The Cost Effectiveness of VOC and NO_x Emission Control Measures

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The Cost Effectiveness of VOC and NO_x Emission Control Measures

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ABSTRACT

The Clean Air Act Amendments of 1990 require that ozone nonattainment areas reduce total volatile organic compound (VOC) emissions by specified amounts, for certain milestone years. In addition, EPA may require similar reductions of nitrogen oxides (NO_x) in the future. For most nonattainment areas, the controls required to meet these Reasonable Further Progress (RFP) milestones may be very costly. Therefore air pollution control plans must evaluate all available emission control options in order to develop the most cost-effective strategy for meeting their RFP reduction targets. Because of local variations in the types of sources and emission rates, these strategies must be developed on an area-specific basis. An RFP analysis was performed for five different ozone nonattainment areas: Baltimore; Chicago; Houston; Philadelphia; and, Washington, D.C.. The first step in this effort entailed collecting VOC and NO_x emission inventory information from the various state agencies. Next, potential control measures were identified from an extensive literature review, considering both technical and economic constraints. In addition, emissions modeling was performed to estimate the effect of mobile source controls for each area. Cost-effectiveness rankings were developed and total progress toward RFP targets were estimated. Available controls range in cost-effectiveness from a net savings up to $500,000 per ton of pollutant. Controls of the currently unregulated non-road mobile source category are essential to meeting these long-run targets. Additional study of the feasibility of applying NO_x controls to major point sources is crucial to assess total reduction potentials accurately.

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EXECUTIVE SUMMARY

Under the requirements of Title I of the 1990 Clean Air Act Amendments (CAAA), all moderate and above ozone nonattainment areas must reduce their volatile organic compound (VOC) emissions by 15 percent by 1996. Depending on the severity of the nonattainment status, a city may have to decrease emissions further, by three percent per year, until attainment is demonstrated. Once attainment is achieved, the city must implement a control plan designed to maintain those standards. In addition to the VOC requirements, specific NO_x reduction requirements may be specified by EPA and the states in the future, based on the results of air quality modeling studies. These emission reduction targets are known as the Reasonable Further Progress, or RFP, requirements, and they present significant technical and economic challenges to state agencies and emission sources.

The main purpose of this study is to provide air pollution control planners and other interested parties with a "menu" of possible control options, using the most up-to-date information and accurate analyses, for <u>all</u> significant sources of VOCs and NO_x. This menu provides a preliminary demonstration of how cost-effective <u>packages</u> of attainment strategies and control measures can be developed to meet RFP targets and achieve attainment, as well as maintain standards after attainment. State agencies may be able to incorporate portions of this study's findings into their 1994 SIP revisions. Final determination of appropriate strategies should be based on the air quality modeling studies required by the CAAA.

One set of control strategies alone cannot be identified that will allow all nonattainment areas to meet their RFP targets and achieve attainment in the most cost-effective manner. Site-specific variations in source distribution and emissions mean that different cities must be analyzed on a case-by-case basis. For this reason, API contracted Radian Corporation to evaluate five different cities: Baltimore, Chicago, Houston, Philadelphia,

and Washington, D.C. These cities are all severe ozone nonattainment areas (with the exception of Washington, D.C., which is serious), and all must develop a broad range of control measures. Various sections of this report may apply to other cities not included in the analysis.

In order to develop site-specific control packages for VOC and NO_x, Radian performed the following tasks:

- Identified major source categories from state inventories;
- Identified feasible control options from literature;
- Model emissions reductions for mobile source controls for each site;
- Conducted technical and economic assessment of options and determined cost-effectiveness rankings; and
- Developed site-specific cost-effective control approaches.

This report provides the initial results of Radian's study. The body of the report discusses the potential control options in a general manner, while the appendices provide a more detailed analysis of costs, effectiveness, and application limitations.

FINDINGS OF RFP ANALYSES

Based upon Radian's analysis, the cities of Chicago and D.C. should be able to meet their 1996 RFP milestones. In addition, Chicago and D.C. can do so in using controls with relatively low cost-effectiveness values (typically $1,000 to $2,000 per ton of VOCs). However, based upon the preliminary emissions inventories provided by the states, the Houston, Baltimore, and Philadelphia areas may not reach their reduction targets, even after applying all available controls, regardless of cost. These shortfalls may be the result of these cities' relatively low emissions from mobile sources (a source category that experiences large percentage reductions by 1996). The shortfalls may also be the result of errors in the emissions inventories received from the states. Figure ES-1 provides a summary of the progress made toward the 1996 RFP milestones, based upon the control strategy packages developed by Radian.[1]

Radian also estimated the potential NO_x reductions available from on and non-road mobile source controls, as well as utility boiler controls, for each city in 1996, 1999, and 2010. Radian adopted a three-tiered control approach for utility boilers, applying low-efficiency controls first, then increasingly more stringent, and costly, controls thereafter. Potential NO_x emission reductions were not estimated for other source categories due to a lack of information on technical feasibility. Nevertheless, Radian found that significant emission reductions could be achieved by applying controls to just these three source categories. Also, potential reductions become greater with time as controls begin to penetrate the non-road source category. Figures ES-2 through ES-4 depict the NO_x reductions that may be obtained in each city, for 1996, 1999, and 2010.

CONCLUSIONS

Based on the findings of this study, the available controls for VOC and NO_x emissions have a wide range of cost-effectiveness values -- anywhere from a cost savings to almost $500,000 per ton of pollutant. Even costs for a given type of control applied to a specific source category can be highly variable, dependant upon site-specific factors such as retrofit feasibility, local conditions, fuel cost, and a host of other factors. Nevertheless, a few general observations can still be made:

- For those cities with relatively high emissions from their vehicle fleet, RFP targets for 1996 may be met without resorting to extremely high cost-effectiveness controls. For those cities with large point source and non-

[1] Since the completion of this study in December of 1993, the state agencies in Pennsylvania and Texas have revised their inventories significantly. Based upon these revisions the agencies anticipate meeting their 1996 ROP targets. However, no speculation was provided regarding the likelihood of meeting later year milestones.

road inventories, 1996 RFP target attainment may require more stringent and expensive measures.

- By and large the mandated mobile source controls, Stage II, RFG, and enhanced I/M provided the greatest boost toward meeting the 1996 RFP targets. Other mobile source controls, such as Clean Fleets and LEVs, cannot generate significant reductions until after 2000.

- Without a downturn in economic growth, and barring major technological breakthroughs, most cities will not be able to meet their RFP targets for 1999 and thereafter relying solely on VOC controls. It is likely that some form of NO_x-for-VOC substitution will be needed to facilitate the process.

- As of this time, non-road mobile sources are one of the last significant uncontrolled sources of VOC emissions. Therefore these sources must be addressed in the future in order to attain and maintain target emission levels.

- With the probable establishment of NO_x emission reduction targets in the near future, it is crucial to assess the feasibility of applying controls beyond the utility and on-road mobile categories. While Radian did find studies in the literature on controls for process heaters, IC engines, and other unregulated NO_x sources, Radian found little to no assessment of the potential application rates of these new controls (i.e., the percentage of sources that can be retrofit with controls considering technical and economic feasibility). A comprehensive technological assessment of retrofit potentials should be undertaken in this regard.

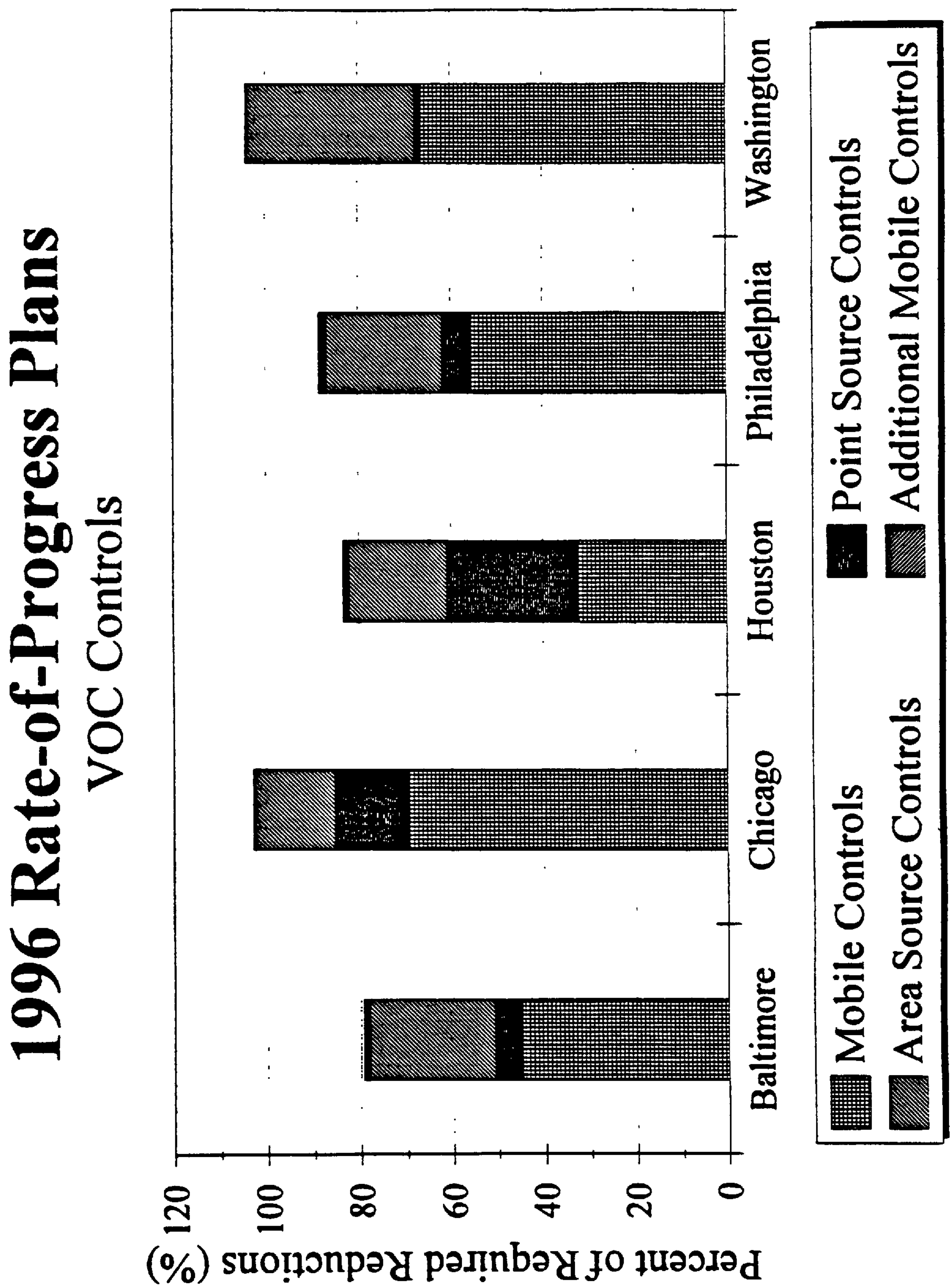

Figure ES-1. Rate-of-Progress Plans by City.

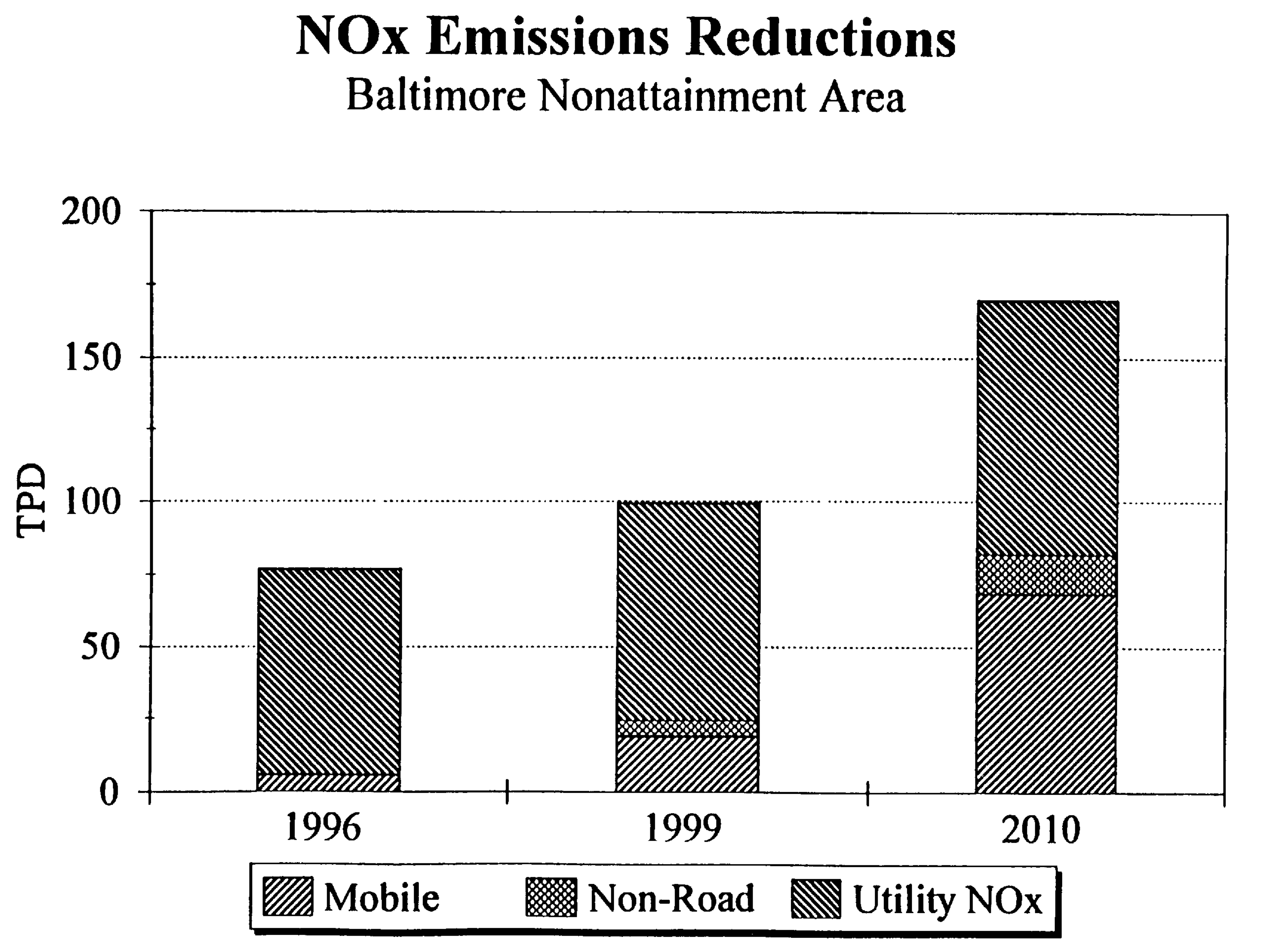

Figure ES-2. NOx Emissions Reductions in Baltimore.

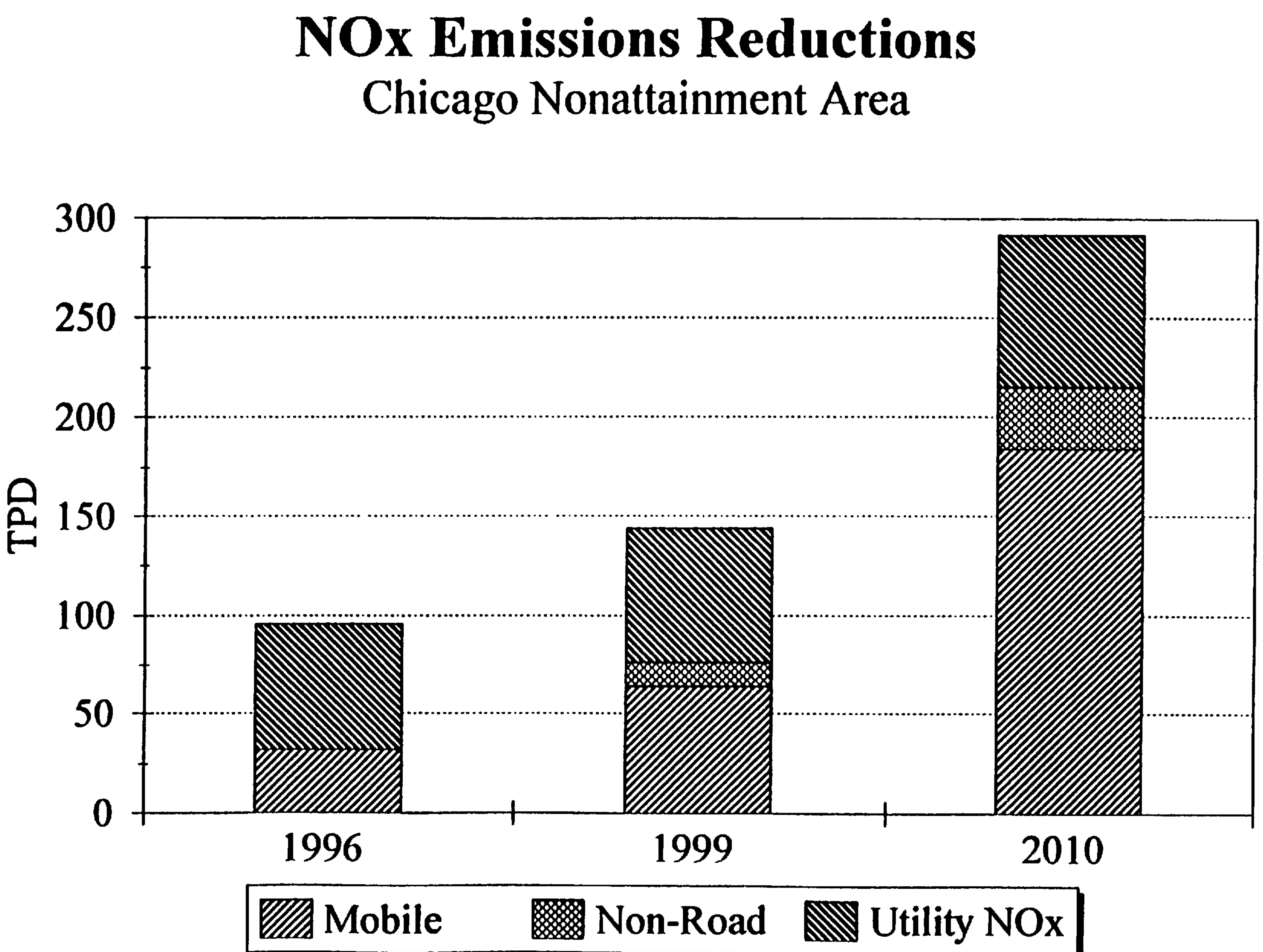

Figure ES-3. NOx Emissions Reductions in Chicago.

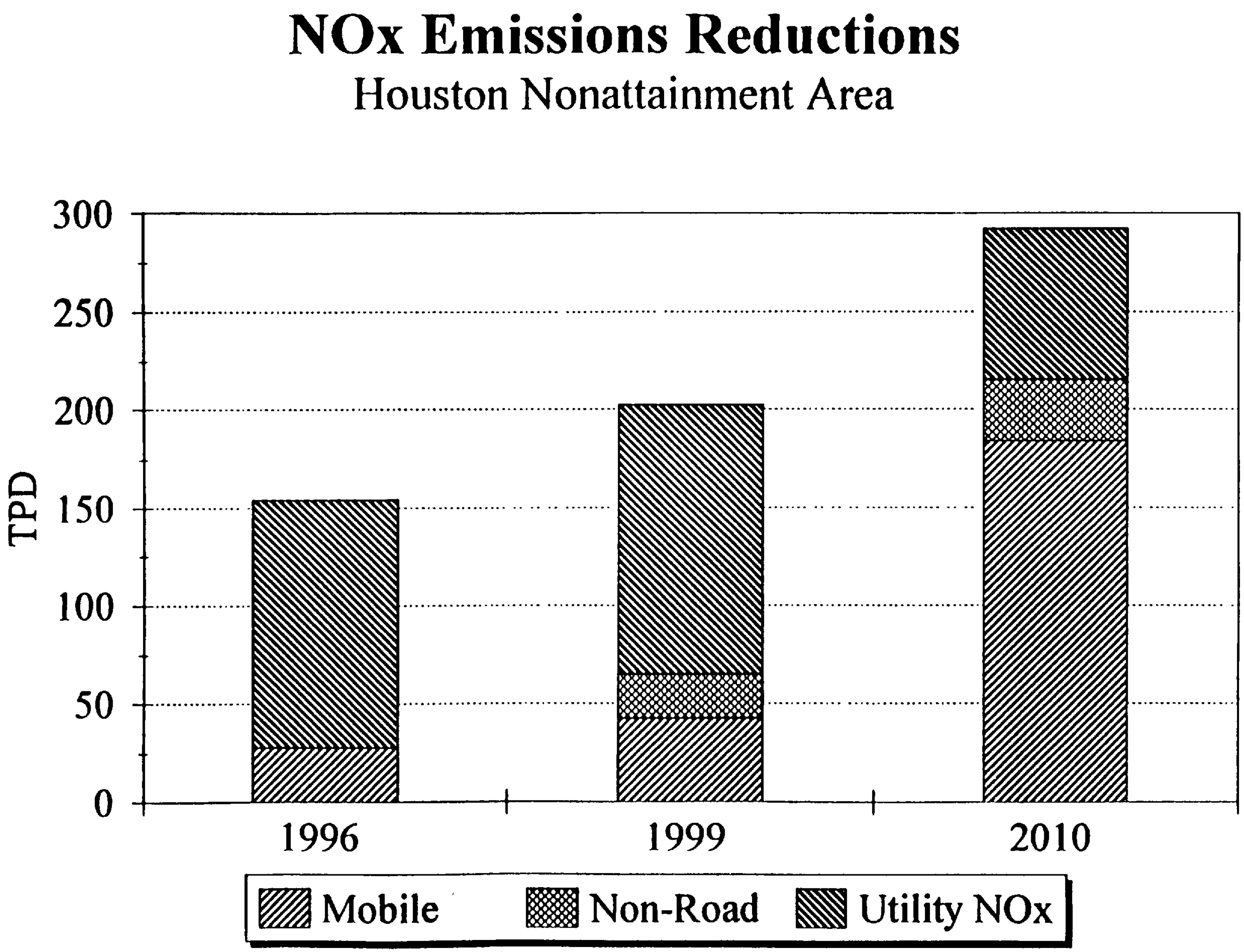

Figure ES-4. NOx Emissions Reductions in Houston.

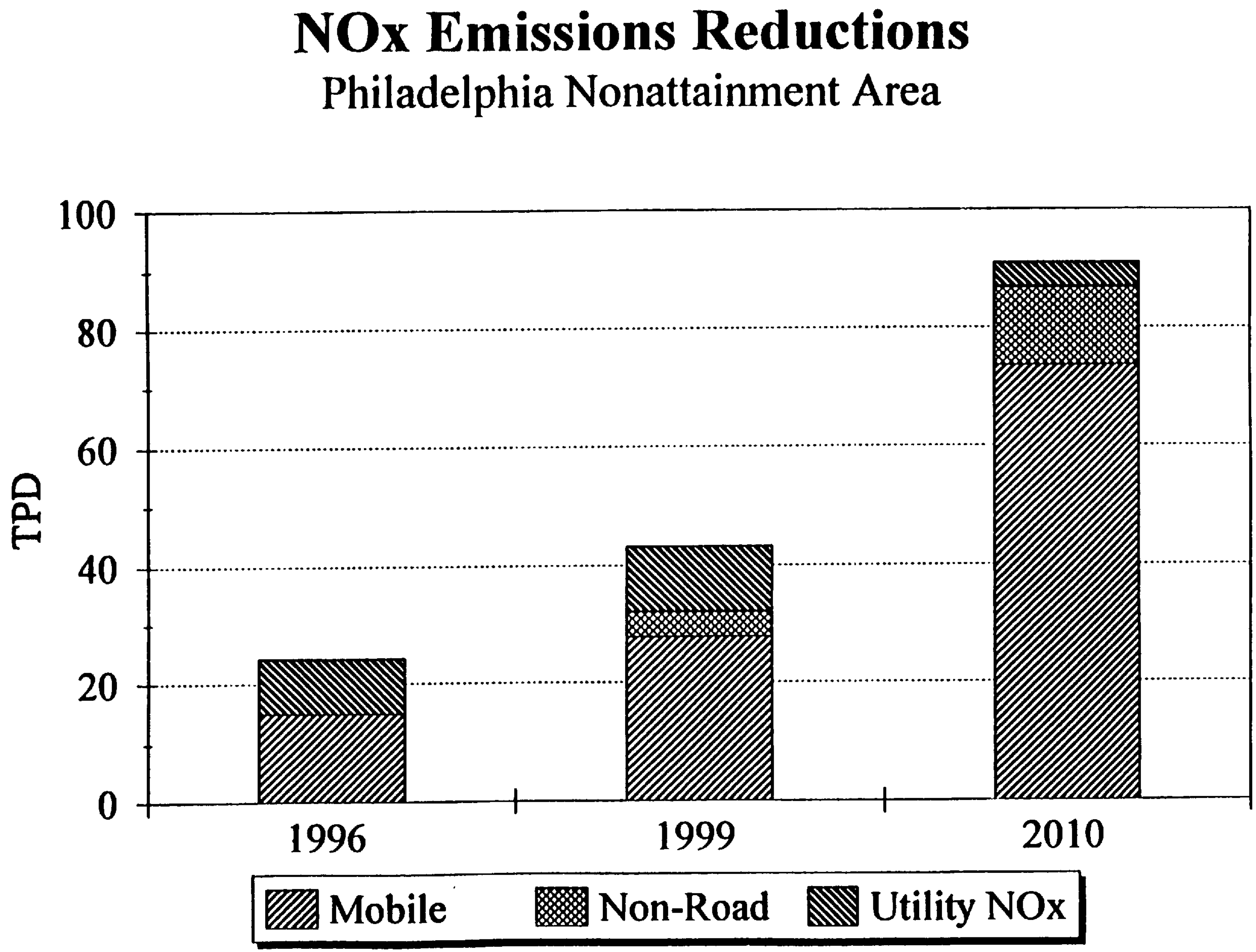

Figure ES-5. NOx Emissions Reductions in Philadelphia.

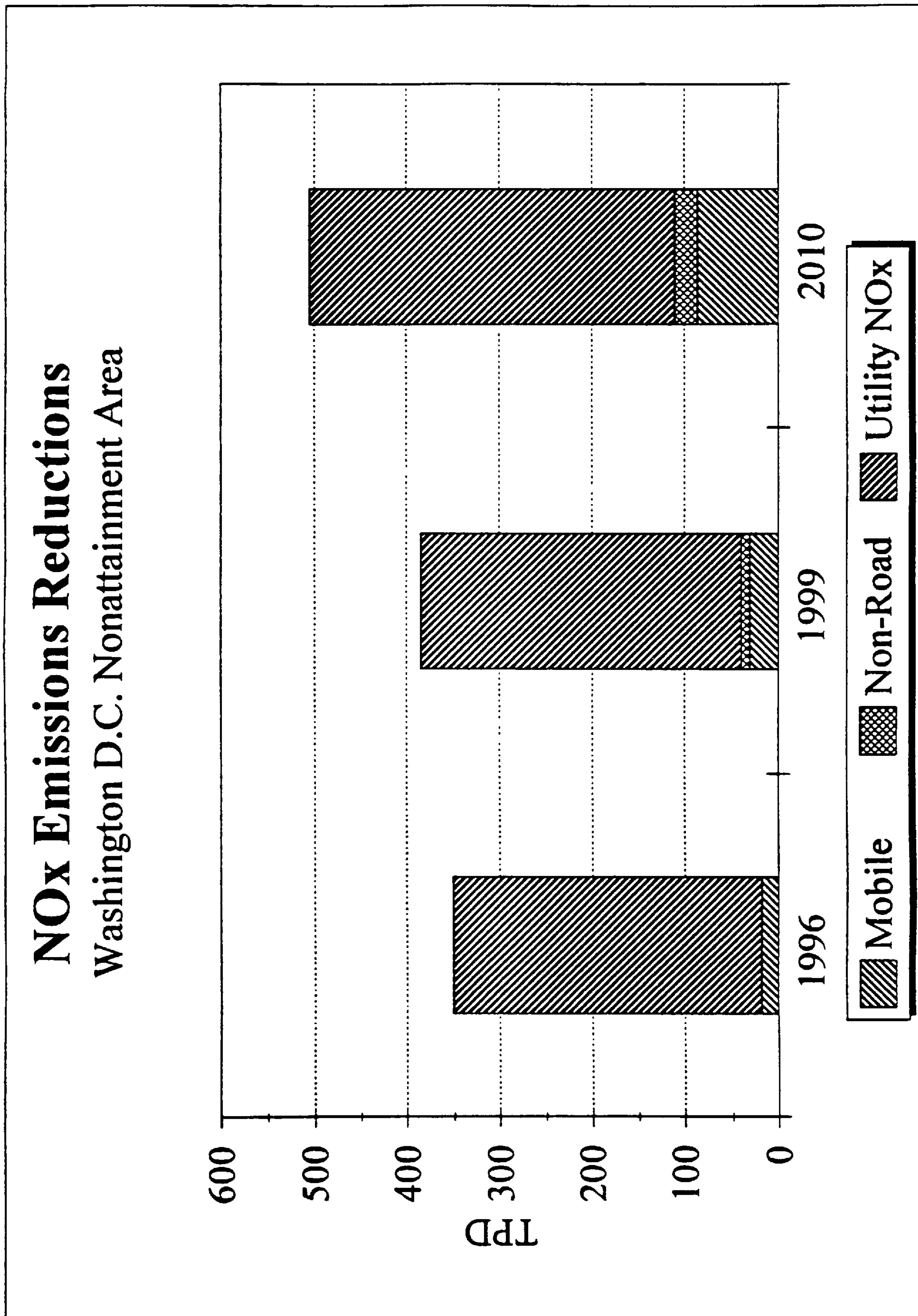

Figure ES-6. NOx Emissions Reductions in Washington D.C.

Section 1

INTRODUCTION

BACKGROUND

Since the initial passage of the Clean Air Act over two decades ago, emissions controls have become increasingly more stringent, and costly, for the largest sources of pollution. These sources include large point sources (e.g., petroleum refineries), and highway vehicles. The first controls applied were very cost-effective by today's standards, often reducing emissions for little or no cost. However, as time progressed and the National Ambient Air Quality Standards (NAAQS) for ozone still were not achieved, more and more stringent and expensive controls had to be adopted in order to continue reducing emissions.

Today, additional air quality regulations may mandate quite costly controls in order to meet new federal requirements. Under the requirements of Title I of the 1990 Clean Air Act Amendments (CAAA), all moderate and above ozone nonattainment areas must reduce their volatile organic compound (VOC) emissions by 15 percent by 1996 from adjusted 1990 levels. Depending on the severity of the nonattainment status, a city may have to decrease emissions further, by three percent per year, until attainment is reached. Once attainment is achieved, the city must implement a control plan designed to maintain those standards. In addition to the VOC requirements, specific NO_x reduction requirements may be adopted by EPA and the states in the future, based on the results of air quality modeling studies. These emission reduction targets are known as the Reasonable Further Progress, or RFP, requirements, and they present significant technical and economic challenges to state agencies and emission sources.

In order to comply with the requirements of the CAA, state air quality agencies must submit a State Implementation Plan, or SIP, demonstrating exactly how they intend to achieve the necessary emissions reductions. States must submit the SIPs to EPA by November of 1993. Revisions to the SIP for the serious and severe nonattainment areas must be submitted one year later to demonstrate attainment based on air quality modeling. To develop these plans, the states can select from a broad "menu" of control strategies and options, covering the entire range of emissions sources, from point and area to on- and non-road mobile sources. Ideally, the state would evaluate all possible controls on the basis of contribution toward meeting the RFP and attainment targets, and choose to implement those that are the most cost-effective first. However, there are large uncertainties associated with both control efficiency and cost estimates. This point is particularly true for sources such as non-road mobile and large NO_x sources, that have not been regulated up to this time.

