Fuel-Lean Reburn with In-Situ Gasification of Coal, Biomass and Biomass-Coal Mixtures and with Biomass-Derived Gases

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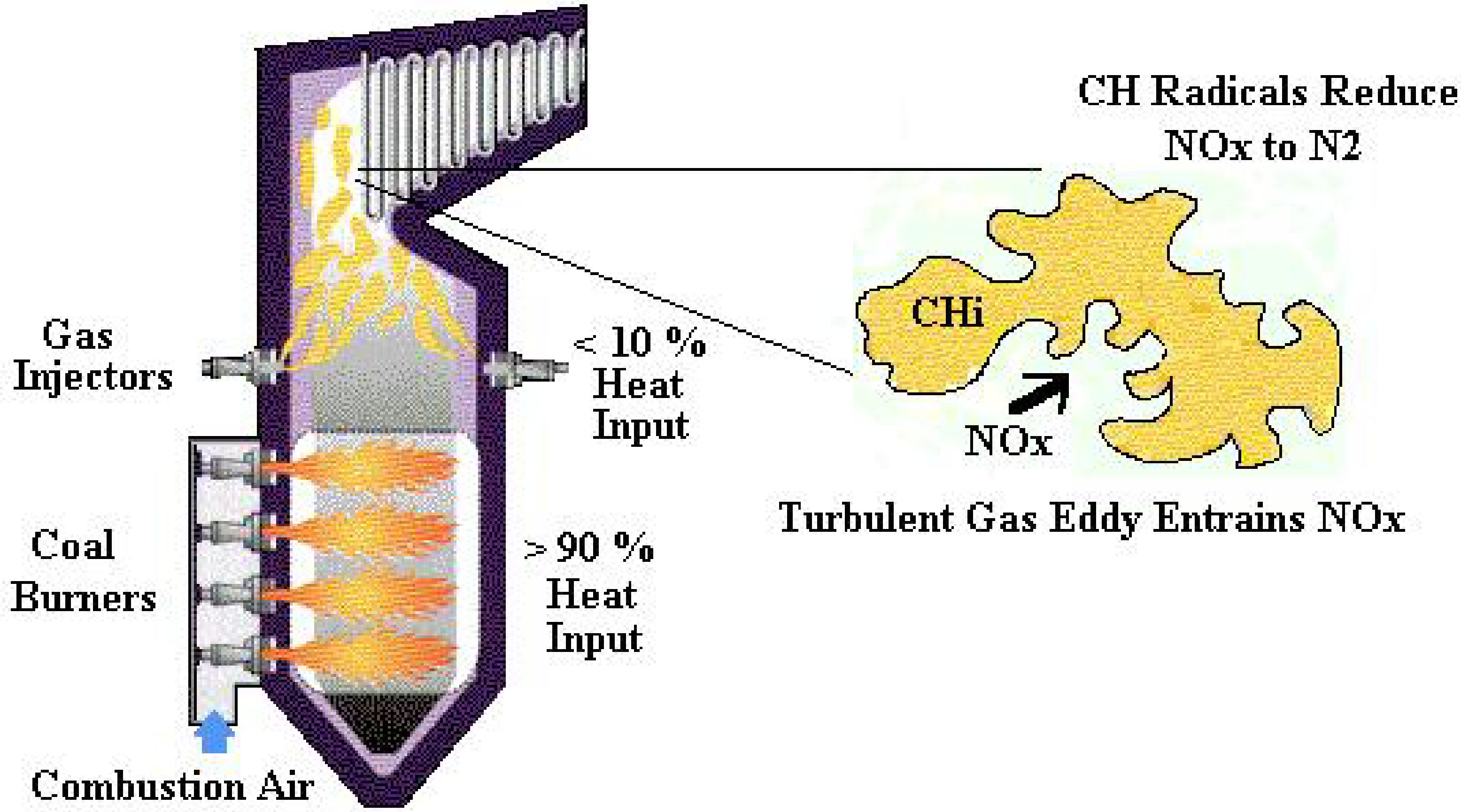
FLGR Process Overview



