

Reinhold Environmental Ltd.



2009 NOx-Combustion Round
Table & Expo Presentation

February 9 & 10, 2009, Cleveland, OH

Babcock Power Inc.



2009 NOx-Combustion/PCUG Conference

Rich Abrams

Babcock Power Inc.

February 10, 2009

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.

bpigreensm

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www.babcockpower.com



Agenda

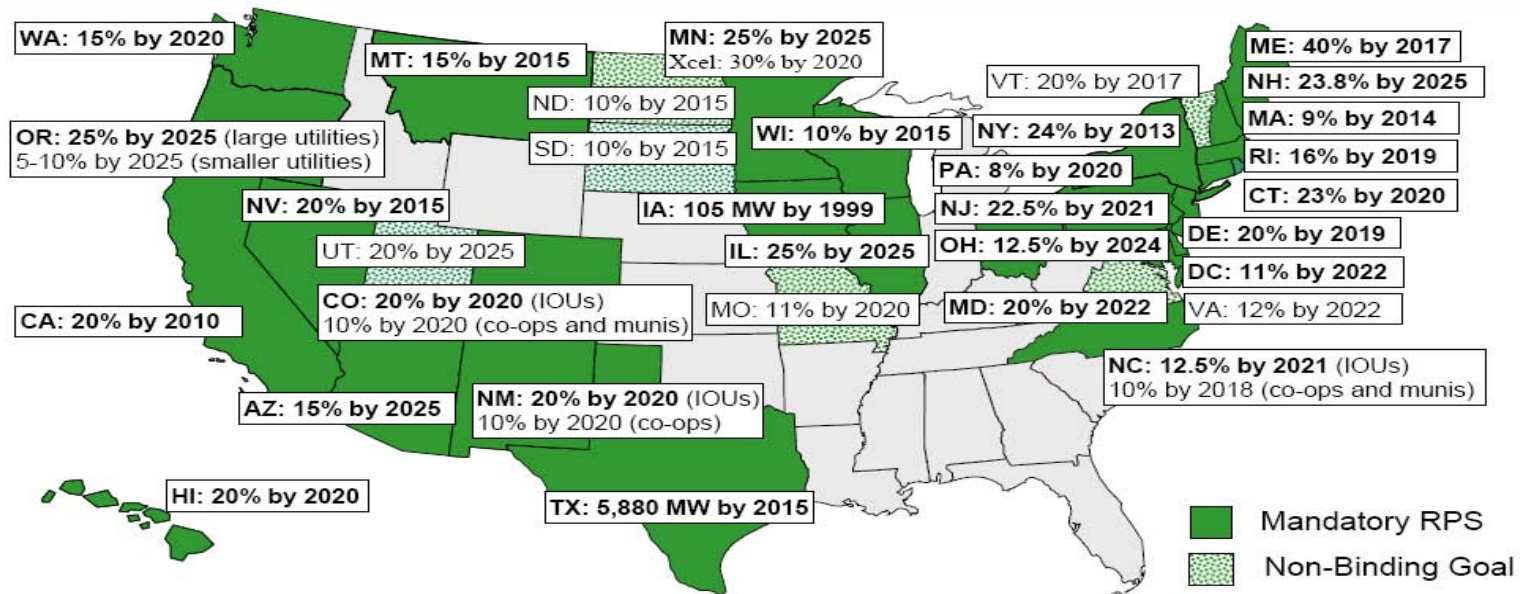
- Introduction
- Babcock Power Inc.
- Biomass Drivers, Fuels, and Issues
- Biomass in Existing Boilers
 - Co-firing
 - Retrofit/Conversion of Existing Units
- New Boilers
- Emissions Control
 - PM
 - NOx/CO
- Summary

BPI: Single Supplier Of Boiler And Emissions Control Systems

- Reduces risk of performance conflicts
- Best system for the least cost and greatest value
- Full “chute to stack” guarantees

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

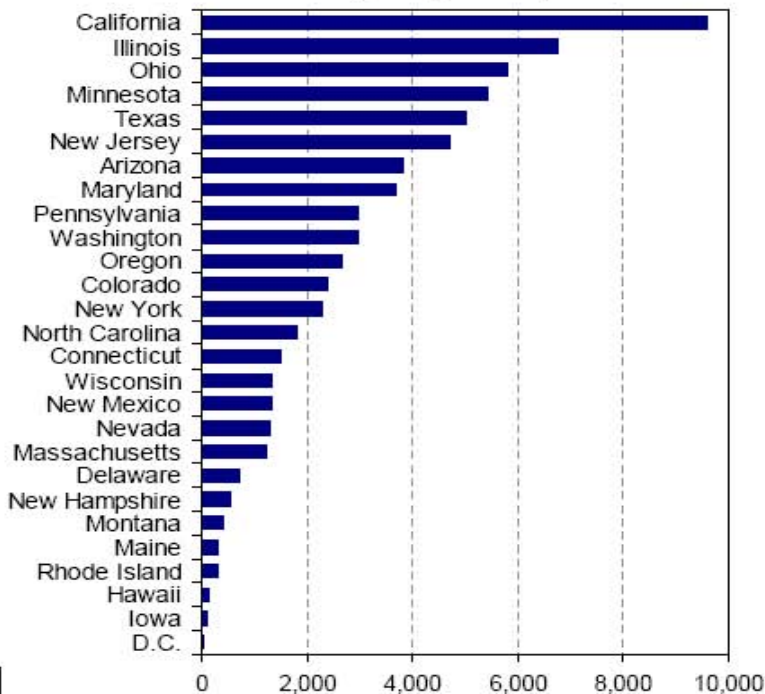
Most policies established through state legislation, but some through regulatory action (NY, AZ) or voter-approved initiatives (CO, WA)



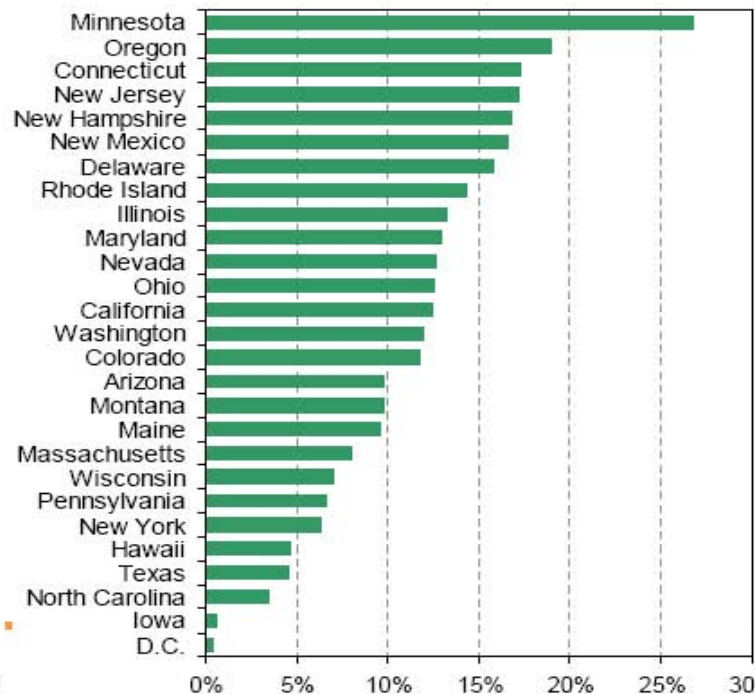
Future Impacts of Existing State RPS Policies Are Projected To Be Relatively Sizable

