Rule 1109.1 – Refinery Equipment

Working Group Meeting #4

September 12, 2018

Agenda

- Summary of Working Group Meeting #3
- Progress of Rule Development
- Rule Applicability – Boiler/Heaters and Flares
- Control Technology Assessment – Commercially Available
- Control Technology Assessment – Emerging Technology
- Next Steps

Progress of Rule Development

Summary of Working Group #3 (8/1/18)

- Reviewed other Air District regulations & current SCAQMD regulations
- Discussed three of the four steps in BARCT technology assessment
- Presented revised equipment emissions data

Since last Working Group Meeting

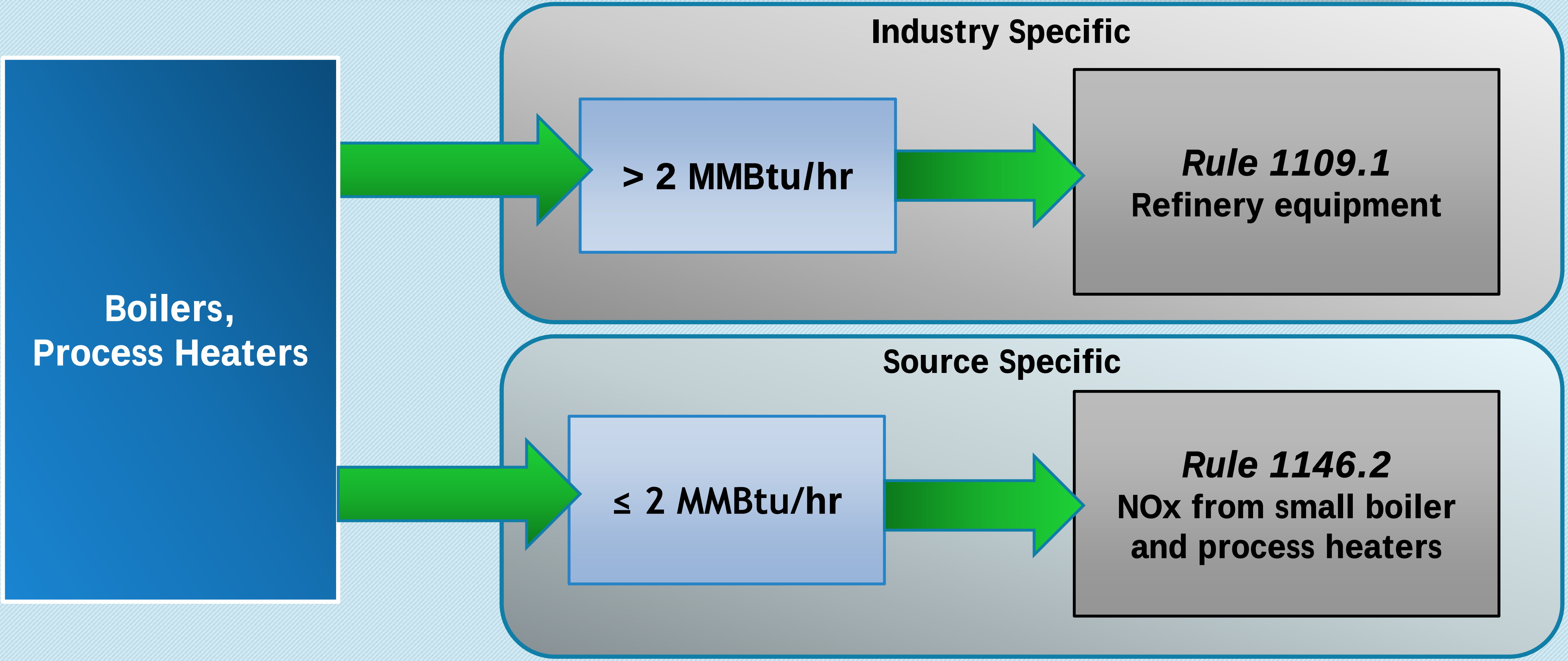
- Analyzing submitted survey data (including ammonia slip)
- Researching NOx control technologies available and currently used in practice
- Completing Request for Proposal (RFP) for 3rd party BARCT validation
- Continuing site visits and meetings with stakeholders

Rule Applicability

Rule Applicability – Boilers/Heaters

- Proposed Rule (PR) 1109.1 applicable to all equipment at refineries?
  - Small heaters used to heat buildings?
- Consider excluding boilers/heaters subject to Rule 1146.2 – *Emissions of Oxides of Nitrogen from Large Water Heaters and Small Boilers and Process Heaters*
  - Rule 1146.2 applicable to:
    - Manufacturers, distributors, retailers, refurbishers, installers and operators of new units
    - Units that have a rated heat input capacity less than or equal to 2 MMBtu/hr

