Rule 1109.1 – NOx Emission Reduction for Refinery Equipment

Working Group Meeting #7

April 30, 2019

Agenda

- Summary of Working Group Meeting #6
- Progress of Rule Development
- Third Party BARCT Review
- Technology Manufacturer Meetings
- Ammonia Slip and Particulate Matter
- Cost Effectiveness
- Next Steps

Progress of Rule Development

Summary of Working Group #6 (1/31/19)

- Presented revised analysis of heater and boiler data from survey
- Presented meetings with technology manufacturers
- Discussed burner control technology

Since Last Working Group Meeting

- Administrative Committee approved staff recommendation for BARCT Request For Proposal on 4/12/19
- Continued meetings with technology suppliers
- Site visit to asphalt refinery using ClearSign Duplex Plug & Play technology
- Western States Petroleum Association (WSPA) Meeting
  - Staff requested more information from stakeholders
- Marathon Petroleum Corporation stakeholder meeting & site visit
- Continuing site visits

Third Party BARCT Review

Third Party BARCT Review

- Recommended two technically qualified consultants:
  - Norton Engineering
  - Fossil Energy Research Corporation (FERCo)
- Each consultant will perform separate task
- Tasks proposed by staff:
  - Norton Engineering
    - Review staff’s BARCT analysis
    - Research international low-NOx installations (achieved in practice)
    - Control technologies
    - Costs
  - FERCo
    - Difficult installations and/or retrofits
      - Space constraints
      - Burner technology installations
    - Selective catalytic reduction (SCR) and Ammonia injection grid (AIG) optimization
- Seeking approval at May Governing Board Meeting

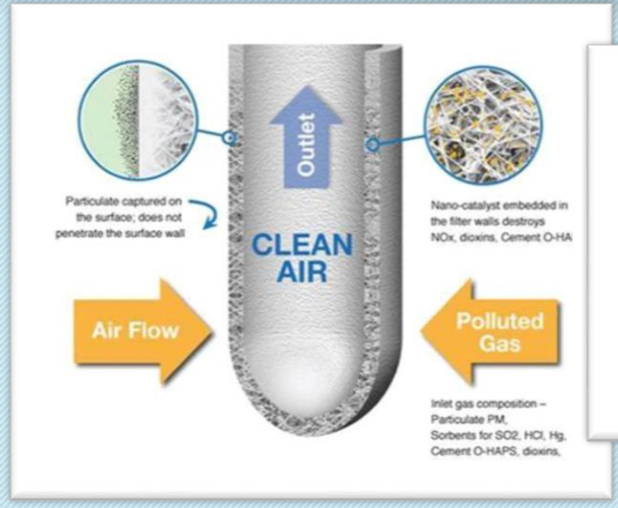
Third Party BARCT Review (cont'd)

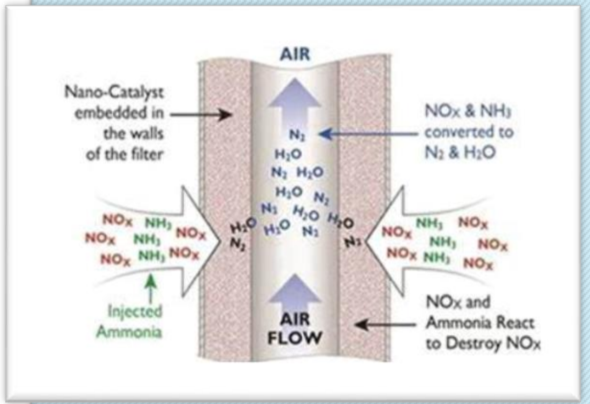
Norton Engineering	Fossil Energy Research Corporation (FERCo)
Extensive experience in refineries and petroleum process	Extensive background/experience in combustion and post combustion NOx control technology
Experienced in refinery NOx control projects	Comprehensive understanding and extensive experience with SCR systems
Experienced in refinery boiler and fired heater emission controls	Numerous technical presentations at technical conferences pertaining to NOx controls
Process design experience with NOx controls	Experienced in configuring process equipment with existing equipment
Experienced in refinery heater optimization	Extensive experience with ammonia injection systems and optimizations
Experienced in refinery FCC NOx controls	Experienced in refinery NOx emission systems and optimization
Performed previous 2015 BARCT RECLAIM assessment for SCAQMD	Numerous NOx technology assessment studies

