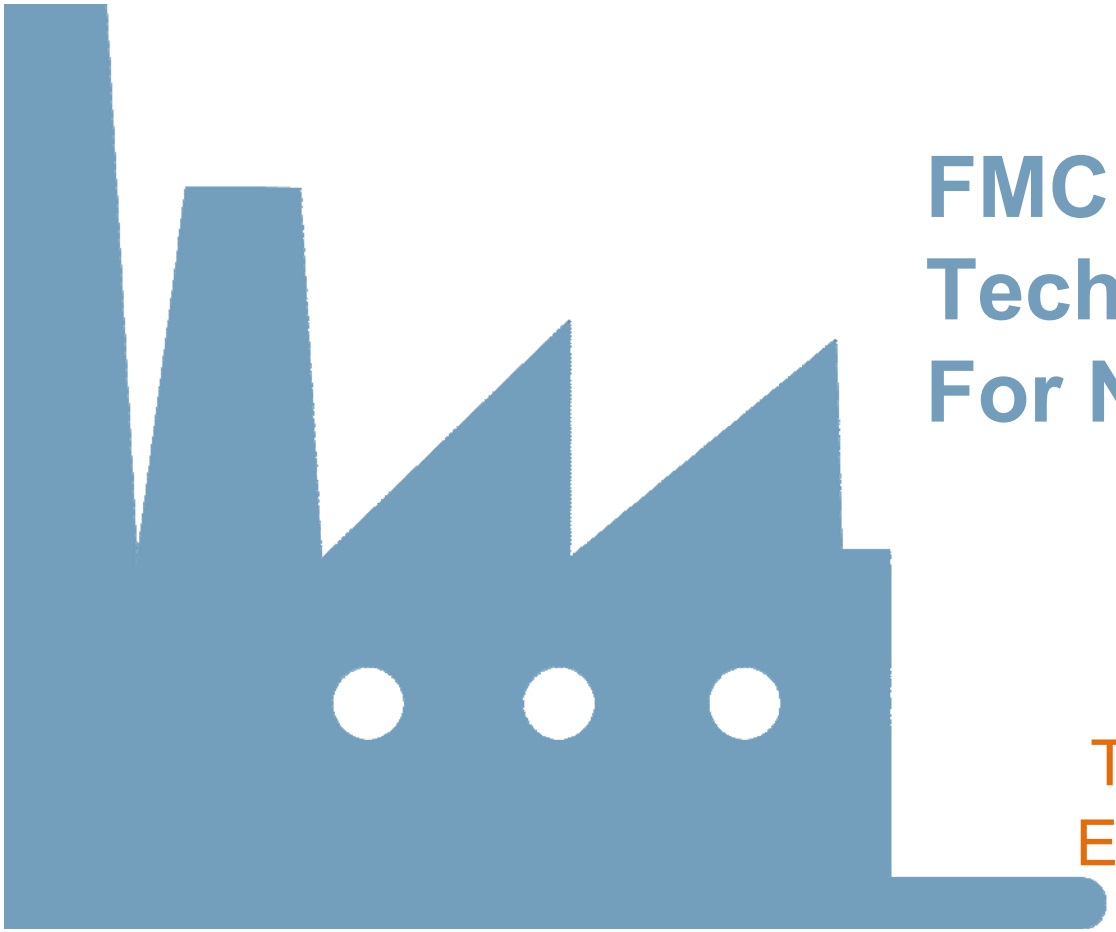

AIR POLLUTION CONTROL

FMC PerNOxide Technology For NOx Control

September 11, 2012
CIBO
Technical Focus Group
Environmental & Energy
Committee Meetings

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ENVIRONMENTAL SOLUTIONS

Agenda

- Introduction to FMC
- Introduction to NOx control
- FMC PerNOxide technology
- Hydrogen peroxide (H_2O_2)
- Status of technology
- Full scale demonstration equipment
- Takeaways and path forward

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ENVIRONMENTAL SOLUTIONS

FMC Corporation

- Global diversified chemical company serving the agricultural, industrial, and specialty markets
- 2011 Sales Revenue $3.4 Billion
- Leading global producer of hydrogen peroxide
- JV partner for supply of EnProve™ sodium-based sorbents to the industrial and utility markets

FMC ESD

- New Environmental Solutions Division
- First new division in over 10 years
- Three environmental platforms
  - Water and waste water
  - Soil and ground remediation
  - Air pollution control
    - PerNOxide
    - Soda ash
      - URS SBS SO3 control technology
      - Wet FGD scrubber slurry/chemistry control
    - FMC JV for EnProve sodium sorbents