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FLGR Modeling Technologies

Employs best features of two models

KINETICS

Mixing Limited
Kinetic Reaction
in Eddies

→ **NO Level**
CO Level

↑

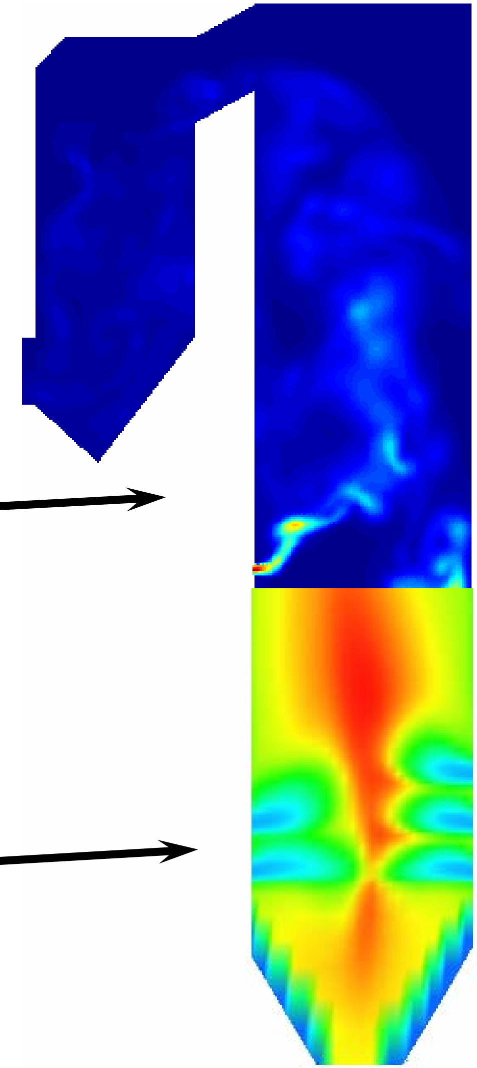
LIM Model

Time Dependent
Eddy Simulation
of Mixing & Reaction

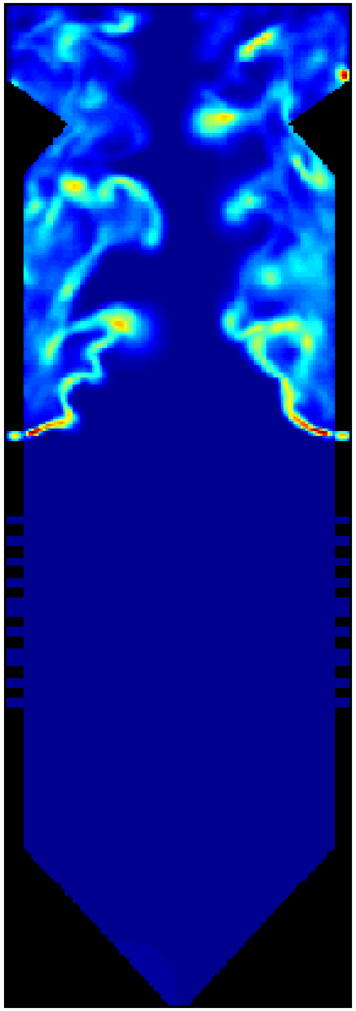
↑

CFD Model

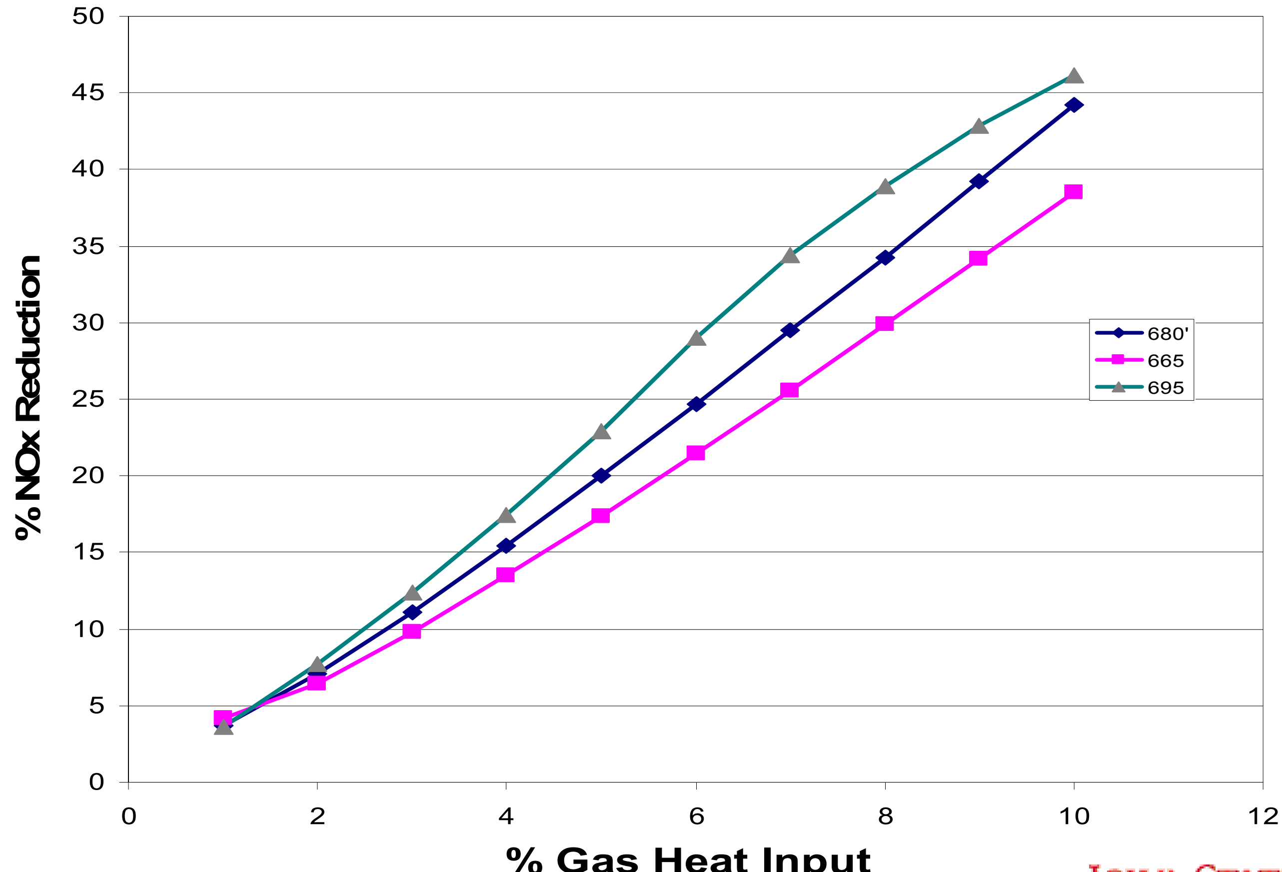
Turbulent Coal
Combustion



Large Eddy Simulation *by NGT*



- Calculates Time-varying Turbulent Distribution of Natural Gas
- Prediction Final NO_x and CO Emissions
- Selection of Optimum Injection Elevations



FLGR Installations

- ***Duquesne Light Company***
  Pittsburgh, PA
  - *Elrama Power Station (1999)*
  - *3 x 100 MW Roof-Fired Units*
- ***Commonwealth Edison***
  Chicago, IL
  - *Joliet Station 9 (1997)*
  - *340 MW Cyclone*
- ***Public Service Electric & Gas***
  Trenton, NJ
  - *Mercer Station (1998)*
  - *2 x 326 MW Wall Fired (4 boilers)*
- ***Wisconsin Electric Power Company***
  Milwaukee, WI
  - *Pleasant Prairie Unit 1 (1999)*
  - *640 MW Turbo Fired*
- ***Duke Power Company***
  Charlotte, NC
  - *Riverbend Unit 7 (1998)*
  - *150 MW Tangentially Fired*
- ***Carolina Power & Light***
  Raleigh, NC
  - *Asheville Unit 1 (2000)*
  - *200 MW Wall Fired*
- ***Ontario Power Generation***
  Hamilton, Ontario
  - *Nanticoke Station (2001)*
  - *510 MW Opposed-Wall Fired*