PURPOSE OF STUDY

The main purpose of this study is to provide SIP planners and other interested parties with a "menu" of possible control options, using the most up-to-date information and accurate analyses available, for <u>all</u> significant sources of VOCs and NO_x. In addition, the study also demonstrates how cost-effective <u>packages</u> of attainment strategies and control measures can be developed to meet RFP targets, as well as maintain standards after attainment. State agencies may be able to incorporate portions of this study's findings into their 1994 SIP revisions.

APPROACH

One set of control strategies alone cannot be identified that will allow all nonattainment areas to meet their RFP targets and achieve attainment in the most cost-effective manner. Site-specific variations in source distribution and other factors mean that different areas must be analyzed on a case-by-case basis. For example, factors such as temperature and average roadway speed have a significant impact on automobile emissions. Therefore mobile source control strategies also will have different impacts, depending on the area. For these reasons, Radian was asked to evaluate controls for five different cities: Baltimore, Chicago, Houston, Philadelphia, and Washington, D.C. These cities are all designated "severe" ozone nonattainment areas (with the exception of Washington, D.C., which is designated "serious"), and all must implement a broad range of control measures. The cities provide a representative cross section of many of the ozone nonattainment areas in the U.S. Therefore, various sections of this report will be applicable to other cities not included in our analysis.

In order to develop site-specific control packages for VOC and NO_x, Radian performed the following tasks:

- Identified major source categories from state inventories;
- Identified feasible control options from literature;
- Modeled mobile source control effectiveness for all five areas;
- Conducted technical and economic assessments of options and determined cost-effectiveness rankings; and
- Developed site-specific cost-effective control approaches.

This report provides the results of Radian's study. The body of the report discusses the potential control options in a general manner, while the appendices provide a more detailed analysis of costs, effectiveness, and application limitations.

Section 2

KEY SOURCE CATEGORIES WITHIN SELECTED OZONE NONATTAINMENT AREAS

INTRODUCTION

Detailed, accurate inventory estimates are critical to the development of effective control strategies and recommendations for meeting RFP requirements. State-generated emission inventories are the basis of all further analysis in our study. The inventories received by Radian from the individual states varied in the level of detail. Quality control checks were done throughout the analysis to determine inconsistencies in the inventories, but resources did not allow us to quantify all the possible discrepancies. Radian therefore acknowledges there are uncertainties with the emissions estimates used in the analysis.

The methods used by the states to generate values in the emission inventories varied with the type of source. Point source estimates were determined using one or more of the following methods: direct measurement from source testing or monitoring data; permits specifying allowable emission rates; and EPA-approved emission factors. Area source emissions were determined using similar methods. The EPA MOBILE (release 5, 5a, or 4.1, depending on the location) emissions model was used to estimate mobile sources emission levels. Non-road mobile source emissions were estimated, primarily using emission factors.

Developing an accurate control strategy analysis also requires a detailed source category breakdown. Therefore the accuracy of this analysis is limited by the degree of detail found in the inventories. For example, if an entry in an emission inventory aggregates chemical manufacturing and petroleum refining activities, it becomes difficult to estimate what specific types of controls are applicable, and their relative contribution to total reduction potentials. Radian found varying levels of source category aggregation in the state inventories.

Uncertainties persist for many source categories, due to differences in the reporting formats among the states. For example, Chicago reported the Storage of Volatile Organic Liquids (VOLs) from all industries as a single source entry, whereas Houston included VOL storage within the Petroleum Refineries and Organic Chemical Manufacturing categories, separately. Another example of differing reporting practices is evident in the Graphic Arts and Printing and Publishing categories. For some of the inventories, emissions from all printing operations were reported within the Graphic Arts category, whereas for other inventories, a distinction was made between the two industries. (Graphic arts consists of flexography and rotogravure printing whereas printing and publishing includes lithography printing.) Similar differences were found with the Gasoline and Crude Oil Storage, Organic Chemical Manufacturing, Industrial Wastewater, Coke Ovens and Coke By-products, Degreasing, and Fuel Combustion categories.

DATA GATHERING

Five nonattainment areas were studied for this project: Baltimore, Chicago, Houston, Philadelphia, and Washington D.C. For each of these areas, Radian contacted the state agency responsible of generating the SIP emission inventory for that area. The main contacts in each city are given in Table 2-1.

Radian asked each agency for the final (or most recent) version of their 1990 SIP inventory, listing point, area and mobile source VOC and NO_x emissions. Most agencies responded promptly to our request providing the necessary information to develop our data base. **However, in some instances the inventories received were not the final inventories used in the November 1993 SIP submittals** -- the Houston and Philadelphia data sent to Radian in September and October of 1993 have been revised significantly since that time. In these instances Radian's analysis may not cover all of the pertinent source categories, and there may be some errors in the projection of future emissions levels. (Nevertheless, Radian believes that the cost-effectiveness values and long-term ROP analysis contained in this report are accurate and dependable.)

The first step in analyzing the data was to obtain a list of all the emission sources in all five areas. In order to do this, Radian chose the list which had the most detailed breakdown of emission sources, and proceeded to complete it with a few missing source categories. The most detailed list was the one developed by the Illinois EPA for the Chicago nonattainment area, which was then entered into a spreadsheet. We reviewed the list of point sources in other cities to find the SIC code corresponding to the Chicago source categories, as several of these inventories were in database form, sorted by SIC code rather than by source category description.

This procedure is not without its drawbacks. In some cases, the classification by SIC Code was done on such a broad basis that all the point sources in a category such as Chemicals and Allied Products were aggregated into one emission number. Given the purpose of this project, a more detailed breakdown was necessary in such cases because it was difficult to identify appropriate control processes without knowing which manufacturing processes were involved. In such cases, we attempted to disaggregate emissions estimates by consulting with industry experts.

Table 2-1. Sources of Inventory Information

City	Agency
Baltimore	Air and Radiation Management Administration
Chicago	Illinois EPA
Houston	TNRCC
Philadelphia	PennDOT, Department of Environmental Resources, City of Philadelphia Department of Public Health
Washington D.C.	Metropolitan Washington Council of Governments

By and large, all area source categories were the same for all cities (e.g. coating sources, solvent use, etc.). Radian completed the inventory compilation by entering on-road mobile source emissions based on the state's MOBILE model runs, as well as non-road mobile emissions.

The completed 1990 emission inventories used in our study can be found in Appendix A.

SOURCE CATEGORIZATION

Due to the size of the emission inventories and the large number of source categories, Radian had to limit the number of categories for detailed review. This selection was done by calculating emission level "cutpoints," and evaluating controls for those sources above this level, specified in tons per year. This level was chosen so as to include approximately 95 percent of the total emissions inventory. Controls for all source categories with total emissions above this cutpoint were evaluated. The cutpoints used to determine these "major" emission sources are provided in Table 2-2.

Table 2-2. Emission Cutpoints

Location	Total 1990 VOC Inventory (tons/day)	VOC Cutpoint (tons/day)	Total 1990 NO_x Inventory (tons/day)	NO_x Cutpoint (tons/day)
Chicago, Illinois	1248.5	3.8	1008.9	10
Washington, D.C.	556.1	8	863.7	20
Baltimore, Maryland	323.5	2.6	430.5	5.9
Philadelphia, Pennsylvania	577.9	6	381.9	7
Houston, Texas	1103.1	10	1347.2	20

Once the cutpoints were established for each city and the major sources were identified, Radian reviewed the available literature to determine possible control strategies. We found that not every source category emitting above the cutpoint level has the potential for further control. Open burning operations, for example, fell within our cutpoints for several areas, but no control can be explicitly applied to this source, with the possible exception of a burning ban. Also, the Chicago inventory has an entry for Other Industrial Processes which is included within the 95 percent level, for which we were unable to assess controls because of its non-descript characterization. Similar situations were found for Plastic Parts Manufacturing and Stage I systems, which were also above the cutpoint levels. Radian did not apply control estimates to these categories for lack of further information.

Perchloroethylene dry cleaning also fell within the 95 percent level. However, perchloroethylene was removed recently from the list of photochemically reactive chemicals and is therefore no longer considered a VOC. Therefore, Radian did not evaluate controls for this source since it is no longer classified as a photochemically reactive emission.

Figures 2-1 through 2-10, presented on the following pages, illustrate the VOC and NO_x inventory breakdowns and provide a visual representation of the relative source contributions for each city.

Although there are some sources within the inventories that account for a large percentage of total emissions, no one source can supply all the emissions reductions needed to meet the RFP targets. It is important to understand that most nonattainment areas have already adopted regulations to limit VOC emissions from stationary sources to a great extent. Therefore, a broad-based, comprehensive control strategy package, including all four source areas (point, area, on-road, and off-road) must be developed.

MAJOR SOURCE CATEGORIES

Table 2-3 provides a summary of the major VOC emission sources by site and Table 2-4 illustrates the distribution of major NO_x sources. Major sources were defined as any category emitting above a region's cutpoint level. If a source was considered major, an "X" is shown in the table to illustrate the distribution of sources within each inventory. Sources denoted by an "○" are sources that were not documented in the emission inventory as major sources but for which, due to the industrial make-up of the region, seem to have been omitted from the inventory.

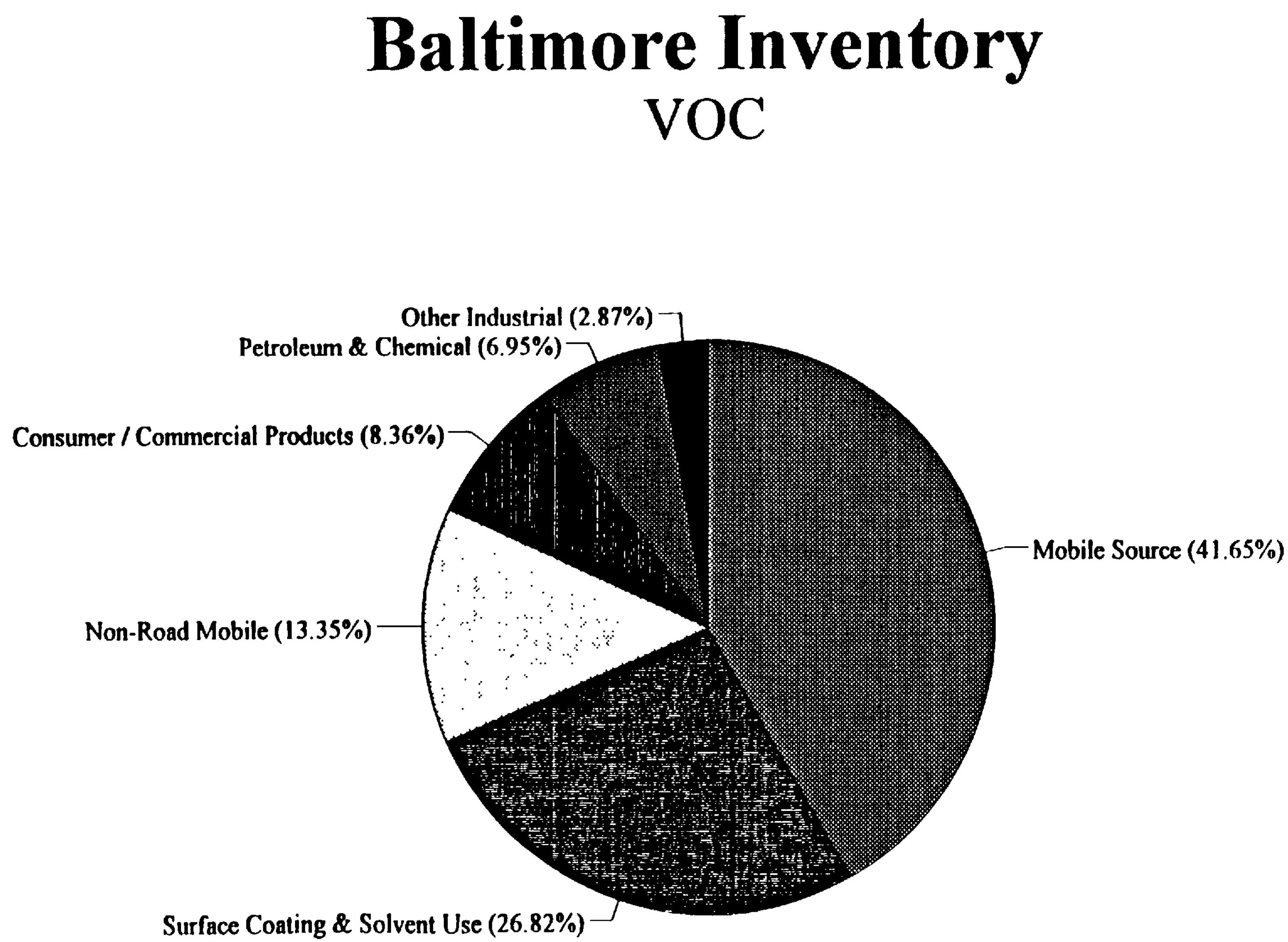

Figure 2-1. 1990 VOC Emissions in the Baltimore Nonattainment Area.

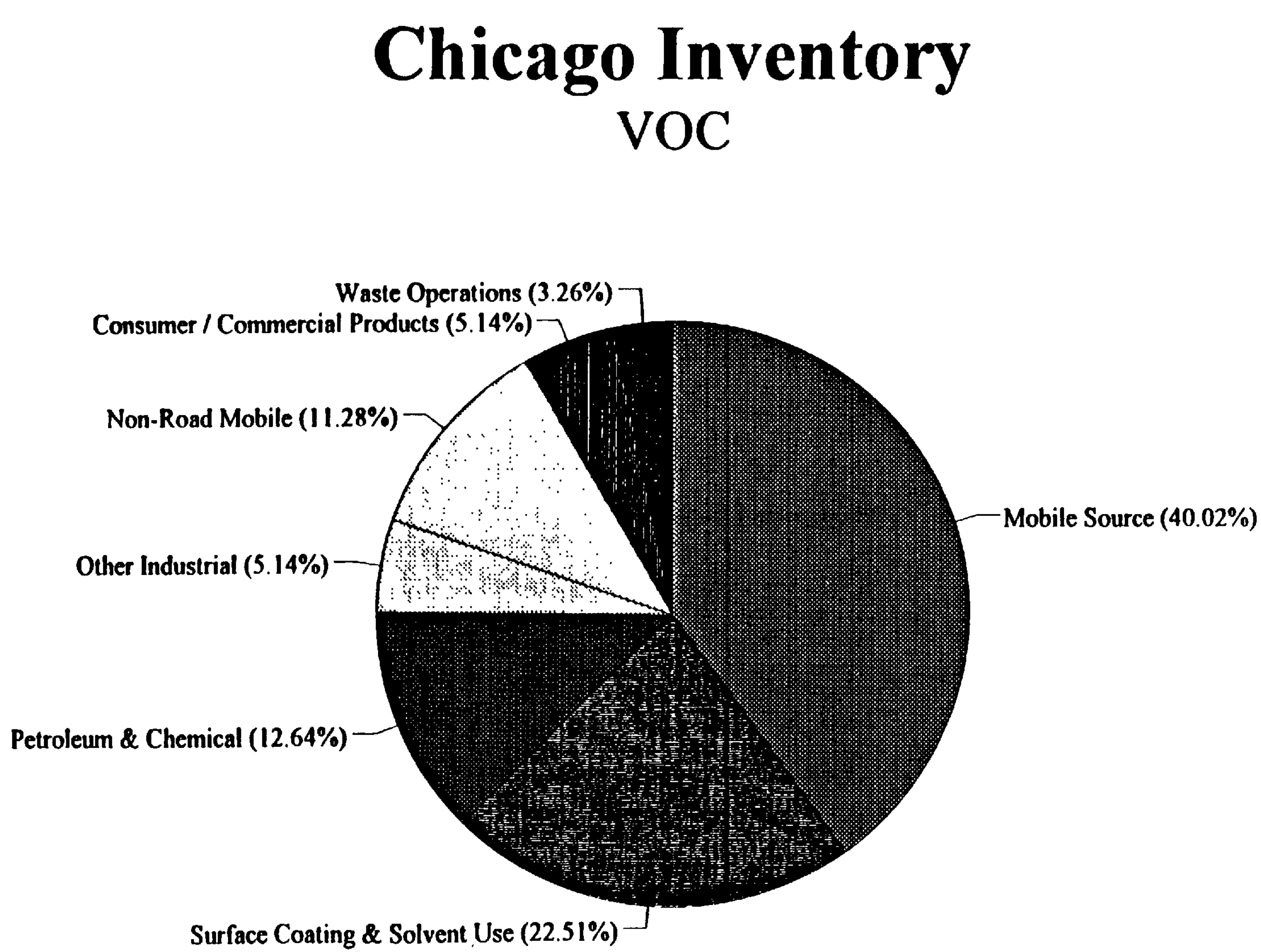

Figure 2-2. 1990 VOC Emissions in the Chicago Nonattainment Area.

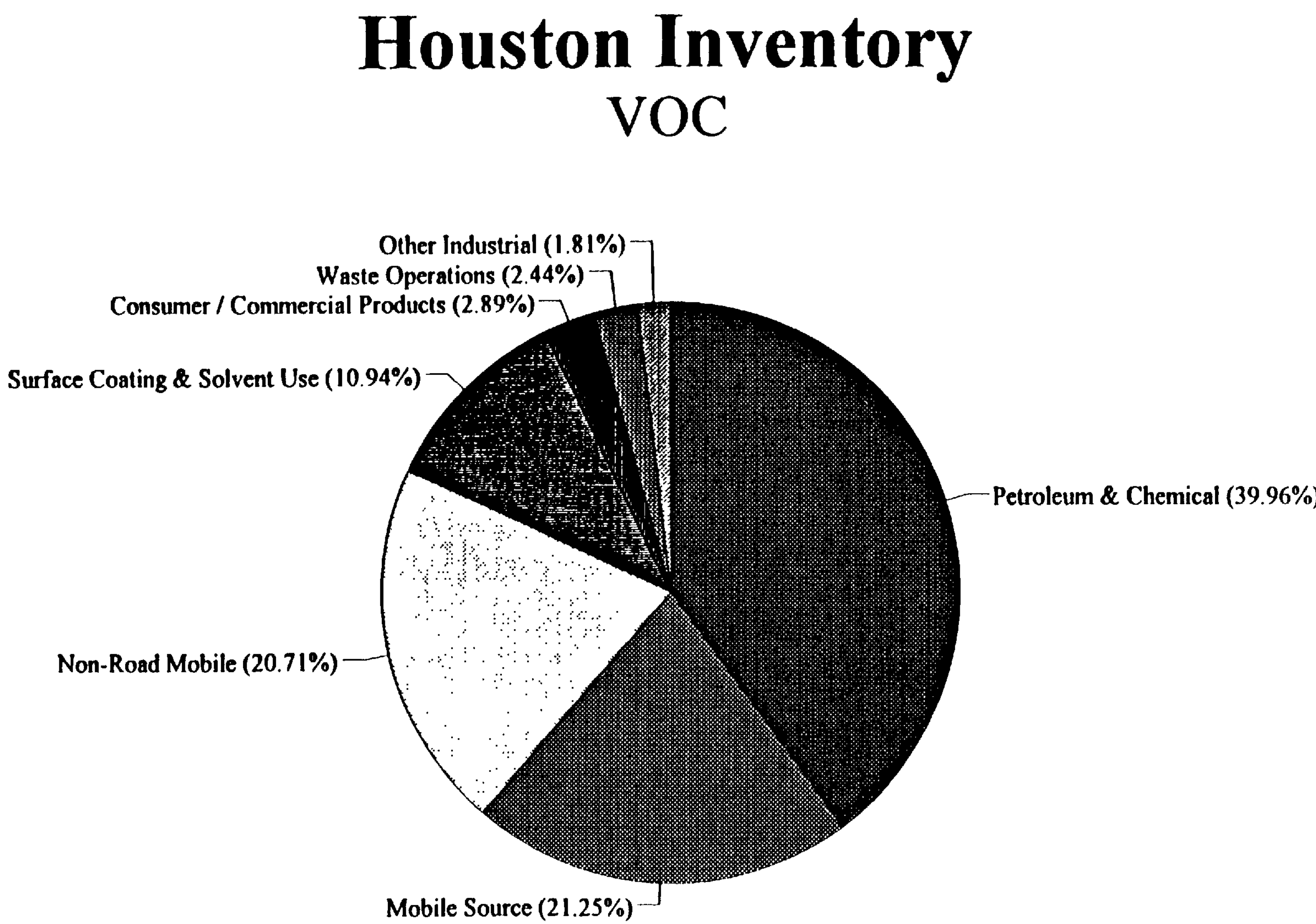

Figure 2-3. 1990 VOC Emissions in the Houston Nonattainment Area.

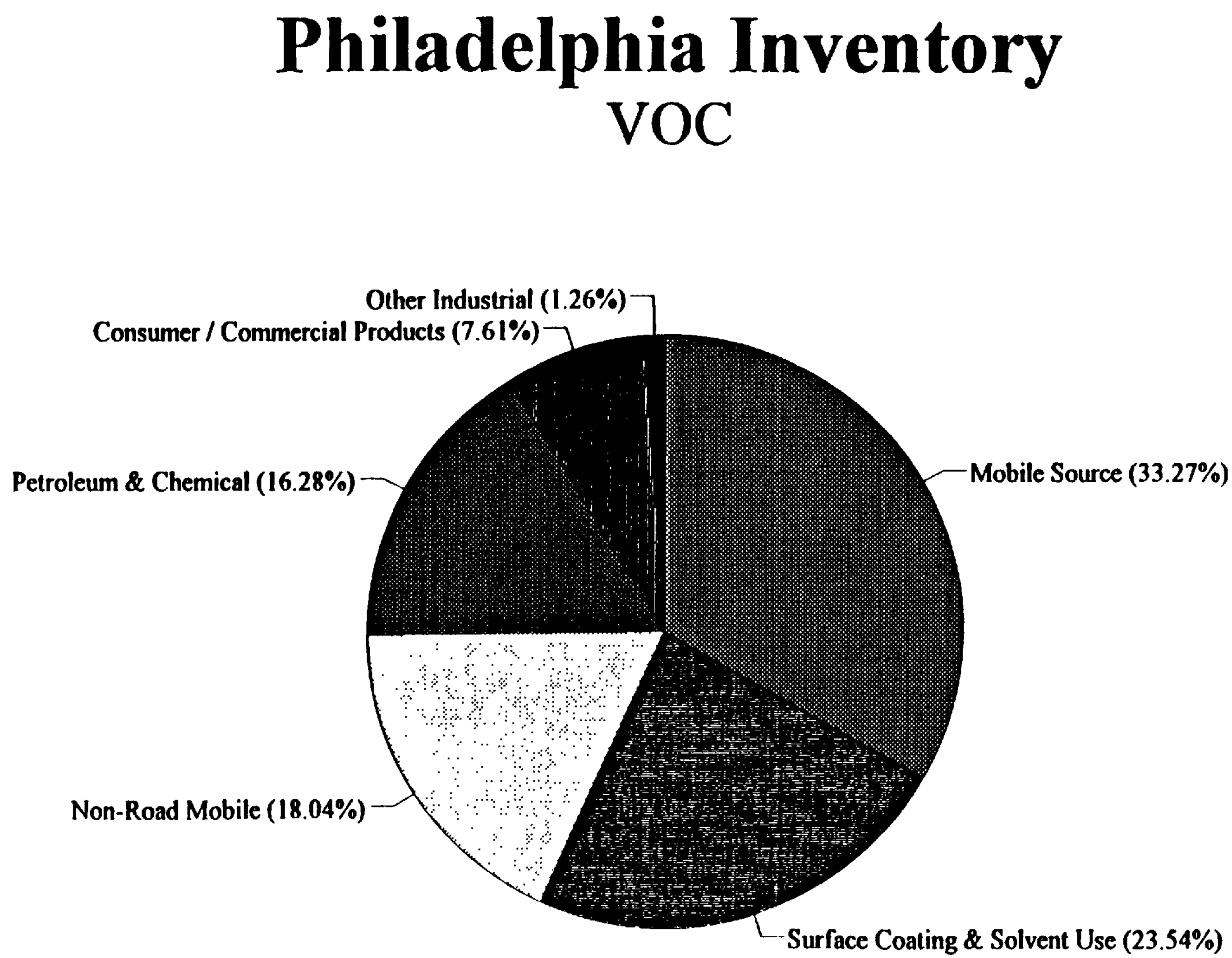

Figure 2-4. 1990 VOC Emissions in the Philadelphia Nonattainment Area.

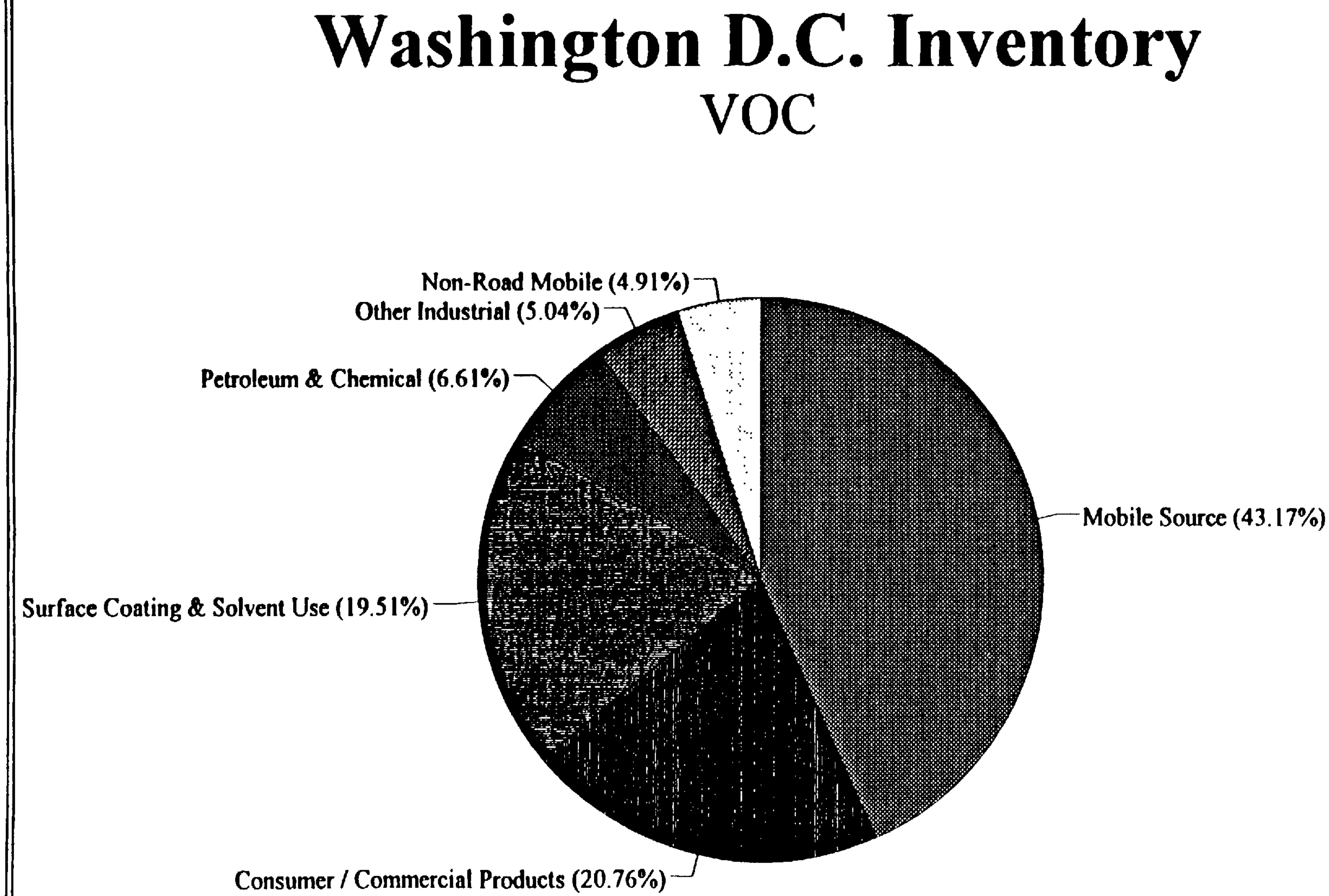

Figure 2-5. 1990 VOC Emission in the Washington D.C. Nonattainment Area.

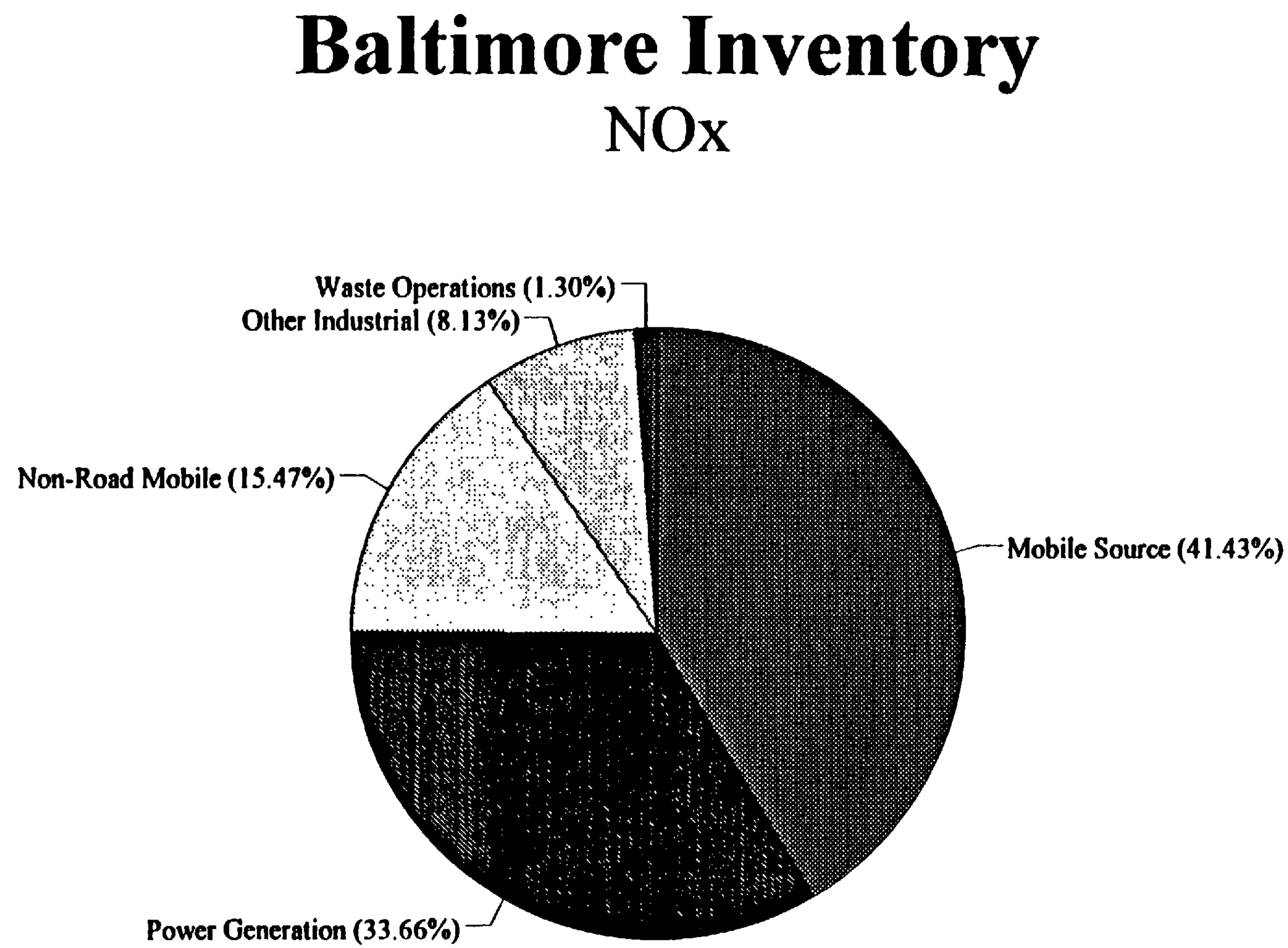

Figure 2-6. 1990 NOx Emissions in the Baltimore Nonattainment Area.