- Roughly 69 GW of new renewables capacity by 2025, if 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

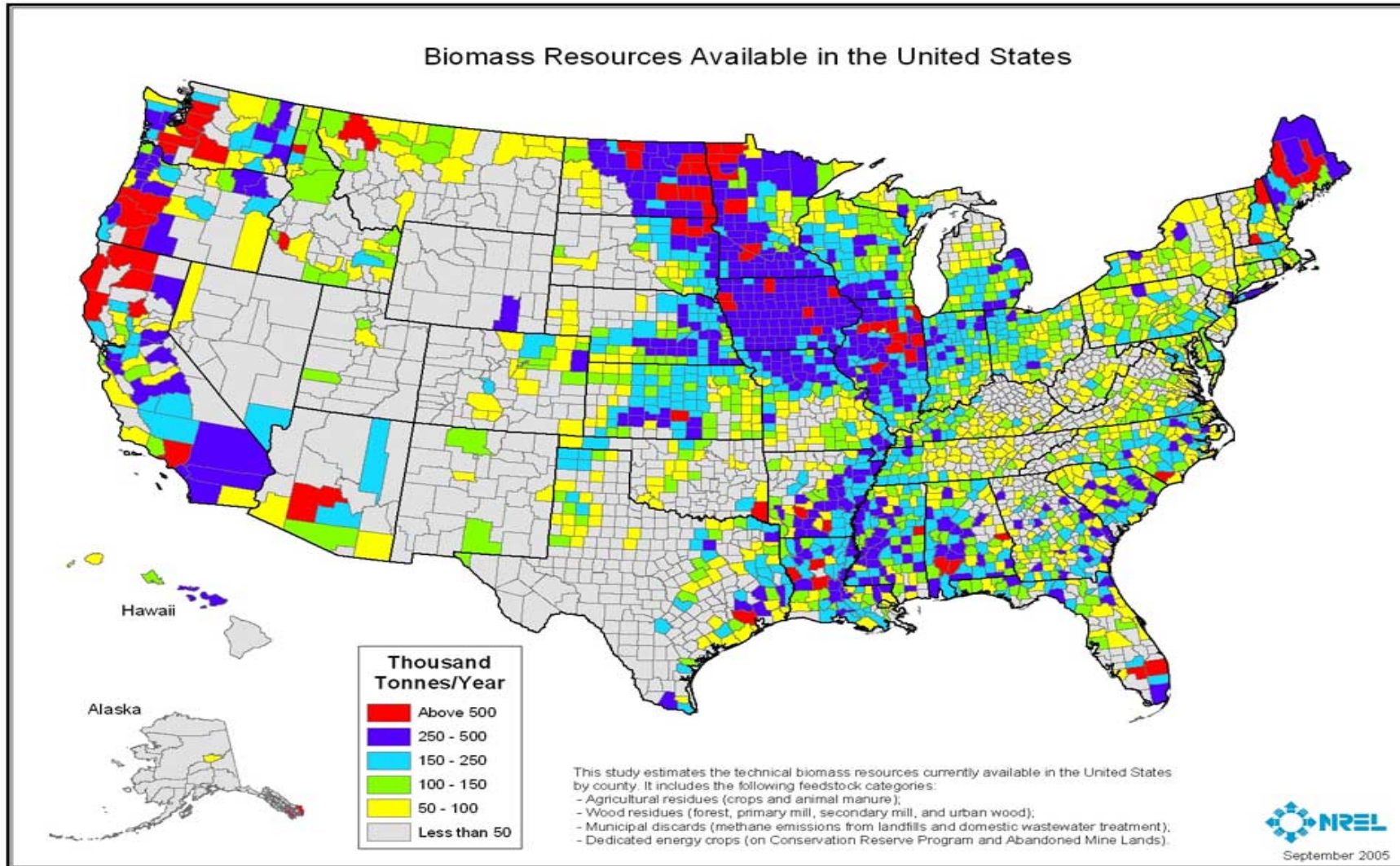


Renewable Energy And Biomass

- 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
 - CO₂ neutral or better
 - Proven, reliable, economical
 - Key negative factor is *emissions*

Biomass Resources In US

Biomass Resources Available in the United States



Common Biomass Fuels

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



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/chlorine content

- SO₂ / SO₃ HCl production
- Acid dew point temperature

- Potential for AH / duct corrosion
- Acid gas removal equipment sizing

- Ash content

- Ash production
- Erosion potential

- Ash removal equipment
- Flue gas flow area / velocity limits

- Ash initial deformation temp.
- T₂₅₀ temperature

- Furnace slagging potential
- Furnace efficiency / heat absorption

- Sootblowers
- Furnace size / platen surface area

- Ash mineral analysis:
Na₂O, CaO, KO

- Convection pass fouling potential
- SCR

- Tube clear space requirements
- Sootblower application

Biomass In

Existing

Boilers



Biomass Options

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

Performance and Design Considerations

- Advanced biomass stoker design
- Emissions control

Biomass Co-Firing Options

1. One approach - biomass fuel mixed with coal and prepared thru the pulverizer
 - Limits on amount of biomass fuel
 - Pulverizer capacity issue
2. Fire biomass through burners with dedicated biomass grinder
3. Combust on a separate/dedicated grate

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



Biomass Retrofit/Conversion Of Existing Units

- Establish fuels
- Evaluate the boiler capacity firing biomass
- Review required modifications
- Perform a feasibility study
 - Phase 1 feasibility study
 - Phase 2 initial engineering phase
 - Phase 3 detail
 - Phase 4 modification and start-up phase

Biomass Conversions

Initial Feasibility Phase

Perform rough analysis of the boiler performance and boiler modifications when converted to biomass fuels

- Evaluation of new boiler equipment required for firing biomass fuels
- Review of retrofitting the new equipment to the existing boiler
- Review ultimate analysis including moisture, high heating value and size distribution of the fuel
- Run combustion calculations to establish a preliminary boiler efficiency, combustion air, flue gas and fuel flow
- Review furnace size for combustion heat release rates and furnace retention time
- Estimate the maximum boiler steaming capacity firing biomass fuels and resultant emissions

Biomass Conversions (Continued)

Initial Engineering Phase

- Perform heat transfer calculations
- Refine the boiler heat balance analysis
- Review superheater (SH), boiler and economizer surfaces
- Review SH tube metals and pressure drop calculations
- Review flue velocities through tube bundles and draft losses
- Calculate airside pressure drop
- Evaluate the auxiliary equipment capacity for firing wood, which includes:
 - Air heater
 - Forced draft fan
 - Induced draft fan
- Evaluate emissions and options for emissions control
- Develop preliminary arrangement drawings

Biomass Conversions (Continued)

