Reinhold Environmental Ltd.

2009 APC Round Table & Expo Presentation

July 12-14, 2009, in The Woodlands, TX

Babcock Power Inc.

Air Pollution Control Considerations

For

Biomass Power Generation

Babcock Power Environmental Inc. / Thermal Engineering International (USA) Inc.
TEi Construction Services, Inc. / Riley Power Inc. / Vogt Power International Inc.
Boiler Tube Company of America / Babcock Power Services Inc.

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Agenda

- Introduction
- Babcock Power Inc.
- Biomass Drivers,
- Fuels
- Emissions Issues for Existing Boilers
    - Co-firing biomass
    - Conversion of Existing Units
- New Boilers Emissions Control
- Summary & Questions

Babcock Power Inc (BPI)

- Danvers, MA based supplier of APC systems, boilers, heat exchangers, HRSG
- Largest supplier of NO_X SCR systems in the US
- Babcock Power 2008 Sales ~$1B
  - Includes Power Services ("Riley Power")
  - Leading supplier of biomass and WTE boilers
    - Thirty-two biomass boilers
    - 60,000 to > 700,000 lb/hr steam
    - Pressures to 1500 PSIG

Developer of the RSCR Technology

Babcock Power Inc.

HRSG

- Heat Recovery Steam Generators
- Engineering and Aftermarket Services

Vogt Power International Inc.

Environmental

- Selective Catalytic Reduction (SCR)
- Flue Gas Desulfurization (Wet & Dry FGD)
- Mercury Control Systems & Management
- System up-rate for SCR and Scrubbers
- Regenerative SCR Systems (RSCR®)

Babcock Power Environmental Inc.
Riley Power Inc.

Services

- Low NOx Burners & Upgrades
- Pulverizers
- WTE Boilers & Upgrades
- Biomass Boilers
- Boiler Condition Assessments
- New Utility Steam Generators
- Spare Parts + Tube Stocking
- Field Engineering
- Replacement Pressure Parts
- Open Shop Construction

Riley Power Inc.
Babcock Power Services Inc.
Boiler Tube Company of America
TEi Construction Services Inc.

Heat Exchangers

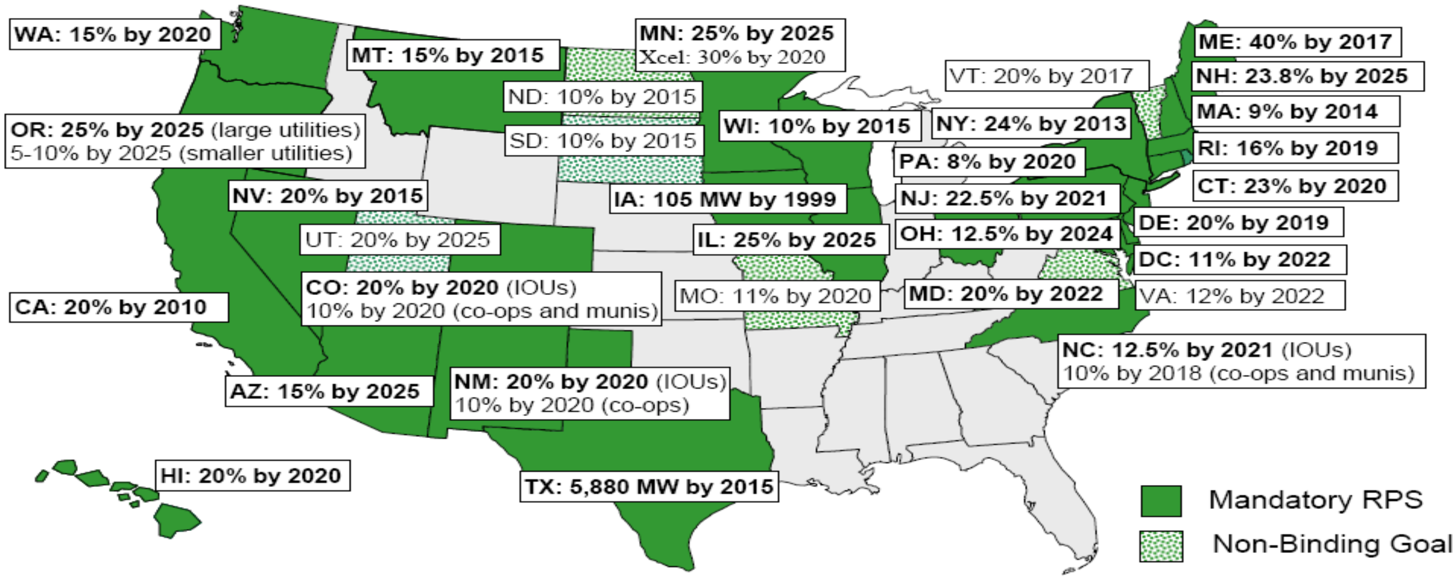
- Condensers
- Feedwater Heaters
- Moisture Separator Reheaters
- Industrial Heat Exchangers
- Fired Process Heaters
- Solar Plant Heat Exchangers
- Repair and Emergency Services

Thermal Engineering International (USA) Inc.

A leading provider of equipment and services for all types of power plants

Market Drivers include State RPS Programs

State RPS Policies Exist in 26 States and D.C.; 6 States Have Non-Binding Goals



Source: Berkeley Lab

Most policies established through state legislation, but some through regulatory action (NY, AZ) or voter-approved initiatives (CO, WA)

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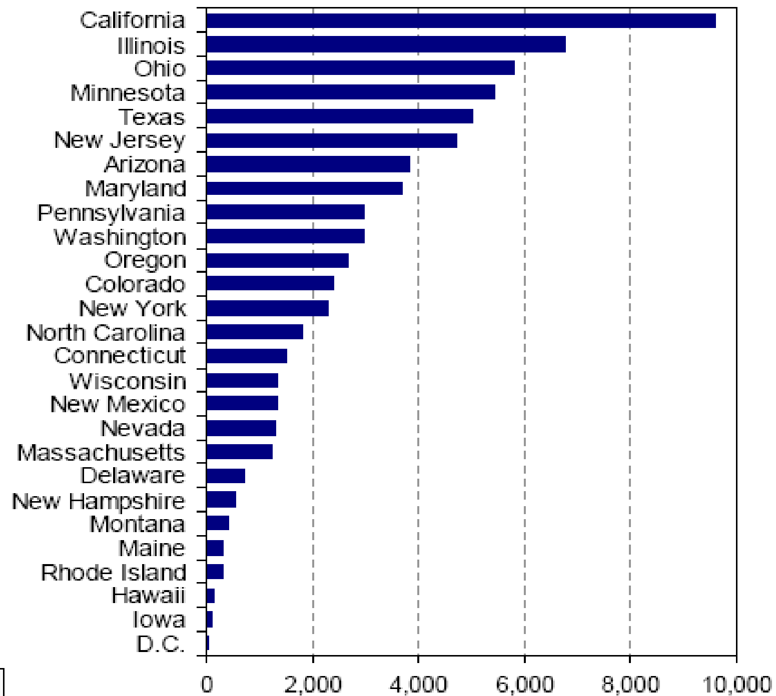
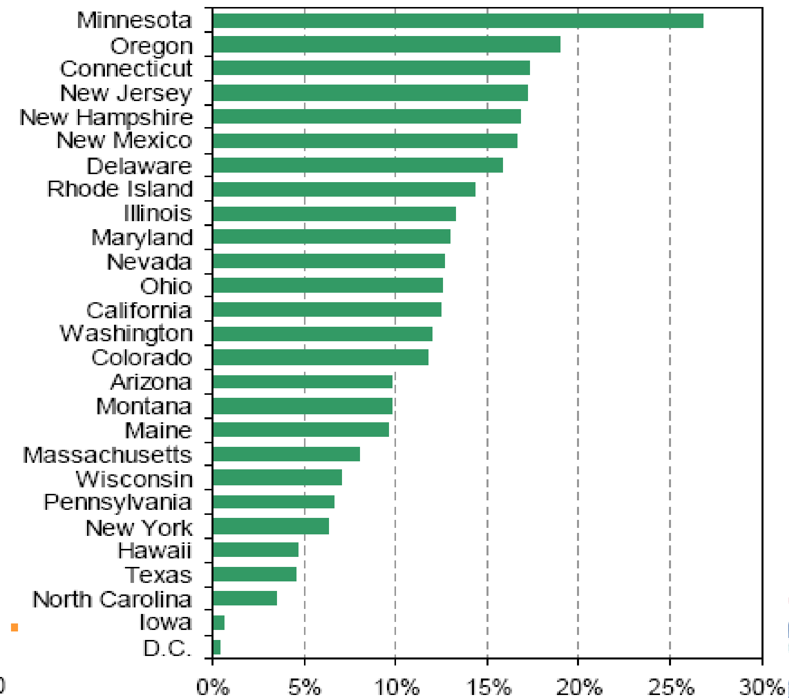
Future Impacts of Existing State RPS Policies Are Projected To Be Relatively Sizable

- Roughly 69 GW of new renewables capacity by 2025, <u>if</u> full compliance is achieved (increases to 86 GW if non-binding renewable targets are included)
- The 69 GW would represent ~5.4% of total projected generation in 2025
- 17% of projected load growth from 1999-2025 met by this new generation