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Safety Commitment

- FMC is a proud member of the American Chemistry Council (ACC) Responsible Care® program

- Continuing focus on improving the safe manufacture, handling, use, and security of our products throughout their life cycle

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Introduction

- Regulatory requirements are creating a need for coal fired boilers to further reduce NO_x emissions
- A technology void exists for units seeking NO_x reductions of 30-70% with minimal capital investment
- FMC is developing a cost effective NO_x control technology that also reduces Hg

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Post Combustion Technologies

- Selective Catalytic Reduction – SCR
- Selective Non-Catalytic Reduction – SNCR
- FMC's PerNOxide technology

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SCR

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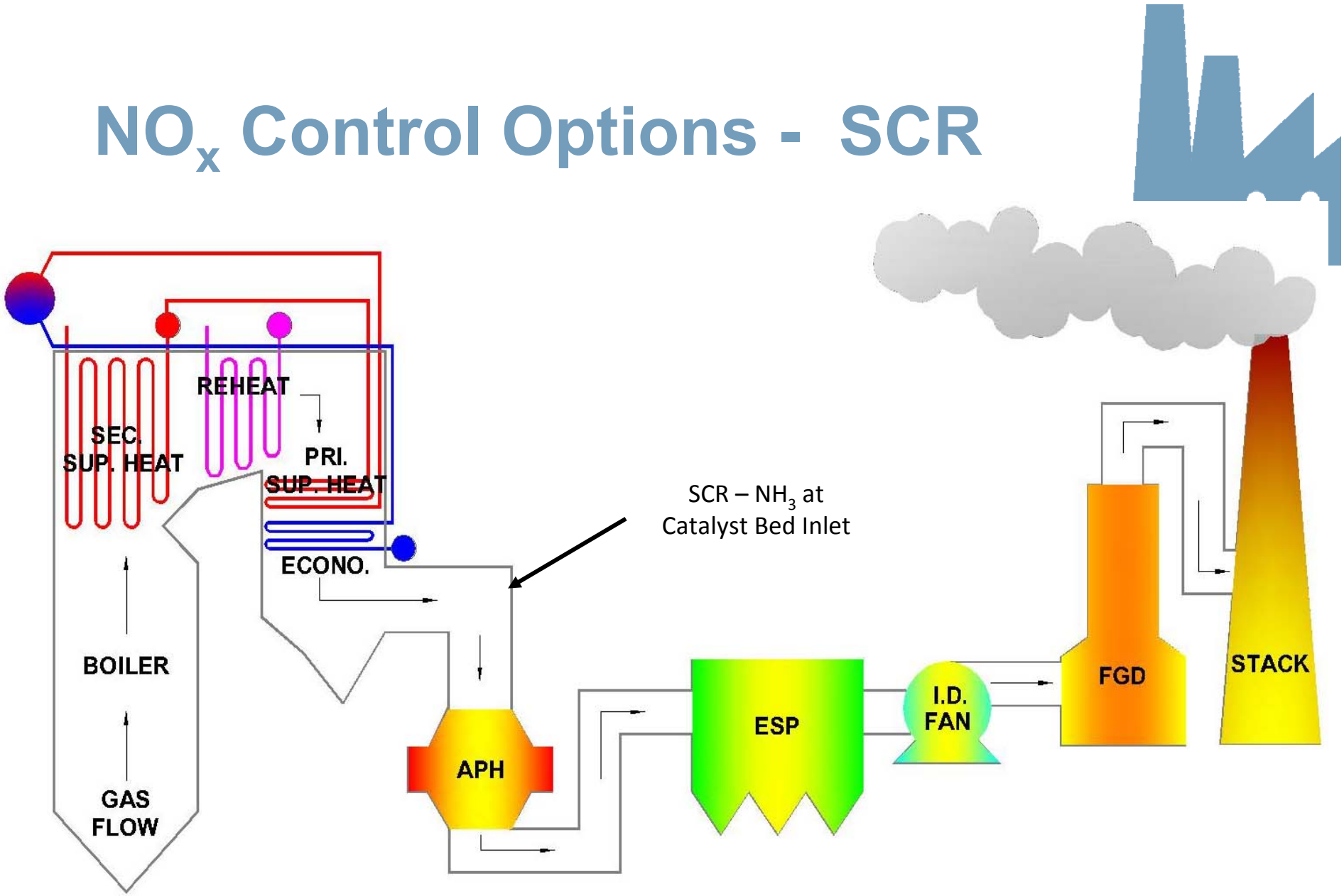
NO_x Control Options - SCR