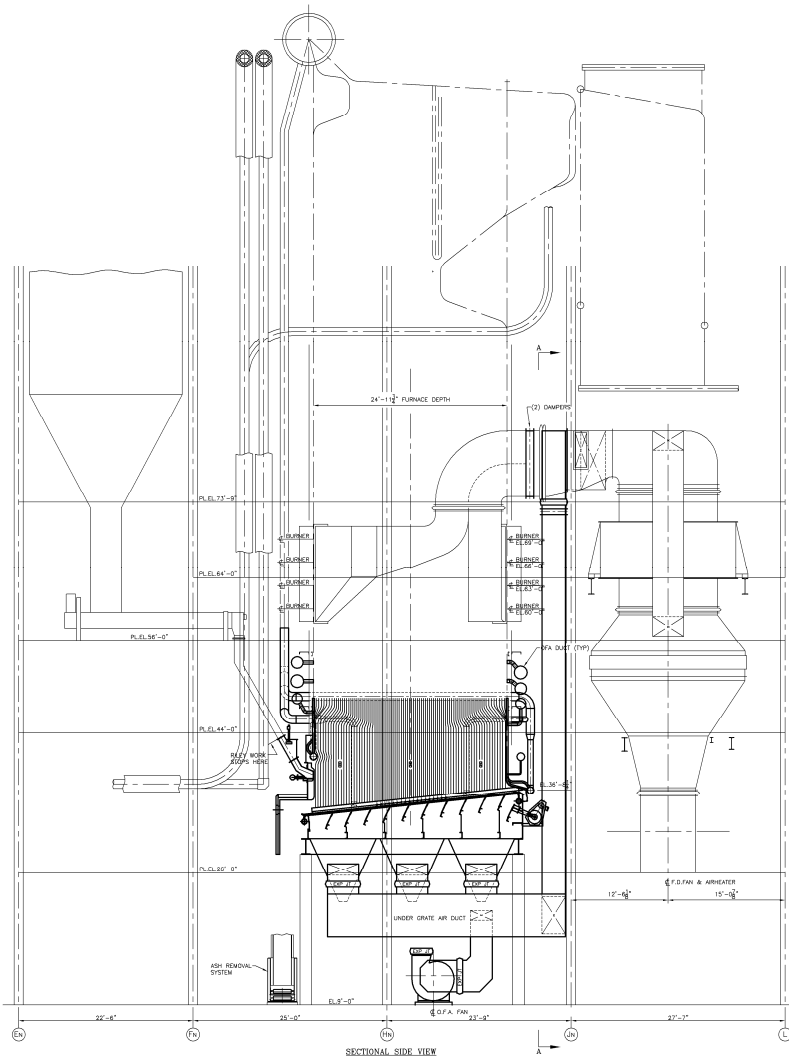
Phase 3

Detail Engineering Phase

- Phase 3 includes site development of accurate arrangement drawings including site equipment interferences. Update the heat transfer performance programs based on site information. At the closure of Phase 3 the following can be developed:
 - “Firm” boiler material cost estimate
 - Adequate drawings to obtain construction cost estimates

Phase 4

Boiler Equipment Manufacturing



New Boilers



New Boilers

Typical Conditions

Steam Flow

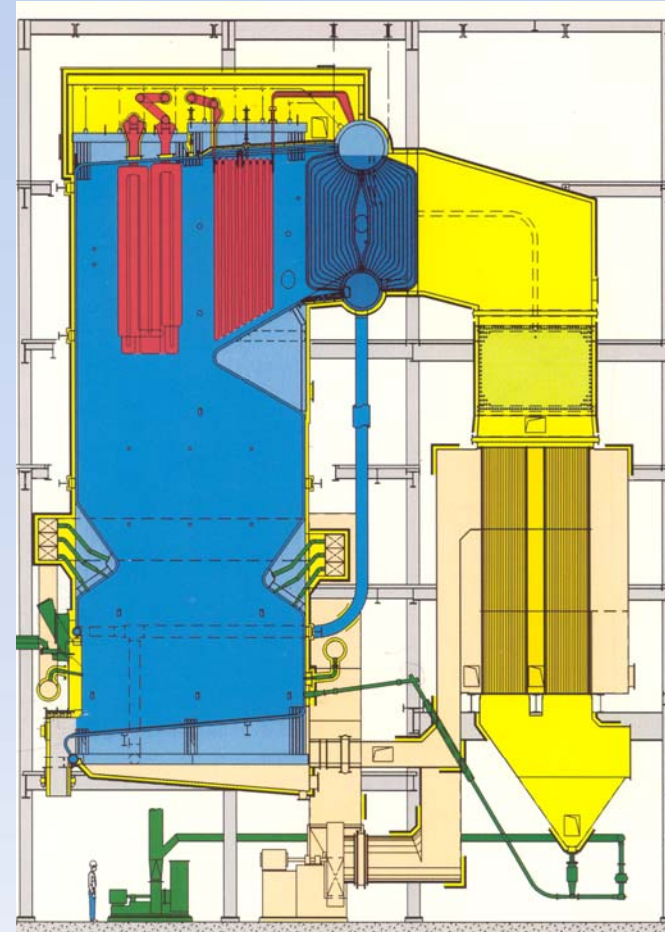
Temp

Pressure

100,000-
500,000 Lbs/hr

650-960°F

650-1700
psig



Three 250,000 lbs/hr—1500 psig operating—950°F
Riley Steam Generating Units
fed by wood on Riley Water Cooled Stationary Grate Stokers

RILEY
Riley Stoker Corp
Worcester, Mass

ZACHRY ENERGY SYSTEMS, INC. FOR
MULTITRADE OF PITTSYLVANIA COUNTY L.P.
Hurt, Virginia

Biomass Power Boiler - Trends

- **Stokers**
 - Largest installed base
 - Fuel flexible
 - Proven, reliable, improved
- **Bubbling/fluidized bed**
 - Fuel flexible
 - In-situ SO₂ control (not req'd for biomass)
 - Somewhat lower uncontrolled emissions; not sufficient
 - High parasitic load
- **Gasifiers**
 - Relatively small scale
 - Typically combust “syngas” from gasifier

Independent Customer Comparison 50 MWe Net Plant Output

Boiler Type	Bubbling Bed	Advanced Stoker
Steam Press/Temp	1,470 psig/950°F	1,470 psig/950°F
Fuel input, lb/hr	129,500	120,528
Heat input, MBtu/hr	667.96	624.68 (incl. RSCR)
S.G. size reduction		5.9%
Aux power req's	5,430 kW	2,324 kW (incl. RSCR)
Plant heat rate	13,605 Btu/kWh	12,635 Btu/kWh
Heat rate benefit		7.1%