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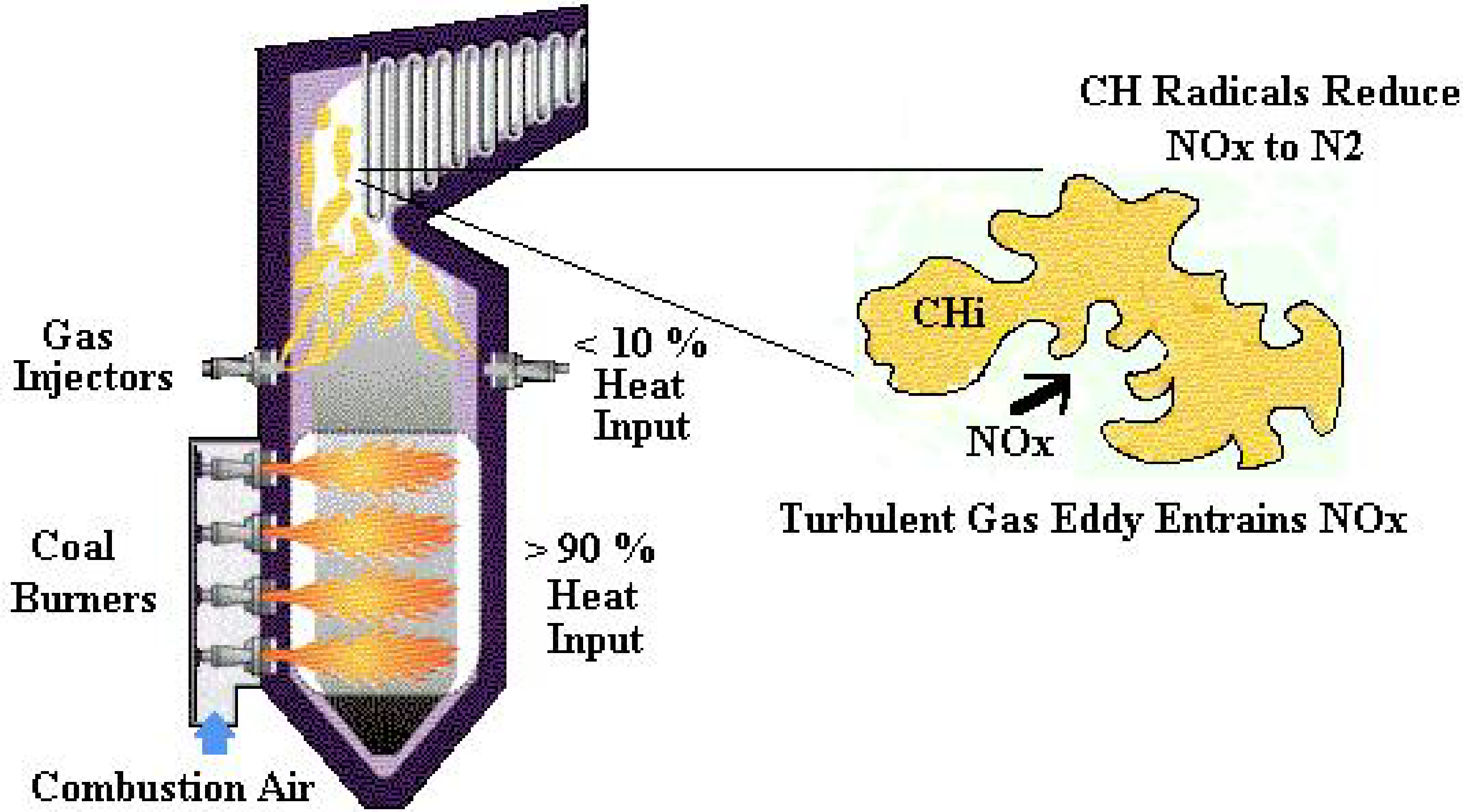
FLGR (with Water Slurry Gasification)



- **Need a More Cost Competitive Fuel**
- Biomass or Coal must have active surface to achieve **<u>Coal-Water Gasification:</u>**

Upper Furnace Injection → H_2O + C → CO + H_2 Volatiles + NH + CHN

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Demonstration of FLCR at Duquesne Light Elrama Power Station

- Work performed on Elrama Unit 2
  - 100 MW, B&W roof-fired unit
- Designed, constructed and tested a coal water slurry injection system on half the furnace of Elrama Unit 2.
- Results proved that the CWS burned completely at low furnace temperatures and that NO_x emissions were reduced by ~20% using 4-5% CWS input.