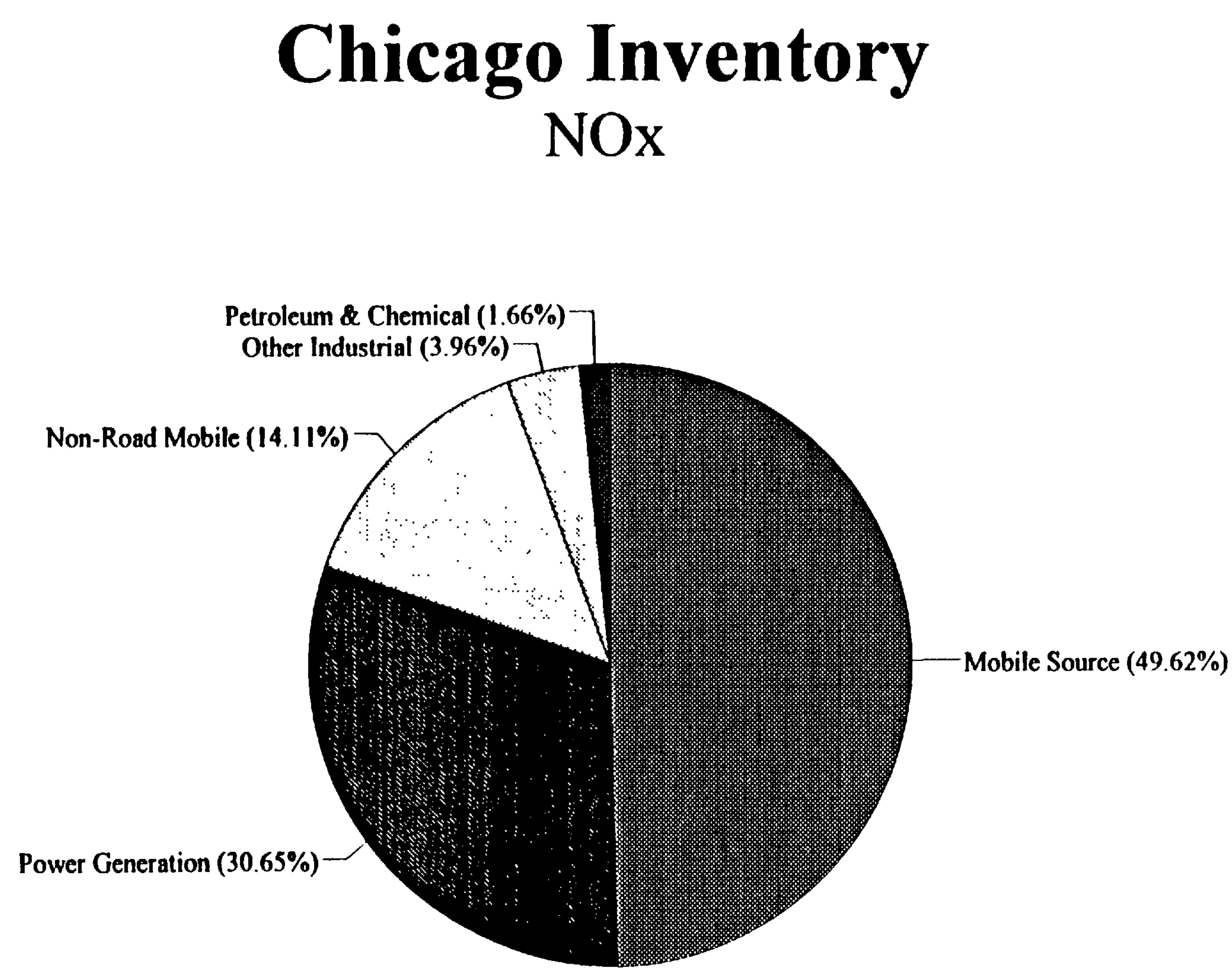

Figure 2-7. 1990 NOx Emissions in the Chicago Nonattainment Area.

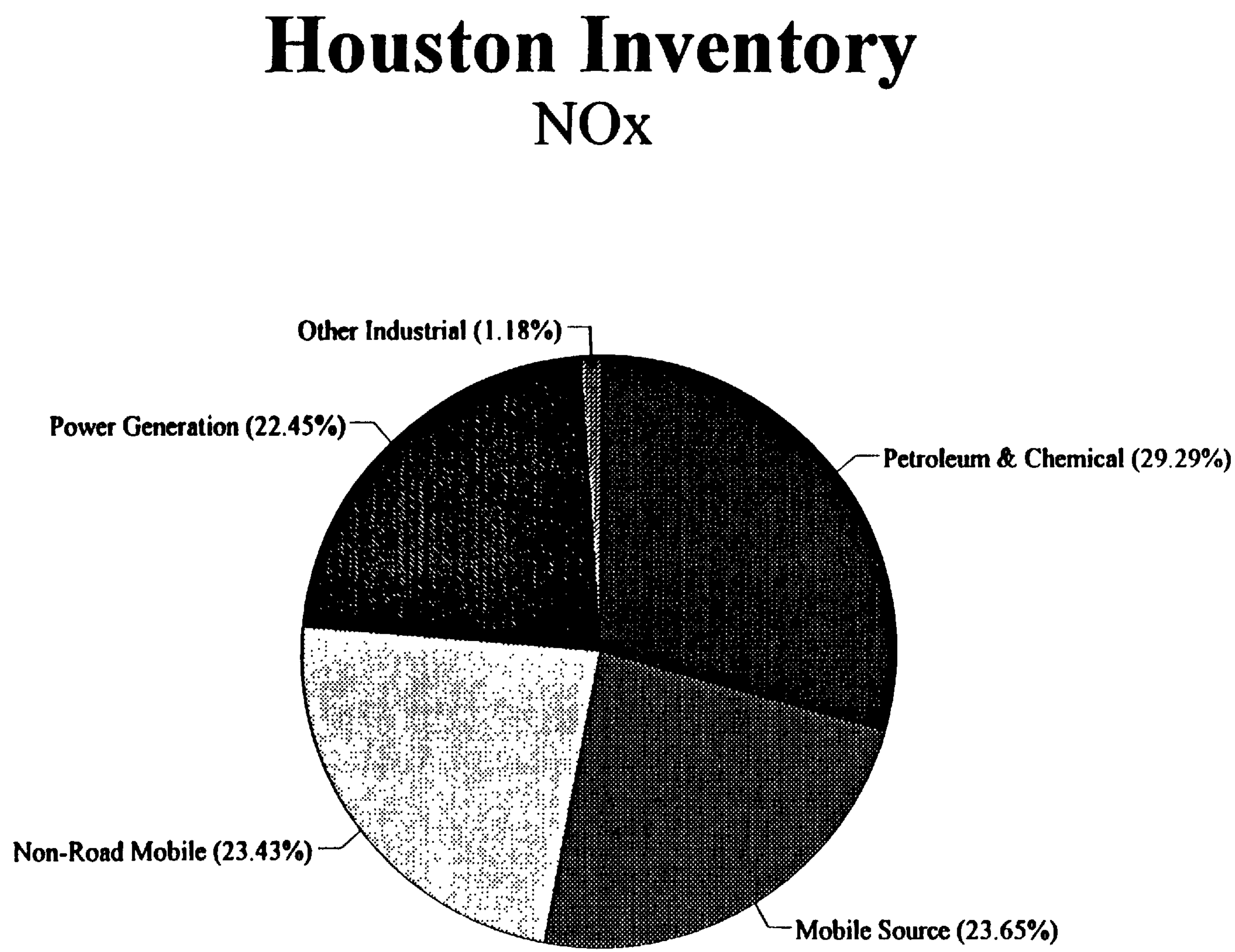

Figure 2-8. 1990 NOx Emission in the Houston Nonattainment Area.

Philadelphia Inventory
NOx

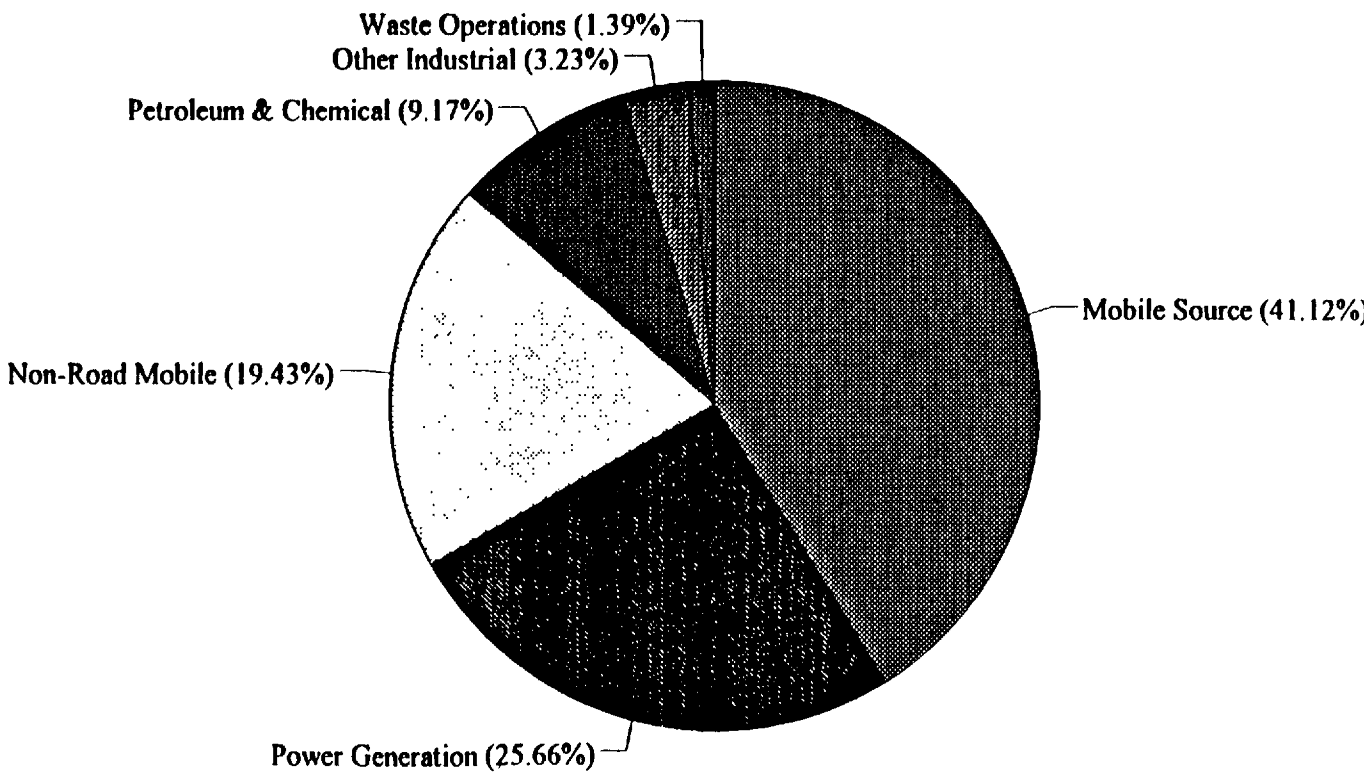

Figure 2-9. 1990 NOx Emission in the Philadelphia Nonattainment Area.

Washington D.C. Inventory
NOx

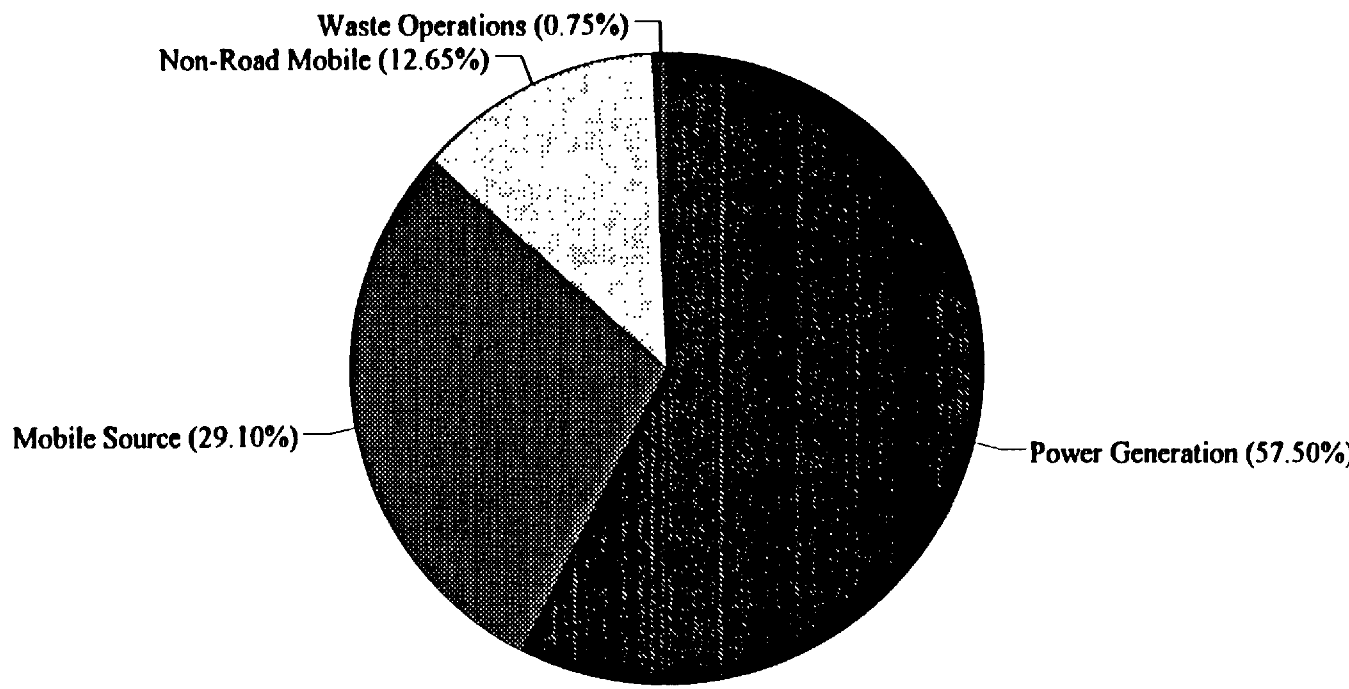

Figure 2-10. 1990 NOx Emissions in the Washington D.C. Nonattainment Area.

Table 2-3. Major VOC Source Distribution

Source Category	Chicago Illinois	Houston Texas	Philadelphia Pennsylvania	Washington D.C.	Baltimore Maryland
Point Sources:					
Bulk Gasoline Terminals	X	X	O		X
Coke Production	X	O			
Degreasing	X	O	X		O
Graphic Arts	X		X		X
Industrial WWTFs	X	X			O
Iron and Steel Mfg.	X				O
Landfills	X				O
Oil and Gas Production		X			
Petroleum Refineries	X	X	X		
Pharmaceutical Mfg.	X				O
Plastic Parts Mfg.	X	X			
POTWs	X				O
SOCMI	X	X	O		
Surface Coating	X	X	X	X	X
Textile, Polymer, and Resin Mfg.	X	O	O		
VOL Storage	X	X	X		O
Waste Operations	X				O
Area Sources:					
AIM Coatings	X	X	X	X	X
Asphalt Paving	X			X	
Consumer and Commercial Products	X	X	X	X	X
Degreasing	X	X	X	X	X
Marine Vessel Loading		X	O		O
Service Station Loading	X	O	X		O
Underground Tank Breathing	X		X		O
On-Road Mobile:	X	X	X	X	X
Off-Road Mobile:	X	X	X	X	X

Table 2-4. Major NO_x Source Distribution

Source Category	Chicago Illinois	Houston Texas	Philadelphia Pennsylvania	Washington D.C.	Baltimore Maryland
Point Sources:					
Glass Production	X				
Industrial Power Generation	X				
Iron and Steel Mfg.	O				X
Oil and Gas Production		X			
Petroleum Refineries	X	X	X		
Stationary IC Engines	X	O	O		X
SOCMI	O	X	O		
Utility Power Generation	X	X	X	X	X
Area Sources:					
Residential	X		X		
On-Road Mobile:	X	X	X	X	X
Off-Road Mobile:	X	X	X	X	X

As illustrated in Tables 2-3 and 2-4, the relative impact of each category on the total emission inventory varies by location. Much of this difference is explained by looking at the industrial and demographic make-up within each nonattainment area. For example, because Washington D.C. has little industrial activity within its boundaries, there is no significant chemical or petroleum refining, manufacturing or production emissions. However, due to its large population, emission sources such as graphic arts, consumer products, and vehicle emissions have more of an effect on the inventory. Conversely, the industrial sectors in the Houston and Chicago areas account for a significant portion of their total emissions inventories. Similar observations can be made for other categories and nonattainment areas of study. It should be noted that if an "X" doesn't appear, is may be a result of Radian's inability to characterize or disaggregate the data.

Several source categories are common throughout all the inventories. Common categories include Degreasing Operations, Consumer and Commercial Solvents, Utility Power

Generation, and On- and Off-Road Mobile sources. These categories are generic, and are essential to urban activity, independent of geographic location.

There were also several sources that were unique to each area. For instance, Chicago was the only area that had Coke Production, Iron and Steel Manufacturing, and Textile, Polymer, and Resin Manufacturing as major sources of VOC emissions. Likewise, Oil and Gas Production is only significant in the Houston inventory.

Section 3

VOC AND NO_x CONTROLS FOR POINT AND AREA SOURCES

Once the major source categories for each nonattainment area were identified, Radian looked for possible technologies for controlling VOC and NO_x emissions. Determination of the baseline level of controls for each area of study was the first step in identifying further control alternatives. Next, numerous documents and reports were reviewed and experts were consulted to determine feasible control measures. Finally, stationary source control options were reviewed to provide estimates for control efficiencies and cost-effectiveness.

CONTROLS IN PLACE IN 1990

The first step in developing accurate and comprehensive control strategies for point and area sources was to determine the baseline level of controls for each of the five non-attainment areas included in the study. This information was gathered from a variety of sources, including: EPA's Control Technology Guideline (CTG) documents that provide possible technologies for meeting the reasonably available control technology (RACT) levels being adopted in nonattainment areas; the Bureau of National Affairs (BNA) reference guide, used to determine the individual states' regulations; the STAPPA report, which provided a detailed description of both current state and federal as well as proposed regulations; and personal contacts with industry representatives, EPA officials, and Radian experts.

For the development of emission reductions estimates, it was assumed, unless explicitly noted, that the baseline controls already adopted in the various regions had a 100% rule penetration. We are aware that in practice this would not be the case, but this assumption provides a conservative baseline and ensures that the study will not overestimate the potential reductions from further controls. Rule effectiveness is another factor that states use to account for uncertainty in the ability of the rule to control the targeted source. The EPA guidelines employ an 80% rule effectiveness value for sources that are currently regulated. States may show an increase in the rule effectiveness value, representing increased compliance or application rates, as a method of increasing emission reductions.

INFORMATION SOURCES

Much of the information gathered for our analysis of further controls came from the following sources:

- U.S. EPA control techniques guideline (CTG) documents describing regulatory alternatives and reasonably available control technology (RACT) alternatives for ozone nonattainment areas;
- Background information document (BIDs) for proposed/promulgated new source performance standards (NSPS) and National Emission Standards for Hazardous Air Pollutants (NESHAP), defining control techniques above CTG-RACT level;
- The South Coast Air Quality Management District (SCAQMD) Final Air Quality Management Plan providing model regulations applicable throughout the five areas of study;
- The Bay Area Air Quality Management District (BAAQMD) Clean Air Plan providing additional regional regulatory alternatives;
- The State and Territorial Air Pollution Program Administrators (STAPPA) list of control measures for meeting the RFP requirements of the Clean Air Act;
- Lake Michigan Ozone Control Program (LMOP) document providing an evaluation of possible VOC and NO_x control measures; and
- Studies performed by Radian for government or private industry.

Each of these documents provided valuable information for determining the 1990 baseline level of control, regulatory activities, impending legislation, incremental control options, and cost-effectiveness estimates.

POINT AND AREA SOURCE VOC CONTROLS

After establishing baseline control estimates for many of the VOC emission sources, it became evident that a majority of the large point source categories were already regulated to varying degrees. These regulations ranged from RACT-level controls to the more rigorous National Emission Standards for Hazardous Air Pollutants (NESHAP) control requirements. Petroleum refining is an example of a large point source currently under multiple regulations. Within this industry, regulated activities include RACT-level standards for storage, transfer, and shipping of petroleum products, process vents throughout facilities, wastewater treatment facilities, and leaks from valves, flanges, and compressors. In addition, the industry is also subject to the Benzene NESHAP and the Benzene Waste Operations NESHAP regulations which provide even more stringent control requirements for toxins and VOCs as a whole. Similar levels of control and regulations were found for the SOCMI industry. Additional controls for the SOCMI industry through the Hazardous Organic NESHAP (HON), and refineries and petroleum marketing terminals through MACT requirements will result in additional VOC reductions. Finally, federal New Source Performance Standards and varying degrees of state regulations affect the baseline level of VOC control for numerous source categories.

Industries for which regulations are not currently in effect provide the greatest potential for further control. The Clean Air Act Amendments of 1990 required the development of thirteen new CTGs by November 1993. The sources targeted by these new control documents are widely available for further control since little or no regulation has been developed in the past for them. The 13 new CTGs cover:

- SOCMI Distillation
- SOCMI Reactors
- Wood Furniture Coating
- Plastic Parts: Business Machines
- Plastic Parts: Other
- Offset Lithography
- Autobody Refinishing
- Batch Processing
- VOL Storage Tanks
- Cleanup Solvents
- Aerospace Coatings
- Ship Building and Repair

- Industrial Wastewater

In addition to the thirteen new CTG documents, other Federal control programs have been, or are being, developed to control VOC emissions at a national level. These measures cover:

- Marine Vessel Loading;
- Consumer and Commercial Products;
- Architectural and Industrial Coatings; and
- Adhesives.

The EPA has also produced alternative control documents (ACTs) for the following sources providing possible control alternatives, including:

- Halogenated Solvent Cleaners;
- Traffic Markings;
- Automobile Refinishing;
- Organic Waste Process Vents; and
- Pesticide Application and Bakeries.

This information was used to develop incremental control options above and beyond those already in place, and to determine the applicability of available VOC controls. Radian compiled detailed descriptions of control methods, control efficiencies, and cost-effectiveness estimates for the VOC categories listed in Table 3-1. Detailed analysis of each source category can be found in the supplemental documentation.

Table 3-1. Ranking of Stationary Source VOC Control Categories

Stationary Source VOC Controls Categories	Effectiveness of Control	Cost of Control ($/ton) (1993$)
Traffic/Maintenance Paints • Reformulation	40-53%	$(1,462)
Emulsified Asphalt • Reduce oil distillate content	50%	$100
Underground Storage Tank Breathing • Pressure/vacuum valves	80-100%	$10-230
Degreasing • Alternative solution/operating requirements	20-40%	$2-368
Landfills • Gas collection systems	79%	$500-930
Oil and Gas Production • Tanks, dehydrators, fugitive, and pneumatic	69-100% (process dependent)	$1,300 (Tanks) $750 (Pneumatic)
Organic Chemical Manufacturing - Others • Add-on controls	20%	$800-2,000
Pesticide Application • Change formulation and appli- cation	30-45%	$1,600
Consumer and Commercial Products • Reformulation	28%	(100)-3,400
Industrial Wastewater Treatment • Steam stripping	83-92%	$400-3,000
Graphic Arts • Offset lithography	43-60%	$0-3,700
Architectural and Industrial Maintenance Coat ings • Reformulation	20%	$(8,600)-12,800
Can Coating • Control technologies	5-10%	$2,200
Industrial Machinery and Equipment Coating • Improved transfer efficiency and reformulation	25-30%	$2,200
Miscellaneous Metal Parts Coating • Improved transfer efficiency and reformulation	25-30%	$2,200

Stationary Source VOC Controls Categories	Effectiveness of Control	Cost of Control ($/ton) (1993$)
Bulk Gasoline Terminals • Improved vapor recovery units	70%	$2,600
Vessel Loading - Marine • Vapor control devices	80-98%	$500-8,000
Petroleum Refineries • Control tank and fugitive emissions	27-34%	$42-6,067
Paper Coating • Low-solvent coatings	1%	$5,000
Automobile Refinishing • Control preparation, coating operation and gun cleaning	43%	$478-7,000
Organic Chemical Manufacturing - Synthetic • WWT, process vents, equipment leaks, and tanks	77-85%	$210-10,032
Storage and Warehousing • Vapor recovery units, internal/-external roofs, and seals	60-95%	$120-12,320
Volatile Organic Liquid Storage • Vapor recovery units, internal/-external roofs, and seals	60-95%	$120-12,320
Auto and Light Truck Surface Coating • Add-on controls	20-30%	$17,400-19,000
Coke Oven Batteries	12%	$37,120

Table 3-1 presents a list of the VOC control options' cost-effectiveness. For those options with a range of dollars per ton values, the average of the range was used for ranking purposes. The "average" cost-effectiveness values given above assume that retrofit costs are evenly distributed between the high and low ends of the cost range. In actuality, the distribution of costs across all sources within a category may be weighted near either end, and may have a "clumpy" distribution, reflecting a variety of unit configurations, fuel types, waste stream flow rates and concentrations, etc. Thus each source category would require detailed model plant breakdowns to precisely estimate cost-effectiveness values, a task beyond the scope of this study. Therefore, because of the large uncertainties associated with the above figures, the reader should consider these rankings a rough approximation of their true order. In addition, due to site-specific factors these rankings will change somewhat from city to city.

Summary of Selected VOC Control Measures

Brief source descriptions with accompanying control strategies are provided in this section for a representative number of source categories. Although a description is not given for every major source category, complete control descriptions are provided in the supplementary document for further review.

Architectural and Industrial Maintenance (AIM) Coatings. AIM coatings are a substantial source of VOC emissions in all five inventories providing a prime candidate for reductions. AIM coatings are used for both commercial and residential applications as surface coatings for homes, buildings, and other structures. The AIM coating category contains more than 35 types of specialty coatings as well a flat and non-flat paints. VOC emissions occur primarily from the evaporation of organic solvents from the coating during application and drying.

The EPA is currently conducting negotiations providing for the development of a national rule. This rule will determine VOC limits for AIM coatings at a federal level. In the interim, adoption of the 1989 California model rule limiting the VOC content of the coatings can serve as an estimate of the magnitude of reductions which can be expected for this category.

Bulk Gasoline Terminals. Bulk gasoline terminals are major sources of VOC emission in the inventories of Chicago, Houston, and Baltimore. These terminals serve as the major distribution points for gasoline produced at refineries. The majority of VOC emissions occur during loading of delivery tank trucks, as the entering gasoline displaces the vapors into a collection system. The collected vapors are then routed to a vapor processing system.

VOC emissions from gasoline bulk terminals can be controlled through the use of available control technologies such as vapor balancing, carbon adsorption, thermal oxidation, or other vapor recovery systems (SCAQMD, 1991a).

Surface Coating Operations. Surface coating operations are major source contributors to all five nonattainment areas. Several industries have significant VOC emissions from surface coating operations, including Auto & Light Truck Coating, Can Coating, Furniture Coating, Paper Coating, and Misc. Products Coatings. VOC emissions occur during both the application processes and drying operations.

Emission reductions are possible through three primary methods: reformulation to water-borne coatings, higher solids coatings, radiation curable coatings, or powder coatings; alternative application methods like high transfer efficiency application methods, high-volume low-pressure (HVLP) sprayers, or further use of electrodeposition; and add-on controls including adsorption, absorption, or incineration (technology depend on factors like exhaust concentration, flow rate, and other factors) (EPA, 1978c). Most of these technologies are applicable to surface coating operations independent of the industry.

Consumer and Commercial Products. Consumer and commercial products are large contributors in all five emission inventories providing a prime candidate for additional controls. They consist of those items sold to retail customers for household, personal or automotive use, along with the products marketed by wholesale distributors for use in commercial or institutional settings.

California has led the way in regulating these industries. CARB has developed the Phase I, Phase II, and Deodorants and Antiperspirants regulations to reduce emissions from these sources.(CARB, 1990) Reductions in VOC emissions from consumer products can be achieved in several ways, including product reformulation, alternative and modified dispensing or delivery systems or product substitution. These controls can represent significant reductions in emissions from this source because few regulations exist to control this category.

Degreasing/Surface Cleaning. As with several of the previous categories, degreasing emissions are significant in all five inventories. Degreasing, or surface cleaning, includes three categories of cleaners: cold cleaners, which remove soils from a metal surface by brushing, flushing, or immersion while maintaining the solvent below its boiling point; open-top vapor degreasers (OTVDs), which uses hot solvent vapor to clean and remove soils from batch metal parts; and conveyorized degreasers, which clean and remove soils from metal parts using either cold or vaporized solvents in a continuous process.

This category has been previously regulated under RACT requirements. EPA is developing a degreasing NESHAP and MACT standards for this industry which will require additional controls for degreasing operations. The SCAQMD has revised Rule 1122 to further reduce emissions from degreasing by minimizing workload requirements, specifying maximum draft rates and proper handling procedures, and requiring installation of control devices.(SCAQMD, 1991a) The standards set by this rule may be applied to other areas providing additional level of control.

Graphic Arts. Graphic arts operations are considered major sources in the non-attainment areas of Chicago, Philadelphia, and Baltimore. The graphic arts industry includes operations covering the flexography, lithography, and rotogravure industries. Rotogravure and flexography printing are both covered under the 1978 CTG addressing the graphic arts industry. A draft CTG for offset lithography, due for finalization in late 1993, discusses ink and cleaning solution reformulation. However, cleaning solutions used in all three industries do not seem to be covered by these rules and it may be possible to regulate the VOC content, thus, reducing emissions.

Further control of the rotogravure and flexography industries would include the use of permanent total enclosures in addition to add-on controls. A more reasonable control scenario may be to adopt the draft RACT controls for offset lithography, which is not currently regulated.

Industrial WWTF. VOC emissions from industrial wastewater treatment facilities are major sources in Chicago and Houston. Emissions occur when industrial wastewaters are treated to remove contaminants prior to final wastewater discharge. Several industries have been regulated by the EPA for wastewater operations. The benzene waste operation NESHAP heavily regulated the petroleum industry as well as others.

A preliminary draft CTG has been developed recommending putting limits on VOC concentrations in the wastewater and utilization of control technologies like steam stripping. Emissions from a steam stripper system must be controlled using carbon adsorption or incineration. The draft CTG is also proposing covering open tanks and surface impoundments. The MACT standards developed by the SOCMI HON have also made an impact on wastewater sources. These reductions are now being implemented. There exists significant potential within wastewater treatment operations to provide further emission reductions. Radian is uncertain why industrial WWTFs are not major sources within the industrial areas of Baltimore and Philadelphia.