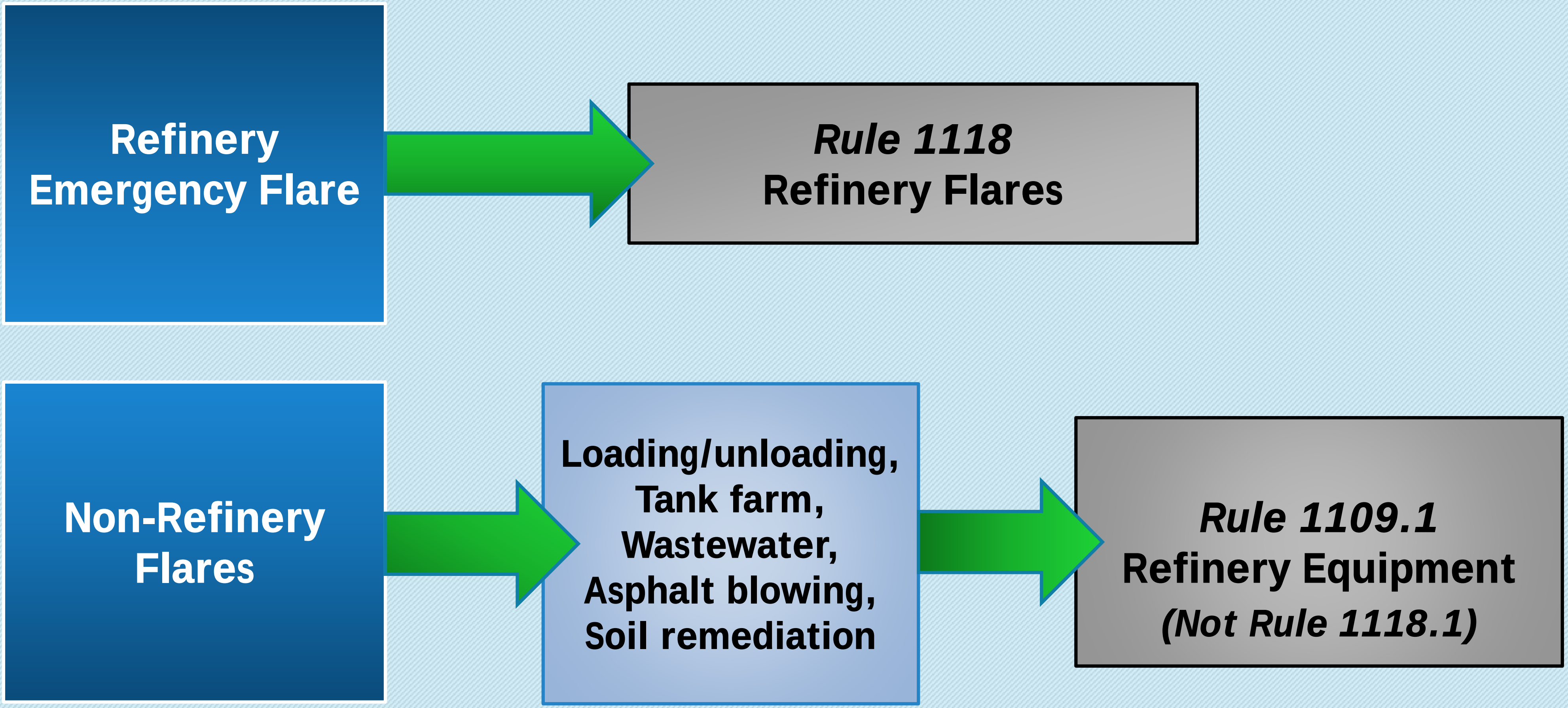
Rule Applicability – Boilers/Heaters



Rule Applicability - Flares

- Staff developing Proposed Rule 1118.1 - *Control Of Emissions From Non-refinery Flares*
- Non-refinery flares could be in operation at PR 1109.1 facilities for:
  - Truck/railcar loading and unloading
  - Wastewater
  - Tank farm
- Consider including all non-refinery flares in PR 1109.1
- Refinery flares will remain subject to Rule 1118 - *Control of Emissions from Refinery Flares*

