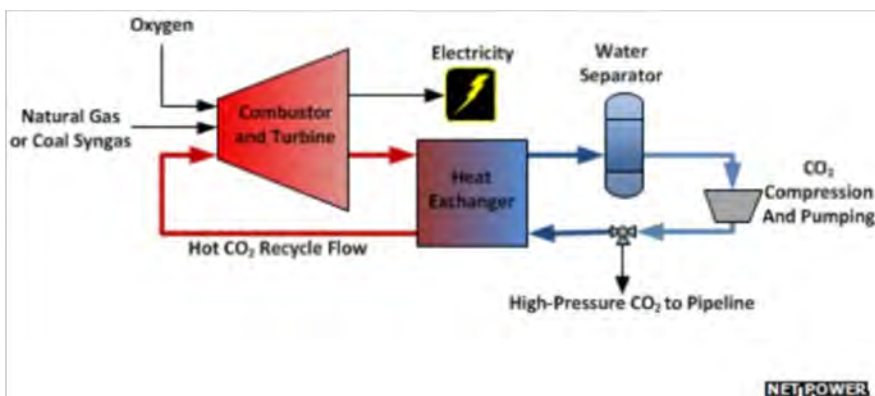


# REI Current Oxy-coal Efforts

- Impact of High Temperatures and Pressures in Oxy-coal Combustion
- Dry Coal Feeding for High Pressure Oxy-coal Combustion
- JOC High Temperature Combustion Retrofit for Power and ECBM
- JOC High Temperature Combustion Retrofit for Power and EOR
- Oxy-combustion of Coal Syngas for Allam Cycle



1<sup>st</sup> Generation  
Oxy-coal  
Burner



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# Oxy-coal Demonstrations

## ■ Vattenfall

- Schwarze Pumpe Large Scale Pilot Plant used for full-scale (30 MWth) burner testing from Alstom, Hitachi Babcock and Doosan Babcock
- Janschwalde Oxy fuel combustion (250 MW) and post-combustion (50MW) FEED. Vattenfall cancelled demonstration due to public opposition and inability to confirm CCS legal framework

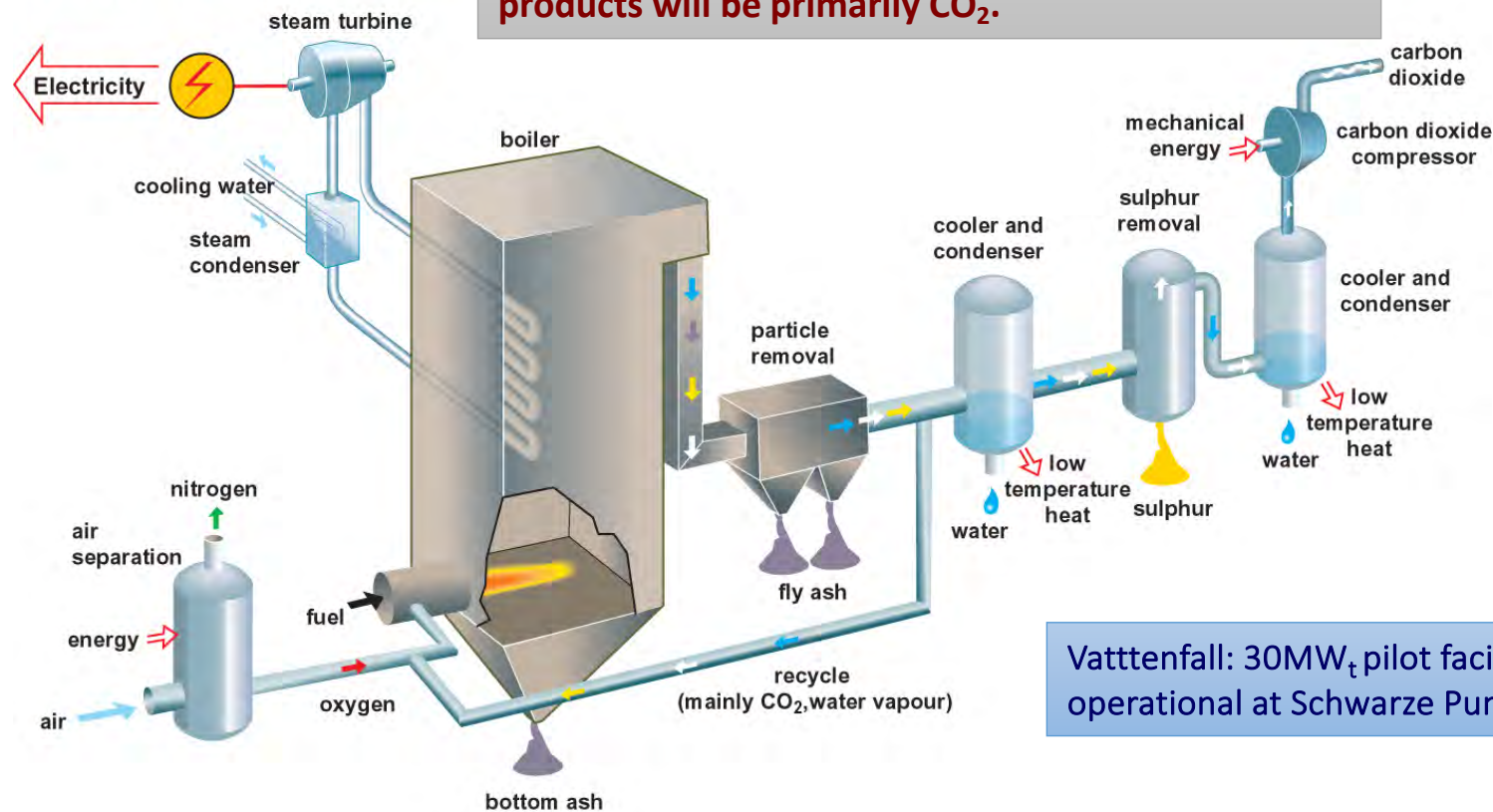
## ■ Callide

- Largest oxyfuel demonstration in the world when it completed its demonstration phase in March 2015



# Schwarze Pumpe Pilot Testing

Oxygen diluted with Recycled Flue Gas mimics combustion air (Stromberg, 2004). Dry combustion products will be primarily CO<sub>2</sub>.