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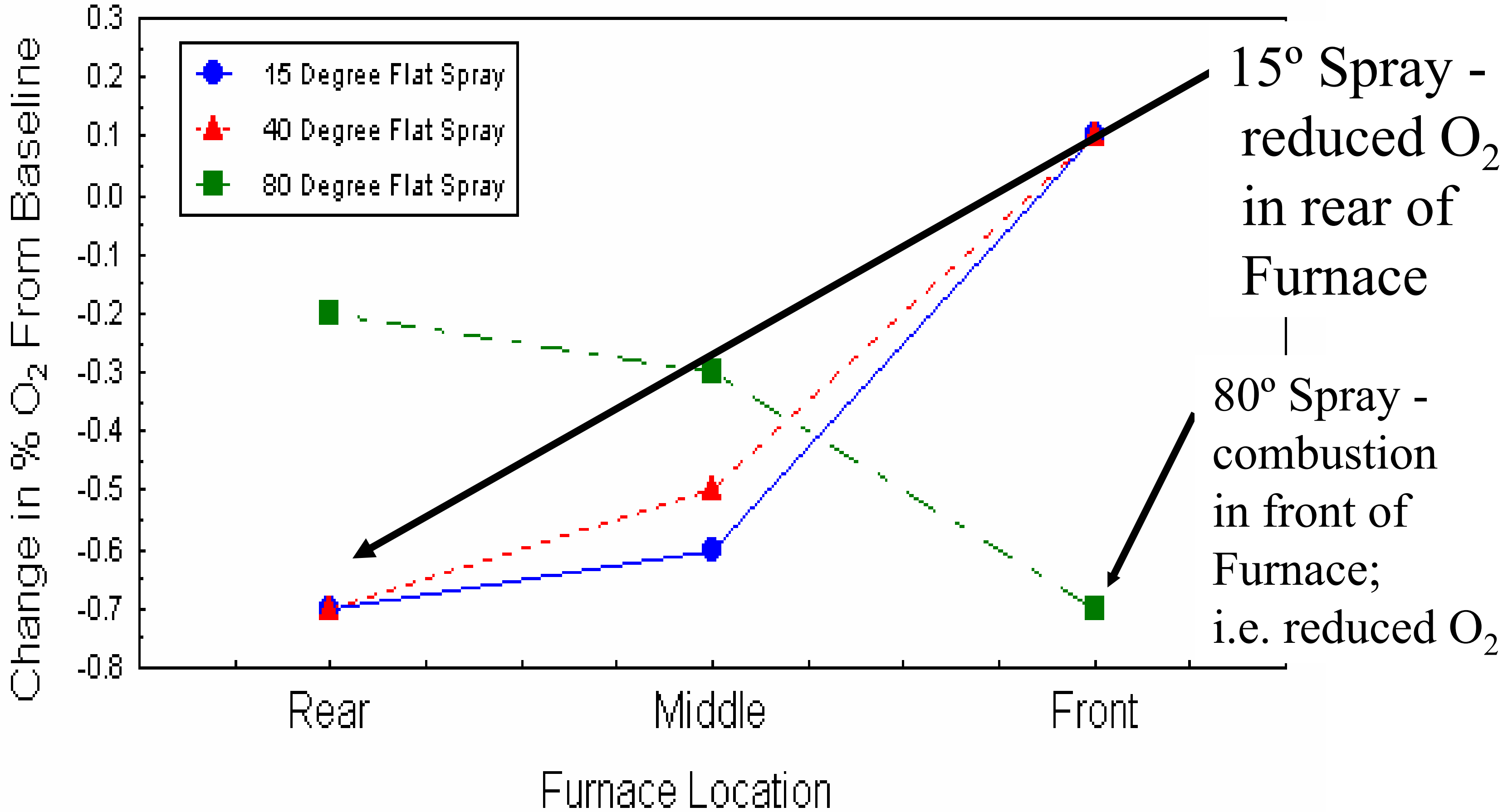
NO_x Emission Results for Various Coal Water Slurry Spray Characteristics

Nozzle Type	Maximum Jet Penetration (ft)	Load (MW)	CWS Heat Input (%)	B Furnace @ Economizer			NO_x Reduction (%)	Max. Local NO_x Reduction (%)
				Change in O_2 (%)	Baseline NO_x (lb/MMBtu)	CWS NO_x (lb/MMBtu)		
Solid Steam	25	90	5.0	-0.30	0.426	0.450	(5.6)	-
15° Flat Fan	18	95	4.2	-0.70	0.441	0.384	12.9	20.6
25° Flat Fan	14	95	4.2	-0.40	0.441	0.403	8.6	15.3
40° Flat Fan	13	86	5.2	-0.40	0.449	0.399	11.1	20.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40° Flat Fan	15	92	8.6	-0.50	0.391	0.404	(3.3)	1.6
40° Flat Fan	11	90	5.0	-0.40	0.434	0.436	(0.5)	8.8
30° Full Cone	10	95	4.4	-0.30	0.448	0.417	6.9	11.9
50° Full Cone	9	95	4.4	-0.10	0.448	0.424	5.4	12.1

Effect of Coal Water Slurry Spray Characteristics on the Furnace Excess Oxygen Profile

5% CWS Heat Input to the B Furnace at the 5th Floor

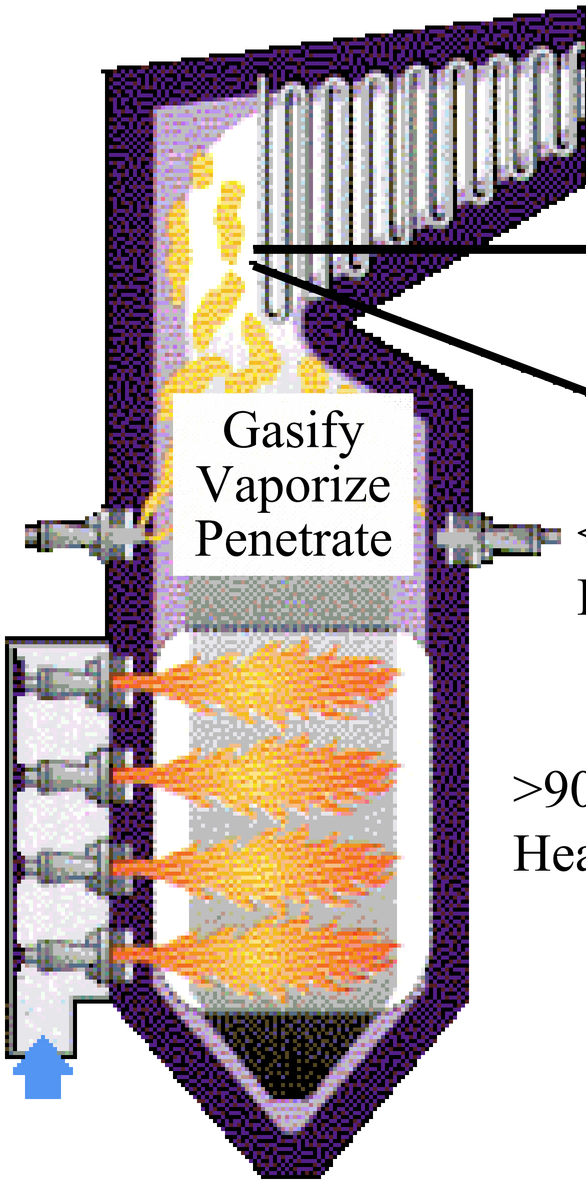


Fuel-Lean Biomass Reburn (FLBR)

Modified version of Fuel-Lean Gas Reburn (FLGR) ~uses ground biomass instead of natural gas as reburn fuel.

