SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT
PLANNING, RULE DEVELOPMENT & AREA SOURCES

Draft Staff Report
SOx RECLAIM
Part II

Consultants' Analyses

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Chapter 10 – Request for Proposals & Contract Awards

10.1 Request for Proposal (RFP)

On July 11, 2008, the Governing Board approved a release of Request for Proposal (RFP) to obtain proposals from qualified contractors to conduct an engineering study on existing commercially viable control technologies to further reduce SOx emissions from RECLAIM facilities to assist staff in identifying Best Available Retrofit Control Technologies (BARCT) to be implemented within the 2011-2014 time frame which would help the Basin attain the PM2.5 ambient air quality standards by the 2015 deadline. The project consisted of three (3) modules with a total budget of $375,000.00 as shown in Table 10-1: [1, 2]

1. Module 1 was to seek an engineering evaluation and cost analysis assessment on SOx reducing additives used in fluid catalytic cracking units.

2. Module 2 was to seek an engineering evaluation and cost analysis assessment on SOx control technologies for refinery fuel gas and sulfur recovery/tail gas treatment units.

3. Module 3 was to seek an engineering evaluation and cost analysis assessment on wet/dry scrubbing technologies for seven categories of equipment identified in Part I of this report: 1) FCCUs, 2) refinery SRU/tail gas systems, 3) refinery heaters/boilers, 4) coke calciner, 5) sulfuric acid plant, 6) container glass melting furnaces, and 7) cement kilns & a coal fired boiler located at a cement manufacturing facility.

Table 10-1
List of Modules and Estimated Budget for SOx RECLAIM RFP

Project Modules	Budget
Module 1- FCCU DeSOx Additives	$36 K
Module 2 – Refinery SRU/Tail Gas and Fuel Gas Systems	$124 K
Module 3 – Wet/Dry Scrubbers for	
FCCUs, SRU/Tail Gas Systems, Boilers/Heaters	$133 K
Coke Calciner	$14 K
Sulfuric Acid Mfg Plants (w or w/o Cesium)	$24 K
Container Glass Melting Furnaces	$14 K
Cement Plant (Kilns & Coal fired boiler)	$15 K
Total	$360 K (+ $15 K for meetings)

[1] South Coast Air Quality Management District Board Meeting July 11, 2008, Agenda # 29, Report of RFPs and RFQs Scheduled for Release in July. July 11, 2008.

[2] South Coast Air Quality Management District, Request for Proposal, RFP #P2009-01, Evaluation of Emission Control Technologies for Further Reducing Sulfur Oxides Emissions from Stationary Sources in the South Coast Air Quality Management District's RECLAIM Program. July 11, 2008.

The contractor was asked to complete five specific tasks for each module (or submodule):

1. Identify promising existing commercially viable SOx control technologies/manufacturers;
2. Conduct field assessment and site-specific engineering evaluations;
3. Perform independent costs and cost effectiveness analysis;
4. Prepare reports describing the methodology, findings and recommendations; and
5. Attend in person and give testimony at the AQMD Governing Board hearings for the proposed amended rule as expert witness if asked by staff.

10.2 Contract Awards

After receiving approval from the AQMD Governing Board in July, staff released the RFP and conducted an extensive 1-month outreach in accordance with the District's Procurement Policy and Procedure. In addition, since this project is highly technical in nature, staff contacted eighteen (18) highly specialized contracting firms/contractors recommended by vendors and manufacturers of air pollution control equipment and the Western State Petroleum Association (WSPA). As a result of this effort, within a short time frame, staff received and accepted a total of six (6) technical proposals submitted by the contractors on August 15, 2008.

A four member panel was convened to evaluate the proposals including: one AQMD Assistant Deputy Executive Officer from Planning, Rule Development, and Area Sources Division; one AQMD Supervisor of the Best Available Control Technology team; one AQMD Supervisor of the Refinery Team; and one representative from WSPA. The evaluation process completed in August and staff drafted a proposal to present to the Board.

At the Board meeting on September 5, 2008, the Governing Board approved staff's proposal and awarded the contracts to two consultants, ETS, Inc. and Nexidea, Inc., to conduct the study for this project at their bidding costs shown in Table 10-2. The total amount of awards provided for this project was $334,860. [3, 4, 5] Note that no contract was awarded to any of the proposals to conduct the Module 1 evaluation.

[3] South Coast Air Quality Management District Board Meeting September 5, 2008, Agenda # 3, Execute Contract to Evaluate Emission Control Technologies for Further Reducing Sulfur Oxides Emissions from Stationary Sources in the SCAQMD SOx RECLAIM Program. September 5, 2008.

[4] South Coast Air Quality Management District, Contract# C09104 with Nexidea, Inc., Evaluation of Emission Control Technologies for Further Reducing Sulfur Oxides Emissions from Stationary Sources in the SCAQMD's RECLAIM Program. September 5, 2008.

[5] South Coast Air Quality Management District, Contract# C09105 with ETS, Inc., Evaluation of Emission Control Technologies for Further Reducing Sulfur Oxides Emissions from Stationary Sources in the SCAQMD's RECLAIM Program. September 5, 2008.

Table 10-2
List of Contracting Firms and Awards

Project Modules	**Consultant Firm**	**Awards**
SRU/Tail Gas & Fuel Gas Systems	ETS	$123,933
Wet/dry scrubbers for FCCUs, SRU/tail gas, boilers/heaters	ETS	$130,107
Wet/dry scrubbers for glass melting furnaces	ETS	$13,910
Wet/dry scrubbers for kilns & coal fired boiler	ETS	$13,910
Attending meetings as requested by AQMD staff	ETS	$7,500
	Total for ETS	*$289,360*
Wet/dry scrubbers for coke calciner (module 3-B)	Nexidea	$14,000
Wet/dry scrubbers for sulfuric acid plants	Nexidea	$24,000
Attending meetings as requested by AQMD staff	Nexidea	$7,500
	Total for Nexidea	*$45,500*
	Total	**$334,860**

Note: Since only one refinery voluntarily participated in the short-term testing with FCCU DeSOx additives, staff decided to conduct the analysis for Module 1 in-house.

The consultants started the projects immediately after receiving the awards. First, the consultants and staff scheduled and conducted site visits at BP, Chevron, ConocoPhillips, Tesoro, Valero, ExxonMobil, California Portland Cement Corp., Owens Brockway, and Rhodia Inc. in September - October 2008. During these site visits, the consultants gathered all necessary technical information on equipment and operating conditions, discussed with the facilities on operational characteristics of the equipment, observed the physical layout of the equipment, as well as listened to any concerns or foreseen constraints provided by the refinery technical experts related to future prospective add-on control devices.

After the site visits, the consultants conducted their own independent research, contacted the control manufacturers and vendors, gathered cost information, and performed their own independent engineering analysis on commercially available control technologies and cost effectiveness. In October 2008, the consultants developed the draft reports which were distributed to the affected facilities and AQMD staff for comments.

After addressing all comments received from the facilities, as well as AQMD staff, the consultants finalized their analyses and reports for coke calciner, cement kilns, coal fired boiler, glass furnaces, and sulfuric acid plant on December 16, 2008 as planned in the contracts.

Because of the complexity associated with the refinery systems and extensive communications between the consultants and the refineries, the consultants finalized their engineering analyses for FCCUs, SRU/tail gas, and fuel gas treatment systems in April 20, 2009, four months after the anticipated dates specified in the contract.

A summary of the consultants' recommendations in these engineering studies are provided in Chapter 11 through Chapter 16.

Chapter 11 – Nexidea's Analysis for Coke Calciner & Sulfuric Acid Plant

Nexidea, Inc. (Marshall Bell) [6, 7] was awarded the contract to study the control technologies for a coke calciner and two sulfuric acid plants in the District (named as Facility A, B and C in the consultant's reports). Nexidea Inc.'s analysis and results are summarized this chapter.

11.1 Recommended BARCT Levels

Nexidea's final conclusions in this study are summarized below:

- It is feasible and cost effective to reduce SOx emissions to a level of 5 ppmv using wet scrubbing with caustic solution from coke calciner and sulfuric acid plants. However, the consultant recommended the District to set BARCT at 10 ppmv due to process control related issues. For sulfuric acid plants, the consultant recommended a BARCT level of 0.14 lbs per ton acid, and for the coke calciner, the consultant recommended a BARCT level of 0.25 lbs per ton coke. Excerpts from the consultant's study are presented below:

  "*The results of the study show that simple caustic treating can cost effectively reduce SO2 emissions to less than 5 ppmv for the all of the units in the study; however, the recommended BARCT level is 10 ppmv due to control issues at near-zero SO2 levels. It is recommended that Facility B Acid Plant and Facility C Calciner add a caustic scrubber to meet the 10 ppmv SO2 level. Facility A Acid Plant already uses an SO2-selective amine to reduce SO2 to 20 ppmv. That unit can be revamped at low cost to meet a 10 ppmv SO2 level, thus addition of a caustic treater to that unit is not recommended.*

  Table 1 presents a summary of the key findings of this study. Recommended BARCT is 10 ppmv SO2, limited by process control issues…..

  Table 1: Summary of Recommendations

Equipment	***BARCT Level***	***Emission Reductions***	***Cost Effectiveness***
Facilities A and B	*0.14 lbs SOx/ton acid (10 ppmv)*	*<0.1 tpd (A)* *1.1 tpd (B)*	*$1.4K - $5.6K*
Facility C	*0.25 lbs SOx/ton coke (10 ppmv)*	*1 tpd*	*$2.5K - $5.0K*

"

[6] A biography of Mr. Marshall Bell is attached in Appendix II-B of this report.

[7] SOx RECLAIM Final Report – Wet/Dry Scrubbing Technology for Sulfuric Acid Plants and Coke Calciner, Nexidea Inc., December 2008.

11.2 Control Technology & Costs

To arrive at the conclusions presented above, Nexidea, Inc. conducted a literature research on wet/dry scrubbing control technology, both regenerative and non-regenerative. The consultant contacted four (4) vendors identified in Part I of the Staff Report and listed below for basic sizing and cost information to achieve 5, 10, and 20 ppmv SOx.

- Cansolv Technologies, Inc.
- Monsanto Envirochem Systems (MECS)
- Belco Technologies
- Tri-Mer

As stated in Nexidea's report:

> *"All four companies were sent requests for basic sizing and cost information for gas treating facilities that can reduce SO2 emissions. Each was asked to supply designs to meet 5, 10 and 20 ppmv SO2 in the treated gas streams. Belco, Tri-Mer and MECS responded with proposals. Cansolv Technologies responded with a letter stating that their technology is not economically attractive as a polishing unit, and they will not bid on Facility B or coke calciner. They will support the necessary upgrades to Facility A's Cansolv Unit to allow it to meet a 10-ppmv SO2 level*."

All four vendors responded that they could achieve 5 ppmv SOx if all process variables are carefully controlled and monitored. Three out of four vendors provided sizing and cost information to achieve 5 ppmv SOx. All four vendors indicated that they could easily treat the existing gas streams from the sulfuric acid plants and the coke calciner to 10 ppmv, and all four vendors provided sizing and cost data for this scenario:

> *"Both Sulfuric Acid Plants and the Coke Calciner start with relatively low levels of SO2 in the current discharge streams: 20 to 145 ppmv. Treating down to 10 ppmv SO2 is easy and straightforward with caustic treating. Belco, Tri-Mer and MECS all state that they can provide designs that will achieve SO2 levels down to 1-2 ppmv with caustic treating for Facilities B and C. Cansolv can achieve 10 ppmv SO2 with minor upgrades to the Facility A Acid Plant, and believe that 5 ppmv is possible if all process variables are carefully controlled."*

Accurate process control at all load changes is critical to achieve 5 ppmv SOx outlet concentration. The consultant recommended 10 ppmv as BARCT to provide the operators some room to respond to plant load changes and to reduce possible scaling of the absorber unit, usage of caustic, and load to the effluent treatment plant:

> *"The recommended treatment level is 10 ppmv for all three facilities. The reason for this slightly higher value is that treating to 5 ppmv is essentially treating to zero. At this extremely low level, control over caustic injection becomes difficult. Refer to Figure 1, which shows caustic addition versus SO2 in the treated gas. Note that the caustic injection rate is given in gallons per hour. A very small change in caustic addition rate has a large impact on SO2 level. Even if the caustic is diluted to 20%, the injection rate*

is still very small, and normal load changes in the units can make constant control difficult. Belco warns that control at <5 ppmv requires an increase in the pH of the caustic solution. As the pH rises, the tendency towards scaling the absorber tower and its internals increases, and the composition of makeup water to the unit must be carefully watched. If the pH is raised too high, it is possible to start absorbing CO2, which can produce a hard, insoluble sodium carbonate scale in the tower. Control at <5 ppmv almost certainly will result in over-injection of caustic, which is both wasteful and adds to the treating load in the effluent treatment plant. Control at 10 ppmv gives the operator more control room to respond to plant load changes without undue attention to the unit."

BELCO and Tri-Mer provided the consultant the inside battery limit (ISBL) equipment costs for caustic scrubbers, whereas MECS supplied the total installed equipment (TIC) for caustic scrubber. It should be noted that the costs for the caustic scrubbers were the same regardless of the SOx desired outlet concentrations (5, 10 or 20 ppmv). Cansolv supported the revamping costs of existing control at Facility A estimated by the contractor.

The estimated installed equipment costs provided in the consultant report were listed in the table below included 1) a 20% location factor increase to account for the difference in labor costs between the U.S. Gulf Coast and the Los Angeles area; and 2) a 35% contingency factor increase to account for other outside battery limit costs that might be needed for the project (e.g. utility upgrade and upgrade for effluent treating system.) added to the base costs.

"*Table 1: Estimated Installed Equipment Costs*

	Facility A	*Facility B*	*Facility C*
Belco	*$3,090,131*	*$6,579,231*	*$13,302,633*
Trimer	*$2,999,249*	*$13,316,664*	*$21,059,914*
MECS	*$4,043,137*	*$7,497,015*	*$16,826,926*
Cansolv	*$500,000*		

The vendors provided the consultant the following information to estimate the operating costs of the equipment:

- Electric power, kilo-watt
- Makeup water, gallons per minute
- Caustic solution (50% grade), gallons per hour
- Waste water treating, gallons per hour
- Operating/Maintenance man-power, # of people

The major differences in the operating costs for the three desired outlet SOx concentrations 5, 10, 20 ppmv were simply the costs of more caustic solution and increased effluent to the waste water treatment.