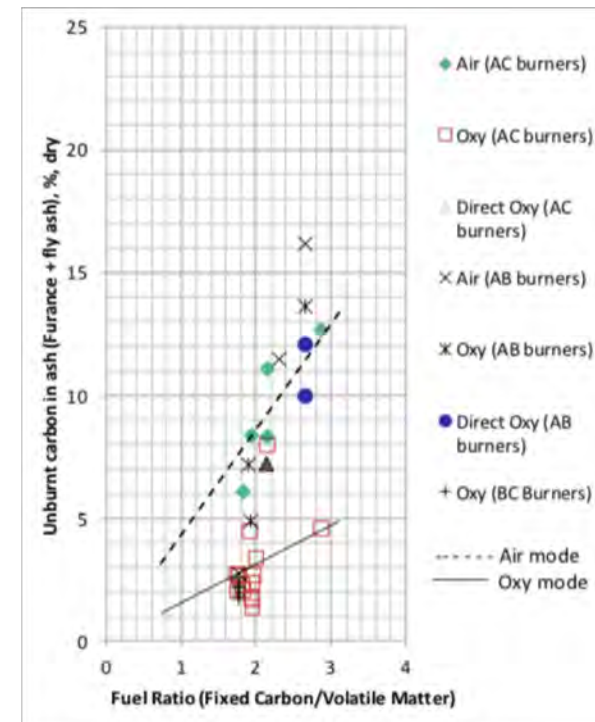
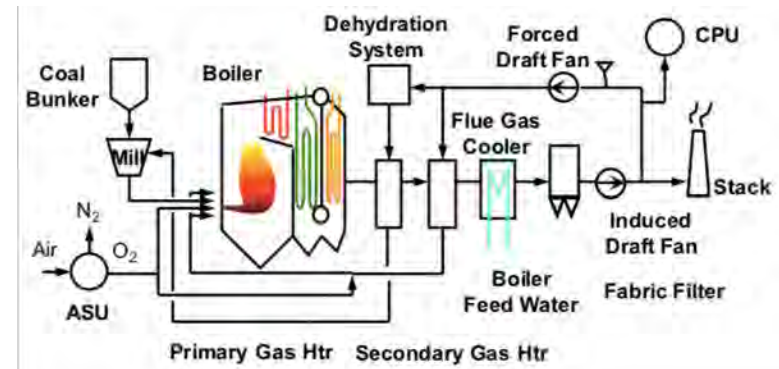


Vatttenfall: 30MW<sub>t</sub> pilot facility operational at Schwarze Pumpe.



# Callide Demo

- >10,000 hrs of operation
- 4 coals
- Unit reliability of 90% achieved during final year
- Significant improvement in combustion efficiency, measured as a reduction in Carbon in ash (typically 50% reduction);
- Significant reduction in NO<sub>x</sub> mass emission rate (mg NO<sub>x</sub>/MJ fuel) – ~60%
- Slight reduction in particulate specific emission rates (mg/kWh).



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# Future Gen 2.0

B&W, Denny McDonald

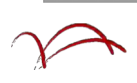
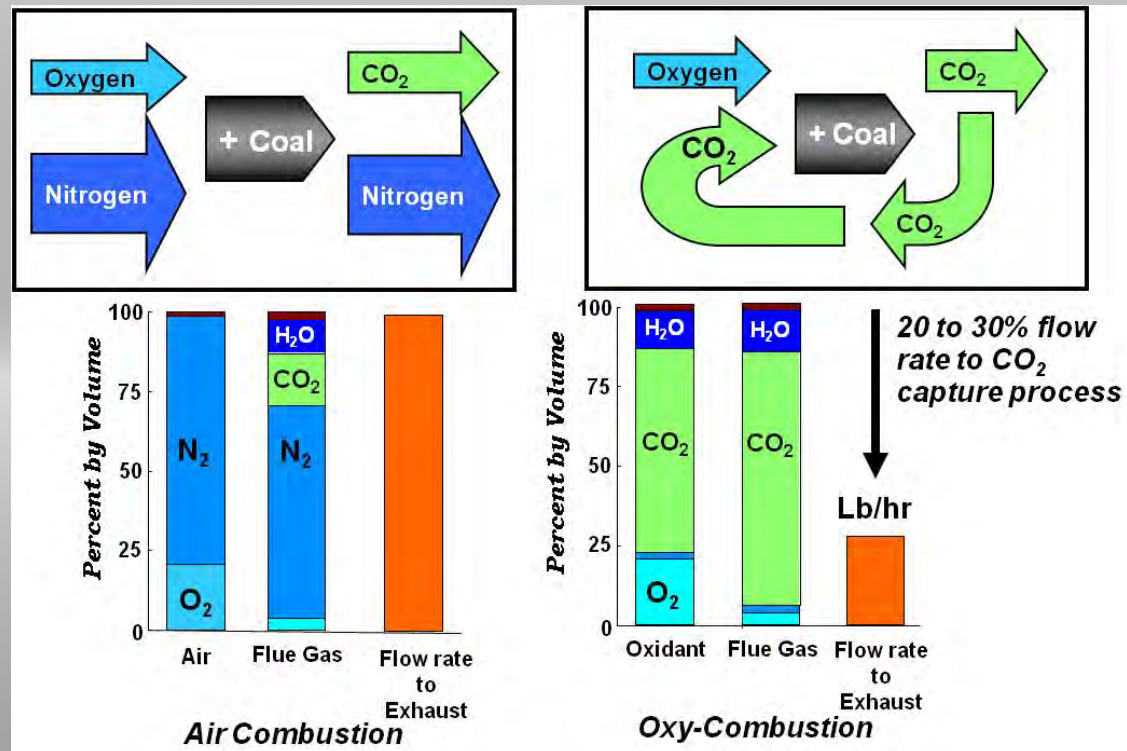
Overview of Oxycombustion Technology