Goals of Today's Advanced Stoker Combustion Systems

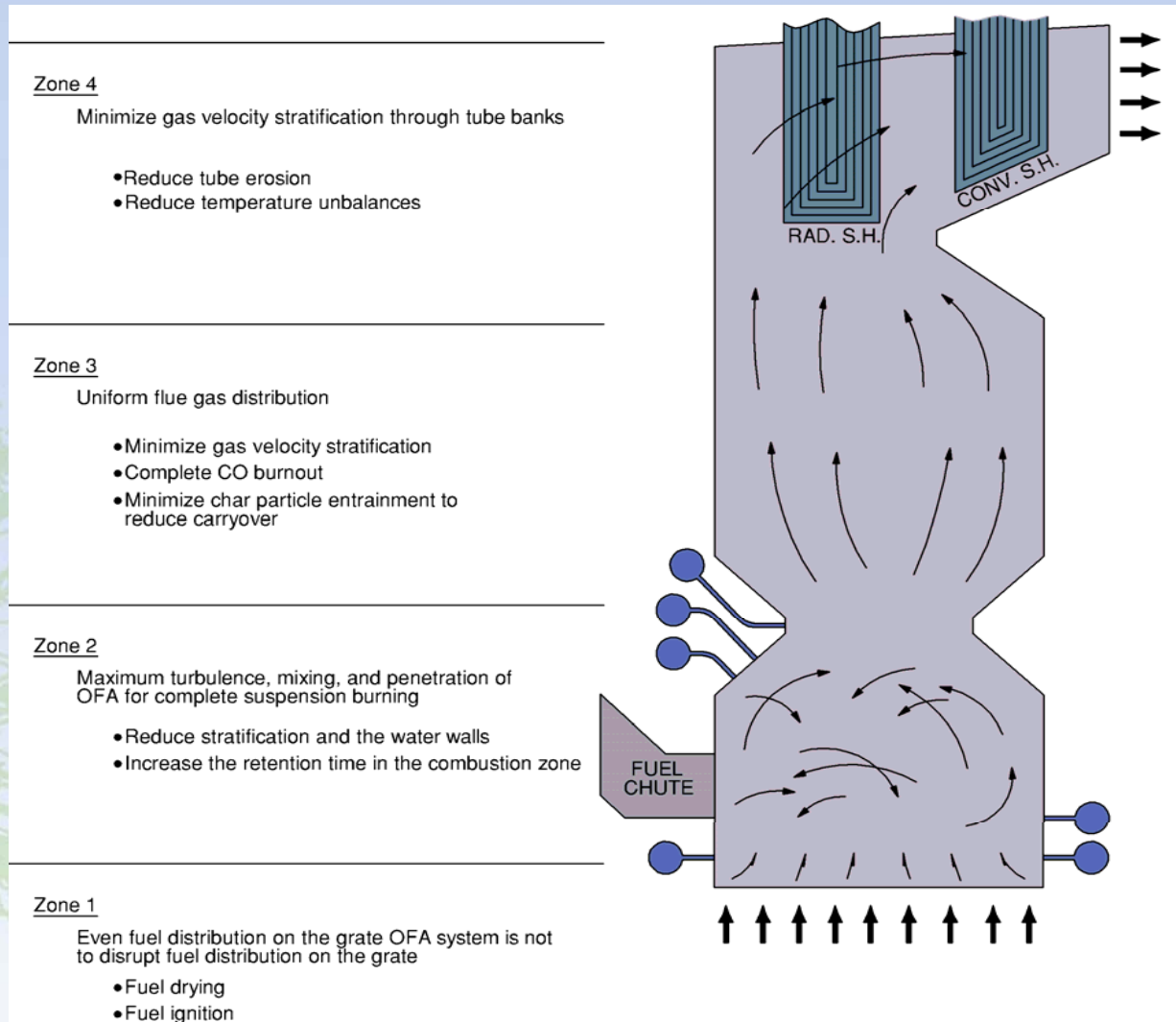
1. Efficient combustion
 - Low unburned carbon
 - Low carbon monoxide emissions
2. Stable combustion
 - Stable heat input resulting in stable boiler steaming conditions
3. Low parasitic losses
4. High boiler efficiency
 - Low stack temperature
 - Low excess air
 - High steam temperature
 - High boiler pressure

To meet current regs, APC systems minimize NO_x, CO, PM emissions

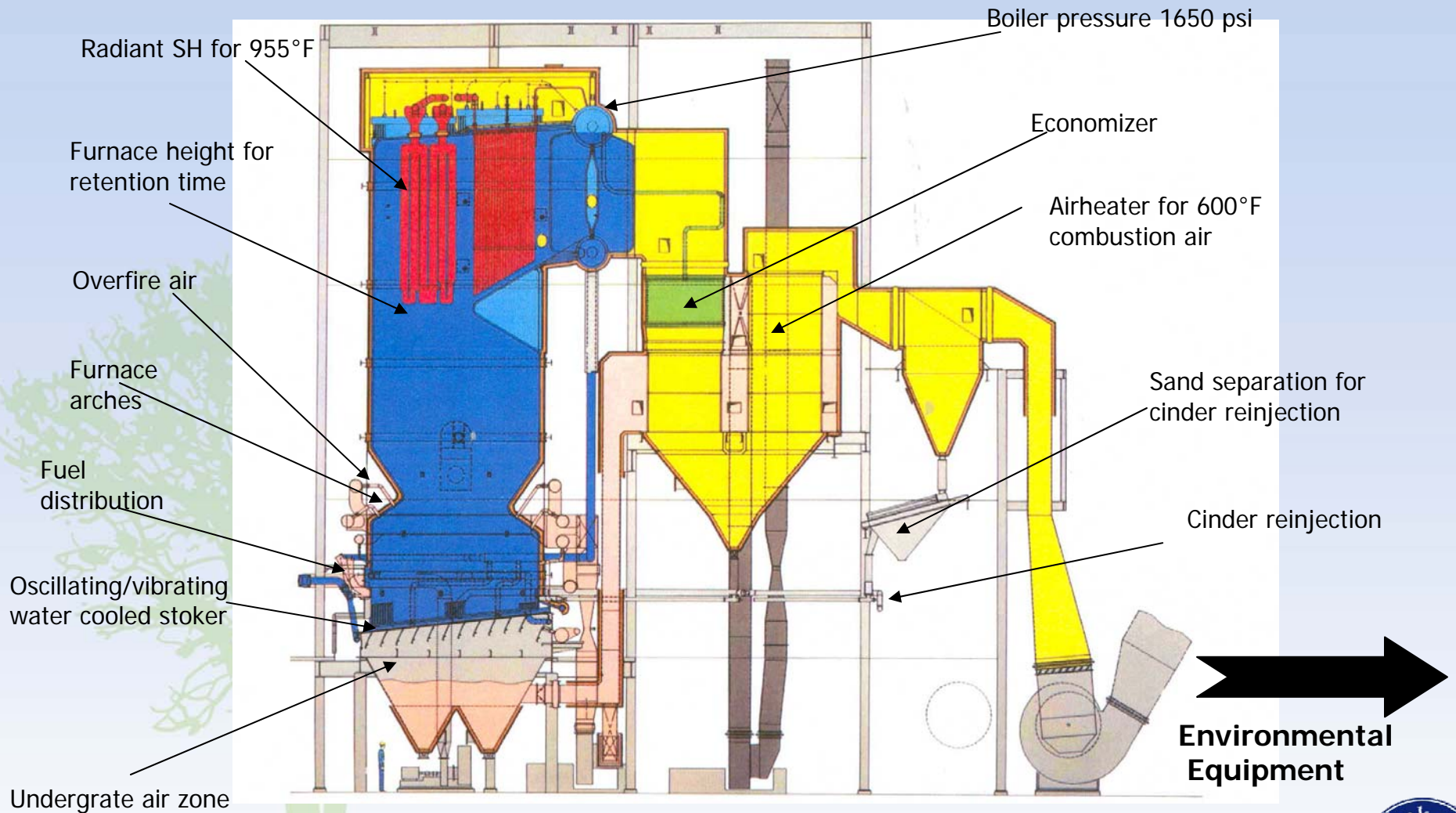
Biomass Stoker Technology

Advanced Biomass Stoker Design

- Consist of both combustion and boiler components
- Complete system, not standalone components



Typical Advanced Biomass Stoker Boiler System



Typical Applications

KES FITCHBURG, L.P.