11.3 Emission Reductions & Cost Effectiveness

The estimated emission reductions from the 2005 actual reported emissions[8] to the feasible levels (5, 10, and 20 ppmv) were presented in the table below from the consultant's final report:

"Table 3: Estimated Emissions Reductions

	TPD SO2 Reduction
Facility A @ 5 ppmv	*0.050*
Facility A @ 10 ppmv	*0.033*
Facility A @ 20 ppmv	*NA*
Facility B @ 5 ppmv	*1.192*
Facility B @ 10 ppmv	*1.149*
Facility B @ 20 ppmv	*1.064*
Facility C @ 5 ppmv	*1.122*
Facility C @ 10 ppmv	*0.997*
Facility C @ 20 ppmv	*NA"*

The consultant estimated the following cost effectiveness numbers assuming a 25-year life of caustic scrubbers, 4% interest rate, and using a cost effectiveness equation provided by staff:

"Table 2: Cost Effectiveness

	Cansolv	*Tri-Mer*	*Belco*	*MECS*
Facility A @ 5 ppmv	*NA*	*$16,682*	*$17,596*	*$18,675*
Facility A @ 10 ppmv	*$5,556*	*$24,906*	*$26,273*	*$27,892*
Facility A @ 20 ppmv	*NA*	*NA*	*NA*	*NA*
Facility B @ 5 ppmv	*NA*	*$2,158*	*$1,594*	*$1,458*
Facility B @ 10 ppmv	*NA*	*$2,229*	*$1,644*	*$1,503*
Facility B @ 20 ppmv	*NA*	*$2,388*	*$1,77*	*$1,605*
Facility C @ 5 ppmv	*NA*	*$3,375*	*$2,469*	*$2,624*
Facility C @ 10 ppmv	*NA*	*$3,768*	*$2,749*	*$2,923*
Facility C @ 20 ppmv	*NA*	*$4,946*	*$3,589*	*$3,821*

[8] The consultant indicated in his report that the following existing average SOx concentrations were provided which the consultant later used in his estimated emission reductions:

"Facility A Acid Plant: 20 ppmv SOs
Facility B Acid Plant: 145 ppmv SO2
Facility C Coke Calciner: 50 ppmv SO2

…..the potential reduction in SO2 from Facility C based on the 50 ppmv level is higher than reported… suggests that ...this study may overstate the potential emission reduction from Facility C."

The consultant indicated that the current levels reported to the District "*…..are in the 20 - 30 ppmv range*".

11.4 Plot Space

The spaces for caustic scrubbers and associated equipment (e.g. ID fan) provided by the vendors and estimated by the consultant were summarized below:

	Facility A	Facility B	Facility C
BELCO	15 ft L x 20 ft W	20 ft L x 25 ft W	30 ft L x 40 ft W
Tri-Mer	18 ft L x 18 ft W	46 ft L x 28 ft W	70 ft L x 52 ft W
MECS	20 ft L x 20 ft W	25 ft L x 25 ft W	30 ft L x 30 ft W
Cansolv	No additional change in plot space	Not available	Not available

For Facility A, the consultant concluded that:

> "*If the Cansolv Unit is revamped to meet a 10 ppmv treated gas SO2 concentration, the existing equipment will be reused in its current location and current plot space will be sufficient. If a caustic polishing system were to be required, the new unit would have to be located some distance away from the Acid Plant. This would make ducting of the gas steam very difficult, and result in a much larger ID fan, as well as a higher capital cost.*"

For Facility B, the consultant concluded that:

> "*There appears to be sufficient plot space ….. to accommodate all three designs.*"

For Facility C, the consultant concluded that:

> *"In all three designs, it appears that some existing equipment will have to be relocated to make room for a new scrubber system.…… There appears to be sufficient plot space on the south and west sides of the cooling tower …. to accommodate the Belco and MECS designs, which use a single tower; however, space to locate the proposed Tri-Mer design is questionable."*

In addition, the consultant provided several suggestions to reduce the footprint of the Tri-Mer scrubber should that becomes the choice for the facilities.

11.5 Project Timing

The consultant estimated that the total project time needed to install the new caustic scrubbers at Facility B and Facility C was about 24 – 30 calendar months, and to revamp the existing control system at Facility A was about 12 months.

Chapter 12 – ETS's Analysis for Glass Manufacturing Plant

ETS, Inc. (John McKenna) [9, 10] was awarded the contract to study the control technologies for two container glass melting furnaces located at a container glass manufacturing facility in the District. ETS Inc.'s analysis and results are summarized in this chapter.

12.1 Recommended BARCT Levels

ETS, Inc.'s final conclusion in this study is that it is feasible and cost effective to reduce SOx emissions to a level of 5 ppmv or less using wet scrubbing with caustic solution for container glass melting furnaces. The consultant recommended the District to set BARCT at 0.0058 lbs/ton glass pulled (or 99% control.)

Excerpts from ETS Inc.'s study are presented below:

> "*ETS has conducted a top down analysis of alternative commercially feasible control technologies for the control of SO_x emissions from the glass plant. This analysis considered the technology which was found to be the most effective in terms of sulfur dioxide removal and which can potentially be installed or retrofitted at O-I. Four vendors (Manufacturer A, Manufacturer B, Manufacturer C, and Manufacturer D) submitted quotes and performance claims and one vendor (Manufacturer E) submitted a description of suggested process improvements on the existing system with a rough budgetary equipment cost. Given the higher removal efficiency (99%), the Manufacturer A wet scrubber was selected as BARCT for the glass furnaces.*
>
> *A cost-effectiveness determination was executed for the BARCT case and a summary of the results is provided in the following table:*

Summary of Recommendations

Equipment	*BARCT Level*	*BARCT Emission Level*	*Emission Reductions*	*Cost-Effectiveness*
Owens-Brockway A, B & C CEMS	*99% control (≤1 ppmv)*	*0.0058 lbs/ton glass pulled*	*0.19 tpd*	*$ 5.0 K/ton SOx*

Note: Baseline SO_x emissions used in calculations were from 2005 (SCAQMD database for the period from January 2005 – December 2005)"

[9] ETS, Inc. team in this project included Dr. John McKenna, John Mycock, Dr. James Turner, Christina Clark and Jeff Smith. (AEC Engineering Inc. was a subcontractor for ETS, Inc. in the refinery study discussed in Chapter 14 – Chapter 16. AEC Engineering Inc. was not subcontracted for the analyses for glass in Chapter 12 and cement in Chapter 13.) The consultants' biographies are included in Appendix II-B of this report.

[10] SOx RECLAIM Study - Final Report – Module 3-D: Wet/Dry Scrubbing Technology for Container Glass Manufacturing Plant, ETS, Inc., December 16, 2008.

12.2 Control Technology & Costs

To arrive at the conclusions presented above, ETS Inc. conducted a literature research on wet scrubbing (non-regenerative) and dry scrubbing control technologies. Sources for their literature research included Air Waste Management Association (AWMA), McIlvaine, U.S. EPA, Industrial Clean Air Companies (ICAC), Glass Manufacturing Industry Council, and the Council of Industrial Boilers Association (CIBA). ETS Inc. contacted seventeen (17) vendors in the field of wet/dry gas scrubbing. The following five (5) vendors responded to their request for information:

- Tri-Mer
- Monsanto Envirochem Systems (MECS)
- McGill Clean Air Technologies
- Dustex
- PPC, Industries

As stated in the ETS Inc.'s report:

"*These vendors were contacted and supplied with a request for a technical response to the RFP shown in Table 6. The vendors were asked to provide a Budgetary Equipment Cost and Estimated Annual Operating Cost at the following three levels of performance:*

1) *Lowest achievable level of efficiency with guarantee*
2) *Next lowest achievable level of efficiency with guarantee*
3) *Most comfortable achievable efficiency with guarantee…"*

"Four vendors (Manufacturer A, Manufacturer B, Manufacturer C, and Manufacturer D) submitted quotes and performance claims, and one vendor (Manufacturer E) submitted a description of suggested process improvements on the existing system with a rough budgetary equipment cost……"

	Control Technology	*Efficiency*	*SOx Outlet Conc.*
Manufacturer A	*wet scrubber with 50% NaOH*	*99%*	*Less than 5 ppmv*
Manufacturer B	*wet scrubber with 25% NaOH*	*95%*	*5 ppmv*
Manufacturer C	*dry gas scrubber*	*90%*	*10 ppmv*
Manufacturer D	*wet scrubber with 20% NaOH*	*90%*	*Less than 10 ppmv*

After carefully reviewing the information collected from the literature research and submitted by the vendors, ETS Inc. concluded:

"Given the higher removal efficiency (99%), the Manufacturer A Wet Scrubber was selected as BARCT for the glass furnaces..."

Regarding vendors' cost estimates, ETS Inc. indicated:

"…..they were asked to provide a budgetary cost estimate for the supply and installation of their equipment. The vendor was also requested to identify any utilities needed and

their expected rate of usage. The vendor was also asked to identify the amount and type of waste generated by the process. If the vendor's approach was to modify or retrofit existing hardware, he was requested to supply a cost estimate for those activities. For example, if the proposed approach was that of dry or wet injection upstream of the baghouse, the proposal should have included an estimate for all required equipment hardware, reagent storage vessels, reagent feed control instrumentation, engineering, construction and installation, etc., as well as pre-engineering costs such as site testing activities to locate the reagent injection site to optimize system performance with respect to SO_2 control and reagent utilization."

The basis for equipment costs was different from each vendor (e.g. two vendors provided total installation costs including freight, and the other two provided just equipment costs without installation costs and freight.) The consultants applied their engineering knowledge and judgment to reconcile all vendors' costs to the same basis. In addition, the consultants included specific costs to cover areas that had been identified by the subject facility in the District (e.g. costs were added to cover additional treatment of the waste stream from the scrubber & additional ducting to the space available at the facility.)

ETS Inc. included the following categories in estimating the capital cost:

"*Demolition and Decommissioning*
Civil/Concrete
Structural
Equipment
Piping & Mechanical
Electrical & Controls
Misc. Direct & Indirect Costs:
- *Contractor overhead and misc. rentals*
- *Contractor field supervision*
- *Mobilization/Demobilization*
- *Overtime/productivity factor*
- *Freight/shipping*
- *Sales Tax*
- *Commissioning and operating spares*
- *Start-up/initial fill material*
- *On-site training/start-up assistance*
- *FEED engineering through detailed design*
- *Project management*"

ETS, Inc. included the following categories in estimating the annual operating and maintenance costs:

"*Annual Maintenance Costs*
Periodic Maintenance Costs
Additional Operating Costs
Utilities:
- *Natural Gas*
- *Electricity*
- *Water*

Wastewater
Cooling Water
Compressed Air
Solid Waste Disposal "

12.3 Emission Reductions & Cost Effectiveness

A summary of emission reductions, cost estimates, and cost effectiveness using 25-year life for a wet gas scrubber and 4% interest rate estimated by ETS, Inc. is shown below:

" *2005 Baseline Emissions*	*0.195 tpd*
Emission Reductions	*0.19 tpd (99% efficiency)*
Equipment Costs	*$1.10 million*
Capital Costs	*$1.90 million*
Annual Operating Costs	*$0.44 million*
Present Worth Value (25-year life)	*$8.80 million*
Cost Effectiveness Factor	*$4,988 per ton SOx reduced* "

ETS, Inc. did not estimate emission reductions and cost effectiveness associated with other levels of control (95%, 90%). ETS, Inc. indicated that:

"In considering a curve of cost-effectiveness versus level of control there are two considerations. Firstly, will the control device capital cost vary with improved efficiency and secondly, will the operating cost increase with increasing efficiency. Since the capital cost is driven largely by the gas volume and since the volume is essentially constant there is little if any change in the capital cost over the considered range of efficiencies. With respect to operating cost versus efficiency, in the case of sodium hydroxide, while the utilization does increase with increasing efficiency, the cost of the sodium hydroxide was low enough to minimize the impact of efficiency on cost. Thus the merit of plotting a curve of cost versus efficiency seemed of little value."

12.4 Plot Space

Two vendors provided overall footprint (below) and two provided dimensions for individual components of the control systems. Manufacturer A estimated a footprint of 32 ft L x 10 ft W, and Manufacturer D estimated a footprint of 20 ft L x 20 ft W. In the analysis for available space, the consultant indicated that:

"*The plant has limited space available for additional equipment, approximately a 14' x 20' footprint between two existing scrubbers. In addition O-I personnel indicated that the height of any new equipment could not exceed 30 feet above the top of the existing scrubbing vessels. A request was made of O-I to provide us with dimensional information pertaining to available space for the Manufacturer A equipment footprint. They stated that there is space available. Horizontal distance is 63' depending on the location of the ducting out of the pieces of equipment. This does not take into account the vertical distance which will depend on location of entry to the stream.*"

Project Timing

The consultant estimated that startup of the control equipment could occur 12 months after the project begins.

Chapter 13 – ETS's Analysis for Cement Plant

ETS, Inc. (John McKenna) [11, 12] was awarded the contract to study the control technologies for two cement kilns and a coal-fired boiler located at California Portland Cement Co. (CPCC). ETS Inc.'s analysis and results are summarized in this chapter.

13.1 Recommended BARCT Levels

ETS, Inc.'s final conclusion in this study is that it is feasible and cost effective to reduce SOx emissions to a level of 5 ppmv or less using wet scrubbing with caustic solution for two cement kilns and a coal-fired boiler. The consultant recommended the District to set BARCT at 0.03 lbs/ton clinker (or 95% control efficiency) for the two cement kilns, and 95% control efficiency for the coal fired boiler.

Excerpts from ETS Inc.'s study are presented below:

> "*ETS has conducted a top down analysis of alternative commercially feasible control technologies for the control of SO_x emissions from the cement plant. This analysis considered the technology which was found to be the most effective in terms of sulfur dioxide removal and which can potentially be installed or retrofitted at CPCC. In the case of the two kilns, three vendors (Manufacturer A, Manufacturer B, and Manufacturer C) submitted quotes and performance claims. Given the higher removal efficiency (95%), the Manufacturer B $CaCO_3$ Scrubber was selected as BARCT for the kilns.*
>
> *Similarly top down analysis was done for the coal-fired fluidized bed boiler emission control at the cement plant. Four vendors (Manufacturer A, Manufacturer B, Manufacturer C, and Manufacturer D) submitted quotes and performance claims. Given the 95% removal efficiency, both the Manufacturer D Venturi Reactor & the Manufacturer B $CaCO_3$ Scrubber can be considered BARCT for the coal-fired fluidized bed boiler.*
>
> *Cost-effectiveness determinations were executed for the BARCT cases and a summary of the results are provided in the following table.*

Summary of Recommendations

Equipment	*BARCT Level*	*BARCT Emission Level*	*Emission Reductions*	*Cost Effectiveness*
Kilns	*95% control (≤2 ppmv)*	*0.03 lbs SO_x/ton clinker*	*0.25 tpd SO_x*	*$18.9 K/ton SOx*
Coal-Fired Boiler	*95% control (≤5 ppmv)*	---	*0.36 tpd SO_x*	*$ 3.8 K/ton SOx*

[11] ETS, Inc. team in this project included Dr. John McKenna, John Mycock, Dr. James Turner, Christina Clark and Jeff Smith. (AEC Engineering Inc. was a subcontractor for ETS, Inc. in the refinery study discussed in Chapter 14 – Chapter 16. AEC Engineering Inc. was not subcontracted for the analyses for glass in Chapter 12 and cement in Chapter 13.)