ASME PTC 4.5 Kick-off Meeting

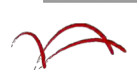
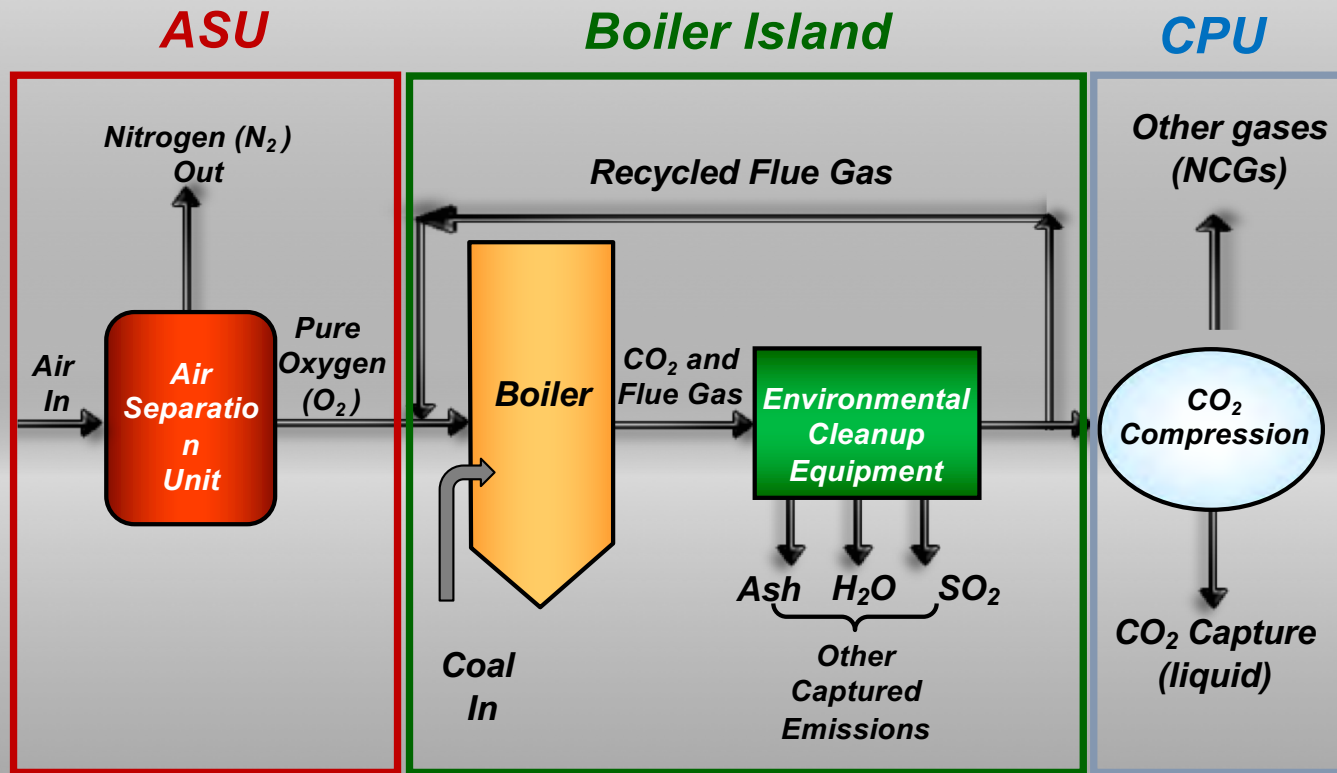
December 16, 2010



Oxy-combustion burns coal with a mixture of oxygen and recycled flue gas instead of air to produce a concentrated CO<sub>2</sub> stream for storage



# Oxy-Coal Plant Configuration



# Oxy-Coal Air Emissions

	Air-Fired Plant	IGCC Plant (2) w/CCS	Oxy-Fuel Plant w/CCS	Air-Fired Plant	Oxy-Fuel Plant w/CCS
<b>Fuel Type</b>	Bituminous	Bituminous	Bituminous	Sub-bit	Sub-bit
<b>Steam Conditions (PSI/F/F)</b>	3600/1100/1100		3600/1100/1100	3600/1100/1100	3600/1100/1100
<b>Plant Performance</b>					
Gross MW	598	745	733	604	733
Net MW	550	556	550	550	550
Net Plant Heat Rate (Btu/kWh)	8662	10505	10143	9250	10831
Capacity Factor (%)	85%	80%	85%	85%	85%
<b>Conventional Emissions (Expected)</b>					
NOx (lb/MBtu)	0.06	0.0470	Note 1	0.06	Note 1
SOx (lb/MBtu)	0.04	0.010	Note 1	0.08	Note 1
Particulate (lb/MBtu)	0.015	0.007	Note 1	0.012	Note 1
Hg (lb/TBtu) (3)	0.784	0.571	Note 1	0.820	Note 1
<b>CO2 Emissions (Expected)</b>					
CO2 Removal Efficiency (%)	0	90.0%	92.5%	0	92.5%
CO2 Produced (Million Metric Tons/Year)	3.26	3.64	3.82	3.68	4.31
CO2 Captured (Million Metric Tons/Year)	0	3.28	3.53	0	3.99
CO2 Emitted (Million Metric Tons/Year)	3.26	0.36	0.29	3.68	0.32

1) Oxy emissions are below practical measurement limits

2) IGCC from GE IGCC system w/CO2 Capture per DOE/NETL-2007/1281 Report, Case 2

3) Air-fired emissions based on 90% removal expected



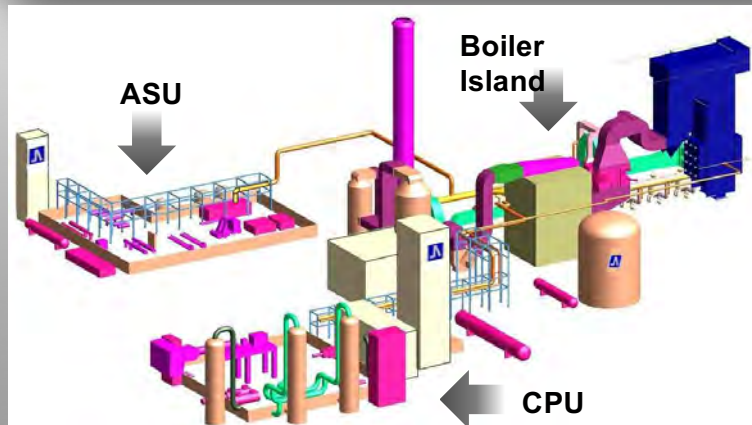
# ***Benefits of Oxy-Coal Combustion***

- Oxy-combustion is potentially the highest efficiency and lowest cost CO<sub>2</sub> capture technology for coal fired plants\*
- Near Zero Emissions of criteria air pollutants (NZEP)
- >90% CO<sub>2</sub> capture at pipeline quality and purity specifications
- Low technology risk – plant components are primarily conventional equipment modified for operation in the oxy-mode. An oxy-plant will look and operate like a conventional power plant.
- Can be retrofit as easily as post combustion capture
  - Same existing plant equipment and space requirements
  - No LP steam requirement (output can be increased by heat integration)
  - No new chemicals or solvents
- Unique operating options can maximize output during the day

\* DOE/NETL 2007-1291 Rev. 2, August 2008, "Pulverized Coal Oxy-combustion Power plants"  
DOE/NETL 2007-1281 Rev.1, August 2007 "Cost and Performance Baseline for Fossil Energy Plants"



# FutureGen 2.0 – Oxy-Combustion Project



## Project Structure

- Capture – Ameren Energy Resources (AER), teamed with B&W and Air Liquide
- Transport & Storage – FutureGen Alliance