New Renewable Capacity Needed by 2025 (Nameplate MW)



New Renewable Generation Needed by 2025 as a Percent of Projected Statewide Retail Sales

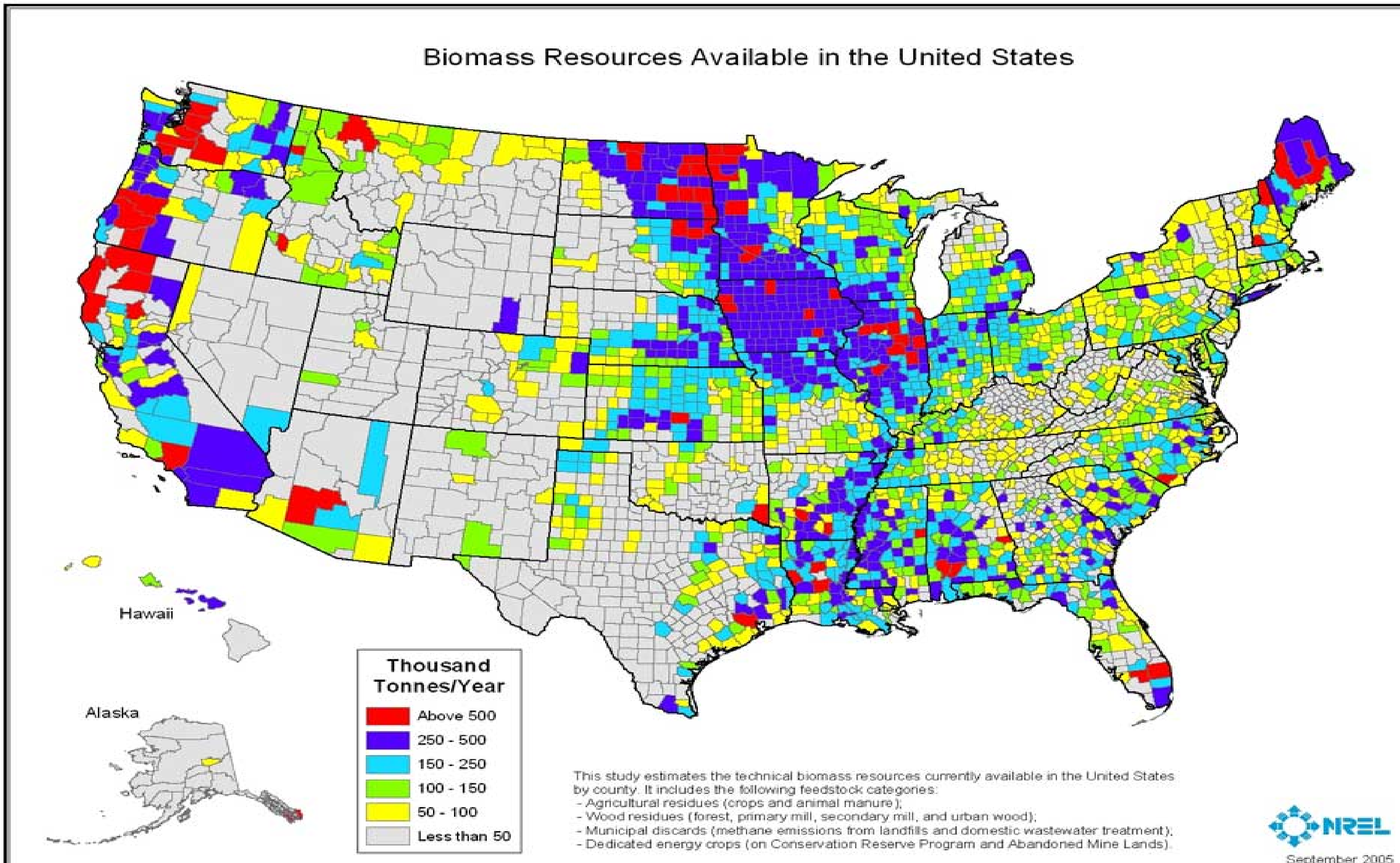


Renewable Energy and Biomass

- Biomass energy:
  - Renewable energy
  - Sustainable fuel supply
  - Significant power generation (15 to 100+MW)
  - Base load power
  - Power is generated day or night; wind or not
  - CO_2 neutral or better
  - Proven, reliable, economical

Key negative factor is emissions

Biomass Resources in US



Common Biomass Fuels

Wood Chips, Wood Sawdust, Wood Bark, Bagasse, Sunflower Seed Hulls, Coffee Grounds, C&D, Paper Waste, Crops

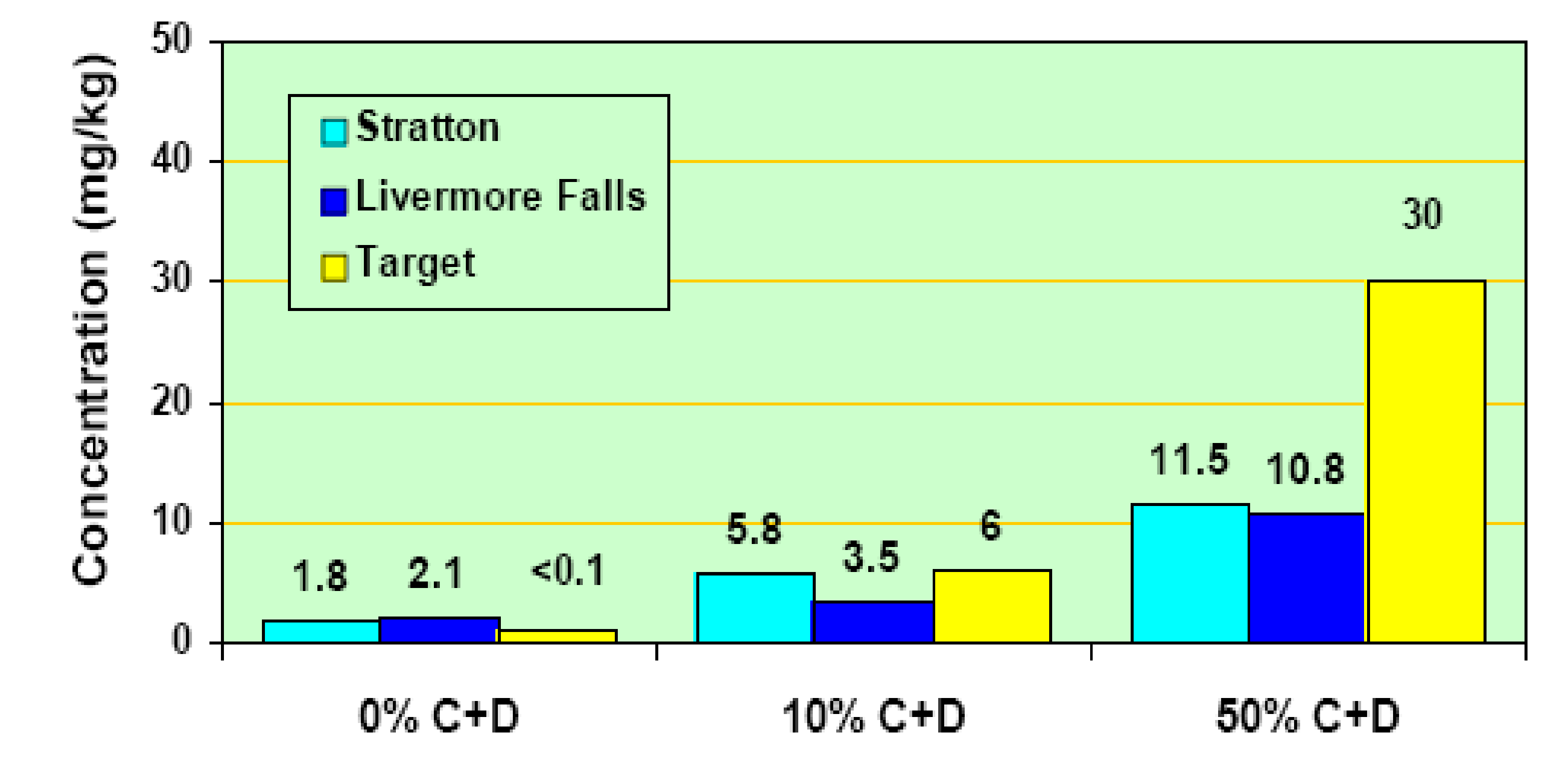
Fuel Considerations for Boiler Design

Fuel parameter	What does it affect?	Impacted equipment / design
• **Ultimate analysis** • **Heating value**	• Air & flue gas flow rates, draft loss • Boiler efficiency, heat rate	• Flue gas flow area – tube spacing • Duct and flue gas equipment sizing • Fan sizing / margins
• **Moisture content**	• Air & flue gas flow rates, draft loss • Boiler efficiency, heat rate • Fuel drying & mill capacity	• Grate sizing • Mill Design • Hot air temperature required
• **Sulfur content**	• SO_2 / SO_3 production • Acid dew point temperature	• Potential for AH / duct corrosion • Desulfurization equipment sizing
• **Ash content**	• Ash production • Erosion potential	• Ash removal equipment • Flue gas flow area / velocity limits
• **Ash initial deformation temp.** • **T_{250} temperature**	• Furnace slagging potential • Furnace efficiency / heat absorption	• Sootblowers • Furnace size / platen surface area
• **Ash mineral analysis: Na_2O, CaO, KO**	• Convection pass fouling potential	• Tube clear space requirements • Sootblower application

