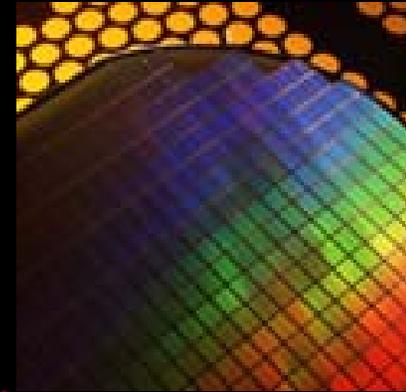

O₂ Enhanced Combustion for NO_x Control



*2002 Conference on SCR
and SNCR for NO_x Control*

*Pittsburgh PA,
May 15-16, 2002*



www.praxair.com

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Discussion Points



- **Where has oxygen been used before?**
- **What role can oxygen play in utility boilers?**
- **What is the effect of oxygen enhanced combustion on NO_x?**
- **What is the cost impact of using oxygen?**

Conventional O₂ Use



- **High temperature oxy-fuel flames**
 - welding, flame polishing, cutting, etc.

- **Oxygen addition for production rate increase**
 - by O₂ lancing
 - by O₂ enrichment
 - by auxiliary oxy-fuel burners

- **Full furnace conversion to oxy-fuel firing**
 - fuel savings, NO_x reduction, capital reduction
 - CO₂ capture and sequestration

Typical Advantages of Oxygen



- **Increased efficiency (lower sensible heat loss)**
 - **less fuel required**
- **Throughput increase**
- **Lower capital requirements**
- **Potential for pollution reduction**

Where is O₂ Used Now?



Industry

Furnace/Kiln Applications

Steel

Reheat, Soaking Pits, Ladles, Forging, EAF

Glass

Melting

Copper

Smelting, Anode

Aluminum

Remelting, Coke Calcining

Pulp&Paper

Lime kiln, Black Liquor

Cement

Cement kiln

Petroleum

Fluid Cat. Cracker Regen., Claus Sulfur

Chemical

Incinerator, Sulfuric Acid

Clay

Brick Kiln

Primarily High Outlet Temperature Processes

Known Benefits of O₂ in Boilers



- **Conventional benefits**
 - increased efficiency

- **Boiler operation benefits**
 - capacity recovery after fuel switching
 - overcome fan limitations

Barriers to O₂ Use in Boilers



- **Cost**
- **Site safety concerns**
- **Siting requirements for on-site oxygen plants or large storage tanks**

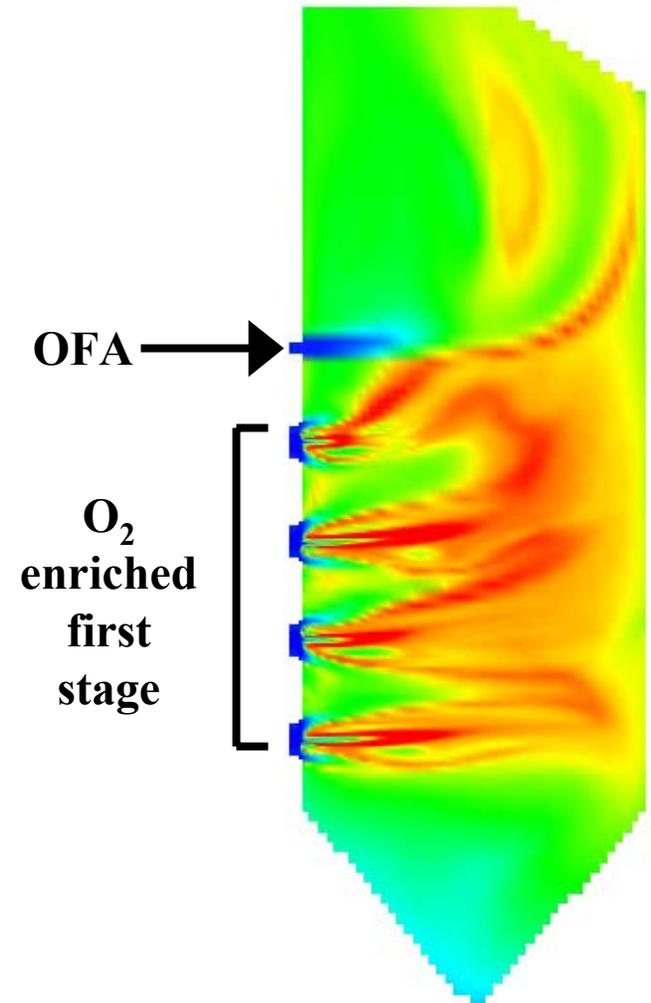
Oxygen for NOx Reduction



- **Oxygen use can reduce NOx formation in the primary combustion zone**
 - promote flame attachment
 - enhance effectiveness of staged combustion
- **Oxygen can enhance NOx destruction technologies in secondary combustion zone**
 - enhance coal-based reburning
 - enhance natural gas reburning and SNCR
- **Oxygen reduces LOI/Unburned Carbon**

Oxygen with Staged Combustion

- O_2 anchors coal flame
- O_2 makes gas phase more fuel rich
- O_2 increases temperature which enhances pyrolysis and accelerates NO_x reduction kinetics
- O_2 allows more fuel rich operation