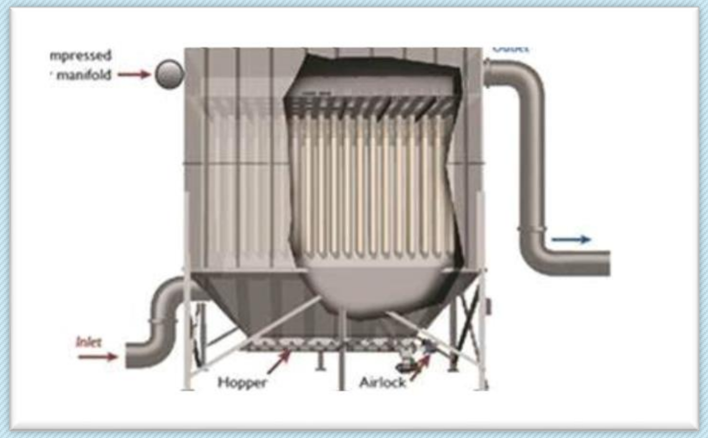
Technology Manufacturer Meetings

Tri-Mer UltraCat Technology

- Met with Tri-Mer on 2/21/19 to discuss UltraCat multi-pollutant control technology
- Catalytic ceramic filter system can remove NOx, SOx, and PM
  - Nano-form of catalyst embedded inside ceramic filter walls
  - Extended catalyst life and performance when compared to SCR
  - Ceramic filters can achieve 10+ years of service
  - New ceramic filters allow for smaller footprint of equipment
  - NOx removal not affected by particulate loading
  - Single system for multi-pollutant control
  - 90% NOx removal at temperatures above 500 F (slightly lower at 400 F)
  - 90% SOx removal at temperatures of 300F to 750F
- Filter removes SO_2, HCl, HF, and other gases utilizing dry sorbent injection of hydrated lime
- Modular design allows for meeting the flow volumes of different applications
- Can retrofit into existing baghouse if equipment is currently in use







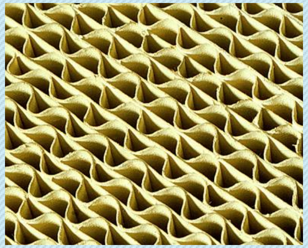
ClearSign Duplex Plug & Play Technology

- ClearSign's Plug & Play is a replacement burner technology with an integrated ceramic tile
- ClearSign achieves very low NOx emissions without the use of SCR and ammonia
- ClearSign is a possible alternative for similar small and midsized heaters due to cost-effectiveness over SCR installation
    - Presently only available in vertical fire configuration
    - Design fits within existing burner opening
- Due to burner design, no issues of flame impingement or coalescing
- Staff conducted site visit on 2/22/19 at an asphalt refinery in Bakersfield, CA to see a demonstration of a ClearSign Duplex Plug & Play burner in operation
    - Operating since May 2018 with no issues
    - Installed in a 15 MMBtu/hr furnace with a single natural draft burner (natural gas)
    - Fired duty for installed Plug & Play burner is 5.5 – 8.0 MMBtu/hr (will be replaced by a new 15 MMBtu/hr Plug & Play burner)
    - NOx emission <5 ppm @3% O_2 and CO emissions <10 ppm
    - Old burner that was replaced was emitting >30 ppm NOx
    - Heater has permit limit of 6 ppm NOx
    - Heater starts and stops daily, ClearSign burner shows no thermal stress/shock

Umicore Catalysis

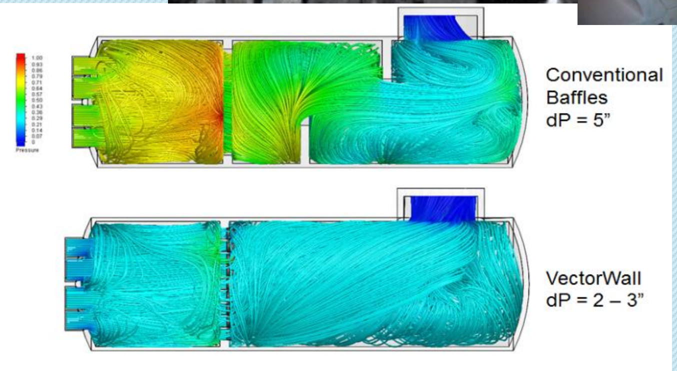
- Meeting with Umicore (Haldor Topsoe) on 3/13/19
- Corrugated catalyst based on a glass finer structure
- Dual function catalyst for NOx, CO, and VOC
- Experienced in refinery applications
  - Unique design allows for lower SO_2 to SO_3 conversion and greater activity/unit volume
  - Lower pressure drop, potentially smaller volume
- More than 1,800 installations (gas turbines, coal , cement, biomass, boilers, etc.)
- 395 refinery/petrochemical installations globally
- For high NOx reductions, NH_3/NOx mixing is critical to meet performance targets
  - 92% removal with < 5 ppm slip, ammonia/NOx mixing critical
  - >92% removal is a challenge