1. Biomass is a renewable energy source.
2. Produces zero net carbon dioxide (CO_2) emissions, can reduce overall CO_2 emissions from fossil-fuel fired boilers by displacing a portion of total energy input.
3. When used as a reburn fuel, biomass is more valuable than direct co-firing because of its ability to reduce NO_x emissions.

FLBR Process Overview



NO_x Reduction Mechanism:

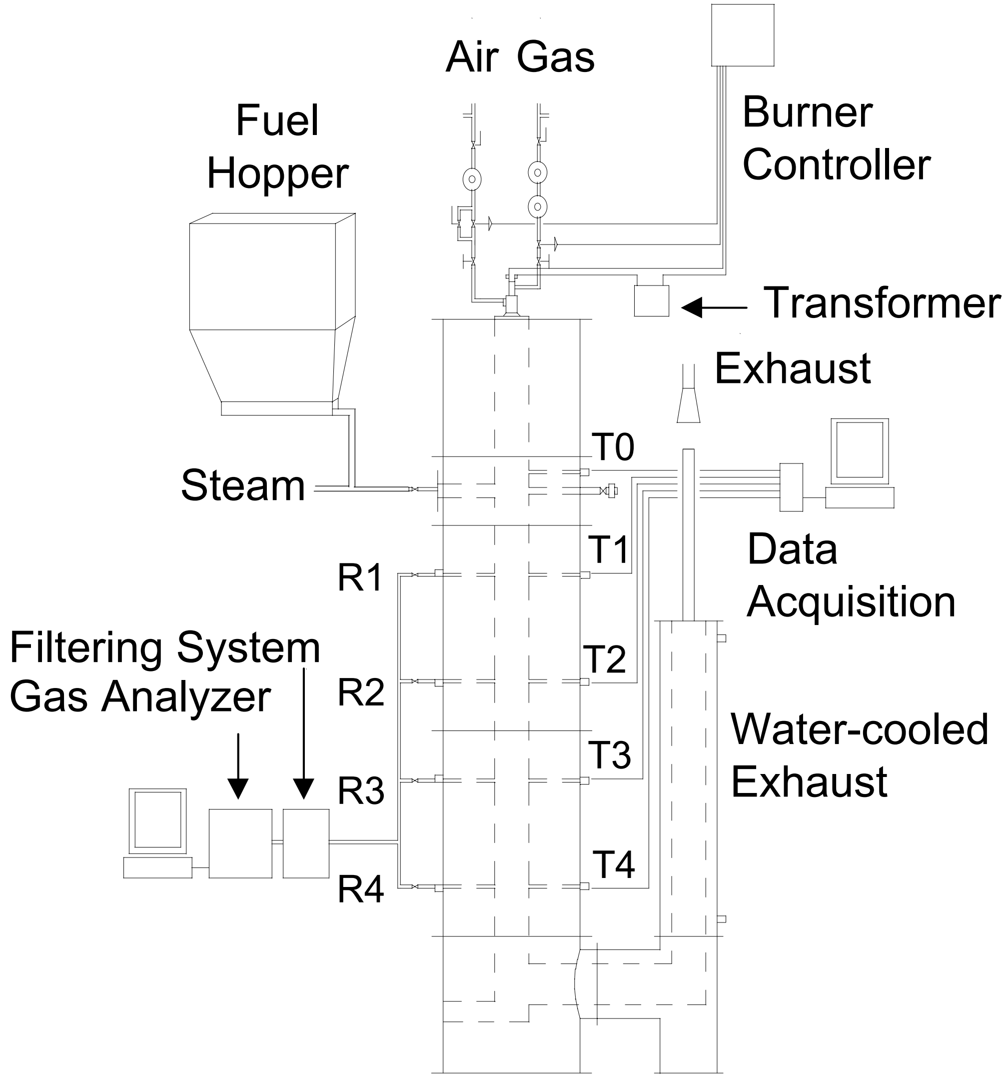
Gasification:

Coal (Biomass) + $H_2O \rightarrow$
$\mathbf{H_2} + \mathbf{CO} + \mathbf{CH_i} + \mathbf{HCN}$

NO_x Reduction:

$\mathbf{H_2} + NO \rightarrow HNO + H$
$\mathbf{CO} + HNO \rightarrow HCN + O_2$
$\mathbf{CH_i} + NO \rightarrow HCN + H_iO$
$\mathbf{HCN} + NO \rightarrow N_2 + CO + H$