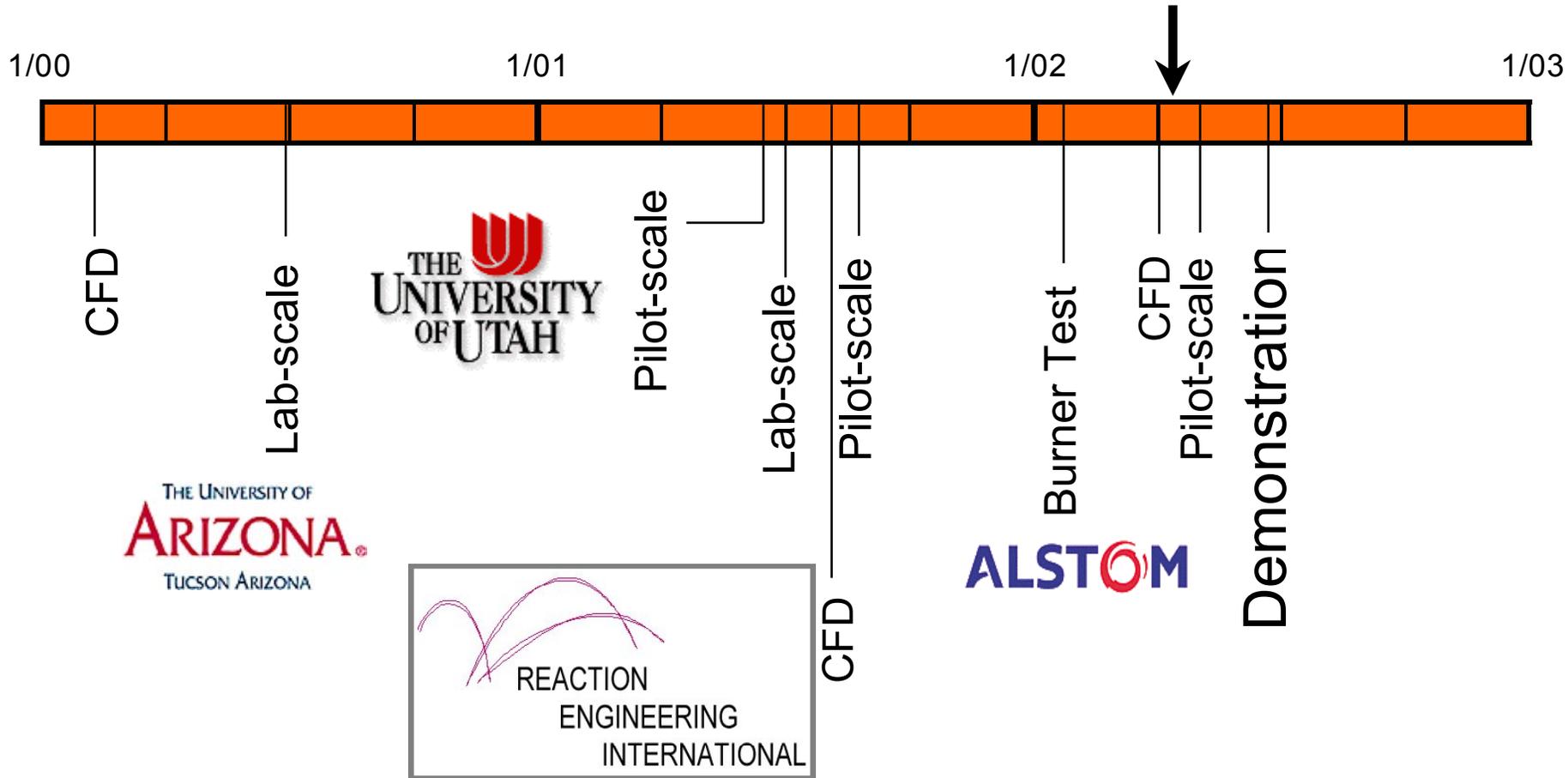
Approach



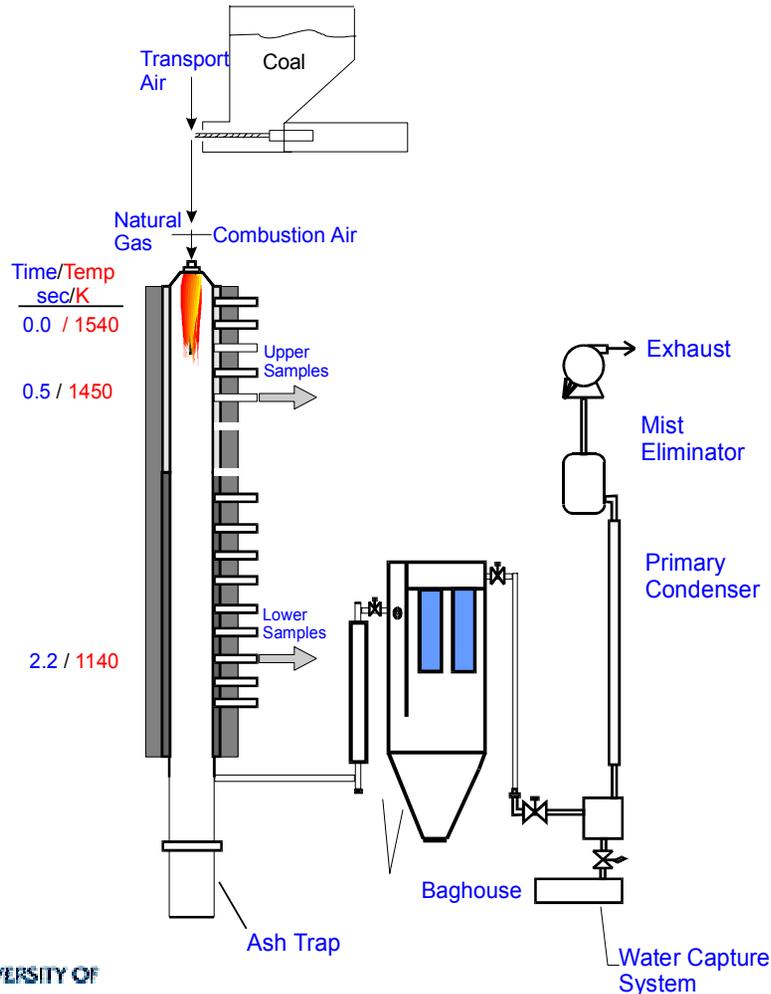
- **Use an expert team to address critical issues**
 - Praxair (oxy fuel combustion)
 - U of A (NO_x formation)
 - U of U (combustion , burner development)
 - REI (CFD modeling)
 - ALSTOM (burner development)
 - Utility advisory panel (commercial application)

- **Move from small-scale studies to pilot-scale testing, and finally large-scale burner testing**