[12] SOx RECLAIM Study - Final Report – Module 3-E: Wet/Dry Scrubbing Technology for Cement Kilns and Coal-Fired Fluidized Bed Boiler, ETS, Inc., December 16, 2008.

Note: Baseline SO_x emissions used in calculations were from 2005 (SCAQMD database for the period from January 2005 – December 2005)"

13.2 Control Technology & Costs

To arrive at the conclusions presented above, ETS Inc. conducted an independent literature research on wet scrubbing (non-regenerative) and dry scrubbing control technologies. Sources for their literature research included Air Waste Management Association (AWMA), McIlvaine Co., U.S. EPA, Industrial Clean Air Companies (ICAC), Portland Cement Association (PCA), and Northeast States for Coordinated Air Use Management (NESCAUM). ETS, Inc. research confirmed the information provided by staff in Part I of Staff Report that scrubbing technology had been used to control SOx for existing as well as new cement kilns and coal fired boilers.

After the literature research, ETS Inc. contacted and asked sixteen (16) vendors in the field of wet/dry gas scrubbing to provide a budgetary equipment cost and estimated annual operating cost at the following three levels of performance:

1) Lowest achievable level of efficiency with guarantee
2) Next lowest achievable level of efficiency with guarantee, and
3) Most comfortable achievable efficiency with guarantee

For the vendors to size and estimate the costs associated with the control device, ETS, Inc. provided the vendors some of the following critical operational parameters:

	Kilns	*Coal-Fired Boiler*
Gas Flow Rate	*170,000 – 200,000 acfm*	*60,000 acfm*
Temperature	*275 °F*	*300 °F*
Inlet SOx Concentration	*5 ppmv – 25 ppmv* [13, 14]	*100 ppmv* [13]
Combustion fuel	*Coal, coke, oil, nat gas, and used tires*	*Coal*
Raw feed material	*Limestone, silica, and clay*	

The following four (4) vendors responded to ETS, Inc.'s request of information:

- Dustex
- BoldEco
- Monsanto Envirochem Systems (MECS)
- Solios

[13] ETS, Inc. reviewed several RATA tests for the two kilns and the cogen, and in addition, conducted a statistical analysis on the 2005 and 2008 CEMS data for the two kilns, and the 2001 CEMS data for the cogen, and determined that a range of SOx concentrations between 5 ppmv – 25 ppmv would reflect a reasonable range of SOx concentrations from the two kilns, and approximately 100 ppmv would reflect a reasonable range of SOx concentration from the coal-fired boiler. These ranges of concentrations were provided to the vendors for quotes and cost estimates.

[14] ETS, Inc. reported that "*In general, the vendors questioned the low SO_2 levels, stating that 200-400 ppm was more typical of long dry kiln operations. Several also indicated that before guaranteeing performance level, they would require pilot testing to confirm design information and to optimize operational parameters.*"

Three vendors proposed SOx emission control, submitted quotes, and performance claims for the cement kilns:

- The first vendor (Vendor C) proposed wet scrubbers using 20% NaOH solution to achieve 90% guaranteed control for the two kilns
- The second vendor (Vendor A) proposed a hybrid technology, a dry fluid bed scrubber (reaction tower) following by a pulse jet fabric filter, using hydrated lime (Ca(OH)2) as absorbent reagent to achieve 90% guaranteed reduction for SOx
- The third vendor (Vendor B) proposed two different approaches for emission control:
  - a moving bed reactor where the gas is contacted and absorbed on a bed of limestone granules (CaCO3) to achieve 95% reduction ; and
  - a hybrid technology including a reactor and a polished fabric filter using hydrated lime (Ca(OH)2) as absorbent reagent to achieve 85% reduction

Vendor	*Control Technology*	*Control Efficiency*	*SOx Outlet Concentration*
A	*Hybrid (reactor/scrubber/pulse-jet filter) using Ca(OH)2*	*90%*	*< 5 ppmv*
B	*Hybrid (reactor/scrubber/pulse-jet filter) using Ca(OH)2*	*85%*	*< 5 ppmv*
B	*Dry scrubber/reactor using limestone CaCO3*	*95%*	*< 5 ppmv*
C	*Wet scrubber using NaOH*	*90%*	*< 10 ppmv*

Four vendors proposed SOx emission control, submitted quotes, and performance claims for the coal-fired boilers:

- The first vendor (Manufacturer C) proposed wet scrubbers using NaOH solution to achieve 90% guaranteed control (<10 ppmv SOx)
- The second vendor (Vendor A) proposed a hybrid technology, a dry fluid bed scrubber (reaction tower) following by a pulse jet fabric filter, using hydrated lime (Ca(OH)2) as absorbent reagent to achieve 90% guaranteed reduction for SOx
- The third vendor (Vendor B) proposed two different approaches for emission control:
  - a moving bed reactor where the gas is contacted and absorbed on a bed of limestone granules (CaCO3) to achieve 95% reduction ; and
  - a hybrid technology including a reactor and a polished fabric filter using hydrated lime (Ca(OH)2) as absorbent reagent to achieve 80% reduction
- The fourth vendor (Vendor D) proposed a dry injection system utilizing a venturi reactor and sodium bicarbonate (NaHCO3) to achieve 95% removal efficiency.

Vendor	*Control Technology*	*Control Efficiency*	*SOx Outlet Concentration*
A	*Hybrid (reactor/scrubber/pulse-jet filter) using Ca(OH)2*	*90%*	*< 5 ppmv*
B	*Hybrid (reactor/scrubber/pulse-jet filter) using Ca(OH)2*	*80%*	*< 5 ppmv*
B	*Dry scrubber/reactor using limestone CaCO3*	*95%*	*< 5 ppmv*
C	*Wet scrubber using NaOH*	*90%*	*< 10 ppmv*
D	*Venturi reactor using NaHCO3*	*95%*	*< 5ppmv*

After carefully reviewing all the information collected from the literature research and submitted by the vendors, ETS Inc. concluded:

> *"Given the higher removal efficiency (95%), the Manufacturer B Dry Scrubber was selected as BARCT for the kilns."*
>
> *"Given the 95% removal efficiency, both the Manufacturer D Venturi Reactor & the Manufacturer B Scrubber can be considered BARCT for the coal-fired fluidized bed boiler."*

Regarding vendors' cost estimates, ETS Inc. indicated:

> *"…..they were asked to provide a budgetary cost estimate for the supply and installation of their equipment. The vendor was also requested to identify any utilities needed and their expected rate of usage. The vendor was also asked to identify the amount and type of waste generated by the process. If the vendor's approach was to modify or retrofit existing hardware, he was requested to supply a cost estimate for those activities. For example, if the proposed approach was that of dry or wet injection upstream of the baghouse, the proposal should have included an estimate for all required equipment hardware, reagent storage vessels, reagent feed control instrumentation, engineering, construction and installation, etc., as well as pre-engineering costs such as site testing activities to locate the reagent injection site to optimize system performance with respect to SO_2 control and reagent utilization.*"

The basis for equipment costs was different from each vendor. ETS, Inc. applied their engineering knowledge and judgment to reconcile all vendors' costs to the same basis. Regarding the capital costs, ETS Inc. included the following categories in estimating the costs:

"*Demolition and Decommissioning*
Civil/Concrete
Structural
Equipment
Piping & Mechanical
Electrical & Controls
Misc. Direct & Indirect Costs:
- *Contractor overhead and misc. rentals*
- *Contractor field supervision*
- *Mobilization/Demobilization*
- *Overtime/productivity factor*
- *Freight/shipping*
- *Sales Tax*
- *Commissioning and operating spares*
- *Start-up/initial fill material*
- *On-site training/start-up assistance*
- *FEED engineering through detailed design*
- *Project management"*

ETS, Inc. included the following categories in estimating the annual operating and maintenance costs:

> "*Annual Maintenance Costs*
> *Periodic Maintenance Costs*
> *Additional Operating Costs*
> *Utilities:*
> - *Natural Gas*
> - *Electricity*
> - *Water*
> - *Wastewater*
> - *Cooling Water*
> - *Compressed Air*
> - *Solid Waste Disposal*"

A list of assumptions used by ETS, Inc. for cost estimation was summarized by ETS, Inc. in Table 11 of the final report.

13.3 Emission Reductions & Cost Effectiveness

A summary of emission reductions, cost estimates, and cost effectiveness using 25-year life for a wet gas scrubber and 4% interest rate estimated by ETS, Inc. is shown below:

		Two Scrubbers for Two Kilns	*One Scrubber for a Coal-Fired Boiler*
2005 Baseline Emissions	*tpd*	*0.27*	*0.38(if operated)*
Emission Reductions	*tpd*	*0.25*	*0.36(if operated)*
Equipment Costs	*$ million*	*16.6*	*4.7*
Capital Costs	*$ million*	*19.6*	*6.1*
Annual Operating Costs	*$ million*	*1.5*	*0.39*
Present Worth Value (25-year life)	*$ million*	*43.7*	*12.6*
Cost Effectiveness Factor	*$ per ton*	*18,893*	*3,818*

ETS, Inc. did not estimate emission reductions and cost effectiveness associated with other levels of control (90% or 80%). ETS, Inc. indicated that:

> *"In considering a curve of cost-effectiveness versus level of control there are two considerations. Firstly, will the control device capital cost vary with improved efficiency and secondly, will the operating cost increase with increasing efficiency. Since the capital cost is driven largely by the gas volume and since the volume is essentially constant there is little if any change in the capital cost over the considered range of efficiencies. With respect to operating cost versus efficiency, in the case of limestone, while the utilization does increase with increasing efficiency, the cost of the limestone was low enough to minimize the impact of efficiency on cost. Thus the merit of plotting a curve of cost versus efficiency seemed of little value."*

13.4 Plot Space

The plot space needed for each hybrid dry limestone scrubber located upstream of the existing baghouse of the Portland cement kiln was estimated to be approximately 50 ft L x 40 ft W. ETS, Inc. conclusion on plot space availability was as follow:

> "*With the exception of moving some existing coal piles, there appears to be no limitation on available space for prospective equipment for additional SO_2 control on the two cement kilns. If necessary, the existing baghouses could be considered for technology approaches (such as spray drying) requiring a filter collector after the reaction vessel. In this scenario the baghouse would serve the dual purpose of particulate control and the dust cake (on the bags) would provide an additional site for the reaction of the reagent with the SO_x.*"

The plot space needed for the dry scrubber located upstream of the existing baghouse of the COGEN coal fired boiler was estimated to be approximately 10 ft L x 10 ft W. ETS, Inc. conclusion on plot space availability was as follow:

> "*……there appears to be no limited space for prospective equipment for additional SO_2 removal on the COGEN. In addition, if the physical integrity of the existing pulse jet baghouse is sound, it could probably be utilized in conjunction with some of the dry or semi-dry scrubbing technologies. This could be accomplished by replacing any malfunctioning components such as valves, timers, dampers, etc., and replacing the existing bag set with high efficiency PTFE membrane bags.*"

Project Timing

The consultant estimated that startup of the control equipment could occur 24 months after the project begins for both the cement kilns as well as the coal fired boiler.

Chapter 14 – ETS/AEC's Analysis for Fluid Catalytic Cracking Units

ETS, Inc. (John McKenna) [15,16] was awarded the contract to study the control technologies (wet/dry scrubbers) for FCCUs located at six refineries in the District. ETS, Inc. subcontracted a part of the study to AEC Engineering Inc.[17] The ETS/AEC's analysis and results for FCCUs are summarized in this chapter.

14.1 Recommended BARCT Levels

ETS, Inc.'s final conclusion in this study is that it is feasible and cost effective to reduce SOx emissions to a level of 5 ppmv or less using wet scrubbing with caustic solution for six refineries in the District. ETS's recommended the District to set **BARCT at 5 ppmv, approximately 2.32 lbs/thousand barrels feed, or 87% control, averaging across six FCCUs** in the District. ETS Inc. estimated total emission reductions from the 2005 baseline were 3.07 tpd at an average cost effectiveness of $24.6 K per ton SOx reduced. [18,19]

Excerpts from ETS Inc.'s study are presented below:

"The final estimates of SOx reductions for the Module 3A BARCT-designated measures are tabulated below:

Module 3A Forecasted SOx Reductions (tons/day) by Refinery

Refinery:	*1*	*2*	*3*	*4*	*5*	*6*	*Total*
Equipment Type FCCU	*0.58*	*0.19*	*0.28*	*0.20*	*0.87*	*0.94*	*3.07*

The following table gives a summary of the Module 3A cost effectiveness ratios by refinery following implementation of the respective measures selected by ETS/AEC:

Module 3A Cost Effectiveness ($/ton of SOx) by Refinery

Refinery:	*1*	*2*	*3*	*4*	*5*	*6*	*Avg. for All*
Equipment Type FCCU	*$14.4k*	*$76.2k*	*$36.6k*	*$42.1k*	*$11.6k*	*$12.8k*	*$24.6k*

[15] ETS, Inc. team in this project included John McKenna, Ph.D., Robert Kunz, Ph.D., P.E., James Turner, Ph.D., Christina Clark and Jeff Smith. The consultants' biographies are attached in Appendix II-B of this report.

[16] SOx RECLAIM Study - Final Report – Module 3-A: Wet/Dry Scrubbing Technology for Refinery Fluid Catalytic Cracking Units (FCCUs), Refinery Boilers/Heaters, and Refinery Sulfur Recovery Units (SRUs) and Tail Gas Treatment Processes, AEC Engineering Inc./ETS, Inc., April 20, 2009.

[17] AEC Engineering, Inc. team in this project included Tav Heistand, P.E., Kristie Williams, P.E., Jason Sowards, Jesse Pikturna, Ph.D., and Britton Miller, P.E.

[18] The estimated emission reductions 3.07 tpd were the reductions calculated from the 2005 baseline described in Part I of the Staff Report for all six FCCUs in the District. Note that this 3.07 tpd estimated reductions from ETS/AEC was not the same as the RTC reductions estimated in Part III of Staff Report for FCCUs.

[19] The cost effectiveness of $24.6 K is an average for five refineries. One refinery in the District already installed and has operated a wet gas scrubber to meet the particulate emission standards in Rule 1105.1, and this gas scrubber also meet the limeit of 5 ppmv proposed by ETS/AEC.

