

Best Available Technology for Air Pollution Control: Analysis Guidance and Case Studies for North America

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List of Acronyms

ASTM	American Society for Testing and Materials
BAT/BACT	best available technology / best available control technology
Btu	British thermal unit(s)
CAT	Caterpillar™
CATC	Clean Air Technology Center
CFR	Code of Federal Regulations
cfm	cubic feet per minute
CO	carbon monoxide
CO ₂	carbon dioxide
EGR	exhaust gas recirculation
EPA	(US) Environmental Protection Agency
ESP	electrostatic precipitator
FGR	flue gas recalculation
FGD	flue gas desulfurization
HAP	hazardous air pollutant
hp	horsepower
kW	kilowatt
LAER	lowest achievable emission rate
LNB	low-NO _x burner
MACT	Maximum Achievable Control Technology program
NAA	Non-attainment Area program
NAAQS	National Ambient Air Quality Standards
NEET	New and Emerging Environmental Technologies
NESHAP	National Emission Standards for Hazardous Air Pollutants
NMHC	non-methane hydrocarbon
NO _x	nitrogen oxides
NSCR	non-selective catalytic reduction
NSR	New Source Review program
NSPS	New Source Performance Standards program
OFA	overfire air
PM	particulate matter
ppm	parts per million
PSD	Prevention of Significant Deterioration program
RACT	reasonably available control technology
RBLC	RACT, BACT, LAER Clearinghouse
SCR	selective catalytic reduction
SNCR	selective non-catalytic reduction
SO ₂	sulfur dioxide
SO _x	sulfur oxides
TDF	tire-derived fuel
THC	total hydrocarbons
tpy	tons per year
TTN	Technology Transfer Network

UHC	unburned hydrocarbons
ULSD	ultra-low sulfur diesel
VOC	volatile organic compound

1.0 Introduction

This best available technologies (BAT) analysis guidance manual has been prepared for North American regulatory air quality specialists. The document provides a step-by-step explanation of the BAT analysis process used in the US and includes three case studies, for: 1) stationary reciprocating engines, 2) residual oil-fired power plants, and 3) cement kilns fired by used tires.

This guidance manual details each step in the BAT analysis process used for stationary source air permitting by the US EPA. In addition to explaining the general principle of each step, the manual illustrates the steps by using the three specific case studies as examples. The BAT analysis steps begin with the identification of each feasible emission control device for a particular emission source and then proceed to an assessment of environmental, energy and economic impacts of each feasible control option as a means to determine the best option.

This BAT guidance manual explains how to use key information resources, such as EPA's RACT, BACT, LAER Clearinghouse (RBLC). Also, this manual presents techniques for acquiring information from US states that may not available in the RBLC. Other sources of emission control technology information are listed, such as equipment vendors, trade associations, EPA publications and existing regulatory standards (i.e., new source performance standards [NSPS] under 40 CFR 60, and maximum achievable control technology [MACT] standards under 40 CFR 63).

The economic impact aspect of the BAT analysis includes specific cost analysis spreadsheets developed from the guidelines given in the *EPA Air Pollution Control Cost Manual* (EPA 452/B-02-001),¹ with an explanation of the key input factors. A listing of informational resources for other source categories is provided, including a list of web site addresses for technology review documents from vendors as well as a compendium of emission control trade associations.

Ultimately, the outcome of a BAT analysis is the determination of an emission rate that can be achieved. There may be a specific type of emission control device that is identified by the BAT analysis, but the resulting emission rate is, ultimately, the regulatory requirement within an issued permit. As such, a BAT analysis is done on a case-by-case basis. While industry may not appreciate that the target for BAT is constantly changing, this fact enables the regulatory agencies to push technological advances in emission controls over time.

In the US, the requirement to perform a BAT analysis is part of the construction permitting approval process. It is incumbent upon the regulatory permit reviewer to understand emission control technologies in order to objectively evaluate the BAT analysis submitted by an applicant.

¹ Available at: <<http://www.epa.gov/ttn/catc/products.html#cccinfo>>

Note: All monetary amounts quoted in this document are in US dollars.

2.0 Background

The following provides insight into how the US EPA has incorporated BAT analysis into its regulatory requirements.

2.1 New Source Review Permitting

In the US there are federal regulations termed “new source permitting” that require a new major source (or an existing major facility undertaking major modification) to obtain pre-approval under the New Source Review (NSR) program before commencing construction of an air pollution source. The federal requirements vary for different areas of the country depending on whether the air quality in the area complies with the National Ambient Air Quality Standards (NAAQS). Areas designated, as being in attainment will be required to adhere to the requirements under the Prevention of Significant Deterioration (PSD) program. Areas that are designated as being non-attainment will be required to adhere to stricter requirements under the Non-attainment Area (NAA) program.

2.1.1 Prevention of Significant Deterioration Permitting

Prevention of Significant Deterioration (PSD) program permitting requires that an applicant analyze all technically feasible emission control alternatives and demonstrate that the emission rate(s) proposed is reflective of the best available control technology (BACT). A BACT analysis evaluates each emission control alternative relative to energy, environmental and economic impacts. The procedure is called a top-down BACT, meaning that the lowest possible emission rate must be considered first. The control technique with the lowest emission rate may only be dropped from consideration if there are legitimate energy, environmental or economic reasons. If so, the emission control technique with the next lowest emission rate may then be considered. The progression continues until an emission rate is identified as BACT. Another PSD requirement is to evaluate the projected impact of the new emissions on the existing ambient air levels in order to show that the attainment area will not fall into non-attainment.

2.1.2 Non-attainment Area Permitting

Non-attainment Area (NAA) program permitting requires that an applicant analyze all technically feasible emission control alternatives and demonstrate that the emission rate(s) proposed is reflective of the lowest achievable emission rate (LAER). A LAER analysis is essentially the same as a BACT analysis, except that economic factors are not considered. As with the BACT analysis, a LAER analysis follows a top-down procedure, but only evaluating energy and environmental factors. A further NAA requirement is to purchase emission offset credits such that there is a net decrease of emissions to the non-attainment area.

2.2 State Implementation Plans

While the federal permitting requirements are applicable to major new sources, or major modifications to existing major sources, each state may have its own construction permitting program for smaller sources of air pollution. Many of the US states have

added the requirement for BACT to their construction permitting requirements for minor sources. For existing sources, in states located in non-attainment areas, EPA requires that a state implement regulations mandating improved emission controls in order to bring the area into attainment. The emission control level for existing sources is called “reasonably available control technology” (RACT). Attainment is re-evaluated each year through ambient monitoring. If attainment is not achieved, the state will lower its RACT limits.

2.3 Construction Permitting

As stated above, most states have their own construction permitting regulations for sources that are below the level of applicability of the federal New Source Review (NSR) program. In many states, the construction permitting requirements incorporate the use of BACT to enable the permit reviewer to push for improved emission control (lower emissions) on a case-by-case basis.

3.0 Procedures for BAT Implementation

There are several factors to consider when choosing which emission control option is the best available technology (BAT). From an environmental perspective, the best option is the one that minimizes the total emission levels of the pollutant considered. However, use of the most effective pollution control option is not always feasible because of the economic, energy, environmental or technical impacts that it might impose. Therefore, a top-down process is used to determine which technology or process would be most suitable for each specific application. This method is relatively fast and simple, and is easily repeatable for all pollutants and all sources under consideration. This section describes this process in detail.

The threshold level of emissions to trigger a BAT analysis in the US is either a new major source (100 to 250 tons per year [tpy]) or a major modification to an existing major source (10 to 50 tpy increase). Some states implement the BAT process for approval of a new process with emission increases greater than 1 tpy.

3.1 Step 1: Identify Possible Control Technologies

The first step in a top-down analysis is to identify all available control options. Available options are those air pollution control technologies or techniques with a practical potential for application to the emission unit and the pollutant under evaluation. Air pollution control technologies and techniques include the application of production processes or available methods, systems, and techniques, including fuel cleaning or treatment or innovative fuel combustion techniques, for control of the affected pollutant. This includes technologies used elsewhere in the world. Technologies required under LAER determinations are available for BACT purposes and must also be included as control alternatives and usually represent the top alternative.

3.2 Step 2: Eliminate Infeasible Options

In the second step, the technical feasibility of the control options identified in step one is evaluated with respect to the source-specific (or emissions unit-specific) factors. Demonstration that an option is not technically feasible should be clearly documented and should show, based on physical, chemical, and engineering principles, that technical difficulties would preclude the successful use of the control option. Control options that are not technically feasible are then eliminated from further consideration in the BACT analysis.

3.3 Step 3: Sort and Rank Feasible Options

In step 3, all remaining control alternatives not eliminated in step 2 are ranked and listed in order of over-all control effectiveness for the pollutant under review, with the most effective control alternative at the top. A list should be prepared for each pollutant and for each emission unit (or grouping of similar units) subject to a BACT analysis. The list should present an array of control technology alternatives and should include the following types of information:

- emission reductions (percent pollutant removed);
- expected emission rate (tons per year, pounds per hour);
- energy impacts;
- environmental impacts (includes any significant or unusual other media impacts, such as water or solid waste, and affect on toxic or hazardous air contaminants);
- economic impacts (cost effectiveness).

An applicant proposing the top control alternative need not provide cost and other detailed information in regard to other control options. In such cases the applicant should document to the satisfaction of the review agency that the control option chosen is, indeed, the top.

3.4 Step 4: Evaluate Most Effective Option

After identification of available and technically feasible control technology options, the associated energy, environmental, and economic factors are evaluated in order to arrive at the final level of control. At this point the analysis presents the associated impacts of the control option in the listing. For each option, the applicant is responsible for presenting an objective evaluation of each impact. Both beneficial and adverse impacts should be discussed and, where possible, quantified. In general, the BACT analysis should focus on the direct impact of the control alternative.

If the applicant accepts the top alternative in the listing as BACT and there are no outstanding issues regarding collateral environmental impacts, the analysis has ended and the results are proposed as BACT. In the event that the control candidate is shown to be inappropriate, due to energy, environmental or economic impacts, the rationale for this finding should be documented. Then, the next most stringent alternative in the listing becomes the new control candidate and is similarly evaluated. This process continues until the technology under consideration cannot be eliminated by any source-specific environmental, energy, or economic impacts which demonstrate that option to be inappropriate as BACT.

The economic impact tends to be the most direct factor, as environmental and energy issues can often be overcome by more expensive systems. The determination of what is economically feasible is a subjective, case-by-case assessment by the regulatory agency. The objective is to establish an acceptable level of cost impact. As such, the cost impact (dollars per ton per year of emissions reduced) determined to be economically feasible can simply be the value that another similar process operation agreed to spend.

In the US, controls for nitrogen oxides (NO_x) have been deemed economically affordable at levels of \$10,000 to \$15,000 per tpy. Sulfur dioxide (SO₂) controls are less costly, and economic feasibility may be in the \$1,000 to \$3,000 per tpy range.

3.5 Step 5: Select BACT

At this point, there should be one option that has been chosen as the best available, feasible emission reduction option. There should also be significant documentation available to support this decision. This decision, along with all the pertinent documentation that led to it, is then submitted to an environmental official for review. Ultimately, the reviewer makes the decision as to which control option is the best and most reasonable. This process is then repeated for each pollutant and each process of interest. Examples of this process can be found in the case studies presented in **Sections 7 through 9**.

It is important to note that the level of control deemed BAT is a moving target. As emission control technologies improve and/or cost impacts decrease, the emission rates deemed BAT will gradually go down, which is the objective of the program. As an example, gas turbines had a new source performance standard several years ago of 65 parts per million (ppm) NO_x. With improvements to the combustion technology, turbines were able to meet 42 ppm. Then, with the use of water and/or steam injection, turbines were able to meet 9 ppm. The advancement of selective catalytic reduction (SCR) post-combustion NO_x controls now has gas turbines in the US being required to meet a BAT level as low as 2 ppm.

4.0 RBLC Overview

The US Environmental Protection Agency (EPA) maintains a publicly available database that is a compilation of emission control techniques that have been approved as RACT, BACT or LAER during a stationary source permitting process. The database is called the RACT, BACT, LAER Clearinghouse (RBLC). The RBLC database is accessible via EPA's web site, at its Clean Air Technology Center (CATC) on its Technology Transfer Network (TTN), at <www.epa.gov/ttn/catc>. This section describes the layout of the site, and gives insight into how to efficiently use the RBLC to search for past projects, their target emission rates and the technologies or practices that each facility used to achieve attainment. Words or phrases that are scripted in bold indicate active links on the RBLC webpage.

The RBLC has four search levels, from basic to advanced, and contains a **Reference Library** with links to other technical information and a **Tool Box** with links to software tools to aid in a BAT analysis. The search capabilities include:

- **Basic Search**, which is the easiest to use;
- **Find Lowest Emission Rate**, which produces a basic search result automatically arranged by emission rate (currently only available for combustion sources);
- **Standard Search**, which allows any combination of 24 search criteria; and
- **Advanced Search**, which can be used for a more complex search.

Currently the RBLC compiles over 5,184 facilities, with over 13,378 processes. However, the input to the database is a voluntary effort by states. As such, it may not have a record of every BACT determination in the US. Also, delays to the data input process can result in as much as a yearlong lag time for the newest determinations. With any BACT determination entered, there is a state contact identified to allow for the request of additional information.