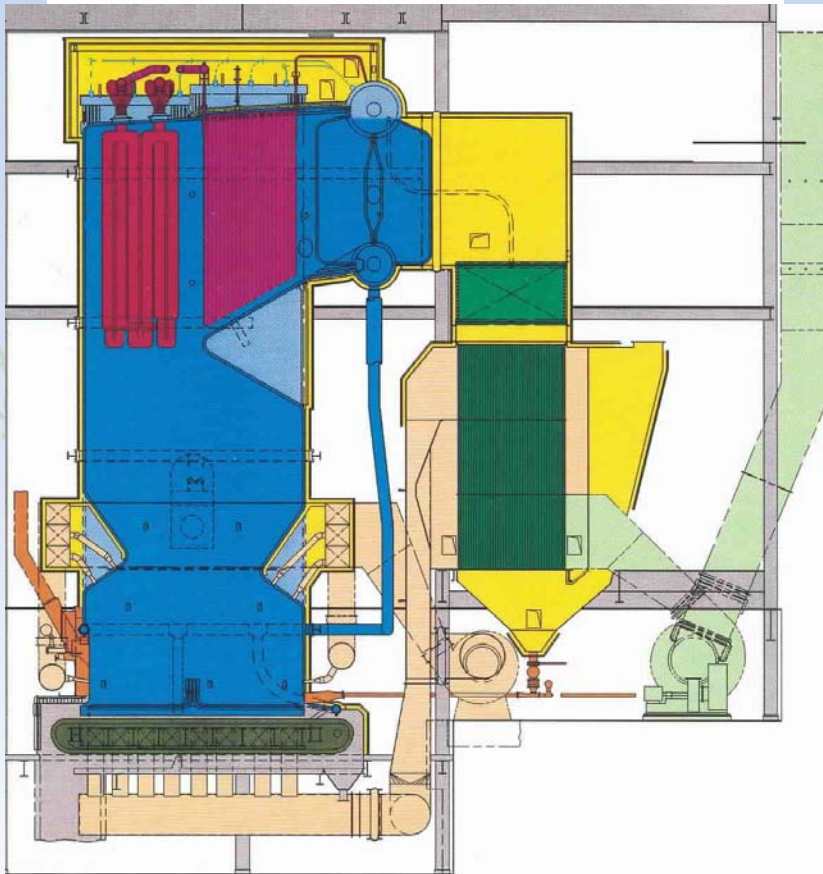
Westminster, Massachusetts

One 170,000 lbs/hr—1280 psig operating—955°F

Riley Steam Generating Unit

Fired by wood chips on a Riley Harrington Stoker

RILEY STOKER CORPORATION WORCESTER, MASSACHUSETTS



CNF CONSTRUCTORS, INC. FOR

RYEGATE POWER STATION

East Ryegate, Vermont

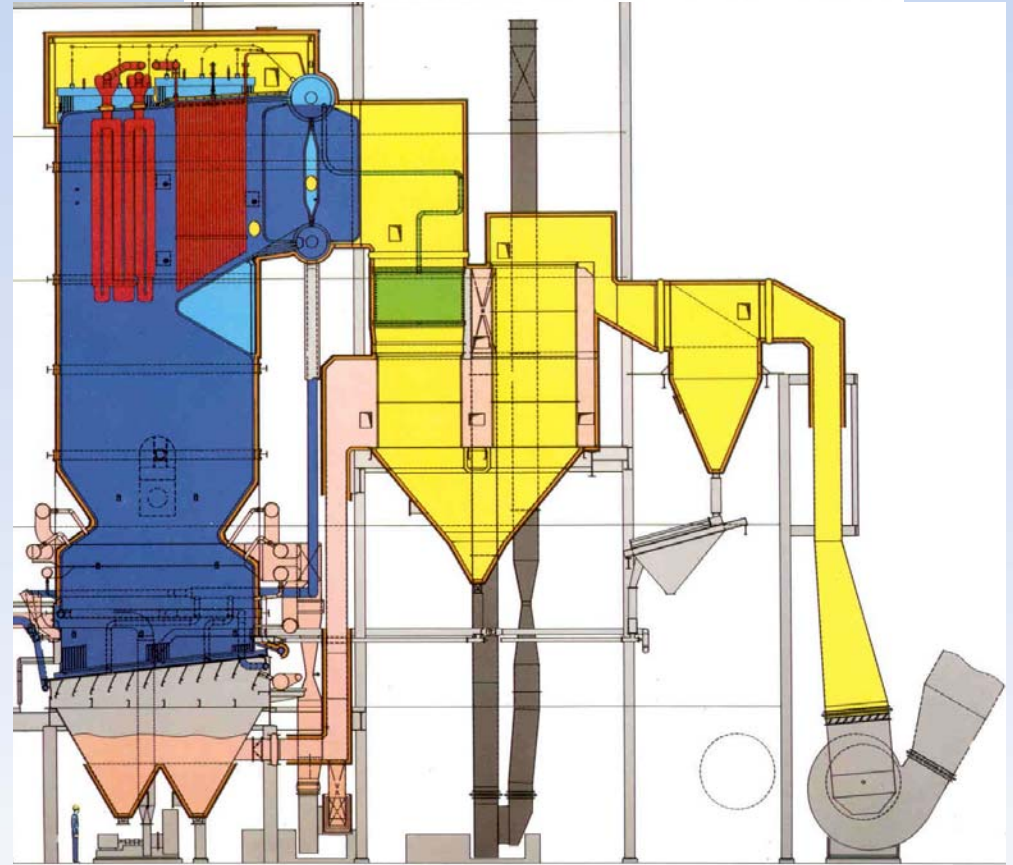
190,000 lbs/hr—1475 psig design—1280 psig operating—955°F