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SCR

- Inject NH_3 ahead of catalyst
  - Anhydrous or aqueous
- NO chemically reduced to N_2
- $4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$
- $NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$
- NOx reductions of 75-90%
- Excess NH_3 can react with SO_3 to form ammonium bisulfate (NH_4HSO_4)
  - Causes air preheater and catalyst fouling
- Catalyst pluggage (ash) and poisoning (As)

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SNCR

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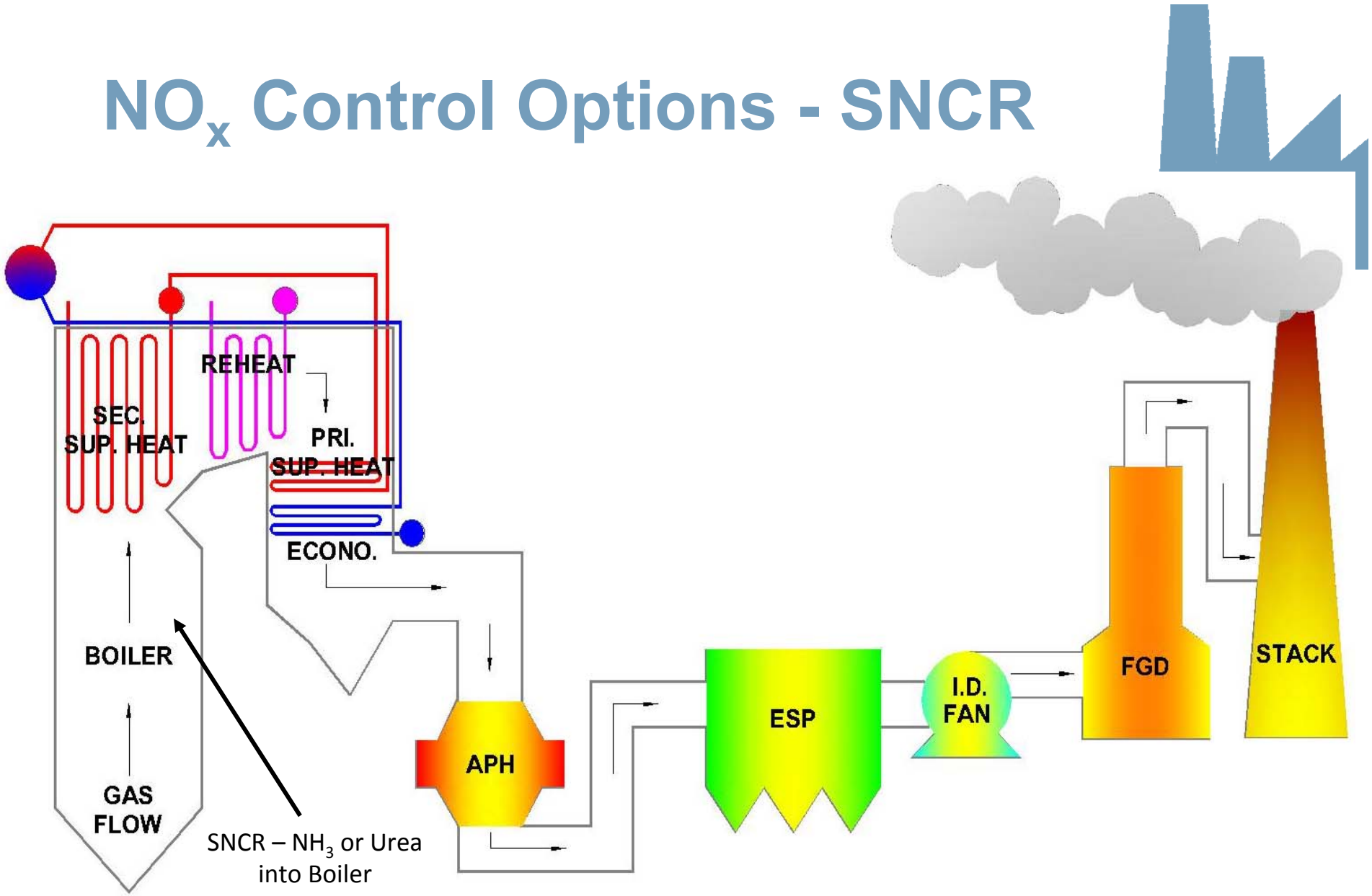
NO_x Control Options - SNCR