Table 1 provides an example of a search conducted on the RBLC using the **Lowest Emission Rate** search function. The specific search is for industrial-size boilers, fired by residual oil, for NO_x emissions. The date range requested was the past four years (2000–2004). **Table 2** provides an illustration of the additional facility and emission control information available by clicking on **RBLC ID**. Other key information is the state contact person (usually the permitting engineer responsible for the BACT determination). **Table 3** provides an illustration of the additional pollutant information available by clicking on **Standard Emission Limit**. This information includes a description of the control technique being proposed.

Table 1 Ranking Report for Search Criteria from RBLC

Pollutant: NOx
 Process Category: Industrial-Size Boilers/Furnaces (more than 100 million Btu/hr, up to/including 250 million Btu/hr)
 Process Type: 12.210
 Process Name: Residual Fuel Oil (ASTM # 4,5,6)
 Permit Date between 12/15/2000 and 12/15/2004

RBLC ID	PERMIT DATE	CORPORATE/COMPANY NAME & FACILITY NAME	STANDARD EMISSION LIMIT
<input type="checkbox"/>			
<input checked="" type="checkbox"/> NC-0092	05/10/2001	INTERNATIONAL PAPER COMPANY RIEGELWOOD MILL	0.3670 LB/MMBTU
<input checked="" type="checkbox"/> VA-0270	03/31/2003	VIRGINIA COMMONWEALTH UNIVERSITY VCU EAST PLANT	0.4000 LB/MMBTU
<input checked="" type="checkbox"/> VA-0278	03/31/2003	Virginia Commonwealth University VCU EAST PLANT	0.4000 LB/MMBTU
<input checked="" type="checkbox"/> OR-0031	03/02/2001	POPE & TALBOT, INC HALSEY PULP MILL	0.4700 LB/MMBTU
<input checked="" type="checkbox"/> OR-0031	03/02/2001	POPE & TALBOT, INC HALSEY PULP MILL	0.4700 LB/MMBTU
<input checked="" type="checkbox"/> OH-0241	11/15/2001	MILLER BREWING COMPANY MILLER BREWING COMPANY - TRENTON	0.7000 LB/MMBTU
<input type="checkbox"/>			

Table 2 Facility Information from RBLC

Date Entered: 03/18/2004

Date Last Modified: 05/17/2004

FINAL

RBLC ID: NC-0092

Corporate/Company: INTERNATIONAL PAPER COMPANY

Facility Name: RIEGELWOOD MILL

Facility Description: PAPER MILL

State: NC

Zip Code: 28456

County: COLUMBUS

EPA Region: 4

Facility Contact Information:

Name: EDWARD KRUEL

Phone:

E-Mail:

Agency Contact Information:

Agency: NC001 - NORTH CAROLINA DIV OF ENV MGMT

Contact: Mr. Fred Langenbach

Address: NC Div. of Environment Mgmt.
Air Quality Section
1641 Mail Service Center

Raleigh, NC 27699

Phone: (919)715-6242

Other Agency RICHARD LASATER

Contact Info: NC
(919) 715-6244

Permit Number: 03138R16

EST/ACT DATE

Application Accepted Date: ACT 01/22/2001

Permit Date: ACT 05/10/2001

FRS Number: 110000861620

Permit Type: B: ADD NEW PROCESS TO EXISTING FACILITY
C: MODIFY EXISTING PROCESS AT EXISTING FACILITY

SIC: 2621

NAICS: 322121

Affected Class I / US Border Area:

Distance to Area

Area Name

210 km

Swanquarter, NC

220 km

Cape Romain, SC

Facility-Wide Emission Increase/Decrease:

(After prevention/control measures)

No facilitywide emissions data available for this facility.

Other Permitting Information:

MODIFICATION FOR INSTALLATION OF NEW EQUIPMENT TO INCREASE PRODUCTION CAPACITY.

5.0 Current Emission Control Technologies

To develop a list of emission control alternatives, it is important to understand that options are not limited to add-on emission control devices. Any technique that reduces the emissions is a valid consideration. Options could be as follows: changes to raw materials, changes to process conditions, and/or the addition of emission control equipment. The following provides some examples of each.

5.1 Raw Materials

Control options for combustion sources could include a change in fuel type. The use of low-sulfur coal and oil can be considered as a control option for SO₂. Wood fuel can be specified for moisture content as a means to control particulate emissions. Burning natural gas can reduce NO_x, SO₂ and particulate matter (PM). Reductions in volatile organic compound (VOC) emissions in the printing or coating industries can be accomplished by the use of low-VOC solvents or even water-based solvents. Degreasing operations may also be able to switch to the use of low-VOC mixtures or citrus-based cleaners.

5.2 Process Conditions

For many types of industrial sources, emissions can be reduced by accepting production limitations. Lacking any production limitation, a regulatory permit engineer would expect emissions to be calculated based on the maximum capability for every hour of the year. In industries, such as coating facilities, there is often a more realistic throughput value that is based on product demand. In the plastics manufacturing industry, the process temperatures and/or pressures may be modified to reduce VOC emissions. Work practices can be part of a BAT plan. Work practice examples would be: maintaining covers on containers containing volatile liquids, or startup/shutdown of a gas turbine. For process operations, such as coaters, the effectiveness of the capture system will be part of the overall BAT consideration. A limitation on operating hours for equipment, such as emergency generators, is a key component to demonstration of a limitation to long-term emissions.

5.3 Emission Control Equipment

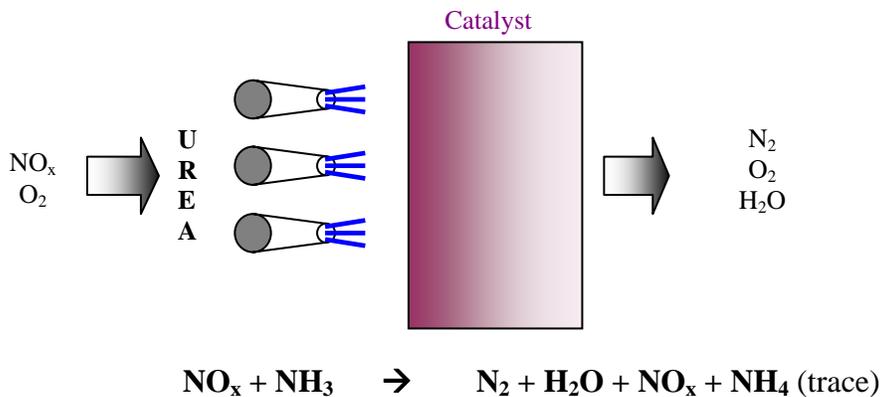
Ultimately, after considering all viable process and operating means to reduce emissions, there will be consideration for installing emission control hardware. The following provides a brief listing and explanation of available emission control devices.

5.3.1 Nitrogen Oxide Controls

The first level of NO_x control, in the case of boilers, would be a low-NO_x burner (LNB). These burners are designed to operate at cooler temperatures in order to minimize the formation of thermal NO_x. The effect of low-NO_x burners is to purposely operate slightly inefficiently, which will result in an increase in carbon monoxide (CO) emissions and a decrease in NO_x. NO_x can be controlled by selective non-catalytic reduction (SNCR), which involves the injection of ammonia or urea into the exhaust to react with NO_x to form nitrogen and water. Without the benefit of a catalyst, the reaction temperature is very high (1,400 to 1,500°F), which makes SNCR only effective in a relatively high, narrow temperature range. Selective catalytic reduction (SCR), illustrated in **Figure 1**, is one of the

most effective NO_x controls for combustion sources. The catalyst allows an efficient reaction to take place at lower temperatures; typically 500–900°F, depending on the type of catalyst.

Figure 1 Schematic of the SCR Reaction



Source: M.J. Bradley & Associates

5.3.2 Particulate Controls

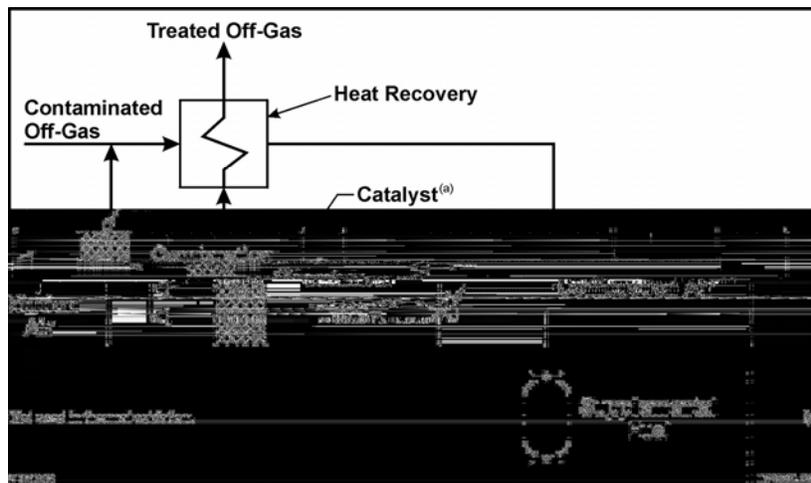
The majority of particulate controls are mechanical collectors, electrostatic precipitators, fabric filters or wet scrubbers. Mechanical collectors, such as cyclones, are used in a pre-control capacity to remove the larger particulates. Electrostatic precipitators are used mostly in high exhaust rate, high emission rate applications such as coal-fired power plants and steel mills. Fabric filters range from large scale to very small emission sources. There are many fabrics that are used, depending on exhaust characteristics such as particulate loading, temperature and moisture content. Although there have been advances in high-temperature fabrics, fabric filters are temperature-limited. Wet scrubbers have many different designs to improve the contact efficiency between the water and the particulate. Because the use of wet scrubbers requires control of the wastewater, applications are generally on large-particulate emission sources.

5.3.3 Volatile Organic Compound Controls

There are a variety of VOC controls, including condensation techniques, thermal oxidation, biofiltration and carbon adsorption. Condensation (refrigeration) control, which cools the exhaust and precipitates out volatiles, is an earlier-generation technique popular with gasoline terminals before the development of carbon adsorption systems. Thermal oxidation, illustrated in **Figure 2**, is a simple and effective way to destroy the VOC. However, the effort to control VOCs will produce combustion byproduct emissions (primarily NO_x and CO). Biofilters have not had widespread use, with most applications being for odor controls in composting operations. Carbon adsorption, as illustrated in **Figure 3**, is one of the most efficient VOC control techniques. The ideal application for carbon adsorption is for recoverable VOC material. Common examples of the use of carbon

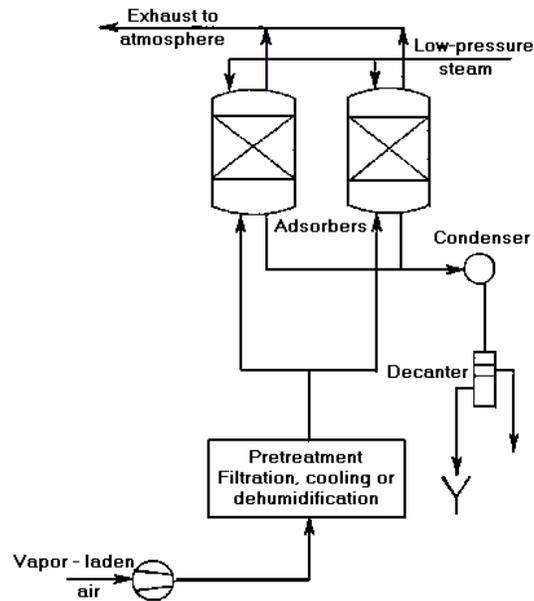
adsorption with a recovery system are gasoline terminals and coatings facilities that utilize a single solvent.

Figure 2 **Diagram of Catalytic Thermal Oxidizer**



Source: <http://enviro.nfesc.navy.mil/erb/restoration/technologies/remed/phys_chem/phc-35.asp>.

Figure 3 **Diagram of Carbon Solvent Recovery**



Source: <www.activated-carbon.com/solrec4.html>.

5.3.4 Sulfur Dioxide Controls

The reduction of SO₂ is primarily focused on fossil-fuel combustion sources. Reductions can be accomplished through the use of lower sulfur-containing fuel and/or installation of wet or dry scrubbers. The economic impact analysis for an option such as dry scrubbing can show an economic benefit, as the waste may be saleable for the manufacture of wallboard.

6.0 Information Sources

6.1 US Federal Regulations

Identification of achievable emission rates and associated control technologies can be obtained through review of certain emission source or pollutant-specific regulations. Three regulatory programs of note are listed below with their Code of Federal Regulations (CFR) citation:

- NSPS 40 CFR 60;
- NESHAP 40 CFR 61; and
- MACT 40 CFR 63.

The New Source Performance Standards (NSPS) program provides emission rate(s) required of a new emission source for which the source category has a standard promulgated under 40 CFR 60. **Appendix A** provides a list of source categories for which there is a promulgated standard under NSPS. Recently promulgated standards would be expected to reflect BAT. However, a BAT analysis conducted in relation to a standard promulgated years ago would use the limit established as a baseline to determine whether there have been improvements to emission reduction methods.