	FCC	Steam Methane Reformer	Crude Heater	Vacuum Heater	Cogen	Aux Boiler	Ethylene Cracker
Plugging from refractory/insulation		X	X	X	X	X	
Plugging from fines	X						X
Chrome poisoning		X					X
Vanadium deposition	X		X	X			
Tube leaks					X	X	
Ammonia salt formation	X				X	X	
Dual Function Possible (Green a Current Reference)	X	X	X	X	X	X	X



DuPont Clean Technologies

- Conference call with MECS & DuPont Clean Technologies on 4/2/19
- Experience in optimizing emission performance of sulfur recovery plant and sulfuric acid plant operation
  - Tail end treatment
  - Combustion optimization
- Tail end treatment control options
  - Dynawave® Reverse Jet Scrubber – Quenching, SOx absorption and particulate removal all in one vessel
- NOx abatement can be realized by an ozone generation process
- Combustion optimization (sulfuric acid plant furnace)
  - Sulfuric acid plant furnace optimization – VectorWall™ Ceramic Tile
    - Creates optimized flow pattern to create optimal combustion environment in furnace
    - Works with industry experts like John Zink Hamworthy Combustion and Blasch Precision Ceramics to optimize furnace emission performance
    - Reduces NOx emissions



Ammonia Slip and Particulate Matter

Co-pollutant (NSR/BACT)

- Stakeholders expressed concern with retrofit co-pollutant emissions
  - Equipment replacement or retrofit with SCR may result in higher PM emissions due to ammonia slip
  - If PM emission increases more than one pound a day, BACT will be required
  - If replaced with new equipment, subject to NSR/BACT but would provide efficiency gains and co-pollutant reductions
  - Feasible technical options to comply, but could be costly:
    - Pre- or Post-treatment
    - Fuel treatment to remove sulfur
- Staff is aware of the concern and more information will be forthcoming

Ammonia/PM Analysis

- Analysis of ammonia slip and PM_{10} in December 2015 Final Program Environmental Assessment for NOx RECLAIM
  - Projected increase use of ammonia by 39.5 tons per day (tpd) does not mean increased emissions of ammonia by 39.5 tpd
  - 39.5 tpd represents the amount injected by all flue gas streams by all potential SCRs needed to reduce NOx
  - Majority of the ammonia will react with NOx in flue gas with a small amount of unreacted ammonia
  - Regional simulation analyses were conducted to determine impacts of increased ammonia
    - NOx reduced by 14 tpd, resulting in an annual $PM_{2.5}$ decrease of approximately 0.7 $\mu g/m^3$
    - Increased use of ammonia results in an annual increase of $PM_{2.5}$ by 0.6 $\mu g/m^3$
    - Increased ammonia from the NOx shave would result in net annual $PM_{2.5}$ decrease of 0.1 $\mu g/m^3$
    - Overall decrease in annual $PM_{2.5}$ would occur provided that all 14 tpd of NOx emissions are reduced
  - Concluded the impacts to regional $PM_{2.5}$ and ozone due to ammonia slip in simulations would not create a significant impact

Cost Effectiveness

Cost-Effectiveness

- Cost-effectiveness is a measure comparing costs of pollution reduction to amount of pollutant reduced
  - Measured in cost per ton of pollutant reduced
- South Coast AQMD typically uses the Discounted Cash Flow Method to calculate cost effectiveness
  - Cost-Effectiveness = Present Value/Emissions Reduced Over Equipment Life
  - Present Value = Capital Cost + (Annual Operating Costs x Present Value Formula)
  - Present Value Formula = $(1-1/(1+r)^n)/r)$
    - $r = (i-f)/(1+f)$
    - i = nominal interest rate
    - f = inflation rate
    - n = number of cycles
- South Coast AQMD Governing Board established $50,000/tons of NOx removed with approval of 2016 Air Quality Management Plan

EPA SCR Cost Model

- Staff will evaluate cost-effectiveness of installing SCRs based on EPA cost model
- U.S. EPA's Air Pollution Control Cost Estimates Spreadsheet for Selective Catalytic Reduction* used to determined retrofit cost
  - Methodology based on U.S. EPA Clean Air Markets Division Integrated Planning Model
  - Costs of SCR depends on size of unit, emission rate, fuel type burned, NOx removal efficiency, reagent consumption rate, and catalyst costs
  - Capital cost annualized over 25 years at 4% interest rate
  - Inflation accounted for in Chemical Engineering Plant Cost Index (CEPCI)
    - Dec 2018 CEPCI equals 616
  - Values reported in 2018 dollars
  - Conservative cost model number and assumes cost for SCR retrofit
  - Staff using degree of difficulty (retrofit factor) to address challenging installations (e.g., space constraints)
    - Retrofit difficulty level: 0.8 to 1.5
    - Retrofit factor provided in survey by stakeholders
    - Retrofit factor of 1.2 is used if not provided
  - Running SCR model at various concentration levels to determine cost effectiveness