14.2 Control Technology & Costs

14.2.1 Control Technology

'To arrive at the conclusions presented above, ETS Inc. and AEC Engineering Inc. conducted an independent literature research on wet and dry scrubbing technologies including non-regenerative, regenerative, and sea water. After that, ETS/AEC contacted vendors for feasibility and cost information. As indicated by ETS/AEC:

> "*Insofar as the wet and dry gas scrubbing technologies are concerned, information provided by SCAQMD was very helpful in identifying some of the vendors that were considered in this study. Contact was made with all vendors listed in the SCAQMD preliminary report and a number of vendors that were not listed. After initial discussions with vendors, careful reviews of various resources were conducted: literature provided by vendors; the April 2008 Preliminary Draft Staff Report; in-house files; public domain articles and reports; and conversations with industry experts. At that point, five different technology providers were selected for detailed analysis of installation and operation economics…."*

The technologies and vendors that ETS/AEC concentrated for further analysis (e.g. costs) for FCCUs were:

- BELCO (non-regenerative wet gas scrubber)
- MECS (non-regenerative wet gas scrubber)
- Hamon (dry scrubber)
- Alstom (sea water scrubber)

Regarding BELCO technology, ETS/AEC stated that:

> "*BELCO (DuPont) has more than 65 EDV wet scrubbing systems in refineries, at least 61 of which are in FCCU applications and 156 EDV [20] wet scrubbing systems in other applications. BELCO also has examples of EDV applications for SRU/TGTU and refinery boilers and heaters (DuPont Power Point Presentation, 2008). In a letter sent to ETS from Nick Confuerto, Vice President, Technology, Sales & Marketing of BELCO, it was confirmed that the guaranteed SOx outlet concentration based on the refinery-specific information provided would be 5 ppmv. The EDV utilizes a Purge Treatment System to decrease the COD [21] and suspended solid content of the effluent. A clarifier is used to collect the solids and then they are filter-pressed and disposed. The oxidation is facilitated*

[20] EDV® is a trademark wet gas scrubber manufactured and supplied by BELCO (Dupont).

[21] COD stands for Chemical Oxygen Demand, a commonly used measurement for water quality. It measures the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrite. It is an indirect measurement of the organic compounds (microorganisms) that survive in the waste water samples.

in a tower with air forced through the effluent to convert all sulfites to sulfates. After these two steps the effluent is safely discharged to the waste water treatment plant."

Regarding MECS technology, ETS/AEC stated that:

"*….MECS developed their DynaWave technology in the 1970s and has over 300 installations worldwide (Kixmiller, 2008). Specific examples are two Sinclair oil refineries in Wyoming. According to a published paper titled, "DynaWave Wet Gas Scrubbing: A New Alternative for Claus Unit Tail Gas Clean-Up", written by Steven F. Meyer, Ed Juno, Nick Watts, and Cristina Kulczycki, each refinery installed a DynaWave scrubber for SRU/TGTU stack treatment. The results of stack testing was a 99.99% sulfur removal. The DynaWave mitigates the effluent COD by injecting air into the sump of the vessel in order to oxidize the sulfites. The sump is also designed to allow adequate retention time for the oxidation to take place. As a result, the effluent water can be discharged directly to the wastewater treatment plant, provided the COD levels are continuously monitored and maintained within an acceptable range. According to the paper, the COD at the Casper, WY refinery ranged between 50 and 150 mg/l.*"

Regarding dry scrubbing technology provided by Hamon, ETS/AEC stated that:

"*The dry scrubbing technology evaluated in this study is Hamon's. It was evaluated for both FCCU and heater and boiler applications. According to information on its website, Hamon FGD technologies are installed in twenty countries and treat over 65,000 MW of power generation capacity. Hamon also has a long standing relationship with refineries world wide with over 100 ESP installations on FCCUs. There is no example of a dry scrubber installation in a refinery. However, the level of experience in FGD and general refinery applications is adequate to describe the technology as field demonstrated. In an email sent to AEC, a Hamon Research employee quoted a 90+% removal efficiency for streams with 300-400 ppmv SOx. Because flue gases in the South Coast refineries are typically below this range, the removal percentage is expected to be below 90% in most cases. Typically, it is governed by the SOx outlet concentration, which is not forecasted to fall below 10 ppmv on a guaranteed basis. Hence, the removal percentage for Hamon's dry gas scrubber is application-specific in these refineries and generally will be below 90%. One additional consideration for all types of dry scrubbers is the issue of solids handling. The effluent gas will have considerable particulate matter that must be removed. Therefore it is necessary to install some type of an ESP or baghouse downstream from the scrubber. The solids handling equipment will need to collect both dry particulate matter from the scrubber and particulate from the FCC. This introduces additional complexity with respect to available plot space and capital expenditure.*"

After several months of technical analysis and couple weeks visiting the refineries, ETS/AEC concluded that wet gas scrubbing was an aged-old technology which should be very familiar to all six refineries in the District:

> *"One WGS vendor, Belco Technologies Corporation (BELCO), has provided a lengthy application list…, with contracts awarded on as many as sixty-one (61) FCCU units and two (2) fluid cokers. Total FCCU capacity treated by BELCO scrubbers is noted as 3,228,700 bbl/day. The concept of using a WGS on an FCCU should be familiar to four (4) of the six (6) refining companies operating the Los Angeles, CA area since they are listed as customers employing BELCO WGS technology on the FCCUs at their other refineries……….*
>
> *Another vendor of WGS technology, Exxon (Now ExxonMobil), has also developed WGS technology. It is used in their own refineries and at others under license…... As of 1999, they cite a total of fourteen (14) such installations. One of the Exxon papers …. pictures a number of FCCU scrubbers located in tight spots because the required plot space was not otherwise available, including a photograph of a creative solution in which the scrubber is mounted on stilts above a road."*

Regarding vendors' guarantee, ETS/AEC indicated that BELCO and MECS were willing to provide guarantee on 5 ppmv:

> *"BELCO has provided numerous wet gas scrubbers for FCCUs in the United States and on a worldwide basis. Based on that experience, BELCO has given a guarantee of 5 ppm SO_2 from a wet scrubber if installed on any of the FCCUs in the District. MECS DynaWave, with at least three installations on FCCU regenerator flue gas, will also guarantee 5 ppmv SO_2. BELCO has indicated that most of their units operate in the near zero ppm range, with the most recent performance test from one of these at a fraction of a ppm (corrected to 0% O_2)…."*

In addition, ETS/AEC cited one full-scale installation that they were aware of:

> *"…. The study team is aware of another full-scale wet gas scrubber operating on an FCCU in a petroleum refinery at an SO_2 emission level of 5 ppmv or less on a long-term basis."*

To be conservative in their BARCT recommendation, ETS/AEC recommended BARCT to be set at 5 ppmv. The vendors and ETS/AEC did not recommend lower levels just to avoid CEMS measurement uncertainty:

> *….. the recommended BARCT level for fluid catalytic cracking unit (FCCU) SOx emissions is 5 ppmv on a dry basis. This is derived from an achievable concentration when employing wet gas scrubbing (WGS), a proven technology demonstrated in practice on this type of emission source. It is believed that a lower outlet concentration is indeed possible. However, a lower concentration may not be reliably measurable because of unavoidable accumulated error in the source test reference methods and/or the permissible tolerance in continuous emission monitoring system (CEMS) measurements."*
>
> *"…After careful consideration of the various scrubbing approaches and review of the technical responses and guarantee statements offered by the suppliers of these technologies, it is the recommendation of the ETS team that non-regenerative wet scrubbing be considered on a purely technical basis as BARCT for the FCCUs, Refinery*

Boiler/Heaters, and SRU/TGTU processes under study in Module 3A, with an overall BARCT level of 5 ppmv."

14.2.2 Costs

To gather budgetary quotes from vendors on costs and sizing information, ETS/AEC provided the vendors important critical information (e.g. gas flow rate, inlet SOx concentration, flue gas temperature) for a generic scenario. ETS/AEC adjusted the vendors' quotes information to match each refinery specific conditions. ETS/AEC claimed that their approach would ultimately generate cost information within +/- 40% range of the expected actual costs. As ETS/AEC stated that:

"*The methodology and techniques utilized during this project in the sizing of equipment for a new application ….. are exactly those used in any engineering endeavor. First, of course, we obtained a full understanding of how the existing system is configured and operates; those things are known by means of the site visit, underlying industry knowledge, interviews of refinery personnel, refinery-submitted data and drawings, etc. The second step was to conceptualize how the equipment under consideration is to be installed. This step also includes identifying the performance parameters to be achieved. In doing so, we quantified the expected ranges of service and efficiency, so that an appropriate over-design allowance could be applied (the purpose of which is to ensure that the performance objectives will reliably be met even if the underlying process is running at one extreme or another of its normal range). Next, all the pertinent information was communicated to the equipment representative, usually for pricing determination, but sometimes also to confirm the sizing exercise. In all cases, evaluating specific technology options required eventual coordination with the manufacturer or licensor to get verification of critical assumptions and/or conclusions.*

Since the study encompassed multiple facilities and systems with widely different process flows and arrangements, and because, furthermore, there were several optional technologies looked at for each installation, the total collection of potential measures was extraordinarily large. Thus, it was impossible—in the timeframe available—to address every one of the individual cases with a full set of vendor inquiries. Instead, the team made use of generic, but representative budgetary quotations and published cost studies for the various technologies. Each such "reference point" (i.e., package cost and performance data for a prescribed process operating condition) was then used as a basis for extrapolation to other locations and design conditions. For a specific application, the key sizing criterion (typically the process throughput—e.g., SCFM of gas) is determined or calculated from the relevant operational data. Then, to generate the probable capital purchase cost ($PC), that criterion value (V) is divided by the comparable numerical capacity (Cr) from the "reference point" package. Using the baseline capital cost ($BCr) for that "reference point", the desired capital cost is mathematically calculated via a conventional power curve relationship:

$PC = $BCr x (V/Cr) ^ n
where n is an appropriate exponent between .5 and 1.0

This approach is commonly used in engineering studies, and has been widely described in reference books such as Marks Standard Handbook for Mechanical Engineers and Perry's Chemical Engineers' Handbook. For our studies, the exponent value, n, was normally assigned a value between 0.6 and 0.7, a range that historically has given good estimates for industrial equipment packages.

In so far as the pertinent sizing criteria were concerned, they were compared to nameplate duties for other, similar units for rough verification purposes. Also, input was sought directly from the manufacturers' representatives, as well as public domain literature and published case studies. In the end, the checking procedures employed by the team members helped us to achieve rough, budgetary purchase costs, knowing that any loss in precision in arriving at those costs would be adequately covered by the very broad overall cost ranges (i.e., +/- 40%) expected for the ultimate results."

Regarding estimates for capital costs, ETS/AEC indicated that:

"*AEC worked as closely as possible with the technology suppliers to gather the direct capital cost estimates for this project. (Where available, too, we compiled net installation costs which had been reported by the manufacturers for "reference points", as described in the preceding section. Those "turn-key" costs were used to check the built-up cost estimates assembled by the project team.) Also, we took advantage of our relevant and extensive corporate knowledge base for similar projects. Every valid method was employed to give the best possible output. (In addition, as mentioned in Section A, above, indirect costs for impacts to utilities and infrastructure were estimated and included.)....*

...Owing to the fact that all the cost estimating tasks were conducted in a very preliminary, conceptual fashion, the overall accuracy of the capital cost determinations is no better than +/- 40%. Considerable engineering study would be required to refine the cost estimates and arrive at narrower accuracy ranges."

Regarding annual operating costs, ETS/AEC explained their approach as follows:

"*Unit rates for the principal cost-incurring utilities were requested from the refineries at the outset of the study. In several cases, explicit values were provided in response to the requests; those values were used as reported to us. For all other instances, generic estimates—obtained from other work by AEC at various U.S. refineries—of the unit rates were utilized...*

…The majority of the suggested control technologies or upgrades include the need not only for additional utilities but also raw materials, such as a scrubbing agent or catalyst. Costs for those items were estimated through consultation with a technology supplier or in-house expert. The appropriate third party resource or corporate engineer(s) based the

quantity determinations on the specific characteristics of the technology under study. Once a quantity was determined, a local material cost was obtained for use in the calculations…

…Early in the project, AEC had requested from the refineries the average hourly costs for various labor classifications on typical capital projects. When plant-specific values were not provided, we used generic labor rates that are intended to reflect average fully-burdened costs for jobs inside a South Coast refinery

…The computation of chemical (such as NaOH) quantities used by the various measures, and the amounts of waste products generated by them, were very straightforward. In almost all instances, the manufacturers' literature provided guidelines and/or explicit case studies. That information was used via direct "scale-up" multipliers, based on the key parameter(s) involved..."

ETS/AEC applied their engineering knowledge and judgment to reconcile all vendors' costs to the same basis. Regarding the capital costs, ETS Inc. included the following categories in estimating the costs:

"*Demolition and decommissioning*
Civil/concrete
Structure
Equipment
Piping and Mechanical
Electrical and controls
Miscellaneous indirect costs include:
- *Contractor overhead, typically 8 % of direct field labor (DFL)*
- *Contractor field supervision, typically 12 % of DFL*
- *Mobilization/demobilization, typically 10 % of DFL*
- *Overtime/productivity factor, typically 12 % of DFL*
- *Freight and shipping, typically 8 %, of materials*
- *Sales tax, typically 7 % of materials*
- *Commissioning and operating spares, typically 5 % of materials*
- *Startup/initial fill material, typically 2 % of materials*
- *On-site training/startup assistance, depends on project*
- *Front-end engineering design, depends on project size*
- *Project management, depends on project size*
- *Design development allowance, 10% of total*
- *Contingency, 25-40% applied against the bottom-line capital cost estimate*"

ETS, Inc. included the following categories in estimating the annual operating and maintenance costs:

"*Annual Maintenance Costs*
Periodic Maintenance Costs
Additional Operating Costs
Utilities:
Natural Gas
Electricity
Water
Wastewater
Cooling Water
Compressed Air
Solid Waste Disposal"

A list of assumptions used by ETS/AEC for cost estimation was summarized in Table 4-1 of the ETS/AEC's final report for Module 3-A.