## Meredosiasia Plant

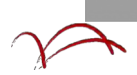
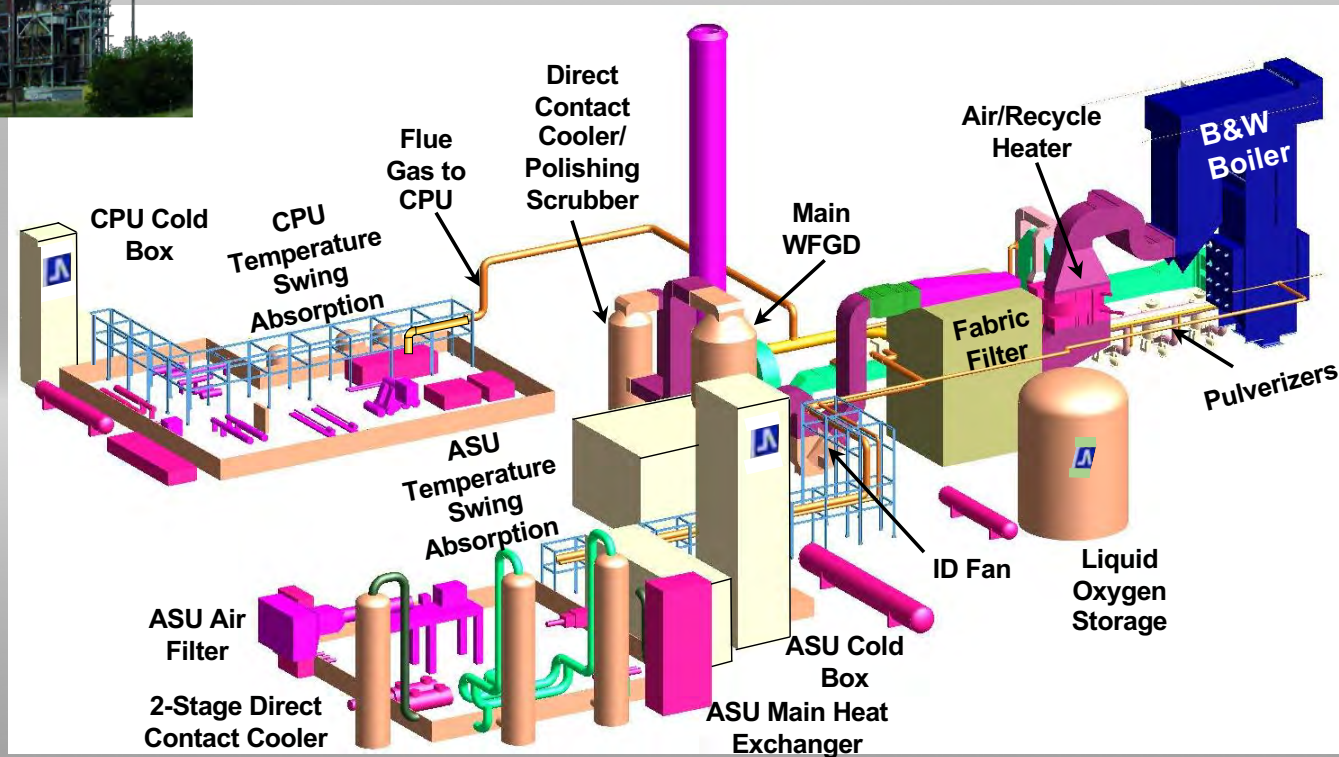
- Meredosiasia, IL: Owned/operated by AER
- 3-coal fired units (2 retired)
- 1-oil-fired unit
- 200 MWe oil-fired Unit 4 built in 1975
- Repower Unit 4 steam-turbine
  - Purpose-built Oxy-PC boiler
- Illinois Coal, PRB or PRB blends

## Project Timeline

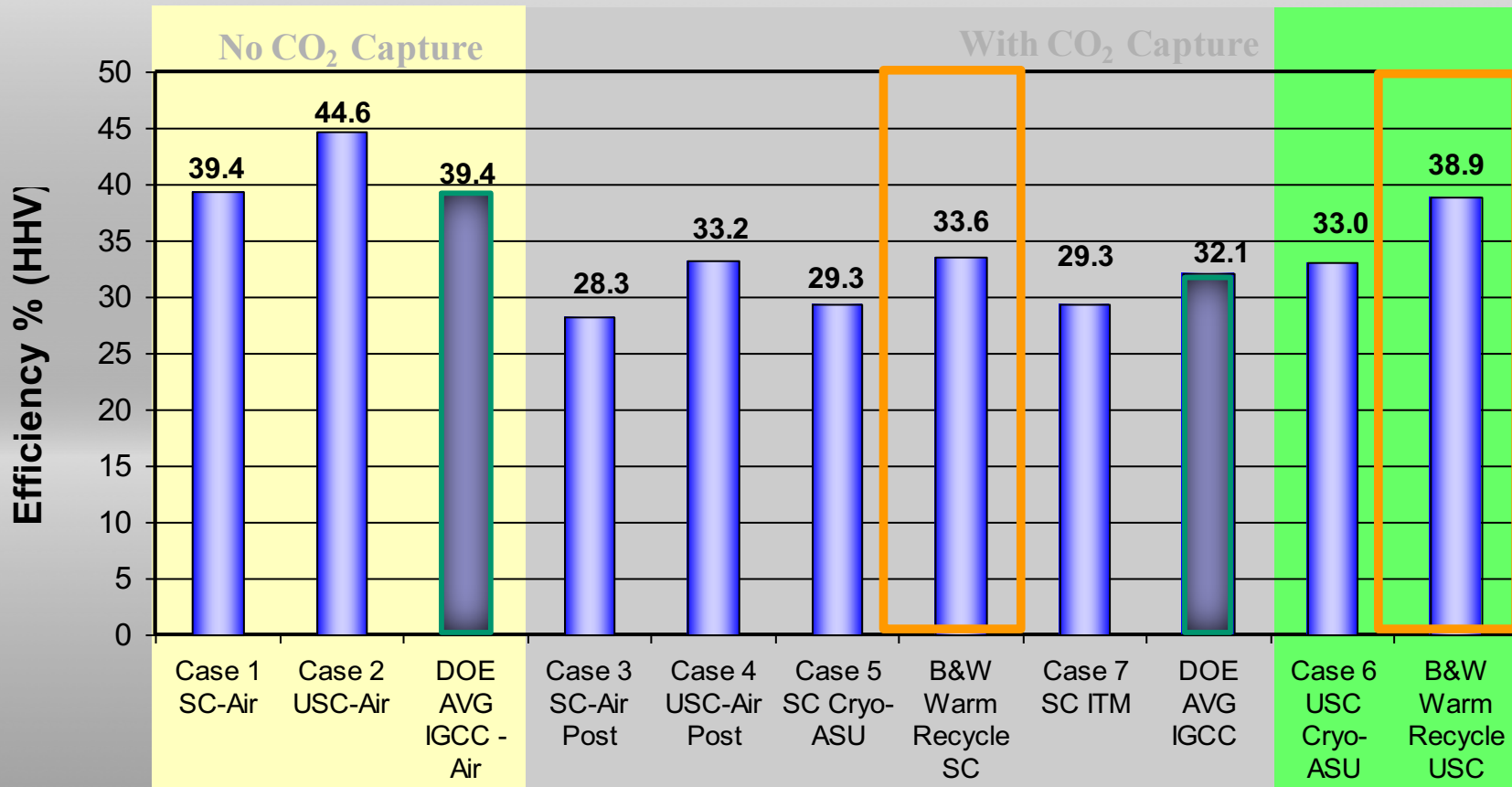
- Expect project award by Sept. 30, 2010
- Phased approach to develop project
- Commission by end of 2015