Landfills. Landfill gases were considered a major source of VOC emissions in the Chicago inventory. Landfill gas is generated naturally by the aerobic and anaerobic decomposition of waste. Such gas consists primarily of methane and carbon dioxide, with VOCs making up less than 1 percent of emissions. EPA has proposed regulations for new and existing municipal landfills, requiring landfills emitting greater than 167 tons per year of VOCs to design and install gas collection systems and combust captured gases.(STAPPA, 1993) A final rule is expected in the fall of 1993.

The available control strategy for reducing landfill gas emissions is a well-designed and well-operated gas collection system with a control device capable of reducing VOCs in the collected gas by at least 98 weight-percent. Energy recovery systems have also been demonstrated to achieve 98 percent emission control at landfills where their use is feasible. Again, Radian expresses uncertainties with the reporting practices within this category.

Marine Vessel Loading. Of the five areas examined, Houston is the only area that includes marine vessel loading as a major source of VOC emissions. Marine vessel loading refers to the loading of tank ships and barges with volatile liquids. Evaporative emissions from marine vessel loading occur primarily as a result of displaced vapors from the vessel being loaded with petroleum liquid.

Vapor balancing, refrigeration, carbon adsorption, incineration or a combination of these methods can be used to reduce VOC emission during loading operations. The EPA is looking into regulating this operation. Regulations have been adopted by individual states.

Publicly Owned Treatment Works (POTWs). VOC emissions from POTWs were only considered major within the Chicago inventory. POTWs, commonly known as sewage treatment plants, treat domestic sewage and industrial and commercial wastes received primarily through underground sewers. Few data are available for control of POTWs.

The proposed methods of control include the development and implementation of emission reduction control programs at POTWs, including enclosures, add-on controls and/or process modifications. A second approach for controlling VOC emission is to implement sewer use and discharge regulations, applicable to all users, that emphasize waste minimization.(STAP-PA, 1993) Although emissions from POTWs are not reported within the Houston and Philadelphia inventories, Radian believes that POTWs may be a more significant source within these areas than reported.

Pesticide Application. Pesticide applications were considered major sources of VOC emissions in the inventories of Baltimore and Houston. Pesticides are widely used by agricultural and commercial enterprises to control insects, fungus, and other undesirable pests.

Techniques for controlling VOC emission from pesticide application include: product reformulation, minimizing the petroleum content of the formulations and substituting with waterborne or dry formulations; changes in application methods including dusting the soil rather than spraying, minimizing atomization of the particle spray, and incorporating the pesticide into the soil; and using alternative methods of controlling pests.(SCAQMD, 1991d)

Petroleum Refineries. The nonattainment areas of Chicago, Houston, and Philadelphia reported emission from petroleum refineries as a major source. Petroleum refineries require a complex analysis of available control options. Controls for this industry vary by site and baseline level of control. The primary sources of VOC emission within a petroleum refinery include: fugitive leaks from valves, flanges, compressors and pumps; wastewater treatment facilities; storage tanks; and process vents.

Petroleum refineries are a significant point source of VOC emissions and therefore are already subject to a variety of state and federal regulations. Available controls for the industry consist of: vapor recovery systems, external and internal floating roofs, and improved primary and secondary seals for storage tanks emissions; improved inspection and maintenance programs for monitoring and repairing sources of fugitive leaks; lower concentration limits for process vents and flares; and improved compliance to the existing regulations.

Plastic Parts Manufacturing. Plastic parts manufacturing was considered a major source in the Chicago and Houston inventories. Radian has not evaluated control strategies for this source because of process uncertainties within the industry. Studies have been done by the State of Michigan and Wisconsin into possible control alternatives for this industry. To date, no information has been released about control options. Although, the production processes are similar to polymer manufacturing and SOCMI production, a direct correlation has not been made.

Synthetic Organic Chemical Manufacturing Industry (SOCMI). SOCMI production was only considered a major source of VOC emissions in the Houston area. The SOCMI industry is very large and diverse, manufacturing hundreds of chemicals through a variety of chemical processes. The primarily sources of VOC emissions come from wastewater treatment facilities, process vents, equipment leaks, storage tanks, and product transfer operations.

Many documents have been developed to facilitate controls for this industry. A CTG for air oxidation processes was developed requiring control of process vents. The EPA has prepared draft CTGs for SOCMI reactors and distillation units, proposing further control of process vents. The draft CTG for industrial wastewater is applicable to the SOCMI industry as well as the draft CTG for volatile organic liquid storage. More recently, the SOCMI industry has come under stricter controls from several individual NESHAP requirements, as well as a NSPS for fugitive emissions. Levels of further control vary by site and are difficult to determine because of the complexity of the processes. However, Radian was able to make general assessments of control potentials for these sources by assuming a relative source breakdown and applying applicable controls to the individual components.

Service Station Loading (Stage I). Service station loading was only considered a major VOC emission source in Chicago and Philadelphia. Stage I vapor recovery systems are required for all tank trucks that deliver gasoline to service stations. The recovery system processes the gasoline vapors displaced from the stationary tank by the incoming fuel.

The SCAQMD has proposed a "fail-safe" stage I system that automatically shuts off gasoline flow any time the system is not functioning properly.(SCAQMD, 1991d) This fail-safe system is not commercially available at this time, therefore no further information is available. Although Stage I was only a major source in Chicago and Philadelphia, the other three nonattainment areas reported minor VOC emissions levels for this category.

Volatile Organic Liquid Storage (VOL)/Storage and Warehousing. VOL storage is a major source category in the nonattainment areas of Chicago, Houston, and Philadelphia. Volatile organic liquids are typically stored in above ground tanks. VOCs are emitted through tank breathing or diffusional losses, which result from changes in ambient air temperature and barometric pressure, and through liquid working losses, which result from the displacement of vapors as the tanks are filled.

Several control documents have been developed for this category including CTGs and NSPS. Most recently, the EPA issued a draft CTG in late 1991 which gives guidelines to further control organic emissions from VOL storage in floating and fixed roof tanks. The draft CTG proposes vapor recovery systems, external and internal floating roof, and improved primary and secondary seals for existing VOL tanks.

Underground Storage Tank Breathing. Underground tank breathing is only considered a major source of VOC emissions in Chicago and Philadelphia. Underground storage tanks at service stations are passively vented to the atmosphere through a vent pipe. Emissions from the vent pipe occur when vehicles are being fueled at the pump, when fuel is filled from a gasoline transport using a Stage I vapor balance system, and from diurnal temperature changes.

The proposed control is a low pressure/vacuum (P/V) relief valve. P/V valves can be installed to maintain pressure within the tank.(STAPPA, 1993) This measure may even improve the control efficiency of the Stage I and Stage II systems.

POINT AND AREA SOURCE NO_X CONTROLS

Unlike VOC sources, which have been regulated for some time, by and large NO_x sources are uncontrolled (with the significant exception of on-road mobile sources). The majority of NO_x emissions are produced in older facilities which are currently uncontrolled. New NO_x sources, although making up only a small percentage of NO_x emissions, have been targeted by new source review (NSR) provisions defining Best Available Control Technologies (BACT) in many areas. While the CAA has mandated EPA to develop Alternative Control Techniques (ACT) documents and RACT levels for NO_x sources emitting greater than 25 TPY, most of these documents are still in the draft stage. Therefore Radian had to rely on information from California, industrial pilot programs, equipment vendors, and Radian experts for information on NO_x controls. (Final ACTs have been issued for stationary IC engines and gas turbines, and were consulted as part of this study -- see Appendix E on NO_x controls.)

The following provides background on the basics of NO_x formation and control.

NO_x Formation and Control

NO_x formation occurs during the fuel combustion process for two reasons. First, nitrogen contained in the fuel itself may oxidize during combustion, forming "fuel NO_x". Second, atmospheric nitrogen combines with oxygen under the high temperature conditions of combustion, to form "thermal NO_x". While fuel NO_x can be practically eliminated by use of low-nitrogen fuels (e.g, natural gas), fuel burning will always produce some amount of thermal NO_x.(Acurex, 1992)

Formation of thermal NO_x can be lowered through either **combustion modifications**, or **post-combustion treatment** (flue gas treatment). Combustion modifications attempt to lower NO_x by lowering the temperatures in the flame zone. One method is reducing the oxygen available for binding with nitrogen. However, by altering the stoichiometry or temperature of the reaction, many combustion modifications inadvertently raise HC and

CO emissions due to incomplete fuel combustion. Often this incomplete combustion can result in significant fuel efficiency losses as well.(LMOP, 1993) Therefore these factors must be considered when selecting a combustion modification for application.

Flue gas treatment systems are of two types: catalytic and non-catalytic reduction. These controls attempt to reduce nitrogen to its molecular form after oxidation has already occurred, downstream from the combustion zone. Catalytic reduction uses a reducing agent (typically ammonia or urea) to react with NO_x in the presence of a catalyst. Non-catalytic reduction relies upon urea or ammonia injection into the exhaust gas stream to remove NO_x. In general, flue gas treatment has the potential to lower NO_x emissions by greater amounts than combustion modifications, but at a much higher cost.(Acurex, 1992)

Unlike VOC control options, which are highly source-specific, NO_x control options are essentially the same for all sources. Regardless of the nature of the process, one must apply either combustion modifications or flue gas treatment of some sort to control NO_x emissions. Therefore the following section will provide a brief description of the most commonly referenced combustion modifications and flue gas treatments. In addition, the next section will discuss the major NO_x sources identified in the inventories, and the specific applications of the control technologies (e.g., use of combustion modifications on utility boilers).

Summary of Selected NO_x Control Measures

Table 3-2 provides a list of the various NO_x control strategies' cost-effectiveness. Average dollars per ton values were calculated based on values found in the literature and Radian engineering estimates. These estimates present a substantial range in costs for two reasons. First, different studies employed differing assumptions regarding baseline emissions, control efficiencies, capital and operating costs, capital recovery period, and a host of other factors. For instance, it is often difficult to define the control efficiency level for combustion modifications because of the lack of data on pre-control emissions rates, and estimates will vary from study to study.(McGuire, 1993) Second, the estimates were developed for a number of different source categories, with different retrofit costs, thereby further increasing the observed range. Therefore any ranking based on average rather than site-specific cost-effectiveness values are subject to some degree of inaccuracy. However, the general ordering of the table appears accurate, with the low-cost operational modifications (e.g., LEA and SCA) at the top, and the capital-intensive flue gas treatments at the bottom.

Table 3-2. Ranking of Stationary Source NO_x Control Categories -- by Technology

Stationary Source NO_x Control Categories	Effectiveness of Control	Cost of Control (1993$) ($/ton)
Low Excess Air (LEA)	4-69%	savings
Staged Combustion Air (SCA)	10-45%	$130-500
Over-Fired Air (OFA)	16-35%	$415-1,026
Low NO_x Burner + Flue Gas Recirculation	80%	$1,400-5,000
Low NO_x Burner (LNB)	18-80%	$704-5,655
Flue Gas Recirculation (FGR)	20-50%	$265-6,200
Fuel Switching (NG in coal boilers)	up to 80%	~$3,500*
Selective Non-Catalytic Reduction (SNCR)	33-80%	$1,000-6,600
Selective Catalytic Reduction (SCR)	70-95%	$800-24,000

* Cost highly dependant on coal/gas price increment.

As noted above, there are few NO_x control standards currently in effect for major point sources, such as utility and industrial boiler NSPSs. Therefore a wide range of control options will be available to these sources. Radian has attempted to evaluate most of the feasible control options available to these point source categories. The following provides a brief description of these control options. A more detailed account can be found in the supplementary document.

Combustion Modifications. There are many possible combustion modifications, in varying stages of development. Combustion modifications are available for most of the major NO_x source categories evaluated in this study, though source-specific limitations exist. Sources can be retrofit with various combustion modifications, obtaining significant emissions reductions from uncontrolled levels at low costs. Many combustion modifications can be combined to obtain even greater reductions than either control alone. Typical reductions are in the 20 to 40 percent range, with cost-effectiveness values often less than $1,000 per ton. If reductions greater than 50 percent are sought, flue gas treatments may be required, either separately, or in addition to, combustion modifications, depending on the source type.

Low Excess Air (LEA). Low excess air is one of the most commonly used combustion modifications, controlling NO_x formation (20 to 30% typical) by limiting the amount of air available for oxidation. In addition, this air/fuel ratio adjustment improves the thermal efficiency of the burner, thereby lowering fuel costs. In fact, application of LEA can often lead to a cost savings in addition to the emissions reductions. For these reasons, LEA is often one of the first controls applied to uncontrolled units and is easiest to do as a retrofit technology.(Pechan, 1991) For instance, Houston Light and Power has employed LEA on most of its boilers since the early 1970s, claiming NO_x reductions of almost 50 percent (Carmine, 1993).

Overfire Air (OFA). Use of overfire air in boilers and process heaters can reduce NO_x emissions in the 15 to 25 percent range.(BAAQMD, 1991c) This technique creates a secondary combustion zone above the burners. The burner zone operates under fuel-rich conditions, lowering NO_x formation, while the secondary zone completes the fuel burning. In the past there have been problems with OFA retrofits, especially on smaller boilers. In addition, OFA can result in fuel efficiency losses, increased ash formation (PC-fired boilers), and accelerated waterwall corrosion. Therefore, OFA is seldom used as a retrofit technique on small boilers, though it may be employed in new boiler configurations.(Acurex, 1992)

Flue Gas Recirculation (FGR). Flue gas recirculation lowers temperatures in the prime flame zone and available oxygen, and therefore NO_x formation, in the combustion zone. (FGR is the equivalent of exhaust gas recirculation (EGR), commonly used in internal combustion engines.) Use of FGR on California utility oil and gas boilers has lowered NO_x emissions by 40 to 65 percent (Acurex, 1992). Unlike many other combustion modifications, FGR produces the greatest reductions for cleaner fuels such as natural gas. When used in conjunction with low-NO_x burners, reductions can be as high as 80%.(Radian, 1993a) The typical package includes operating FGR with low-NO_x burners.

Burners Out Of Service (BOOS)/ Biased Burner Firing. BOOS refers to an operational modification where selected burners in a very large, multi-burner unit inject only air instead of fuel into the upper combustion zone. Biased burner firing varies the air/fuel ratio amongst different burner areas. Both of these techniques have the effect of creating rich and lean-burn fuel zones, lowering NO_x emissions similar to OFA. These modifications require almost no capital expenditures, so cost-effectiveness values are low. These combustion modifications are usually applied only to previously uncontrolled oil and gas-fired utility boilers. Boiler performance and peak load may be reduced in order to minimize increased HC and CO emissions.(Acurex, 1992)

Low-NO_x Burners (LNB). LNBs are considered a "second generation" combustion modification, applied to units already using one of the lower cost controls (BOOS, OFA, FGR). The burners make use of a longer flame zone, air staging, fuel staging, or internal FGR to lower thermal NO_x formation. Major advances have been made in LNB technology in the last few years, providing potential emissions reductions in the 50 percent (or more) range.(Acurex, 1992) The development of

"Ultra-LNBs" may reduce emissions even further, at similar costs.(LMOP, 1993) LNBs also have great retrofit potential. However, field testing has been limited, especially on smaller burners. Cost-effectiveness estimates vary considerably, but are usually in the $1,000 to $2,000 range.(Acurex, 1992; Pechan, 1991; Radian calculations -- see Appendix B).

Natural Gas Reburn (NGR) or Fuel Staging. This technique introduces natural gas above the primary combustion zone. NO produced in the primary zone passes through the natural gas zone and is destroyed. Emissions reductions are on the order of 40 to 60 percent.(Acurex, 1992) This method is best used in coal-fired boilers, where gas can substitute for up to 15 percent of the heat input.(Kaplan, 1992) The cost-effectiveness of this measure is directly tied to the cost differential between natural gas and coal/oil. Given current gas and coal prices, NGR reduces NO_x emissions for about $1,000/ton.(See Radian calculations, Appendix B)

Natural Gas Cofiring/Seasonal Fuel Switching. Though not technically a "combustion modification", changing from a more to a less polluting fuel can significantly reduce NO_x emissions. Cofiring refers to the partial substitution of gas for another fuel, while fuel switching entails a 100 percent switch, usually during the peak ozone season. This approach is most common for uncontrolled coal-fired systems, where reductions can be up to 80 percent.(Pratapas, 1993) As with NGR, the cost of these approaches varies greatly with the cost of gas and coal.

Other Controls. Other control options utilize the same emission reduction principles as the above combustion modifications. For instance, **pre-stratified charge** used in internal combustion engines creates a dual-combustion zone much like OFA. **Ignition-timing retard** can be applied to internal combustion (IC) engines to lower temperatures as well. **Water or steam injection** serves to cool the combustion zone in gas turbines, similar to FGR. Finally, **electrification** of certain IC engines is similar to fuel switching, lowering emissions by avoiding the use of high emitting fuels. These controls are discussed in more detail in the supplemental documentation.

Flue Gas Treatment. After the consideration of "first" and "second generation" combustion modifications, flue gas treatments must be applied to achieve further NO_x reductions. Because these controls are applied after NO_x formation has occurred, there is no risk of increasing HC and CO emissions, as with combustion modifications. However, there are other pollutants that may form as a result of applying flue gas technologies, such as ammonium salts from ammonia slip. In addition, the application of flue gas treatments has both technical and economic limitations. First, both SNCR and SCR must operate within a specified temperature window, with a minimum flue gas residence time.(Acurex, 1992) Second, the flue gas characteristics must be compatible with the equipment. Also, because these controls are very capital intensive, they are only economical for larger sources. Therefore both cost and feasibility must be evaluated in order to assess the viability of flue gas treatments. The possible application rates for these techniques are assessed in Section 5.

Selective Non-Catalytic Reduction (SNCR). SNCR uses urea or ammonia injected into the exhaust stream at 1600 - 1900°F to reduce NO to molecular nitrogen and water. This process can reduce emissions by 25 to 50 percent, with moderately large capital costs.(BAAQMD, 1991a) However, test facilities have had problems with ammonia "slip", where unreacted reduction agents are emitted from the stack. Also, because of the narrow temperature window, SNCR loses efficiency with variable boiler loads. In addition, some units have encountered significant retrofit difficulties, especially with coal boilers.(Acurex, 1992) SNCR may be combined with various combustion modifications to achieve lower emissions levels.

Selective Catalytic Reductions (SCR). SCR uses ammonia in the presence of a zeolite or metal catalyst to reduce NO emissions. Generally, SCR must be applied downstream of economizer before air preheat to be in the catalyst's temperature window.(McGuire, 1993) The reaction operates at lower temperatures than SNCR, from about 450 to 850°F, due to the presence of the catalyst.(Acurex, 1992) SCR is possibly the most effective single control that can be applied to NO_x sources, with reported reductions over 80 percent.(Pechan, 1991; Acurex, 1992) Even further reductions are possible in combination with combustion modifications. The same problems with variable boiler load, ammonia slip, and retrofit difficulties have been encountered with SCR as with SNCR. Similarly, application of SCR to small sources is certainly not cost-effective. Further demonstration and development may be needed for full scale commercialization. Retrofit modifications can be difficult where the existing structure does not have adequate room for SCR hardware.(McGuire, 1993)

Possible Controls for Major NO_x Source Categories

Following is a brief description of the major NO_x sources identified in this project, and potential control techniques. Please refer to Appendices D and E accompanying this report for a detailed analysis of potential emissions reductions and cost-effectiveness values. The analysis is based on retrofit requirements for existing sources rather than new sources.

Chemical Manufacturing Facilities. This category encompasses several SIC codes. Houston is the only one of the five cities with significant NO_x emissions from this category. Radian assumed that most chemical plants have similar NO_x sources, primarily boilers and process heaters. In addition, Radian assumed that oil or gas is the primary firing fuel, given Houston's high dependence on these fuels in general. Although LNBs are beginning to penetrate the industrial market, by and large emissions remain uncontrolled. Possible retrofit controls include FGR on smaller sources, LNBs, BOOS and OFA, SNCR and SCR on larger units.(Pechan, 1991; LMOP, 1993)

Glass Melting Furnaces. Glass melting furnaces are used in the manufacture of container glass, flat glass, pressed and blown glass, and fiberglass, with container glass facilities being the most common. These furnaces can be significant sources of NO_x due to the very high temperatures involved. This source category is only significant for the Chicago area. There are currently no controls placed on these sources outside of California. Possible controls include various combustion modifications, electrical furnace boosting, SNCR, SCR, and various furnace modifications.(LMOP, 1993; SCAQMD, 1991).

Industrial/Commercial/Institutional Boilers -- (Coal, Oil, Gas). These boilers are typically 30 to 150 MMBtu/hr in size, with a few ranging up into the utility boiler size. They are used for a variety of applications, including steam and hot water production, small-scale electrical generation, and miscellaneous process needs.(LMOP, 1993) Coal-fired units typically have higher emissions than oil and gas units. According to the NO_x inventories, these boilers are significant sources in Chicago and D.C. However, we expect that these boilers are actually significant in all cities, but their emissions may have been catalogued under an industry-specific source category, such as petroleum refineries or SOCMI (Houston). While newer, larger coal-fired units are subject to NSPS standards, the vast majority of these boilers probably are operating at uncontrolled emissions levels. Possible controls include most combustion modifications, SNCR, SCR, and seasonal fuel switching.(Pechan, 1991; LMOP, 1993)

Stationary Internal Combustion (IC) Engines. Stationary IC engines are used in a wide variety of applications, including electricity generation (usually standby), oil and gas pumping, agriculture, and refrigerator compression. These engines burn gasoline, natural gas, diesel, or diesel/gas mixtures, and come in 2 and 4-stroke configurations. They may also be categorized as rich or lean-burn. In general, 2-stroke spark-ignition engines and large diesel engines are the highest emitters in this category.(LMOP, 1993) The NO_x inventories indicate that IC engines are a significant sources in Baltimore and Chicago. However, these sources are probably common in all cities, and may be included in other source categories such as oil and gas production. There are no current regulations affecting stationary IC engines in the study regions, though there are extensive regulations governing their mobile counterparts. Possible controls include pre-stratified charge, air/fuel adjustment, ignition timing retard, and 3-way catalysts for rich burn engines; air/fuel adjustment, timing retard, lean-burn combustion, exhaust gas recirculation, and SCR for lean-burn engines.(Acurex, 1992; LMOP, 1993; EPA, July 1993)

Iron and Steel Manufacture. NO_x emissions from iron and steel manufacturing come from a multitude of different processes, all having different uncontrolled emissions levels and retrofit/control potentials. The majority of these processes involve differing furnace types, excluding coke plant operations. This source category is significant in Baltimore and Philadelphia. There are currently no regulations governing these sources. Possible controls include LEA, BOOS, FGR, LNB, and flue gas treatments, depending on process.(LMOP, 1993; EPA, 1983; Pechan, 1991)

Oil and Gas Production. NO_x emissions from this category almost entirely originate from stationary IC engines and gas turbines used for pumping gas and oil. Our evaluation is based on data for gas pipelines. We assume that NO_x sources are also similar for oil pipelines. Gas pipeline IC engines are more common but smaller than gas turbines, ranging from 50 to 10,000 hp. Turbines range from 1,000 to 30,000 hp. The total hp split between engines and turbines is about equal nationwide.(Acurex, 1990) Turbines are becoming more common with time, given their higher efficiency and lower emissions rates (from five to ten times lower than IC engines). This source category is only significant for the Houston area, with most emissions located in remote areas. While there are NSPS standards for larger turbines, the majority of emissions from this category are uncontrolled. Potential controls include those noted above for IC engines, and water/steam injection, dry low NO_x, and SCR for turbines.(Acurex, 1990; Pechan, 1991)

Petroleum Refineries. Process heaters and CO boilers are the primary sources of NO_x emissions for this source category. This source category is a common one in major U.S. cities, including three in our study -- Chicago, Houston, and Philadelphia. Process heaters are used extensively to promote chemical reactions requiring heat input, and burn either oil or gas. Typical heater sizes range from 30 to 100 MMBtu/hr, with some heaters up to 500 MMBtu/hr.(LMOP, 1993) While some process heaters have adopted LNB technology (especially in California), most remain uncontrolled. Potential controls for process heaters include BOOS, OFA, LNBs, and flue gas treatments.(Pechan, 1991; LMOP, 1993; Radian, 1993a)

CO boilers are industrial-sized boilers that burn the off-gas from fluid catalytic cracking units, which contain significant CO concentrations, along with standard fuel. CO boilers emit much higher levels of NO_x than comparable boilers. Due to retrofit limitations, CO boilers are very difficult and expensive to control, and are currently unregulated. Flue gas treatments may not be an option for these combustion devices as well.(Buening, 1993)

Residential Heating. Residential heating systems are used extensively in every urban area of the country, and consist of space heaters, warm air furnaces, and water heaters. These systems typically use natural gas or distillate oil, with gas systems having lower emissions. Little control information is available on these units, and they are not regulated. While the inventories only identify home heating systems as a major source for Chicago, we believe that this may represent an inaccuracy in the remaining inventories. (Home heating in Philadelphia has an anomalous value of 65 tpd, more than five times than Chicago value. We are still attempting to resolve this issue.) Control options are numerous, but generally involve the introduction of new units, rather than retrofitting.(EPA, Feb 1992; BAAQMD, 1991; SCAQMD, 1991)

Utility Boilers (Coal, Oil and Gas). Utility boilers, used for electricity generation, consistently represent the single largest point source of NO_x emissions for all cities (excluding those areas heavily dependant on nuclear power, such as Philadelphia). In fact, utility boilers were the only point source category classified as a major source for all five cities, for both coal and oil/gas units. These boilers are greater than 250 MMBtu/hr. In general, uncontrolled coal boilers emit twice as much NO_x per Btu as do oil and gas boilers, primarily due to fuel NO_x.(Acurex, 1992) Because of the importance of this source category to the total NO_x inventory, there is a substantial amount of data on industrial boiler controls. (In fact, the level of detail in the literature allowed Radian to develop cash flows for various boiler control options. See Appendix B for the results of this analysis.) Larger and newer coal boilers are subject to NSPS standards. In addition, some simple combustion modifications have begun to penetrate this sector, including LEA applied to many of Houston's gas boilers.(Edison Electric, 1993) Nevertheless, most utility boilers remain uncontrolled. Possible controls include most major combustion modifications, NGR, flue gas treatments, and fuel switching (for coal boilers).(Acurex, 1992, Pechan, 1991; Pratapas, 1993)

Utility Turbines (Oil and Gas). Electric utilities traditionally have employed turbines as peaking units, commonly operating at capacity factors of two percent or less. More recently larger, base load combined cycle units have begun to penetrate the market, taking advantage of these units' high efficiency ratings.(Carmine, 1993) The uncontrolled NO_x emissions from both oil- and gas-fired turbines are quite low, often lower than those of uncontrolled tangentially-fired boilers.(Buening, 1993) Given their low emission factors, the small capacity factors of the peakers, and the rarity of the combined cycle units, turbines were not found to be significant sources of NO_x in any of the five study areas and therefore were not evaluated in this study. Note however that many of the controls evaluated for turbines in the oil and gas productions sector should also apply to utility turbines.

The following table presents a listing of the major NO_x sources, with a range of the cost-effectiveness of applicable controls for each.

This table uses average cost-effectiveness values, based on the highest and lowest dollars per ton values found in the literature. However, because each source category typically has four or more control options available, and because these controls often vary in cost-effectiveness by over an order of magnitude, using average values for ranking purposes is not particularly instructive. We can develop more insight regarding cost-effective control applications be referring to Table 3-2, which ranks specific control technologies by dollars per ton values, independent of source categories.

Table 3-3. Ranking of Stationary Source NO_x Control Categories -- by Source Type

Stationary Source NO_x Control Categories	Effectiveness of Control	Cost of Control (1993$)
Utility Boilers -- PC-Fired	16-84%	$94-6,880
Industrial/Commercial/Institutional Boilers -- Coal Fired	4-90%	savings-9,200
Iron and Steel Manufacturing	20-90%	$230-9,300
Oil and Gas Production	50-95%	$60-14,000
Petroleum Refineries	30-85%	$20-14,300
Chemical Manufacturing (SOCMI, Others)	30-85%	$130-14,300
Utility Boilers -- Oil/Gas Fired	17-83%	$234-15,686
Industrial/Commercial/Institutional Boilers -- Oil/Gas Fired	5-90%	$(5,900)-24,000
Stationary IC Engines	0-90%	$125-23,000
Glass Melting Furnaces	5-95%	$570-22,800
Residential Heating	29-100%	$2,000-63,000

NON-ROAD VOC AND NO_x SOURCES

Non-road vehicles, while less numerous than their on-road counterparts, are still significant contributors of VOC and NO_x inventories in many nonattainment areas. Most of the categories within the non-road heading are currently exempt from any emission control requirements. Consequently, they produce far more pollution than similar emission-controlled engines used in on-highway vehicles. For the purposes of reducing VOCs from non-road vehicles and engines, controls for lawn and garden and recreational marine engines need to be addressed because they represent the bulk of emissions. As for NO_x controls, construction and agricultural equipment appear to hold the greatest potential.

VOC emissions from non-road mobile sources account for between 5 and 20 percent of the total VOC emissions from the five nonattainment areas included in our study. These sources account for a significant portion of VOC emissions in each nonattainment area representing a possible source of further reductions. Table 3-4 illustrates the significance of non-road mobile sources relative to the total VOC emissions, broken out by category.

Table 3-4. Impact of Non-Road Sources on Total VOC Inventory

VOC	Chicago (%)	Washington (%)	Baltimore (%)	Philadelphia (%)	Houston (%)
Rail	0.47	0.06	0.15	0.03	0.05
Airplanes	0.66	0.44	0.84	1.37	0.83
Commercial Vessels	0.03	0.00	0.13	0.78	0.93
Lawn & Garden	4.96	1.27	5.32	6.11	5.29
Industrial Equipment	1.86	0.28	2.20	3.51	2.14
Heavy Construction Equipment	1.02	2.25	1.16	3.15	1.50
Pleasure Craft	1.90	0.13	2.38	0.0	6.22
TOTAL	10.87	4.88	12.18	14.95	17.80

As with the stationary sources discussed in previous sections, non-road sources are distributed differently throughout each nonattainment area. The lawn and garden category registered significant levels in the Chicago, Baltimore, and Houston inventories producing 62, 17, and 58 tons per day, respectively. These emissions values are greater than or equal to many of the large point source categories discussed earlier. Conversely, Houston reported a 68 tpd VOC emission level from recreational pleasure crafts, which is disproportionally higher than the emission inventories for the other four cities.

NO_x emissions from non-road sources also account for a significant proportion of the emission inventories for the five nonattainment areas. Non-road sources represent approximately 13 to 23 percent of the total NO_x emissions for each area. Non-road sources, therefore, contribute a large amount to the total inventory. The relative percentage of non-road NO_x sources for each of the five nonattainment areas is illustrated in Table 3-5.

Table 3-5. Impact of Non-Road Sources on Total NO_x Inventory

NO_x	Chicago (%)	Washington (%)	Baltimore (%)	Philadelphia (%) *	Houston (%)
Rail	2.21	0.85	2.32	3.89	1.33
Airplanes	1.36	0.65	0.52	2.00	0.48
Commercial Vessels	0.19	0.00	0.59	3.93	6.01
Agricultural Equipment	1.10	0.59	1.67	0.53	1.43
Industrial Equipment	1.81	0.49	2.65	1.95	0.00
Heavy Construction Equipment	7.61	10.12	6.16	6.19	7.39
TOTAL	14.49	12.81	14.17	18.56	16.84

* Based on State-wide emissions totals.

Similar to the non-road VOC sources, non-road NO_x sources account for a large percentage to the total inventory. The category, heavy construction equipment, represents a notable source of NO_x emissions in all five inventories, producing 80, 87, 29, 74, and 98 tpd for Chicago, Washington, Baltimore, Philadelphia, and Houston, respectively. These emissions are comparable to other large industrial sources. Sources like railroad and commercial vessel also represent large sources of NO_x emissions.