Program Timeline

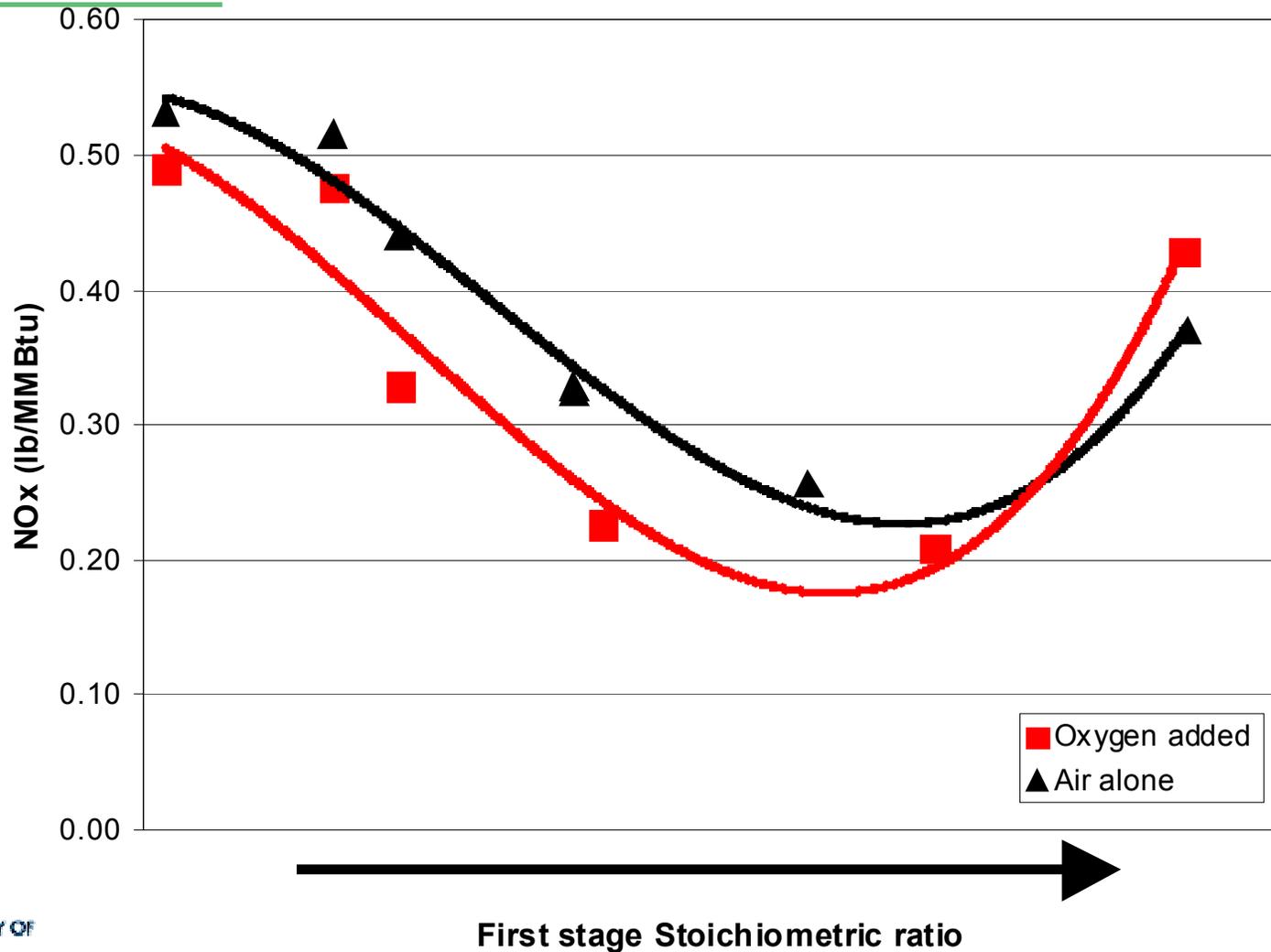


UA Experiments



- 17kW “premixed” pulverized coal downflow combustor
- Staged combustion
- Parametric study
 - response surface methodology
 - O₂ enrichment in first stage
 - SR in first stage
 - first stage residence time
 - O₂ enrichment at staging point
- Measurements
 - water cooled, water quenched probe for gases
 - gas species NO, CO, CO₂, O₂
 - ash for carbon burnout