Rule Applicability - Flares



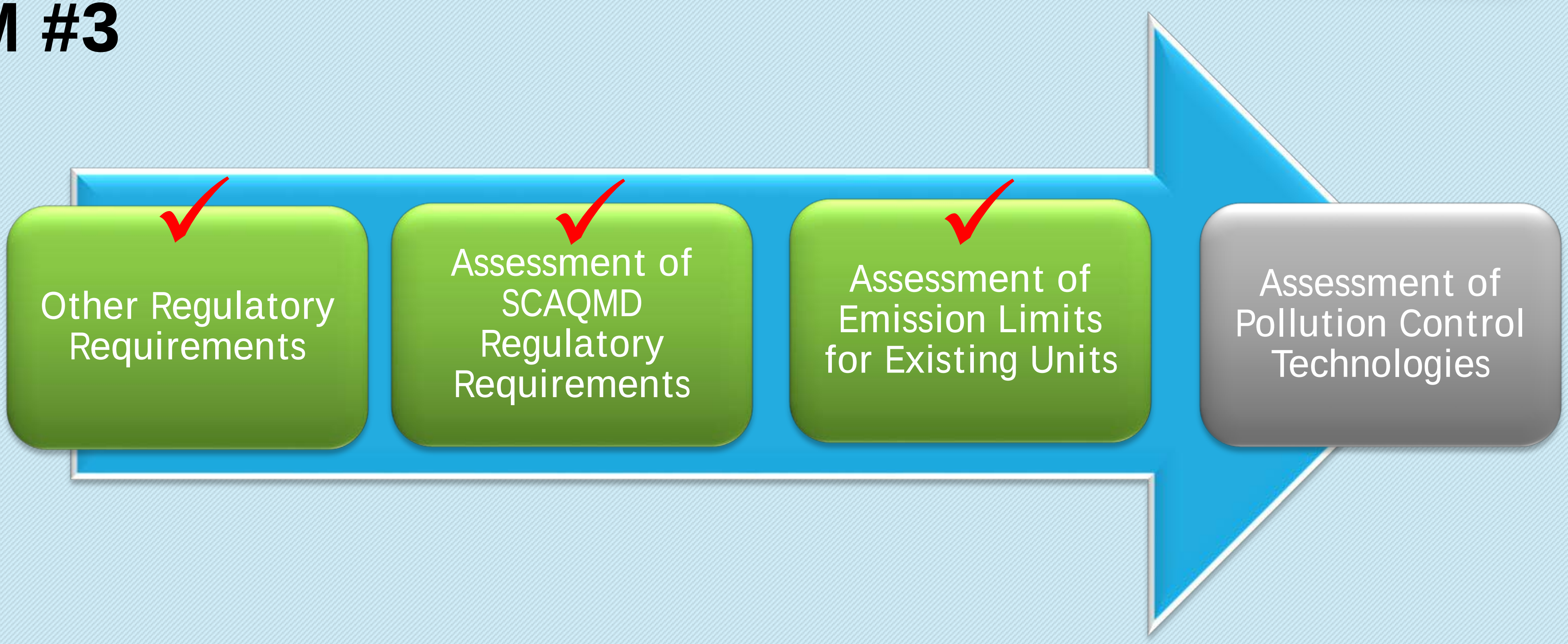
Pollution Control Technology Assessment

BARCT Analysis Approach Overview

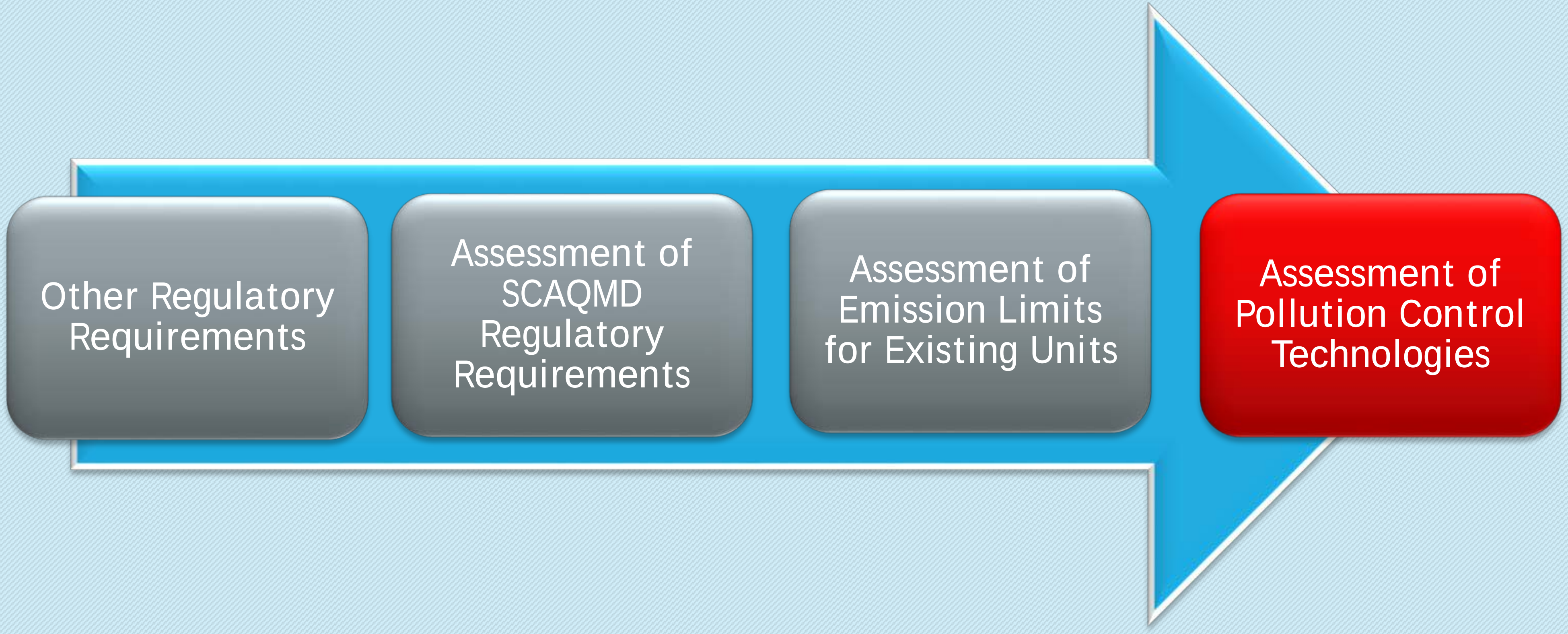
- Identify Emission Levels for Existing Units
- Assess Rules in Other Air Districts for Same Source
- Technology Assessment
- Establishing the BARCT Emission Limit and Other Considerations
- Cost Effectiveness