The National Emission Standards for Hazardous Air Pollutants (NESHAP) program provides emission control and/or work practice requirements for a select number of hazardous air pollutants (HAPs) that have been determined to not have a “safe limit.” The pollutants regulated under 40 CFR 61 include: asbestos, benzene, beryllium, coke oven emissions, inorganic arsenic, mercury, **radionuclides**, and vinyl chloride. Information from NESHAP may provide some beneficial background information for a BAT analysis conducted for an emission source that emits one of the listed HAPs.

The Maximum Achievable Control Technology (MACT) program provides emission control and emission rate requirements for existing sources that are deemed to be “major” sources for one or more HAPs. In the Clean Air Act Amendments of 1990, the approach for regulating HAPs changed from the health-based approach of the NESHAP program, to a control technology–based approach called the MACT program. The program began with a list of 189 pollutants and set forth a schedule to develop a MACT standard for source categories that emit one or more of those pollutants. **Appendix B** provides a list of the MACT standards developed to date under 40 CFR 63.

The purpose of the MACT standards is to establish emission control and emission rate requirements for existing sources. The standards represent the level of control being used by the top 15% of sources in a particular source category (based on emission performance). The MACT information can serve as background information for a BAT analysis, in terms of denoting a minimum level which the BAT would be expected to achieve.

6.2 Publications

There is a wealth of publications that can assist a regulatory review engineer when conducting a BAT analysis. The following are a few titles and web site addresses indicating where to obtain copies:

- *Compilation of Air Pollutant Emission Factors, Vol. 1: Stationary Point and Area Sources (AP-42)* (EPA)
www.epa.gov/ttn/chief/ap42
- *EPA Air Pollution Control Cost Manual* (EPA 452/B-02-001)
<http://epa.gov/ttn/catc/products.html#cccinfo>
- *Air Pollution Engineering Manual* (\$149)
www.awma.org/pubs/bookstore
- *Air Pollution Control Equipment Selection Guide* (\$127)
www.awma.org/pubs/bookstore
- *Industrial Ventilation: A Manual of Recommended Practice, 25th Edition* (\$100)
www.acgih.org/store

The AP-42 emission factors manual (accessible online) provides baseline emission factors for many source categories. The emission factors represent an average calculated by EPA from available stack test data. For sources that utilize different types of controls or multiple controls, the emission factors will be itemized for each option. AP-42 is a valuable starting point, if needed, to establish the baseline level of emissions before applying BAT. Additionally, AP-42 contains process descriptions and a discussion of emission controls that have been used with a process type.

EPA's *Air Pollution Control Cost Manual* contains a detailed explanation of various emission control technologies and provides cost factors that enable an economic impact analysis to be derived in terms of dollars per tons of emissions reduced per year. The spreadsheets (available electronically) contain predetermined factors for the various phases of construction and operating cost that are calculated based on a proportion of the base emission control unit. If a base cost for an emission control device is not available, the *Control Cost Manual* provides guidance for using factors such as dollars per cubic feet of airflow per minute (\$/cfm) as baselines for equipment cost estimates.

The other documents identified may be useful in some instances. The *Air Pollution Engineering Manual* provides some additional details of process descriptions and emission controls from AP-42. The *Air Pollution Control Equipment Selection Guide* provides guidelines for what controls are effective for various pollutants. The *Industrial Ventilation* manual is available for sizing capture hoods, ductwork and exhaust stacks in the event that those items are included in the design and cost of a system within a BAT analysis. Other useful documents can be identified through key word searches on the Web.

6.3 State Agencies

In the US, the state agencies usually serve in the capacity of reviewing new (or modified) source permit applications. As such, questions about recently approved permit applications may be accomplished through discussions with the state permit review engineer. In the RBLC database, the entered information includes a contact person from the approving state agency to allow for questions to be answered. For the newest approved BAT analyses, the information is not likely available in the RBLC database and contact with the state may be necessary to understand the level of emission reduction.

6.4 Trade Associations

By their nature, trade associations serve as a conduit for information. When an emission control vendor develops a new product, it typically broadcasts the information to the public through one or more trade associations. The information may be on a web site, in conference proceedings or in technical journals. The following is a partial list of trade associations that may contain air quality–related emission control information.

- Air and Waste Management Association (AWMA)
www.awma.org
- Institute of Clean Air Companies (ICAC)
www.icac.com
- Electric Power Research Institute (EPRI)
www.epri.com
- American Petroleum Institute (API)
www.api.org
- National Asphalt Pavement Association (NAPA)
www.hotmix.org
- Portland Cement Association (PCA)
www.portcement.org
- Composite Panel Association
www.pbmdf.com
- Diesel Technology Forum
www.dieselforum.org
- DieselNet
www.dieselnet.com
- Manufacturers of Emission Controls Association (MECA)
www.meca.org

6.5 Equipment Vendors

Inevitably some of the best sources of information about emission control technologies are the vendors who design, manufacture and install emission control devices. There are many vendors and many control technologies ranging from older proven systems to new innovative concepts. Unfortunately, vendors will generally present only the positive aspects of their controls in an effort to make a sale. However, a knowledgeable inquiry can sort through the sales pitch and gain valuable insight. Below is a listing of some vendors within various categories of emission control equipment and their respective web sites.

- Diesel Engines
 - Caterpillar www.cat.com
 - Cummins www.cummins.com
 - Mack www.macktrucks.com
 - Detroit Diesel www.detroitdiesel.com

- Turbines
 - GE www.gepower.com
 - Pratt & Whitney www.pratt-whitney.com

- Thermal Oxidation
 - Trewin & Smith www.tsix.com
 - ADWest Technologies, Inc. www.adwestusa.com
 - MEGTEC Systems www.MEGTEC.com

- SCR
 - Siemens www.siemens.com
 - Cormetech www.cormetech.com
 - Johnson Matthey www.matthey.com
 - Engelhard www.engelhard.com
 - Fleetguard Emission Solutions www.fleetguard.com

- Carbon
 - Barneby Sutcliffe www.bsicarbon.com
 - John Zink Company www.johnzinc.com
 - Calgon www.calgoncarbon.com

- General Search
 - Thomas Registry of American Manuf. www.thomasregistry.com

6.6 Conference Proceedings

In a BAT analysis investigation, the challenge is always to thoroughly research any new innovative emission control techniques. On the reverse side, a challenge for the designer of a new innovative emission control technology is to get the word out. One popular method is to present a paper at a technical conference. Most conferences publish their proceedings and make them available for free or for a modest fee.

7.0 Case Study: Stationary Reciprocating Diesel Engine

This section describes an example of a BAT analysis for a diesel fuel-powered engine. The case study will assume a 2,000 kilowatt (kW) engine. Common uses of a 2,000 kW (2,885 horsepower [hp]) diesel engine would include: asphalt batch plant, stone crushing, metal crushing, and small power generation (continuous or backup use). The case study will assume the engine is used for backup power generation with a limit of 500 hours of operation per year. The top-down method described in **Section 3** will be used to determine the BAT.

7.1 Project Specifications

XYZ Company seeks approval for the installation of a CAT 3516B power generation unit at a location that is in attainment with the national ambient air quality standards. The generator will be operated on an emergency backup basis and will not exceed 500 hours per year. The vendor specifications for the CAT 3516B operating at 100% power indicate the following emission rates, listed in units of grams of pollutant per brake horsepower-hour.

- NO_x 6.9 g/hp-hr
- CO 0.35 g/hp-hr
- VOC 0.13 g/hp-hr
- Particulate 0.103 g/hp-hr

This B-series Caterpillar engine is their low-emission lean-burn unit, meaning that the ration of fuel flow to combustion air is minimized. The older A-series engines had mechanical fuel injection and produced NO_x emissions of approximately 12 g/hp-hr. The lean-burn technology utilized electronic injection to get down to the 6.9 g/hp-hr guarantee, which is the California NO_x emission rate for diesel-powered generators of this size.

7.2 Emission Calculations

Based on the 500 hours per year, annual emissions are calculated to be as follows. Note that the SO₂ emissions were calculated using the EPA published emission factor of 0.00809(%S) lb/hp-hr, assuming a sulfur content of 0.3%.

- NO_x 8.1 tpy
- CO 1.9 tpy
- SO₂ 1.9 tpy
- VOC 0.21 tpy
- Particulate 0.16 tpy

This case study investigates emission control alternatives for pollutants with annual emissions greater than 1 tpy. Based on the calculated annual emissions listed above, this BAT analysis will include NO_x, CO, and SO₂.

7.3 RBLC Database

The RBLC database contained entries under that category of stationary internal combustion burning liquid fuel. However, emissions were only reported for NO_x and CO.

Table 4 provides the results of a sort for the **Lowest Emission Rate** in EPA’s RBLC database for the category of NO_x emissions from oil-fired reciprocating engines. Review of emission control information linked to the **Standard Emission Limit** indicates that NO_x emissions in the range of 0.7 to 3.6 g/hp-hr were achieved by engines equipped with an SCR control system. For NO_x emissions in the range of 5.2 to 5.6 g/hp-hr, the engines utilized ignition retard. For NO_x emissions in the range of 6.4 to 6.9 g/hp-hr, the engines were designed with lean-burn technology. The engines approved at 6.9 g/hp-hr reflect an emergency use-only system. The level of 6.9 g/hp-hr is a minimum specification for diesel fired stationary reciprocating engines in California.

Table 4 Results of RBLC NO_x Search for Internal Combustion Engines

Pollutant: NOX
 Process Category: Internal Combustion Engines
 Process Type: 17.110
 Process Name: Fuel Oil
 Permit Date Between 12/29/1999 And 12/29/2004

	RBLCID	PERMIT DATE	CORPORATE/COMPANY NAME & FACILITY NAME	STANDARD EMISSION LIMIT
<input type="checkbox"/>	VT-0013	06/08/2000	MILL RIVER LUMBER, Ltd. MILL RIVER LUMBER, LTD.	0.7500 G/B-HP-H
<input checked="" type="checkbox"/>	AK-0059	09/29/2003	USAF EARECKSON AIR STATION USAF EARECKSON AIR STATION	1.0900 G/B-HP-H
<input checked="" type="checkbox"/>	PA-0209	11/08/2002	BOROUGH OF CHAMBERSBURG ORCHARD PARK GENERATING STATION	1.5000 G/B-HP-H
<input checked="" type="checkbox"/>	VT-0014	09/05/2000	OKEMO MOUNTAIN INC. OKEMO MOUNTAIN INC.	1.6000 G/B-HP-H
<input checked="" type="checkbox"/>	PA-0158	06/19/2000	FORD ELECTRONICS AND REFRIGERATION, LLC FORD ELECTRONICS AND REFRIGERATION, LLC	3.6000 G/BHP-H
<input checked="" type="checkbox"/>	AK-0053	03/21/2000	TESORO ALASKA COMPANY KENAI REFINERY	5.2000 G/B-HP-H
<input checked="" type="checkbox"/>	NC-0074	01/24/2003	BRIDGESTONE/FIRESTONE NORTH AMERICAN TIRE BRIDGESTONE/FIRESTONE NORTH AMERICAN TIRE	5.6700 G/B-HP-H
<input checked="" type="checkbox"/>	AK-0060	10/10/2003	WESTWARD SEAFOODS, INC. DUTCH HARBOR SEAFOOD PROCESSING FACILITY	6.4500 G/B-HP-H
<input checked="" type="checkbox"/>	CA-0988	02/01/2003	PACIFIC BELL PACIFIC BELL	6.9000 G/B-HP-H

Table 5 provides the results of a sort for the **Lowest Emission Rate** in EPA’s RBLC database for the category of CO emissions from oil-fired reciprocating engines. Review of emission control information linked to the **Standard Emission Limit** indicates that the four entries with CO

emissions below 1 g/hp-hr all were equipped with an oxidation catalyst. The remaining entries listed their CO control as “good combustion practices” and were all installations for emergency use only.

Table 5 Results of RBLC CO Search for Internal Combustion Engines

Pollutant: CO
 Process Category: Internal Combustion Engines
 Process Type: 17.110
 Process Name: Fuel Oil
 Permit Date Between 12/29/1999 And 12/29/2004

	RBLCID	PERMIT DATE	CORPORATE/COMPANY NAME & FACILITY NAME	STANDARD EMISSION LIMIT
<input type="checkbox"/>	VT-0013	06/08/2000	MILL RIVER LUMBER, Ltd. MILL RIVER LUMBER, LTD.	0.2700 G/B-HP-H
<input checked="" type="checkbox"/>	OH-0266	08/15/2002	UNIVERSITY OF CINCINNATI UNIVERSITY OF CINCINNATI	0.3000 G/B-HP-H
<input checked="" type="checkbox"/>	AK-0059	09/29/2003	USAF EARECKSON AIR STATION USAF EARECKSON AIR STATION	0.5000 G/B-HP-H
<input checked="" type="checkbox"/>	VT-0014	09/05/2000	OKEMO MOUNTAIN INC. OKEMO MOUNTAIN INC.	0.6000 G/B-HP-H
<input checked="" type="checkbox"/>	IA-0058	04/10/2002	MIDAMERICAN ENERGY GREATER DES MOINES ENERGY CENTER	1.3800 G/B-HP-H
<input checked="" type="checkbox"/>	AK-0053	03/21/2000	TESORO ALASKA COMPANY KENAI REFINERY	1.4500 G/B-HP-H
<input checked="" type="checkbox"/>	MN-0053	07/15/2004	MN MUNICIPAL POWER AGENCY FAIRBAULT ENERGY PARK	1.8300 G/B-HP-H
<input checked="" type="checkbox"/>	TX-0384	08/23/2000	AVISTA-STEAG BRAZOS VALLEY ELECTRIC GENERATING FACILITY	3.0000 G/B-HP-H
<input checked="" type="checkbox"/>	PR-0005	03/02/2000	PUERTO RICO ELECTRIC AUTHORITY (PREPA) SAN JUAN REPOWERING PROJECT	3.0200 G/B-HP-H
<input checked="" type="checkbox"/>	TX-0407	12/06/2002	STEAG POWER LLC STERNE ELECTRIC GENERATING FACILITY	3.0300 G/B-HP-H
<input checked="" type="checkbox"/>	TX-0262	01/03/2000	ARCHER POWER PARTNERS, L.P. ARCHER GENERATING STATION	5.9000 G/B-HP-H

7.4 Existing US Regulations

Interestingly, the regulatory push for reducing NO_x emissions from diesel-fired reciprocating engines has focused on mobile sources. However, the same manufacturers that produce mobile-source diesel engines also produce stationary-source diesel engines. As such, new stationary reciprocating engines NO_x emissions have been reduced significantly over the past few years without the benefit of a focused stationary source regulation.