UA Experiments



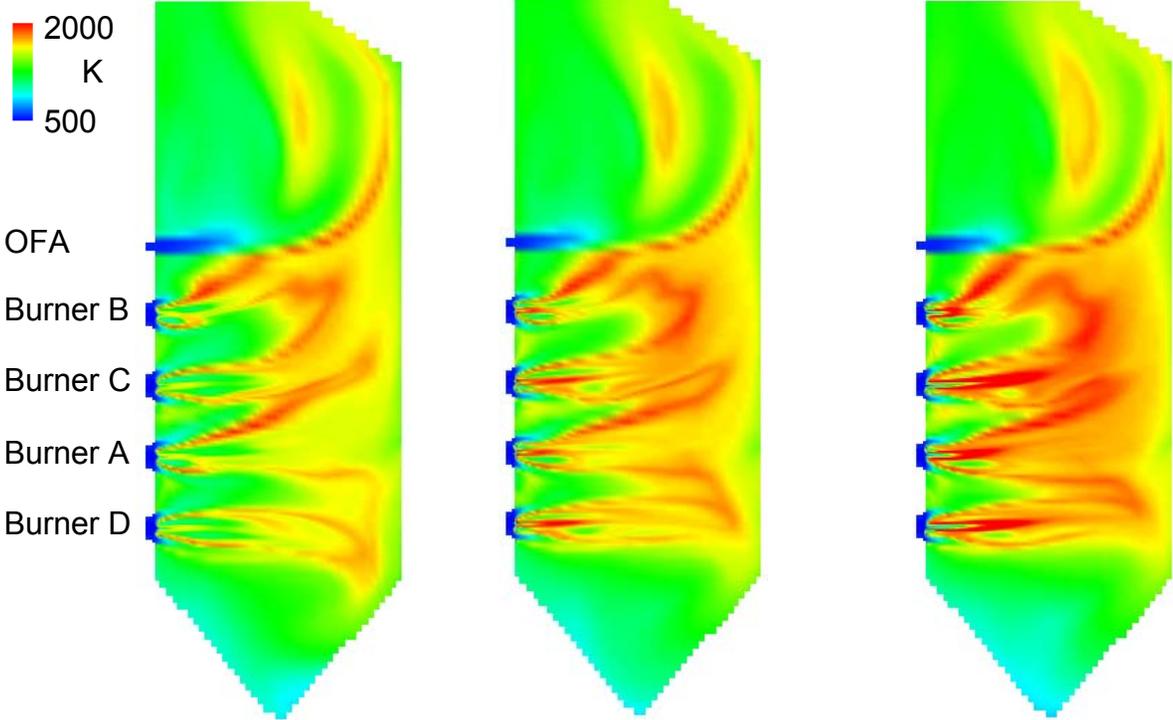
- **Proprietary model used to evaluate concept**
- **Model of UA furnace agreed well with data**
- **Model indicates O₂ addition reduces NO_x**
- **Parametric mixing studies suggested NO_x emissions below 0.10 lb/MMBtu**

- **Existing boiler model used to evaluate effectiveness of oxygen**
 - NO_x control
 - LOI
- **Method of oxygen addition based on experimental data**
- **Different burner type, including different coal spreader, that explored experimentally**
 - evaluate sensitivity to burner type

CFD Modeling Results for O₂



Gas temperature (Side view, Centerline of the burners on the RHS)