Schematic of Experimental Apparatus



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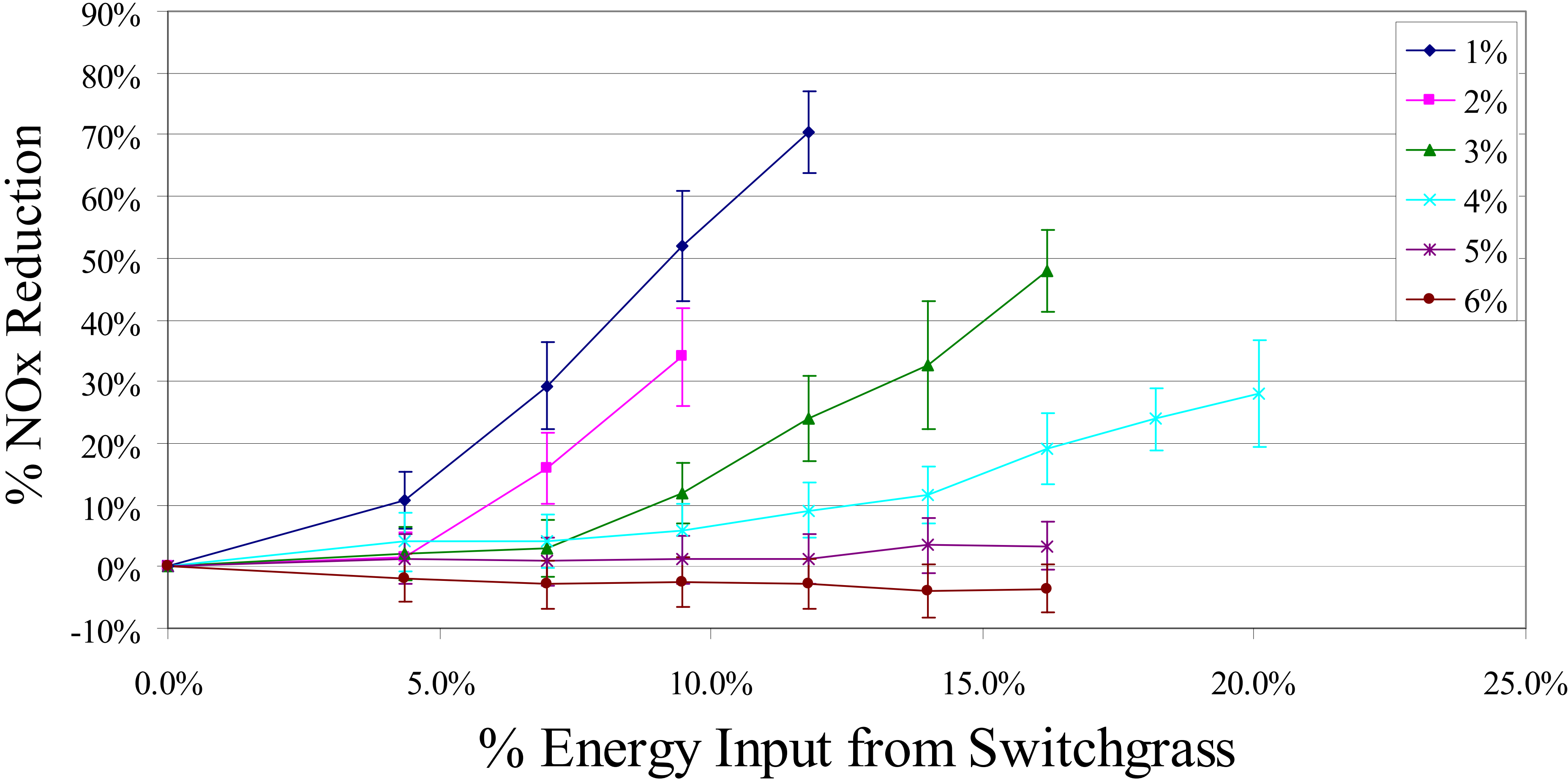
Laboratory Experiments Performed

- 35kW natural gas with >1% NH_3 addition to artificially increase initial NO_x concentration
  - 500 ± 40 ppm NO initially
- 1% – 6% initial oxygen concentration
- Low nitrogen-containing switchgrass
- High nitrogen-containing alfalfa
  - Amine enhancement?
- Steam or nitrogen as carrier fluid
  - In situ gasification with steam?
  - $CO + H_2O \rightarrow CO_2 + H_2$

Laboratory Experiments Performed (con't)

- 4% – 23% Energy Input from Biomass
  - FLGR averages of 3% – 10% energy input from the reburn fuel.
    - Specific regions within the boiler are targeted for natural gas injection
    - Within the turbulent eddies, the eddy is fuel-rich but the boiler is fuel-lean.
  - Scale of down-flow reactor does not produce radial concentration gradients: Assumed instantaneous radial dispersion
    - Individual eddies are simulated, rather than the entire FLGR process
    - To use the experimental results obtained from this research, a weighted average of different simulation must be performed such that the weighting factors are specific to a particular boiler, and any CO remaining in one eddy could react with any O_2 from a different eddy, resulting in lower CO concentrations than those to be presented in this research
    - These "weighted-average simulations" can be performed by *NGT's* LIM Model