Typical Fuels - Comparison

Fuel	Green Chips	C&D Waste	Miscanthus	Bituminous Coal	Typical PRB
Carbon	30.60	40.0	44.4	69.79	47.51
Hydrogen	3.5	5.3	5.4	4.43	3.53
Nitrogen	0.03	0.16	0.22	1.51	0.53
Oxygen	24.4	35.5	37.3	9.34	11.86
Chlorine	0.006	0.10	0.039	0.1	0.01
Sulfur	0.03	0.086	0.05	0.80	0.35
Ash	2.2	0.80	2.2	7.28	5.42
Moisture	40.00	18.0	10.6	6.85	30.79

Construction & Demolition Waste (C&D) Arsenic Issue



Biomass Options

1. Co-firing in existing boilers
2. Retrofit/conversion of existing units to 100% biomass firing
3. New boilers

Each option will have different considerations for APC systems

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Co-Firing Biomass

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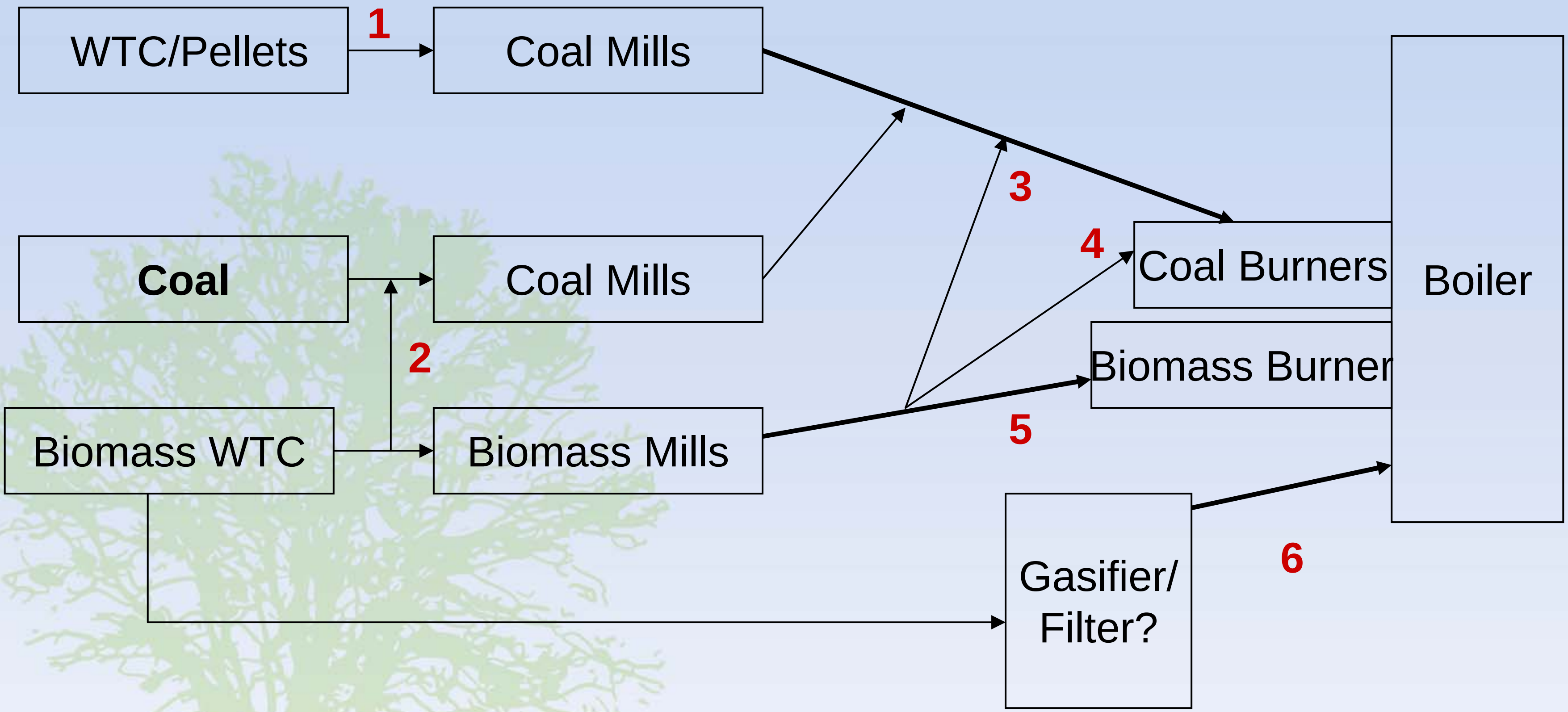
Biomass Co-firing Options for PC Boilers



Typically 10% to 20% by heat input limit

Issues with Biomass Co-Firing with Pulverized Coal

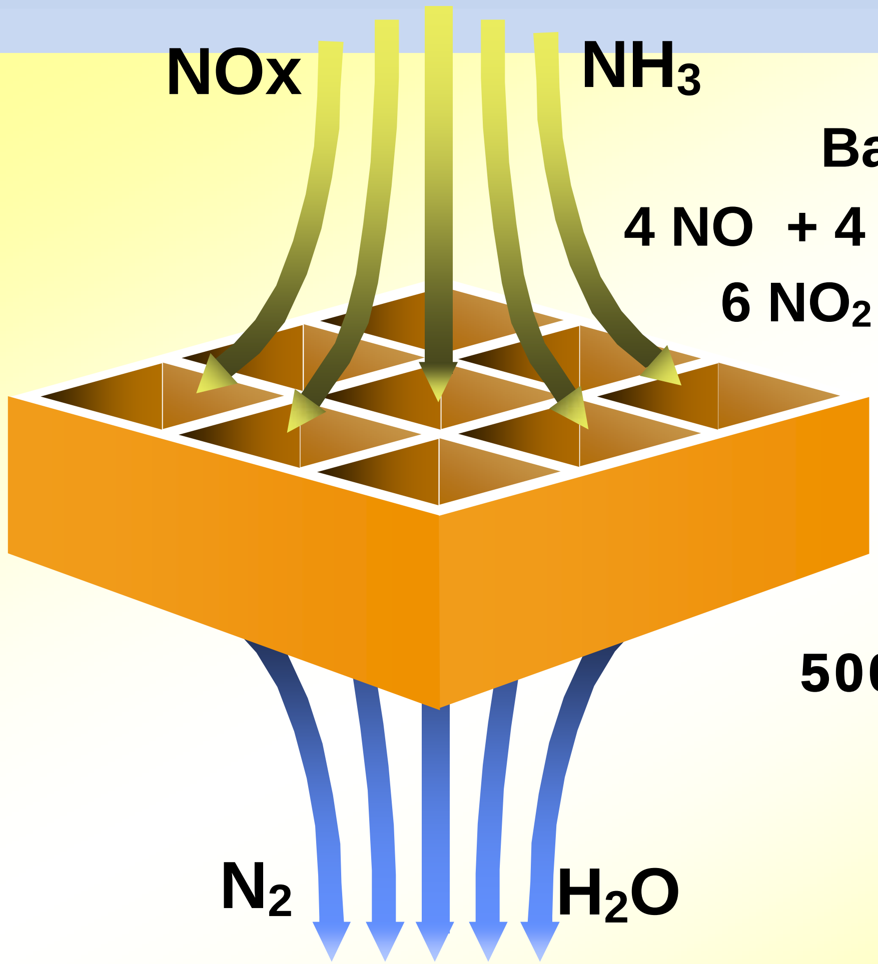
- Areas to carefully evaluate
  - Fuel handling and mixing
  - Burners
  - Boiler fouling and slagging
  - **Environmental equipment (ESP & SCR)**