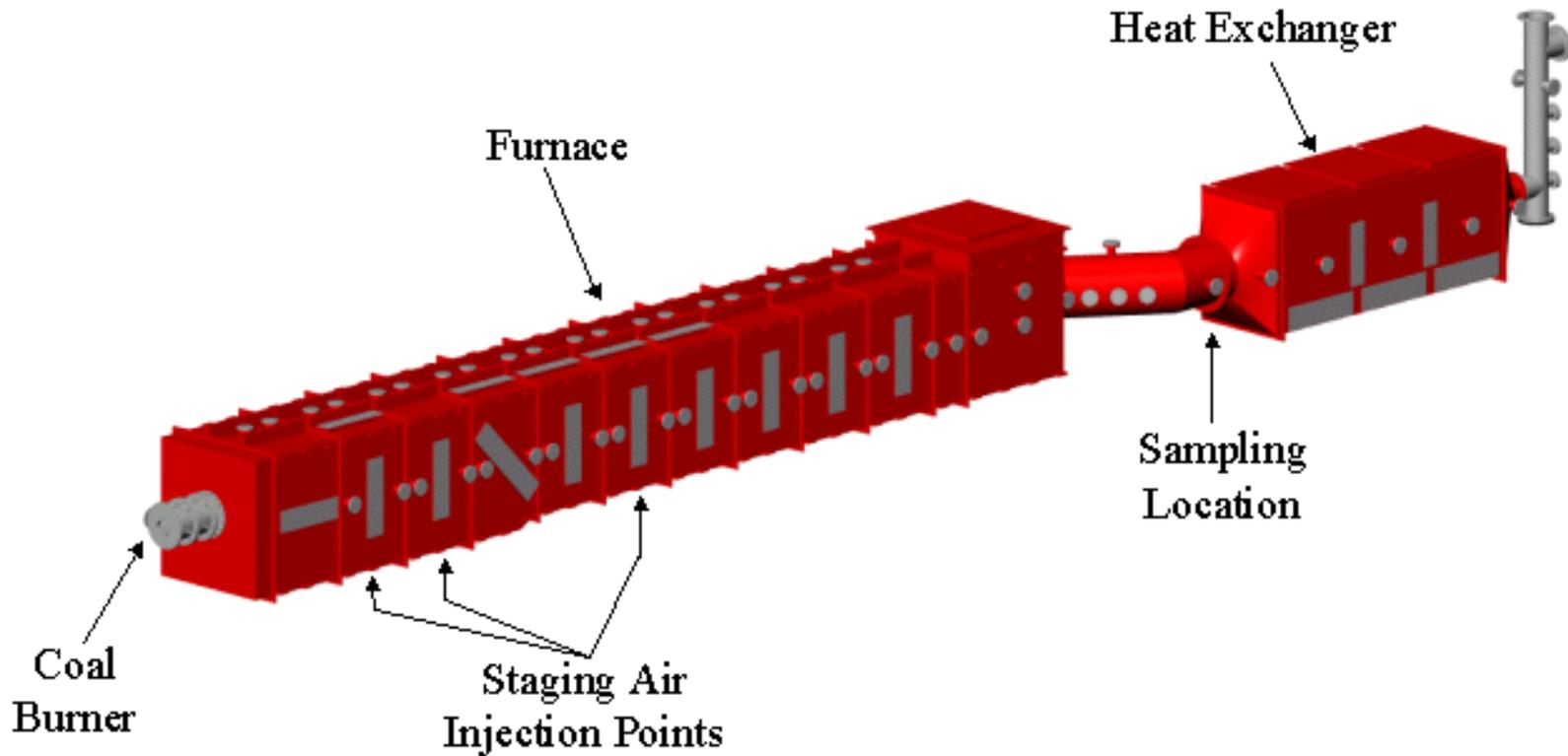
Air
NOx reduction: ---%
LOI Reduction: ---%

A% replacement
NOx reduction: 17%
LOI Reduction: 12%

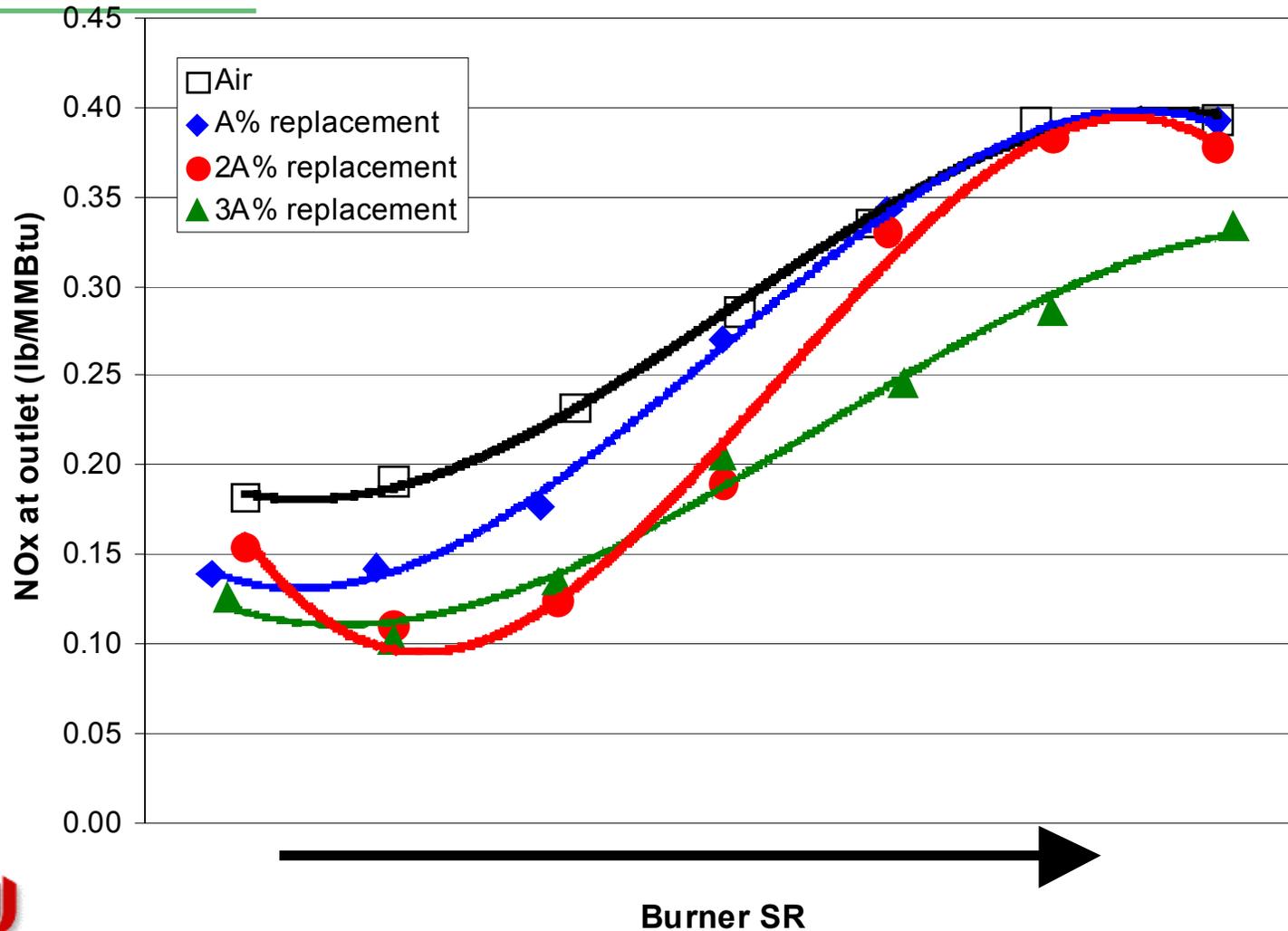
2A% replacement
NOx reduction: 24%
LOI Reduction: 24%