Switchgrass Reburn Results: % NO_x Reduction



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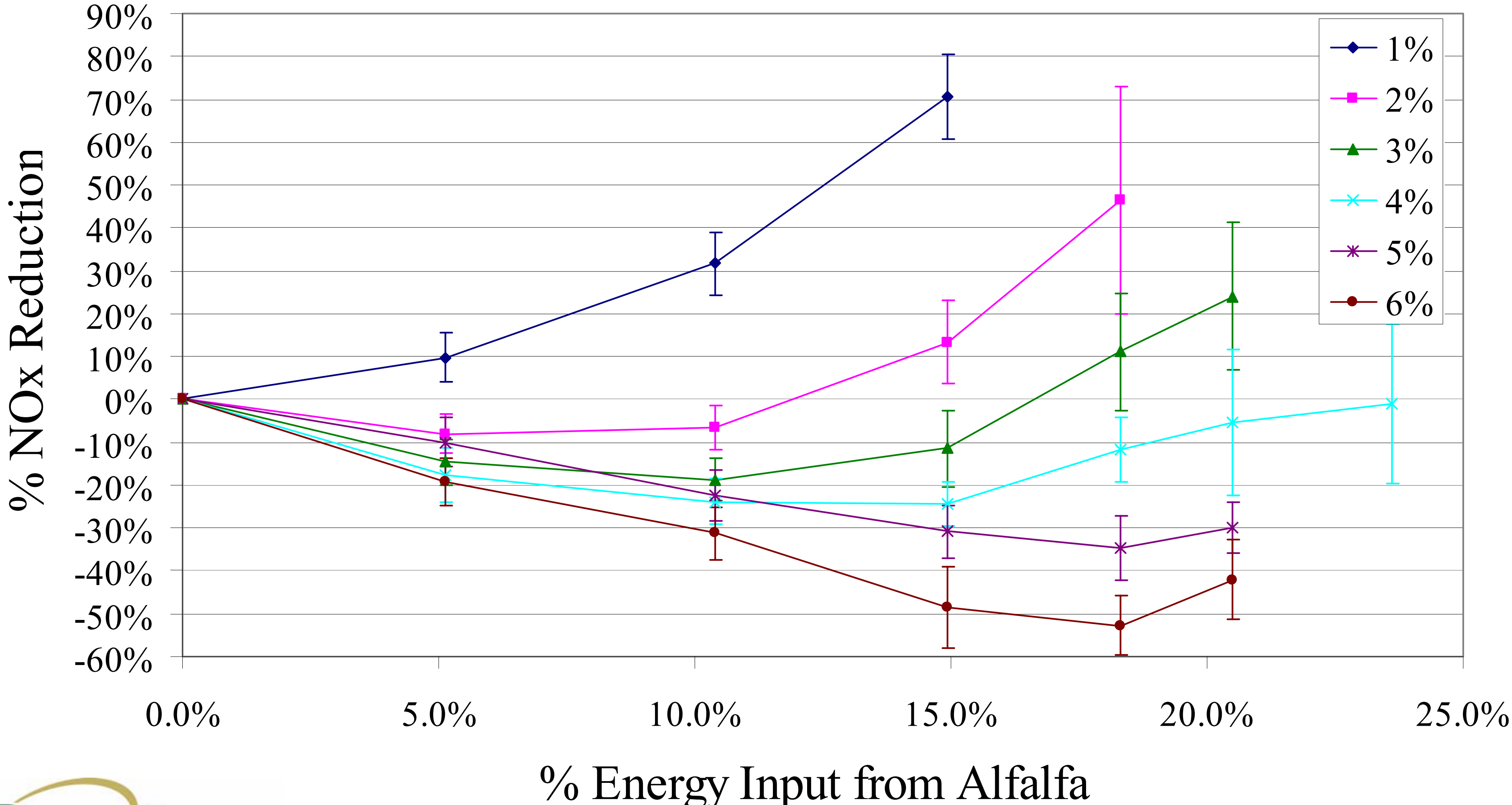
Alfalfa Reburn Results: % NO_x Reduction



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Experimental Summary

- The four parameters of Fuel-Lean Biomass Reburning (FLBR) that were investigated experimentally in this research were:
  - Type of carrier gas (nitrogen and steam)
  - Initial oxygen concentration (1% – 6%)
  - % Energy input from biomass (4% – 23%)
  - Type of biomass used (high nitrogen-containing alfalfa and low-nitrogen containing switchgrass)