Technology Assessment (Steps 1 - 3 of 4)

WGM #3



Technology Assessment (Step 4 of 4)



Assessment of Pollution Control Technology

Objective: Identify and evaluate pollution control technologies, approaches, and potential emission reductions

- Pollution control technology assessment all encompassing
- Assess current status of technologies and potential emission reductions
  - Retrofit/replacement/technology transfer
- Consider environmental impacts
  - Impacts from equipment installation
  - Disposal or treatment of waste product
  - Transportation of hazardous material

Assessment of Pollution Control Technology (cont'd)

Identified NOx controls technologies for

- Gas turbines
- Primary internal combustion engines (ICE)
- Boiler/process heaters
- Fluidized Catalytic Cracking Unit (FCCU)
- SRU/TG incinerators & Non-SRU incinerators
- Coke calciner

Sources of information

- Scientific literature
- Vendor information and meetings
- Technologies currently utilized in practice
- Other regions with petroleum refineries (e.g., MARAMA, BAAQMD, NW Clean Air Agency, Texas-Houston/Galveston)

Assessment of Pollution Control Technology (cont’d)

For each source category, staff evaluated:

- Available technology
- NOx control principles, key features, and considerations
- Emission reduction potential
- Technology transfer

NOx control technologies include:

- Combustion control technologies
- Post-combustion control (add-on)
- Trim technologies (low cost with limited reduction potential)
- Replacement with new cleaner equipment

Assessment of Pollution Control Technology (cont’d)

NOx emission limit achievable for each control technology still being evaluated

- Evaluation will continue through RFP
- Staff will continue to meet with vendors
- NOx emission limit achievable for each technology will be presented in future working group meeting

NOx Control Principles

Principles	Description
Reduce peak flame temperature	Excess of fuel, air, steam, or flue gas to reduce thermal NOx
Reduce residence time	Prevents formation of thermal NOx
Chemical reduction of NOx	Chemically reducing/removing oxygen from NOx to form N_2
Oxidation of NOx with absorption	Convert NOx to N_2O_5 using catalyst, ozone, or H_2O_2 with subsequent scrubber
Sorbent	Injected into flue, baghouse, and combustion chamber followed by filtration and/or ESP
Removal of N_2 (O_2 Enhanced)	Remove N_2 as a reactant in the combustion process
Combination of these methods	Methods can be combined to achieve lower NOx

Assessment of Pollution Control Technology

Technology Assessment evaluated

Commercially available control technologies

- Available and applicable
- Commercially demonstrated/licensed
- Source-specific application with considerations for technology transfer

Emerging control technologies

- Not commonly used in industry/not reached commercial demonstration/licensing
- Novel technologies not yet demonstrated in the field applications
- Limited data available for source specific applicability

Commercially Available Control Technology

Combustion Source	Commercially Available Control Technology Applicability									
	Water/Steam Injection	FGR	NOx Additive	Dry Low-NOx Combustor	Ultra Low-NOx Burners	Low-NOx Burners	LoTOx™ w/ WGS	WGS+™	SNCR	NSCR	SCR
Boilers/Steam Generators	X	X			X	X			X		X
Heaters/Furnaces	X	X			X	X	X		X		X
FCCU			X				X	X	X		X
CO Boilers						X	X	X	X		X
Internal Combustion Engine										X	X
Gas Turbines	X	X		X							X
SRU/TG Incinerators					X	X	X				X
Incinerators					X	X					X
Thermal Oxidizers					X	X					X

Boiler/ Heaters NOx Control Technologies

Control Type	Description	Principle	Key Features	Considerations
Selective Catalytic Reduction (SCR)	Promotes reaction between NH_3 and NOx	Chemical reduction of NOx	• High NOx removal	• Increased pressure drop • NH_3 and secondary pollutant • Space requirements • Hazardous storage • Waste disposal
Ultra-Low NOx Burner (ULNB)/ Low-NOx Burner (LNB)	FGR pre-mix upstream and rapid mixing of air/fuel near ignition point	Reduce peak flame temperature/ residence time	• Low operating cost • Stable short flame	• Complex design • Requires FGR • Long flame length • Fan capacity • Coalescing/Impingement
Selective Non-Catalytic Reduction (SNCR)	Inject reducing reagent to react with NOx	Chemical reduction of NOx	• Low operating cost • Moderate NOx removal	• Temperature dependent • NOx reduction less at lower loads • NH_3 handling/slip • Furnace geometry temperature profile
Flue Gas Recirculation (FGR)	<30% flue gas (inert) recirculated with air	Reduce peak flame temperature	• High NOX reduction potential	• Affects heat transfer/system pressures • Fan capacity • Furnace pressure • Burner pressure drop • Turndown stability