* Available at: http://epa.gov/sites/production/files/2017-12/documents/scrcostmanualchapter7thedition_2016revisions2017.pdf

EPA SCR Cost Model and CEPCI

Chemical Engineering Plant Cost Index (CEPCI)

Components of Index	Weight of Components	
Equipment Index:		
Heat exchangers and tanks	34	
Process machinery	13	
Pipe, valves, and fittings	19	
Process instruments	10	
Pumps & compressors	6	
Electrical equipment	7	
Structural supports & miscellaneous	11	**% of total**
	100	51
Construction Labor Index		29
Buildings Index		5
Engineering and Supervision		15
Total		100

Cost Estimates

- EPA SCR cost model only applicable to SCR installations (e.g., not burner retrofits, other control technologies)
- Stakeholders provided cost estimates for currently installed and planned SCR when available
- Technology control suppliers provided additional cost estimates (site specific considerations not included)
- For those units requiring >92% removal efficiency from SCR to achieve BARCT, the cost of burners will be added to the overall cost effectiveness from the EPA SCR cost model
  - Burner costs and operating cost provided in survey from stakeholders
  - Discounted Cash Flow will be used to calculate cost effectiveness for burner control in units that require burner control

Enter the following data for your combustion unit:

Is the combustion unit a utility or industrial boiler?	Industrial
Is the SCR for a new boiler or retrofit of an existing boiler?	Retrofit
Please enter a retrofit factor between 0.8 and 1.5 based on the level of difficulty. Enter 1 for projects of average retrofit difficulty.	1.2

Retrofit factor provided by stakeholder in survey and default of 1.2 used if not provided

Complete all of the highlighted data fields:

What is the maximum heat input rate (QB)?	28.5	MMBtu/hour
What is the higher heating value (HHV) of the fuel?	1,400	Btu/scf
What is the estimated actual annual fuel consumption?	99,760,143	scf/year
Enter the net plant heat input rate (NPHR)	8.2	MMBtu/MW

Reported input values from survey

Default value – used to estimate the amount of electricity needed for daily operation of SCR (e.g. ammonia vaporization, ID fan, etc.)

Enter the following design parameters for the proposed SCR:

Number of days the SCR operates (t_{SCR})	365 days
Number of days the boiler operates (t_{plant})	365 days
Inlet NO_x Emissions (NOx_{in}) to SCR	0.045 lb/MMBtu
NOx Removal Efficiency (EF) provided by vendor	86.5 percent
Stoichiometric Ratio Factor (SRF)	1.050

*The SRF value of 1.05 is a default value. User should enter actual value, if known.

Estimated operating life of the catalyst ($H_{catalyst}$)	24,000 hours
Estimated SCR equipment life	25 Years*

* For industrial boilers, the typical equipment life is between 20 and 25 years.

Concentration of reagent as stored (C_{stored})	19 percent
Density of reagent as stored (ρ_{stored})	58 lb/cubic feet
Number of days reagent is stored ($t_{storage}$)	14 days

Based on operating hours reported in survey

NOx permit limit (CEMS Data if no permit limit)

Reduction required to achieve proposed BARCT limit

Typical catalyst life 3 to 5 years (3 years used)

Aqueous ammonia

Number of SCR reactor chambers (n_{scr})	1
Number of catalyst layers (R_{layer})	3
Number of empty catalyst layers (R_{empty})	1
Ammonia Slip (Slip) provided by vendor	5 ppm
Volume of the catalyst layers ($Vol_{catalyst}$) (Enter "UNK" if value is not known)	UNK Cubic feet
Flue gas flow rate ($Q_{fluegas}$) (Enter "UNK" if value is not known)	UNK acfm

Gas temperature at the SCR inlet (T)	650 °F
Base case fuel gas volumetric flow rate factor (Q_{fuel})	484 ft^3/min-MMBtu/hour

To validate the data inputs, staff set reduction to 99.9% to verify NOx removed is within 2 tons/year of reported annual emissions (actual reported NOx emissions used and adjusted accordingly)