14.3 Emission Reductions & Cost Effectiveness

A summary of emission reductions, cost estimates, and cost effectiveness assuming 90% control (5ppmv), 25-year life for a wet gas scrubber, and 4% interest rate estimated by ETS/AEC is shown below:

SOx Reductions (tons/day) for FCCUs by Refinery (5 ppmv)

Refinery:	*1*	*2*	*3*	*4*	*5*	*6*	*Total*
Equipment FCCU	*0.58*	*0.19*	*0.28*	*0.20*	*0.87*	*0.94*	*3.07*

Cost Effectiveness ($/ton of SOx) for FCCUs by Refinery (5 ppmv)

Refinery:	*1*	*2*	*3*	*4*	*5*	*6*	*Avg. for All*
Equipment FCCU	*$14.4k*	*$76.2k*	*$36.6k*	*$42.1k*	*$11.6k*	*$12.8k*	*$24.6k*

In addition, ETS/AEC provided an estimate for the following emission reductions and cost effectiveness associated with the most stringent, but feasible level of control (98%) in Table A-3 and A-4 of their final report:

SOx Reductions (tons/day) for FCCUs by Refinery (98%)

Refinery:	*1*	*2*	*3*	*4*	*5*	*6*	*Total*
Equipment FCCU	*0.60*	*0.30*	*0.35*	*0.24*	*0.94*	*1.01*	*3.45*

Cost Effectiveness ($/ton of SOx) for FCCUs by Refinery (98%)

Refinery:	*1*	*2*	*3*	*4*	*5*	*6*	*Avg. for All*
Equipment FCCU	*$14.0k*	*$48.0k*	*$29.5k*	*$35.2k*	*$10.7k*	*$11.9k*	*$21.5k*

Regarding the average cost effectiveness, ETS/AEC indicated that:

> "*One refinery has already installed a wet gas scrubber on its FCCU regenerator…. the cost effectiveness ratio for this refinery was not included in any of the average cost effectiveness calculations.*"

14.4 Plot Space

ETS/AEC conducted an analysis for plot space at the refineries to accommodate the wet gas scrubber and its associated equipment (e.g. additional fan, waste water handling system, plume mitigation system), presented their analysis in the confidential portion of the report, and concluded that space was available at all five refineries for additional control:

> "*Wet gas scrubber equipment footprints and space requirements for the FCCUs and the SRU/TGTUs are shown in the confidential appendices for each refinery where measures have been selected. These specifications have been compared with the plot plans provided by the respective refineries, and where applicable, are presented in the costing workbooks*."

14.5 Project Timing

AEC/ETS estimated that startup of the control equipment could occur within 3 calendar years after the project begins:

> *"ETS believes that it is conceivable that ….emission reduction ….. can be achieved from the refineries implementing the commercially available measures described in this project within a construction time frame of approximately 3 calendar years or less following the completion of study designs and engineering."*

Chapter 15 – ETS/AEC's Analysis for SRU/Tail Gas Systems

15.1 Recommended BARCT Levels

Through the data provided to ETS/AEC by the refineries, there was one refinery regularly vented the flue gas to the atmosphere, and the remaining refineries treated or incinerated the tail gas from their SRU/TG systems. Because of this distinction in the refinery's operations, ETS divided their recommendations for SRU/TG into two areas: the first recommendation is for the uncombusted tail gas:

> *"For uncombusted tail gas, the limits of Subpart J (Ja), namely 10 ppm H2S and 300 ppm reduced sulfur species (total of H2S, COS, and CS2), should continue to apply. Refineries should be encouraged to reduce emissions so as to be able to vent rather than having to combust SRU / TGTU tail gas."*

The ETS's second recommendation for the combusted tail gas is as follows:

> *"For combusted / incinerated tail gas, 5 ppmv SOx @ 0% O2 should be defined as the overall BARCT level for all refineries, based on scrubbed flue gas, but permissible to achieve by whatever means possible. A level of 10 ppmv would allow a greater number of refineries to meet the overall BARCT level by the gas treatment methods of Module 2 without having to install a wet gas scrubber (Module 3A)"*

15.2 Control Technology & Costs

To arrive at the conclusions presented above, ETS Inc. and AEC Engineering Inc. conducted an independent literature research on wet and dry scrubbing technologies including non-regenerative and regenerative for Module 3A; and numerous technologies for Module 2 including expansion of Claus process, sub-dewpoint process, selective oxidation catalyst, TG-10 additives, and additional sulfur capture at the sulfur pit. After the literature search, ETS/AEC contacted vendors for feasibility and cost information.

The five technologies and vendors that ETS/AEC concentrated for further analysis (e.g. costs) for SRU/TG systems were:

- Lurgi (sub-dewpoint HydroSulfreen process)
- EmeraChem Power LLC (selective oxidation catalyst)
- Gas Spec (TG-10 additive)
- Cansolv & BELCO (regenerative wet gas scrubber)
- Tri-Mer (non-regenerative wet gas scrubber)

For Lurgi Hydrosulfreen process, ETS/AEC stated that:

> "*The HydroSulfreen process is an improvement on Lurgi's Sulfreen process. It adds a hydrolysis step to this process. There are over 45 Sulfreen processes in operation worldwide. In August of 2000, there were four HydroSulfreen plants licensed.*
>
> *The HydroSulfreen® process is typically used for treatment of tail gas from refineries. The effluent from an existing Claus plant is first treated in a hydrolysis reactor, where species such as SOx, CS_2, and COS are hydrolyzed to form H_2S. The effluent from the hydrolysis reactor is typically sent to the Sulfreen® process, which operates at temperatures lower than the dew point of sulfur. Operating the converters at these temperatures increases the conversion to elemental sulfur, thereby increasing the overall efficiency of the unit.*"

ETS/AEC estimated that the costs of conversion from normal Claus unit to HydroSulfreen were high and the cost effectiveness was in a range of $37,000 - $600,000 per ton of SOx reduced. This technology was not recommended by ETS/AEC at the final selection stage.

Regarding EmeraChem Power LLC's catalyst oxidation process, ETS/AEC stated that:

> "*EmeraChem ESx catalyst can capture multiple sulfur species, including SO_2, SO_3, and H_2S. In addition to sulfur capture, the catalyst will destroy CO, VOC, and Particulate Matter (PM_{10}). These units are typically used to treat combustion exhaust gases from incinerators, heaters, turbines and boilers.*
>
> *EmeraChem does not appear to have its ESx technology installed as a stand-alone SOx control technology at any refinery……EmeraChem has provided assurances that their technology works to reduce pollution in exhaust gases across many types of unit operations, including refinery processes, gas turbines, boilers, process heaters, and diesel engines."*

EmeraChem platinum catalysts can be used to treat tail gas that has or has not been incinerated. The tail gas that has not been incinerated must be heated to the temperatures where the ESx catalyst is active (minimum at 600^{o}F). ETS/AEC estimated that the cost effectiveness for Emerachem catalysts was in a range of $10,000 - $60,000 per ton of SOx reduced.

EmeraChem provided ETS/AEC a letter specifically stated the following performance guarantee:

"*EMx System Emission Concentration:*

Parameter		*Percent Removal*
NOx at Catalyst Outlet (EMx)	*< 2.0 ppmvd*	*92% guaranteed*
CO at Catalyst Outlet	*< 3.0 ppmvd*	*98% guaranteed*
SO2 at System Outlet	*3.85 ppmvd*	*98% guaranteed*
H2S at System Outlet	*0 ppmvd*	*98% guaranteed*

> *The catalyst warranty period is 5 years. Expected life of the catalysts is 10-15 years."*

Regarding TG-10 additives, ETS/AEC stated that:

> "*TG-10 can be added to tail gas treating amine systems. TG-10 is a proprietary amine mixture offered by INEOS Gas/Spec. It has been designed to be highly selective for H_2S. INEOS Gas/Spec has published data, comparing the capabilities of TG-10 and MDEA in actual tail gas plants…….For many reasons similar to those in fuel gas treating, the effectiveness ratios for TG-10 can appear to be quite attractive.*"

ETS/AEC estimated that the cost effectiveness for TG-10 additives was between $2,000 and $3,000 per ton of SOx reduced, however the potential of emission reductions was quite small 0.04 tpd - 0.07 tpd, and most of the refineries already used TG-10 in some fashion. Therefore, this measure was not recommended by ETS/AEC at the final selection stage.

Regarding Cansolv and BELCO regenerative wet gas scrubbing technology, ETS/AEC stated that:

> *"Regenerative wet gas scrubbing was studied as a potential measure to reduce emissions from the SRU/TGTUs. Two manufacturers were considered for RWGS: BELCO's Labsorb and Cansolv. Cansolv was chosen, in particular for SRU/TGTU stack treatment, because they had more experience with SRU/TGTU incinerator stack gas scrubbing."*

Regarding Tri-Mer non-regenerative wet gas scrubber, ETS/AEC stated that:

> "*Non-regenerative wet gas scrubbing of the sulfur plant tail gas was also studied (Tri-Mer's Cloud Chamber Technology). These units are typically less expensive to install than a regenerative system, but they consume large volumes of water and produce waste water. However, they are very effective at reducing SOx emissions."*

Tri-Mer provided ETS/AEC a guaranteed letter specifically stated the inlet parameters (gas volume and temperature) provided to Tri-Mer and the following statement of guarantee:

> *"With regard to the specifications provided to Tri-Mer by ETS Inc., based on the design conditions, Tri-Mer will guarantee ≤330 ppmv inlet SO2 to ≤1.0 ppmv outlet for SO2."*

ETS/AEC indicated with confidence:

> *"Guaranteed outlet SOx concentrations of 5 ppmv after scrubbing can be achieved, in the worst case at 95% SOx removal efficiency; in most cases, the required scrubbing efficiency for a 5-ppmv SOx outlet is considerably less. BELCO has demonstrated experience in scrubbing the SOx from incinerated sulfur plant tail gas as well.*

Besides wet scrubbing technology, ETS/AEC also indicated that flue gas treating techniques (e.g. EmeraChem) can possibly bring down the SOx to a level of 5 ppmv – 10 ppmv:

> *"…….it has been found possible in this study also to reduce SRU ppm SOx to the atmosphere by the gas treating techniques investigated. Those results are all below 10 ppmv, and in many cases below 5 ppmv"*

To gather budgetary quotes from vendors on costs and sizing information, ETS/AEC provided the vendors important critical information (e.g. gas flow rate, inlet SOx concentration, flue gas temperature) for a generic scenario. ETS/AEC adjusted the vendors' quotes information to match each refinery specific conditions. ETS/AEC claimed that their approach would ultimately generate cost information within +/- 40% range of the expected actual costs. Please refer to section 14.2 for further information on ETS/AEC's approach.

15.3 Emission Reductions & Cost Effectiveness

For three refineries (Refinery #1, #3 and #4), ETS/AEC recommended to implement the control technologies described in Module 2 report. For these three refineries, ETS/AEC estimated the following emission reductions (estimated from the 2005 actual emissions) and cost effectiveness:

SOx Reductions (tons/day) for SRU/TG by Refinery

Refinery:	*1*	*3*	*4*	*Total*
Equipment SRU/TG	*0.13*	*0.15*	*0.04*	*0.31*

Cost Effectiveness ($/ton of SOx) for SRU/TG by Refinery

Refinery:	*1*	*3*	*4*	*Avg. for All*
Equipment SRU/TG	*$22.4k*	*$12.9k*	*$54.7k*	*$21.9k*

For the remaining three refineries (Refinery #2, #5 and #6), ETS/AEC recommended to implement wet gas scrubbers described in Module 3A report. For these three refineries, ETS/AEC's recommendations for the emission reductions (estimated from the 2005 actual emissions) and cost effectiveness are as follows:

SOx Reductions (tons/day) for SRU/TG by Refinery

Refinery:	*2*	*5*	*6*	*Total*
Equipment SRU/TG	*0.17*	*0.06*	*0.29*	*0.52*

Cost Effectiveness ($/ton of SOx) for SRU/TG by Refinery

Refinery:	*2*	*5*	*6*	*Avg. for All*
Equipment SRU/TG	*$39.0k*	*$123.2k*	*$36.3k*	*$46.8k*

The overall estimates for emission reductions (estimated from the 2005 actual emission levels) and average cost effectiveness for six SRU/TG systems are as follows:

SOx Reductions (tons/day) for SRU/TG by Refinery

Refinery:	*1*	*2*	*3*	*4*	*5*	*6*	*Total*
Equipment SRU/TG	*0.13*	*0.17*	*0.15*	*0.04*	*0.06*	*0.29*	*0.83*

Cost Effectiveness ($/ton of SOx) for SRU/TG by Refinery

Refinery:	*1*	*2*	*3*	*4*	*5*	*6*	*Avg. for All*
Equipment SRU/TG	*$22.4k*	*$39.0k*	*$12.9k*	*$54.7k*	*$123k*	*$36.3k*	*$37.4k*

15.4 Plot Space

With plot space information estimated directly by the vendors, ETS/AEC conducted an analysis for plot space at the refineries to accommodate the wet gas scrubber and its associated equipment (e.g. additional fan, waste water handling system, plume mitigation system). Their analysis was included in the confidential portion of the reports. ETS/AEC concluded that space was available at all refineries for this type of control:

> "*Wet gas scrubber equipment footprints and space requirements for the FCCUs and the SRU/TGTUs are shown in the confidential appendices for each refinery where measures have been selected. These specifications have been compared with the plot plans provided by the respective refineries, and where applicable, are presented in the costing workbooks*."

15.5 Project Timing

AEC/ETS estimated that startup of the control equipment could occur within 3 calendar years after the project begins:

> *"ETS believes that it is conceivable that ….emission reduction ….. can be achieved from the refineries implementing the commercially available measures described in this project within a construction time frame of approximately 3 calendar years or less following the completion of study designs and engineering."*

Chapter 16 – ETS/AEC's Analysis for Refinery Boilers/Heaters

16.1 Recommended BARCT Levels

For refinery boilers/heaters, ETS/AEC studied the technologies for pre-treatment of fuel gas prior to combustion in Module 2, and the technologies for post-treatment of flue gas after combustion in Module 3A.

Regarding the pre-treatment of fuel gas prior to combustion, ETS/AEC stated that:

> *"the present value of 40 ppmv total sulfur in refinery fuel gas be retained as the Best Available Retrofit Control Technology (BARCT) level"*, and

Regarding the post-treatment of flue gas from boilers/heaters after combustion, ETS/AEC stated that:

> "*For the heaters and boilers, post-combustion emission control is often expensive due to the combination of the relatively low concentrations of SOx in flue gases and the division of the fuel gas stream among a number of heaters and boilers. Pre-combustion control, studied in Module 2, has been found to be more suitable for the majority of situations."*

ETS/AEC's conclusions on emission reductions (estimated from the 2005 actual emissions) and cost effectiveness for pre-treatment of fuel gas for boilers/heaters are:

> "*The measures recommended by AEC are the measures that gave the largest expected SOx reduction potential while also featuring the most reasonable cost effectiveness. The total overall emissions reduction is approximately 0.89 tons per day SOx.*
>
> *The overall cost effectiveness for refinery fuel gas, averaged over the commercially available measures that AEC recommended for the refineries in this study, is estimated to be $16,823 per ton SOx reduced. The study team estimates that any given cost effectiveness number has an expected range someplace within the band of -10% to +50%.*"

Since ETS/AEC does not recommend a new BARCT level for boilers/heaters, staff will not describe this portion of ETS/AEC analysis in details, however a summary is included in Appendix II-A of this report.

References – Part II

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AQMD, 2008-4. *South Coast Air Quality Management District – Contract# C09104 – Contract with Nexidea, Inc. – Evaluation of Emission Control Technologies for Further Reducing Sulfur Oxides Emissions from Stationary Sources in the SCAQMD's RECLAIM Program.* September 5, 2008.

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ETS, 2008-3. *SOx RECLAIM Study - Final Report – Module 3-D: Wet/Dry Scrubbing Technology for Container Glass Manufacturing Plant.* ETS, Inc. December 16, 2008.