General VOC and NO_x Controls

Non-road sources are very diverse in the size rating, combustion type, and usage patterns. The control measures for gasoline engines under 25 hp and diesel engines over 50 hp involve several changes in the design of the engine and the fuel storage system. The changes would result in a reduction of VOCs emitted during engine operation as well as during refueling and storage. Possible engine improvements include:

Combustion Modifications:

- Improvements to carburetion and fuel injection systems;
- Modifications to port timing;
- Adjustments to compression ratios and to rated speed;
- Changes in ignition timing and sparkplug design;
- Adjustments to engine cooling characteristics;
- Recirculation of exhaust gases;
- Changes to valve placement;

Aftertreatment Controls:

- Catalytic converters; and
- Regeneration techniques.

Examples of storage system improvements are:

- Improvements to gasoline containers;
- Leakless nozzles; and
- Spouts and funnels.

Potential reductions in the VOC emissions were estimated assuming the following efficiency improvements in engines:

Exhaust emission reductions:	40% for 2-stroke, 70% for 4-stroke
Evaporative and crankcase reductions:	33%
Refueling emission reductions:	50%

(LMOCP, 1993)

Changes in the NO_x inventory are based on overall control efficiencies resulting in a 15 percent increase for gasoline engines and a 35 percent decrease for diesel engines over 50 hp.(LMOCP, 1993)

Proposed standards must take into account that certain engine design changes that decrease VOC emissions will cause an increase in NO_x emissions. In addition, consumer maintenance of the engines will have a significant effect on whether the emission reductions achieved by designing more efficient engines are maintained over their useful lifetime. Because of the uncertainty associated with owner maintenance, Radian conservatively assumed a 50 percent rule effectiveness level for these controls (compared to the default level of 80 percent used for other sources).

VOC emissions may be reduced further by the use of reformulated gasoline. Additional reductions are also possible from increased use of electric motors or alternative fuels for the smaller engines used in utility or lawn and garden applications. The SCAQMD also have looked into scrappage programs as a source of reductions. For example, replacing two-stroke engines with four-stroke engines would have the potential of further reducing emissions. No long turnover time problem is addressed by these options. Since retrofit is not a good option, other controls are maintenance strategies. Implementation of the available controls will not show significant emission reductions by 1996 due to phase-in constraints.

The EPA is proposing standards for NO_x and smoke emissions from non-road compression-ignition engines greater than or equal to 50 horsepower. The goal of the proposed rule is to reduce NO_x emission, from these sources by 35 percent by the first decade of the 21st century.(LMOCP, 1993) The dates for implementing the NO_x standard will be staggered, depending on the horsepower of the engine, beginning with the 1996 model year. The standards explicitly exclude the following engines: large non-road CI engines previously regulated by the mining industry; engines used in aircraft; engines used to propel locomotives; and engines used in marine vessels. It is important to note that because these efforts focus primarily on new vehicles, very little if any emissions reduction can be expected prior to 1996. The EPA is looking at regulatory alternatives for locomotives and marine vessels.

In addition, the EPA conducted a public workshop for off-road engines under 50 hp in March of 1992 and an exploratory meeting for small off-road engine regulations in November of 1992. The EPA is currently working with engine manufacturers, state regulatory agencies and health and environmental groups in order to propose regulations to cover gasoline engines under 25 hp.(LMOCP, 1993).

There are currently no existing regulations applicable to non-road sources in the five areas of study. States are prohibited from developing standards or other requirements related to the control of emissions from non-road engines, but they may adopt federal regulations or an EPA-approved California program.

Brief source descriptions are provided in this section for a number of non-road source categories providing potential control measures and cost-effectiveness estimates.

<u>Agricultural Equipment</u>

Agricultural equipment is a major source of NO_x emissions in Chicago, Baltimore, and Houston. Agricultural equipment includes tractors, cultivating and harvesting equipment such as combines, sprayers, balers, and tillers. The horsepower range covered by the different types of equipment is wide, under 10 for a typical tiller, between 50 to 100, and larger for a typical combine. High hp equipment is typically equipped with diesel engines and low hp equipment with 4-stroke gasoline engines.

The control costs for VOC and NO_x reductions are highly dependent on the usage rates. It is estimated that net savings of $960 per ton of VOC and NO_x removed to a net cost of $240 per ton of VOC and NO_x removed, though the feasibility and extent of application is unknown (LMOCP,1993).

Rail

NO_x emissions from railroad locomotives are considered major in the Chicago, Baltimore, and Philadelphia inventories. Modern railway locomotives are almost exclusively diesel-electric. Individual locomotives range from under 1,000 hp to over 7,000 hp.

Implementation of the available control measures could provide a 55 percent reduction in NO_x emissions from railroad locomotives at a cost ranging from $1,328-1,648 per ton NO_x + HC.(LMOCP, 1993) These estimates are based on previous Radian studies. Due to the engine manufacturer's practice of making new-technology components available for rebuilding older engines, it is feasible to get significant reductions on both new and existing engines.

Airplanes

Airplanes account for significant levels of VOC and NO_x emissions in the inventories of Chicago, Baltimore, and Philadelphia. Pollutants are emitted from aircraft whenever the engines are operating. The emissions characteristics vary as a function of both the type of aircraft and the operating mode. Aircraft emissions are affected by the throttle power setting, that is, the percentage of maximum power that the engines produce at any given time.

After review of the literature, no information has been found for controlling emissions from aircraft engines. Aircraft are categorically exempt from all emission standards and very little technology exists for controlling emissions.

Marine Vessels

Philadelphia and Houston reported VOC and NO_x emissions from marine vessels as major sources. Marine vessels include ships, diesel-powered tug and towboats, passenger vessels, and commercial fishing vessels. The vast majority of large ships are now diesel powered, due to the high efficiency of the diesel engines. Vessels such as commercial fishing boats, small workboats, towboats, and similar vessels are typically powered by engines similar to those used in highway trucks, therefore similar control technologies are applicable.

Application of the available control measures for marine vessels, intended to correspond in stringency to the 1988 on-road emission standards, have been estimated to reduce NO_x emissions by up to 55 percent at a cost of $832-1,100 per ton of NO_x + HC removed, though feasibility and extent of application is uncertain (Weaver, 1987).

Lawn and Garden

VOC emission for lawn and garden equipment are considered major sources in the inventories of Chicago, Baltimore, Philadelphia, and Houston. In fact, VOC emissions from lawn and garden equipment accounts for almost a third of all emissions from non-road sources. Lawn and garden equipment are generally used in numerous general utility applications. Equipment in the lawn and garden category includes: mowers, lawn tractors, string trimmers, snow blowers, chain saws and others. Equipment used in general utility applications includes: pumps, generators, compressors, and grinders. The vast majority of this equipment is powered by internal combustion engines less than 25 horsepower including diesel, two-stroke, and four-stroke engines.

Review of the CARB Rule for lawn and garden equipment suggests that reductions of VOC emissions from exhaust gases based on redesign and replacement of engines to be approximately 40 percent for 2-stroke and 70 percent for 4-stroke gasoline engines. (LMOCP, 1993) Additional reductions can be achieved by the installation of catalytic convertors. The cost of redesign and manufacturing improvements will range from $160 per ton VOC removed for above 50 cc, 2-stroke engines to $1,960 per ton VOC reduced for below 50 cc, 2-stroke engines.(LMOCP, 1993) The control costs for 4-stroke engines also fall within this range. Add-on controls are cost prohibitive and unproven to be a viable option at this time. The cost effectiveness of substituting electric lawn mowers for gasoline-fueled mowers is estimated by SCAQMD to be $2,700-28,000 per ton of VOC removed.(LMOCP, 1993)

Industrial/Commercial Equipment

Industrial equipment is considered a major source of VOC and NO_x emissions in Chicago, Baltimore, Houston, and Philadelphia. The industrial equipment category includes for the most part equipment used in manufacturing and warehouse applications. It encompasses a large variety of equipment, including aerial lifts, self-propelled elevating platforms, sweepers, scrubbers, and forklifts. Because the industrial equipment category is so diverse, typical horsepower ratings for the different equipment types cover a typical range of 50 to 100 hp. Most industrial equipment uses either diesel or 4-stroke gasoline engines; however, some of them run on liquid petroleum gas or compressed natural gas.

Emission reduction potentials are consistent with those discussed above assuming an average retirement period for the equipment of 5 years. Because industrial equipment has a high usage rate, the fuel use reduction incurred by converting to a more efficient engine design can be substantial, representing a cost savings of approximately $1,220 per ton of VOC + NO_x removed. (LMOCP, 1993)

Heavy Construction Equipment

Heavy construction equipment is considered a major source of VOC and NO_x emissions in all five nonattainment areas. NO_x emissions from construction equipment represents approximately 50 percent of the non-road NO_x emissions. The heavy construction equipment category includes road construction equipment such as asphalt pavers, building construction equipment such as cranes, and general supporting equipment such as non-highway trucks. Because the industrial equipment category is so diverse, typical horsepower ratings for different equipment cover a wide range.

Emission reduction potentials are consistent with the ones described previously providing a 40 to 70 percent reduction in exhaust emissions, a 33 percent reduction in evaporative and crankcase emissions and a 55 percent reduction in refueling emissions. The average retirement period for the equipment was assumed to be 5 years. The cost of controls range from a savings, based on high usage rates and fuel savings, of up to $660 per ton of VOC + NO_x for diesel equipment, and a cost of up to $6,560 per ton of VOC + NO_x for gasoline equipment.(LMOCP, 1993)

Pleasure Craft. Chicago, Baltimore, and Houston reported pleasure crafts as major VOC emission sources. Pleasure craft, or recreational marine vessels, include outboards, inboards, sterndrives and personal watercraft. The vast majority of these vessels are powered by internal combustion engines less than 250 hp with 40-50 hp being typical. The types of engines used include diesel, 2-stroke, and 4-stroke, where 2-stroke engines dominate outboard applications, while 4-stroke engines are used for inboard applications (LMOCP, 1993).

The possible control measures for recreational vessels differ from those for other sources. Examples of possible engine modifications might include:

- dual-intake stratified charge or lean burn fuel charge;
- exhaust gas recirculation;
- electronic controls; or
- turbo charging and intercooling.

No control of VOC or NO_x from diesel engines is recommended due to a small contribution to the inventory.

Emission reduction potentials for recreational marine vessels are similar to those described in the previous section based on the engine type. The cost of control ranges from $160-1,960 per ton of VOC reduced. All costs take into consideration fuel savings that will result by using the more efficient engine design. These estimated were developed using an average engine lifetime estimate of 27 years.(LMOCP, 1993)

<u>Summary of Potential Reduction for Non-Road Mobile Sources</u>

Non-road mobile source controls can provide small yet important emissions reductions for both VOC and NO_x emissions. VOC reductions from non-road sources in the year 2010 account for an average of 4 percent of the total inventory in that year. Due to phase-in limitations, significant reductions are not possible until after 1999. Tables 3-6 to 3-10 represent the potential VOC and NO_x emissions reductions from non-road mobile sources for the year 2010. The phase-in periods were accounted for in the calculations through the rule penetration estimate. Given the average lifetime of the equipment within each category, we assumed that 80 percent of the sources would be retrofitted or replaced with controlled systems by the end of the equipment life. Cost-effectiveness values found in the literature were given in dollars per ton of combined VOC + NO_x. To break this down, we assumed a one-to-one correlation between VOC and NO_x reductions and ratioed the cost-effectiveness values based on the actual inventory values for each nonattainment area. Given that a detailed source description was not available, especially for the split between diesel- and gasoline-powered vehicles, the lowest control efficiency was applied to make a conservative estimate of VOC reduction potentials. We assumed that almost all NO_x emissions were produced by diesel vehicles, since the NO_x emission factor for diesel fueled vehicles is significantly larger than the emission factor for gasoline fueled vehicles. Cost-effectiveness estimates yielding a net savings were represent as no cost for calculation purposes.

Table 3-6. Non-Road Mobile Source Controls – Baltimore

Year 2010	VOC		NO_x	
	Reductions (TPD)	Cost Effectiveness ($/ton)	Reductions (TPD)	Cost Effectiveness ($/ton)
Agricultural Equipment	---	---	1.1	$0-293
Heavy Construction Equipment	1.0	$0-57,128	7.0	$0-7,411
Industrial and Commercial Equipment	2.0	(savings)	3.0	(savings)
Lawn & Garden	4.8	$160-1,960	---	---
Marine Vessels	---	---	0.6	$954-1,262
Pleasure Craft	0.6	$160-1,960	---	---
Rail	---	---	1.9	$1,387-1,722
Total	8.4 (4.7%)[a]		13.6 (3.1%)[b]	

[a] Relative to the required VOC reductions in 2010.
[b] Relative to the total NO_x inventory in 2010.

Table 3-7. Non-Road Mobile Source Controls -- Chicago

Year 2010	VOC		NO_x	
	Reductions (TPD)	Cost Effectiveness ($/ton)	Reductions (TPD)	Cost Effectiveness ($/ton)
Agricultural Equipment	---	---	1.6	$0-232
Heavy Construction Equipment	3.6	$0-48,228	20.0	$0-7,592
Industrial and Commercial Equipment	6.5	(savings)	4.7	(savings)
Lawn & Garden	17.5	$160-1,960	---	---
Marine Vessels	---	---	0.5	$991-1,310
Pleasure Craft	3.1	$160-1,960	---	---
Rail	---	---	4.1	$1,658-2,058
Total	30.7 (4.2%) [a]		30.9 (3.1%) [b]	

[a] Relative to the required VOC reductions in 2010.
[b] Relative to the total NO_x inventory in 2010.

Table 3-8. Non-Road Mobile Source Controls -- Houston

Year 2010	VOC		NO_x	
	Reductions (TPD)	Cost Effectiveness ($/ton)	Reductions (TPD)	Cost Effectiveness ($/ton)
Agricultural Equipment	---	---	4.1	$0-273
Heavy Construction Equipment	4.6	$0-45,705	38.0	$0-7,659
Industrial and Commercial Equipment	6.5	(savings)	0.0	(savings)
Lawn & Garden	16.0	$160-1,960	---	---
Marine Vessels	---	---	28.6	$938-1,240
Pleasure Craft	5.8	$160-1,960	---	---
Rail	---	---	5.1	$1,366-1,695
Total	**32.9 (5.0%) [a]**		**75.8 (4.9%) [b]**	

[a] Relative to the required VOC reductions in 2010.
[b] Relative to the total NO_x inventory in 2010.

Table 3-9. Non-Road Mobile Source Controls -- Philadelphia

Year 2010	VOC		NO_x	
	Reductions (TPD)	Cost Effectiveness ($/ton)	Reductions (TPD)	Cost Effectiveness ($/ton)
Agricultural Equipment	---	---	0.3	$0-240
Heavy Construction Equipment	5.0	$0-51,723	6.0	$0-6,560
Industrial and Commercial Equipment	5.5	(savings)	1.9	(savings)
Lawn & Garden	9.6	$160-1,960	---	---
Marine Vessels	---	---	0.0	$832-1,100
Pleasure Craft	---	$160-1,960	---	---
Rail	---	---	5.4	$1,368-1,698
Total	**20.1 (6.6%)** [a]		**13.4 (3.5%)** [b]	

[a] Relative to the required VOC reductions in 2010.
[b] Relative to the total NO_x inventory in 2010.

Table 3-10. Non-Road Mobile Source Controls -- Washington

Year 2010	VOC		NO_x	
	Reductions (TPD)	Cost Effectiveness ($/ton)	Reductions (TPD)	Cost Effectiveness ($/ton)
Agricultural Equipment	---	---	0.7	$0-345
Heavy Construction Equipment	3.5	$0-52,548	21.5	$0-7,500
Industrial and Commercial Equipment	0.4	(savings)	1.0	(savings)
Lawn & Garden	2.1	$160-1,960	---	---
Marine Vessels	---	---	0.0	---
Pleasure Craft	0.1	$160-1,960	---	---
Rail	---	---	1.3	$1,385-1,719
Total	**6.1 (2.8%)** [a]		**24.5 (2.7%)** [b]	

[a] Relative to the required VOC reductions in 2010.
[b] Relative to the total NO_x inventory in 2010.

MARKET-BASED APPROACHES

Although beyond the scope of this report, Radian believes that market-based approaches to emission control may provide a cost-effective mechanism for meeting RFP targets. Market-based emission control programs include emission fees and taxes, subsidies for control investments, bubbles, offsets, and marketable permit programs. All of these approaches provide the actual emission source with an economic incentive to lower emission rates, without specifying how the reductions must be achieved. For example, under an emission fee system, an emitter may chose among any number of control options to lower emissions and minimize costs. Emission reduction trading programs provide sources with the added flexibility of lower emissions beyond the fence line, further broadening the array of control opportunities. By providing sources with a number of different control options such programs can lower the overall cost per ton of emission reductions compared to the technology-specific command-and-control approaches discussed above.

However, such programs can be particularly difficult to monitor, and administrative and enforcement costs may be high. In addition, the overall impact of fee and subsidy programs cannot be known in advance without knowing the control costs of the sources themselves. (For example, if a tax of $1,000 per ton of pollutant is placed on a source, the source may find it cheaper to pay the tax than adopt controls at $2,000 a ton, if no other controls are available. In this case the tax does not lower emissions at all, though it does serve as a source of revenue.) For these reasons, great care must be taken to guarantee that market-based control programs result in reductions that are quantifiable, enforceable, surplus to other required reductions, and permanent. Only when a program meets all of these criteria can it be used toward meeting a city's RFP targets.

Section 4
EMISSION REDUCTION STRATEGIES FOR MOBILE SOURCES

As depicted in Figures 2-1 to 2-10, on-road mobile sources are significant contributors to both the VOC and NO_x inventories of all cities, ranging from approximately 20 to 50 percent of total emissions. While a number of controls have been adopted over the past two decades as part of the Federal Motor Vehicle Control Program, further emissions reductions are still possible, and in fact necessary to reach attainment in all five study areas.

Titles I and II of the 1990 CAAA require the adoption of additional controls for on-road mobile sources. Title I focuses on reducing in-use emissions through better maintenance, controls on service station refueling emissions, reducing vehicle miles travelled, and other measures that could be implemented at the state or local level. Title II focuses on reducing vehicle emissions through more stringent vehicle emission standards and fuel property specifications. These requirements must be adopted by the states in their SIPs to reduce mobile source pollution, with the goal of attaining the NAAQS. The five study areas must adopt the following controls:

- Refueling control measures (Stage II and onboard vapor recovery);
- Federal reformulated gasoline (excluding D.C.);
- Enhanced inspection/maintenance (I/M) programs;
- Centrally fueled fleet programs; and
- Transportation control measures (TCMs) (excluding D.C.).

In addition to these mandated controls, states may consider other options to further reduce emissions, such as the California Low Emission Vehicle (LEV) program, expanded fleet or I/M programs, and early vehicle retirement (scrappage) programs.

Washington, D.C. also may "opt-in" to those programs required of the other four cities, as it already has for RFG. Both the mandated and optional control measures are described below.

OVERVIEW OF CONTROL OPTIONS

Stage II Refueling Controls

With this approach, service stations are required to install nozzles that capture vapors emitted as the vehicle is refueled. Stage II refueling emission control systems have already been adopted in several areas, including D.C. proper (but not the surrounding areas) to reduce hydrocarbon emissions. The amendments also require onboard refueling emission control systems, whereby refueling emissions are collected and consumed in the vehicle. (While Radian has evaluated the impacts of Stage II control systems, we have not estimated the impact of onboard controls due to the lack of an adequate model.) Both of these strategies control VOC but not NO_x emissions.

Reformulated Gasoline (RFG)

The federal RFG program consists of the simple model and Phases I and II of the complex model, with emissions reduction requirements in ozone precursors (VOCs and NO_x) and toxics relative to a baseline fuel. Simple model (or early use of the Phase I complex model) RFG sales must commence in designated areas in 1995. VOC, NO_x and toxics percentage reduction requirements increase in the year 2000 with the introduction of complex model Phase II RFG. In addition to opting in for federal RFG, states could, with EPA's approval, adopt California RFG fuel standards. California RFG is expected to have greater emissions benefits (and be more costly) than federal RFG. In particular, early modeling results indicate that California RFG may produce greater NO_x emission reductions (7.7%) than federal Phase II RFG (5.5%, from Complex Model) (Schleyer, 1993).

Enhanced and Expanded Inspection/Maintenance Programs

In an I/M program, vehicles are periodically inspected, and those with evidence of emission control malfunction or tampering are required to be repaired. EPA requires that states exceeding the NAAQS for ozone implement vehicle I/M programs targeting both VOC and NO_x emissions. Serious (and worse) ozone areas must adopt legislation for enhanced I/M programs by 1992.

Implementing an enhanced I/M program in place of the currently operating programs will require substantial changes. First, the basic operation must be changed from decentralized to centralized, with test and repair functions performed in different locations. Second, the emission test must be changed from an unloaded idle emission test to a transient loaded-mode test, following EPA's "IM240" test cycle. (A transient loaded-mode test uses a chassis dynamometer to simulate on-road driving, including accelerations and decelerations. This procedure allows accurate identification of vehicles that are high emitters in actual use.) The inspection also must include functional tests of the evaporative emission control system. These tests will include checking the gas tank for pressure leaks and the evaporative emission control system canister for proper purging of collected vapors while the vehicle is running. States may increase I/M program emission reduction potentials further by testing more vehicles than required by EPA (e.g., vehicles older than 1986 models, or heavy-duty vehicles). Radian's analysis evaluates both enhanced and expanded enhanced I/M programs.

California Low Emission Vehicle (LEV) Program

The CAA allows California to establish its own vehicle emission standards. Individual states may elect to adopt these alternate standards, if identical to those in California . California's standards involve the phase in of increasingly more stringent exhaust standards over the next decade because of its extremely severe ozone problem. The grams per mile (gpm) emissions standards may be met by gasoline- or alternatively-fueled light-duty vehicles and trucks. Beginning with the 1994 model year, a portion of the California vehicle population must meet Transitional-LEV, or TLEV exhaust standards, approximately 50 percent lower than the national VOC standards (termed Tier I). Beginning with the 1997 model year, 25 percent of vehicles must meet the LEV standards, approximately one third the Tier I VOC and one half the Tier I NO_x standards. At this same time, Ultra-LEVs, or ULEVs, begin to penetrate the fleet, lowering standards even further. The next year Zero Emission Vehicles, or ZEVs, begin to be sold. These vehicles will be powered by electricity.[1] Other states may adopt the LEV program, using different phase-in dates, and weighted-average emission requirements across the different standards. Irrespective of the California LEV program, the federal government has the option of adopting similar standards (without ZEVs), termed **Tier II**, which may be mandated nationwide beginning with model year 2004. The EPA and the automakers currently are discussing the possibility of early adoption a modified version of these standards, Federal LEV or FLEV (Austin, 1993). Because of this interest, Radian has evaluated the cost-effectiveness of Tier II vehicles as well.

Centrally Fueled Fleet Program

Centrally fueled fleet programs require the use of "clean-fuel vehicles" in serious, severe, and extreme ozone and CO nonattainment areas (currently 21 areas, including all five study areas). "Clean-fuel vehicles" are any vehicles certified to meet the clean-fuel vehicle VOC and NO_x emissions standards of Title II of the CAAA. These standards may be met using alternative fuels such as methanol or natural gas, or through the use of RFG and cleaner vehicle technologies. This program will apply to fleets of 10 or more vehicles which can be centrally fueled. Vehicles garaged at personal residences, emergency and other specified vehicles are exempt. Actual program phase-in will not begin until 1998. States can accelerate the phase-in of clean fueled vehicles by adopting a more aggressive schedule, or can increase the number of vehicles covered in order to increase emissions reductions. Radian evaluated emissions reductions for both the federal requirements and an accelerated, expanded schedule.

[1] ZEVs do not actually eliminate emissions associated with vehicle operation, but merely displace the emissions to the electric utility used to charge the vehicle battery. Depending upon the fuel used by the utility, gpm-equivalent NO_x emissions may be comparable to Tier I vehicles, though VOC emissions are practically eliminated.

Early Vehicle Retirement (Scrappage)

Although vehicle scrappage programs are not mandated by the CAA, this strategy may provide significant short-term emission reduction benefits. This approach addresses the fact that a large portion of mobile source emissions come from older, high-emitting vehicles. Therefore these programs attempt to take these vehicles off the road by first identifying them through registration records (age-based programs), or by emission testing (emission-based programs). Once identified, the state or other party can offer the vehicle owner cash for the rights to permanently destroy the vehicle. Emission-based programs are easily integrated into I/M programs, where a failed vehicle may be offered a scrap "bounty" as an alternative to making costly repairs. Because these older vehicles only have a limited remaining life, removing them from the road will only generate emission reductions for the period before which retirement would have occurred without incentive. Therefore EPA assumes that emission reductions resulting from these programs are valid for only three years.

Transportation Control Measures

The CAA requires severe/extreme areas to implement transportation control measures (TCMs) that will maintain vehicle miles travelled (VMT) at their 1990 levels. (Washington, D.C., a serious non-attainment area, need only consider adopting TCMs in its SIP.) By lowering VMT, vehicle emissions often are lowered as well.

TCMs commonly include trip reduction ordinances, mass transit improvements, and infrastructure efficiency improvements. Because of problems with quantifying emissions reductions and enforceability, Radian only performed a qualitative analysis of TCM cost-effectiveness in this study. Therefore the cost-effectiveness of TCMs are not compared directly with those of other control options, but are considered separately at the end of this section.

The following sections evaluate the effectiveness and costs of both the mandatory and optional mobile source controls noted above, on a per-vehicle basis. Emission reductions and cost-effectiveness values are reported for incremental control applications (e.g., going from enhanced to expanded enhanced I/M). We first describe how we determined the grams per mile emission factors for each measure. We then provide a brief account of our cost estimates for these measures, and conclude by calculating cost-effectiveness, in dollars per ton of pollutant. These values then may be compared to the cost-effectiveness values for point and area source controls calculated in sections 2 and 3.

BASELINE MOBILE SOURCE EMISSIONS ESTIMATES

In order to estimate VOC and NO_x emissions from mobile sources, Radian used EPA's latest emission factor model, MOBILE5a, to estimate emission factors in grams per mile. The model evaluates emission factors for eight different vehicle types (e.g., cars and light trucks, gasoline and diesel vehicles), considering local parameters such as ambient temperature, fleet age, fuel characteristics, and other factors. These values then are averaged across all vehicle types to obtain a fleet-average emission factor for each city. Once the grams per mile factors are established, they can be multiplied by vehicle miles travelled values to determine total emissions (see Section 5).

In order to accurately evaluate the incremental reductions resulting from mobile source controls, Radian needed to develop the most accurate "base case" emission estimates possible. (The base case scenario corresponds to the mobile source emission levels in 1990, before CAAA or other controls were adopted.) To do this, Radian attempted to duplicate the total emissions values reported by the state agencies in their inventories, using the state's local parameter values as inputs into MOBILE5a.

However, it was impossible to duplicate the state values exactly for two reasons. First, not all of the states used the latest version of the MOBILE model[2] -- Houston used the draft version of MOBILE5, and D.C. used MOBILE4.1. Therefore the reported values of these cities contained discrepancies with Radian's values, though Radian values should be more accurate since the later model was used. Second, the mobile source emissions inventory developed by the different state agencies used a distribution of average speeds corresponding with different road links. (The emission factors themselves vary as a function of vehicle speed, and therefore road link.) Each type of road was assigned a specific VMT and an average speed of travel. Total city-wide emissions were calculated by summing up the emissions for each link. It was impossible for Radian to exactly duplicate these link-based transportation emissions inventories because detailed link information was not available for three of the areas, and because we did not have the necessary post-processor programs used by the different agencies. Instead, Radian used a surrogate average speed that represented an emissions-weighted, link-based average, chosen to come as close to the reported VOC/NO_x combination as possible. Radian then used these emission factors to estimate the incremental emission reductions associated with each control strategy.

Table 4-1 provides a summary of the information used to generate each city's emission factors. Table 4-2 contains the comparison between Radian's emission estimates and those generated by the state agencies, applying VMT factors to the gpm values to obtain totals in tons per day.

[2]These areas may have since updated their mobile source emission estimates using MOBILE5a, though the results were not available for inclusion in this report.

Table 4-1. Emission Factor Modeling Summary.

City	Model Used by State	Radian Speed	Comments
Baltimore	5a	40.1	The D.C. speed value was used, assuming similar conditions. Only city without link-VMT estimates.
Chicago	5a	40.5	Actual weighted speed 36 mph. Ill EPA considers 40.5 for best link-based match. Also, oxygenated fuel fraction of 30% modelled.
Houston	Draft 5	38.6	Modeling performed for five different regions, depending on I/M-ATP combinations.
Philadelphia	5a	30.0	Actual weighted speed 25 mph. Radian found 30 produced closest match.
Washington, DC	4.1	40.1	Modeled five areas: D.C.; Md urban/rural; Va urban/rural.

Table 4-2. Comparison of Radian and State TPD Estimates.

1990	Radian VOC (t/day)	Local VOC (t/day)	Delta	Radian NO_x (t/day)	Local NO_x (t/day)	Delta
Baltimore	110.8	132.0	-16.0%	140.3	161.0	-12.9%
Chicago	463.0	523.7	-11.6%	467.2	543.0	-14.0%
Houston	209.6	235.7	-11.1%	275.8	315.6	-12.6%
Philadelphia	213.7	188.4	+13.4%	133.2	157.7	-15.5%
Washington	224.4	235.8	-4.9%	239.9	253.6	-5.4%

The discrepancies between the tons per day estimates generated using Radian-derived emission factors and the tons per day values reported by the states appear significant. However, Radian's emission factors were only used to establish percent reductions for each control option, rather than to directly estimate tons per day reductions. The percentages were then applied to the state-derived emission estimates to determine final emission reduction potentials (see Section 5). Therefore Radian is confident that the emission factors generated in our MOBILE5a runs provide an accurate basis for estimating reductions for each control option.

After establishing the base-case emission factors, Radian proceeded to evaluate the incremental emission reductions for each additional control option, on a per-vehicle basis. The following section discusses the potential emission reductions for each of the mobile source control options.

EMISSION REDUCTIONS FROM ADDITIONAL MOBILE SOURCE CONTROLS

The emissions inventories discussed in Section 1 were adjusted to account for the implementation of additional state and local mobile source controls. These adjustments were made by using MOBILE5a to generate site-specific emission factors for different control scenarios. Emission reductions were calculated incrementally for progressively more stringent controls by comparing new emissions levels with those of the previous level of control. The control options are listed below in Table 4-3, in order of application.

Table 4-3. Mobile Source Control Scenarios.

Cases	Description
1	Base Case
2	Base+Stage II
3	Base + Stage II + RFG
4	Base + Stage II + RFG + Enhanced I/M
5	Base + Stage II + RFG + Expanded I/M
6	Base + Stage II + RFG + Enhanced I/M + LEV/Tier II
7	Base + Stage II + RFG + Enhanced I/M + Clean Fleets
8	Base + Stage II + RFG + Enhanced I/M + Scrappage

Unlike the stationary source emissions and controls evaluated earlier, mobile source emissions vary substantially between areas, because of variations in emission levels with temperature, fuel characteristics, local I/M programs, and other factors. Therefore a city-by-city analysis was necessary to determine emission reduction values. In addition, the vehicle fleet in all cities is becoming cleaner with time, due to retirement of dirtier vehicles and their replacement with cleaner ones. Therefore the effectiveness of controls not only varies with location, but also with time. (For example, the effect of RFG on old, high-emitting vehicles is proportionally greater than on new, well-performing vehicles, so as the fleet becomes newer, the benefits of RFG decrease.) For this reason Radian estimated vehicle emission factors for the years 1994 - 2003, and 2010. The following tables present the estimates for three different target dates; 1996, 1999, and 2010.