Specific to stationary reciprocating engines, the US EPA promulgated a new MACT standard, 40 CFR Part 63 subpart ZZZZ, titled Stationary Reciprocating Internal Combustion Engine NESHAP. However, it only applies to engines that release more than 10 tpy of HAP. The motivation for the MACT standard is to minimize formaldehyde emissions (a listed HAP). The required control is either 1) installation of an oxidation catalyst, or 2) establish operating limitations. Because an oxidation catalyst also reduces CO, the MACT standard also contains CO reduction requirements for stationary engines which are classified for other than emergency use only.

7.5 Resources for Emission Control Options

One resource for identifying emission control options is the EPA-sponsored database entitled New and Emerging Environmental Technologies (NEET) Clean Air Technologies Database. The database can be reached as a link to the RBLC database or directly at <<http://neet.rti.org/>>. Sorting by pollutant, stationary source, captured emissions, and commercial availability provided a list of control options. Additionally, the document *EPA Air Pollution Control Cost Manual—Sixth Edition* (EPA 452/B-02-001) provides a chapter for each criteria pollutant. The manual can be accessed electronically through the RBLC under the link called **Reference Library**, at <<http://www.epa.gov/ttn/catc>>.

7.6 Review of NO_x Emission Control Options

The following provides information about each possible NO_x emission reduction option, based on past experience and research of similar applications.

7.6.1 Selective Catalytic Reduction (SCR)

An SCR system is an exhaust after-treatment device that utilizes the abilities of certain compounds, most commonly urea or ammonia, to react with NO_x emissions, to form benign chemical compositions. A controlled amount of the reactive chemical is sprayed into the exhaust stack, and is met by an intricate arrangement of precious metals which act as catalysts for the chemical reaction. Historically, SCRs have been very successful NO_x control devices. The drawbacks of SCRs are that they tend to have high capital costs, and the engine exhaust must meet certain temperature and pressure values for the device to function properly.

Environmental Impacts

Past examples indicate that SCRs have achieved significant NO_x reductions for reciprocating diesel engines. At optimum operating conditions, NO_x reductions of approximately 90% are expected to be realized by the installation of an SCR. The efficiency and final emissions rates are very difficult to

predict, however, as they depend on the SCR unit, and the pressure and temperature achieved in the stack. Furthermore, the SCR will have little effect on the NO_x emissions while the engine is cold. Based on data found in the RBLC, it is predicted that the SCR will achieve approximately 90% NO_x reductions. While the ammonia feed rates in SCR systems are designed to minimize any release of ammonia, most manufactures specify an ammonia slip rate between 2 and 10 ppm.

Energy Impacts

Although an SCR is not normally considered a powered device, it will necessitate slight increases in energy consumption. Since hardware will be installed directly into the exhaust stack, the exhaust fans will have to do more work to achieve an appropriate flow rate. Furthermore, the ammonia sprayers draw small amounts of power as well. Operating an SCR also implies certain indirect increases in energy consumption, such as the energy required to create and transport ammonia.

Economic Impacts

Table 6 illustrates the total capital and operating costs associated with the installation of an SCR device at this facility. Essentially, it will require an invested capital cost of \$384,000 and an additional \$62,000/yr to operate. Considering the NO_x emission reductions that are expected to be realized, this equates to a cost of approximately \$22,200 per ton of NO_x controlled, assuming 500 hours of operation per year. Essentially, it is the most expensive control method presented.

7.6.2 Selective Non-catalytic Reduction (SNCR)

This method of NO_x reduction introduces new compounds (most commonly ammonia or urea) to the diesel exhaust which break down NO_x molecules into nitrogen and oxygen, much like an SCR. The difference between the two technologies is that an SNCR lacks the precious-metal catalyst that facilitates the ammonia-NO_x reaction. SNCR systems can realize NO_x reductions of 60%, but only at temperatures greater than 1,700°F. At lower temperatures, the reaction proceeds too slowly, resulting in unused ammonia emitting from the stack. Because this temperature is well above the standard operation temperature of the generator, this option was not deemed to be technically feasible for this application.

7.6.3 Non-selective Catalytic Reduction (NSCR)

NSCR utilizes a three-way CO and hydrocarbon catalyst to reduce NO_x to nitrogen and water. The reducing agent is applied to the exhaust, upstream from a catalyst, and therefore requires rich-burning engines. This option was deemed to be not technically feasible, as reciprocating engines are typically lean-burn by design.

7.6.4 Combustion Controls

Several combustion controls, such as fuel injection controls, after cooling systems and lean combustion techniques are already implemented in the design of the CAT 3516B. Such devices were considered as possible BATs prior to the discovery that the engine produced more NO_x than allowable, even with these controls in use.

Exhaust gas recirculation (EGR) is a technique that involves rerouting a portion of the exhaust back to the engine intake, which lowers combustion temperature and therefore reduces NO_x emissions by

up to 15%. This method was deemed to be not technically feasible however, as the pollutants in the exhaust gas would cause damage to the intake system and would promote increased engine wear rates.

Steam injection techniques, applicable to boilers and turbines, also reduce combustion temperature, and for these applications realize a 15% decrease in NO_x emissions. However, the water particles found in steam would rust the interior of internal engines, and increase engine wear, and therefore these techniques were considered to be technically infeasible for this application.

Engine timing offsets can be effective, inexpensive means of realizing slight NO_x reductions, though carry the burden of increased VOC and CO emissions. Furthermore, Caterpillar indicates that engine retardation may result in reduced engine efficiency, performance, reliability and life. Therefore, this method was found to be not technically feasible for this application.

7.7 Review of CO Emission Control Options

The following provides information about each possible CO emission reduction option, based on past experience and research of similar applications.

7.7.1 Oxidation Catalyst

Oxidation catalyst modules and pre-engineered packages are the cost-effective way to eliminate or reduce carbon monoxide and have a side benefit of also reducing unburned hydrocarbon emissions. Oxidation catalysts are manufactured with durable, high-efficiency, precious metal-based formulations, providing low pressure-drop and high catalytic activity. Typical catalysts are made with a metal and ceramic honeycomb substrate coupled with application-specific wash coats and catalyst coatings. The precious metal-based formulations provide high destruction levels at lower operating temperatures. Use of high-activity, poison-resistant formulations means reduction of carbon monoxide (CO), of unburned hydrocarbons and of odors, at lower temperatures and with less catalyst volume—less volume means lower capital cost and lower temperatures means lower operating cost. In some cases, pollutant destruction levels of over 98% can be achieved.

Environmental Impacts

In addition to the positive reduction in CO emissions, the oxidation catalyst will lower VOC emissions. A negative environmental impact is that CO₂ (a greenhouse gas) is produced through the process of oxidizing CO.

Energy Impacts

The use of an oxidation catalyst will create an additional pressure drop, resulting in a slight increase in energy consumption.

Economic Impacts

The capital cost of an oxidation catalyst capable of handling an exhaust-flow rate of 17,000 cubic feet per minute is \$150,000. Based on the capital cost and estimated operating cost of \$25,000, the economic impact would be \$20,000/tpy of CO reduced.

7.8 Review of SO₂ Emission Control Options

The following provides information about each possible SO₂ emission reduction option, based on past experience and research of similar applications.

7.8.1 Ultra-low Sulfur Diesel Fuel (ULSD)

Because of its reduced sulfur content, ULSD is capable of achieving significant reductions in SO₂ emission rates. ULSD, while marginally more expensive than No. 1 diesel, is an easy, environmentally practical means of achieving emissions reductions without the need to install or maintain any new equipment or after-treatment device. The use of this fuel in place of the standard diesel is a strong candidate for the BAT for SO₂ reduction.

Environmental Impacts

In addition to the positive reduction in SO₂ emissions (directly proportional to the difference in sulfur content), the ULSD has a co-benefit of resulting in slightly lower NO_x emissions. Through the refining process to remove sulfur, there is likely to be a slight reduction in elemental nitrogen, which translates to potentially lower NO_x emissions.

Energy Impacts

The combustion of ULSD does not require any additional energy consumption. The refinery producing the ULSD, however, will require more energy.

Economic Impacts

The additional cost of ULSD is approximately \$0.05 per gallon. Assuming maximum firing rate of 147.6 gal/hr and 500 hr per year of operation, the economic impact would be \$2,300/tpy of SO₂ reduced.

7.9 BAT Analysis Conclusion

The top-down BAT evaluation technique indicated that if cost were not a factor (or the unit were not limited to 500 hrs per year), the CAT 3516B would be equipped with SCR to control NO_x, an oxidation catalyst to control CO and would be required to fire ULSD. However, as this case study is for an emergency use-only generator (limited to 500 hrs per year), the SCR is well above the economically affordable threshold of \$15,000 used in some regions of the US. Likewise the oxidation catalyst for CO and ULSD for SO₂ are not considered economically feasible. As such, BAT for this case study will be lean-burn specification on the engine, with good combustion practices to assure that CO is not increased by poor combustion efficiency.

Table 6 SCR NO_x Control Cost Analysis for an Internal Combustion Engine

SCR Unit (Per unit)

DIRECT COST		Factor	
TOTAL FLOW RATE (CFM)	10,607 CFM		
PURCHASED EQUIPMENT COST			
EQUIPMENT COST			A = \$150,000
PREHEATERS (1 Preheater @ \$2,000.00 Included in equipment cost)			
INSTRUMENTATION		0.10 A	\$15,000
DUCTS, FANS & ROOF PENETRATIONS		0.03 A	\$4,500
SALES TAX		0.05 A	\$7,500
FREIGHT		0.05 A	\$7,500
PEC			B = <u>\$184,500</u>
HANDLING & ERECTION			
HANDLING & ERECTION		0.30 B	\$55,350
FOUNDATIONS & SUPPORTS			
FOUNDATIONS & SUPPORTS		0.04 B	\$7,380
ELECTRICAL			
ELECTRICAL		0.08 B	\$14,760
PIPING, PAINTING			
PIPING, PAINTING		0.03 B	\$5,535
TOTAL INSTALLATION		0.45 B	<u>\$83,025</u>
INDIRECT INSTALLATION COSTS			
ENGINEERING & SUPERVISION		0.20 B	\$36,900
CONSTRUCTION, FIELD EXPENSES		0.20 B	\$36,900
START-UP, PERFORMANCE TEST		0.01 B	\$1,845
CONTINGENCY		0.03 B	\$5,535
TOTAL INDIRECT COSTS		0.44 B	<u>\$81,180</u>
TOTAL CAPITAL COST			C = \$348,705
DIRECT ANNUAL COST			
UTILITIES			
ELECTRICITY @ \$0.08/kWH		Est 2,000 kWH	\$160
Aq. Ammonia @ 19% \$ 0.50 / gallon		5 gallons / hr * 300 hrs	\$750
Catalytic Bed Preheater			
Nat. Gas @ \$6.50 mmBtu		3' X 2' Maintained at 700 F 0.05 mmBtu / hr *300 hrs	\$98
MAINTENANCE			
MAINTENANCE TIME (HOURS)			156
LABOR @ \$30.00/HR			D= \$0
MATERIALS @ 100% OF LABOR			E= \$0
TOTAL DIRECT ANNUAL COSTS			<u>\$1,008</u>
INDIRECT ANNUAL COST			
OVERHEAD	0.6 (D + E)		\$0
PROPERTY TAX	0.014 C		\$4,882
INSURANCE	0.02 C		\$6,974
ADMINISTRATIVE	0.24 C		\$8,369
CAPITAL RECOVERY	0.117 x C		\$40,739
TOTAL INDIRECT ANNUAL COSTS			<u>\$60,964</u>
TOTAL ANNUAL COST			\$61,971
CONTROLLED EMISSIONS (TONS) = Engine potential x Control Efficiency = 3.4 x 0.9 = 3.1 tpy			
	3.10	90%	<u>2.79</u>
COST PER TON CONTROLLED			\$22,212

8.0 Case Study: Oil-fired Boiler

This section will describe the process used to determine the BAT for a small power plant. The power source is a 200 million Btu/hr boiler that burns No. 6 residual oil. Controlled pollutants will include byproducts of combustion; nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO) and particulate matter (PM). Common uses of a 200 million Btu/hr boiler would be steam generation for heat and cooling of a large industrial facility or, if equipped with a steam-powered electric generator, serving as a small electric power plant. The case study will assume that the boiler is for steam production of an industrial facility, operational 24 hours/day and 7 days/week. Possible control options will be analyzed by using the top-down BAT technique described in **Section 3**.