Riley Steam Generating Unit

Fired by whole tree chips

Stone & Webster Engineering Corporation, Consulting Engineers

RILEY STOKER CORPORATION WORCESTER, MASSACHUSETTS





Emissions

Control

Biomass Issues

Emissions - The Primary Concern

Pollutant

Typical Emissions

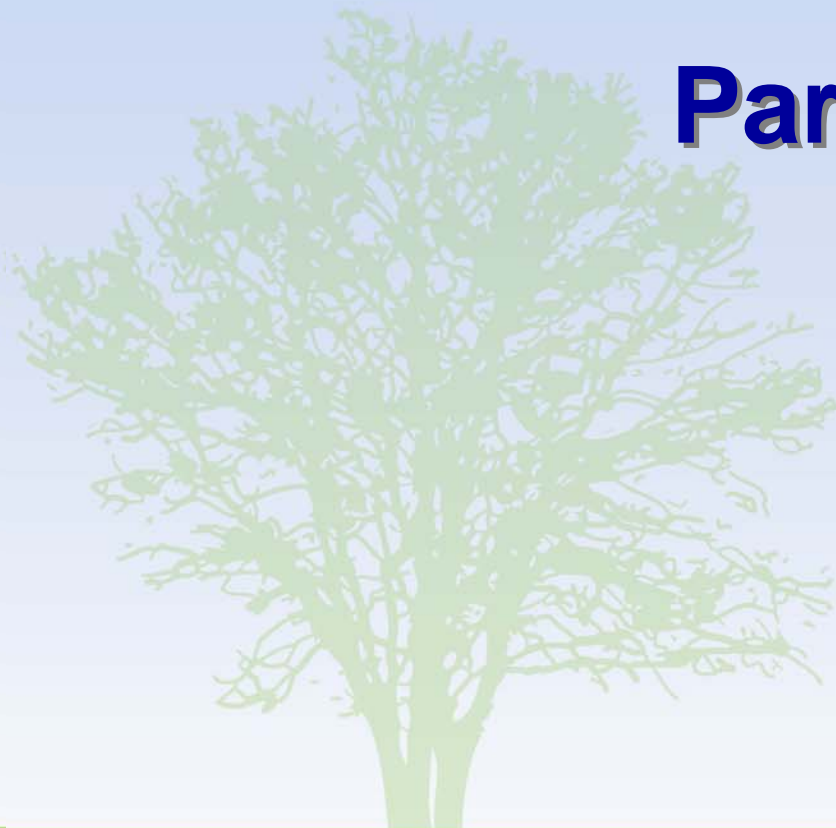
- PM Low (ESP)
- SO₂ Low
- HCl Low
- CO Moderate
- VOC Low
- NO_x Moderate/High

NO_x and CO are main pollutants

Uncontrolled Emissions

(lb/MBtu)	Coal	Biomass
	<i>Uncontrolled</i>	<i>Uncontrolled</i>
NOx	0.32 to >1.5	0.15 to 0.48
SO2	0.8 to >6.0	<0.08
CO	0.04 to 0.15	0.15 to 0.45
PM	3 to 15	0.2 to >1.0

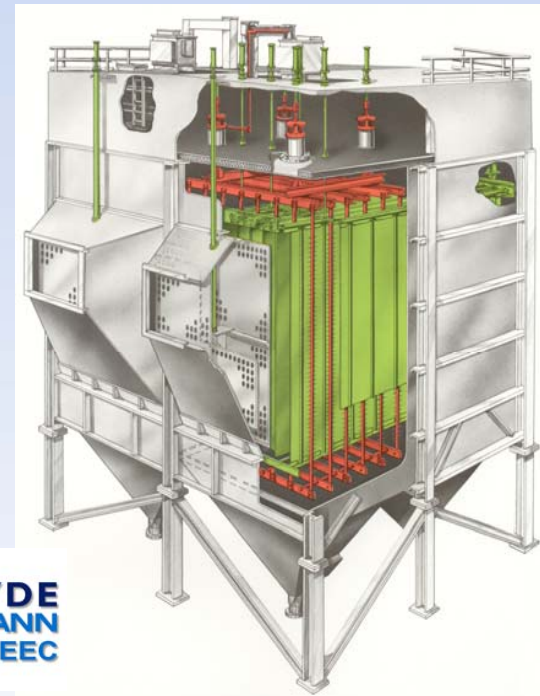
Particulate Matter



Electrostatic Precipitator (ESP)

– Device that removes wet or dry suspended matter from combustion or process gas streams through an electrostatic process:

- Gas Ionization
- Particulate Charging
- Influence of Electric Field



Electrostatic Precipitator

- High efficiency particulate control device
 - Controls emissions down to 0.01 lbs/MBtu (20-30 mg/Nm³)
- 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

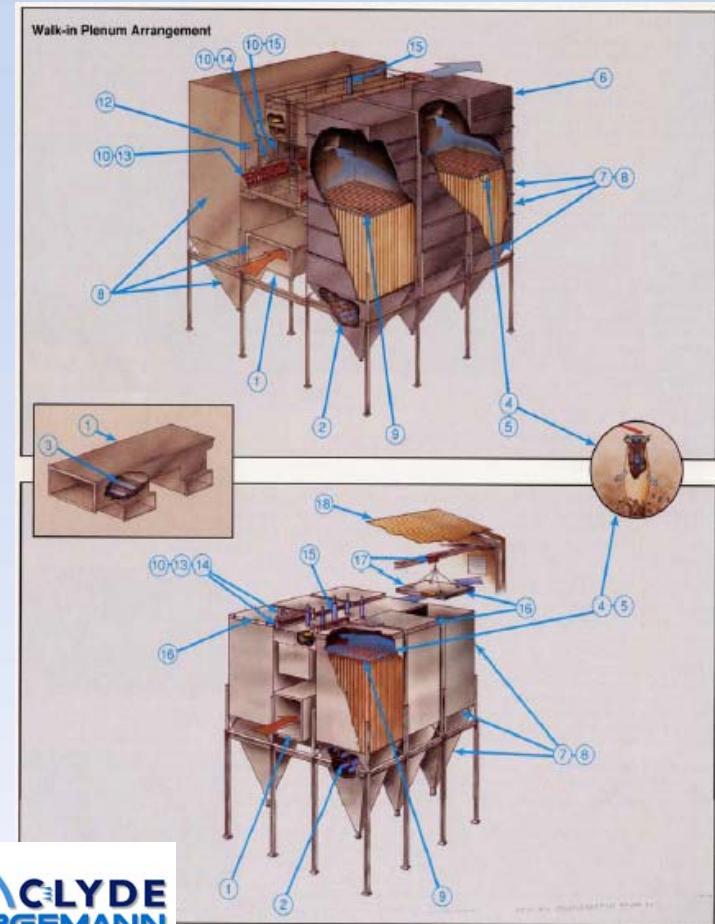
- Very low pressure drop (< 0.75 inches wc)
- High collection efficiency (> 99.5% is possible)
- Applied to a wide variety of power and industrial applications
- Able to tolerate “sparklers” from biomass

Disadvantages

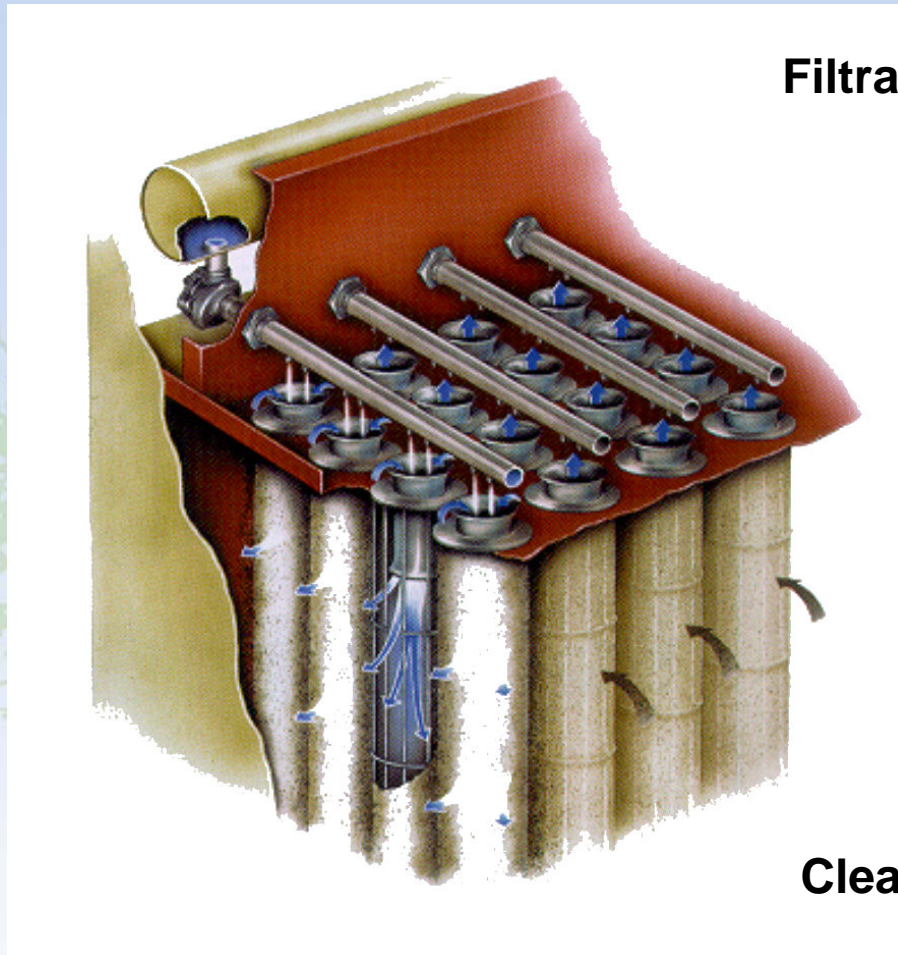
- Sensitive to operating conditions – volume & flue gas chemistry