Stage II

To account for the effect of Stage II controls, the states' MOBILE5a input files were revised, assuming that Stage II was implemented in 1993, that stations had up to 4 years to comply, and that controls had an efficiency of 90% both for light-duty, and heavy-duty gasoline vehicles. Table 4-4 presents the estimated incremental emission reductions from Stage II controls.

Table 4-4. VOC Emission Reductions (% per vehicle) from Stage II.

	Baltimore	Chicago	Houston	Philadelphia	Washington*
VOC					
1996	9.1	8.2	9.7	6.0	9.3
1999	11.7	10.2	12.3	7.6	11.9
2010	14.4	12.9	15.2	9.8	13.5

* Stage II controls were present in the baseline year of 1990 in D.C.-proper, but not in the surrounding nonattainment areas of northern Virginia and southern Maryland. Therefore incremental emission reductions are only calculated for the addition of Stage II in these other areas.

In Philadelphia and Houston, the states chose to account for refueling emissions in the Area Source category, and not in the Mobile Source inventory. Therefore the effect of the Stage II option could not be seen for these two cities using the state's MOBILE input files. In order to quantify these reductions, Radian ran another case for those two cities where refueling losses were calculated. We then estimated the incremental reduction in emissions from applying Stage II in those two cities.

Finally, note that the emission reductions become relatively greater with time for Stage II controls. This occurs because the controls generate a constant gpm emission reduction, regardless of when refueling takes place, and the overall fleet emission factors are lowering with time. Therefore, the relative percentage reductions associated with this control actually increase with time. Therefore Stage II controls become relatively more important with time, and may prove to be a key air quality maintenance strategy in the future.

Reformulated Gasoline (RFG)

The incremental reductions in VOC emissions resulting from the use of Phase I federal RFG, in addition to Stage II, are summarized in Table 4-5. Radian used Mobile5a to estimate VOC reductions (no NO_x reductions are projected by MOBILE5a for Phase I RFG). Note that Phase II RFG will replace Phase I beginning in the year 2000.

Note that the resulting emission reductions for Baltimore, Houston and D.C. are somewhat less than those for the other cities. Radian determined that these three cities currently have lower vapor pressure (RVP) fuel (approximately 7.8 psi, based upon current fuel specifications) than for the other cities. Therefore these cities are using cleaner baseline fuels, resulting in smaller emission reductions upon introduction of RFG.

Table 4-5. VOC Emission Reductions (% per vehicle) from Phase I Federal RFG.

	Baltimore	Chicago	Houston	Philadelphia	Washington
VOC					
1996	12.9	30.9	12.8	20.0	12.6
1999	13.6	32.3	14.2	20.6	12.6

Emissions will decrease further in the year 2000, with the initiation of Phase II RFG sales. For the purposes of this study Radian used EPA's proposed Phase II emission standards from February of 1993 to estimate potential VOC and NO_x reductions. These standards require a reduction of approximately 30 percent for VOCs, and seven percent for NO_x, relative to a standard gasoline (not Phase I fuel). Therefore Radian assumed this constant level of reductions for all cities.

Radian also estimated the potential emission reductions associated with California RFG, assumed to be available outside of California by 2000. Based on results from the complex model developed by EPA and the oil industry, this fuel may reduce NO_x emissions by an additional seven to eight percent, relative to Phase II RFG. The model also predicts an additional four percent VOC reduction (Schleyer, 1993). Like Phase II gasoline, Radian assumed California RFG will produce constant emission reductions, regardless of location (see Table 4-6).

Table 4-6. VOC and NO_x Reductions (% per vehicle) for Phase II and California RFG

	Phase II	Cal RFG*
VOC	30.2	4.3
NO_x	7.5	7.7

*Values incremental to Phase II reductions.

While the introduction of federal Phase II or California RFG in the year 2000 will generate substantial emission reductions, after this time percentage reductions will slowly decrease, as

RFG has less of an impact on cleaner, later technology vehicles. For this reason, RFG becomes slowly less cost-effective with time after the year 2000.

RFG -- Complex Model Results

In developing their ROP plans for 1996 the States are required to use the MOBILE model to estimate emission reductions from the use of RFG. However, this model does not provide the most up-to-date estimate of the likely reductions. EPA's Complex Model, made available after the submission of the 1993 SIPs, provides a more accurate assessment of the potential emission reductions resulting from the introduction of Phase I and II RFG. For this reason Radian is presenting emission reduction results from the Complex Model as well as MOBILE5, although the upcoming ROP analyses use the MOBILE5 results, as required of the states. It is evident from the difference in emission reduction estimates that MOBILE5 overestimates the reductions obtainable from Phase I RFG, and further emission controls may need to be adopted in order to make up for this shortfall in the future (see Section 5).

The incremental reductions in VOC emissions resulting from the use of Phase I federal RFG, according to the Complex Model, are summarized in Table 4-7. Unlike the MOBILE models, the Complex Model does not calculate the impact of fleet turnover and other site-specific factors on emissions. The reductions are expressed in terms of percentages relative to a standard baseline fuel. The only difference between the emission reductions for the cities lies in the baseline RVP values (7.8 psi for Baltimore, Houston and D.C.). These percentage reductions predicted by the Complex Model were then corrected to reflect the emission split between evaporative and exhaust emissions predicted by MOBILE5. (The ratio of evaporative to exhaust emissions calculated by MOBILE5 -- about 2/3 evaporative and 1/3 exhaust -- are more representative of real-world conditions using Phase I RFG than the Complex Model's estimate, about 1/3 evaporative and 2/3 exhaust.)

Note that the resulting emission reductions for Baltimore, Houston and D.C. are somewhat less than those for the other cities. Radian determined that these three cities currently have lower vapor pressure (RVP) fuel (approximately 7.8 psi, based upon current fuel specifications) than for the other cities. Therefore these cities are using cleaner baseline fuels, resulting in smaller emission reductions upon introduction of RFG.

Table 4-7. VOC Emission Reductions (% per vehicle) from Phase I Federal RFG.

City	Percentage Reduction
Baltimore	9.0
Chicago	15.2
Houston	7.6
Philadelphia	13.9
D.C.	8.2

Emissions will decrease further in the year 2000, with the initiation of Phase II RFG. Radian used the percentage reductions required by EPA for northern and southern regions, corrected for baseline RVP levels (see Table 4-8).

Table 4-8. VOC and NO_x Reductions (%/vehicle) for Phase II RFG -- Complex Model.

Phase II	Percent Reduction
VOC	29.5 (Chicago, Philadelphia) 17.5 (Baltimore, DC, Houston)
NO_x	7.5

<u>Enhanced I/M and Evaporative Systems Check</u>

The incremental reductions in VOC and NO_x emissions from implementing an enhanced I/M program that meets EPA's enhanced I/M requirements, as published in the Federal Register, are summarized in Table 4-9. EPA's requirements include the following:

- IM240 tests (with EPA recommended cutpoints) on 1986-plus vehicles;
- Pressure check of the evaporative system;
- Purge check of the evaporative system;

- 96% compliance rate; 3% waiver rate; and
- Biennial testing.

In most cases the MOBILE5a inputs used to generate these emission factors were taken from each state's records. As noted above, a single weighted-average speed was chosen for each city to approximate the total tons per day values produced by the states.

Table 4-9. VOC & NO_x Emission Reductions from Enhanced I/M of Light-Duty Fleet.

	Baltimore	Chicago	Houston	Philadelphia	Washington
VOC	%	%	%	%	%
1996	11.6	13.6	25.0	20.3	19.8
1999	21.6	19.5	32.0	28.6	25.8
2010	39.4	29.1	40.5	41.3	35.7
NO_x					
1996	3.9	6.3	8.2	9.3	7.9
1999	11.8	11.6	14.2	15.8	11.9
2010	25.6	18.5	20.5	23.7	18.7

Unlike many of the other control strategies noted above, I/M programs may produce greater percentage emission reductions as time passes. This possibility results from the constant increase in high and super-emitting vehicles in the fleet, regardless of the baseline level of controls. I/M programs identify these high/super emitters for repair. In other words, although the average fleet vehicle is becoming cleaner with time, the total fraction of "dirty" vehicles remains roughly the same from year to year, so relative emission reductions become greater for programs cleaning up these dirty vehicles. For this reason, I/M programs may increase in relative importance over time.

Expanded I/M and Evaporative Systems Check

The expanded I/M case is an expansion of the enhanced I/M program beyond that required by EPA. Further emission reductions may be obtained by either performing IM240 tests on vehicles older than required (i.e., pre-1986), or testing heavy-duty gasoline vehicles. Radian chose to evaluate the impact of including heavy-duty gas vehicles in each city's I/M program, knowing that significant VOC reductions could be obtained.

The incremental emissions reductions, relative to an enhanced I/M program, are presented in Table 4-10 below. First note that no NO_x reductions were predicted by MOBILE5a. Second, note that emission reductions are given for heavy-duty gasoline vehicles, rather than for "fleet average" light-duty vehicles as in Table 4-6.

Table 4-10. VOC Emission Reductions for Expanded I/M of Heavy-Duty Fleet.

	Baltimore	Chicago	Houston	Philadelphia	Washington
VOC	%	%	%	%	%
1996	8.5	4.1	12.3	8.5	6.8
1999	12.9	8.4	17.9	14.7	12.1
2010	22.5	25.3	29.6	34.1	29.1

Much like the emission reductions resulting from enhanced I/M programs, the percent reductions for heavy-duty gasoline vehicles increase with time, due to the continual lowering of the fleet's baseline emissions. The implementation of more stringent federal standards for these vehicles in 1998 will further improve the effectiveness of such tests.

LEV/Tier II

The incremental reductions for VOC and NO_x emissions from adopting the California Low Emitting Vehicles (LEV) program, beginning in 1994, are summarized in Table 4-11. The MOBILE5a modeling runs assumed that an enhanced I/M program was in place. Radian did not model LEV emissions for EPA's maximum (or "appropriate") I/M cases, because we feel that these scenarios are unrealistic (see Radian's Virginia Petroleum Council Report for further discussion). Furthermore, emissions reductions were estimated without the Zero Emission Vehicle (ZEV) component of the program for two reasons. First, it is unclear whether ZEVs will be mandated outside of California or even in California. Second, as ZEVs never constitute more than ten percent of new model years under the LEV program, emission reduction estimates are impacted only slightly in 1996 and 1999, but become significant in later years.

Table 4-11 VOC & NO_x Emission Reductions (% per vehicle) for LEVs (w/out ZEVs).

	Baltimore	Chicago	Houston	Philadelphia	Washington
VOC					
1996	1.0	0.9	1.0	0.7	1.2
1999	1.9	1.1	1.4	1.8	1.4
2010	9.8	5.4	4.5	8.2	8.8
NO_x					
1996	1.8	1.2	1.4	1.9	2.4
1999	2.1	1.5	1.8	2.3	2.1
2010	8.2	4.4	4.8	7.5	8.8

Emission reductions also may be obtained from the adoption of the Tier II federal emission standards, which may be required starting in 2004. These standards are similar to the LEV standards, without cold-start controls or the ZEV component.

Radian used a modified version of MOBILE5a, developed by SAI Corporation for the American Automobile Manufacturers Association, to estimate the emission benefits of Tier II vehicles. Because of the late start date of this program, emission reductions are calculated for the year 2010 only. Table 4-12 presents the estimated reductions for the Tier II program.

Table 4-12. VOC and NO_x Emission Reductions (% per vehicle) for Tier II.

	Baltimore	Chicago	Houston	Philadelphia	Washington
VOC					
2010	8.4	3.2	4.3	4.6	5.3
NO_x					
2010	13.1	4.3	5.6	7.6	8.0

Clean Fuel Fleet Programs

For a clean fuel fleet program, Radian assumed that existing fleet vehicles will be replaced by dedicated natural gas vehicles (NGVs). The existing gasoline vehicles (light-duty cars and trucks) were assumed to have an emission factor equivalent to an average Tier I vehicle subject to enhanced I/M, RFG, and Stage II vapor recovery programs. The VOC emission rates for dedicated NGVs were based upon the CAAA 50,000 mile exhaust standards for clean fleet vehicles. Note that Phase II standards, which are significantly lower than the Phase I standards, take effect in 2001. Table 4-13 provides a listing of the potential per-vehicle emission reductions for each city, for both Phase I and II vehicles.

Radian believes that dedicated natural gas vehicles can reasonably be expected to meet their VOC certification standards over their useful life due to their inherently low-emitting characteristics.(Radian, Dec 1992) Therefore potential emission reductions vary from city to city, depending upon each city's baseline Tier I vehicle emissions. However, NO_x emissions should deteriorate at a rate similar to gasoline vehicles. Therefore Radian assumed that NO_x percentage reductions would be constant, corresponding to the percentage difference in emission standards between the Tier I gasoline vehicles and the Phase II Clean Fleet standards. (Note that there is no difference between the Phase I Clean Fleet standards and the Tier I NO_x standards.)

Table 4-13. VOC and NO_x Reductions (% per vehicle) for Clean Fleet Program

	Baltimore	Chicago	Houston	Philadelphia	Washington
VOC					
Phase I	68.8	76.1	69.5	78.0	70.2
Phase II	80.2	84.8	80.7	86.1	81.1
NO_x					
Phase I	0	0	0	0	0
Phase II	44	44	44	44	44

Vehicle Scrappage Programs

The emission reductions for scrappage programs assume that the vehicle to be scrapped falls into the "very high" emission category (i.e., >= 4.8 gpm VOC), as defined by MOBILE5a. It also assumes that the age of the replacement vehicle equals the average age of the vehicle fleet (i.e., approximately 8 years) and that this vehicle meets the requirements of an enhanced I/M program. Therefore the emission improvement is determined from the very high emitter gpm level, and the fleet-average replacement vehicle, from MOBILE5a. The emission benefits also assume that the vehicle being scrapped has fairly low mileage accumulation rates and would continue to be driven for three years, as per EPA guidance. Table 4-14 summarizes the per-vehicle emission reduction estimates for each city. Note that no NO_x emission benefits are expected from a scrappage program.

Table 4-14. VOC Emission Reductions (% per vehicle) for Scrappage Program.

	Baltimore	Chicago	Houston	Philadelphia	Washington
VOC					
1996	79.4	76.3	81.9	67.7	81.5
1999	84.2	81.0	85.4	74.2	85.0
2010	91.0	88.3	90.8	87.3	90.6

COSTS AND COST-EFFECTIVENESS OF MOBILE SOURCE CONTROL OPTIONS

Calculating the cost-effectiveness of mobile source controls entails some unique considerations. Unlike many stationary source controls, which provide a constant yearly reduction from a specified emission baseline, mobile source controls will vary in their effectiveness over time due to vehicle deterioration and ever-changing new vehicle emission standards. In addition, percentage reductions for mobile controls will vary from city to city, so separate cost-effectiveness estimates are needed for different sites. Finally, unlike most stationary source controls, many mobile source controls reduce both VOC and NO_x emissions. In this case, some method must be chosen to partition costs across these different pollutants (e.g., dollars per ton of VOC, NO_x, or some combination of the two).

For these reasons Radian calculated the cost-effectiveness of mobile source controls in a number of different ways. Values are reported for each city for both a "short-run" and a "long-run" case. The short-run cases, covering the years 1994 to 2003, account for the yearly variation in baseline emission factors during this period. This case considers the yearly costs and emission reductions made in an effort to reach attainment. The long-run cases evaluate the cost-effectiveness of controls designed to maintain air quality standards, once achieved. These values differ from one another because of differing investment cost and emission reduction profiles over time.

Radian also calculated the cost-effectiveness of the mobile source controls for dollars per ton of VOC and NO_x. Differing combinations of these denominators may be appropriate for different nonattainment areas, depending on the relative importance of VOC and NO_x to ozone formation. However, because the relative importance of these two pollutants will not be known with more certainty until UAM computer models are completed, Radian chose not to report the cost-effectiveness values for weighted combinations of pollutants. However, the resulting cost-effectiveness values easily can be combined to reflect different weightings, if necessary.

The cost-effectiveness calculations did have several common features, however. First, all costs and emission reductions were discounted at six percent to obtain net present values.[3] Second, all calculations were performed over a ten year period (either 1994-2003, or 2010-2019). Third, all costs used in the calculations were expressed in 1993 dollars. Finally, any labor costs were increased at a two percent per year level, to reflect the real rise in wages (though fuel costs were assumed to stay constant, in real terms).

Following is a description of the estimated cost and cost-effectiveness for additional state or local controls and more stringent emission standards. The assumptions behind these costs are presented.

Stage II Vapor Recovery Controls

Radian estimated the cost-effectiveness of Stage II vapor recovery controls to be $2,800 per ton of VOCs, independent of location. This value is based on an analysis performed by API, assuming regional implementation across a nonattainment area. Costs could be slightly lower if exemptions for specified "hardships" had been allowed.

Conclusion: Uncontrolled refueling emissions remain constant over time per mile of vehicle travel, while most other mobile source emissions decrease with fleet turnover. Therefore this source of emissions becomes relatively more important to the mobile source inventory with time, and Stage II controls should prove to be a cost-effective maintenance as well as attainment strategy.

Reformulated Gasoline (RFG)

The cost for Phase I reformulated gasoline (RFG) was estimated to be $0.109 per gallon. In addition, a $0.028 per gallon fuel economy penalty as a result of the oxygen content

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[3]Not all net present value cost-effectiveness calculations discount emissions reductions, as Radian does in this study. However, discounting costs without a corresponding discounting of emission reductions will result in biasing cost-effectiveness values toward those controls that produce reductions later in time. Radian believes that this bias is not appropriate, considering the goal of meeting RFP deadlines in a timely fashion. See Section 5 for a further discussion of this topic.

requirement was assumed, bringing the effective total to $0.137. Phase II estimates bring the cost up to $0.176 per gallon. Table 4-15 summarizes the National Petroleum Council estimates used here. The price for California RFG was estimated to be between 0.14 and 0.20 dollars per gallon, with an average value of 0.165 (Mid-Atlantic Universities Transportation Center, 1993).

Total costs for the federal RFG program were estimated assuming Phase I fuel was sold from 1994 to 1999, and Phase II thereafter. Radian also assumed that California RFG would not be available before the year 2000 outside of that state (Energy and Environmental Analysis, 1988). Per-vehicle costs were determined using average mileage accumulation rates (about 10,000 miles per year), and future fuel economy estimates (about 31 MPG -- projected fleet average values for the year 2000). Costs and emission reductions were estimated for the ten year period ending 2003.

Tables 4-16a and 4-17a provide the cost-effectiveness estimates for RFG programs for the five cities, for the MOBILE5 emissions reduction estimates.[4] The "short-run" values reflect the cost-effectiveness of Phase I and II RFG over the 1995-2004 time frame, while the "long-run" values are for the year 2010 -- strictly Phase II cost-effectiveness. (We present both short and long-run values to provide an estimate of the cost-effectiveness of RFG as both an attainment and a maintenance strategy.) Note that the values for federal RFG are very high for NO_x, due to the small reductions of this pollutant. Also note that all California RFG estimates are incremental to the implementation of the federal program. Finally, the variance from city to city can be explained in part by the differing baseline RVPs -- those cities with low RVP gasolines such as Houston obtain less incremental benefit from adopting RFG than other cities such as Chicago. Additional variance is due to the differing final RVP values between cities (7.1 psi for Houston, Baltimore and D.C.; 8.0 for Chicago and Philadelphia).

[4] Calculating dollar per ton values for RFG using the more up-to-date Complex Model emission reductions generally yields costs two to three times the value of the short-run MOBILE5 figures, for both VOCs and NO_x. Dollar per ton values for long-term costs are about 50 to 100 percent higher than for MOBILE5.

Table 4-15. Estimated Incremental Cost of Phase I and II RFG (1993 cents).

Cost Category	Phase I	Phase II
Stationary Source Controls	2.9	5.0
Refining Costs & Oxygenates	5.3	7.0
Logistics and Other	1.1	1.1
Retail Marketing Regulations	1.7	1.7
Fuel Economy Penalty	2.8	2.8
TOTAL	13.7	17.6

Table 4-16a. Cost-Effectiveness of Federal RFG (1993$/ton).

Short-Run	Baltimore	Chicago	Houston	Philadelphia	D.C.
VOC	19,483	6,603	18,713	7,984	21,431
NO_x	75,807	60,881	73,335	87,686	88,409
Long-Run					
VOC	20,283	7,829	16,679	8,339	19,180
NO_x	30,998	26,229	32,168	36,797	37,063

Table 4-17a. Cost-Effectiveness of California RFG (1993$/ton).

Short-Run	Baltimore	Chicago	Houston	Philadelphia	D.C.
VOC	143,629	56,689	133,917	60,334	156,864
NO_x	35,697	28,668	34,533	41,376	41,631
Long-Run					
VOC	144,909	64,694	137,826	68,913	158,500
NO_x	35,585	30,110	36,928	42,241	42,547

The above calculation assesses the cost-effectiveness of RFG assuming both costs and benefits (emissions reductions) accrue over an entire year.[5] However, because RFG control

[5] Radian assumed that all other studies of point and area source controls used in this analysis performed their cost-effectiveness calculations in a similar manner, as per EPA guidance. Therefore in order to accurately compare values, Radian calculated all of its mobile source cost-effectiveness values in the same fashion.

costs do not accrue outside of the ozone season when the fuel is not sold, this method of calculation overestimates the dollar-per-ton value relative to other controls. (All other controls accrue costs even when there is no corresponding benefit -- e.g., winter months).

In order to compare the cost-effectiveness of RFG with that of other controls calculated in the above fashion, Radian recalculated the cost-effectiveness of both federal and California RFG. First, Radian assumed that ozone reduction benefits were only possible six months of the year (this value will vary in actuality from city to city). Given this assumption, only 50 percent of the costs are needed to operate an RFG program for the same amount of emissions reductions, compared to other controls. Therefore the dollar-per-ton values calculated above are divided by two to provide an accurate relative comparison with other cost-effectiveness values. These values are provided in Tables 4-16b and 4-17b below, for federal and California RFG, respectively.

Table 4-16b. Cost-Effectiveness of Federal RFG (1993$/ton) -- Ozone-season Weighted.

Short-Run	**Baltimore**	**Chicago**	**Houston**	**Philadelphia**	**D.C.**
VOC	9,742	3,302	9,357	3,992	10,716
NO_x	37,904	30,440	36,668	43,843	44,205
Long-Run					
VOC	10,142	3,915	8,340	4,170	9,590
NO_x	15,500	13,115	18,084	18,400	18,532

Table 4-17b. Cost-Effectiveness of Cal RFG (1993$/ton) -- Ozone-Season Weighted.

Short-Run	**Baltimore**	**Chicago**	**Houston**	**Philadelphia**	**D.C.**
VOC	71,915	28,345	66,959	30,167	78,432
NO_x	17,849	14,334	17,267	20,684	20,816
Long-Run					
VOC	72,455	32,347	68,913	34,457	79,250
NO_x	17,793	15,055	18,464	21,121	21,274

Conclusion: In general, federal RFG is more cost-effective than California RFG for VOC reduction, while California RFG produces comparable or superior cost-effectiveness numbers for NO_x. Choice between the two fuels should depend upon appropriate weighting factors between the two pollutants. By and large, the short- and long-run VOC cost-effectiveness values are similar for each fuel, though NO_x values become much lower for federal RFG with the introduction of Phase II in the long-run cases. Finally, note that RFG is most cost-effective for cities having high-RVP baseline fuel (Baltimore, Chicago, and Philadelphia).

Inspection/Maintenance (I/M) Programs

Radian evaluated the cost of two different I/M scenarios:

- Enhanced I/M as required by EPA; and
- Expanded enhanced I/M, including heavy-duty gasoline vehicles.

The costs for the expanded I/M program were incremental to the costs for the enhanced I/M scenario.

The costs for both I/M scenarios are based on privately-operated biennial programs with ten year capital recovery periods. The inspection fee for the I/M programs was calculated using a spreadsheet model that considers equipment, labor, land, and operating and maintenance costs. The model also accounts for the effect of financing, taxes, and profit margins.

Table 4-18 presents the assumptions used to calculate the fee for both enhanced and expanded inspections. (Enhanced costs only differ from expanded costs in the equipment category -- $30,000 vs. $500,000 (Marko, 1993) per dynamometer, respectively). Radian assumed that IM240 tests were performed along with innovative purge and pressure tests of the evaporative emission control system approved by EPA. We also assumed that program costs will be roughly similar in all five cities.

The estimated costs for enhanced and expanded inspections are presented in Table 4-19, which also breaks down the different factors contributing to the overall inspection cost. Short-run costs for both programs (calculated over the 1994-2003 time period) include capital recovery factors, and are therefore higher than long-run costs (2010 values), which include only labor and O&M costs, plus contractor profit margin. As with RFG, both short and long-run values are presented to reflect differences in attainment and maintenance strategies. The enhanced programs are dominated by labor costs, whereas the expanded programs are more heavily weighted toward equipment cost recovery and O&M. For both the short- and long-run cases, expanded (heavy-duty) tests are more costly than standard enhanced tests.

The average inspection cost per vehicle considers the number of vehicles that require retests. Consequently, the average inspection cost per vehicle varies depending upon the failure rate. The first year of the enhanced program will witness a very high failure rate which will decline during subsequent years due to the effectiveness of fleet repairs. Radian estimated the first year failure rate to be approximately 50%, based on the high emitter category sizes and high emitter identification rates assumed in EPA's MOBILE5 model. This figure includes both exhaust and evaporative system failures. Radian used emission deterioration rates found in MOBILE5 to determine the incremental growth in the high emitter categories over the two-year period between testing. By the second year

Table 4-18. Parameters Used in I/M Cost Model (Enhanced and Expanded).

GENERAL PROGRAM CHARACTERISTICS	
Lanes per station	4
Land per station (acres)	1
LAND, CONSTRUCTION/MODIFICATION	
$/Sq. ft. of land (new)	5
Sq. ft./Ln	10,890 (1 acre plot, 4 lanes)
$/lane - new constr.	137,500 (1 position)
$/lane - new constr.	75,000 (each additional position)
$/lane/position - mod.	50,000

GENERAL PROGRAM CHARACTERISTICS	
LANE THROUGHPUT	
Limiting time per Ln (Min)	4.5
Bldg. capacity factor	2
Equipment down-time	0.10 (fraction of time)
Lane efficiency factor	0.85
LABOR	
# Skilled inspectors/lane	0
# Unskilled inspectors/lane	4
Skilled wage ($/hr)	10.40 (30% benefits)
Unskilled wage ($/hr)	7.80 (30% benefits)
Operation hrs/yr	3,120 (60/wk)
OPERATION AND MAINTENANCE	
Computer cost ($/test)	0.10
Lanes/technician	12
Technician wage ($/hr)	16.9 (30% benefits)
Misc Op costs ($/yr)	12,820
Admin. costs $/ln/yr	10,350 - (76% labor)
Training hrs/insp - yr 1	160
Recurring training hrs/yr	32 (20% employee turnover)
EQUIPMENT COSTS ($)	
Pressure meter	600
Gas cap tester	600
Purge equipment	3,500
Dynamometer	30,000 (enhanced) / 500,000 (expanded)
Driver's aid monitor	2,500
Analyzer	95,000
ECONOMIC PARAMETERS	
Discount rate (real)	0.06
Equip. depreciation rate/yr	0.2 (straight line over 5 years)

Table 4-16. (Continued).

GENERAL PROGRAM CHARACTERISTICS	
Bldg. depreciation rate/yr	0.2 (straight line over 5 years)
Wage rate increase (real)	0.02
Inflation rate	0.04
Nominal interest rate	0.1024
After tax profit margin	0.1024
Corporate income tax rate	0.40
Property tax rate	0.01

of testing, the failure rate drops to about 23 percent. A steady-state failure rate was achieved by the third year of testing (year five of the biennial program) at approximately 19 percent. Thus, the overall cost per vehicle (including testing and repair) decreases over the first years of the program, reflecting reduced failure rates.

Table 4-19. Inspection Costs (1993$/vehicle).

Cost Category	Enhanced (per average vehicle)		Expanded (per heavy-duty vehicle)	
	Short-Run	Long-Run	Short-Run	Long-Run
Labor	7.88	8.44	7.88	8.44
O&M	3.70	3.96	9.29	12.31
Equipment	3.41	--	12.90	--
Land	0.45	--	0.45	--
Construction	4.29	--	4.29	--
Interest	3.02	--	6.29	--
TOTAL	22.76	12.40	41.12	20.75

Vehicle repair costs depend on the type of failure identified. Radian used EPA cost estimates from the Federal Register NPRM for exhaust ($120), as well as purge ($70) and pressure ($38) failure repairs. Radian believes that repair costs for heavy-duty gas vehicles in an expanded program will be similar to those for light-duty vehicles noted above. Radian assumed that exhaust repairs consisted of 50% labor and 50% parts. A real rise of 2% per year in labor wages was assumed for the calculation. Radian believes EPA's repair cost estimates are low, with repair costs for marginal emitters possibly being much higher.

In addition to repair costs, Radian also included inconvenience costs and fuel economy benefits resulting from evaporative system repairs. An inconvenience cost estimate of $15 per test was derived from EPA's background support document for the enhanced I/M rule. Instituting the evaporative system checks is assumed to cause a fuel savings approximately equal to the evaporative emission reductions - 0.14 g/mi. Assuming fleet average VMT, this corresponds to a cost savings of about 55 cents per year. Inconvenience costs and fuel savings are calculated in the same way for light- and heavy-duty vehicles.

The estimated inspection cost is added to repair, inconvenience, and fuel cost estimates to obtain a final cost estimate, discounted over time. The emission reductions are then discounted and combined with net present costs to determine cost-effectiveness values. Tables 4-20 and 4-21 provide a listing of the cost-effectiveness estimates for enhanced and expanded I/M programs, by city.

Conclusion: The cost-effectiveness of VOC reductions for enhanced and expanded I/M programs are roughly comparable within each city, ranging from about $6,000 to $20,000 per ton. However, total reduction potentials for the enhanced program are much larger for the enhanced program than for the expanded component, simply due to the relatively small number of heavy-duty versus light-duty vehicles. Also, VOC and NO_x values are very similar for enhanced programs within the same city. Note that no values are reported for NO_x for expanded programs, as resulting NO_x reductions are very small. Note also that long-run cost-effectiveness values are significantly less than short-run values, because no further capital recovery is necessary at this point, thereby lowering costs. This cost drop occurs in spite of rising labor wage rates. Finally we observe a wide variation in dollar per ton values across different cities, with Philadelphia having the lowest values, and Baltimore and Chicago the highest (in general).

Low Emission Vehicles/Tier II

California LEV Program. Radian estimated costs to meet the different emission standards established by the California LEV program. The LEV program includes the following vehicle types:

- Transitional low emission vehicles (TLEV);
- Low emission vehicle (LEV); and
- Ultra-low emission vehicles (ULEV).

Table 4-22 provides the phase-in schedule for the different vehicle types. Table 4-23 presents the estimated cost to comply with these emission standards, and Table 4-24 presents the weighted cost, in constant 1993 dollars, for compliance with the standards. All costs are incremental to Tier I vehicles.

Table 4-20. Cost-Effectiveness of Enhanced I/M Programs (1993$/ton).

Short-Run	Baltimore*	Chicago	Houston	Philadelphia	D.C.
VOC	19,339	16,936	11,036	8,329	13,364
NO_x	19,105	15,143	14,685	15,915	20,301
Long-Run					
VOC	8,505	10,354	7,938	5,538	9,526
NO_x	5,670	6,615	7,217	7,217	9,160

*The Baltimore Enhanced I/M program will incorporate HDGVs.