ETS, 2008-4. *SOx RECLAIM Study - Final Report – Module 3-E: Wet/Dry Scrubbing Technology for Cement Kilns and Coal-Fired Fluidized Bed Boiler.* ETS, Inc. December 16, 2008.

TESORO, 2009.

Appendix II-A – Summary of Consultants' Recommended Control Technology & Costs

Type	Fluid Catalytic Cracking Units						
	Refinery 1	Refinery 2	Refinery 3	Refinery 4	Refinery 5	Refinery 6	Total Costs for FCCUs
Control Technology	WGS						
Number of Vendors Provided Quotes & Vendor's Names	3 Vendors: BELCO, Hamon, MECS	3 Vendors: BELCO, Hamon, MECS	4 Vendors: Belco, Hamon, MECS, Alstom	3 Vendors: BELCO, Hamon, MECS		3 Vendors: BELCO, Hamon, MECS	
Vendor Guarantee/Quote #1	BELCO <5ppmv	BELCO <5ppmv	BELCO <5ppmv	BELCO <5ppmv		BELCO <5ppmv	
Vendor Guarantee/Quote #2	MECS 5ppmv	MECS 5ppmv	MECS 5ppmv	MECS 5ppmv		MECS 5ppmv	
Inlet Parameters Provided for Costs & Sizing	Flow: 93 Kscfm; Temp:400-600F SOx: 54.8 ppmv	Flow: 225 Kscfm Temp: 560 ºF SOx: 11.5 ppmv	Flow: 145 Kscfm Temp: 539 ºF SOx: 20.7 ppmv	Flow:101 Kscfm Temp: 500 ºF SOx: 20.6 ppmv	Flow: 65 Kscfm Temp: 539 ºF SOx: 21.8 ppmv	Flow:158 Kscfm Temp: 545 ºF SOt: 54.7 ppmv	
Vendor for costs/sizing (note 1)	BELCO	BELCO	BELCO	BELCO	BELCO	BELCO	
Plot Space Estimated	35' L x 45' W	40' L x 50' W	40' L x 50' W	35' L x 45' W	30' L x 40' W	40' L x 50' W	
Equipment Cost ($ million)	21	39	29	24		34	**147**
Capital Cost ($ million)	60	101	78	66		90	**395**
Present Worth Value ($ million)	76	133	95	78		110	**493**

Appendix II-A (Continued)

Type	Sulfur Recovery Units/Tail Gas						
	Refinery 1	Refinery 2	Refinery 3	Refinery 4	Refinery 5	Refinery 6	Total Costs for SRU/TG
Control Technology	Emerachem	WGS	Emerachem	Emerachem	WGS	WGS	
Number of Vendors Provided Quotes & Vendor's Names	2 Vendors: Lurgi, Emerachem	3 Vendors: Lurgi, Cansolv, Tri-Mer	4 Vendors: Lurgi, Cansolv, Emerachem, Tri-Mer	2 Vendors: Lurgi, Emerachem	3 Vendors: Lurgi, Cansolv, Tri-Mer	4 Vendors: Lurgi, Cansolv, Gas Spec, Tri-Mer	
Vendor Guarantee/Quote #1	Emerachem: 3.85 ppmvd (95%)		Emerachem: 3.85 ppmvd (95%)	Emerachem: 3.85 ppmvd (95%)			
Vendor Guarantee/Quote #2		Tri-Mer: ≤ 1.0 ppmv	Tri-Mer: ≤ 1.0 ppmv		Tri-Mer: ≤ 1.0 ppmv	Tri-Mer: ≤ 1.0 ppmv	
Inlet Parameters Provided for Costs & Sizing	Flow: 109.8 Klb/hr Temp: 600-700 ºF SOx: xx ppmvd	Flow:180.6 Kacfm Temp: 1000 ºF SOx: xx ppmv	Flow: 109.8 Klb/hr Temp: 600-700 ºF SOx: xx ppmvd	Flow: 109.8 Klb/hr Temp: 600-700 ºF SOx: xx ppmvd	Flow: 48.5 Kacfm Temp: 1000 ºF SOx: xx ppmv	Flow: 117.9Kacfm Temp: 1000 ºF SOx: xx ppmv	
Vendor for costs/sizing (note 1)	Emerachem	Tri-Mer	Emerachem	Emerachem	Tri-Mer	Tri-Mer	
Plot Space Estimated	25' L x 100' W	88.5' L x 67' W	25' L x 100' W	25' L x 100' W	29.5' L x 67' W (2 units required)	59' L x 67' W (2 units required)	
Equipment Cost ($ million)	4	14	5	4	15	20	**61**
Capital Cost ($ million)	13	38	13	11	39	51	**164**
Present Worth Value ($ million)	26	60	17	19	64	97	**282**

Appendix II-A (Continued)

Type	Refinery Boilers/Heaters		
	Refinery 1	Refinery 2	Refinery 3
Control Technology	FGT	FGT	FGT
Number of Vendors Provided Quotes & Vendor's Names	2 Vendors: Shell Sulfinol, Gas Spec	2 Vendors: Shell Sulfinol, UOP	1 Vendor: Shell Sulfinol
Vendor Guarantee/Quote #1	Sulfinol: 59% total SOx removal	Sulfinol: 0.2% total SOx removal	Sulfinol removal of non-H2S sulfur: 85%, 56%Total SOx reduction
Vendor Guarantee/Quote #2		UOP Merox removal of non-H2S ethyl- and methyl-mercaptans: 93% ethyl-mercaptan, 80% methly-mercaptan; 91%Total SOx reduction	
Inlet Parameters Provided for Costs & Sizing	Flow: 821,000 scfh, Temp: not available, SOx inlet: 42.48 ppmv	Flow: 3 MMscfd, Temp: not available, SOx inlet (total mercaptans): 300 ppmv	Flow: 9.6 MMscfd for H2S absorber #5 and 20.2 MMscfd for H2S absorber #6, Temp: 100 ºF, SOx inlet (combined): 5 ppmv for H2S and 20 ppmv for non-H2S species
Vendor for costs/sizing (note 1)	Gas Spec	UOP	Shell
Plot Space Estimated	Small plot space required	UOP: 40' L x 150' W	Small plot space required
Equipment Cost ($ million)	0.2	5	5
Capital Cost ($ million)	0.5	16	12
Present Worth Value ($ million)	1.4	20	15

Appendix II-A (Continued)

Type	Refinery Boilers/Heaters			Total Costs for B/H
	Refinery 4	Refinery 5	Refinery 6	
Control Technology	FGT	FGT	FGT	
Number of Vendors Provided Quotes & Vendor's Names	2 Vendors: Shell Sulfinol, UOP	2 Vendors: Shell Sulfinol, UOP	2 Vendors: Shell, UOP	
Vendor Guarantee/Quote #1	Sulfinol: 97% or 5 ppmv, 54%Total SOx reduction	Sulfinol removal for Wilmington: 85% removal for non-H2S sulfur in fuel gas , 68.4%Total SOx reduction	Sulfinol removal: 88%Mercaptans, 31%COS, 11%Total SOx reduction	
Vendor Guarantee/Quote #2	UOP Merox: 47.6% total SOx reduction	UOP Merox removal of Carson non-H2S ethyl- and methyl-mercaptans (191.4 ppmv of total): 93% ethyl-mercaptan, 80% methly-mercaptan; 90%Total SOx reduction	UOP Merox: 7.8% total SOx reduction	
Inlet Parameters Provided for Costs & Sizing	Flow: 19,059 MMscf/yr, Temp: 100 ºF, SOx inlet: 146 ppmv	Location A--> Flow:14 MMscfd, Temp:100 ºF, SOx: 50 ppmv. Location B--> Flow:20 MMscfd, Temp:not available, SOx: 200 ppmv	Flow: 42.4 MMscfd, Temp: 100 ºF, SOx: not available	
Vendor for costs/sizing (note 1)	Shell	Shell + UOP	Shell	
Plot Space Estimated	Small plot space required	Shell:small plot space required for Location A. UOP: 40' Lx150' W for Location B	Small plot space required	
Equipment Cost ($ million)	5	21	9	**44**
Capital Cost ($ million)	13	53	23	**116**
Present Worth Value ($ million)	16	64	21	**136**

Appendix II-A (Continued)

Type	Coke Calciner		Sulfuric Acid Plant			
	Fac C	Total Costs for Calciner	Fac A	Fac A	Fac B	Total Costs for SAP
Control Technology	WGS		Equip Modification	WGS	WGS	
Number of Vendors Provided Quotes & Vendor's Names	4 Vendors: BELCO, Tri-Mer, MECS, Cansolv		4 Vendors: BELCO, Tri-Mer, MECS, Cansolv	4 Vendors: BELCO, Tri-Mer, MECS, Cansolv	4 Vendors: BELCO, Tri-Mer, MECS, Cansolv	
Vendor Guarantee/Quote #1	MECS: <10 ppmv, expected <5 ppmv		MECS: <10 ppmv, expected <5 ppmv	MECS: <10 ppmv, expected <5 ppmv	MECS: <10 ppmv, expected <5 ppmv	
Vendor Guarantee/Quote #2	***BELCO: <10 ppmv, <5ppmv is achievable with existing scrubbers***		BELCO: <10 ppmv, <5ppmv is achievable with existing scrubbers	***BELCO: <10 ppmv, <5ppmv is achievable with existing scrubbers***	***BELCO: <10 ppmv, <5ppmv is achievable with existing scrubbers***	
Inlet Parameters Provided for Costs & Sizing	Flow: 205,000 acfm Temp: 405 oF SOx inlet: 50 ppmv		Flow: 27,383 acfm Temp: 86 oF SOx inlet: 20 ppmv	Flow: 27,383 acfm Temp: 86 oF SOx inlet: 20 ppmv	Flow: 70,000 acfm Temp: 134 oF SOx inlet: 145 ppmv	
Vendor for costs/sizing (note 1)	BELCO (Note 2)		Cansolv (Note 3)	BELCO (Note 4)	BELCO (Note 4)	
Plot Space Estimated	30' L x 40' W		No plot space needed	15' L x 20' W	20' L x 25' W	
Equipment Cost ($ million)	8.2	**8.2**	0.5	2.3	4.9	**7.2**
Capital Cost ($ million)	13.3	**13.3**	0.5	3.1	6.6	**9.7**
Present Worth Value ($ million)	25.3	**25.3**	1.7	8.0	17.3	**25.3**

Appendix II-A (Continued)

Type	Glass Plant	Total Costs for Glass	Cement Plant		Total Costs for Cement	TOTAL COSTS
Control Technology	WGS		Limestone Absorber	DGS or Limestone Absorber		
Number of Vendors Provided Quotes & Vendor's Names	4 Vendors: Tri-Mer (NWGS), MECS (NWGS), McGill (NWGS), Dustex (DGS), PPC (Process Mod)		3 Vendors: MECS (NWGS), BoldEco (Limestone Absorber), BoldEco (Hybrid DGS + Baghouse), Dustex (Hybrid DGS + Baghouse)	4 Vendors: MECS (NWGS), BoldEco (Limestone Absorber), BoldEco (Hybrid DGS+Baghouse), Dustex (Hybrid DGS+Baghouse), Solios		
Vendor Guarantee/Quote #1	MECS: 90% (<10 ppmv)		MECS: 90% (<10 ppmv)	MECS: 90% (<10 ppmv)		
Vendor Guarantee/Quote #2	McGill: 95% (5 ppmv)		***BoldEco Limestone Absorber: 95% (<2 ppmv)***	***BoldEco Limestone Absorber: 95% (5 ppmv)***		
Inlet Parameters Provided for Costs & Sizing	Flow: 30,000 - 60,000 acfm Temp: 650 - 675 oF SOx inlet: 100 ppmv		Flow: 170,000 - 203,000 acfm Temp: 275 oF SOx inlet: 25 ppmv	Flow: 60,000 acfm Temp: 275 oF SOx inlet: 100 ppmv		
Vendor for costs/sizing (note 1)	Tri-Mer		BoldEco	BoldEco		
Plot Space Estimated	32' L x 10' W		50' L x 40' W	Solios:10' Diax71' H Boldeco:35' Diax35' H		
Equipment Cost ($ million)	1.1	**1.1**	16.6	4.7	**21.3**	**290**
Capital Cost ($ million)	1.9	**1.9**	19.6	6.1	**25.7**	**726**
Present Worth Value ($ million)	8.8	**8.8**	43.7	12.6	**56.3**	**1,027**

Appendix II-B – Consultants' Biographies

This section includes the biographies of the consultants. Staff will add more in a near future.

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EDUCATION

1966 BS CHEMICAL ENGINEERING-CLEMSON UNIVERSITY

1968 MS CHEMICAL ENGINEERING- GEORGIA TECH

1994 EXECUTIVE MBA-CLAREMONT GRADUATE UNIVERSITY

Mr. Bell has a very strong background in refining and power technologies, and in plant operations and management. He has 41 years of refining and power experience, covering activities ranging from research and development to refinery operations and maintenance work; and has held the position of General Manager of Refining for a prototype heavy crude refinery. During his tenure as General Manager, the refinery achieved record levels of profitability, safety and environmental compliance. Mr. Bell provided much of the strategic planning for Conoco/Phillip's Wilmington Refinery, and helped develop and bring to the market several new refining technologies. He is currently President of Carson Industrial Steam Company, and is developing a large residual oil-fired cogeneration complex in southern California. Mr. Bell recently completed a three-year assignment as Owner's Engineer on a world-scale gasification project in North America.

EXPERIENCE

Mr. Bell's most recent job in refining was as Process Manager for Conoco/Phillips Petroleum Company's Wilmington, California refinery. While in this position, Mr. Bell worked as part of a project team assessing the technical and economic merits of building an 8,000 TPD IGCC plant at the refinery. He helped set the design basis, evaluated potential gasification technologies and assisted in developing the plant layout and coke handling systems. He also advised the development team on ways to maximize project returns, and on ways of meeting the very stringent air emission standards. During his tenure at this refinery, Mr. Bell helped develop, design and build the most sophisticated flue gas SO2 removal system in the refining industry. He also developed a novel approach to cracking jet fuel at low pressure to produce California-grade gasoline and isobutane.

Mr. Bell was previously Technology Manager for Petroleum Refining for Black & Veatch Pritchard (BVPI) in Overland Park, Kansas. In this role, he was responsible for all aspects of petroleum refining and petrochemical technologies. He assisted the Power Division in assessing the viability of several direct-fired and IGCC power projects, and spent considerable time with the Power Group doing business development, both in the U.S. and overseas. Mr. Bell was involved in the training of engineers from major oil companies in the basics of power production using various technologies.

After leaving Conoco/Phillips, Mr. Bell began development of a 600 MWeq petroleum coke-fired cogeneration project in the Los Angeles basin. The project will burn petroleum coke in an ultra-supercritical steam boiler to generate power and process steam, while meeting the most stringent air quality standards in the world. The project will have the capability of removing 90 per cent of the CO_2 in the boiler flue gas at less than $50 per tonne cost.