Boiler/Heaters

- NOx control may vary depending on
  - Unit size
  - Burner configuration
  - Fuel combusted
- Primary control technologies used are SCR, ULNB/LNB, SNCR, and FGR
- Control technologies can be combined to increase overall NOx reductions
- Other technologies considered, but NOx reduction is limited

Control Type	Reduction Achievable
SCR	90% to 95%
ULNB/LNB	60% to 85%
SNCR	40% to 50%
FGR	30% to 50%

FCCU NOx Control Technologies

Control Type	Description	Principle	Key Features	Considerations
Selective Catalytic Reduction (SCR)	Promotes reaction between NH_3 and NOx	Chemical reduction of NOx	• High NOx removal	• Increased pressure drop • NH_3 and secondary pollutant • Space requirements • Hazardous storage • Waste disposal
LoTOx™ w/Wet Gas Scrubber	Inject ozone to flue gas (NOx to N_2O_5) followed by wet scrubbing	Oxidation of NOx with subsequent absorption	• Low operating temp • Multi-pollutant control • Not affected by load swings	• Waste treatment • Recovery of Nitric Acid generated
ExxonMobil WGS+ (Wet Gas Scrubber Plus)™	New 20' to 30' section added to existing scrubber/inject additive to remove NOx	Oxidation of NOx with subsequent absorption	• Easily Retrofit • Small plot space	• Wastewater unit impact/upgrades • Nitrates impact biological treatment • High operating cost
DENOX® or ELIMINOx™ NOx Reduction Additive	Low NOx promoter catalyst added 1% to 3% of fresh catalyst feed	Promotes reduction of NOx or minimizes precursor conversion to NOx	• Low cost, no additional infrastructure • Little secondary impact	• Limited NOx reduction • FCCU operational variability affects efficiency • Requires best practice to min NOx
Selective Non-Catalytic Reduction (SNCR)	Inject reducing reagent (urea) to react with NOx	Chemical reduction of NOx	• Low operating cost • Moderate NOx removal	• Temp dependent • NOx reduction less at lower loads • Space requirement • NH_3 slip

FCCU

- NOx control retrofits for FCCU vary according to
  - Size
  - Type of unit
- Primary control used is SCR
- LoTox™ with WGS
  - Achieve same reductions as SCR (multi-pollutant)
  - Successfully installed and operated in FCCU Marathon Texas City refinery
  - Achieving NOx levels <10 ppm
  - Outlet NOx can be varied by controlling ozone

Control Type	Reduction Achievable
SCR	90% to 95%
LoTOx™ w/Wet Gas Scrubber	80% to 95%
ExxonMobil WGS+ (Wet Gas Scrubber Plus)™	50% to 90%
DENOX® or ELIMINOx™ NOx Reduction Additive	50% to 75%
SNCR	40% to 50%

Gas Turbines (combined cycle) NOx Control Technologies

Control Type	Description	Principle	Key Features	Considerations
Selective Catalytic Reduction (SCR)	Promotes reaction between NH_3 and NOx	Chemical reduction of NOx	• High NOx removal	• Increased pressure drop • NH_3 and secondary pollutant • Space requirements • Hazardous storage • Waste disposal
Ultra-Low NOx Burner (ULNB)/ Low-NOx Burner (LNB)	FGR pre-mix upstream and rapid mixing of air/fuel near ignition point	Reduce peak flame temperature/ residence time	• Low operating cost • Stable short flame	• Complex design • Requires FGR • Long flame length • Fan capacity • Coalescing/Impingement
Flue Gas Recirculation (FGR)	<30% flue gas (inert) recirculated with air	Reduce peak flame temperature	• High NOx reduction potential	• Affects heat transfer/system pressures • Fan capacity • Furnace pressure • Burner pressure drop • Turndown stability
Water/Steam Injection	Inject water or steam to mix with air flow	Reduce peak flame temperature	• Moderate capital cost • NOx reduction similar to FGR • Increased system efficiency	• Higher power for fan • Increases CO • Reduces steam available for process

Gas Turbines (Combined Cycle)

- SCR is primary post combustion control
- Burners are intrinsic to the turbine – not usually available as retrofit
- Combination control technology can further increase NOx reduction
  - ULNB, SCR, CO
  - ULNB, WI, SCR w/CO catalyst
  - 95% or more achievable

Control Type	Reduction Achievable
SCR	90% to 95%
ULNB	50% to 85%
FGR	30% to 50%
Water/Steam Injection	25% to 60%
LNB	25% to 35%