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SNCR

- Injection at high temperatures in boiler
- Injection temperature is critical ~1400 - 2000 °F
- Usually multiple injection levels to get close to temperature “sweet spot” under varying operating conditions
- Urea or NH_3 injected. No catalyst needed
- $4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$
- $2NO + (NH_2)_2CO + 1/2O_2 \rightarrow 2N_2 + 2H_2O + CO_2$
- NOx reductions of 15-40%

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PerNOxide Technology

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FMC NO_x Technology

- NASA Kennedy Space Center (KSC) developed technology in conjunction with University of Central Florida
- FMC Corporation is the exclusive licensee for US Patent # 6,676,912
- Use of hydrogen peroxide (H_2O_2) to oxidize NO and Hg° to forms for capture in downstream equipment

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Hydrogen Peroxide (H_2O_2)

- Strong, environmentally friendly oxidizing agent
- Major end uses: pulp & paper, chemicals, food, hair treatment, antiseptic, and electronics
- Product provided in various grades and concentrations

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ENVIRONMENTAL SOLUTIONS

Hydrogen Peroxide (H_2O_2)

- Strong, environmentally friendly oxidizing agent
- Major end uses: pulp & paper, chemicals, food, hair treatment, antiseptic, and electronics
- Product provided in various grades and concentrations
- FMC is a leading global supplier

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Peroxide Characteristics

- Specific gravity: 1.2
- Weight: 10 #/gal @ 50% concentration
- Apparent pH: ≤ 3.0
- Freezing point: - 62 °F @ 50% concentration

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Hydrogen Peroxide Chemistry

(1) Decomposition Reaction

$$H_2O_2 \rightarrow H_2O + \tfrac{1}{2} O_2 \uparrow$$

(2) Catalytic activation at elevated temperatures

$$H_2O_2 \rightarrow 2\ OH^{\bullet} \quad \text{or} \quad H_2O_2 \rightarrow OOH^{\bullet} + H$$

(3) Simplified oxidation of NO with H_2O_2

NO_2
N_2O_5
HNO_2
HNO_3

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PerNOxide – A Two Step Process

- Oxidation of NO
- Capture of oxidized NO species

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Oxidation Performance

- Oxidation of NO up to 80% has been achieved in laboratory, pilot, and full scale demonstrations
- Key to technology is capture of nitrogen species in downstream FGD equipment

Nitrogen Species Capture Options

- Wet lime/limestone/sodium scrubbers
- Circulating dry scrubbers (CDS)
- Spray dryer absorbers (SDA)
- Other dry/semi-dry scrubbers
- Dry injection (lime/trona) with ESP or FF

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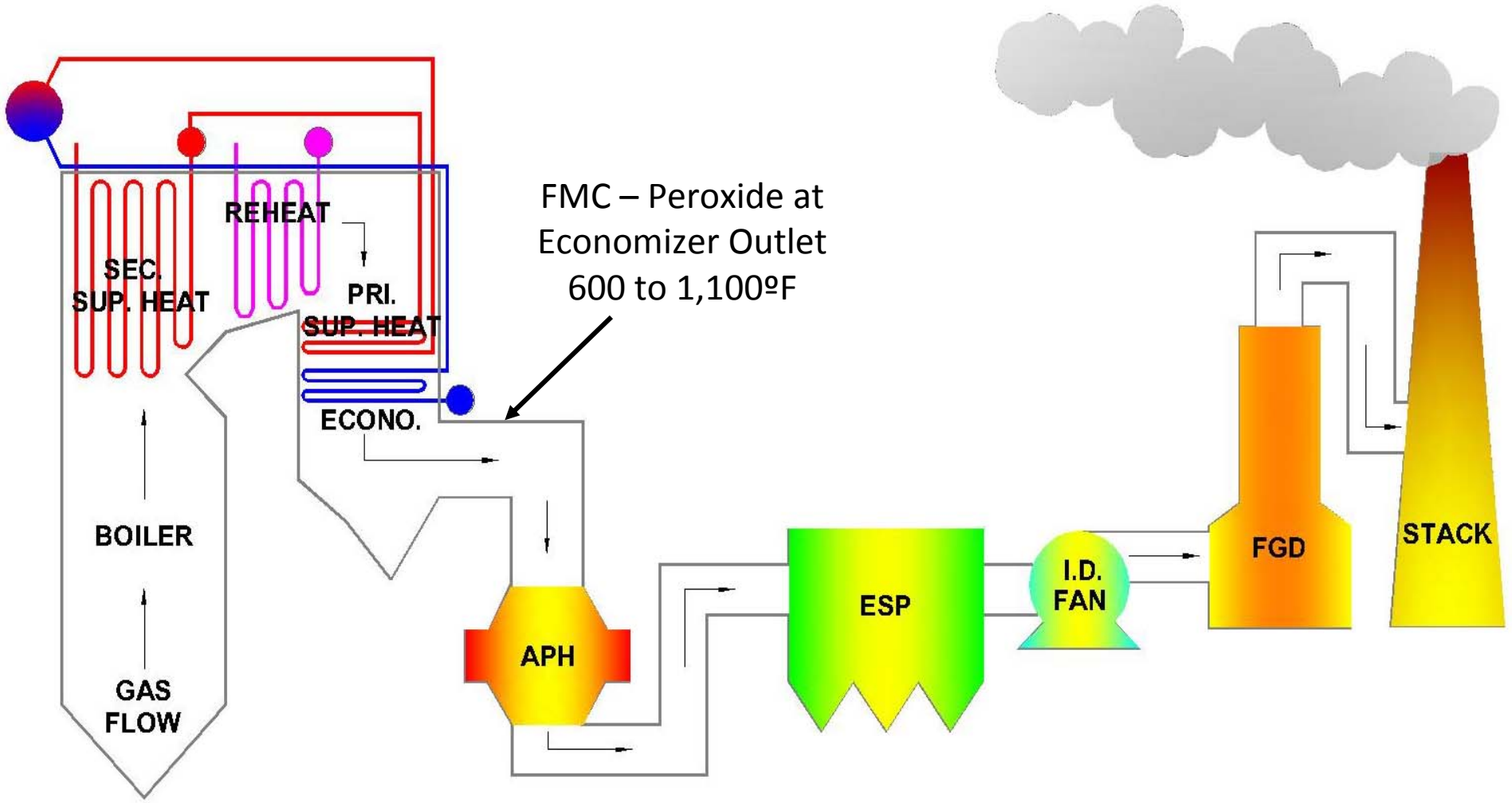
PerNOxide Technology