8.1 Project Specifications

XYZ Company seeks approval for the construction of a 200 million Btu/hr oil-fired boiler at a location that is in attainment with the National Ambient Air Quality Standards. Vendor specifications for the boiler indicate the following emission rates, in pounds of pollutant per million British thermal units of heat input

- NO_x 0.40 lb/mmBtu
- CO 0.03 lb/mmBtu
- Particulate 0.10 lb/mmBtu (assumes 1% sulfur oil)
- SO₂ 1.0 lb/mmBtu (assumes 1% sulfur oil)
- VOC 0.005 lb/mmBtu

The emission rates reflect a new boiler that would be designed to meet the EPA's New Source Performance Standards for a 200 mmBtu/hr boiler (Subpart Db). The standard only addresses NO_x, SO₂ and particulate. Emission rates for CO and VOC are consistent with emission factors published by EPA in its emission factor reference manual (AP-42).

8.2 Emission Calculations

Based on 8,760 hours per year, annual tons of emissions are calculated to be as follows.

- NO_x 351 tpy
- CO 26 tpy
- Particulate 88 tpy
- SO₂ 877 tpy
- VOC 4.4 tpy

In this case study, BAT analysis was conducted only for pollutants with annual emissions greater than 1 tpy. Based on the calculated emissions listed above, this BAT analysis will include NO_x, CO, particulate, SO₂ and VOC.

8.3 RBLC Database

The RBLC database contained entries under the category of "external combustion burning oil." However, emissions were only reported for NO_x, particulate and CO.

Table 7 provides the results of a sort for the **Lowest Emission Rate** in EPA’s RBLC database for the category of NO_x emissions from oil-fired boilers (100 to 250 million Btu/hr). Review of emission control information linked to the **Standard Emission Limit** indicates that the lower emission rates reflected use of low-NO_x burners and flue gas recirculation (FGR). The higher emission rates reveal no indication of emission controls.

Table 7 Results of RBLC NO_x Search for Oil-fired Boilers

	RBLCID	PERMIT DATE	CORPORATE/COMPANY NAME & FACILITY NAME	STANDARD EMISSION LIMIT
<input type="checkbox"/>				
<input checked="" type="checkbox"/>	NC-0092	05/10/2001	INTERNATIONAL PAPER COMPANY RIEGELWOOD MILL	0.3670 LB/MMBTU
<input checked="" type="checkbox"/>	VA-0270	03/31/2003	VIRGINIA COMMONWEALTH UNIVERSITY VCU EAST PLANT	0.4000 LB/MMBTU
<input checked="" type="checkbox"/>	FL-0182	12/17/1998	RAYONIER, INC. RAYONIER, INC.	0.4250 LB/MMBTU
<input checked="" type="checkbox"/>	NY-0089	03/19/1996	UNIVERSITY OF ROCHESTER CENTRAL UTILITIES PLANT UNIVERSITY OF ROCHESTER	0.4250 LB/MMBTU
<input checked="" type="checkbox"/>	OR-0031	03/02/2001	POPE & TALBOT, INC HALSEY PULP MILL	0.4700 LB/MMBTU
<input checked="" type="checkbox"/>	DE-0017	10/26/2001	SPI POLYOLS, INC. SPI POLYOLS, INC.	0.4800 LB/MMBTU
<input checked="" type="checkbox"/>	NJ-0031	06/26/1997	UNIVERSITY OF MEDICINE & DENTISTRY OF NEW JERSEY UNIVERSITY OF MEDICINE & DENTISTRY OF NEW JERSEY	0.5500 LB/MMBTU
<input checked="" type="checkbox"/>	OH-0241	11/15/2001	MILLER BREWING COMPANY MILLER BREWING COMPANY - TRENTON	0.7000 LB/MMBTU

Table 8 provides the results of a sort for the **Lowest Emission Rate** in EPA’s RBLC database for the category of PM emissions from oil-fired boilers (100 to 250 million Btu/hr). The lowest emission rate reflects the use of a multi-clone and high-pressure scrubber in series to control the particulate.

Table 8 Results of RBLC PM Search for Oil-fired Boilers

RBLCID	PERMIT DATE	CORPORATE/COMPANY NAME & FACILITY NAME	STANDARD EMISSION LIMIT
<input type="checkbox"/>			
<input checked="" type="checkbox"/> NC-0092	05/10/2001	INTERNATIONAL PAPER COMPANY RIEGELWOOD MILL	0.0562 LB/MMBTU
<input checked="" type="checkbox"/> VA-0278	03/31/2003	Virginia Commonwealth University VCU EAST PLANT	0.0600 LB/MMBTU
<input checked="" type="checkbox"/> OR-0031	03/02/2001	POPE & TALBOT, INC HALSEY PULP MILL	0.1360 LB/MMBTU
<input checked="" type="checkbox"/> DE-0017	10/26/2001	SPI POLYOLS, INC. SPI POLYOLS, INC.	0.3000 LB/MMBTU HEAT INPUT

Table 9 provides the results of a sort for the **Lowest Emission Rate** in EPA’s RBLC database for the category of CO emissions from oil-fired boilers (100 to 250 million Btu/hr). The lowest emission rate reflects the use of good combustion practices to control the CO. It can be noted that CO emission rates in 2001 were lower than in 2003. Because the quantity of CO from stationary combustion sources is a small fraction of the quantity from mobile sources, BAT determinations generally conclude that no control is needed. However, with more attention to reducing NO_x emissions from stationary combustion sources, through tuning the boiler to be less efficient, CO emissions have gone up. Some states have implemented CO limits of 200 ppm to assure the boilers do not get overly inefficient.

Table 9 Results of RBLC CO Search for Oil-fired Boilers

	RBLCID	PERMIT DATE	CORPORATE/COMPANY NAME & FACILITY NAME	STANDARD EMISSION LIMIT
<input type="checkbox"/>				
<input checked="" type="checkbox"/>	NC-0092	05/10/2001	INTERNATIONAL PAPER COMPANY RIEGELWOOD MILL	0.0330 LB/MMBTU
<input checked="" type="checkbox"/>	OH-0241	11/15/2001	MILLER BREWING COMPANY MILLER BREWING COMPANY - TRENTON	0.0340 LB/MMBTU
<input checked="" type="checkbox"/>	OR-0031	03/02/2001	POPE & TALBOT, INC HALSEY PULP MILL	0.0350 LB/MMBTU
<input checked="" type="checkbox"/>	VA-0278	03/31/2003	Virginia Commonwealth University VCU EAST PLANT	0.1000 LB/MMBTU

8.4 Existing US Regulations

A 200 mmBtu/hr boiler that is constructed, reconstructed or modified may need to comply with the New Source Performance Standards (40 CFR 60 subpart Db). The NSPS provides emission standards for SO₂, particulate and NO_x. The limits differ by fuel type (coal, oil natural gas) and by boiler type (low-heat release, high-heat release, etc.). There is a new regulation for hazardous air pollutants (40 CFR 63 subpart DDDDD) for industrial, commercial, and institutional boilers with more than 10 tpy of HAP emissions. The purpose of the regulation is to minimize the release of hazardous metals (cadmium, chromium, mercury, nickel, etc.) and hazardous organics (acetaldehyde, formaldehyde). The metals will be controlled by traditional particulate controls, such as scrubbers and electrostatic precipitators (ESPs). Organics will be controlled by good combustion practices, as monitored by CO levels.

8.5 Resources for Emission Control Options

One resource for identifying emission control options is the EPA-sponsored database entitled New and Emerging Environmental Technologies (NEET) Clean Air Technologies Database. The database can be reached as a link to the RBLC database or directly online at <<http://neet.rti.org>>. Sorting by pollutant, stationary source, captured emissions, and commercial availability provided a list of control options. Additionally, the document *EPA Air Pollution Control Cost Manual—Sixth Edition* (EPA 452/B-02-001) provides a chapter for each criteria pollutant. The manual can be accessed electronically through the RBLC under the link called **Reference Library**, at <<http://www.epa.gov/ttn/catc>>.

8.6 Review of NO_x Emission Control Options

Boiler NO_x reductions can be achieved either by affecting the combustion conditions or by applying an exhaust after-treatment technology. In many cases, both can be applied. The goal of combustion controls is either to limit the amount of oxygen within the combustion chamber, or to lower the combustion temperature, both of which hinder NO_x formation. Exhaust after-treatment for large boilers most often includes selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR) systems. All of these techniques are discussed below.

8.6.1 Flue Gas Recirculation

FGR involves re-admitting a portion of the exhaust gas back into the boiler via the furnace hopper or the burner wind box. This achieves both goals of combustion controls—reducing flame temperature while simultaneously reducing the oxygen content of the air inside the furnace. This technique has realized NO_x reductions of up to 50%. The drawback to this and other NO_x combustion controls is that lower furnace temperature results in increased CO emissions, which will have to be controlled by other means.

8.6.2 Overfire Air

Overfire air is a technique in which a portion of the air within the furnace is redirected away from the burners and out the exhaust stack. Like FGR, this technique causes both a decrease in flame temperature as well as diminished oxygen levels within the furnace, resulting in a 5–10% reduction in NO_x formation. Overfire air is also relatively inexpensive, but results in increased CO emissions.

8.6.3 Bias Burner Firing

This technique, which is more common in large boilers, involves firing the lower burner levels more fuel-rich than the upper levels. Doing so provides a form of air staging, which limits the oxygen content in the lower burners. In some cases, it may be beneficial to entirely restrict fuel flow to the top burners, allowing only air from the lower burners to pass through, which results in an even more dramatic effect. This technique, although very boiler-specific, is capable of yielding NO_x reductions in the range of 10–20%.

8.6.4 SNCR

Selective non-catalytic reduction (SNCR) is a post-combustion treatment in which ammonia is injected into the flue gas stream. The ammonia reacts with the NO_x compounds, forming nitrogen and water. In order for this technique to be effective, the ammonia must be injected at a proper temperature range within the stack (~1,700°F) and must be in a proper ratio to the amount of NO_x present. Although it is not a widely used technique for boiler applications due to the problem of stack temperature compatibility, if properly executed, SNCR could realize NO_x reductions of 25–40% on top of any combustion controls implemented.

8.6.5 SCR

Selective catalytic reduction (SCR) is similar to SNCR, in that ammonia is used to cause a reaction with the NO_x. However, SCR systems inject a catalyst as well, which helps to facilitate the reaction and improve performance. This method also is effective at lower and wider temperature ranges (500–900°F). Additionally, the specific NO_x/ammonia and ammonia/catalyst ratios can be designed

to optimize a specific application. Because an SCR is capable of achieving NO_x reductions of up to 85% when properly implemented, the overall economic impact is only \$3,520/tpy. **Table 10** provides the support cost calculation.

Table 10 SCR NO_x Control Cost Analysis for an Oil-fired Boiler

DIRECT COST	Factor	
EQUIPMENT COST	A =	\$2,000,000
INSTRUMENTATION	0.10 A	\$200,000
DUCTS, FANS & ROOF PENETRATIONS	0.03 A	\$60,000
SALES TAX	0.05 A	\$110,000
FREIGHT	0.05 A	\$100,000
PEC	B =	\$2,470,000
HANDLING & ERECTION	0.30 B	\$741,000
FOUNDATIONS & SUPPORTS	0.04 B	\$98,800
ELECTRICAL	0.08 B	\$197,600
PIPING, PAINTING	0.03 B	\$74,100
TOTAL INSTALLATION	0.45 B	\$1,111,500
INDIRECT INSTALLATION COSTS		
ENGINEERING & SUPERVISION	0.20 B	\$494,000
CONSTRUCTION, FIELD EXPENSES	0.20 B	\$494,000
START-UP, PERFORMANCE TEST	0.01 B	\$24,700
CONTINGENCY	0.03 B	\$74,100
TOTAL INDIRECT COSTS	0.44 B	\$1,086,800
TOTAL CAPITAL COST	C =	\$4,668,300
<hr/>		
DIRECT ANNUAL COST		
UTILITIES		\$3,000
MAINTENANCE		
MAINTENANCE TIME (HOURS)		150
LABOR @ \$0.00/HR	D =	\$6,000
MATERIALS @ 100% OF LABOR	E =	\$6,000
TOTAL DIRECT ANNUAL COSTS		\$15,000
INDIRECT ANNUAL COST		
OVERHEAD	0.6 (D + E)	\$7,200
PROPERTY TAX	0.014 C	\$65,356
INSURANCE	0.02 C	\$93,366
ADMINISTRATIVE	0.24 C	\$112,039
CAPITAL RECOVERY	0.149 C ⁽¹⁾ i = 0.08, n = 10	\$695,577
TOTAL INDIRECT ANNUAL COSTS		\$973,538
TOTAL ANNUAL COST		\$988,538
CONTROLLED EMISSIONS (TONS)	351.00 80%	280.80
COST PER TON CONTROLLED		\$3,520

8.6.6 Cleaner Fuel Substitution

NO_x reductions can be realized simply by using distillate oil rather than residual oil. Based on published emission factors, NO_x emissions would be 40% less if burning distillate oil. Although residual oil and distillate oil prices fluctuate day to day, the current price differential is \$0.62 per gallon. Assuming an annual fuel use based on full operation for 8,760 hours per year, the economic impact would be \$51,700/tpy, which is not considered economically feasible.