Fabric Filter

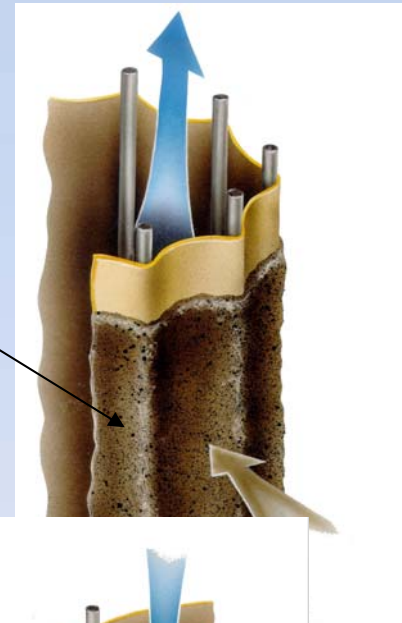
- Fabric filter systems (“Baghouses”)
 - A particulate laden gas stream passes through a fabric filter bag whereby the particulate is collected on the surface of the fabric
- Major types:
 - Pulse-Jet Filters
 - Walk-in Plenum or Top Door
 - Tall Bag Designs
 - Low, Med, High Pressure
 - Reverse-Air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



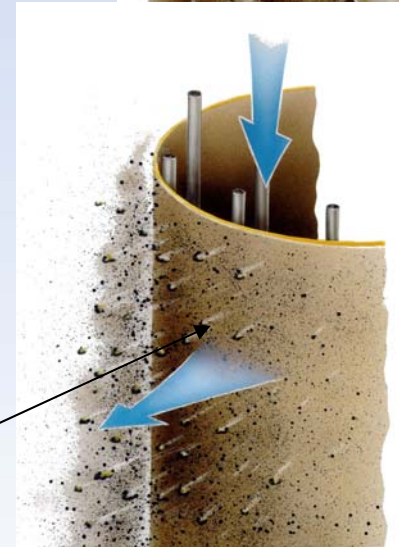
Pulse Jet Fabric Filter



Filtration



Cleaning



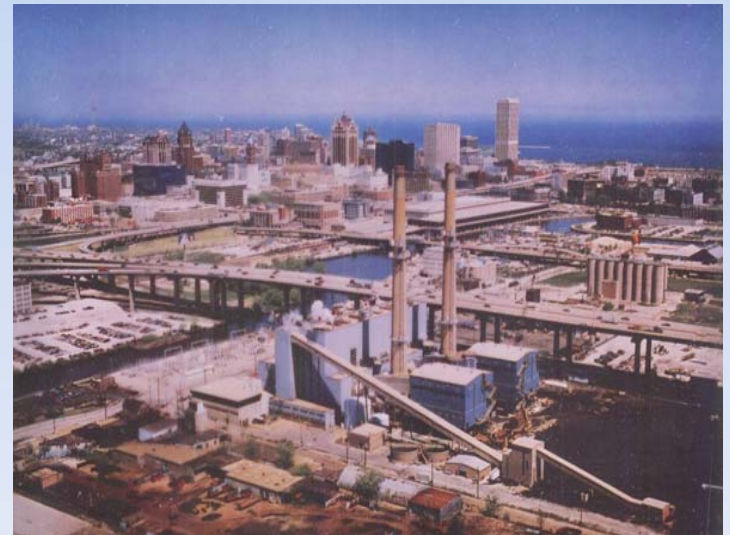
Fabric Filters

Advantages

- Constant emission control device
 - Controls emissions to 0.01 lbs/MBtu (20-30 mg/Nm³)
- 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



*Clyde Bergemann EEC
Pulse-Jet Fabric Filter*



NO_x/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/NH₃ injection
 - High pressure rotating OFA/NH₃ injection
- SCR – high reduction efficiency

Selective Non-Catalytic Reduction (SNCR)

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

Primary Reaction



NITROGEN OXIDE + UREA + OXYGEN \Rightarrow 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, O₂, NO_x
- ◆ **NO_x 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 NO_x reduction processes
- ◆ Relatively low capital cost
- ◆ Good biomass experience

Disadvantages

- ◆ High chemical cost
- ◆ Limited removal efficiency (to about 0.09 – 0.15 lb/MBtu)

Low NO_x Emissions Drivers

- **New England RPS programs require low NO_x emissions**
 - 0.075 lb/MBtu (CT)
 - 0.065 lb/MBtu (MA, NH)
- **Applications elsewhere for NO_x offsets**
- **BACT: <0.075 lb/MBtu offered commercially**
- **Avoidance of PSD review (<250 TPY)**

Typical NO_x removal efficiency required ~ 75%

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/NH₃ injection
 - High pressure rotating OFA/NH₃ injection

***Conclusion: SCR required to achieve <0.075
lb/MBtu***

RSCR

System To Reduce NO_x Emissions From Biomass Boilers

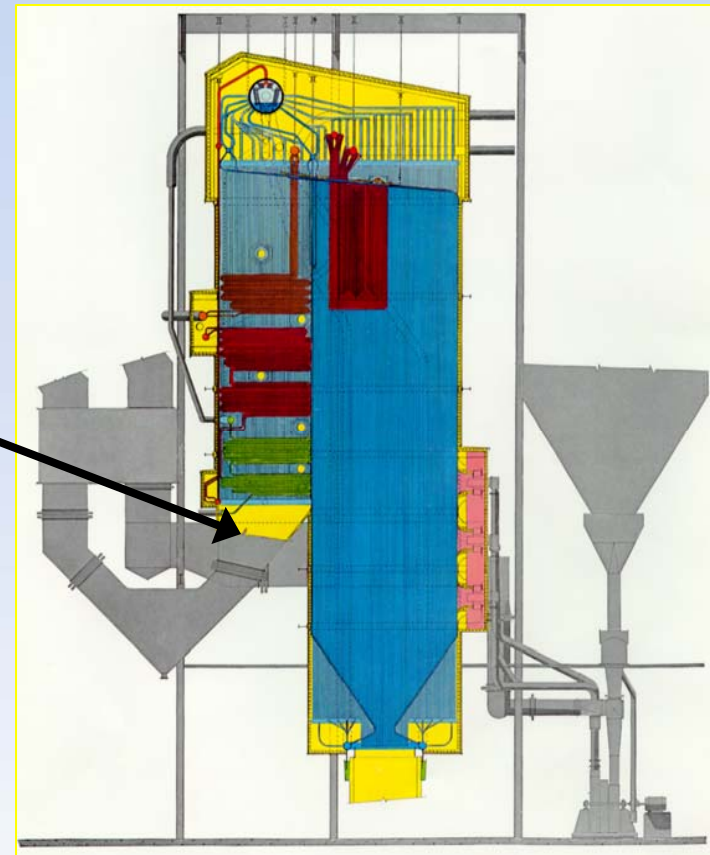


Regenerative Selective Catalytic Reduction (RSCR)