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Peroxide Injection

- Injected into duct between economizer and APH inlet
- Concentration controlled to achieve required NOx reduction
- Two fluid nozzles (air assisted atomization) used to produce fine droplets
- Water evaporates and peroxide dissociates
- NO oxidized

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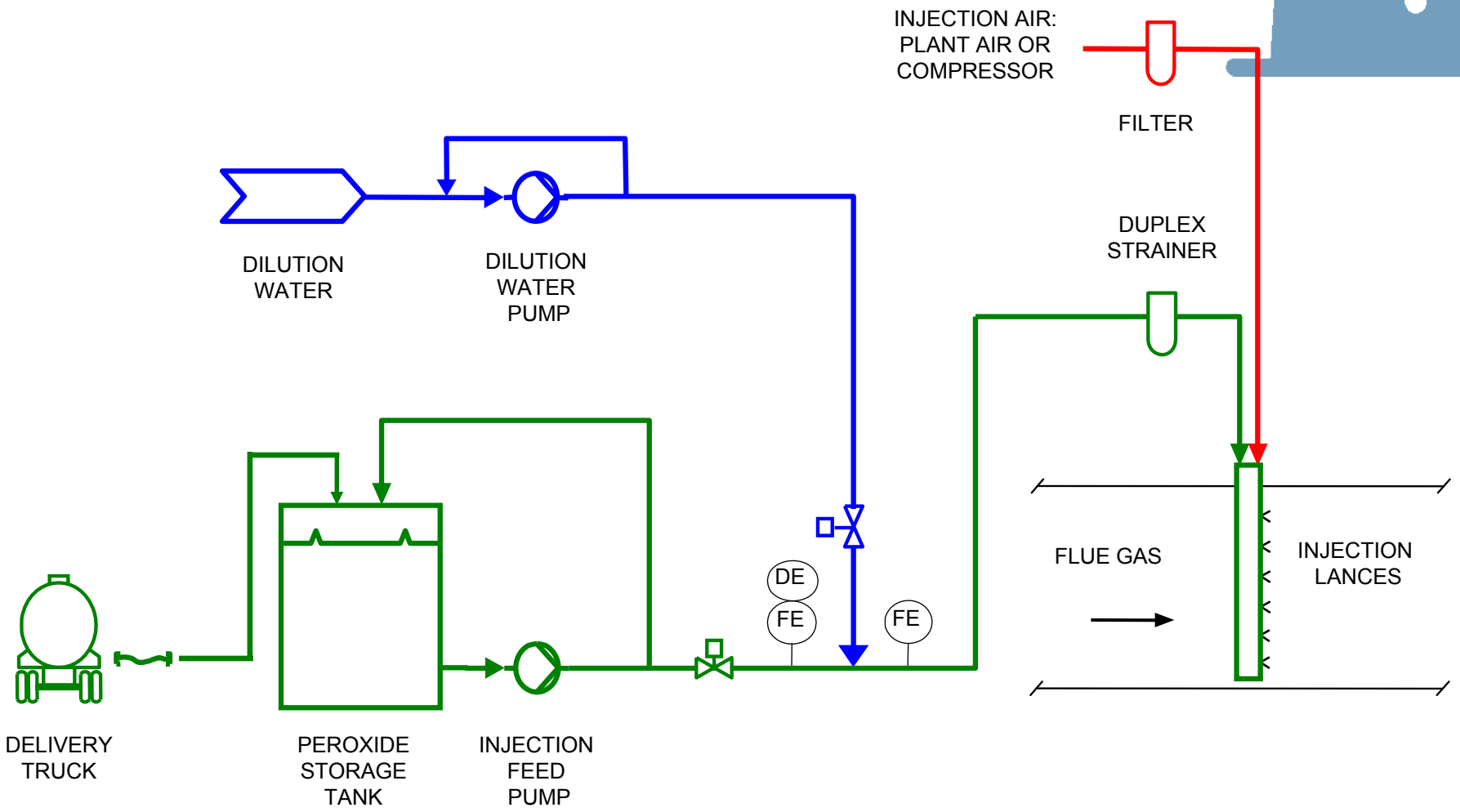
Simplified Process Flow Diagram