8.7 Review of SO₂ Emission Control Options

SO₂ emissions will be directly proportional to the sulfur content of the oil being burned. Residual oil typically is refined into three sulfur content categories: 1) 2.2%, 2) 1.0%, and 3) 0.5%. This case study has assumed a project specification of 1.0% residual oil. The following are SO₂ control alternatives.

8.7.1 Flue Gas Desulfurization

A post-combustion flue gas desulfurization (FGD) system uses an alkaline reagent to absorb SO₂ in the flue gas and produce a sodium and calcium sulfate compound. These solid sulfate compounds are then removed in downstream equipment. FGD technologies are categorized as wet, semi-dry, or dry, depending on the state of the reagent as it leaves the absorber vessel. These processes are either regenerable (such that the reagent material can be treated and reused) or nonregenerable (in which case all waste streams are de-watered and discarded). Wet regenerable FGD systems are attractive because they have the potential for better than 95% SO₂ control, have minimal wastewater discharges, and produce a saleable sulfur product. The economic impact was determined to be \$570/tpy

8.7.2 Cleaner Fuel Substitution

SO₂ reductions can be realized simply by using distillate oil rather than residual oil. Based on published emission factors, SO₂ emissions would be 73% less if distillate oil were burned. Although residual oil and distillate oil prices fluctuate day to day, the current price differential is \$0.62 per gallon. Assuming an annual fuel use based on full operation for 8,760 hours per year, the economic impact would be \$11,300/tpy, which is not considered economically feasible.

8.8 Review of Particulate Emission Control Options

Particulate matter (PM) can be challenging to control, as the particles vary greatly in size and composition. Typically, large particles are removed from the flue gas by means of an exhaust after-treatment. Smaller particles are able to escape the post-combustion controls in the form of vapor, and condense later to form aerosol. These particles can be controlled only by modifying the type of fuel burned in the boiler.

8.8.1 Electrostatic Precipitator

ESPs are a common means of reducing PM emissions from boilers, kilns and engines. The system consists of electrically charged metal plates, which attract the charged particulates, thus cleaning the flue gas as it exits the stack. Collection efficiencies vary, depending on the size and quality of the ESP, but in some cases have reached levels upwards of 99%. The economic impact was found to be \$5,430/tpy.

8.8.2 Baghouse

A baghouse system is another form of post-combustion PM control, and consists of several layers of filters, along with a cleaning system. Baghouse efficiencies are dependent upon the size, consistency and electrical resistivity of the particles, as well as the amount of cloth used, and the filter-cleaning schedule. A boiler at higher temperature will require a special bag construction material. In many cases, baghouses have been able to achieve efficiencies greater than 99%.

8.8.3 Cyclone

A cyclone involves blowing air into the exhaust stack, causing the flue gas to swirl around inside the stack. This causes large particulates to separate from the gas and stick to the sides of the stack wall, much in the same manner that a centrifuge separates dense material from a less dense fluid. Unfortunately, even the most efficient cyclone systems are capable of eliminating only larger-sized particulates and, therefore, are usually used as a pre-control for a higher-efficiency PM control system.

8.8.4 Scrubbers

Wet scrubbers use a water spray in various designs and pressures to accomplish PM control. The water particles combine with the particulates, causing droplets of dirty condensation to fall to the bottom of the scrubber for collection. Scrubbers are also capable of PM reductions of up to 95%. Unfortunately, the system requires a source of continuous water supply, and creates a liquid waste that must be handled by a waste water system.

8.8.5 Cleaner Fuel Substitution

PM reductions can be realized simply by using distillate oil rather than residual oil. Based on published emission factors, PM emissions would be 84% less if distillate oil were burned. Although residual oil and distillate oil prices fluctuate day to day, the current price differential is \$0.62 per gallon. Assuming an annual fuel use based on full operation for 8,760 hours per year, the economic impact would be \$98,300/tpy, which is not considered economically feasible.

8.9 Review of CO Emission Control Options

Carbon monoxide is created during a combustion process when excess carbon in the fuel reacts with oxygen in the air. Therefore, there are only three control options: to use a fuel with a lower carbon content, to increase the combustion efficiency (thus increasing NO_x emissions) or to impose an exhaust after-treatment.

8.9.1 Good Combustion Practices

While increasing the furnace efficiency will realize CO reductions, this practice will cause a steep increase in NO_x emissions. Therefore, the efficiency must be within a certain range offering the lowest possible combined NO_x and CO emissions that cannot be sacrificed as it would be environmentally infeasible.

8.9.2 Oxidation Catalyst

Oxidation catalyst modules and pre-engineered packages are the cost-effective way to eliminate or reduce carbon monoxide and have a side benefit of also reducing unburned hydrocarbon emissions. Oxidation catalysts are manufactured with durable, high-efficiency, precious metal-based formulations providing low pressure-drop and high catalytic activity. Typical catalysts are made with a metal and ceramic honeycomb substrate coupled with application-specific washcoats and catalyst coatings. The precious metal-based formulations provide high destruction levels at lower operating temperatures. The use of high-activity, poison-resistant formulations means reduction of carbon monoxide (CO), unburned hydrocarbons and odors, at lower temperatures and with less catalyst volume—less volume means lower capital cost and lower temperatures means lower operating cost. In some cases, pollutant destruction levels of over 98% can be achieved. Post-combustion CO oxidation techniques have been applied to gas turbines and reciprocating engines, and would theoretically be applicable to boilers as well.

8.9.3 CO Spray Catalyst

Theoretically, the oxidation of CO to CO₂ could be achieved by adding the catalyst to the mist of a wet scrubber, if applied at the high temperature point in the exhaust stack. However, as this has not yet been attempted for this application, to institute this system would require considerable research and development, and the emission reduction percentages would be unknown unless tested both before and after implementation, which would require even further capital. Therefore, this technique was not considered economically feasible for this application.

8.10 Bat Analysis Conclusion

For PM, the boiler vendor specified an emission rate of 0.1 lb/mmBtu, which matches the EPA's new source performance standard promulgated in 1984. However, EPA recently promulgated a particulate standard of 0.03 lb/mmBtu, under its hazardous pollutant program that is based on the performance levels of the top 12% emission rates for existing boilers. This PM BAT analysis has concluded that either a baghouse, scrubber or ESP would be feasible. Based on the potential additional operating cost for maintaining a baghouse or scrubber, an ESP was selected.

For NO_x, the boiler vendor specified an emission rate of 0.4 lb/mmBtu, which matches the EPA's new source performance standard promulgated in 1984. However, in the US there have been advancements in combustion technology such that 0.3 lb/mmBtu can be readily achieved through combustion optimization or installation of FGR. This NO_x BAT analysis has concluded that SCR is considered economically feasible by US cost standards, and can accomplish over 80% control with minimal ammonia emissions.

For SO₂, the boiler vendor specified an emission rate of 1.0 lb/mmBtu, which represents an uncontrolled rate that would need some level of control to meet the new source performance standard promulgated in 1984. This SO₂ BAT analysis has concluded that some form of flue gas desulfurization would be feasible. Based on the potential for reselling the captured sulfates, a wet regenerable FGD system was selected.

For CO, the boiler vendor specified an emission rate of 0.03 lb/mmBtu (50 to 100 ppm), which can be accomplished through good combustion practices. Interestingly, under its hazardous pollutant program EPA recently promulgated a CO standard of 400 ppm, which is based on the performance levels of the top 12% emission rates for existing boilers. Due to efforts to reduce NO_x through combustion adjustments, CO levels can easily approach 200 ppm. Because the NO_x BAT analysis recommended a post-combustion control SCR, the boiler will be able to be tuned for the most efficient operating points which will keep CO levels down to the vendor-specified rate. As such, the CO BAT analysis concluded that CO control will only be “efficient operation.”

For VOC, the boiler vendor specified an emission rate of 0.005 lb/mmBtu, which can be accomplished through good combustion practices. EPA tracks boiler VOC through the monitoring of CO, as both pollutants increase proportionally the same if combustion adjustments allow inefficient combustion. Because the NO_x BAT analysis recommended a post-combustion control SCR, the boiler will be able to be tuned for the most efficient operating points which will keep VOC levels down to the rate specified by the vendor. As such, the VOC BAT analysis concluded that VOC control will only be “efficient operation.”

9.0 Case Study: Tire-fueled Concrete Kiln

This section describes the procedures used to determine a BAT for a tire-fueled concrete kiln. The case study will assume a 150 mmBtu/hr dry process rotary cement kiln (30 tons clinker per hour), which burns wire-in shredded scrap tires as the primary fuel source. The use of whole tires and shredded tires as a fuel source is an alternative means of fuel that has become increasingly more popular in recent years in the cement, paper and electricity production industries. The intrinsic properties of the material offer higher heat content than coal and less nitrogen and sulfur, which can result in reduced NO_x and SO₂ emissions. This study will assume constant kiln operation. The best available technology will be chosen using the top-down evaluation process described in **Section 3**.

9.1 Project Specifications

XYZ Company seeks approval for the construction of a tire-fueled cement production facility at a location that is in attainment with the National Ambient Air Quality Standards. The tire-fueled rotary kiln is designed to produce 150 mmBtu/hr, and is intended to operate continuously. Minimal documentation was found for emissions from a tire-fueled kiln. However, there are facilities in the US, Canada and Mexico that currently burn whole tires or shredded tires, known as tire-derived fuel (TDF). A list of all such facilities, as displayed on the Energy Justice Network web site, is presented in **Table 11**, below. The proposed emission rates presented below are hypothetical (estimated based on information gathered from some of the companies listed in **Table 11**), as well as information found on traditional portland cement plants. Emissions are expressed in terms of pounds of pollutant per million British thermal units.

- NO_x 0.40 lb/mmBtu (controlled with SNCR)
- CO 0.03 lb/mmBtu
- Particulate 0.06 lb/mmBtu (controlled by cyclone and baghouse)
- SO₂ 0.04 lb/mmBtu
- VOC 0.03 lb/mmBtu

Again, these numbers represent theoretical rates, based on a variety of data, some of which contradicted each other, due to limited data for this type of application. It was assumed that the low sulfur content of tires would result in lower SO₂ rates as compared to coal and oil combustion emissions. Also, the expected high flame temperatures suggested lower CO and VOC values as well.

Table 11 List of US and Canadian Facilities Utilizing Tire-derived Fuel

State	Town	Company	Plant	Type
AL	Leeds	Lehigh	Leeds	Cement
AL	Theodore	Holcim		Cement
AL	Mobile	IPSCO Steel		Electric Arc Furnace
AR	Foreman	Ash Grove		Cement
AZ	Tucson	California Portland	Rillito	Cement
BC	Port Alberni	Pacifica Papers		Specialty Paper (1200 tonnes/day lightweight coated, telephone directory and newsprint)
BC	Richmond	LaFarge		Cement
BC	Tilbury	CBR		Cement
CA	Baja	Cemex		Cement
CA	Cupertino	Kaiser Cement		Cement
CA	Davenport (near Santa Cruz)	RMC Lonestar	Davenport	
CA	Lebec	National Cement Co.		Cement
CA	Lucerne Valley	Mitsubishi Cement Co.	Cushenbury	Cement
CA	Modesto	Modesto Energy Limited Partnership (MELP)		Dedicated Tire Incinerator
CA	Mojave	California Portland	Mojave	Cement
CA	Monolith	Calaveras Cement Co.		Cement
CA	Ora Grande	Riverside		Cement
CA	Redding	California Portland		Cement
CA	Redding	Calaveras Cement Co.		
CA	Riverside	Riverside Cement Co.	Crestmore	Cement
CA	San Bernardino	California Portland	Colton	Cement
CA	Victorville	Southwestern Portland Cement	Quarry	Cement
CO	Portland	Holnam		Cement
CT	Sterling	Exter Energy Limited Partnership		Dedicated Tire Incinerator
FL	Brooksville	FL Crushed Stone		Cement
FL	Brooksville	Southdown		Cement
FL	Ridge	Wheelabrator Technologies	Ridge	Incinerator
FL	Suwannee	Suwannee American (Anderson-Columbia)		Cement
GA	Clinchfield	Medusa		Cement
IA	Mason City	Holcim		Cement
ID	Inkom	Ash Grove		Cement
IL	Ford Heights	KTI Inc. / Casella Waste Systems		Dedicated Tire Incinerator
IL	LaSalle	Illinois Cement		Cement
IL	Oglesby	Lone Star		Cement