Table 4-21. Cost-Effectiveness of Expanded I/M Programs (1993$/ton).

Short-Run	Baltimore	Chicago	Houston	Philadelphia	D.C.
VOC	17,420	18,687	13,897	7,172	14,040
Long-Run					
VOC	11,238	8,193	9,073	3,937	7,470

Table 4-22. Implementation Rates for the California LEV Program.

Model Year	TLEV	LEV	ULEV	ZEV	Fleet Average Levels (gpm)
1994	10%				0.205
1995	15%				0.231
1996	20%				0.225
1997		25%	2%		0.202
1998		48%	2%	2%	0.157
1999		73%	2%	2%	0.113
2000		96%	2%	2%	0.073
2001		90%	5%	5%	0.070
2002		85%	10%	5%	0.068
2003		75%	15%	10%	0.062

Radian did not estimate the incremental costs for zero emission vehicles (ZEVs). At this time, there is a wide range of estimates on the cost for ZEVs. Estimates by the State of California are as low as $1,000 per vehicle, while those by the automakers are as high as $20,000 per vehicle (Austin, 1993). Furthermore, there is uncertainty as to whether or not the automakers will proceed with plans to comply with ZEV requirements. GM has shelved its plans to place its electric vehicle, the Impact, into production and recently, there have been reports that Ford's electric vehicle program may be terminated. As a result of these concerns and uncertainties, Radian did not estimate the cost for ZEVs. In addition, the cost-effectiveness analysis does not include any emission reductions from ZEVs.

Table 4-23. Costs for Meeting Low Emission Vehicle Standards (1993 $).

Standard	Cost
Transitional Low Emission Vehicles (TLEVs)	$224
Low Emission Vehicles (LEVs)	$486
Ultra Low Emission Vehicles (ULEVs)	$795

Table 4-24. Average Per-Vehicle Cost for Meeting California LEV Standards[a] (1993$).

Model Year	Average Cost
1994	$ 22
1995	34
1996	45
1997	137
1998	254
1999	375
2000	492
2001	501
2002	520
2003+	538

[a] Not including ZEVs

Table 4-25 presents the assumptions behind the cost for TLEVs, LEVs, and ULEVs. The estimated cost for TLEVs is based upon estimates by the Automotive Consulting Group (ACG). These estimates were adjusted for increased volume of California vehicles. By increasing the volume of the California vehicles, engineering and investment costs for each vehicle are reduced. As shown, Radian estimates that TLEVs will cost $224 above the price of a standard Tier I vehicle.

The estimated cost for LEVs assumes that the following items must be added to the TLEVs:

- Increased catalyst loading;

- Hydrocarbon trap for 50% of the vehicles (those with 6 or more cylinders);
- Additional sensors and controls; and
- Packaging and assembly of additional components.

Table 4-25. Cost Estimating Procedure

A.	TLEVs			
	Cost Basis: ACG cost estimates adjusted for increased volume of California vehicles.			
	•	ACG estimate (4 cylinder):	$298 (ACG, 1992)	
	•	Corporate variable cost (CVC):	298 ÷ 2.06 = $145	
	•	Plus mark-up for engineering and investment (55%):	$ 79	
	•	Total cost:		$224
B.	LEVs			
	Cost Basis: TLEV cost plus the following (ACG, 1992)			
	•	Increased catalyst load ($125)		
	•	Hydrocarbon Trap ($200) (50% of vehicles; % with 6 or more cylinders)		
	•	Sensors/Controls ($55)		
	•	Packaging/Assembly ($68)		
	Cost Estimate:			
	•	TLEV cost:		$224
	•	Estimated cost for additional components (ACG, CA only):	$348	
		- CVC 448 ÷ 2.06 =	$169	
		- + 55% Mark-up		$ 93
		Subtotal	$262	
	•	Total LEV Cost:	$486	

C. ULEVs

Cost Basis: LEV costs plus incremental cost for electrically heated catalysts (EHCs) on all vehicles with 6 or more cylinders and hydrocarbon trap on all 4-cylinder vehicles (ACG, 1991; ACG, 1992).

• EHC cost (ACG, CA only):	$822	
- CVC $822 ÷ 2.06 =	$399	
- + 55% Mark-up	$219	
Subtotal:		$618
• Hydrocarbon Trap (ACG, CA only):		$200
- CVC 200 ÷ 2.06 =	$ 97	
- + 55% Mark-up		$ 53
Subtotal:		$150
• Incremental Cost:		$309
• LEV Cost:		$486
• Total ULEV Cost:		$795

Again, these costs were based upon ACG estimates, adjusted for increased volume by California vehicles. Total LEV costs are estimated to be $486 per vehicle.

The estimated cost for ULEVs assumes that electrically heated catalysts (EHCs) will be required on all vehicles with 6 or more cylinders, and hydrocarbon traps will be required on all 4-cylinder vehicles. Costs for EHCs include required engine modifications and an additional battery. The energy requirements for an EHC preclude using a single battery on these vehicles. In addition, all the controls required for TLEVs and LEVs will be required for ULEVs. The estimated cost for ULEVs is $795 per vehicle.

Once the LEV program has been fully implemented, the weighted cost per vehicle (using the projected implementation rates established by the State of California) are $538 per vehicle. In our study for the Virginia Petroleum Council on the cost of the LEV program in northern

Virginia, Radian estimated a low cost of $337 per vehicle and a medium cost of $645 per vehicle (Radian, 1992).

No fuel economy penalty is assumed for complying with TLEV or LEV standards. A fuel economy penalty of 1.5% is assumed for complying with ULEV standards (ACG, 1991). This assumes that electrically heated catalyst-equipped vehicles have a 3% fuel economy penalty and that these devices are used on 50% of these vehicles. This penalty is included in the cost-effectiveness estimate for the LEV program. Overall, fuel economy penalties are very small.

Because the LEV program is phased in over time, with increasing numbers of lower-emitting vehicles being added to the fleet, the cost-effectiveness values were not calculated on a per-vehicle basis, as with the other control strategies. (The same is true with the Clean Fleet analysis -- see below.) Instead Radian determined the costs and emission reductions associated with the incremental additions to the fleet each year, over a ten year period for the short-run calculation. However, the vehicles purchased in year ten do not have the chance to "recover their costs" through extended emission reductions as do the vehicles purchased in year 1. For this reason the dollar per ton values in the short-run are significantly higher than in the long-run, which calculates the cost-effectiveness of purchasing one fleet-average LEV vehicle <u>once the program is fully implemented</u>. Radian believes it is necessary to evaluate cost-effectiveness in this fashion <u>when determining the value of controls in meeting RFP deadlines</u> as well as their value as a maintenance strategy after attainment is achieved. The resulting cost-effectiveness values are presented in Table 4-26.

<u>Tier II Vehicles</u>. Radian based its cost estimates for Tier II vehicles on the figures calculated for the LEV program. Radian believes that vehicles will be able to meet the Tier II emission standards using TLEV technology, plus the increased catalyst loadings required in LEVs. Tier II vehicles will not be required to meet stringent cold-start standards and will therefore not require EHCs. For this reason Tier II vehicles also will not suffer a fuel economy penalty. Combining TLEV costs with the cost of in-creased catalyst loading yields

a total cost estimate of $349 per vehicle, relative to Tier I vehicles. Table 4-27 presents the cost-effectiveness values for Tier II vehicles, using the SAI model emission reduction estimates. Assuming that Tier II vehicles will not become available until after the year 2000, Radian only calculated values for the long-run scenario.

Conclusion: The dollar per ton values calculated for the LEV and Tier II programs are very high, ranging from about $44,000 up to close to $500,000. In general NO_x values are lower than those for VOCs, and long-run values are lower than those for the short-run. Though somewhat lower than the LEV values the Tier II values are also very high. The reader should note that these cost-effectiveness values are based upon very small emission reductions increments (typically .02-.04 gpm) taken from MOBILE5a outputs. Given the inherent uncertainties in emission factor modelling, the resulting dollar per ton values could be significantly lower (or higher), depending upon the accuracy and precision of the emission factor model at these small increments.

Table 4-26. Cost-Effectiveness of California LEV Program (1993$/ton).

Short-Run	Baltimore	Chicago	Houston	Philadelphia	D.C.
VOC	423,440	154,642	466,361	373,484	384,151
NO_x	134,550	141,204	152,796	150,685	120,166
Long-Run					
VOC	144,461	202,246	303,368	121,347	151,684
NO_x	55,158	86,677	101,123	75,842	60,674

Table 4-27. Cost-Effectiveness of Tier II Program (1993$/ton).

Long-Run	Baltimore	Chicago	Houston	Philadelphia	D.C.
VOC	98,274	196,547	196,547	131,031	393,094
NO_x	43,677	56,156	56,156	49,137	43,677

Clean Fuel Fleet Program

Radian evaluated the cost-effectiveness associated with a clean fuel fleet program assuming natural gas vehicles (NGVs) operating over a 10-year period. Conversion to bi-fuel or dedicated natural gas operation currently costs about $3,500 per vehicle, although future OEM vehicles may be produced for as little as $1,000 more than a comparable gasoline vehicle (Papayoti, 1992). These costs assume use of state-of-the-art gaseous fuel injection systems. Radian also assumed that vehicles participating in such a program are likely to be high-mileage fleet vehicles (20,000 or more miles per year) that are retired after five years. Thus, a second NGV purchase is required in year six of the program.

Fuel cost savings also result from an NGV program. Currently, natural gas costs approximately 40¢ per gasoline-equivalent gallon less than gasoline. Assuming that gasoline and natural gas prices rise roughly together, fuel savings is dependent only on the vehicle's yearly VMT. Radian found that vehicles travelling approximately 25,000 to 30,000 miles a year will break even on their investment after five years, given a discount rate of six percent. (This is especially true of light-duty trucks, which have lower mpg ratings than cars.)

Table 4-28 provides cost-effectiveness estimates on a per vehicle basis, using baseline vehicle emission factors from MOBILE5a for each city.

Conclusion: The cost of VOC reductions ranges from about $19,000 to $31,000 in the short-run, and from about $7,000 to $11,000 in the long-run. Long-run values are lower because of the adoption of the Phase II Clean Fleet standards in 2001. No significant NO_x reductions occur during the short-run for NGV programs. However, NO_x reductions will be obtained in the long-run, with the implementation of the Phase II Clean Fleet standards in 2001. The resulting NO_x reductions are of a constant percentage relative to Tier I vehicles, so the cost-effectiveness values shown are the same for all cities.

Table 4-28. Cost-Effectiveness of Natural Gas Vehicle (NGV) Program (1993$/ton).

Short-Run	Baltimore	Chicago	Houston	Philadelphia	D.C.
VOC	25,842	21,027	30,779	18,566	30,429
NO_x	N/A	N/A	N/A	N/A	N/A
Long-Run					
VOC	11,011	7,998	10,701	7,236	10,407
NO_x	17,430	17,430	17,430	17,430	17,430

Vehicle Scrappage Program

Radian estimated the costs of an early vehicle retirement program for all five cities. We assumed that a scrapped vehicle would continue to operate for an additional three years. Thus, the cost-effectiveness was calculated for a three-year period. In order to compare cost-effectiveness values for the scrap programs with those of other programs, we projected the costs and emission reductions expected over a ten year period, assuming that a new vehicle was scrapped in years four and seven to compensate for the loss of emission "credits" after three years.

The scrappage program cost estimates are based on the recommendations of the Virginia subcommittee on scrappage and the UNOCAL analysis performed by Radian (Radian, 1991). The vehicle owner will be paid $700, and an additional $100 per vehicle will be required for program administration. Radian assumed that the replacement vehicle would be purchased for $3,000, and would have a final liquidation value after three years of $2,250. (These values for the replacement vehicle are speculative, and should be refined before proceeding with a scrappage program.)

Radian anticipates significant fuel savings from a scrappage program, since the replacement vehicle will consume much less fuel than the retired vehicle. According to the UNOCAL report, the average mpg of the retired vehicles was 12.1. If we assume a fleet average vehicle, the replacement will have an average mpg of about 27 (the 1986 CAFE standards). For the purposes of calculating the fuel savings benefit resulting from scrappage, Radian evaluated total savings based on a 5,500 mileage accumulation rate (average value for scrapped vehicle (Radian, 1991)), and a fuel cost of $1.20 per gallon. Although the replacement vehicle can be expected to travel several thousand more miles a year, the actual fuel savings is calculated only relative to the baseline level of travel.

Table 4-29 presents the cost-effectiveness estimates for a vehicle scrappage program in each city.

Table 4-29. Cost-Effectiveness of Scrappage Program (1993$/ton).

VOCs	Baltimore	Chicago	Houston	Philadelphia	D.C.
Short Run	13,644	15,621	12,444	16,600	12,455
Long Run	10,033	10,541	10,070	10,750	10,108

Conclusion: Because the average replacement vehicle becomes slowly cleaner with time while the "clunkers" retain their very-high emission status, scrappage programs become slowly more cost-effective with time. However, the cost-effectiveness levels themselves are highly uncertain, being <u>very</u> sensitive to vehicle "bounty", fuel costs, replacement vehicle costs and depreciation rates. All of these factors will vary widely from city to city, with variations in local vehicle resale markets and fuel costs. Therefore a more site-specific analysis should be undertaken before adopting a vehicle scrappage program in any particular area.

<u>Summary of Mobile Source Control Cost-Effectiveness</u>

Unlike stationary source controls, mobile source controls are highly variable from one area to another. Tables 4-30 through 4-34 provide a summary of the cost-effectiveness of the VOC and NO_x controls evaluated in this section, for each of the five cities. A complete ranking of control options, for both stationary and mobile sources, is provided for each city in Appendix C.

Table 4-30. Cost-Effectiveness of Mobile Source Controls - Baltimore.

Control Measure	1993$/Ton (Short-run)		1993$/Ton (Long-run)	
	VOC	NO_x	VOC	NO_x
Stage II	2,802	NA	2,802	NA
RFG*	9,742	37,904	10,142	15,500
California RFG*	71,915	17,849	72,455	17,793
Enhanced I/M	19,339	19,105	8,505	5,670
Expanded I/M	17,420	NA	11,238	NA
LEV	423,440	134,550	144,461	55,158
Tier II	NA	NA	98,274	43,677
NGVs	25,842	NA	11,011	17,430
Scrappage	13,644	NA	10,033	NA

* Ozone season weighted

Table 4-31. Cost Effectiveness of Mobile Source Controls - Chicago.

Control Measure	1993$/Ton (Short-run)		1993$/Ton (Long-run)	
	VOC	NO_x	VOC	NO_x
Stage II	2,802	NA	2,802	NA
RFG*	3,302	30,440	3,915	13,115
California RFG*	28,345	14,334	32,347	15,055
Enhanced I/M	16,936	15,143	10,354	6,615
Expanded I/M	18,687	NA	8,193	NA
LEV	154,642	141,204	202,246	86,677
Tier II	NA	NA	196,547	56,156
NGVs	21,072	NA	7,998	17,430
Scrappage	15,621	NA	10,541	NA

* Ozone season weighted

Table 4-32. Cost Effectiveness of Mobile Source Controls - Houston.

Control Measure	1993$/Ton (Short-run)		1993$/Ton (Long-run)	
	VOC	NO_x	VOC	NO_x
Stage II	2,802	NA	2,802	NA
RFG*	9,357	36,668	8,340	18,084
California RFG*	66,959	17,267	68,913	18,464
Enhanced I/M	11,036	14,685	7,938	7,217
Expanded I/M	13,897	NA	9,073	NA
LEV	466,361	152,796	303,368	101,123
Tier II	NA	NA	196,547	56,156
NGVs	30,779	NA	10,701	17,430
Scrappage	12,444	NA	10,070	NA

* Ozone season weighted

Table 4-33. Cost Effectiveness of Mobile Source Controls - Philadelphia.

Control Measure	1993$/Ton (Short-run)		1993$/Ton (Long-run)	
	VOC	NO_x	VOC	NO_x
Stage II	2,802	NA	2,802	NA
RFG*	3,992	43,843	4,170	18,400
California RFG*	30,167	20,684	34,457	21,121
Enhanced I/M	8,329	15,915	5,538	7,217
Expanded I/M	7,172	NA	3,937	NA
LEV	373,484	150,685	121,347	75,842
Tier II	NA	NA	131,031	49,137
NGVs	18,566	NA	7,236	17,430
Scrappage	16,600	NA	10,750	NA

* Ozone season weighted

Table 4-34. Cost Effectiveness of Mobile Source Controls - Washington.

Control Measure	1993$/Ton (Short-run)		1993$/Ton (Long-run)	
	VOC	NO_x	VOC	NO_x
Stage II	2,802	NA	2,802	NA
RFG*	10,716	44,205	9,590	18,532
California RFG*	78,432	20,816	79,250	21,274
Enhanced I/M	13,364	20,301	9,526	9,160
Expanded I/M	14,040	NA	7,470	NA
LEV	384,151	120,166	151,684	60,674
Tier II	NA	NA	393,094	43,677
NGVs	30,429	NA	10,407	17,430
Scrappage	12,455	NA	10,108	NA

* Ozone season weighted

TRANSPORTATION CONTROL MEASURES (TCMs)

The 1990 Clean Air Act Amendments (CAAA) have significantly expanded the role of transportation control measures (TCM) in meeting air quality goals. This section discusses the use of TCMs in meeting the air quality goals for the subject cities. Little region-specific data on TCM emission reductions and cost-effectiveness were available. To compensate for this lack of data, we have gathered representative data from other cities to characterize the range of emission reductions and cost-effectiveness that could be expected from TCM implementation.

Section 108(b) of the CAAA lists 16 TCMs that must be considered as potential control measures when developing Rate-of-Progress (ROP) and Attainment Plans. These measures are listed in Table 4-35. TCMs can be classified into two general areas, those involving transportation systems management (TSM), and those addressing travel demand management (TDM). TSM measures are designed to improve efficiency of the transportation system infrastructure. Examples of such improvements include park-and-ride lots, high occupance vehicle (HOV) lanes, and public transit system improvements. TDM measures are generally regulations, programs, or ordinances designed to reduce travel demand or shift the mode of travel away from the single-occupant vehicle to more efficient, multiple-occupant vehicle modes of travel (carpools, vanpools, or public transit). In general, TDM measures tend to be less capital-intensive than most TSM measures. Because of the variety of potential TCMs, there is a great degree of interaction between TSM and TDM measures.

Accurate analysis of the effects of TCMs is more difficult than many other control measures, because TCMs address changes in travel behavior. Most TCMs are designed to provide more efficient alternative modes of transportation. However participation by

Table 4-35. TCMs Included in the 1990 CAAA.

#	Description
1.	Trip Reduction Ordinances
2.	Employer-Based Transportation Management Programs
3.	Work Schedule Changes
4.	Area-wide Rideshare Incentives
5.	Improved Public Transit
6.	High Occupancy Vehicle Lanes
7.	Traffic Flow Improvements
8.	Parking Management
9.	Park-and-Ride/Fringe Parking
10.	Bicycle and Pedestrian Measures
11.	Specialized Transit Services
12.	Vehicle Use Limitations/Restrictions
13.	Accelerated Vehicle Retirement
14.	Downtown Area Vehicle
15.	Minimization Restrictions Extended Vehicle Idling
16.	Extreme Low-Temperature Cold Start Minimization

the general population is usually voluntary. This provides a large amount of uncertainty in the predictions of TCM effectiveness relative to other control measures, such as reformulated gasoline or LEV programs.

Under the CAA, the use of TCMs to meet air quality goals varies based on the classification of the non-attainment region. All of this study's areas except Washington, D.C, are classified as Severe non-attainment areas. Washington, D.C. is classified as a Serious non-attainment area. While serious non-attainment areas must consider TCMs in the development of their Rate-of-Progress Plans and Attainment Plans, severe areas are required to adopt TCMs to offset any emission increase resulting from growth in vehicle miles travelled (VMT) and vehicle trips. In addition, Severe areas must adopt rules requiring all employers with 100 or more employees to implement trip reduction plans to reduce commute-related VMT. The programs must increase average employee vehicle occupancy by at least 25 percent above the current area average.

For this project, we have gathered available data on the development of TCMs for the areas of: Baltimore, Chicago, Houston, New York, Philadelphia, and Washington, D.C. For those areas where data were available, most of the local agencies were still in the early stages of analyses of potential TCMs, their emission reduction potential, and cost-effectiveness. No data were located for New York City. Of the remaining areas, only Washington, D.C. had developed TCM cost-effectiveness data in response to the CAA for the preparation of the ROP Plans due November 15, 1993.

All of the areas had some existing or planned TCMs in place. These projects were planned and budgeted in response to other legislative mandates primarily designed to address traffic congestion. The most important of these mandates are the Congestion Management and Air Quality (CMAQ) provisions of the Intermodal Surface Transportation Efficiency Act (ISTEA). Most regions have already developed congestion reduction plans, which must be coordinated with their SIP under the CAA. These existing projects are being included in the early years of the ROP plans as TCMs. The specific measures included from each area vary, but generally include improvements in commuter park-and-ride lots, traffic signal synchronization, and public transit system improvements.

Future potential TCMs in the subject cities are being considered as measures to meet the ROP goals in later years. In most cases, they have been included as contingency measures to be implemented if the ROP Plan fails to achieve the required emission reductions. At this time however, the analyses on these measures have not been completed and little emission reduction or cost-effectiveness data were available.

Because of this lack of data, we gathered available data on TCM implementation in other cities. These were assembled to provide an estimate of the potential emission reductions and cost-effectiveness ranges that could be expected for the subject cities. In addition to the data from Washington, D.C., we gathered data from San Diego, Los Angeles (South Coast Air Basin), San Francisco/Oakland/San Jose (Bay Area), Phoenix, and Sacramento.

A summary of the data from these cities is presented in Table 4-36. This table groups the TCMs from each area into eight categories:

- Travel Demand Management Measures - Trip Reduction Ordinances. These are local governmental regulations or ordinances designed to shift commuters away from single-occupant vehicles toward more efficient modes of travel. Such ordinances are required under the CAA for employers with more than 100 employees in Severe and Extreme non-attainment areas.

- Travel Demand Management Measures - Mode Shift Strategies. These are programs designed to shift travel to multiple-occupant vehicles, such as carpools, vanpools, or public transit.

- Travel Demand Management Measures - Goods Movement. These are local governmental regulations that control the movement of delivery vehicles, and seek to shift their activity away from periods of peak congestion and toward hours of lighter traffic flow.

- Travel Demand Management Measures - Miscellaneous. A variety of TDM strategies are presented here, including pricing strategies for registration fees, employer-provided parking, and direct gasoline or

VMT taxes. Work hour and work place alternatives such as compressed or flexible work weeks, and telecommuting are presented here also.

- Transportation Systems Management Measures - Traffic Flow Improvements. These projects improve the efficiency of the transportation system rather than attempting to reduce VMT (the assumption here is that decreased stop/start driving and increased vehicle speeds will result in lower emissions for the same VMT. Note however, that this is not always the case). Projects in this category include signal synchronization, installation of traffic operations control systems, incident (accident) response systems, and general highway capacity improvements.

Table 4-36. Potential Effectiveness of TCMs.

Control Measure Category	Emission Reduction Potential[1,2]	Rate of Reduction[1,3]	Cost Effectiveness[1,4]
Demand Management (Trip Reduction Ordinances, Ridesharing, Parking Management, Telecommuting)	Medium/High	Fast/Slow	Medium/High
Alternative Work Schedules	Low	Fast	N/A
Pricing (Gasoline Tax, VMT Tax, Emission-based Fees)	High	Fast	High
Goods Movement	Low	Fast	N/A
Traffic Flow Improvements (Capacity Increases, Signal Improvements, Turn Lanes)	Low/Medium	Slow/Fast	N/A
Transit Improvements (Park and Ride Programs, Service Improvements, HOV Lanes)	Low	Fast/Slow	Low/Medium
Freeway Management (Incident Management, Motorist Information)	Low	Fast	N/A
Bicycle Improvements	Low	Fast/Slow	N/A
Land Use Management (Jobs/Housing Balance, Densification, Growth Controls)	Low/-Medium/High	Slow	N/A

1. Sierra Research, 1991. Methodologies for Quantifying the Emission Reductions of Transportation Control Measures, Table 7-1.

2. Rankings are summaries of rankings for individual control measures. Different rankings within a control measure category relate the different emission reduction potentials or rates of reduction for individual measures.

3. Rankings based on results reviewed in this report. Rankings only provided in cases where conclusions were drawn based on these results.

4. High cost effectiveness implies low cost per ton of pollutants reduced. Low cost effectiveness implies high cost per ton reduced.

- Transportation Systems Management Measures - Mode Shift Strategies. These projects include facility construction or improvement projects designed to discourage use of single-occupancy vehicles. Strategies in this category include construction of HOV lanes, bicycle facilities, rail/ferry or other transit systems, and park-and-ride lots

- Land Use Control Measures. These are longer term projects to alter land use patterns to reduce the need for vehicle travel. These projects include placement of higher density housing near transit facilities, and growth management to direct development towards integration of housing and work sites.

The data in Table 4-36 were developed by different agencies using differing methodologies. Data from Sacramento are not included because the estimated emission reduction data were not provided on a basis consistent with the other cities. One item to note is that the projected year for which the emission reductions are stated varies between areas, generally dependent upon the expected date of attainment. Further, the methods for calculating cost-effectiveness results varied. Some regions included both reactive organic gases (ROG) and nitrogen oxides (NO_x) and carbon monoxide reductions in the calculations, while others attributed the full cost of the measure to ROG or NO_x, or just ROG only. Finally, it could not always be determined whether the cost-effectiveness results were presented in constant dollars, what year was used as the constant, or what discount rate was used.

From these data, we can expect to derive only very general conclusions about the potential emission reductions and cost-effectiveness of various TCMs. Extrapolation of the results to the specific study areas is not possible due to the importance of site-specific factors. For example, the effectiveness of installing HOV lanes could differ in separate areas depending upon whether commute patterns are centralized or spread-out geographically, the present ability of the existing freeway to support the lanes, and availability of support facilities such as park-and-ride lots.

The above example also points out the potential for different TCMs to interact with each other in beneficial or detrimental ways. As noted, HOV lanes and park-and-ride lots would be mutually beneficial, perhaps increasing their effectiveness together more than the individual measures separately. As an example of detrimental interaction, the construction of additional highway capacity might reduce transit use through reduced congestion leading current transit users back into their automobiles. With the exception of some of the LA TCM initiatives, the results in Table 4-36 do not account for interactions between multiple TCM alternatives.

From these data, the following conclusions can be made:

- Trip reduction ordinances, mandated for some areas by the CAA, have relatively high emission reduction potentials, and better cost effectiveness results than other potential TCMs.

- Many of the TSM alternatives requiring significant capital expenditures, such as HOV lanes, park-and-ride lots, and transit improvements, appear to have reasonable emission reduction potential, but the cost effectiveness results are poorer than other TCMs.

- Direct pricing strategies, such as emission-based registration fees, VMT taxes, and gasoline taxes, have high emission reduction potential, and good cost-effectiveness results. However, such measures are politically unpopular and can be regressive to lower income groups unless structured correctly.

- In general, TDM and TSM mode shift strategies have low-to-medium emission reduction potential and tend to have poorer cost effectiveness results compared to other TCMs.

These results are summarized in Table 4-34 which presents emission reduction potential, rate of reduction, and estimated cost effectiveness for eight general TCM categories. The table provides general rankings (low/medium/high) for each of the three variables. The emission reduction potential and rate of reduction rankings are based on software and analysis methodologies developed for the San Diego Association of Governments (Sierra Research, 1991a). These methods were used for analysis of the San Diego and Phoenix TCMs shown in Table 4-36. The cost effectiveness results reflect the conclusions drawn from the data analyzed for this report. Rankings are only provided where generalized conclusions were supported by the available data. Note that the rankings only reflect effectiveness of a category of TCMs relative to other TCMs. Table 4-36 does not portray TCM effectiveness relative to other non-TCM control options.

Section 5

EVALUATION OF STRATEGIES FOR MEETING RFP REQUIREMENTS

RFP MILESTONES

According to the CAA, each of the five areas evaluated in this report must achieve certain reductions in their VOC inventories by specified dates, referred to as milestones. All of the areas must achieve a 15 percent reduction from their adjusted 1990 baseline inventories by 1996, and a further 9 percent by 1999. Depending upon the severity of the ozone designation, some cities must continue to lower their VOC emissions by an average of 3 percent per year until the specified attainment deadline. In addition to these reduction requirements, EPA specifies that these nonattainment areas provide for a 3 percent contingency level of controls to be implemented upon failure to meet any RFP milestone. Table 5-1 provides a listing of the percentage reduction requirements and attainment deadlines for each of the five areas.

Table 5-1. Required VOC Reductions and Attainment Deadlines.

Area	**Attainment Date**	**Reduction from Baseline (%)**
Baltimore	2005	42%
Chicago	2007	48%
Houston	2007	48%
Philadelphia	2005	42%
D.C.	1999	24%

The above reduction requirements relate to VOC emissions. The CAA does not specify NO_x reduction requirements, though they do allow for substitution of NO_x reductions for VOCs after the 1996 milestone. The substitution ratio will be determined by EPA based upon the UAM results prepared by the states. These ratios will vary depending upon the relative contribution of VOCs and NO_x to the formation of ozone in each of the areas. Note that no NO_x substitutions will be permitted for the 1996 milestone, with or without modeling results.

ANALYTICAL APPROACH

In order to evaluate cost-effective approaches to meeting RFP milestones, Radian developed several spreadsheets to project emissions and track controls for each significant source category, for each city, for both VOC and NO_x. Projected emissions and controls were evaluated for the milestone years 1996 and 1999, as well as the year 2010. The target dates allowed Radian to evaluate controls for both attainment and maintenance strategies. This section describes the general methodology used by Radian to project future emissions, determine required RFP reductions, and design cost-effective control options.

Adjusted Baseline and Target Reductions

To calculate the emission reduction targets, a baseline must be determined; 1990 has been designated by the CAA as the base year for target calculations. The baseline emission inventory is calculated by first estimating the stationary (point and area) source contribution to total emissions. These emissions should be representative of typical summertime conditions during which ozone formation is most common.

The mobile source contribution to the baseline inventory is determined from EPA's MOBILE5a model, and 1990 vehicle miles travelled (VMT) estimates for each area. The CAA specifies that the beneficial effects of turnover of the pre-1994 fleet and certain future RVP fuel requirements should not be applicable to the reduction targets. Thus the baseline estimate is "adjusted" by incorporating the emission reductions resulting from fleet turnover and future RVP regulations. To do this, MOBILE5a is run for each milestone year, accounting for controls pre-dating the CAAA (e.g., basic I/M) and RVP changes, but excluding all other CAAA requirements. The resulting emission factors are then multiplied by the VMT estimates for 1990 to obtain the total mobile source emission estimates. Thus while there is only one stationary source baseline for each target year, there are multiple mobile source baseline -- one to be used for each target year. Each of the adjusted mobile source emission estimates are added to the stationary source baseline to obtain the total adjusted baseline for each target year.

Once the adjusted baseline emission levels are determined, target emission levels for VOCs are determined in the following manner. First, the 1996 baseline is multiplied by 85% to obtain the target emission level for 1996. The 1999 target level is based on a three percent per year (or nine percent total) reduction from the 1996 target level. Thus there is a total reduction of 24% (15+9%) from the 1999 baseline. As noted in Table 5-1, final target levels vary with attainment date.