Mr. Bell also recently completed a three-year assignment as Owner's Engineer on a world-scale gasification project for a fertilizer plant in North America. The plant will gasify up to 15,000 TPD of coal or pet coke to make syngas for an IGCC unit, plus hydrogen for an ammonia/urea complex. Mr. Bell created the physical and economic model of the facility, as well as a pro forma model for various feedstocks and product offtakes. He provided novel ways of reducing capital and operating costs for the project, while increasing plant throughput.

Prior to joining BVPI, Mr. Bell was Product Line Manager for Refining for Brown and Root Braun in Alhambra, California. In this position, he was responsible for the basic designs of refining and petrochemical units, and the proper execution of process designs on refining projects. Mr. Bell's previous assignment with Brown and Root Braun was as Chief Process Engineer, where he supervised approximately 75 Process Engineers on numerous refining, petrochemical, ammonia and ethylene studies and projects.

Prior to joining Brown and Root, Mr. Bell was General Manager of Refining for Ultramar Refining Company's 75,000 BPD heavy crude refinery in Wilmington, California. Under his guidance, the refinery established the best refinery environmental record in the Los Angeles basin, and one of the best safety records in the refining industry. Mr. Bell also held Operations Manager and Technical Manager position with Champlin Petroleum Company, the predecessor to Ultramar at the Wilmington plant.

Prior to joining Champlin, Mr. Bell held a number of engineering and management positions with Chevron in their Richmond and El Segundo, California facilities, and was involved with two major expansions of both refineries.

Mr. Bell's first industrial job was as a Technical Services and Operations Engineer with Shell Chemical Company in Martinez, California.

ROBERT G. KUNZ, PH.D.

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OBJECTIVE

Continuing participation in trend-setting environmental control activities utilizing proven strengths in planning, organization, analysis, and formulation of strategy to reduce costs, develop technology, and prevent downtime.

BACKGROUND SUMMARY

Professional with over 40 years experience and a consistent track record of completing projects on spec, on time, and on budget. Areas of accomplishments include leadership, negotiation skills, problem solving, and the ability to correlate diverse facts. Excellent communicator with the talent to instruct, train, and mentor others.

Earned both Ph.D. and M.B.A. degrees. Published technical author including book, journal articles, presentations, and one patent. Experienced team leader. Skills range from management to research and development, with awards received in both areas.

Expertise in petroleum refining and chemical / gas plants:

- Air emission control and testing
- Cooling water treatment and corrosion control
- Processes including fluid catalytic cracking
- Wastewater treatment
- Noise generation, control, and measurement
- Environmental permitting

SELECTED ACCOMPLISHMENTS

- Designed, built, and operated a pioneering pilot SO_2 and particulate flue-gas scrubber on fluid catalytic cracker (FCC) regenerator, allowing installation of full-scale scrubber at oil refinery to meet new air quality regulations.

- Led a team to respond quickly to pinpoint source of excessive particulate emissions from electrostatic precipitator treating cat cracker regenerator flue gas and others at California oil refinery.

- Co-authored U.S. patent while serving on elite task force to identify high-cost and missing technology necessary to comply with increasingly stringent environmental regulations in the refining industry.

- Over a 15-yr period, managed engineering group and supervised a team of environmental professionals responsible for negotiating environmental approvals needed for construction of new plants / projects. No capital project was ever delayed by failure to obtain permits in a timely manner.

- Served as member of "SWAT" team in discretionary siting of new $20M - $30M industrial gas plants to identify any fatal flaws which might prevent, delay, or jeopardize plant construction or unduly increase the cost.

- Supported sales of hydrogen gas to petroleum industry by providing expertise in environmental regulatory compliance.

- Developed a correlation to predict hydrogen reformer furnace NOx emissions (later extended to ethylene plants). Presented results at industry conferences and in the technical literature.

- Secured permits for and field-tested selective catalytic reduction (SCR) units, a post-combustion NOx control technique, located at / adjacent to several refineries / chemical plants. Published findings in *Journal of the Air & Waste Management Association.*

- Developed procedure for forecasting SCR catalyst life to prevent untimely shutdown of operations, presented at a petroleum industry conference and published in the literature (*Environmental Progress*).

- Presented technical paper on the successful application of SCR to FCC units at multiple locations. This presentation at a petroleum industry conference was co-authored by the SCR system manufacturer and a representative of a U.S refinery.

- Directed multi-location environmental site assessment for $65M acquisition, which was completed on schedule and at less than 50% of budget, allowing timely acquisition of new product line.

- Formulated the "Kunz Equation," which correlates system pH from alkalinity measurements in over 100 cooling towers to allow independent cooling water calculations, used as objective criteria to evaluate vendor proposals. These procedures were published in *Chemical Engineering* magazine and are now taught in college classrooms.

- Received Harrison Prescott Eddy Medal, a prestigious award given annually by the Water Pollution Control Federation, for noteworthy research in wastewater treatment.

PROFESSIONAL EXPERIENCE

RGK ENVIRONMENTAL CONSULTING, L.L.C., **Hillsborough, NC** 2003-Present
Independent Consultant / Author

CORMETECH, INC. ENVIRONMENTAL TECHNOLOGIES**, Durham, NC** 2001-2003
Technical Project Manager

AIR PRODUCTS AND CHEMICALS, INC.**, Allentown, PA** **1974-2000**
Senior Engineer / Manager / Senior Engineering Associate

1968-1974
ESSO RESEARCH AND ENGINEERING COMPANY**, Florham Park, NJ**
Engineer / Project Engineer

MILITARY SERVICE

Lieutenant, United States Air Force **-** Honorably separated from Active Duty and transferred to Retired Reserve.

Received Certificate of Outstanding Achievement from United States 17th Air Force for Communications Cost Reduction and Management Improvement Programs at conclusion of final assignment.

EDUCATION

Ph.D., Chemical Engineering, Rensselaer Polytechnic Institute, Troy, NY
M.B.A.., Executive Program, Temple University, Philadelphia, PA
M.S., Environmental Engineering, Newark College of Engineering, Newark, NJ
B.Ch.E. (with honors), Chemical Engineering, Manhattan College, Bronx, NY

Additional college courses in Psychology, Economics, Accounting, and Marketing

PROFESSIONAL LICENCES

Registered Professional Engineer NJ, PA, AL, TX, LA
Former Certified Community Noise Measurement Specialist, NJ

PROFESSIONAL ASSOCIATIONS

American Institute of Chemical Engineers (AIChE)
American Chemical Society (ACS)
Air & Waste Management Association (A&WMA)
Sigma Xi **-** The Scientific Research Society

JOHN D. MCKENNA
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EDUCATION

B.S.Ch.E. - Manhattan College - 1961
M.S.Ch.E. - New Jersey Institute of Technology - 1968
M.B.A. - Rider University - 1974
Ph.D. - Walden University - 1991

Doctoral Thesis Topic: A Study of Factors Underlying Growth for Industrial Firms During Their Early Years After Startup

Master Thesis Topic: The Effect of Nitrilotriacetic Acid Upon the Biodegradability of Synthetic Detergents

Certified On-line Trainer - Walden University - 2000

EXPERIENCE

Dr. McKenna has over forty years of technical and business management experience. His background includes a wide range of entrepreneurial activities including the start-up of six environmental firms, one of which he took public. His direct experience includes corporate acquisitions and mergers as well as the invention and commercialization of a flue gas desulphurization (FGD) system. In light of the weak USA market conditions, an office was established in Taiwan and thereby the initial FGD system sales were achieved. In 1996, ETS International Inc. was listed in "The Nations Fastest Growing Technology Companies," having recorded a 5-year revenue growth of 542%. In addition to business and technical management experience, he has also been providing international training for over 30 years. Currently he is a principal of ETS Inc. He has taught online business and environmental courses for the University of Phoenix.

2002-2007 Co-chair Southampton Corp
A private venture capital firm specializing in the environmental industry.

2002-2006 University of Phoenix
Teaching on-line: Management, Marketing, Environmental Ethics, Environmental Science

1999-present Principal ETS Inc.
A provider of environmental training, testing, troubleshooting and testimony.

Chairman/President, ETS International, Inc.
Responsible for general management and long range planning functions.
Program Manager – FGD (LEC) – Full Scale Commercial Systems.

President, ETS, Inc., June 1979 to June 1988.
Responsible for general management and R&D strategic planning/priorities
Program Manager – Pilot Plant FGD (LEC) Semi-Dry System.

President, January l, 1978 to June 1979.
Enviro-Systems & Research, Inc. and Environmental Testing Services, Inc. Director '72-'82.

Vice President, Enviro-Systems & Research.
Directed all application engineering, research and development related to air and water pollution control. Concentration of effort on fabric filters, mechanical collectors and scrubbers for a wide variety of industrial applications. Program manager for million dollar EPA contract.

1968-72 Research Cottrell, Projects Director of Environmental Systems Division.
Supervised the development of RC's wet limestone scrubber for SO_2 removal FGD Pilot Plant and first RC full scale FGD system at Arizona Public Service. Responsible for execution of all projects and laboratory activities for both air and water pollution control, including in-house research and development and industrial and EPA R&D contracts. Supervised technical services which encompassed stack and stream sampling, laboratory analytical determinations, bench analysis, pilot plant fabrication and research. Major R&D efforts, oriented to particulate control and SO_2 removal. Consulting included comprehensive pollution control studies for complete industrial plants.

1967-68 Princeton Chemical Research, Project Leader.
Assigned to execute industrial and government contracts for water and air pollution control, including a NAPCA contract concerned with SO_2 control by catalytic reduction.

1964-67 Eldib Engineering & Research, Inc., Technical Assistant to the President.
Senior Engineer for pollution control problem solving. Investigated industrial wastewater, municipal sewage and industrial air pollution problems.

PROFESSIONAL ACTIVITIES

Air and Waste Management Association Technical Council – AE Chair 2002-2005
Virginia Environmental Business Council – Board of Directors 2000-2004
Air and Waste Management Association Technical Program – Chairman, Specialty Conference Fabric Filter VII 1994
Air and Waste Management Association South Atlantic Section – Board of Directors 1993-1996
Virginia State Advisory Board of Air Pollution – 1992 Vice Chair, 1993 Chair
Advisory Board Member: Wiley Series in Chemical Engineering
Air and Waste Management Association Technical Program – Chairman, Specialty Conference Fabric Filter VI 1992
Technical Program Committee, Scientific Evaluation of the National Acid Precipitation Assessment Program's (NAPAP), Final Report – 1991
Technical Advisory Committee, Ohio Air Quality Development Authority (OAQDA) – 1991
Air and Waste Management Association Emission Control Technology - Division Chairman, 1988-1991
Air and Waste Management Association Technical Program – Chairman, Specialty Conference Fabric Filter V 1990
NSF Consultant for the College Faculty Workshop Program-Grant
EPA Fabric Filter Workshop Lecturer
Scientific Reviewer for EPA Publications
AIChE - Central VA Section – Chairman 1980-84
APCA Lecturer "Particulate Control Device Cost Optimization"
Member of National Association of Environmental Professionals
EPA Course 413 Lecturer, "Fabric Filters and Selection and Cost of Control Equipment." – Presented at Rutgers University, March 18-19, 1987.

LISTINGS AND AWARDS

Distinguished Alumni Medal for Outstanding Achievement - New Jersey Institute of Technology

Manhattan College School of Engineering Centennial Award - Outstanding Engineering Graduate

New York Xi, Chapter of Tau Beta Pi, National Honor Society of Engineering - Eminent Engineer

Fellow -- American Institute of Chemical Engineers
Fellow – Air and Waste Management Association.
Who's Who in Engineering
Who's Who Environmental Registry
Who's Who in Finance and Industry
Who's Who in Technology Today
Who's Who in the World
Who's Who in Science and Engineering
Appointed by VA Governor G. Allen 97-01 World Trade Alliance of the Blue Ridge

COMMUNITY ACTIVITIES

Chairman, Roanoke Catholic School Board, 1984-1986
Roanoke Memorial Hospital Pastoral Care Visitor 1988-1992

TRAINING COURSES DELIVERED

Domestic
Fine Particle Emission Measurement & Control
Toxic Air Pollutants - Prevention and Control
Particulate Emission Control Cost Optimization
Introduction to Air Pollution Control
Introduction to Water Pollution Control
Incineration
Regulatory and Permitting Policies
Particulate Emission Control
Gaseous Emission Control
Baghouse Operation and Maintenance
Project Costs and Financing
Project Management
Public Involvement in Large-Scale Development Projects with Significant Environmental Impacts - AED/USAID for Russian Group
Pollutant Release and Transfer Registers Program - AED/USAID for Ukrainian Group

Foreign
Developing and Implementing Emission Inventories - Saudi Arabia/SABIC
Energy and the Environment - Univ. of La Laguna - Canary Islands
Baghouse Technology - National Taiwan University - Taipei, Taiwan
Air Pollution Technology Workshop - Floreanopolis, Brazil - IIE/USAEP
Methods of Effective Environmental PR - AED/USAID Kazakhstan
National Park Management Capacity Building - AED/USAID Armenia

PROJECT MANAGEMENT EXPERIENCE

John D. McKenna has gained comprehensive technical project management experience over the past 40 years.

In 1967-1968, while at Princeton Chemical Research, Dr. McKenna was the Program Manager of a research project funded by the National Air Pollution Control Agency (NAPCA) to evaluate SO_2 control by catalytic reduction.

While at Research Cottrell, during 1968-1972, he was the Program Manager on an EPA/HEW project which dealt with the design, installation, operation and testing of a wet scrubbing pilot plant for SO_2 control. Managed pilot wet scrubber FGD testing at AEP (Tidd Station) and RC's first full scale SO_2 FGD system at Arizona Public Service (Cholla Station).

During this time, he was also the technical manager of a program funded by Research Cottrell to acquire and develop the RC/Bacho system for SO_2 removal.

In 1973, Dr. McKenna was the Program Manager of EPA 68-02-1093. The purpose of this ETS contract was to conduct a preliminary techno-economic evaluation of the application of fabric filters to coal-fired industrial boilers. The success of this project led to a larger scale demonstration program (EPA 68-02-2148) and a subsequent follow on program (EPA 68-02-3674) both managed by Dr. McKenna.

In 1976, he managed a program to install, operate and test a fabric filter pilot plant on the slipstream of a refuse-fired boiler. The study, EPA R804223, was initiated to determine if a fabric filter was a viable control alternative for this application.

In 1981, Dr. McKenna managed an ETS contract received from EPA Region 5 (EPA task order 116) to execute an air pollution control engineering study. The purpose of this study was to settle a dispute between a federal agency and state government. In this effort, ETS technical personnel successfully executed 12 major tasks both within budget and on schedule.