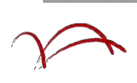
# Meredosia Clean Coal Facility



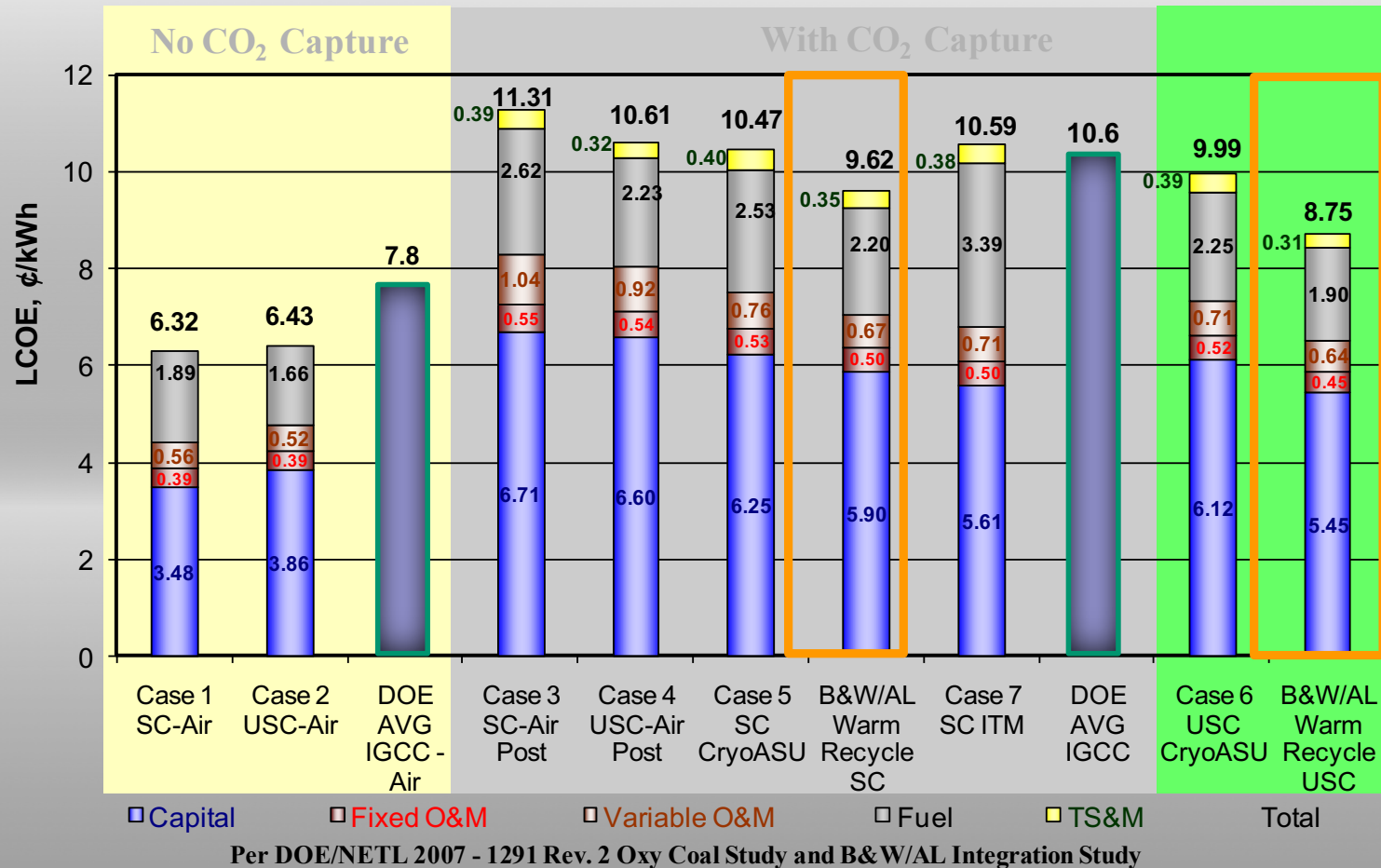
# Comparison of Net Plant Efficiency for Carbon Capture Technologies



Per DOE/NETL 2007 - 1291 Rev. 2 Oxy Coal Study and B&W/AL Integration Study

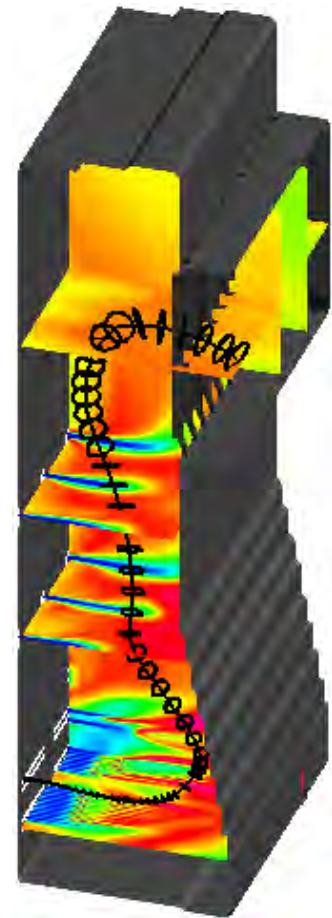


# Comparison of Levelized COE for Carbon Capture Technologies



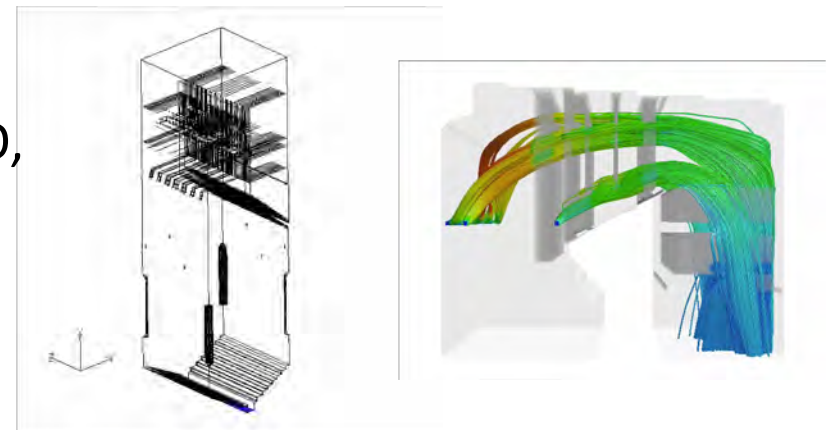
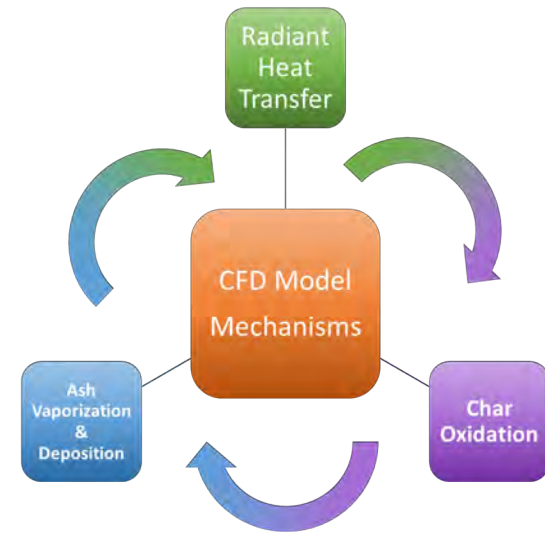
# REI's Modeling Experience