- New technology developed by BPE
- Development goal was high thermal efficiency/low total cost for WFB, WTE, and industrial boilers
- US Patent # 7,294,321 issued 11/14/07
- First SCR system operating on US biomass boiler

“Conventional” SCR? *Where does it Fit?*

- Economizer outlet
- 600° - 800°F
- Full flyash loading



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

Difficult NO_x Control Applications

- Biomass boilers
- WTE furnaces
- Boilers with physical constraints (coal,oil)
- Process applications

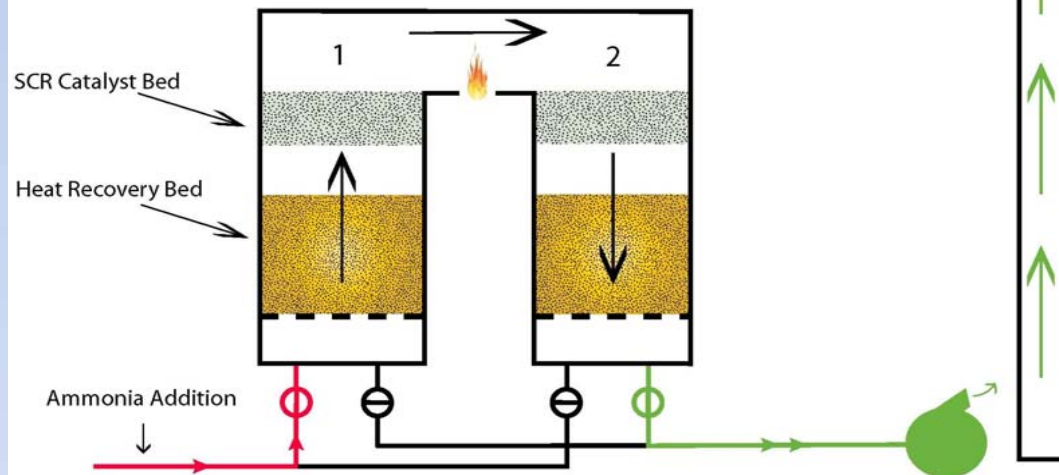
Require the use of a “tail-end” SCR system

Regenerative SCR (RSCR)

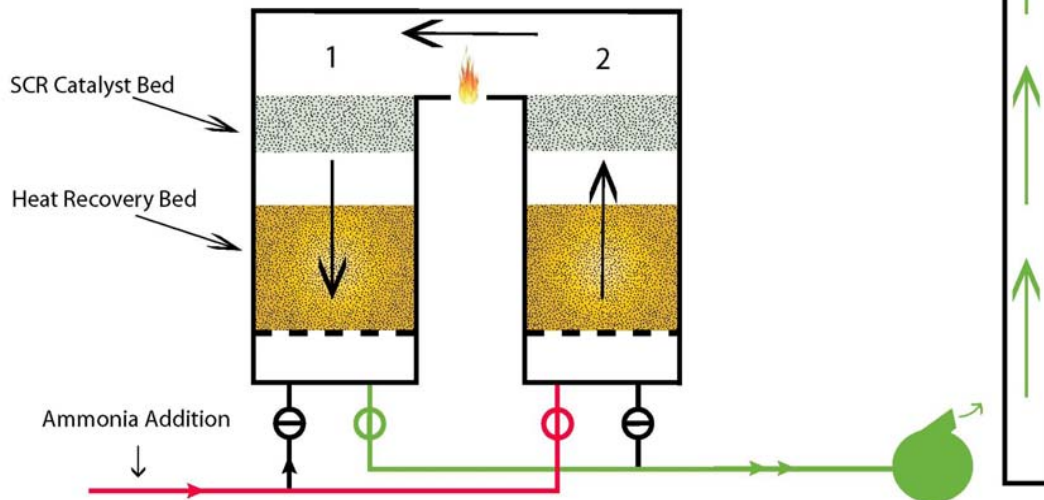
- Targeted at tail-end applications
 - Gas relatively free of particulates, poisons (As, Pb, Na/K)
 - Low SO₃ content
 - Low temperature flue gas (approx. 200° to 350°F)
- Achieves high heat recovery to minimize energy costs
- Modular, standard design to minimize installation cost
- Uses proven, guaranteed catalyst
- Proven high NO_x reductions
- **Thermal efficiency ~95%** (1/10 the fuel of typical tail-end unit)

RSCR Flow Sequence

RSCR® Flow Sequence Cycle One



RSCR® Flow Sequence Cycle Two



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 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/Mbtu	RSCR Layout	Guaranteed NO _x Out* lb/Mbtu	Renewable Energy Certificates	Start Date
New Hampshire	15	Whole tree chips	0.25	1 train / 3 canisters	0.075	CT Earned RECs every quarter	Oct. 2004
Boralex Stratton	50	Whole tree chips Waste wood C&D	0.25	2 trains / 5 canisters	0.075	CT Earned RECs every quarter	Dec. 2004
Bridgewater Power	16	Whole tree chips	0.28	2 canisters	0.075	CT Earned RECs every quarter	Oct. 2007
Burlington Electric	54	Whole tree chips Urban wood	0.26	6 canisters	0.065	CT / MA	Oct. 2008
Erie Renewables	2 X 50	Tire derive fuel	0.22	2 trains / 6 canisters	0.075	N/A	2010
Palmer Renewables	38	C&D/WTC	0.25	4 canisters	0.065	CT / MA	2010
Mahoney County	2 X 35	C&DRDF	0.25	2 trains / 4 canisters	0.075	N/A	2010

*RSCRs have demonstrated continuous NO_x reduction significantly below the guaranteed levels

RSCR Guarantees

- Emissions guarantee
 - ***Outlet NO_x***
 - ***NH₃ slip***
- Catalyst life
- Project schedule

Cost Information

PLANT GROSS MW	<u>50</u>
GROSS HEAT INPUT, MMBTU/HR	642
NO _x REMOVED, TONS/YEAR	499
AMMONIA COST, \$/TON NO _x	\$419
NATURAL GAS, \$/TON NO _x	\$296
POWER COST, \$/TON NO _x	\$729
CATALYST COST, \$/TON	\$477
CAPITAL COST, \$/TON	\$1,978
<i>TOTAL COST PER TON NO_x REMOVED</i>	<i>\$ 3,603 (\$0.0043/kW)</i>

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 clean 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?

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bpigreenSM

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