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NOx Capture by Scrubbers

- Not new. Considered since 1970s when scrubbers became popular and technologists were looking for “multi-pollutant” use of scrubbers
- NO is not water soluble
- Oxidation of NO can lead to many N species
  - NO_2, N_2O_5, HNO_3
- NO_2 is water soluble, but less than SO_2
- N_2O_5 reacts with H_2O to form HNO_3, which is highly water soluble

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NOx Reduction Capability

- Wet scrubbers: up to 70%
- Dry scrubbers: up to 50%

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Wet Scrubber Development

- 3 full scale demonstrations
  - Up to 80% NO oxidation
  - Only 20-30% reduction due to unforeseen chemistry issues
- FMC & URS Collaboration
  - Process development
  - Technology demonstrations
  - Commercial applications
- FMC/URS testing
  - 2 lab test programs
  - 1 pilot scale program
  - 1 full scale demonstration scheduled for 10/12

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Wet Scrubber Performance

- PerNOxide works best with high sulfite scrubber chemistries
  - Lime
  - Magnesium lime
  - Inhibited oxidation limestone
  - Natural oxidation limestone

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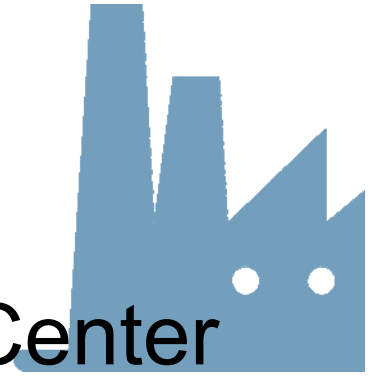
Dry Scrubber Development



- Energy & Environmental Research Center
- Pilot combustor and SDA/FF
- Primary sulfite formation
- Better oxidation and capture with
  - Higher inlet temperature
  - Higher SR
  - Longer treatment time
- Small variations with coal
- Still need further full scale data

PerNOxide Technology Advantages

- Lower capital & maintenance costs than SCR
- Higher removal efficiencies than SNCR
- Operational flexibility
- Mercury oxidation and capture
- Immune to SCR catalyst poisons
- Environmentally friendly reagent
- Limited downtime for installation
- Project execution < 1 year

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PerNOxide Technology Challenges

- Developing technology
- Close to commercialization
- May require modification to FGD chemistry
- Possible increase in NO_2 emissions
- Possible increase in SO_3 formation
- Waste stream management

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PerNOxide Bridges NO_x Control Gap

	SNCR	PerNOxide	SCR
NO_x Removal	20-30%	30-70%	75-90%
Capital Costs	Moderate	Low	High
Boiler Impacts	Yes	No	No
Operational Issues	Ammonia Slip	Potential Visible Emissions	Ammonia Slip & SO_3 Generation

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FMC Trial Scope

- Peroxide storage tank & containment
- Chemical delivery system
  - Pumps
  - Valves
  - Controllers
  - Interconnecting piping
- Spray lances and nozzles
- Contracted testing services