Default values in SCR cost model - Quote from manufacturer for typical install is 2 chambers (1 empty) with 1 layer of catalyst

Enter the cost data for the proposed SCR:

Desired dollar-year	2018	
CEPCI for 2018	616	Enter the CEPCI value for 2018 · 584.6 · 2012 CEPCI
Annual Interest Rate (i)	4	Percent
Reagent ($Cost_{reag}$)	3.56	$/gallon for a 19 percent solution of ammonia
Electricity ($Cost_{elect}$)	0.128	$/kWh
Catalyst cost ($CC_{replace}$)	285.00	$/cubic foot (includes removal and disposal/regeneration of existing catalyst and installation of new catalyst
Operator Labor Rate	60.00	$/hour (including benefits)*
Operator Hours/Day	24.00	hours/day

Note: The use of CEPCI in this spreadsheet is not an endorsement of the index, but is there merely to allow for availability of a well-known cost index to spreadsheet users. Use of other well-known cost indexes (e.g., M&S) is acceptable.

CEPCI December 2018

INDUSTRIAL			
Revenue	Sales	Customers	Price
Thousand Dollars	Megawatthou	Count	Cents/kWh
138,776	773,396	1,402	17.94
[illegible]	19,699,178	8,238	6.04
567,569	[illegible]	34,251	5.56
515,209	7,902,409	[illegible]	6.52
3,480,735	27,148,427	148,661	12.82
662,415	9,144,625	14,667	7.24
244,392	1,753,431	4,304	13.94

(default: $0.071)

Confirmed price of reagent grade aqueous ammonia from local supplier (factored freight cost into price)

Adjusted to 24 hours for refinery operations (default: 4 hours)

Quote from several catalyst manufacturers and averaged catalyst cost* (default: $160)

*Catalyst volume proprietary and based on catalyst technology selection

=(K19+L19)*('Data Inputs'!C52/'Data Inputs'!F52)*0.6+(K19+L19)*('Data Inputs'!C52/'Data Inputs'!F52)*0.4*1.2

E	F	G	H

Cost Estimate

Total Capital Investment (TCI)

TCI for Oil and Natural Gas Boilers

For Oil and Natural Gas-Fired Utility Boilers between 25MW and 500 MW:

$$TCI = 80{,}000 \times (200/B_{MW})^{0.35} \times BMW \times ELEVF \times RF$$

For Oil and Natural Gas-Fired Utility Boilers >500 MW:

$$TCI = 60{,}670 \times B_{MW} \times ELEVF \times RF$$

For Oil-Fired Industrial Boilers between 275 and 5,500 MMBTU/hour :

$$TCI = 7{,}270 \times (2{,}200/Q_B)^{0.35} \times Q_B \times ELEVF \times RF$$

For Natural Gas-Fired Industrial Boilers between 205 and 4,100 MMBTU/hour :

$$TCI = 9{,}760 \times (1{,}640/Q_B)^{0.35} \times Q_B \times ELEVF \times RF$$

For Oil-Fired Industrial Boilers >5,500 MMBtu/hour:

$$TCI = 5{,}275 \times Q_B \times ELEVF \times RF$$

For Natural Gas-Fired Industrial Boilers >4,100 MMBtu/hour:

$$TCI = 7{,}082 \times Q_B \times ELEVF \times RF$$

Total Capital Investment (TCI) =	$1,568,994	in 2018 dollars

Installation cost varies, but using 40% of Total Capital Investment. Staff proposing to increase installation cost by 20% to account for Senate Bill (SB) 54 labor (construction) rates in CA

Rule Considerations

Considerations for Initial Rule Concept

- Difficult installations
  - Firebox floor spacing constraints for burner retrofit
  - Space constraints around specific equipment
  - Establish physical criteria and/or definition that constitutes space constraint or firebox constraint
  - Potential options for new more efficient equipment with similar foot print
- Phased in implementation schedule to allow additional time for difficult installations and turnaround schedule
  - Phase one – X% of equipment, focusing on the oldest units with no control and highest emissions
  - Phase two – Y% of additional equipment
  - Phase three – 100% of equipment, difficult installations and/or equipment replacements
- Low-usage exemptions
  - Capacity threshold
  - Hours operated per year or over multiple years
- Allow keeping higher NOx limits for units close to BARCT limit
- Maintain existing ammonia permit limit, only if:
  - Meeting the NOx BARCT limit and not upgrading equipment

Next Steps

- Consultant Recommendation to May Governing Board
- Continue BARCT Assessment and CEMS data analysis
- Continuing Site Visits
- Propose BARCT Limits
- Consultant Final Assessment Report
- Finalize BARCT Limits

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