BPI study for 150MW unit concluded 10% co-firing limit

Biomass Co-Firing with Pulverized Coal

Evaluate fouling and slagging of the mixed fuel

Chemistry of the SCR Process



Basic reaction equations

$$4\,NO + 4\,NH_3 + O_2 \rightarrow 4\,N_2 + 6\,H_2O$$

$$6\,NO_2 + 8\,NH_3 \rightarrow 7\,N_2 + 12\,H_2O$$

500°F - 800°F

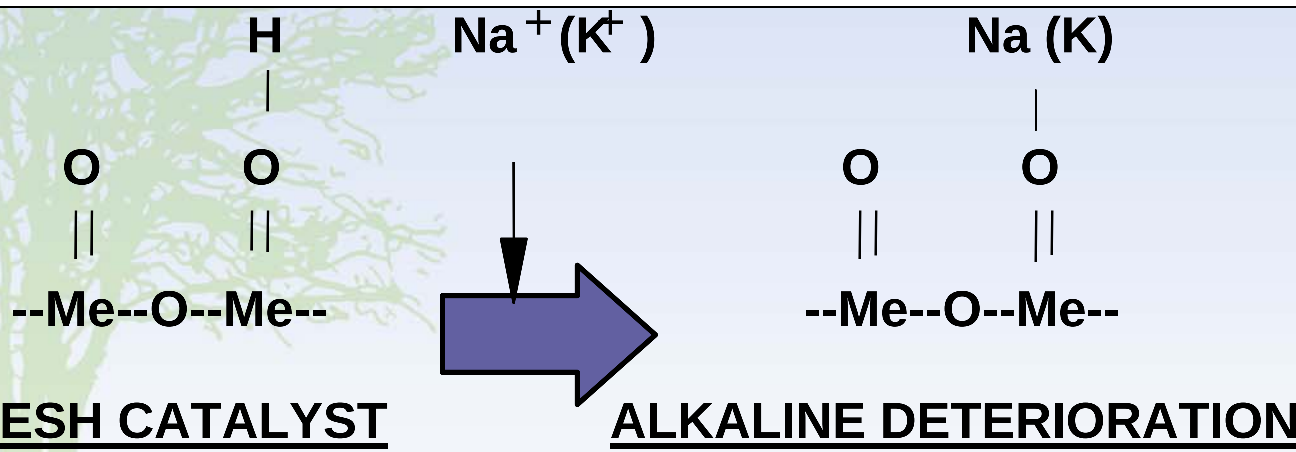
Biomass Applications and SCR

- Poisons affect all SCR catalysts the same
  - Potassium, sodium, arsenic, phosphorus are irreversible
- High poison concentrations in fly ash adversely affect the SCR catalyst
- Studies show biomass >15% of heat input produces significant catalyst life degradation

Understanding Ash Characteristics

Alkaline Metal (Na, K).

- Exist in the dust as sulfates, Na_2SO_4 and K_2SO_4, readily soluble in water. The alkaline ion moves freely through the catalyst wall and bonds with acid sites resulting in decreased capability to adsorb ammonia thus decreasing catalyst potential.



Catalyst Deactivation

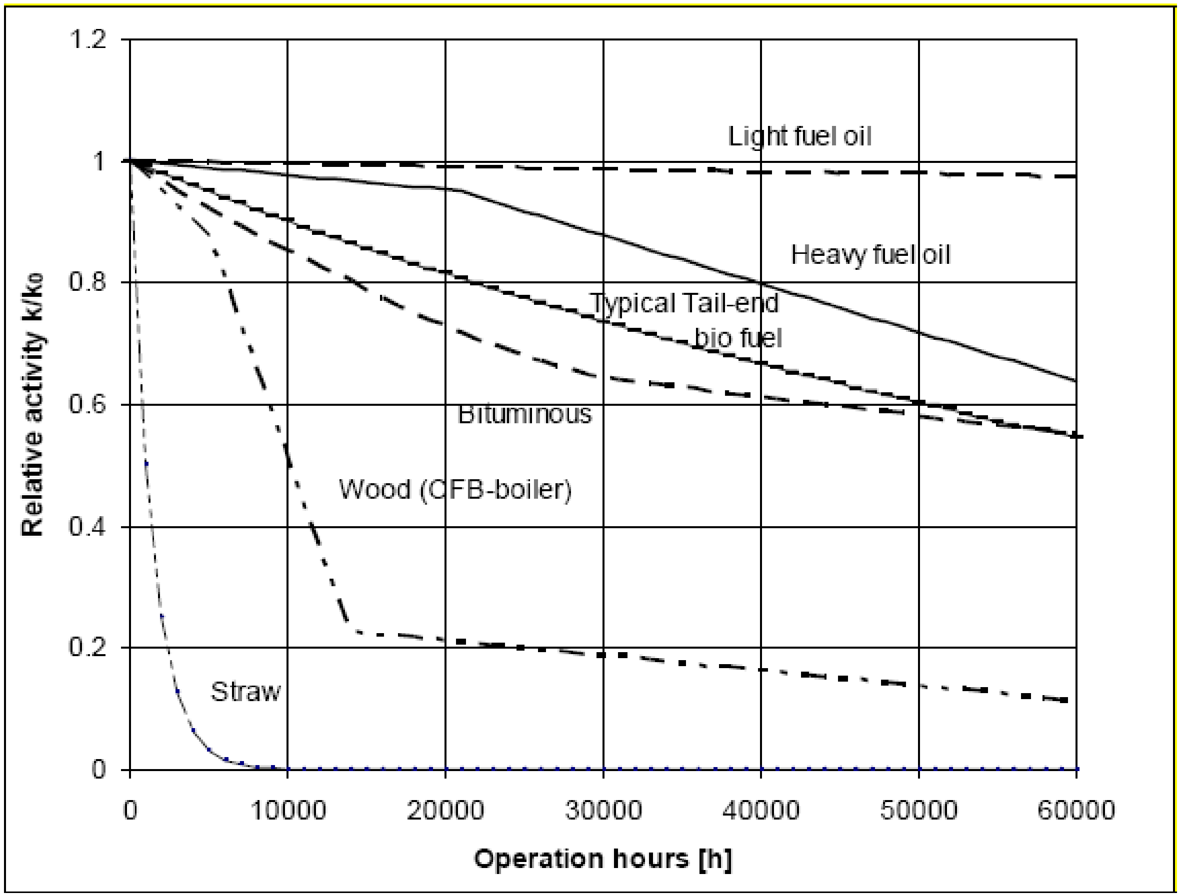


Figure 3: typical catalyst deactivation ratios for different fuel and plant configurations [6]

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Impact on ESP

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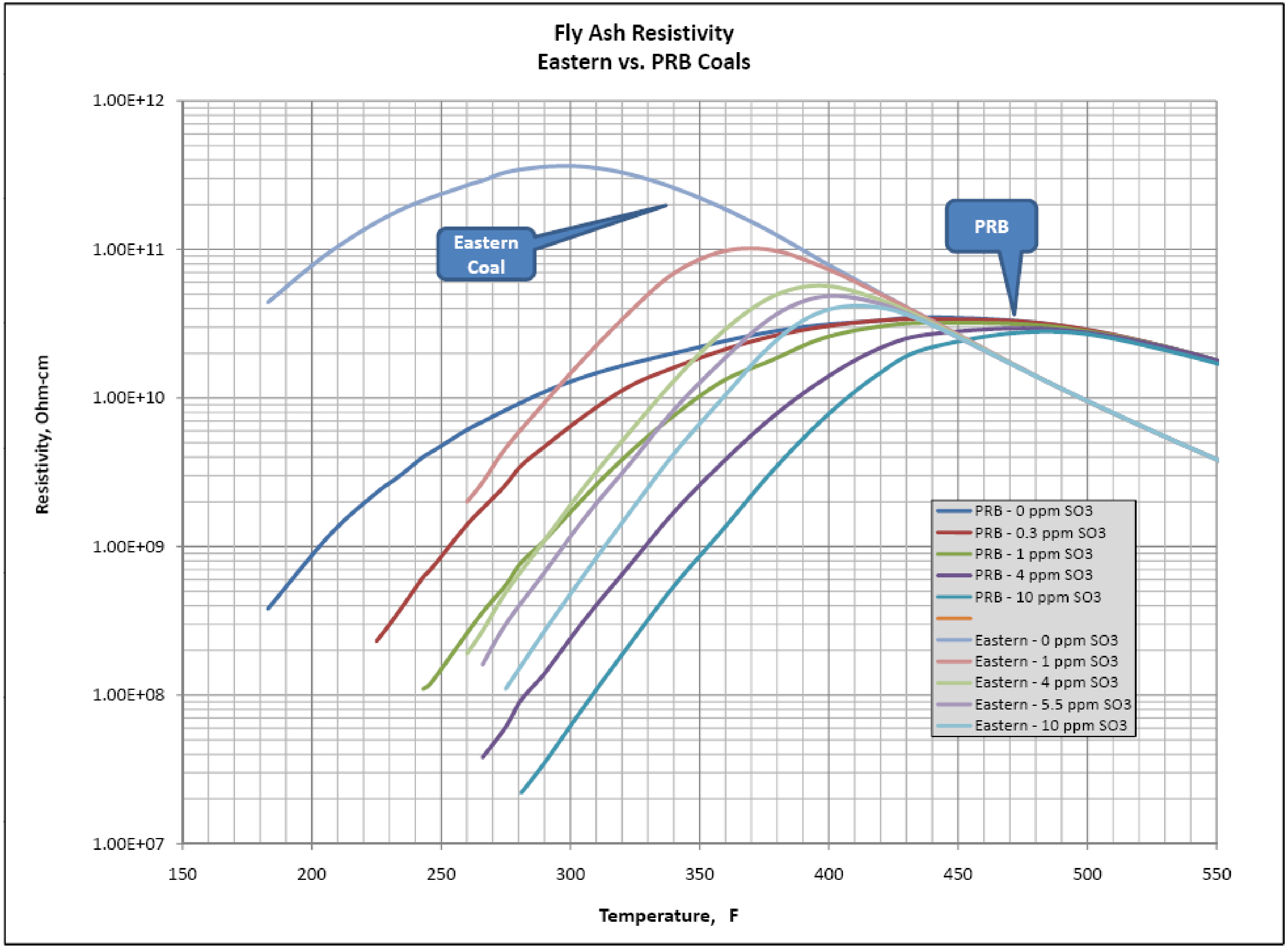