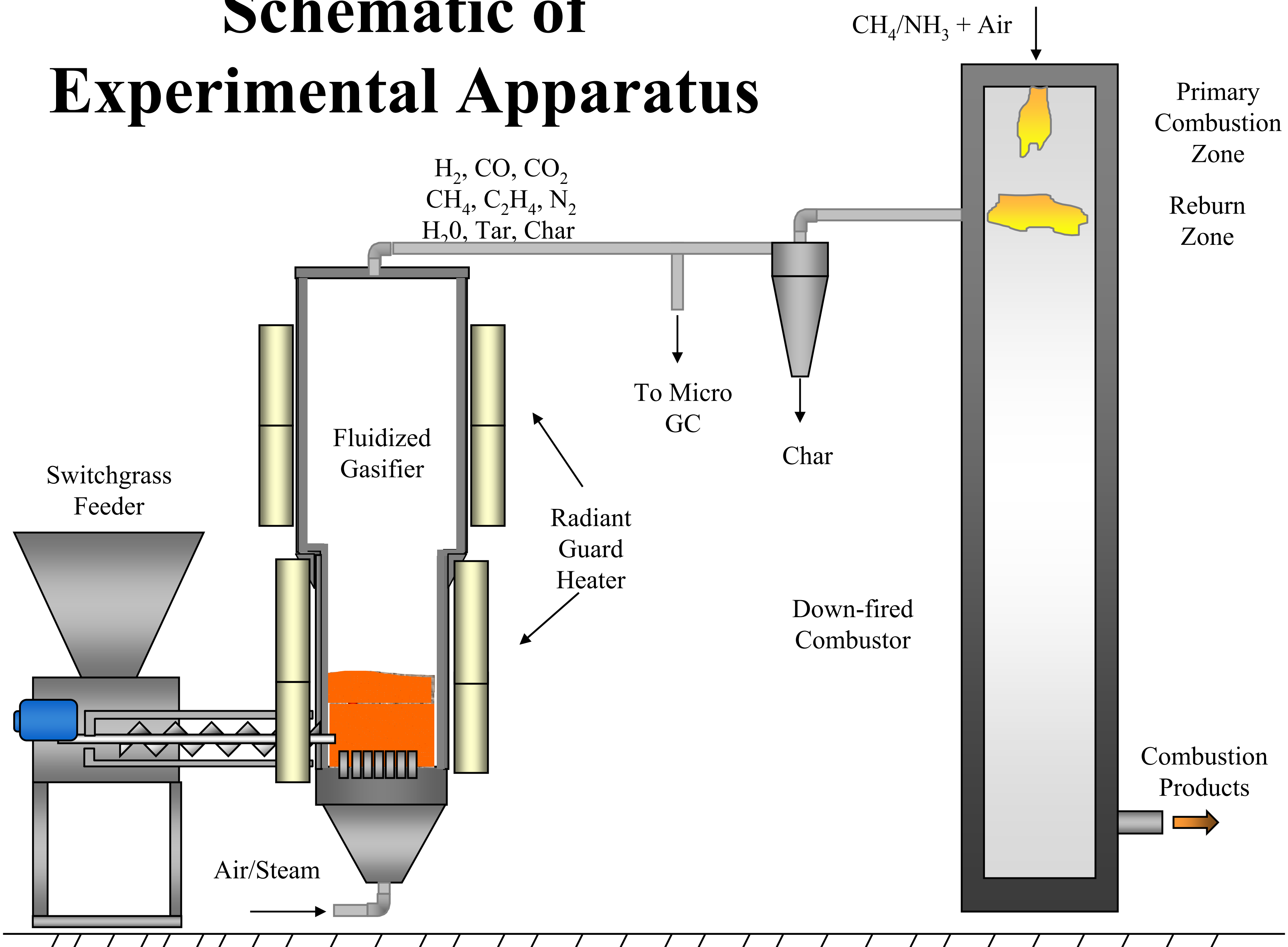
Experimental Conclusions

- Switchgrass proved to be the better reburn fuel. Nitrogen from alfalfa did not enhance the reburn process, but oxidized to form NO_x
- No reduction occurred for high initial oxygen conditions
- Experiments using steam as the carrier gas or as an additive failed due to clogging of the biomass.
- For initial O_2 concentration of 3% – 4%, estimated NO_x were 20% – 25%, based on 10% – 12% energy input from switchgrass.

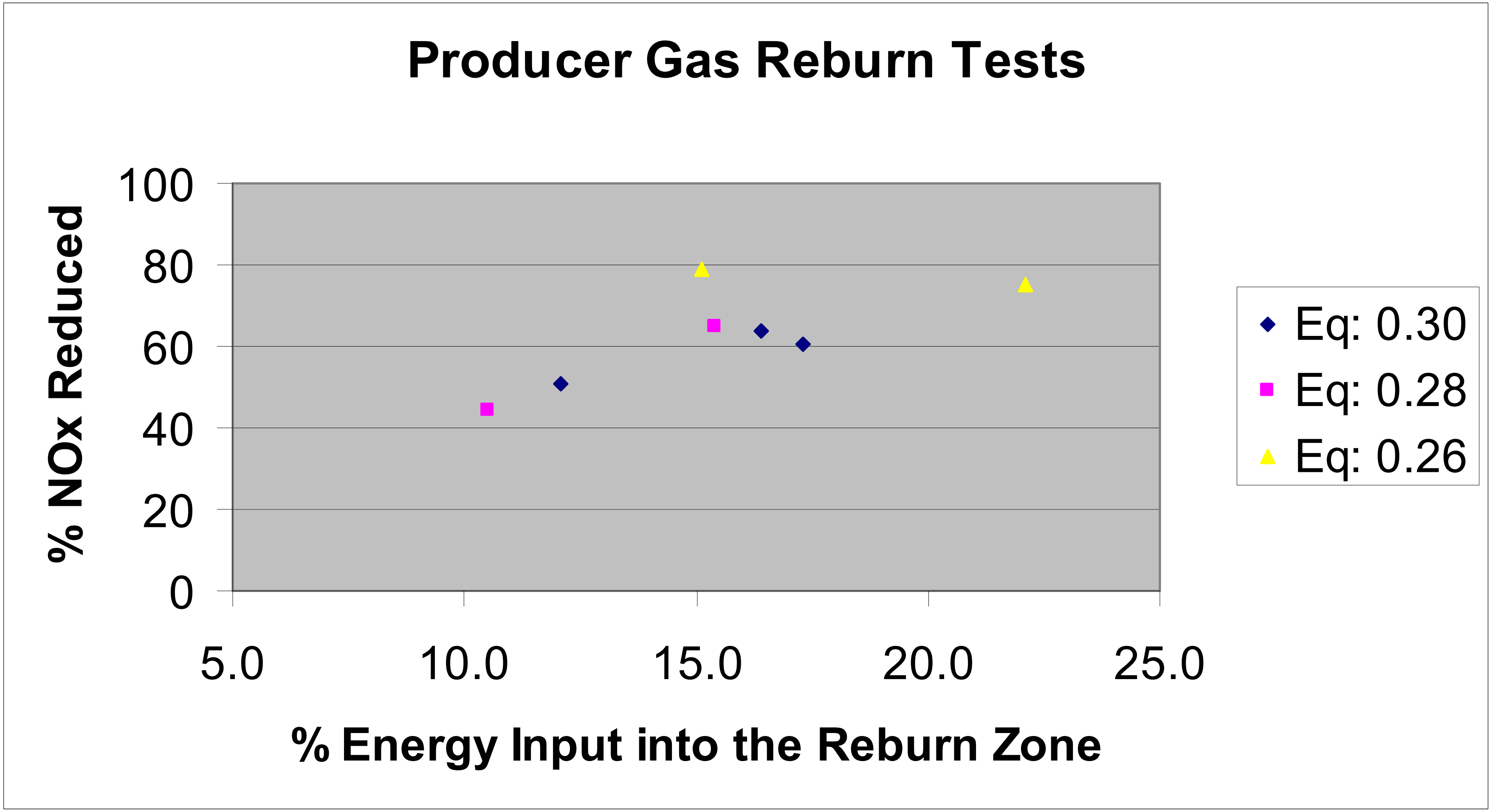
Switchgrass Derived Producer Gas As A Reburn Fuel

- Potential Benefits
  - Preliminary results show that producer gas could be just as successful a reburn fuel as natural gas,
  - Low volumetric Heating Value is advantage to mixing,
  - Using gasification as a fuel pretreatment creates the opportunity to greatly reduce ash co-mingling and boiler tube fouling

Schematic of Experimental Apparatus



Preliminary Results



Example Test from 3/11/2004

Important Parameters		
Reburn Ratio	16.4	%
Cold Gas Efficiency	60.9	%
Volumetric Flow (producer gas)	69.5	slpm
Producer Gas Heating Value	157.4	Btu/scf

Flue Gas Composition	
N_2	81.4%
O_2	0.0%
CO_2	12.3%
CO	1.4%
H_2	0.9%

Producer Gas Composition	
H_2	12.2%
CO	16.4%
CH_4	3.8%
C_2H_4	1.5%
CO_2	15.9%
N_2	47.2%

Combustor Baseline		
O_2	3.17	%
NOx	0.652	lb/mmbtu
NOx Emissions		
NOx	0.236	lb/mmbtu

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