Primary ICE NOx Control Technologies

Control Type	Description	Principle	Key Features	Considerations
Selective Catalytic Reduction (SCR)	Promotes reaction between NH_3 and NOx	Chemical reduction of NOx	• High NOx removal	• Increased pressure drop • NH_3 and secondary pollutant • Space requirements • Hazardous storage • Waste disposal
Non-Selective Catalytic Reduction (NSCR)	Unburned hydrocarbon fuel as reducing agent	Chemical reduction of NOx	• Low operating cost • No reducing agent	• Runs rich (catalyst requires <0.5% O_2 in exhaust)
Air/Fuel Ratio	Air/fuel ratio mixture non-stoichiometric	Reduce peak temperature	• Low cost	• Combustion instability • Engine performance
Exhaust Gas Recirculation (EGR)	Adding combustion products to fresh air/fuel during intake	Reduce peak temperature and combustion pressure	• Low cost • Increase knocking tolerances	• Loss in engine performance • Engine efficiency

Primary ICE

- Primary control for stationary ICE is SCR and/or EGR
- Combining both SCR and EGR can achieve up 95% or more achievable
- NSCR can achieve up to 90% reduction, but increases fuel consumption
- EGR and/or air/fuel alone
  - Low cost
  - Achieve up to 54% reduction
  - Adversely affects engine performance

Control Type	Reduction Achievable
SCR	90% to 95%
NSCR	70% to 90%
Air/Fuel Ratio	35% to 50%
EGR	22% to 54%

Coke Calciner NOx Control Technologies

Control Type	Description	Principle	Key Features	Considerations
LoTOx™ w/Wet Gas Scrubber	Inject ozone to flue gas (NOx to N_2O_5) followed by wet scrubbing	Oxidation of NOx with subsequent absorption	• Low operating temp • Multi-pollutant control • Not affected by load swings	• Waste treatment • Recovery of Nitric Acid generated
UltraCat	Ceramic filters with embedded catalyst and particulate capture	Chemical Reduction of NOx	• Multi-pollutant control • Low operating temperature	• Operating cost • Large plot space requirement
Selective Catalytic Reduction (SCR)	Promotes reaction between NH_3 and NOx	Chemical reduction of NOx	• High NOx removal	• Increased pressure drop • NH_3 and secondary pollutant • Space requirements • Hazardous storage • Waste disposal

Coke Calciner

- Control technology is currently being evaluated
- Assessed other coke calciners
  - Calciners are either equipped with
    - Wet gas scrubber or gas-fired pyroscrubber with dry scrubbing system for SOx control
    - Flue gas waste heat recovery boilers with steam turbine (electricity generation)
    - Multiclone Dust Collection System (particulate and flue gas SO_2 neutralization byproduct control)
- Added complexity of controlling SOx
  - Multi-pollutant control technology is most feasible approach

Control Type	Reduction Achievable
LoTOx w/WGS	85% to 92%
UltraCat	85% to 95%
SCR	90% to 95%

SRU/TG Incinerators NOx Control Technologies

Control Type	Description	Principle	Key Features	Considerations
LoTOx™ w/Wet Gas Scrubber	Inject ozone to flue gas (NOx to N_2O_5) followed by wet scrubbing	Oxidation of NOx with subsequent absorption	• Low operating temp • Multi-pollutant control • Not affected by load swings	• Waste treatment • Recovery of Nitric Acid generated
Selective Catalytic Reduction (SCR)	Promotes reaction between NH_3 and NOx	Chemical reduction of NOx	• High NOx removal	• Increased pressure drop • NH_3 and secondary pollutant • Space requirements • Hazardous storage • Waste disposal
Ultra-Low NOx Burner (ULNB)/ Low-NOx Burner (LNB)	FGR pre-mix upstream and rapid mixing of air/fuel near ignition point	Reduce peak flame temperature/ residence time	• Low operating cost • Stable short flame	• Complex design • Requires FGR • Long flame length • Fan capacity • Coalescing/ Impingement

SRU/TG Incinerators

- Primary control technology used for SRU/TG incinerators is SCR and ULNB/LNB
- LoTOx™ with WGS has good reduction potential and multi-pollutant control

Control Type	Reduction Achievable
LoTOx™ with Wet Gas Scrubber (WGS)	**85% to 95%**
Selective Catalytic Reduction (SCR)	**90% to 95%**
Ultra-Low NOx Burner (ULNB)	**50% to 80%**
Low-NOx Burner (LNB)	**25% to 35%**

Non-SRU

- Incinerators or thermal oxidizers not used in SRU
  - 12 total units
- Actual emissions are uncertain due to inadequate monitoring
- Variable fuel characteristics (composition, heating value, contaminants)
- Used in other refining related processes
  - Loading racks
  - Wastewater
  - Air pollution control
  - Soil remediation
- Control technologies used
  - LNB or ULNB

Commercially Available Technology Summary

NOx Control Technologies	Application	Reduction Achievable (%)
LoTOx™ with WGS	Calciner, FCCU	92
Water/Steam Injection, ULNB, SCR	Gas Turbines	95 or more
ULNB and SCR	Boilers/Heaters	95
LNB	SRU Incinerators	80
SCR	ICE (Diesel)	95
ULNB and SCR	Gas Turbines	95
	Boilers/Heaters	95
	SRU/TG Incinerators	95
	FCCU	95

Emerging Control Technologies

Emerging Control Technology

- Not commonly used in industry or not reached commercial demonstration/licensing
- Limited data available for source specific applicability
- Multi-pollutant control
  - EMx Catalyst
- Technology examples:
  - Great Southern Flameless Heater
  - ClearSign Duplex burner technology
- SCAQMD continually reviews emerging technologies