- Over 250 boilers, burners, process furnaces, kilns, and incinerators in several countries burning a range of fuels including coal, oil, gas, wood, straw, petcoke, tires, hazardous waste
- Complementary relationships with OEMs, owners and service/equipment providers to develop solutions in areas including:
  - Burner/furnace design/optimization
  - Heat flux/distribution
  - Corrosion and deposition
  - NO<sub>x</sub>/SO<sub>x</sub> control
  - CO, hydrocarbon emissions
  - Carbon-in-flyash
  - Opacity
  - Air toxics (fine particulate, mercury, soot)



# CFD Tools: GLACIER

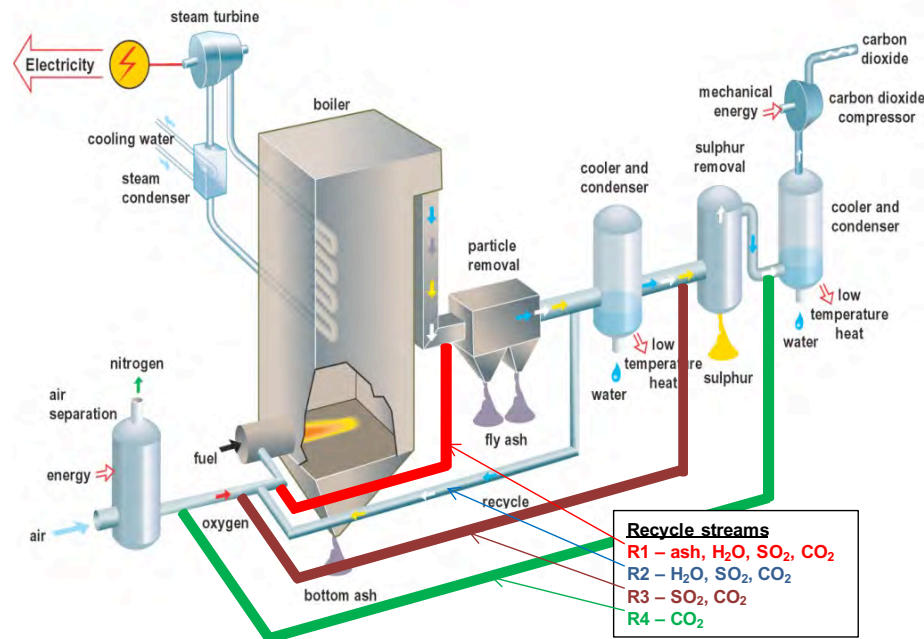
- REI's in-house CFD software
- Developed specifically for application to solid fuel fired furnaces and boilers
- 3D, steady-state, turbulent flows
- Coupling between turbulent fluid mechanics, radiative and convective heat transfer, homogeneous and heterogeneous reactions
- Statistical description of particles including particle dispersion
- Pollutant formation kinetics for NO<sub>x</sub>, SO<sub>x</sub>, CO, Hg and fine particles
- Continually evolving including recent developments for atmospheric pressure and pressurized oxy-coal applications



# Example – Oxy-combustion FGR

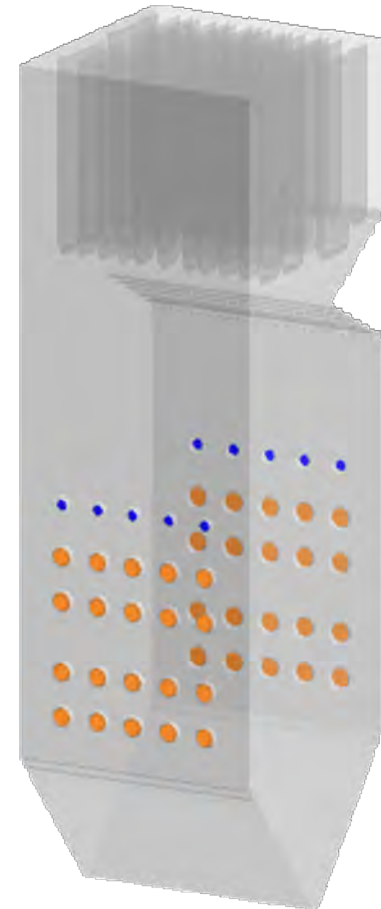
- In oxy-combustion, FGR rate determines  $O_2$  concentration in FGR/ $O_2$  mixture (at fixed 3% exit  $O_2$ )

*Increased  $O_2$  increases AFT, which increases radiant heat transfer; reduces flue gas volume which reduces convective heat transfer*



# Hunter 3 Oxy-combustion

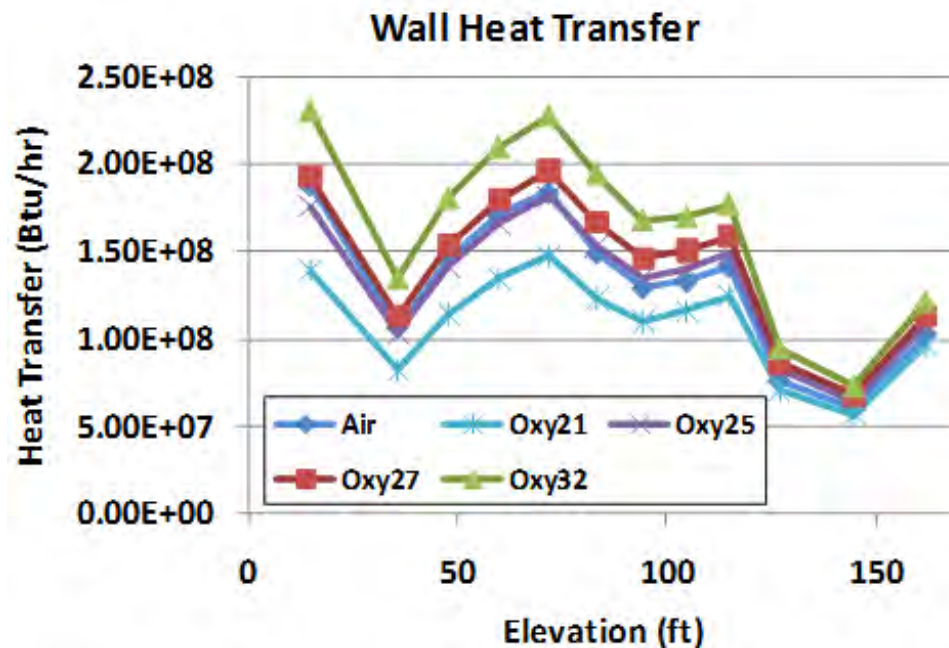
- Evaluate impact of flue gas recycle (FGR) rate on heat transfer in 490 MWe Hunter 3 coal-fired boiler under oxy-firing conditions
- Adjust FGR to match air-fired heat transfer in radiant and convective sections
  - Evaluate 21%, 25%, 27% and 32% O<sub>2</sub> (wet)
- Baseline SGE model:
  - Include all radiant and convective HT surfaces
  - Flue gas-steam heat transfer behavior tuned to match air-fired data