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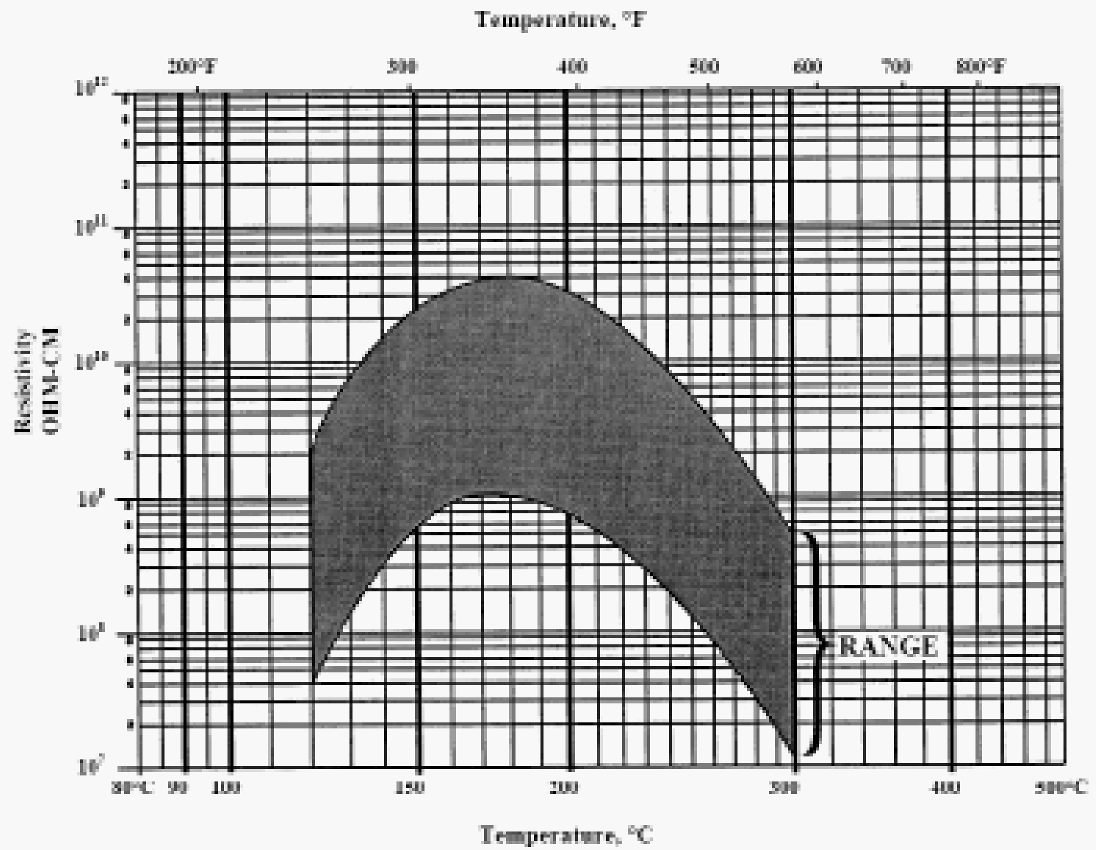
TYPICAL BIOMASS RESISTIVITY



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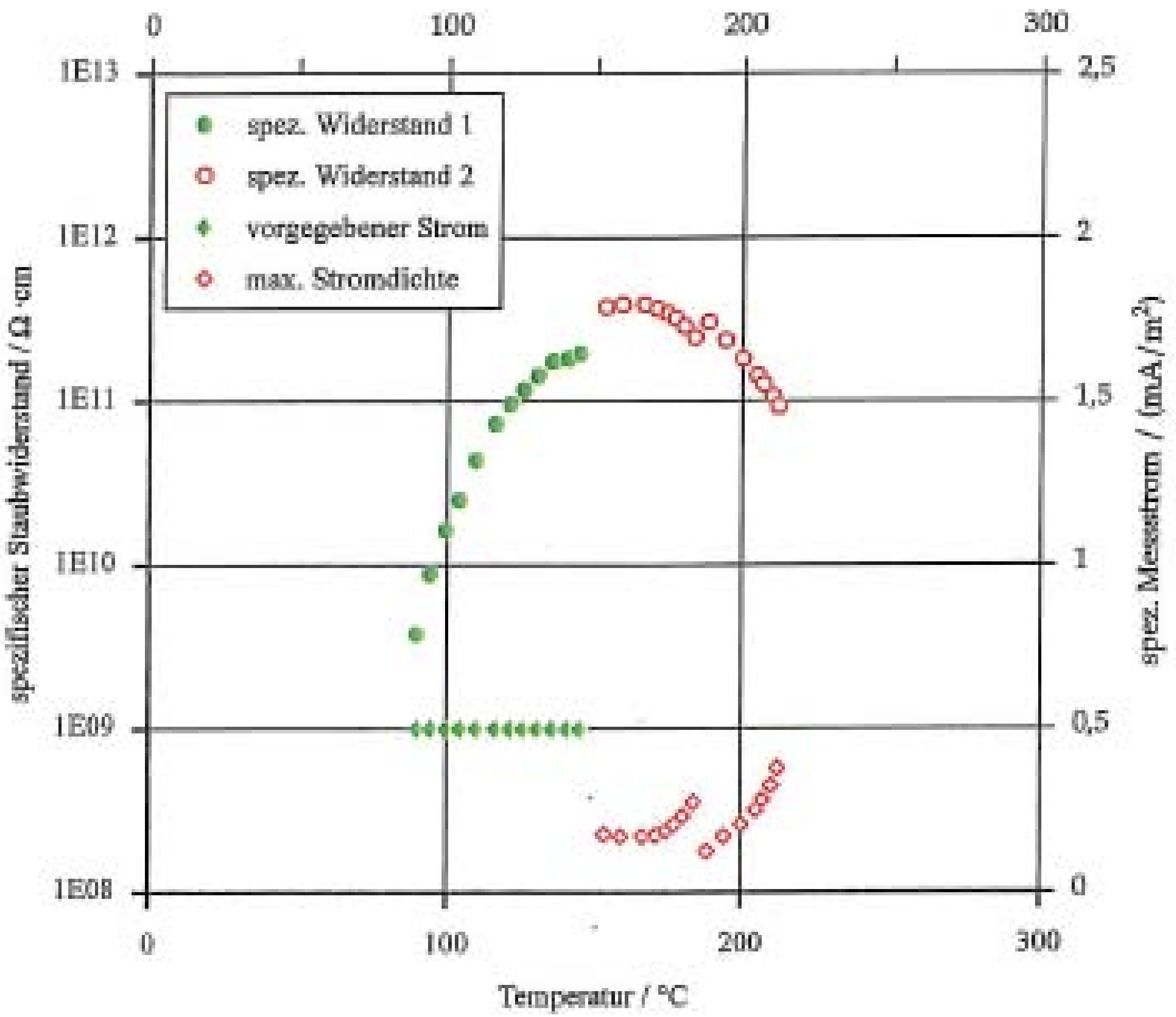

0
100
200
300
1E13
1E12
1E11
1E10
1E09
1E08
2,5
2
1,5
1
0,5
0
spez. Widerstand 1
spez. Widerstand 2
vorgegebener Strom
max. Stromdichte
spezifischer Staubwiderstand / Ω·cm
spez. Messstrom / (mA/m²)
Temperatur / °C

Co-firing Impact on Emissions

- SO_2 reduction
- NO_x plus/minus
- Boiler efficiency slightly lower
- Flue gas flow rate slightly higher

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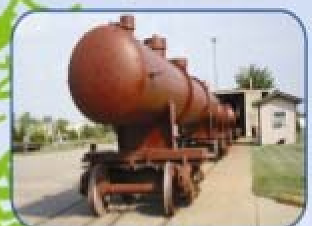