EMx Catalyst

- EMx is the 2nd generation of SCONOx technology
  - SCONOX was determined BACT for combine-cycle and cogeneration gas turbines (natural gas) by SCAQMD 2.5 ppmvd NOx at 15% O_2 (1-hr avg)
- Applicability
  - Coke calciners
  - Gas turbines
  - Reciprocating IC engines
  - Industrial/utility boilers
- Proven on gas turbines, but not refinery applications
  - Transferable technology

Key Features	Considerations
Single system multi-pollutant control technology, 90 to 95% for NOx	High upfront cost due to precious metals
Single catalyst for NOx, CO, PM and VOC	No current refinery application
No Hazardous byproducts	Requires hydrogen to regenerate catalyst
Wide operating temperature (400°F to 1100°F)	Proven in cogeneration gas turbines only

Great Southern Flameless Heater

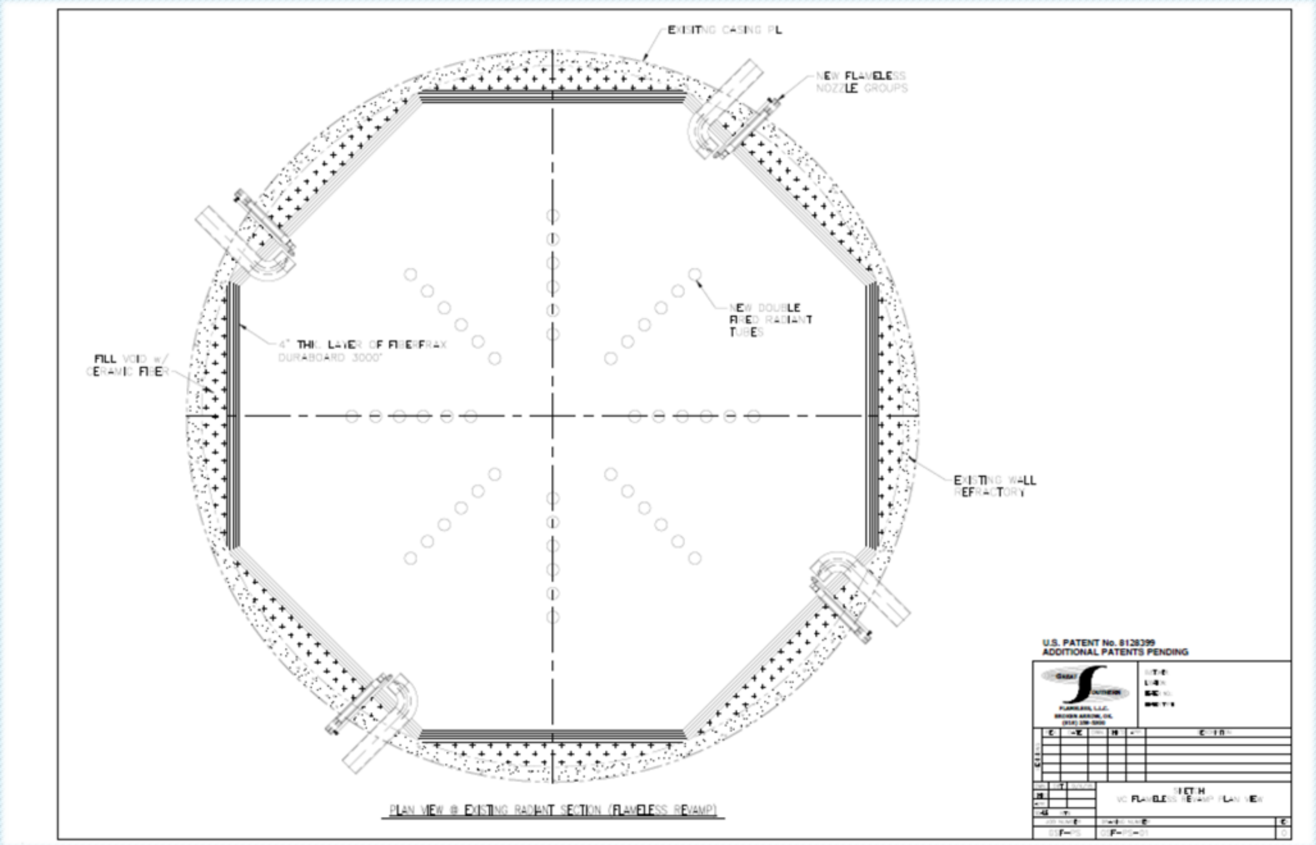
- Flameless crude heater has been operating continuously since March 15,2013 (5+ years) at Coffeyville, KS Refinery (3,442 BPD) using refinery fuel gas
- Can be scaled up to any required process heater size
- GSF has recently developed a retrofit option for existing heaters rather than replacing entire heater