In 1982, he managed a major ETS environmental engineering contract funded by the Government of Mexico. The program objectives were to design and specify a continuous ambient monitoring network for a developing industrial port and surrounding residential towns on the west coast of Mexico. Not only did the program involve the management of ETS technical personnel, but also the coordination of activities between ETS and several consulting subcontractors, Mexican authorities and various Mexican industrial representatives.

In 1983, ETS received a contract (EPA 68-02-3649) to characterize the performance of fabric filters on three large utility boilers. This program not only demonstrated the field testing and other technical capabilities of ETS, but also Dr. McKenna's program management abilities since two major subcontractors were involved (RTI and TRC) and field teams of over 20 engineers, scientists and technicians were mobilized.

In 1985, he was the ETS manager in a program in which ETS was subcontractor to Malcolm Pirnie. The program was funded by the Power Authority of the State of New York (PASNY). The purpose was to evaluate the techno-economic feasibility of applying fabric filtration and dry scrubbing to control MSW emissions. The major outputs of the study included capital and operating costs estimates and recommended design specifications for the subject control techniques.

Dr. McKenna has managed an ETS program funded by the Ohio Coal Development Office. The program initiated in 1987, evaluates an approach to control acid rain precursors. In this program, he has been responsible for the coordination of all activities between ETS and the prime contractor, Ohio University.

In the 1990s managed EPA Contract No. 68D20029, "Source Testing and Method Evaluation for Stationary Source Emissions."

From 1998 to present via an ETS subcontract from RTI, he has been the manager of the Air Pollution Control Technology (APCT) Business and Marketing Planning activity for EPA's Environmental Technology Verification Program (EPA Coop. Agreement CR826152-01-0). He has also provided the coordination and technical support of the APCT's Baghouse Filtration Products (BFP) Verification Program. This activity includes the preparation of generic protocols and test Q/A plans, review and coordination of recommended modifications to existing generic protocols and test Q/A plans, and continued review and commentary of the BFP verification process.

In 2008-2009 Dr. McKenna managed an ETS contract received from the South Coast Air Quality Management District (SCAQMD) for the evaluation of emission control technologies for further reducing sulfur oxide emissions from stationary sources in the SCAQMD's RECLAIM program. The purpose was to identify the Best Available Retrofit Control Technologies (BARCT) that could be implemented within the 2011-2014 timeframe to help South Coast Basin attain the PM2.5 ambient air quality standards. The industries covered included refineries, cement manufacturing, and container glass manufacturing.

PUBLICATIONS – TEXTBOOKS

McKenna, John D.; Turner, James H.; "Fabric Filter - Baghouses I Theory, Design, and Selection." Published in 1989, ETS, Inc., Roanoke, VA.

Mycock, John C.; McKenna, John D.; Theodore, L.; "Handbook of Air Pollution Control Engineering and Technology" Published by Lewis Publishers, 1995.

McKenna, John D.; Turner, James H.; McKenna, James P., "Fine Particle (2.5 Microns) Emission Regulations, Measurement and Control" Published by John Wiley & Sons Inc., 2008

PUBLICATIONS – TEXTBOOK CHAPTERS

McKenna, John D.; Greiner, Gary P.; "Air Pollution Control Equipment: Operation and Maintenance"; Chapter 8: "Baghouses" - Published in 1982, Prentice Hall, Englewood Cliff, NJ. Ed. Theodore & Buonicore.

Turner, J.H.; McKenna, J.D.; "Control of Particles by Filters", Chapter in Air Pollution Technology Handbook, Seymour Calvert, ed. John Wiley & Sons, Inc., 1984.

Turner, J.H.; Lawless, P.A.; Yamamoto, T.; Coy, D.W.; Greiner, G.P.; McKenna, J.D.; Vatavuk, W.M; "Electrostatic Precipitators," Chapter 3 in Air Pollution Engineering Manual, Van Nostrand Reinhold, New York, NY, Ed. by Buonicore, A.J. and Davis, W.T., 1992.

McKenna, J.D.; Furlong, D.A.; "Fabric Filters," Chapter 3 in Air Pollution Engineering Manual, Van Nostrand Reinhold, New York, NY, Ed. by Buonicore, A.J. and Davis, W.T., 1992.

Mc Kenna, John D. "Air Pollution Management of Stationary Sources" Section 25 in Perry's Chemical Engineer's Handbook, Seventh Edition, Mc Graw-Hill, NYC, 1997

PUBLICATIONS – ARTICLES AND PRESENTATIONS

McKenna, J.D.; Eldib, I.A.; New Markets for Chemicals and Equipment to Combat Pollution. Presented at Farleigh Dickinson University Summer Conference, "The Demands of Pollution Control Legislation", August 22-26, 1966. Cited in C&EN 44, 37 (Sept. 4, 1966).

M.S. Thesis: The Effect of Nitrilotriacetic Acid Upon the Biodegradability of Linear Alkylbenzene Sulfonate (1968).

McKenna, J.D.; Evaluation of a Two-Stage Particulate Scrubber and Gas Absorber Applied to Power Plant Flue Gas. Presented at the NAPCA International Symposium on Wet Limestone Scrubbing, Pensacola, FL, March 16-20, 1970.

McKenna, J.D.; Atkins, R.S.; The RC/BAHCO System for Removal of Sulfur Oxides and Fly Ash from Flue Gases, Power Engineering, May 1972, pp. 50-52. Presented at the

Second International Lime-Lime-Stone-Wet Scrubbing Symposium, New Orleans, LA,
Nov. 8-12, 1971.

McKenna, J.D.; The International Competitiveness of the U.S. Air Pollution Control Industry. Presented at the International Air Pollution Control and Noise Abatement Exhibition, Jonkoping, Sweden, September 1971.

Gleason, R.J.; McKenna, J.D.; Scrubbing of Sulfur Dioxide From a Power Plant Flue Gas. Presented at the 69th National Meeting of the American Institute of Chemical Engineers, Cincinnati, OH, May 16-19, 1971.

Roberts, R.M.; et al; Systems Evaluation of Refuse as a Low Sulfur Fuel, November 1971, EPA Contract CPA 22-69-22.

McKenna, J.D.; Coy, D.W.; Techno-Economic Selection in Times of Changing Costs and Performance Requirements. Published in the Proceedings of the Fifth Annual Northeast Regional Anti-Pollution Conference, University of Rhode Island, July 1972.

McKenna, J.D.; Applying Fabric Filtration to Coal-Fired Industrial Boilers. Environmental Protection Technology Series, July 1974,
EPA-650/2-74-058.

McKenna, J.D.; Mycock, J.C.; Lipscomb, W.O.; Performance and Cost Comparisons Between Fabric Filters and Alternate Particulate Control Techniques. Presented at the symposium on the

"Use of Fabric Filters for the Control of Submicron Particulates", 4/8/74, Boston, MA. Sponsored by the Environmental Protection Agency and GCA Corporation.

McKenna, J.D.; Weisberg, R.; A Pilot Scale Investigation of Fabric Filtration as Applied to Coal Fired Industrial Boilers. Published in the Proceedings of the Fourth Annual Industrial Air Pollution Control Conference, University of Tennessee, March 28, 1974, Knoxville, TN.

McKenna, J.D.; The Application of Fabric Filter Dust Collectors to Coal-Fired Boilers. Presented at the Fourth Annual Environmental Engineering & Science Conference, Louisville, KY, March 4, 1974.

Theodore, L.; et al; Selected Problems in Design of Air Pollution Equipment. National Science Foundation, August 1975, NTIS PB 246-363 (Contributing consultant).

McKenna, J.D.; Mycock, J.C.; Lipscomb, W.O.; Applying Fabric Filtration to Coal-Fired Industrial Boilers: A Pilot Scale Investigation. EPA Technical Services, August 1975, EPA 650/2-74-058a.

McKenna, J.D.; and Brandt, K.D.; Demonstration of a High Velocity Fabric Filtration System Used to Control Fly Ash Emissions. Presented at The Third Symposium on Fabric Filters for Particle Collection, Tucson, AZ, December 1977.

McKenna, J.D.; Greiner, G.P.; Brandt, K.D.; Applying High Velocity Fabric Filters to Coal-Fired Industrial Boilers. Presented at the Symposium on the Transfer and Utilization of Particulate Control Technology, sponsored by the U.S. Environmental Protection Agency at the University of Denver, Denver, CO, July 24-28, 1978.

McKenna, J.D.; Mycock, J.C.; Miller, R.L.; Brandt, K.D.; Applying Fabric Filtration to Refuse-Fired Boilers: A Pilot-Scale Investigation. EPA Contract No. R804223, May 1978, Office of Energy, Minerals and Industry, U.S. Environmental Protection Agency, EPA-600/7-78-078.

McKenna, J.D.; Mycock, J.C.; Brandt, K.D.; Szalay, J.F.; Assessment of a High Velocity Fabric Filtration System used to Control Fly Ash Emissions. Annual Report for Contract No. 68-02-2148 for the U.S. Environmental Protection Agency, April 1979.

Richardson, J.W.; McKenna, J.D.; Mycock, J.C.; An Evaluation of Full Scale Fabric Filters on Utility Boilers**.** Presented at the Fourth Symposium on the Transfer and Utilization of Particulate Control Technology, Houston, TX, October 11-15, 1982.

Beachler D.S.; Richardson, J.W.; McKenna, J.D.; Mycock, J.C.; ETS, Inc., and Harmon, D., EPA - Emission Reduction Performance and Operating Characteristics of a Baghouse Installed on a Coal-Fired Power Plant, August 1984, EPA Contract 68-02-3649.

McKenna, J.D., Ross, J.M., Foster, J.M., Gibson, R.A., Continued Assessment of a High-Velocity Fabric Filtration System Used to Control Fly Ash Emissions, EPA-600/7-84-037, March 1984.

McKenna, J.D., Ross, J.M.; What One Small Environmental Firm Requires of Its Chemists. Presented at the 62nd Annual Meeting of American Institute of Chemists, Hollywood, Florida, April 1985.

Richardson, J.W., McKenna, J.D., Mycock, J.C., Evaluation of Full Scale Fabric Filters on Utility Boilers: SPS Harrington Station Unit 3, NTIS PB85-235513/WEP, July 1985.

Richardson, J.W., McKenna, J.D., Mycock, J.C., Evaluation of Full Scale Fabric Filters on Utility Boilers: PP and L Brunner Island Station Unit 1, NTIS PB85-235521/WEP, July 1985.

Mycock, J.C., McKenna, J.D., Richardson, J.W., Baghouse Troubleshooting - A Case History. Presented at the Professional Development Conference - Developments in Filtration Technology, Clemson University, May 14-15, 1986.

Greiner, G.P., Smith, J.K., Ross, J.M., McKenna, J.D., Demonstration, Operation, and Testing of a Fabric Filter on an Industrial Boiler for an Extended Period of Time, EPA-600/7-86-030, September, 1986.

McKenna, J.D., Haley, L.H., Industrial Fabric Filter Bag Test Methods: Usefulness and Limitations. Presented at the ASTM Symposium on Gas and Liquid Filtration, Philadelphia, PA, October 20-22, 1986.

McKenna, J.D., Furlong, D.A., Baghouses As Applied to Municipal Solid Waste Incinerators. Presented at Filtration Technology Conference in Clemson, SC, April 15-16, 1987.

Kapner, M., Schwarz, S., McKenna, J., An Evaluation of Alternate Emission Control Systems for Refuse-to-Energy Plants. Presented at the 80th Annual Meeting of APCA, New York, NY, June 21-26, 1987.

Turner, J.H.; Viner, A.S.; Jenkins, R.E.; Vatavuk, W.M.; McKenna, J.D.; Sizing and Costing of Fabric Filters, JAPCA September, 1987 issue, Volume 37, Number 9, Page 1105.

Turner, J.H.; Lawless, P.A.; Yamamoto, T.; Coy, D.W.; Greiner, G.P.; McKenna, J.D.; Vatavuk, W.M.; Sizing and Costing of Electrostatic Precipitators, JAPCA April, 1988 issue, Volume 38, Number 4.

McKenna, J.D.; Toxic Particulate Control. Presented at the EPA Workshop on Hazardous and Toxic Air Pollutant Control Technologies and Permitting Issues, Raleigh, NC, March 22-23, 1988 and San Francisco, CA, April 12-13, 1988.

Bahner, Mark A. and John D. McKenna; Inlet-Precharged Limestone Emission Control (LEC). Presented at the American Filtration Society Annual Meeting - Fine Particle Filtration & Separation, Minneapolis, MN, April 22-24, 1991.

Prudich, M.E.; Reddy S. N.; McKenna, J.D.; Appell, K.W.; A Pilot Demonstration of the Moving-Bed Limestone Emission control (LEC) Process. Paper presented at the 1991

EPRI/EPA/DOE SO_2 Control Symposium, Washington, DC, December 306, 1991. Also presented at the 85th Annual Meeting and Exhibition of the AWMA, Kansas City, MO, June 21-26, 1992.

McKenna, J.D.; Energy and the Environment. Presented to graduate students at LaLaguna University, Tenerife Island, Spain, November 8, 9, 10, 1993.

Prudich, M.D.; Appell, K.W.; McKenna, J.D.; Pilot-Scale Limestone Emission Control (LEC) Process: A Development Project. Final Report - March 1994.

McKenna, J.D.; Mycock, J.C.; Fabric Filter Baghouse Seminar. Presented at National Taiwan University, Taipei, Taiwan, R.O.C., October 12, 13, 14, 1994.

Mc Kenna, J.D.: ETS, Inc. 1st International Cleanable Filter Symposium: Status of EPA's Baghouse Filtration Products / Environmental Technology Verification Program. Chiba-Ken, Japan. The Association of Powder Process Industry and Engineering, Japan (APPIE) November 15, 2000.

Mc Kenna, J.D. :ETS, Inc. 2nd International Cleanable Filter Symposium: Baghouse Filtration Products Verification Status Report. Osaka, Japan. The Association of Powder Process Industry and Engineering, Japan (APPIE) October 29, 2001.

Mc Kenna, J.D.; Mycock, J.C.; Practical Implications of ETV for Fine Particle Control, The Air & Waste Association Annual Meeting June 23, 2004

McKenna, J. D.: A New Tool for Improving Control of Fine Particle Emissions. Institute of Electrical and Electronics Engineers, Roanoke Va. September 21, 2006

McKenna, J. D.: Filter Media Selection for Coal Fired Plants, McIlvaine Company Hot Topic Hour October 16, 2008

WORKSHOPS

Drexel University, 2001 Olin Workshop On The Environment, Philadelphia, PA "Environmental Technology for Particulate Emission Control"

Rheinhold Environmental 2002 ESP/FF Roundtable & Expo, Dallas, TX "Fabric Filter Application & Selection"

PETROBRAS 2007 Seminar on Atmospheric Emissions, Rio de Janeiro, Brazil "Air Shed Management PM10/PM2.5/0zone"

END OF DOCUMENT