Conversions of Existing Boilers

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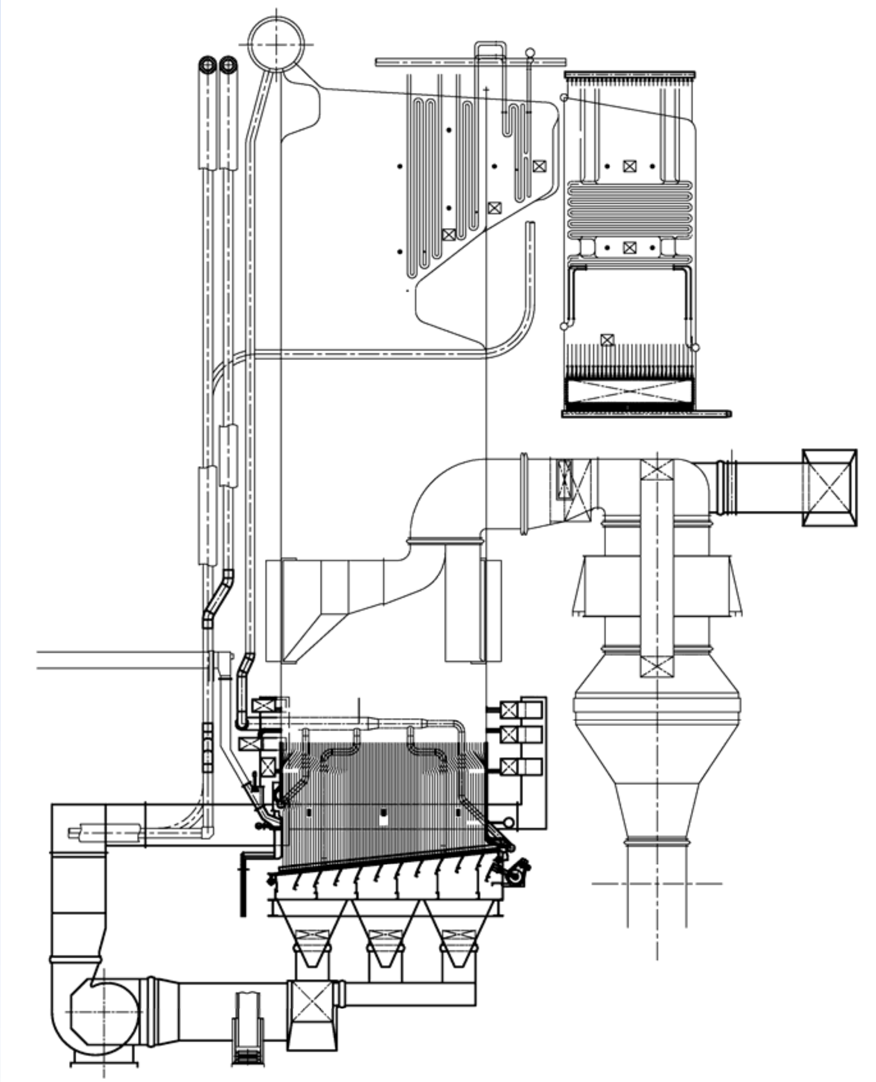
Biomass Conversion of Existing Units to 100% Biomass

- Establish fuels
- Evaluate the boiler capacity firing biomass –slagging review
- Review required modifications
- Perform a feasibility study –fatal flaw
  – Includes evaluation of APC systems

Conversion Project with New Detroit Stoker



APC Modifications – 100 % Conversion

- Multiclones added
- New ESP to achieve 0.012 lb/MBtu
- RSCR added to achieve 0.065 lb/MBtu (permit and REC issue)

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New Boilers

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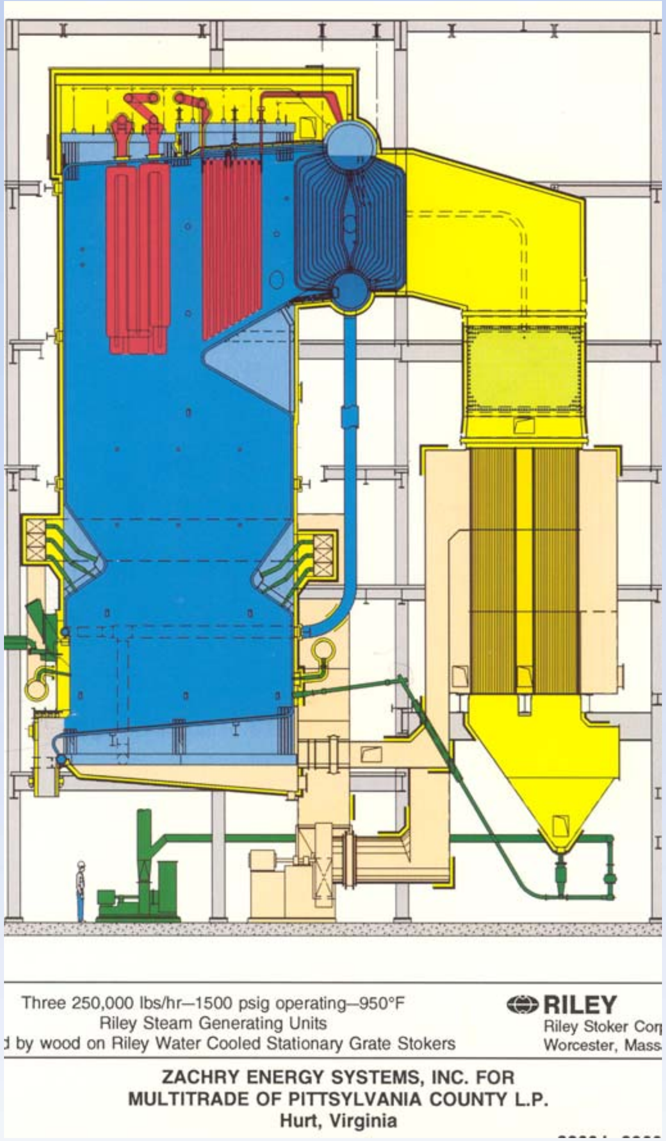
New Boilers

Typical Conditions

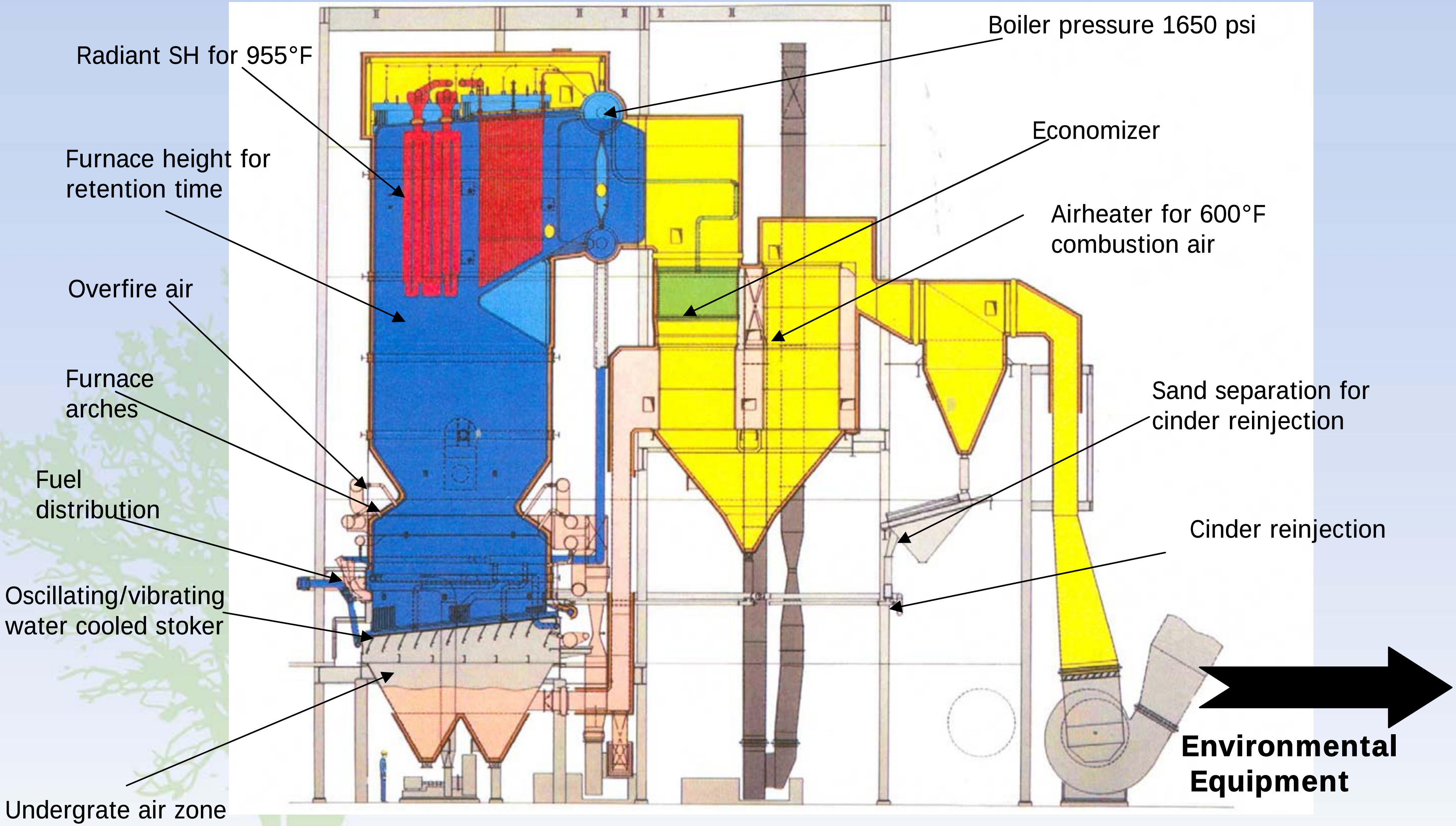
Steam Flow	Temp	Pressure
100,000->700,000 Lbs/hr	650-960°F	650-1700 psig



Biomass Power Boiler - Trends

- **Stokers**
  - Largest installed base
  - Fuel flexible
  - Proven, reliable, improved
- **Bubbling / fluidized bed**
  - Fuel flexible
  - In-situ SO_2 control
  - Somewhat lower uncontrolled emissions; not sufficient
  - High parasitic load
- **Gasifiers**
  - Relatively small scale
  - Typically combust "syngas" from gasifier

Typical Advanced Biomass Stoker Boiler System



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Emissions Control – New Boilers

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Biomass Issues

Emissions - The Primary Concern

Pollutant	Emissions
• PM	Low (ESP)
• SO_2	Low
• HCl	Low
• CO	Moderate
• VOC	Low
• NO_X	Moderate/High

NO_X and CO are main pollutants, but….