KS	Humboldt	Monarch		Cement
MD	Frederick	ESSROC		Cement
MD	Hagerstown	Independent		Cement
MD	Hagerstown	St. Lawrence		Cement
MD	Union Bridge	Lehigh		Cement
MN	Preston	Heartland Energy and Recycling		Dedicated Tire Incinerator
MO	Cape Girardea	Lone Star		Cement
MO	Clarksville	Holcim		Cement
MO	Columbia	Missouri University		Power plant (produces steam and electricity to entire university)
NE	Norfolk	Nucor Steel	Nucor Steel Nebraska	Electric Arc Furnace
NE	Louisville	Ash Grove Cement	Louisville Plant	Cement
NY	Hempstead	American Ref-Fuel		Trash Incinerator
NY	Hudson	Holcim / St. Lawrence Cement		Cement
NY	Ticonderoga	International Paper		Paper Mill
NY	Auburn	Nucor Steel	Nucor Auburn	Electric Arc Furnace
NY	Niagara Falls	WPS Empire State		Power Plant
OR	Durkee	Pt. Ash Grove		Cement
PA	Bessemer	ESSROC		Cement
PA	Point Twp.	Tractebel/Viking		Wood Burner
PA	Allentown	Lehigh		Cement
PA	Whitehall	LaFarge		Cement
PA	Chester	Kimberly-Clark		Paper mill (tissue products)
PA	Ebensberg	El Paso Corp.	Cambria Cogen	Power Plant
PA	Evansville	Lehigh Portland Cement		Cement
PA	Lock Haven	International Paper		Paper
QC	Joliette	St. Lawrence		Cement
SC	Harleyville	Blue Circle		Cement
TN	Chattanooga	Signal Mt.		Cement
TX	Midlothian	Holcim		Cement
TX	Midlothian	No.Tex.Cem		Cement
UT	Devil's Slide	Holcim		Cement
UT	Leamington	Ash Grove		Cement
WA	Seattle	Ash Grove		Cement
WA	Seattle	Holcim		Cement
WI	Ashland	Xcel	Bay Front	Coal Power Plant
WV	Grant Town	American Bituminous Power LP	Grant Town Power Plant	Power Plant
WV	Martinsburg	Capitol Cement		Cement

9.2 Emission Calculations

Using the estimated, expected emission rates listed above, the following ton-per-year values were calculated based on an expected 150 mmBtu power output, and 8,760 hours per year operating time. Note that some emission factors are available in pound per ton of clinker produced. The average heat required to produce a ton of cement clinker is 5 mmBtu.

- NO_x 262 tpy
- CO 20 tpy
- Particulate 39 tpy
- SO₂ 26 tpy
- VOC 20 tpy

For this case study, emission control alternatives within a BAT analysis are assessed for pollutants with annual emissions greater than 1 tpy. Based on the calculated emissions listed above, this BAT analysis will include NO_x, particulate, SO₂, CO and VOC.

9.3 RBLC Database

A search of the RBLC returned no entries for cement kilns fueled by TDF.

9.4 Existing US Regulations

A portland cement plant that is constructed, reconstructed or modified may need to comply with New Source Performance Standards (40 CFR 60 Subpart F). The NSPS provides emission standards for particulate from the kiln of 0.3 lb per ton (approximately 0.06 lb per mmBtu/hr). There is also a MACT regulation for hazardous air pollutants (40 CFR 63 Subpart LLL) for the portland cement manufacturing industry. The purpose of the regulation is to minimize the release of the hazardous components of the particulate and organic emissions. The particulate standard is unchanged from the NSPS, but has more clarity for the different types of cement manufacturing technologies. Additionally, the MACT standard includes a limit for VOC of 50 ppm.

9.5 Emission Control Options

One resource for identifying emission control options is an EPA-sponsored database entitled New and Emerging Environmental Technologies (NEET) Clean Air Technologies Database. The database can be reached as a link to the RBLC database or directly online at <<http://neet.rti.org>>. Sorting by pollutant, stationary source, captured emissions, and commercial availability provided a list of control options. Additionally, the document, *EPA Air Pollution Control Cost Manual—Sixth Edition* (EPA 452/B-02-001), provides a chapter for each criteria pollutant. The manual can be accessed electronically through the RBLC under the link called **Reference Library** at <<http://www.epa.gov/ttn/catc>>. Another resource was an EPA guidance manual entitled *Alternative Control Techniques Document—NO_x Emissions from Cement Manufacturing* (EPA-453/R-94-004).

9.6 Particulate Control Technologies

While the use of scrap tires as fuel offers significant reductions in CO, SO₂ and THC over its fossil fuel counterparts, historical data and past experience indicate that tire fuel has significantly higher particulate emission rates and certain metal emission rates, specifically lead (Pb), arsenic (As) and zinc (Zn). Uncontrolled particulate emission rates are expected to be approximately 20 lb/mmBtu, whereas the NSPS standard for cement kilns is 0.3 lb per ton (0.06 lb/mmBtu). In order to comply with air quality standards, a flue gas control technology of a cyclone followed by a baghouse was proposed by the vendor. Because the use of scrap tires as fuel is a relatively unique method of power generation, few control technologies exist which were designed specifically for use on tire-fueled kilns. However, wide ranges of particulate controls have been used for similar applications, which offer practical solutions for tire-fueled situations as well.

9.6.1 Electrostatic Precipitator

ESPs are a commonly used means of collecting particulates from flue gas. The precipitators consist of electrically charged plates or tubes installed inside an exhaust stack. A first set of plates is negatively charged, which causes the particles that pass through it to take on a negative charge. The second, positively charged set of plates captures the charged particulates. Research has indicated that the use of ESPs has been the only solution to particulate control of tire-fueled flue gas, making it a very attractive option for BAT.

Environmental Impacts

ESP systems have achieved emission reductions of up to 99% in past tire-fueled particulate reduction applications. Furthermore, they can produce significant reductions in SO₂ as well. The plates must be cleaned occasionally, generating a small amount of solid waste, but otherwise ESPs generate no negative environmental backlashes.

Energy Impacts

Some electricity is required to charge the plates within the electrostatic precipitator. The amount of energy depends on the type of device, the exhaust flow rate, and the desired reduction rate.

Economic Impacts

A typical ESP system will cost \$15/scfm of exhaust flow. For a system of this size this would equate to approximately \$750,000 total capital cost, or about \$17,300 per ton reduced.

9.6.2 Wet Scrubber

Wet scrubbers have been used as particulate controls for many stationary source applications, though there is little documentation available on the applicability of wet scrubbers to tire-fueled plants. Theoretically, wet scrubbers are a practical means of particle reduction for any application. Wet scrubbers spray mist into smoke stacks. The water particles collide with ash particles, and fall into a collection area. The disadvantages of this system are that a continuous water supply is needed, and a wastewater is produced. Additionally, it is unknown how effective the system will be in handling the specific pollutants caused by tire burning (Zn, As, Pb, etc.). Although feasible, this option is not

considered the best available control option because of the negative environmental impacts and the uncertainty of its ability to properly cleanse the smoke of these heavy metals.

9.6.3 Baghouse

A baghouse consists of several layers of cloth-like material that the polluted exhaust gases are forced to flow through. The cloth bags collect dry particles and exhume fresh air. While efficient, they carry the burden of high capital cost, and create a pressure drop within the combustion chamber. A pressure drop will increase operating cost, and could possibly have unforeseen effects on the combustion process. Although the high exhaust temperature and organic content of the particulates create design challenges for a baghouse, the technology has been utilized in similarly challenging applications. The burden of meeting the NSPS standard for particulate from a cement-manufacturing kiln would require the control efficiency offered by a baghouse.

9.6.4 Cyclone

A cyclone system simply accelerates the exhaust gas to high speeds, causing large particulates to separate from the gas, much like a large centrifuge. Because only the larger particles are removed by this method, it is rarely used as a stand-alone solution to particulate emissions. Furthermore, the cyclone causes a pressure drop, much like a baghouse system, which decreases combustion efficiency and may actually increase the emission rate for certain pollutants for this application. This option was deemed infeasible.

9.7 Review of NO_x Emission Control Options

Research has indicated that test data show an expected 20–30% decrease in NO_x emissions when using tires as combustion fuel over coal. Therefore, the target emission rate will be based upon a search of the EPA literature (for NO_x emissions), which indicates an uncontrolled NO_x emission rate of approximately 1.0 lb/mmBtu. Based on the use of TDF and controlled by an SNCR, the emission rate of 0.4 lb/mmBtu is attainable. Therefore, NO_x control methods will have to be implemented. Because this is an unprecedented project, it is assumed that NO_x controls for coal-fired kilns will have a similar effect on tire-fueled kilns. A review of other cement kiln information indicates SNCR systems are popular NO_x treatments. All other options will also be explored.

9.7.1 Low-NO_x Burner (LNB)

An LNB is a specially designed burner that is capable of controlling flame temperatures in such a manner as to minimize NO_x emissions. By forcing additional air into the outer firing zone, a staged combustion is created, which limits NO_x by decreasing the flame temperature and residence time. This system is effective as a stand-alone solution to NO_x emissions, but is also often supplemented by an overfire air (OFA) or selective non-catalytic reduction (SNCR) system.

Environmental Impacts

LNBs typically generate NO_x reductions in the range of 30–50%, without the use of overfire air. The use of an OFA system will push these numbers even higher. NO_x reduction techniques that involve reduced flame temperature and residence time, such as an LNB, carry the burden of increased CO emissions.

Energy Impacts

LNBs require only slight increases in energy consumption. The cooler flame temperatures associated with LNBs are essentially a decrease in burner efficiency, which results in the need to burn more fuel to reach the same power output. Furthermore, an LNB utilizes blowers to control airflow, which require small amounts of energy to operate.

Economic Impacts

Installing LNBs in a new device (as opposed to retrofitting an existing burner) is surprisingly inexpensive, at approximately \$0.3/kWh. Assuming 40% NO_x reduction efficiency, this system will cost approximately \$62 per ton NO_x removed. The addition of an OFA system at a rate of \$0.5/kWh with an expected efficiency of 60% decreases this number to \$60 per ton NO_x removed.

9.7.2 Selective Non-catalytic Reduction

A selective non-catalytic reduction (SNCR) system is an exhaust after-treatment device that utilizes the abilities of certain compounds, most commonly urea or ammonia, to react with NO_x emissions to form benign chemical compositions. At temperatures of 1700 F, the reaction takes place very quickly, resulting in significant NO_x reductions. Historically, SNCRs have been successful NO_x control devices for high temperature exhaust stream applications. The drawbacks of SNCRs are that they tend to have high operating costs, and the exhaust must meet certain temperature and pressure values for the device to function properly.

Environmental Impacts

At optimum operating conditions, expected NO_x reductions of approximately 60% on top of any pre-combustion controls (such as LNB or OFA) are realized by the installation of an SNCR. The efficiency and final emissions rates are very difficult to predict, however, as they depend on the SNCR unit, and the pressure and temperature achieved in the stack. While the ammonia feed rates in SNCR systems are designed to minimize any release of ammonia, most manufactures specify an ammonia emission rate between 2 and 10 ppm.

Energy Impacts

The ammonia sprayers draw small amounts of power, and operating an SNCR also implies certain indirect increases in energy consumption, such as the energy required to create and transport ammonia. Otherwise, SNCR systems have no significant effect on power usage.

Economic Impacts

The installation of an SNCR for this size system is expected to cost approximately \$60,000, plus additional annual maintenance and urea costs. At this price, with an expected 60% efficiency, the system will cost \$22,800 per ton NO_x removed. Coupled with an LNB and OFA system, the overall system efficiency is expected to increase to approximately 90%. Under these conditions, the total cost would be \$15,200 per ton NO_x removed.

9.7.3 Selective Catalytic Reduction

A selective catalytic reduction (SCR) system works in much the same way as an SNCR system. The difference between the two is that SCR systems also contain a mesh of precious-metal catalysts within the exhaust stack that facilitate a more efficient reaction at a wider temperature range. While more efficient than SNCR, the catalysts used in SCR systems are quite expensive and not entirely necessary for conditions where ideal reaction temperatures are met. Since the catalyst cost will increase the already high cost-per-ton values expected from an SNCR, this option was determined not to be technically feasible.

9.8 Review of CO Emission Control Options

Carbon monoxide is created during a combustion process when excess carbon in the fuel reacts with oxygen in the air. Therefore, there are only three control options: 1) to use a fuel with a lower carbon content, 2) to increase the combustion efficiency (thus increasing NO_x emissions), or 3) to impose an exhaust after-treatment.

9.8.1 Good Combustion Practices

While increasing the furnace efficiency will achieve CO reductions, this practice will cause a steep increase in NO_x emissions. Therefore, the efficiency must be within a certain range offering the lowest possible combined NO_x and CO emissions that cannot be sacrificed, as it would be environmentally infeasible.

9.8.2 Oxidation Catalyst

Oxidation catalyst modules and pre-engineered packages are the cost-effective way to eliminate or reduce carbon monoxide and have a side benefit of also reducing unburned hydrocarbon emissions. Oxidation catalysts are manufactured with durable, high-efficiency, precious metal-based formulations on modules providing low pressure-drop and high catalytic activity. Typical catalysts are made with a metal and ceramic honeycomb substrate coupled with application-specific washcoats and catalyst coatings. The precious metal-based formulations provide high destruction levels at lower operating temperatures. The use of high-activity, poison-resistant formulations means reduction of carbon monoxide (CO), of unburned hydrocarbon and of odors, at lower temperatures and with less catalyst volume—less volume means lower capital cost and lower temperatures means lower operating cost. In some cases, pollutant destruction levels of over 98% can be achieved. Post-combustion CO oxidation techniques have been applied to gas turbines and reciprocating engines, and would theoretically be applicable to boilers as well.