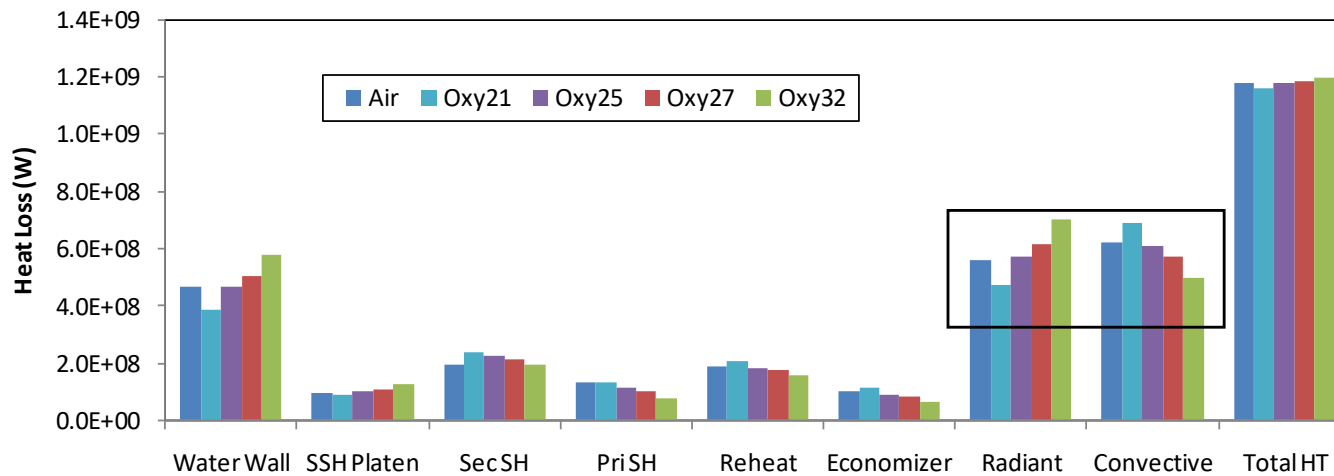


# Furnace Wall HT Results

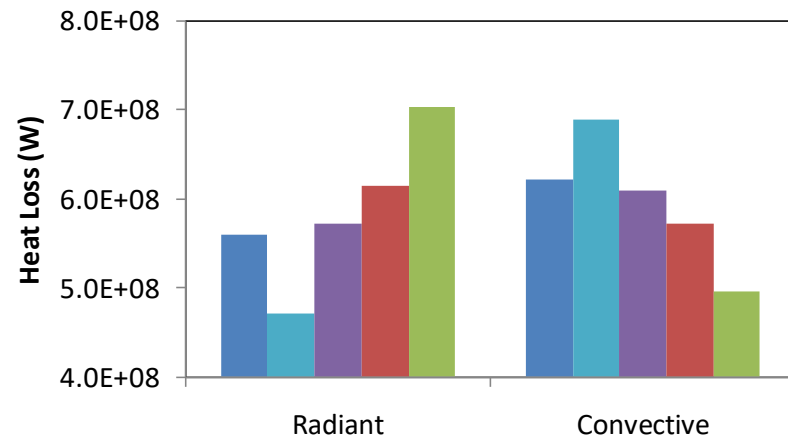
- Oxy25 is best match to air-fired furnace wall heat transfer



# System Heat Transfer Results



- Heat transfer predicted to match at 25% O<sub>2</sub> in the O<sub>2</sub>/FGR mixture
- Radiant heat transfer increases with increasing O<sub>2</sub> concentration
- Convective heat transfer decreases with increasing O<sub>2</sub> concentration



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# Heat Transfer Summary

- Lower oxygen concentrations resulted in lower combustion (flame) temperatures, lower heat transfer in the radiant furnace, and higher heat transfer in the convective section
- As the oxygen concentration increased, flame temps increased, heat transfer in the radiant furnace increased, flue gas furnace exit temp decreased, and convective heat transfer decreased
- “Re-balancing” of heat transfer between radiant and convective zones was consistent with the small changes in economizer gas exit temp
- SGE results were used to guide inputs for more detailed CFD models of the radiant furnace, which suggested that 26% O<sub>2</sub> concentration would better match the air-fired heat transfer



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# SGE Conclusions

- SteamGen Expert (SGE) process modeling tool was effective in evaluating modifications to boiler design and operating conditions
  - Fast running to evaluate many scenarios
  - Can be used in conjunction with other analysis tools such as CFD
- Illustrated trade-offs between heat transfer, spray flow, and exit temperatures for modified heat transfer surfaces
- Illustrated trade-offs between radiant and convective heat transfer for different flue gas recycle rates and compositions in a oxy-coal retrofit boiler design



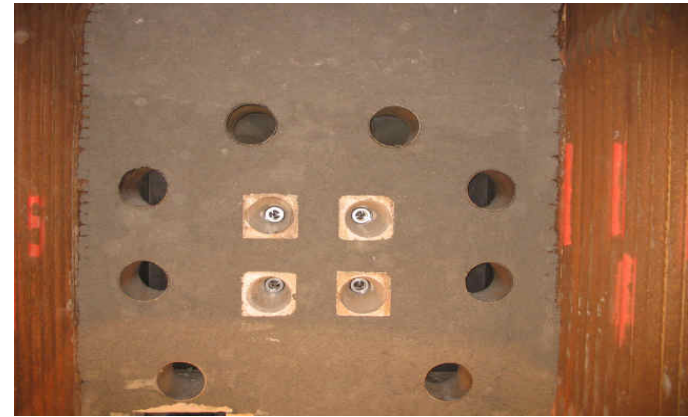
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# High Flame Temperature Oxy-coal Combustion