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Storage Tank

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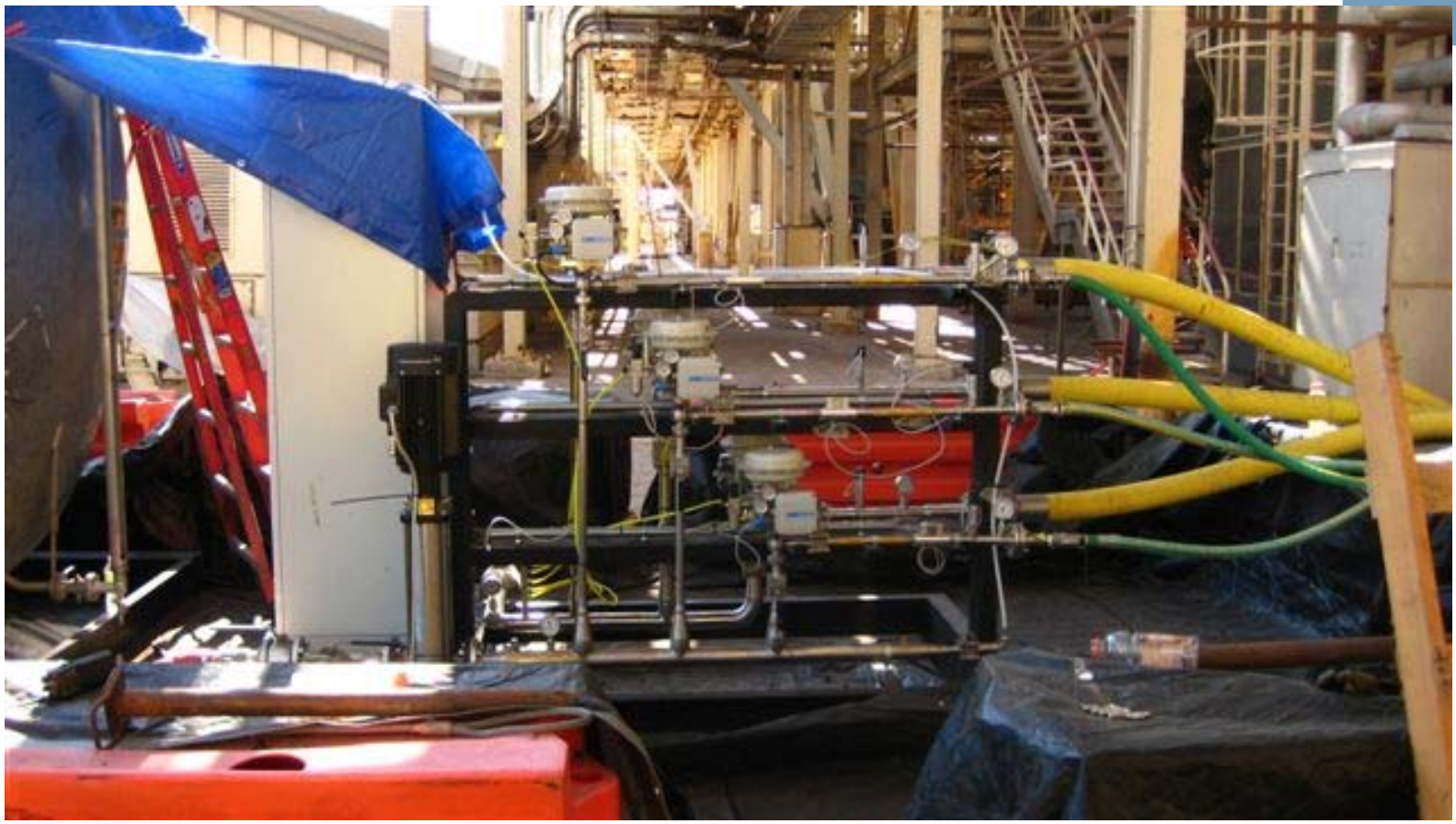
Injection Skid and Control