9.8.3 CO Spray Catalyst

Theoretically, the oxidation of CO to CO₂ could be achieved by adding the catalyst to the mist of a wet scrubber, if applied at the high temperature point in the exhaust stack. However, as this has not yet been attempted for this application, to institute this system would require considerable research and development, and the emission reduction percentages would be unknown unless tested both before and after implementation, which would require even further capital. Therefore, this technique was deemed to be economically infeasible for this application.

9.9 Review of SO₂ Emission Control Options

SO₂ emissions will be directly proportional to the sulfur content of the fuel being burned. Tires are expected to have a very low sulfur content as compared to traditional liquid or solid fuels used in cement kilns. In the following are SO₂ control alternatives.

9.9.1 Flue Gas Desulfurization

A post-combustion FGD system uses an alkaline reagent to absorb SO₂ in the flue gas and produce a sodium and calcium sulfate compound. These solid sulfate compounds are then removed in downstream equipment. FGD technologies are categorized as wet, semi-dry, or dry, depending on the state of the reagent as it leaves the absorber vessel. These processes are either regenerable (such that the reagent material can be treated and reused) or nonregenerable (in which case all waste streams are de-watered and discarded). Wet regenerable FGD systems are attractive because they have the potential for better than 95% SO₂ control, have minimal wastewater discharges, and produce a saleable sulfur product.

9.10 BAT Analysis Conclusion

For PM, the vendor specified an emission rate of 0.06 lb/mmBtu, which matches the EPA's new source performance standard promulgated in 1977 and the more recently promulgated MACT standard. Because of the decision to utilize tires as a fuel source, the best available particulate controls will be needed just to meet the existing standard. Lowering of the particulate emission level beyond the existing standard does not appear reasonable. As such, the proposed emission control of a pre-control cyclone followed by a baghouse is considered BAT. (The purpose of the pre-control cyclone is to reduce the maintenance cost of the baghouse.)

For NO_x, the vendor specified an emission rate of 0.4 lb/mmBtu, which matches the rate based on control with an SNCR. This NO_x BAT analysis identified that SCR is capable of achieving higher control efficiencies. However, the particulate loading and high exhaust temperature would be problematic for SCRs. Currently in the US, there is much controversy about the capability of SCR to control NO_x from cement kilns. The State of New York approved the construction of a new cement manufacturing plant with NO_x controlled approximately 60% by an SNCR. An environmental group challenged the decision during the public hearing process. The environmental group provided information about a cement plant in Germany that was showing success with the use of an SCR to control NO_x from a slipstream of a cement kiln. Discussion with a US-based manufacturer of SCR catalyst indicated that, at this time, it didn't feel that it could guarantee the effective use of SCR to control a cement kiln exhaust over time due to the potential damage by the chemical makeup of the cement dust.

For SO₂, the vendor specified an emission rate of 0.04 lb/mmBtu, which represents an uncontrolled rate due to the low sulfur content anticipated in tires. As such, this SO₂ BAT analysis has concluded that no additional SO₂ control was economically feasible.

For CO, the vendor specified an emission rate of 0.03 lb/mmBtu, which can be accomplished through good combustion practices. Due to efforts to reduce NO_x through add-on controls, CO levels

can be minimized through combustion optimization. Because the NO_x BAT analysis recommended a post-combustion control SNCR, the boiler will be able to be tuned for the most efficient operating points which will keep CO levels down to the vendor-specified rate. As such, the CO BAT analysis concluded that CO control will only be “efficient operation.”

For VOC, the boiler vendor specified an emission rate of 0.03 lb/mmBtu, which can be accomplished through good combustion practices. The level of 0.03 lb/mmBtu is approximately 50 ppm, which is the MACT standard for the portland cement manufacturing industry. Because the NO_x BAT analysis recommended a post-combustion control SNCR, the unit will be able to be tuned for the most efficient operating points which will keep VOC levels down to the vendor-specified rate. As such, the VOC BAT analysis concluded that VOC control will only be “efficient operation.”

Appendix A – New Source Performance Standards

40 CFR 60 - NEW SOURCE PERFORMANCE STANDARDS	
Subpart	Title
Cb	Large Municipal Waste Combustors
Cc	Municipal Solid Waste Landfills
Cd	Sulfuric Acid Production Units
Ce	Hospital/Medical/Infectious Waste Incinerators
D	Fossil Fuel-Fired Steam Generators
Da	Electric Utility Steam Generating Units
Db	Industrial-Commercial-Institutional Steam Generating Units
Dc	Small Industrial-Commercial-Institutional Steam Generating Units
E	Incinerators
Ea	Municipal Waste Combustors (Construction post 12/89 or prior to 9/94)
Eb	Large Municipal Waste Combustors (Construction post 9/94 or Reconstruction post 6/96)
Ec	Hospital/Medical/Infectious Waste Incinerators (Construction post 6/96)
F	Portland Cement Plants
G	Nitric Acid Plants
H	Sulfuric Acid Plants
I	Asphalt Concrete Plants
J	Petroleum Refineries
K	Storage Vessels (Construction June 11, 1973-May 19, 1978)
Ka	Storage Vessels (May 18, 1978-July 23, 1984)
Kb	Storage Vessels (Commenced after July 23, 1984)
L	Secondary Lead Smelters
M	Secondary Brass and Bronze Ingot Production Plants
N	Iron and Steel Plants Constructed after June 11, 1973
Na	Iron and Steel Plants Constructed after January 20, 1983
O	Sewage Treatment Plants
P	Copper
Q	Zinc
R	Lead
S	Primary Aluminum Reduction Plants
T	Phosphate Fertilizer Industry
U	Superphosphoric Acid Plants
V	Diammonium Phosphate Plants
W	Triple Superphosphate Plants
X	Granular Triple Superphosphate Storage Facilities
Y	Coal Preparation Plants
Z	Ferroalloy Production Facilities
AA	Steel Plants: Electric Arc Furnaces
AAa	Steel Plants: Electric Arc Furnaces and Argon-Oxygen Decarburization Vessels Constructed after 8/17/83
BB	Kraft Pulp Mills
CC	Glass Manufacturing Plants
DD	Grain Elevators
EE	Surface Coating of Metal Furniture
GG	Stationary Gas Turbines
HH	Lime Manufacturing Plants
KK	Lead-acid battery manufacturing plants
LL	Metallic Mineral Processing Plants
MM	Automobile and Light-Duty Truck Surface Coating Operations
NN	Phosphate Rock Plants
PP	Ammonium Sulfate Manufacture Plants
QQ	Graphic Arts Industry: Publication Rotogravure
RR	Pressure Sensitive Tape and Label Surface Coating Operations

SS	Industrial Surface Coating: Large Appliances
TT	Metal Coil Surface Coating
UU	Asphalt Processing and Asphalt Roofing Manufacture
VV	Equipment Leaks of VOC in the Synthetic Organic Chemicals Manufacturing Industry
WW	Beverage Can Surface Coating Industry
XX	Bulk Gasoline Terminals
AAA	New Residential Wood Heaters
BBB	Rubber Tire Manufacturing Industry
DDD	Polymer Manufacturing Industry
FFF	Flexible Vinyl and Urethane Coating and Printing
GGG	Equipment Leaks of VOC in Petroleum-Refineries
HHH	Synthetic Fiber Production Facilities
III	Synthetic Organic Chemical Manufacturing Industry Air Oxidation Unit Processes
JJJ	Petroleum Dry Cleaners
KKK	Onshore Natural Gas Processing Plants
LLL	Onshore Natural Gas Processing
NNN	Synthetic Organic Chemical Manufacturing Industry Distillation Operations
OOO	Nonmetallic Mineral Processing Plants
PPP	Wool Fiberglass Insulation Manufacturing Plants
QQQ	Petroleum Refinery Wastewater System VOC Emissions
RRR	Synthetic Organic Chemical Manufacturing
SSS	Magnetic Tape Coating Facilities
TTT	Industrial Surface Coating: Plastic Parts for Business Machines
UUU	Calciners and Dryers in Mineral Industries
VVV	Polymeric Coating of Supporting Substrates Facilities
WWW	Municipal Solid Waste Landfills
AAAA	Small Municipal Waste (Commenced Post 8/99 or Reconstruction 6/01)
BBBB	Small Municipal Waste Combustion (Construction prior to 8/99)
CCCC	Solid Waste Incineration (Commenced post 11/99 or Reconstruction post 6/01)
DDDD	Solid Waste Incineration (Commenced prior 11/99)

Appendix B – National Emission Standards for Hazardous Air Pollutants

National Emission Standards for Hazardous Air Pollutants	
last updated: 12/13/04	
NESHAP (MACT) STANDARD Source Categories Affected	CFR Subparts
Aerospace	GG
Asbestos	M
Asphalt Processing and Asphalt Roofing Manufacturing	LLLLL
Auto & Light Duty Truck* (surface coating)	IIII
Benzene Waste Operations*	FF
Boat Manufacturing	VVVV
Brick and Structural Clay Products Manufacturing	JJJJJ
Clay Ceramics Manufacturing	KKKKK
Cellulose Products Manufacturing	UUUU
Chromium Electroplating	N
Coke Ovens: Pushing, Quenching, & Battery Stacks*	CCCCC
Coke Ovens	L
Combustion Sources at Kraft, Soda, and Sulfite Pulp & Paper Mills (Pulp and Paper MACT II)	MM
Commercial Sterilizers	O
Degreasing Organic Cleaners	T
Dry Cleaning	M
Engine Test Cells/Stands	PPPPP
Fabric Printing, Coating & Dyeing	OOOO
Ferroalloys Production	XXX
Flexible Polyurethane Foam Fabrication Operation	MMMMM
Flexible Polyurethane Foam Production	III
Friction Products Manufacturing	QQQQQ
Gasoline Distribution (Stage 1)	R
General Provisions	A
Generic MACT +	YY
Generic MACT +	YY
Hazardous Waste Combustion	Parts 63,261 and 270
Hazardous Organic NESHAP	F, G, H, I
Hydrochloric Acid Production	NNNNN
Industrial, Commercial and Institutional Boilers and Process Heaters	DDDDD
Industrial Cooling Towers	Q
Integrated Iron and Steel	FFFFF
Iron and Steel Foundries*	EEEEE
Large Appliances (surface coating)	NNNN
Leather Finishing Operations	TTTT
Lime Manufacturing	AAAAA
Magnetic Tape (surface coating)	EE
Manufacturing Nutritional Yeast (formerly Bakers Yeast)	CCCC
Marine Vessel Loading Operations	Y
Mercury Cell Chlor-Alkali Plants (formerly Chlorine Production)	IIIII
Metal Can (surface coating)	KKKK
Metal Coil (surface coating)	SSSS

Metal Furniture (surface coating)	RRRR
Mineral Wool Production	DDD
Misc. Coating Manufacturing	HHHHH
Misc. Metal Parts and Products (surface coating)	MMMM
Misc. Organic Chemical Production and Processes (MON)	FFFF
Municipal Solid Waste Landfills	AAAA
Natural Gas Transmission and Storage	HHH
Off-Site Waste Recovery Operations	DD
Oil & Natural Gas Production	HH
Organic Liquids Distribution (non-gasoline)	EEEE
Paper and Other Web (surface coating)	JJJJ
Petroleum Refineries	CC
Petroleum Refineries	UUU
Pharmaceuticals Production	GGG
Phosphoric Acid	AA
Phosphate Fertilizers	BB
Plastic Parts (surface coating)	PPPP
Plywood and Composite Wood Products (formerly Plywood and Particle Board Manufacturing)	DDDD
Polyether Polyols Production	PPP
Polymers & Resins I	U
Polymers & Resins II	W
Polymers & Resins III	OOO
Polymers & Resins IV	JJJ
Polyvinyl Chloride and Copolymers Production	J
Portland Cement Manufacturing	LLL
Primary Aluminum	LL
Primary Lead Smelting	TTT
Primary Copper	QQQ
Primary Magnesium Refining	TTTTT
Printing and Publishing (surface coating)	KK
Publicly Owned Treatment Works (POTW)	VVV
Pulp & Paper (non-combust) MACT I	S
Pulp & Paper (non-chem) MACT III	S
Reciprocating Internal Combustion Engines (RICE)	ZZZZ
Refractory Products Manufacturing	SSSSS
Reinforced Plastic Composites Production	WWWWW
Rubber Tire Manufacturing	XXXX
Secondary Aluminum	RRR
Secondary Lead Smelters	X
Semiconductor Manufacturing	BBBBB
Shipbuilding & Ship Repair (surface coating)	II
Site Remediation	GGGGG
Solvent Extraction for Vegetable Oil Production	GGGG
Stationary Combustion Turbines*	YYYY
Steel Pickling-HCL Process	CCC
Taconite Iron Ore Processing	RRRRR
Tetrahydrobenzaldehyde Manufacture (Formerly Butadiene Dimers Production)	F
Wet Formed Fiberglass Mat Production	HHHH
Wood Building Products (surface coating) (formerly Flat Wood Paneling Products)	QQQQ
Wood Furniture (surface coating)	JJ
Wool Fiberglass Manufacturing	NNN