Typical Emissions –New Boilers

(lb/MBtu)	Biomass	Biomass
	Uncontrolled	*With Controls*
NOx	0.15 to 0.48	0.06 to 0.10
SO2	0.8 to >6.0	<0.04 to 0.08
CO	0.04 to 0.15	0.07 to 0.1
PM	3 to 15	0.010 to 0.015

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Control Options

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Particulate Matter

Electrostatic Precipitator

- High Efficiency Particulate Control Device
  - Controls emissions down to 0.010 lbs/MBtu (20-30 mg/Nm^3)
- Applicable to a wide variety of fuels and boiler types
  - WTC, urban waste
  - Stoker, CFB, BFB
- Size of ESP is a Function of Particle Characteristics & Gas Conditions

Typical ESP

Electrostatic Precipitators

Advantages

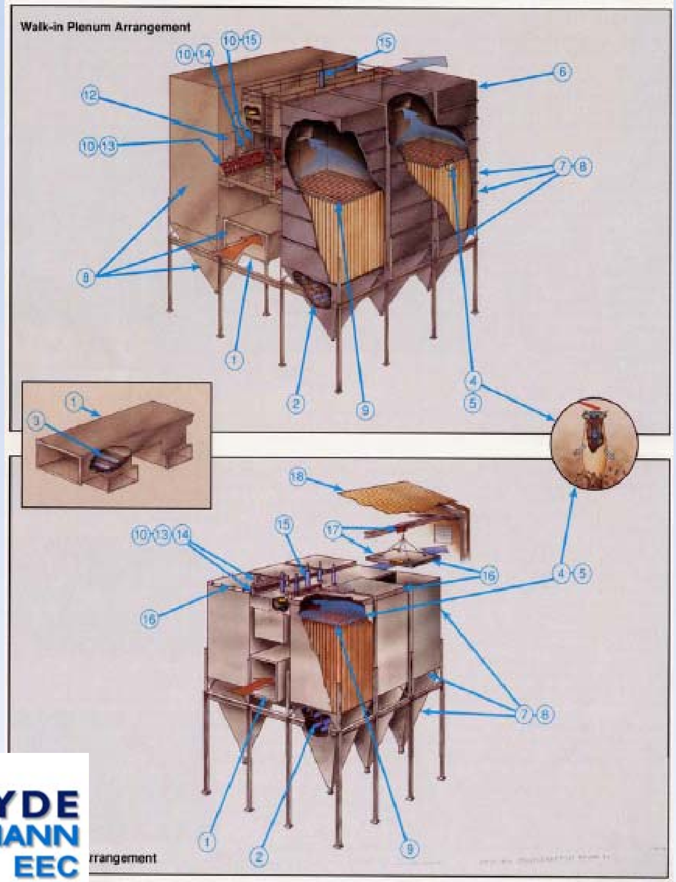
- Very Low Pressure Drop (< 0.75 inches wc)
- High Collection Efficiency (> 99.5% is possible)
- Applied to a wide variety of Power and Industrial Applications
- Able to tolerate “sparklers” from biomass

Disadvantages

- Sensitive to Operating Conditions- Volume & Flue Gas Chemistry

Fabric Filter

- Fabric Filter Systems ("Baghouses")
  - A particulate laden gas stream passes through a fabric filter bag whereby the particulate is collected on the surface of the fabric.
- Major types:
  - Pulse-Jet Filters
    - Walk-in Plenum or Top Door
    - Tall Bag Designs
    - Low, Med, High Pressure
  - Reverse-Air Filters

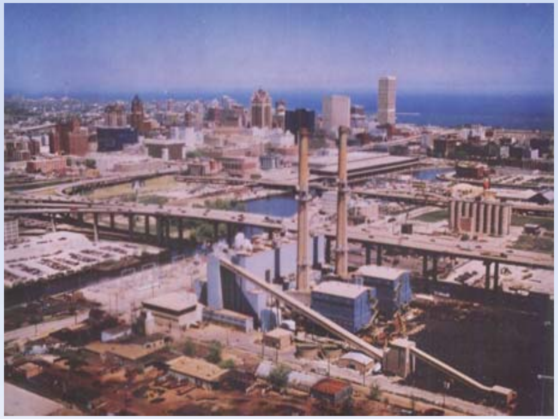


CLYDE BERGEMANN EEC

Fabric Filters

Advantages

- Constant Emission Control Device
  - Controls emissions to 0.01 lbs/MBtu (20-30 mg/Nm^3)
- Applicable to a wide variety of fuels and boiler types
- Function of Particle Characteristics & Gas Conditions



Disadvantages

- High pressure drop (6” wg)
- **Bags can burn, melt**

NOx/CO Control

Options to Achieve Low NO_X for Biomass Boilers

- "Conventional" technologies – limited reduction (OFA/FGR)
- SNCR – moderate reduction
- Modified SNCR - limited/moderate reduction
  - Ceramic injection tubes/NH_3 injection
  - High pressure rotating OFA/NH_3 injection

- SCR – high reduction efficiency

Selective Non-Catalytic Reduction (SNCR)

Introduction of Specific Nitrogenous Reagents at Specific Temperature Regimes to Effect a Reducing Reaction.

NOxOUT® Process Chemical Reaction

$$2NO + NH_2CONH_2 + \frac{1}{2}O_2 \Rightarrow 2N_2 + CO_2 + 2H_2O$$

NITROGEN OXIDE + UREA + OXYGEN ⇨ NITROGEN + CARBON DIOXIDE + WATER

Critical SNCR Process Parameters

- **Temperature** – 1600°F to 2200°F (Process Dependent)
- **Residence Time** – 0.2 Seconds to 2.0 Seconds
- **Background Gas Composition** – CO, O_2, NOx
- **NOx Reduction** – Baseline and Target
- **Reagent Distribution** – Access and Penetration

SNCR Process

Advantages

- Independent of Fuel Type
- Easily Retrofit
- Tunable to Specific Reduction Needs
- Compatible with Other Combustion and Post-combustion NOx Reduction Processes
- Relatively Low Capital Cost
- Good biomass experience

Disadvantages

- High Chemical Cost
- Limited Removal Efficiency (to about 0.1 – 0.15 lb/MBtu)

Low NO_X Emissions Drivers

- **New England RPS programs require low NO_X emissions**
  - 0.075 lb/MBtu (CT, NH) (52 ppm)
  - 0.065 lb/MBtu (MA) (46 ppm)
- **BACT for biomass and WTE**
- **Avoidance of PSD review (<250 TPY)**

Typical NO_X removal efficiency required ~ 75% to 85%

Emissions to Achieve <250TPY

			8000 hrs/yr	8760 hrs/yr	
Major Source Emission Limit		**250 TPY**	**62.5 lb/hr**	**57.1 lb/hr**	
Site	**MW**	**MMBtu/hr**	**Max CO/NOx**	**Max CO/NOx**	**With Margin**
Project R	50	705	.089 lb/MMBtu	.081 lb/MMBtu	**0.073**
Project D	50	725	.086 lb/MMBtu	.079 lb/MMBtu	**0.071**
Project M	50	617	.101 lb/MMBtu	.093 lb/MMBtu	**0.083**
Palmer	35	509	.123 lb/MMBtu	.112 lb/MMBtu	**0.101**
Jefferson	2 x 35	473	.132 lb/MMBtu	.121 lb/MMBtu	**0.109**
Project C	18	292	.214 lb/MMBtu	.195 lb/MMBtu	**0.176**

Biomass Options to Achieve Low NO_X/CO

- "Conventional" technologies can't get reduction
  - SNCR
  - OFA/FGR
- "Advanced" technologies can't get reduction
  - Ceramic injection tubes/NH_3 injection
  - High pressure rotating OFA/NH_3 injection

Conclusion: SCR required to achieve <0.070 lb/MBtu

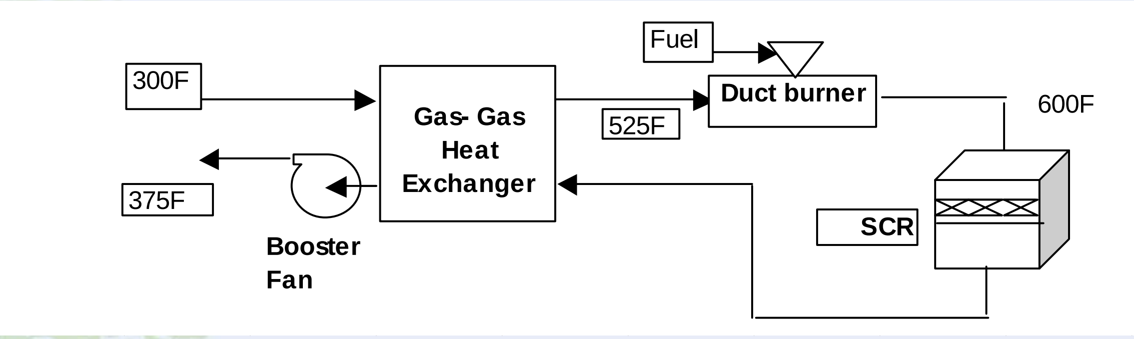
Biomass and WTE Applications

Initial consideration was for "conventional"SCR

- Poisons affect all SCR catalysts the same
  - Potassium, sodium, arsenic are irreversible
- High K/Na concentrations in wood ash preclude use of conventional SCR – very short catalyst life