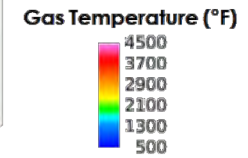
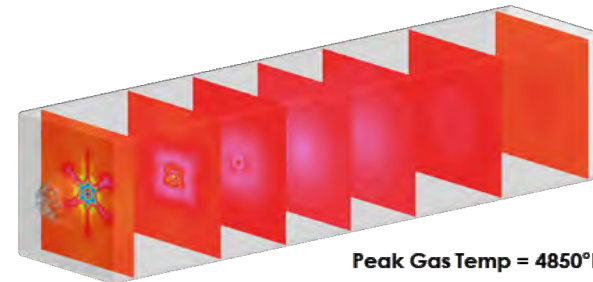
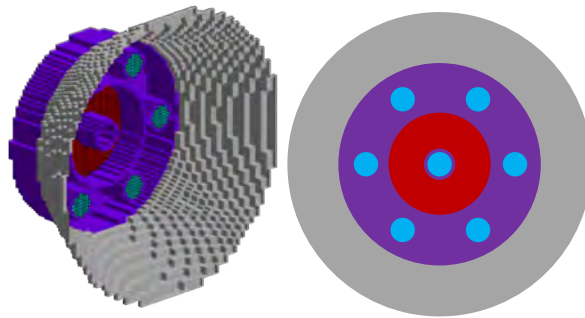
# Industrial Boiler Demonstration

- JOC/DOE Albany Keeler Boiler demonstration
- Patented process results in flame temperatures  $>4500^{\circ}\text{F}$
- At the pilot test facility, the team successfully designed, constructed, and operated a boiler and integrated pollutant removal evaluation

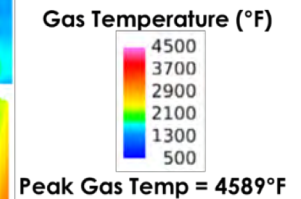
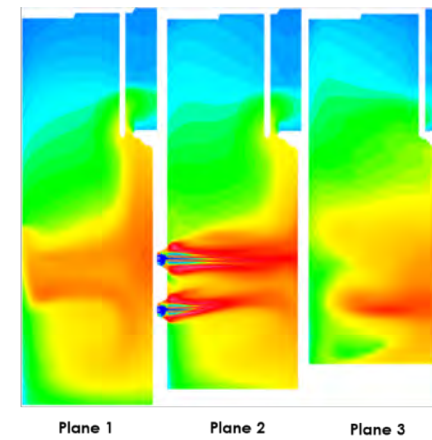
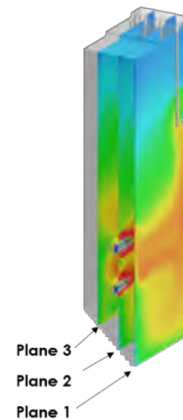
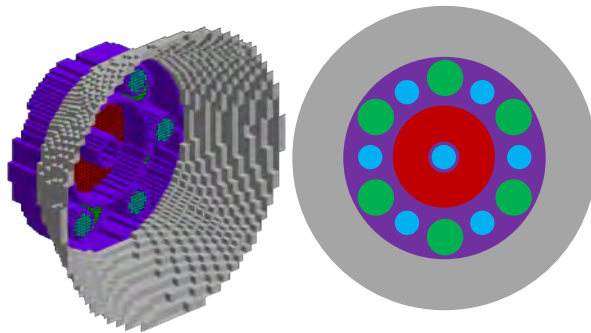


# HT Oxy-Coal at Utility Scales

1) 30 MW



2) 120 MW

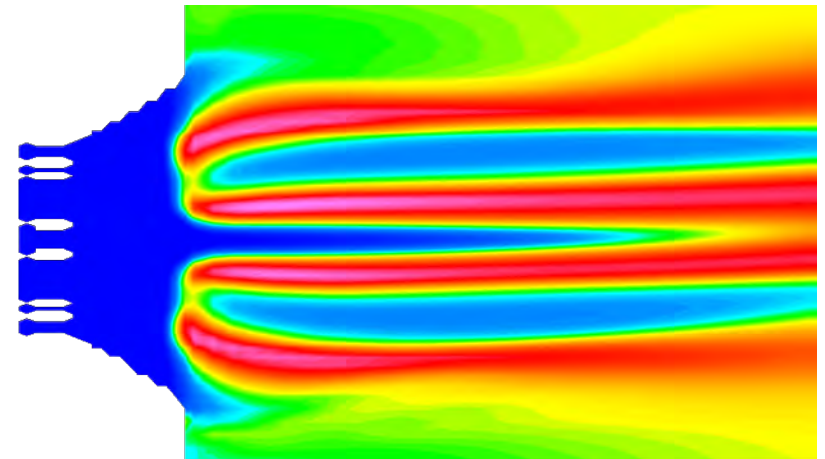
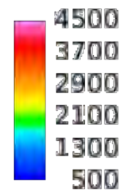
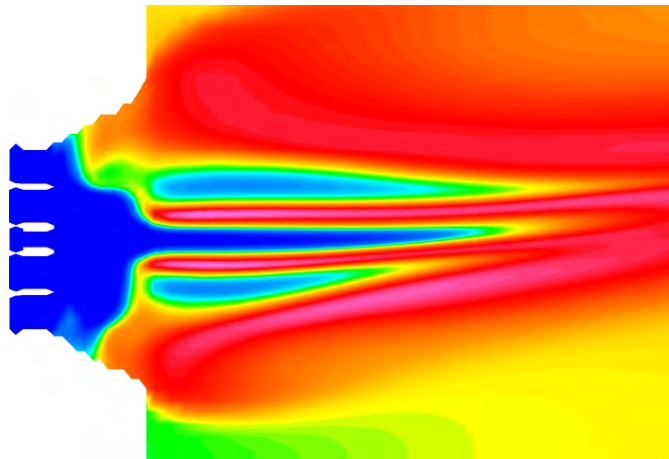


# Burner Optimization

*Moderating High Radiant Flux*

2) 120 MW

Gas Temperature (°F)



Discrete Ports Burner  
Peak: 4581°F

Optimized Burner  
Peak: 4572°F




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# Summary

- Post-combustion CCUS demonstrations using CO<sub>2</sub> from pulverized coal power plants have established the technical feasibility of existing technology
- Recent enhancements of Section 45Q tax credits improve the economics of future CCUS projects
- Pilot-scale demonstrations and modeling of full-scale oxy-coal retrofits illustrate the feasibility and potential advantages of oxy-coal combustion for CCUS in reducing emissions, increasing efficiency, reducing capital and operating costs





# **Reaction Engineering International**

ENERGY & ENVIRONMENTAL CONSULTING

*Committed Individuals, solving challenging problems.*

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