L1500 - Furnace



Results From L1500 Testing



ISBF Test Overview

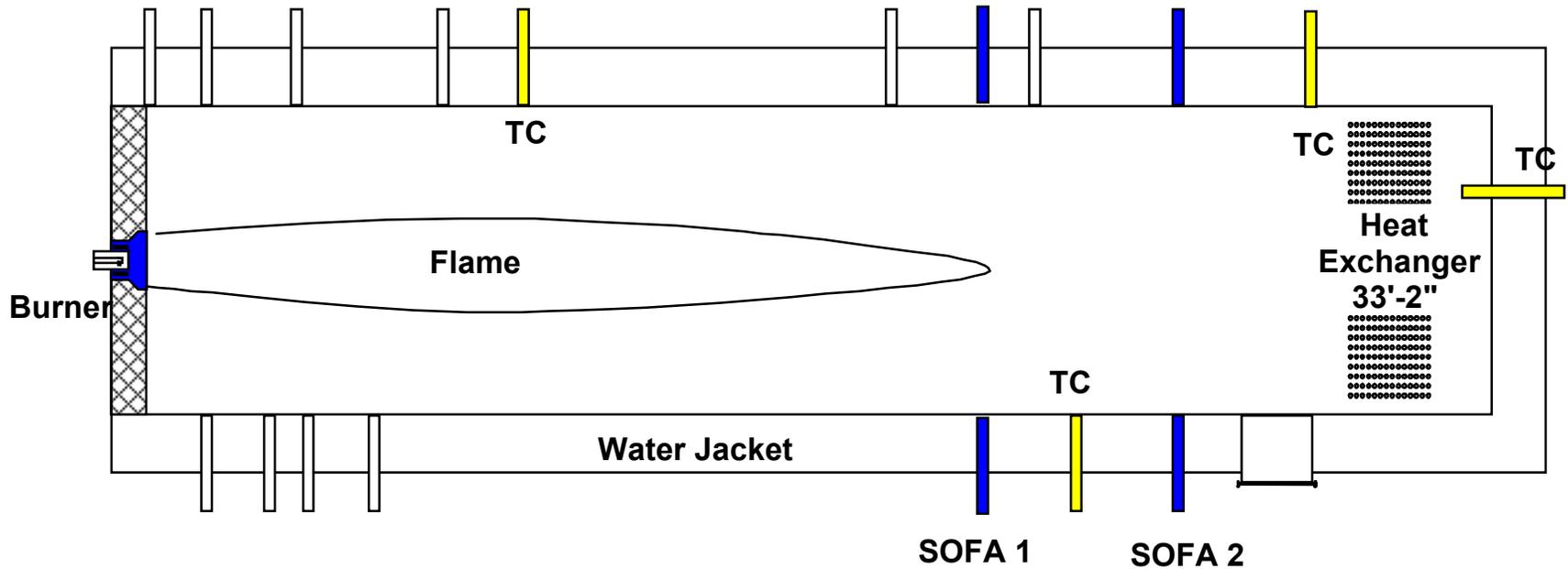


- **Well characterized boiler simulator at Alstom Power has been used to demonstrate oxygen enhanced combustion using a full scale commercial burner.**
- **Various proprietary oxygen injection techniques were evaluated**
- **Various parameters were measured: NO_x, FOT, CO, UBC**