Typical Tail-End SCR Systems

- Installed downstream of particulate removal, upstream of stack
  - Clean gas
  - Low temperature gas (~ 300°F)
- Large physical size, high initial, erection, and operating costs
- Typical tail-end unit consists of:
  - HX
  - Duct burners
  - SCR
  - HX
  - Fan



- NO_X reductions 60 - 90%; energy efficiency **~ 60 to 75%**

Regenerative Selective Catalytic Reduction (RSCR)

- New technology developed by BPE
- Development goal was high thermal efficiency/low total cost for WFB, WTE, and industrial boilers
- US Patents # 7,294,321; #7,494,625
- First RSCR system operating on US biomass boiler

Regenerative SCR (RSCR)

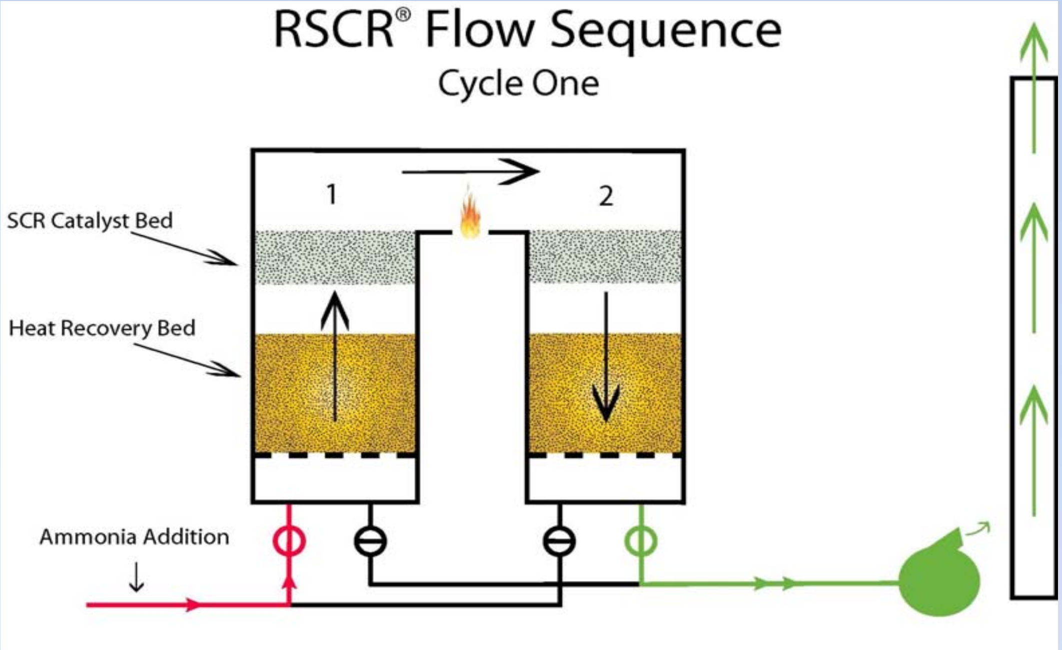
- Targeted at tail-end applications
  - Gas relatively free of particulates, poisons (As, Na/K)
  - Low SO_3 content
  - Low temperature flue gas (approx 200° to 350°F)
- Achieves high heat recovery to minimize energy costs
- Modular, standard design to minimize installation cost
- Uses proven, guaranteed catalyst
- Proven high NO_X reductions over long term (4+ years)
- **Thermal efficiency ~95%**

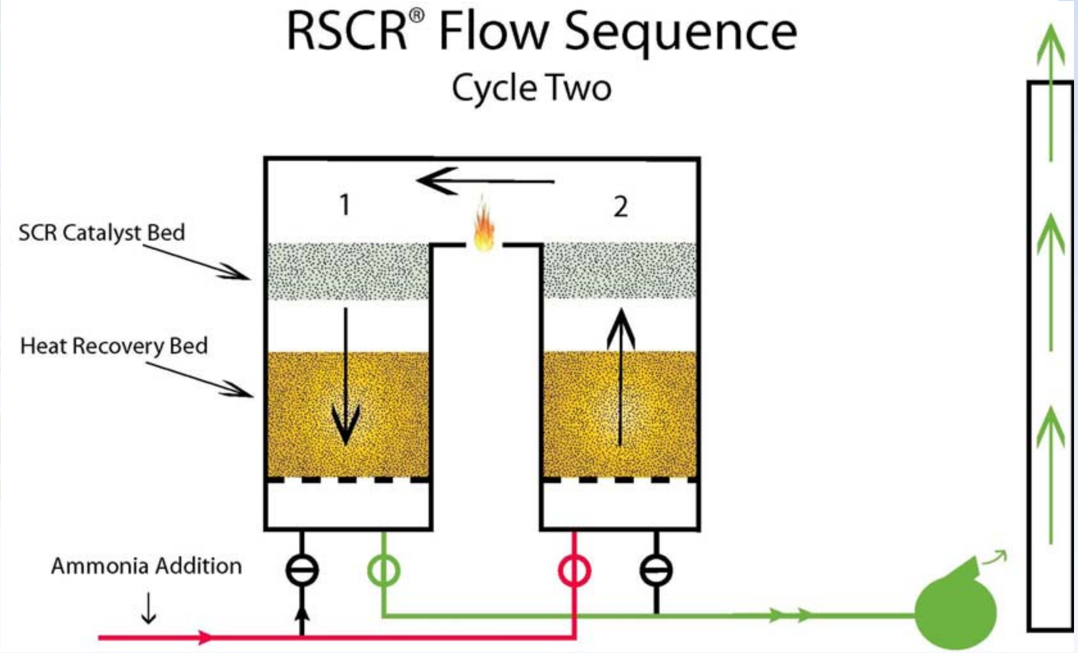
Flue Gas is heated only 7 °F

RSCR Design

- Unique ammonia injection mixing
- Ceramic media for heat transfer
  - Provides uniform gas distribution to catalyst
- Catalyst bed above heat transfer bed
- Multi-chamber design
- Beds cycled rapidly to ensure proper gas temperature into catalyst

RSCR Flow Sequence





RSCR Thermal Module

- Based on conventional RTO/RCO system
- Over 4000 RTO units in operation since early 80's
  - Many industries; low gas temperature; particulate laden
- Issues on media, controls, valving, etc. have been solved

Key modification is addition of mixers, reactant, and catalyst dynamics

RSCR - CO

- Ongoing BPEI development program to enhance the technology
- Proven precious metal catalyst on metal monolith
- Performance is 50 to >75% reduction of CO
- Low (<1" WG) pressure drop across each bed

Enables simultaneous NO_X & CO reduction

RSCR Features (cont'd)

Modular Construction

RSCR Features (cont'd)

Installing Catalyst Modules

Headspace Burners

RSCR- Commercial Units

50 MW RSCR System

Regenerative Selective Catalytic Reduction (RSCR) Experience List

Site	Boiler Size MW_e	Fuel	NO_x In lb/MMBtu	RSCR Layout	Guaranteed NO_x Out * lb/MMBtu	Renewable Energy Certificates	Start Date
New Hampshire	15	Whole Tree Chips	0.25	1 train / 3 cannisters	0.075	CT Earned RECs every quarter	October 2004
Boralex Stratton	50	Whole Tree Chips Waste wood C&D	0.25	2 trains / 5 cannisters	0.075	CT Earned RECs every quarter	December 2004
Bridgewater Power	16	Whole Tree Chips	0.28	2 cannisters	0.075	CT Earned RECs every quarter	October 2007
Burlington Electric	54	Whole Tree Chips Urban wood	0.26	6 cannisters	0.065	CT / MA	October 2008
Erie Renewables	2 x 50	Tire Derive Fuel	0.22	2 trains / 6 cannisters	0.075	N/A	2010
Palmer Renewables	38	C&D/WTC	0.25	4 cannisters	0.065	CT / MA	2010
Mahoning County	2 x 35	RDF C&D	0.25	2 trains / 4 cannisters	0.075	N/A	2010

* RSCRs have demonstrated continuous NOx reduction significantly below the guaranteed levels.

RSCR - Summary

- Patented, proven technology for biomass
- High NO_X removal efficiency
- Capable of simultaneous CO reduction
- Low energy consumption (>95% recovery)
- Guaranteed performance

Enables biomass to be <u>clean</u> renewable energy

Summary

- Biomass is a sustainable renewable resource
- Fuel is plentiful in certain parts of the country
- Growth rate for new biomass power projects is high
- Trend is to use well proven, efficient, and reliable combustion technologies
- Trend is to lower emissions, which can be controlled to low levels

Thank You!

Questions?

Rich Abrams
508 854 1140
rabrams@babcockpower.com