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Spray Lances

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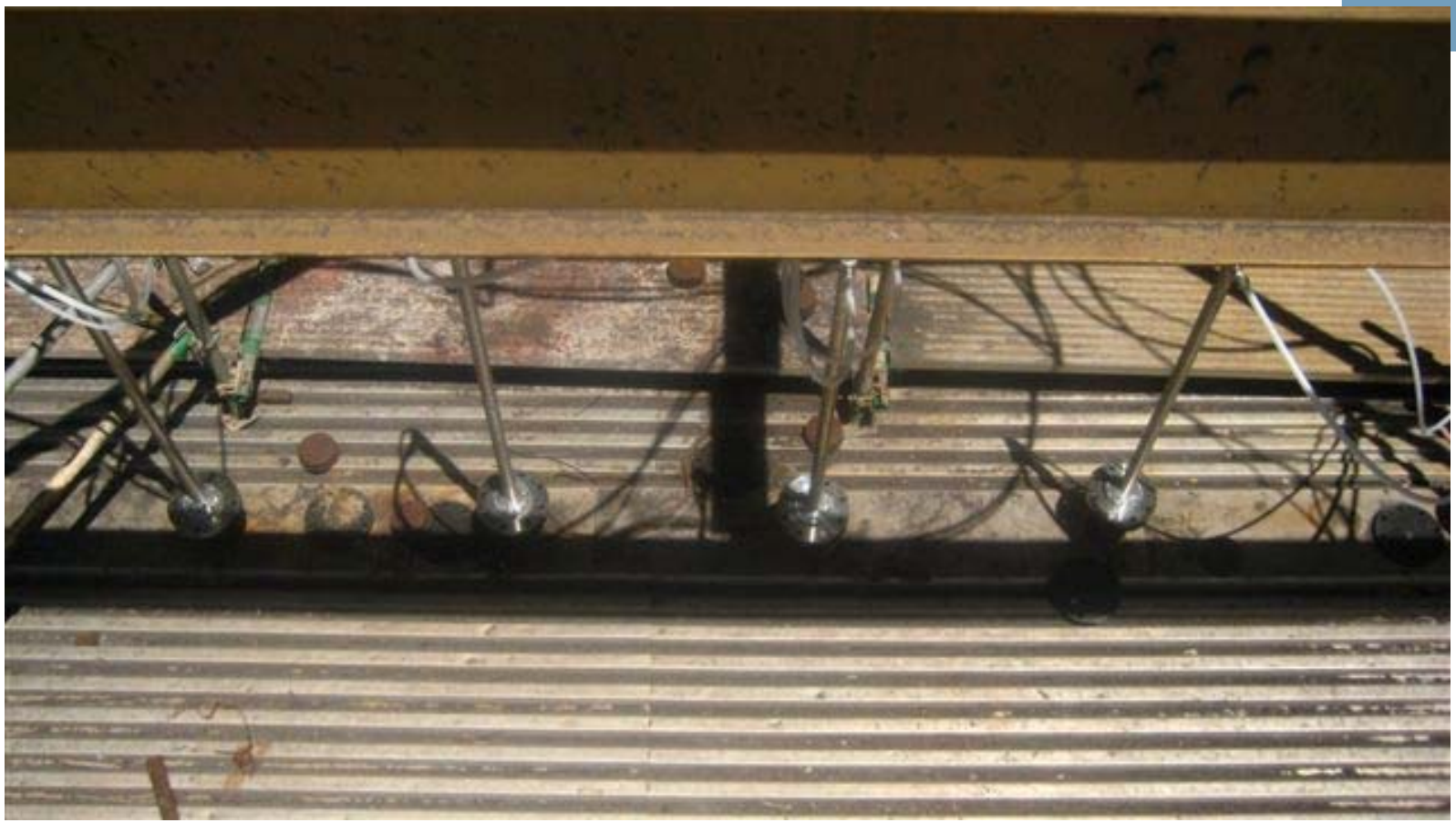
Injection Ports



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Applications

- Stand alone system
- In conjunction with
  - Low NOx burners (LNB)
  - Over-fired air systems
  - SNCR
  - SCR

NOx Technology Comparison

	SNCR	PerNOxide	SCR
Reagent	Urea	Peroxide	Ammonia
Nox Removal	15-40%	30-70%	75-90%
Capital Cost	Low	Low	High
Operating Cost	Low	Mid-High	Mid

PerNOxide offers moderate NOx reductions with low upfront capital investment

FMC Environmental Solutions

Costs

- Capital
  - $1-5M
  - Large variation due to site requirements
- Operating
  - $2500 – 3500 per ton NOx removed

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Summary

- PerNOxide technology is a 2-step process
  - Oxidation of NO to NO_2 and other N-O forms
  - Capture of NO_2 and other N-O forms
- High NO oxidation achieved using peroxide
- Capture of NO_2 is critical
  - Key variables: Scrubber mass transfer, dissolved sulfite, pH, & additives
  - Modification of scrubbing liquor composition may be required

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Takeaways

- Soon to be commercialized
- Low capital cost solution for NOx control
- NOx reductions up to 70%
- Chemical costs only as much as needed
- Easy to demonstrate and establish performance on a specific unit

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Path Forward

- **FMC is seeking opportunities for full scale demonstrations on both wet and dry scrubber applications**

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Thank You!

Questions???

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