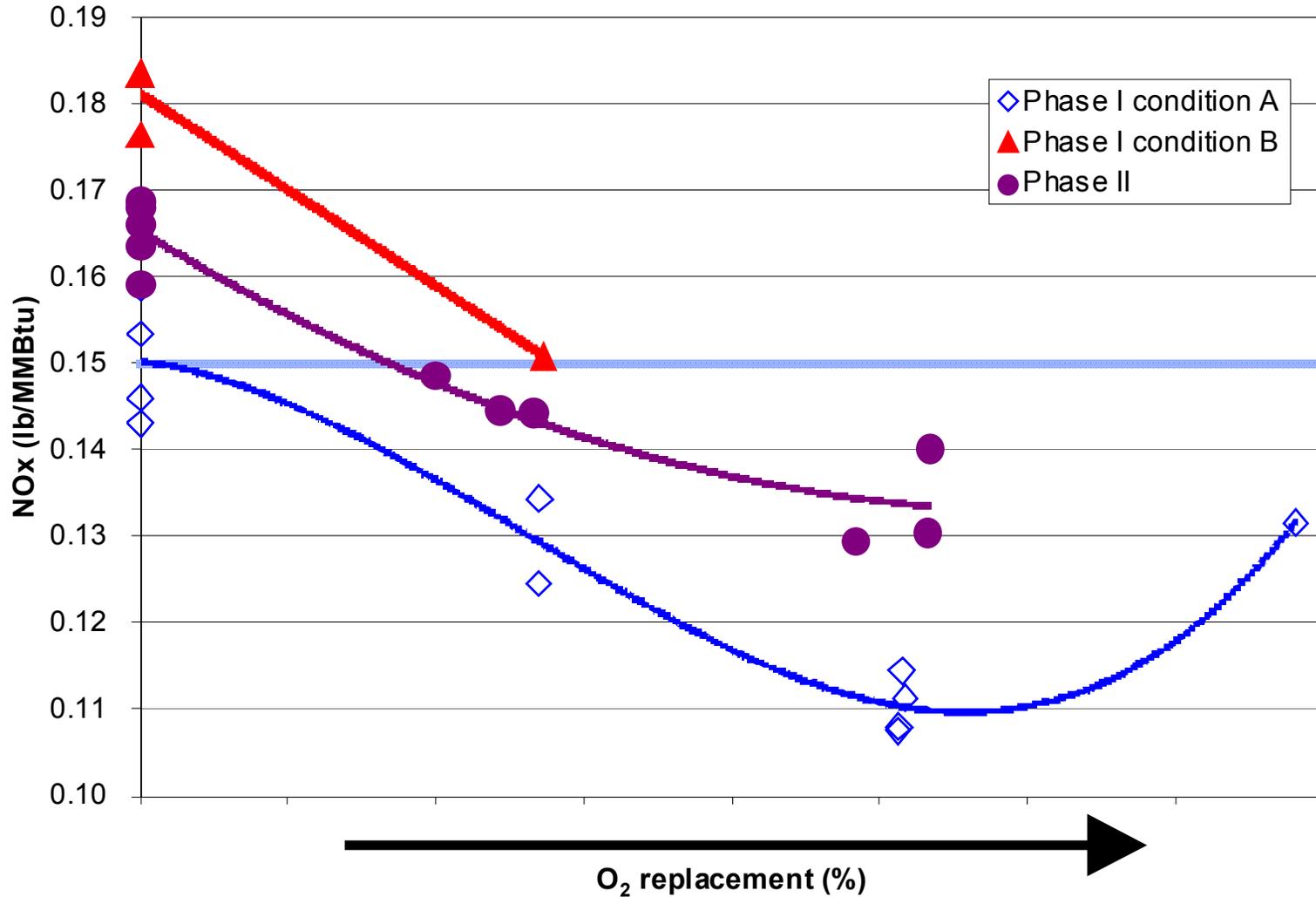
Industrial Scale Burner Facility



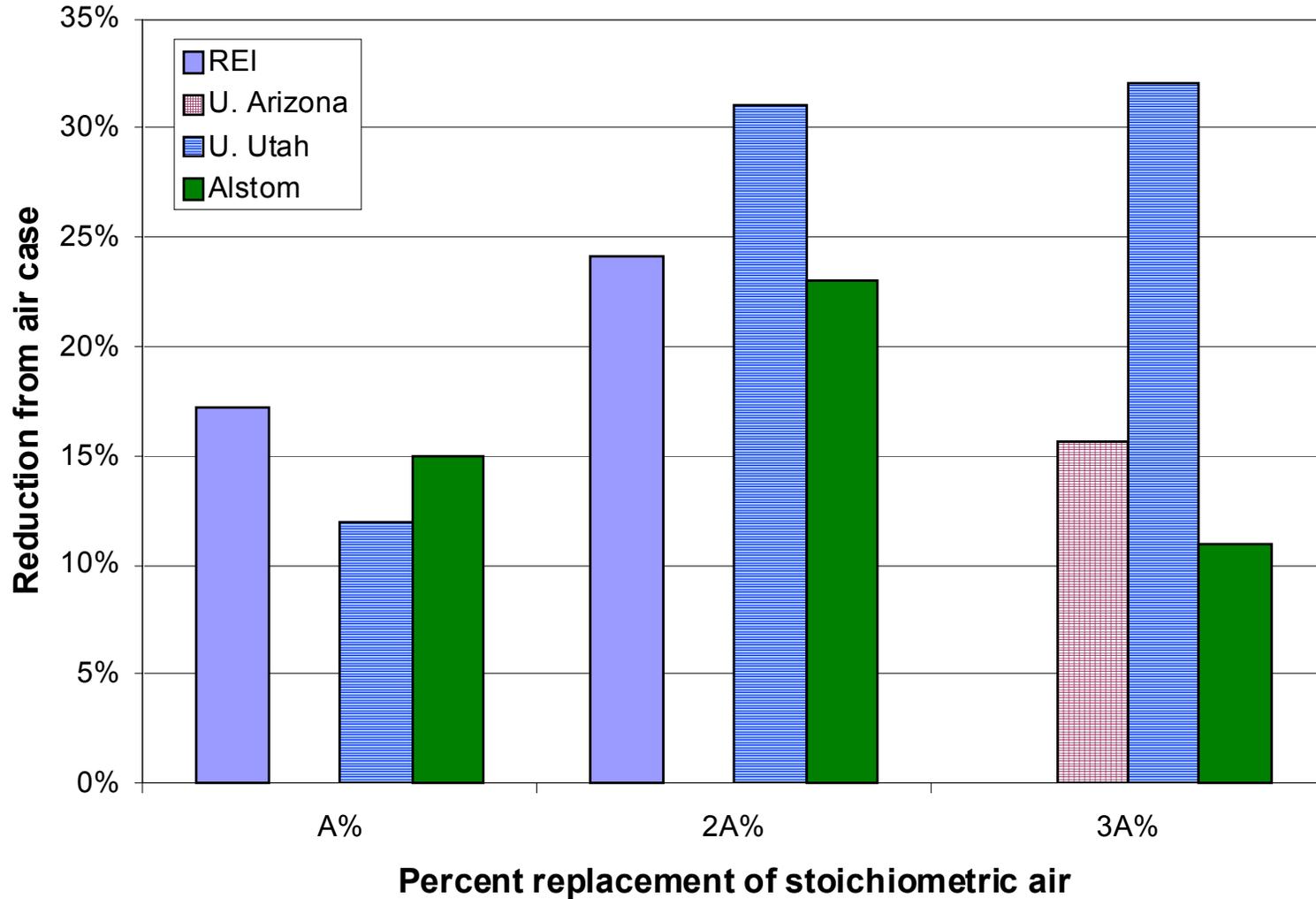
ALSTOM ISBF



Results From ISBF Testing



Summary of Results



O₂ Supply for Utility Operation



- Oxygen supply from either onsite plant or product pipeline
- Oxygen plant can be economically scaled to accommodate units from < 100 MW to 1,000 MW
- Well proven, reliable technology



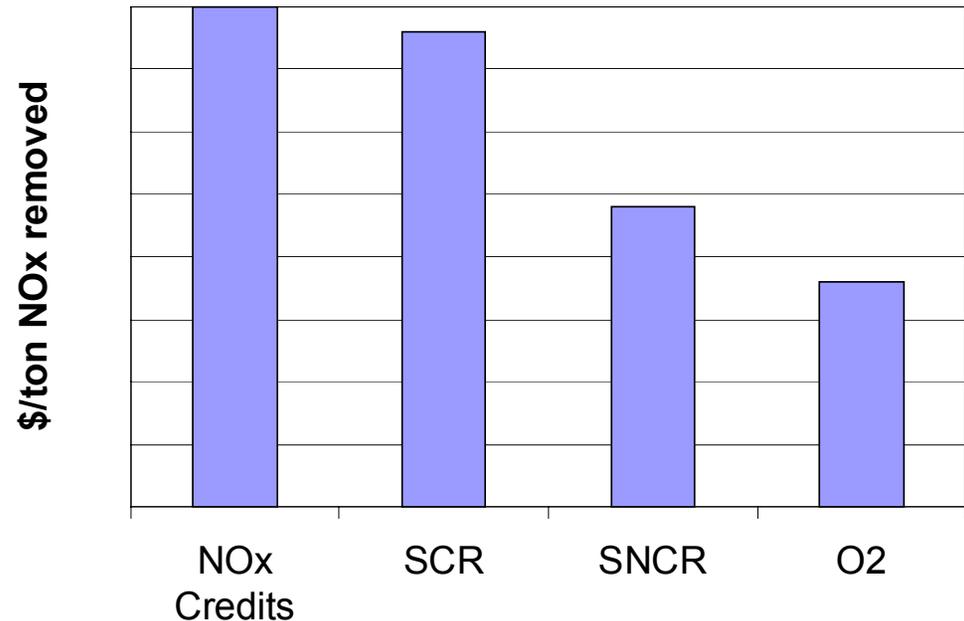
Two bed Praxair VPSA plant

But can we afford it?



- **Minor burner modification required**
- **Other benefits**
 - **reduced LOI**
 - **increased efficiency**
 - **reduced fan limits**
 - **technology additive**

Typical Economics*

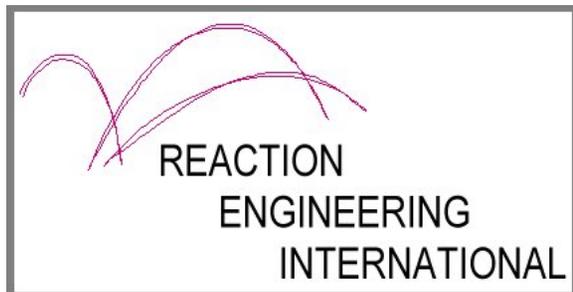


*based on 5 month operation

Conclusions



- **Testing and modeling indicate oxygen addition can significantly reduce NOx emissions**
- **Even when initial NOx concentrations are low O₂ addition reduces NOx even further**
- **Oxygen is an economically attractive alternative to purchasing NOx credits or conventional technologies (SCR and SNCR)**



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