Patented dimple pattern Interior radiant wall

Key Features	Considerations
NOx emissions equal to or lower than traditional combustion with SCR (2-4 ppm)	No current data for large refinery applications (>90,000 BPD)
Elimination of any possibility for hot flue gas or flame impingement (no coil fouling)	
No handling of hazardous chemical	
Improved reliability compared to traditional combustion with varying refinery fuel gas composition	
No ammonia slip	

Great Southern Flameless Heater (cont’d)

- Cost is equivalent to a conventional double fired heater with conventional balanced draft air preheat system (actual cost is dependent on system)
- Replacement technology
- Retrofit/revamp option currently being developed
  - Vertical cylindrical heaters
  - Horizontal cabin heaters



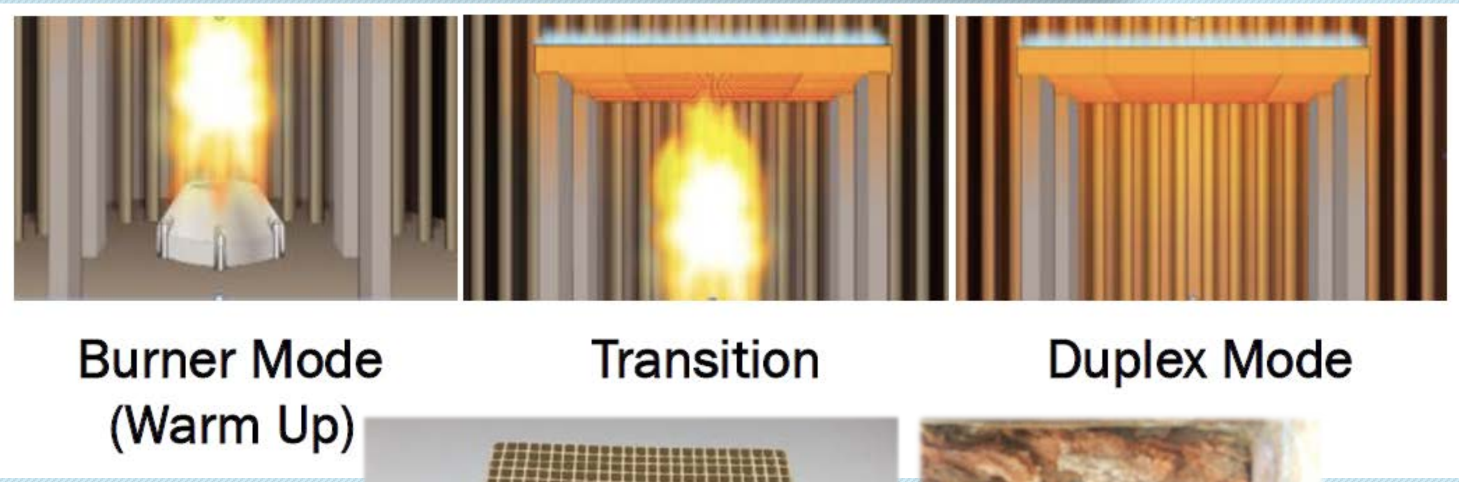
ClearSign Duplex™ Burner

Key Features	Considerations
5 ppm or less without FGR and SCR systems	Refinery application data limited
Flame length reduced 80%	> 40 MMBtu application not proven in refineries
Stable flame (wide operating range)	Limited data for refinery fuel gas
Improved fuel efficiency and throughput	
No ammonia slip	

- Duplex system consists of upper and lower tile system
- Duplex burner keeps oxygen at normal operating levels (1 to 3%), unlike low NOx burner systems
- Duplex burner delays combustion until sufficient entrainment of air and fuel gas which ensures low flame temperatures
- Does not pose safety risk

ClearSign Duplex^{TM} Burner (cont'd)

- Does not require FGR system
- Radiates heat to process and away from combustion products, lowering temperature and NOx emissions
- Retrofit technology
- Has been retrofitted into a multiple-burner, vertical-cylinder (VC) reformer process heater
- Does not require ammonia
- Lower cost than SCR systems



Emerging Control Technology Summary

- Both ClearSign Duplex and GSF process heaters:
  - Produce NO_x levels which have previously only been achievable with SCR (<5 ppm)
  - Eliminate the operational cost and chemical exposure hazards associated with SCR operation
  - Enhance heat transfer characteristics
  - Eliminate flame impingement issues associated with ULN burners on furnace process tubes
  - Potential for improved operational performance and longer run lengths

Next Steps

- Compile and Evaluate Survey Data
- BARCT Limits
- Cost Effectiveness Analysis
- Issue RFP for 3rd Party Validation
- Develop Rule Concepts

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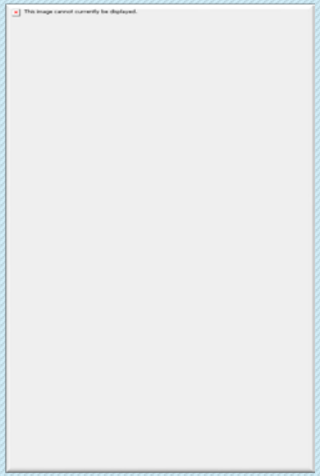

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