Projected Emission Levels

After determining target emission levels for each milestone year, Radian estimated the likely growth in emissions from each source category from 1990 to each target year. For point, area, and non-road mobile sources, this growth is due to increased economic output over time. Although there may not be a strict one-to-one relationship between economic production and resulting emissions (e.g., due to improved efficiency), EPA believes that production changes are the best surrogate measure for changes in emissions. Therefore Radian employed growth factors taken from the Bureau of Economic Analysis' growth factor model, BEAFAC, to project future emissions levels for each source category.

BEAFAC calculates growth factors at the state level from the inputs of start year, end year, and state identification code, and matches the calculated growth factors to source categories by source identification (SIC) or standard classification codes (SCC) and area and mobile source (AMS) codes. BEAFAC only keys on the 2 digit SIC code and the first 4 digits of the SCC/AMS code to match growth factors. There are uncertainties associated with these growth factors because they lack source-specificity. For example, SIC Code 28, Chemicals and Applied Products, represents sources ranging from organic chemical manufacturing, such as polyethylene and propylene, to pharmaceutical and resins manufacturing. For all these sources, a singular growth factor is recommended. It is unlikely that such differing industries would have the same growth rates. Similar cases appear for both SIC and AMS codes, where a singular growth factor is applied to a wide variety of categories.

In addition, BEAFAC develops growth factors across an entire state. It is not certain that average growth estimates for the state of Texas, for example, can accurately represent of the economic conditions in Houston. For lack of better information, Radian assumed that the growth factors were representative across the state. Also, further uncertainties exist with the validity of using current economic production estimates to project emissions as far into the future as the year 2010. It is difficult to forecast changes in economic production, supply demands, and the effects forthcoming regulations this far into the future.

Mobile source emissions also will change over time because of increasing vehicle miles travelled (VMT), and decreasing fleet average emission factors. Radian used a 1.9 percent per year VMT growth factor, a value representative of the expected growth in each city (taken from inventory support documentation). Radian used MOBILE5a to determine future emission factors, accounting for reductions due to fleet turnover, the introduction of Tier I vehicles, and lowered gasoline RVP, for each city and target year. See Section 4 for a complete discussion of the use of MOBILE5a in estimating emissions.

Once emission projections were obtained for each source category, they were summed to estimate future emission totals for each target year. These projections then were compared to target emission levels to determine the reductions needed for each city and year. These values served as the basis for developing control strategy packages for each city. Table 5-2 provides a summary of the 1990 baseline and required emission reductions for each city, for 1996, 1999, and 2010.

The required emission reductions increase over time, due to the steady influence of growth factors on all but the on-road mobile source categories. In fact, by 2010 required emission reductions have grown to over 150 percent of the value of the original baseline inventory.

Table 5-2. Necessary Reductions (TPD) from Pre-Control Levels (Growth Included).

Location	1990 Baseline (Un-adjusted)	1996	1999	2010
Baltimore	323	71	104	180
Chicago	1248	258	385	728
Houston	1103	216	335	657
Philadelphia	578	114	178	305
D.C.	556	99	163	215

Reductions from Controls

The next step in the RFP analysis consisted of applying those mobile source controls mandated by the CAAA. These controls include Stage II refueling, RFG[1], Enhanced I/M, and Clean Fuel Fleets (1998+). Radian then selected from the menu of available control options developed in previous sections, based on cost-effectiveness ranking. These controls were then applied to the inventory for each source category to determine incremental progress toward meeting the required reductions.

Cost-Effectiveness Rankings. Cost-effectiveness is the primary criteria for choosing preferred control strategies in this analysis. Ideally, entire packages of control strategies would be evaluated to minimize total costs to the regulated community while still reaching required reduction levels. However, given the large number of significant source categories present in the cities, with no one source category dominating the overall inventory, applying controls sequentially by increasing cost-effectiveness generally minimizes total costs as well. (The calculation and ranking of RFG cost-effectiveness values are unique -- see Section 4 for further discussion.) Therefore controls were applied in this analysis based on the cost-effectiveness criterion.

As described above, Radian developed its own cost-effectiveness estimates for the various mobile source controls as well as for utility boiler NO_x controls. However, all of

[1] Not mandated for D.C., though they have opted in.

the other cost-effectiveness values used in this report were developed in other studies, many of which did not specify the assumptions and methodologies used to calculate their values. Therefore there is some uncertainty in the validity of comparing these different dollars-per-ton values to one another.

First, many studies may not discount emission reductions as well as costs in their analyses, as Radian chose to do. Where emission reductions are more or less constant from year to year, calculating annualized cost-effectiveness values will yield similar results to the net present value (NPV) approach used by Radian. Based on Radian's past experience, the annualized approach is the one most commonly taken in evaluating the cost-effectiveness of point source controls. However, if an NPV analysis were performed discounting costs but not emission reductions, cost-effectiveness values would be depressed relative to Radian's values (e.g., about 26 percent for a 6 percent discount rate over a ten year period). Such an approach might be taken in the event of variable emission reductions over time for a given control technique. While Radian believes that few if any studies used this later approach, it remains a potential source of error.

Second, many of the studies employed by Radian did not specify the discount rate or period of time used in their analyses. Radian used a standard 10 year analysis period and 6 percent real discount rate in all of its calculations (excluding utility boilers, which used a 20 year capital recovery period for NO_x controls). While the discount rate of 6 percent (10 percent with inflation) is fairly standard in economic analyses, the time period is not. The time period of an analysis becomes important for those controls requiring large capital investments, which in turn require some sort of capital recovery period. For example, a $100,000 capital costs spread over three years of emission reductions will result in much higher dollar-per-ton values than the same control with costs spread over 10 years. Therefore any discrepancy between the time period chosen for Radian's analysis and periods used in other studies will exacerbate differences in cost-effectiveness values for capital-intensive controls. The degree of any such discrepancies in this study is not known.

Third, it is not known if the cost-effectiveness values found in other studies included ozone season weighting factors. These weighting factors consider the fact that many controls accrue costs all year, although corresponding emissions reductions only generate benefits during the ozone season. It is EPA's standard approach not to use seasonal weighting factors, and Radian has adopted this approach as well (although an account was made of this in the RFG dollar-per-ton calculation -- see Section 4). However, it is possible that some of the studies referenced did apply these factors. In this event, Radian's cost-effectiveness values would be inflated relative to those seasonally-corrected values.

Despite the potential for methodological differences, Radian believes that its cost-effectiveness values can be compared to those of other studies with a fair degree of confidence, allowing controls for point, area, on- and non-road mobile sources to be ranked for each of the five cities. Radian developed five sets of rankings, and applied the controls sequentially, from most to least cost-effective, until reduction targets were met for each city and target date. This process is discussed below.

Application of Controls. Once a control measure was selected for application, the first step was to estimate the percentage of all sources in the given source category that actually can apply the control. This percentage is referred to as the Rule Penetration (RP) factor, and is dependant upon the technical feasibility of applying the control to sources within a category. For example, while reformulation of consumer solvents may be feasible for almost all sources in this category (RP = 0.99+), application of combustion modifications to utility boilers may only be feasible for one half of these sources (RP = 0.5).

Ideally, the RP factor would reflect the percent of the total emissions inventory impacted by the control, for each source category and city. For example, RP values for Houston may, in general, be lower than in Baltimore because Houston has already adopted more stringent controls. Thus, further penetration of new controls will be more difficult.

However, given data limitations, Radian just attempted to make an assessment of the percent of total sources impacted, when information was available. Radian did not attempt to estimate how the RP values would vary from city to city. For the majority of stationary point and area VOC sources a RP value of 80 percent was applied to provide a conservative estimate of possible reductions. Utility boilers were the only stationary NO_x source evaluated for potential reductions, and RP values were taken from a survey of boilers in the northeast (Acurex, 1992). A RP value of 80 percent was also adopted for most non-road mobile source controls, assuming that implementation took place upon replacement of a retired source, rather than retrofitting.

Finally note that MOBILE5a incorporates RP in its emission factor estimates, so an additional RP factor was not applied to controls for this source category, with the exception of Clean Fleets and scrappage programs. To estimate the number of vehicles effected by the Clean Fleet requirements, Radian applied the conversion requirements of the CAAA [2] to the estimated number of covered fleets in each nonattainment area. Conversion rates assume an average turnover time of five years for covered fleet vehicles. An additional scenario was evaluated as an option to the CAAA, which would provide emission reductions beyond those mandated. This scenario used the implementation rate used in the state of Texas, which converts more vehicles than the federal program, and at a faster rate.[3] The number of vehicles involved in a scrappage program were assumed to equal 1.5 percent of the total I/M program failures each year. This figure is highly speculative, and will vary with the vehicle "bounty" offered.

After RP factors have been applied to the inventory totals for each source category, Radian applied Rule Effectiveness (RE) factors to the remaining portion of the inventory. RE factors provide an estimate of how well a given control will operate in the field, relative to the stated control efficiency found in the literature. EPA recommends a

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[2] 30% of new purchases in 1998, 50% in 1999, and 70% thereafter.

[3] 30% of total covered fleets (as opposed to new purchases) by 1998, 50% by 2000, and 90% by 2002.

default RE value of 80 percent, unless site-specific studies justify a higher value. Radian used this default value for all stationary point and area source controls. However, for non-road mobile source controls, Radian assumed only a 50 percent RE value, to account for the uncertainty of regular maintenance in this source category (e.g., lawn and garden equipment and recreational boats). MOBILE5a accounted for RE values automatically in its emission factor calculations.

After applying both RP and RE values to the uncontrolled inventory, Radian estimated the potential reductions resulting from the selected control measures for a range of possible control efficiencies. Based upon the range of efficiencies found in the literature Radian evaluated Low, High, and Average emission reduction scenarios. All three of these reduction estimates were then totalled across all source categories for each city and target year to determine progress toward meeting RFP reduction requirements. If totals fell short of the target for the Low efficiency scenario, Radian then applied the next control on the cost-effectiveness rankings list and recalculated the total. This process was iterated until either RFP targets were met or control options were exhausted.

Finally note that the application of the chosen controls are dependant upon phase-in schedules. For the purposes of this analysis, Radian assumed that all stationary point and area source controls could be implemented by 1996, given the conservative RP values used. For non-road mobile sources Radian assumed that new controls would only be applied to new equipment, rather than retrofitting current sources. Therefore the control phase-in schedule was limited by the equipment turnover rates for each category. With turnover rates ranging from 5 to 27 depending on the equipment category (based on a rough estimate from LMOP, 1993), controls of these sources contributed little to the early milestone years but made significant contributions to long-term maintenance strategies.

1996 ROP ANALYSES -- VOCs

The following section presents the findings of the ROP analyses for each city, for 1996. The controls listed were selected according to cost-effectiveness ranking, selecting increasingly costly controls until reduction targets were obtained. The controls are listed in the following tables, under four headings: Mandatory Mobile Source Controls; Pending Federal Programs; State and Local Programs; and Additional Mobile Source Controls. (The order indicated on these tables does not reflect a control's cost-effectiveness ranking relative to other controls on the same table.)

Baltimore

Like most other cities Baltimore achieves the majority of its RFP target simply by implementing the mobile source controls required by the CAAA (Stage II, RFG, and enhanced I/M). However, Baltimore is unique in that there are numerous different point and area source controls, all contributing small amounts to the reduction target. In fact, with the exception of consumer solvent reformulation (about 10%) no single stationary source control contributes more than 4 percent toward the reduction goal. However, even after applying all of the available controls, the total reduction target could not be met, leaving a 15 tpd shortfall.

Because of the large number of small size emission source categories, Radian had to apply numerous controls in order to meet the RFP target. Each of these controls accounted for only a small percentage of the total reduction. The moderate contribution of mobile source reductions, left Baltimore unable to reach its RFP target.

The control options available varied in their cost-effectiveness. The most expensive control applied, in terms of dollars-per-ton of reduction, was that for auto and light-truck coatings, averaging about $18,000 per ton. However, the vast majority of the non-mobile controls applied fell in the $1,000 to $2,000 per ton range. Mandated mobile controls ranged from $2,800 per ton for Stage II to $20,000 per ton for enhanced I/M.

Chicago

The Chicago area featured the largest inventory of all the cities evaluated. Significant reductions were estimated for mandated mobile source controls, especially for RFG. The large emission reductions available from RFG can be attributed to the high-RVP baseline fuel used there. (The large gasohol sales fraction in Chicago generates greater evaporative emissions than in other areas using regular gasoline.) Other significant reductions were projected for the commercial and consumer product, graphic arts, and SOCMI categories.

Meeting the RFP target in Chicago can be done in a cost-effective manner, relative to other cities. The highest cost control applied in Chicago was for SOCMI sources, at about $5,000 per ton. Typical non-mobile controls ranged from $1,000 to $2,000, as in Baltimore. Mandated mobile source controls ranged from $2,800 for Stage II to $17,500 for enhanced I/M.

Houston[4]

As with the other cities, substantial emission reductions were projected for the mandated mobile source controls. However, the relative RFG benefits seen in other areas were much lower in Houston, due to a relatively low RVP baseline fuel. Houston also was unique among the five cities in that emission reductions from major point sources were comparable to the mobile controls. In fact, reductions from the petroleum and chemical sectors

[4] As discussed in Section 2, the TNRCC has updated the Houston inventory since the time of this analysis. Based on this revision the TNRCC claims that Houston can actually meet its 1996 ROP targets. Given the constraints of this study Radian could not evaluate the new data for further emission reduction opportunities.

Table 5-3. Rate-of-Progress Plan for Baltimore Nonattainment Area -- 1996.

Baltimore ROP Plan	Tons Per Day (VOC)	% of ROP Target
1. 1990 Base Year Anthropogenic VOC Emissions	323.5	
2. Adjustment for FMVCP and RVP (1990-1996)	-31.9	
3. 1990 Adjusted Base Year Inventory	291.6	
4. 15% Reduction Requirement from Adjusted Base Year Inventory	43.7	
5. Expected Growth in Emissions for 1990-1996	27.6	
6. Emission Reductions Required under the 1990 Clean Air Act	**71.3**	
7. Total Reductions Proposed from the Rate-of-Progress Plan	**56.4**	
8. Difference (+) or (-) in State Proposed Reductions from Federal Required Reductions	-14.9	
Rate-of-Progress Volatile Organic Compounds (VOCs) Control Strategy Detail:		
9. Mobile Source Control Measures:		
Enhanced I/M Program	8.4	11.7
Stage II Vapor Recovery	10.5	14.6
Reformulated Gasoline *	13.0 (9.1)	39.5
Total	**31.9**	**65.9**
10. Pending Federal Programs		
Architectural and Industrial Surface Coatings	2.7	3.7
Consumer and Commercial Products	6.6	9.2
Automobile Refinishing	3.0	4.2
Pesticide Reformulation	1.5	2.1
Traffic/Maintenance Paints	0.2	2.2
Total	**13.9**	**19.4**
11. State and Local Programs		
Emulsified Asphalt	0.2	2.2
Underground Storage Tank Breathing	0.6	0.8
Degreasing/Surface Cleaning	1.4	2.0
Municipal Landfills	1.8	2.5

Table 5-3. (Continued).

Baltimore ROP Plan	Tons Per Day (VOC)	% of ROP Target
Industrial Wastewater Treatment	0.1	0.2
Graphic Arts	1.4	1.9
Can Coating	0.2	0.3
Miscellaneous Metal Coatings	0.1	0.2
Bulk Gasoline Terminals	2.7	3.7
Marine Vessel Loading	0.1	0.1
Volatile Organic Liquid Storage	0.3	0.4
Auto and Light Truck Coating	0.8	1.1
Total	**9.7**	**13.6**
12. Additional Mobile Source Controls:		
Expanded I/M Program **	0.3	0.4
Vehicle Scrappage Program	0.6	0.8
Total	**0.9**	**1.3**
Grand Total	**71.8**	**100.2**

* The value in parenthesis represents the emissions reduction estimate from the RFG Complex Model. Although the value is significantly smaller, states are still permitted to use the MOBILE5a values generated before the release of the complex model.

** Expanded I/M for Baltimore has already been incorporated into the Maryland SIP.

Table 5-4. Rate-of-Progress Plan for Chicago Nonattainment Area -- 1996.

Chicago ROP Plan	Tons Per Day (VOC)	% of ROP Target
1. 1990 Base Year Anthropogenic VOC Emissions	1248.5	
2. Adjustment for FMVCP and RVP (1990-1996)	-136.4	
3. 1990 Adjusted Base Year Inventory	1112.0	
4. 15% Reduction Requirement from Adjusted Base Year Inventory	166.8	
5. Expected Growth in Emissions for 1990-1996	90.9	
6. Emission Reductions Required under the 1990 Clean Air Act	**257.8**	
7. Total Reductions Proposed from the Rate-of-Progress Plan	**262.3**	
8. Difference (+) or (-) in State Proposed Reductions from Federal Required Reductions	+4.6	
Rate-of-Progress Volatile Organic Compounds (VOCs) Control Strategy Detail:		
9. Mobile Source Control Measures:		
Enhanced I/M Program	34.1	13.0
Stage II Vapor Recovery	32.4	12.4
Reformulated Gasoline *	112.1 (55.1)	42.7
Total	**178.6**	**68.1**
10. Pending Federal Programs		
Architectural and Industrial Surface Coatings	6.9	2.6
Consumer and Commercial Products	15.6	5.9
Automobile Refinishing	6.4	2.4
Pesticide Reformulation	2.2	0.8
Traffic/Maintenance Paints	1.6	0.6
Total	**32.8**	**12.5**
11. State and Local Programs		
Emulsified Asphalt	4.2	1.6
Underground Storage Tank Breathing	2.7	1.0
Degreasing/Surface Cleaning	5.0	1.9
Organic Chemical Manufacturing -- Others	2.8	1.1

Table 5-4. (Continued).

Chicago ROP Plan	Tons Per Day (VOC)	% of ROP Target
Municipal Landfills	2.6	1.0
Industrial Wastewater Treatment	1.9	0.7
Graphic Arts	13.2	5.0
Can Coating	0.3	0.1
Miscellaneous Metal Coatings	5.5	2.1
Bulk Gasoline Terminals	2.1	0.8
Petroleum Refineries	2.5	0.9
Marine Vessel Loading	1.4	0.5
Organic Chemical Manufacturing -- Synthetic	9.9	3.8
Total	**54.1**	**20.6**
Grand Total	**262.3**	**101.2**

* The value in parenthesis represents the emissions reduction estimate from the RFG Complex Model. Although the value is significantly smaller, states are still permitted to use the MOBILE5a values generated before the release of the complex model.

contributed between 4 to 12 percent of the required amounts. However, even after applying all of the available controls, the total reduction target could not be met, leaving a 38 tpd (16%) shortfall.

One reason for the shortfall may be the relatively low contribution of mobile sources to the total inventory. In other cities, where mobile sources account for between 33 and 43 percent of the total VOC inventory, vehicles only contribute 21 percent to the Houston total. As the mandated mobile source controls are the greatest contributors to meeting reduction requirements, the reduced importance of mobile sources in Houston in turn reduce the relative importance of these controls. In addition, this situation is exacerbated by the low reductions resulting from RFG.

The Houston inventory also has an inordinately large contribution from the non-road mobile category, approximately 21 percent compared to 5 - 18 percent for most other cities. Because non-road mobile controls have no impact until after the 1996 deadline, this category is essentially "dead weight", and its large contribution in Houston makes meeting the RFP target even more difficult.

However, Radian believes that the initial inventory provided to us may contain significant errors, causing an underestimation of potential reductions. For example, based upon a recent ROP summary sheet released by the state, reductions of 29 tpd are possible from controls of marine vessel loading operations. However, this value is greater than the entire estimated inventory for this source category, based upon the numbers used by Radian in its analysis. Therefore the state must have raised its baseline emission estimate from this source category, allowing it to progress further toward the RFP target. Similarly, the state has shown a 35 tpd reduction resulting from general fugitive controls, a value much higher than that calculated by Radian. This increased reduction may be the result of a revised inventory with higher baseline fugitive emissions. For these reasons Radian believes that the 1996 target can be reached in Houston, but without the aid of a revised inventory, we cannot determine the associated cost-effectiveness range.

<u>Philadelphia</u>[5]

The Philadelphia baseline inventory is similar to Houston's, having a relatively small contribution from on-road mobile sources (33 percent, compared to the other three cities, each having over 40 percent). This reduced mobile source impact makes reaching the RFP target more difficult. Similarly, Philadelphia's inventory also has a large non-

[5] As discussed in Section 2, the state agencies in Pennsylvania have updated the Philadelphia inventory since the time of this analysis. Based on this revision the state claims that Philadelphia can actually meet its 1996 ROP targets. Given the constraints of this study Radian could not evaluate the new data for further emission reduction opportunities.

road mobile source component, further hindering efforts to reach the reduction target. For these reasons

Table 5-5. Rate-of-Progress Plan for Houston Nonattainment Area -- 1996.

Houston ROP Plan	Tons Per Day (VOC)	% of ROP Target
1. 1990 Base Year Anthropogenic VOC Emissions	1103.1	
2. Adjustment for FMVCP and RVP (1990-1996)	-82.0	
3. 1990 Adjusted Base Year Inventory	1021.1	
4. 15% Reduction Requirement from Adjusted Base Year Inventory	153.2	
5. Expected Growth in Emissions for 1990-1996	63.3	
6. Emission Reductions Required under the 1990 Clean Air Act	**216.5**	
7. Total Reductions Proposed from the Rate-of-Progress Plan	**178.5**	
8. Difference (+) or (-) in State Proposed Reductions from Federal Required Reductions	-38.0	
Rate-of-Progress Volatile Organic Compounds (VOCs) Control Strategy Detail:		
9. Mobile Source Control Measures:		
Enhanced I/M Program	33.6	15.5
Stage II Vapor Recovery	16.6	7.7
Reformulated Gasoline *	19.7 (11.7)	9.1
Total	**69.9**	**32.3**
10. Pending Federal Programs		
Architectural and Industrial Surface Coatings	6.2	2.9
Consumer and Commercial Products	8.0	3.7
Automobile Refinishing	4.9	2.3
Pesticide Reformulation	0.8	0.4
Traffic/Maintenance Paints	0.7	0.3
Total	**20.7**	**9.6**
11. State and Local Programs		

Table 5-5. (Continued).

Houston ROP Plan	Tons Per Day (VOC)	% of ROP Target
Emulsified Asphalt	0.3	0.2
Underground Storage Tank Breathing	1.3	0.6
Degreasing/Surface Cleaning	2.3	1.1
Organic Chemical Manufacturing -- Others	9.8	4.5
Municipal Landfills	0.3	0.1
Industrial Wastewater Treatment	10.5	4.8
Graphic Arts	2.75	1.3
Bulk Gasoline Terminals	20.41	9.4
Petroleum Refineries	25.56	11.8
Marine Vessel Loading	8.1	3.7
Storage/Warehousing	6.24	2.9
Total	**87.5**	**40.4**
12. Additional Mobile Source Controls:		
Expanded I/M Program	0.1	0.0
LEV Program	1.0	0.5
Scrappage Program	1.3	0.6
Total	**2.3**	**1.1**
Grand Total	**178.5**	**83.4**

• The value in parenthesis represents the emissions reduction estimate from the RFG Complex Model. Although the value is significantly smaller, states are still permitted to use the MOBILE5a values generated before the release of the complex model.

the reduction target was not reached, even after application of all available controls -- Radian projected a shortfall of 13 tpd, or 12 percent of the required reductions. As with Houston, it is possible that late revisions of the emission inventory may allow the target to be obtained, but without revised figures, Radian cannot assess the cost-effectiveness of the resulting control strategy.

Table 5-6. Rate-of-Progress Plan for Philadelphia Nonattainment Area -- 1996.

Philadelphia ROP Plan	Tons Per Day (VOC)	% of ROP Target
1. 1990 Base Year Anthropogenic VOC Emissions	577.9	
2. Adjustment for FMVCP and RVP (1990-1996)	-47.9	
3. 1990 Adjusted Base Year Inventory	530.0	
4. 15% Reduction Requirement from Adjusted Base Year Inventory	79.5	
5. Expected Growth in Emissions for 1990-1996	34.0	
6. Emission Reductions Required under the 1990 Clean Air Act	**113.5**	
7. Total Reductions Proposed from the Rate-of-Progress Plan	**100.2**	
8. Difference (+) or (-) in State Proposed Reductions from Federal Required Reductions	-13.3	
Rate-of-Progress Volatile Organic Compounds (VOCs) Control Strategy Detail:		
9. Mobile Source Control Measures:		
Enhanced I/M Program	23.9	21.1
Stage II Vapor Recovery	9.4	8.3
Reformulated Gasoline *	29.4 (20.4)	25.9
Total	**62.7**	**55.2**
10. Pending Federal Programs		
Architectural and Industrial Surface Coatings	4.1	3.6
Consumer and Commercial Products	10.7	9.4
Automobile Refinishing	5.1	4.5
Traffic/Maintenance Paints	0.8	0.7
Total	**20.7**	**18.2**
11. State and Local Programs		
Underground Storage Tank Breathing	1.0	0.9
Degreasing/Surface Cleaning	2.4	2.1
Organic Chemical Manufacturing -- Others	0.8	0.7
Can Coating	0.3	0.2
Miscellaneous Metal Coating	0.4	0.4

Table 5-6. (Continued).

Philadelphia ROP Plan	Tons Per Day (VOC)	% of ROP Target
Graphic Arts	2.2	1.9
Bulk Gasoline Terminals	1.7	1.5
Petroleum Refineries	4.8	4.3
Industrial Machinery & Equipment	0.6	0.5
Auto & Light Truck	1.0	0.9
Total	**15.1**	**13.3**
12. Additional Mobile Source Controls:		
Expanded I/M Program	0.4	0.4
LEV Program	0.7	0.6
Scrappage Program	0.7	0.6
Total	**1.8**	**1.6**
Grand Total	**100.2**	**88.3**

- The value in parenthesis represents the emissions reduction estimate from the RFG Complex Model. Although the value is significantly smaller, states are still permitted to use the MOBILE5a values generated before the release of the complex model.

D.C.

The D.C. inventory is unique among the cities evaluated in that it features almost no major point sources of VOCs. The inventory is dominated by mobile sources, at 43 percent, facilitating attainment of the RFP target. In addition, the inventory features a very large contribution from consumer and commercial solvents. In fact, this category is almost a factor of 2 greater than that found in Chicago, the city with the second largest total for this category. Although Radian is uncertain of the reason for this inordinately large contribution, its presence allows for substantial emission reductions (28% from baseline) at a relatively low cost (about $1,600 per ton). These two aspects of D.C.'s emission profile allow it to reach its 1996 target with relatively little difficulty. The highest cost control applied to this inventory was $1,650 per ton for consumer/commercial solvents, with typical non-mobile costs well below $1,000. Mandated mobile controls ranged from $2,800 for Stage II to $14,000 for enhanced I/M.

Table 5-7. Rate-of-Progress Plan for D.C. Nonattainment Area -- 1996.

Washington ROP Plan	Tons Per Day (VOC)	% of ROP Target
1. 1990 Base Year Anthropogenic VOC Emissions	556.1	
2. Adjustment for FMVCP and RVP (1990-1996)	-73.7	
3. 1990 Adjusted Base Year Inventory	482.4	
4. 15% Reduction Requirement from Adjusted Base Year Inventory	72.4	
5. Expected Growth in Emissions for 1990-1996	26.6	
6. Emission Reductions Required under the 1990 Clean Air Act	**98.9**	
7. Total Reductions Proposed from the Rate-of-Progress Plan	**102.5**	
8. Difference (+) or (-) in State Proposed Reductions from Federal Required Reductions	+3.5	
Rate-of-Progress Volatile Organic Compounds (VOCs) Control Strategy Detail:		
9. Mobile Source Control Measures:		
Enhanced I/M Program	28.2	28.5
Stage II Vapor Recovery	16.7	16.9
Reformulated Gasoline *	20.6 (13.4)	20.8
Total	**65.5**	**66.2**
10. Pending Federal Programs		
Consumer and Commercial Products	27.8	28.1
Traffic/Maintenance Paints	1.1	1.1
Total	**28.9**	**29.2**
11. State and Local Programs		
Underground Storage Tank Breathing	0.6	0.6
Degreasing/Surface Cleaning	2.3	2.3
Emulsified Asphalt	4.4	4.4

Table 5-7. (Continued).

Washington ROP Plan	Tons Per Day (VOC)	% of ROP Target
Municipal Landfills	1.3	1.3
Total	**8.5**	**8.6**
Grand Total	**98.9**	**103.6**

- **The value in parenthesis represents the emissions reduction estimate from the RFG Complex Model. Although the value is significantly smaller, states are still permitted to use the MOBILE5a values generated before the release of the complex model.**

1999 AND 2010 ROP ANALYSES – VOCs

The emission projections and control estimates for years after 1996 were calculated in the same fashion as above. However, in every case the reduction targets could not be met – even after applying all available control options, regardless of cost. For this reason we do not provide a similar ROP table for each city as for 1996. Instead, Table 5-8 provides a summary of the required targets and estimated reductions from applying all available controls. The "targets" in this table refer to the emission reductions needed to meet RFP reductions, considering future growth in the inventories. Note that all reductions are based upon Radian's Low Control Efficiency case; therefore actual shortfalls may be less than those shown below.

As expected, the most significant 1999 shortfalls occur in Houston and Philadelphia, the two cities which did not meet their 1996 targets. D.C. is consistently the closest to meeting its reduction requirements for both 1999 and 2010. This is primarily due to its earlier attainment date (1999) and correspondingly lower long-term reduction requirements. In fact, due to penetration of new and more stringent on- and non-road mobile controls, D.C. actually gets relatively closer to meeting its targets with time.

Table 5-8. ROP Targets and Projected Shortfalls (TPD) for 1999 and 2010.

Location	1999		2010	
	Target	Shortfall	Target	Shortfall
Baltimore	104	34 (32%)	180	91 (50%)
Chicago	385	80 (21%)	728	362 (50%)
Houston	335	129 (38%)	657	401 (61%)
Philadelphia	178	51 (29%)	305	140 (46%)
D.C.	163	26 (15%)	215	23 (11%)

Unlike D.C., the other cities experience a large increase in their shortfall totals between 1999 and 2010. The primary reason for this increase is the influence of the BEAFAC growth factors. Over the twenty year period from 1990 to 2010 cumulative growth factors average 20 to 50 percent, with some source categories approaching 100 percent. For this reason growth from the baseline inventory quickly outstrips all available control reductions. (However, Radian's projections did not estimate the beneficial effect of stationary source retirement and replacement with lower-polluting facilities, which should provide significant credits in the future. Therefore the shortfalls noted above are somewhat overestimated.)

The assumption of unrestricted growth over the next 17 years may itself be faulty. Given RACT and NSR restrictions it is unlikely that sources can continue to grow at current rates. Therefore growth rates may be limited in the long-run by environmental regulations. However, estimating the impact of such restrictions is beyond the scope of this report.

Figure 5-1 illustrates the shortfalls of the rate-of-progress plans for each of the five nonattainment areas. This figure shows the impact of mobile, area, point, and additional mobile source controls relative to total reduction targets.

POTENTIAL NO_x REDUCTIONS

Unlike VOC emissions, the CAAA do not specify reduction targets for NO_x, although requirements may be defined for the 1999 and later milestones. For this reason Radian did not develop ROP strategies akin to those for VOCs. Instead we simply calculated the total potential emission reductions which could result from specific controls. These estimates may be used in developing ROP plans after VOC / NO_x equivalence ratios are established.

The controls chosen for evaluation were limited to only the largest NO_x sources, namely on and non-road mobile sources, and electric utilities. Due to a lack of RP estimates for other NO_x sources, such as refineries and SOCMI facilities, Radian did not attempt to estimate the potential reductions from these smaller source categories. (In most cases determination of RP values for these sources would require site-specific surveys of a large number of facilities to estimate retrofit potentials.)

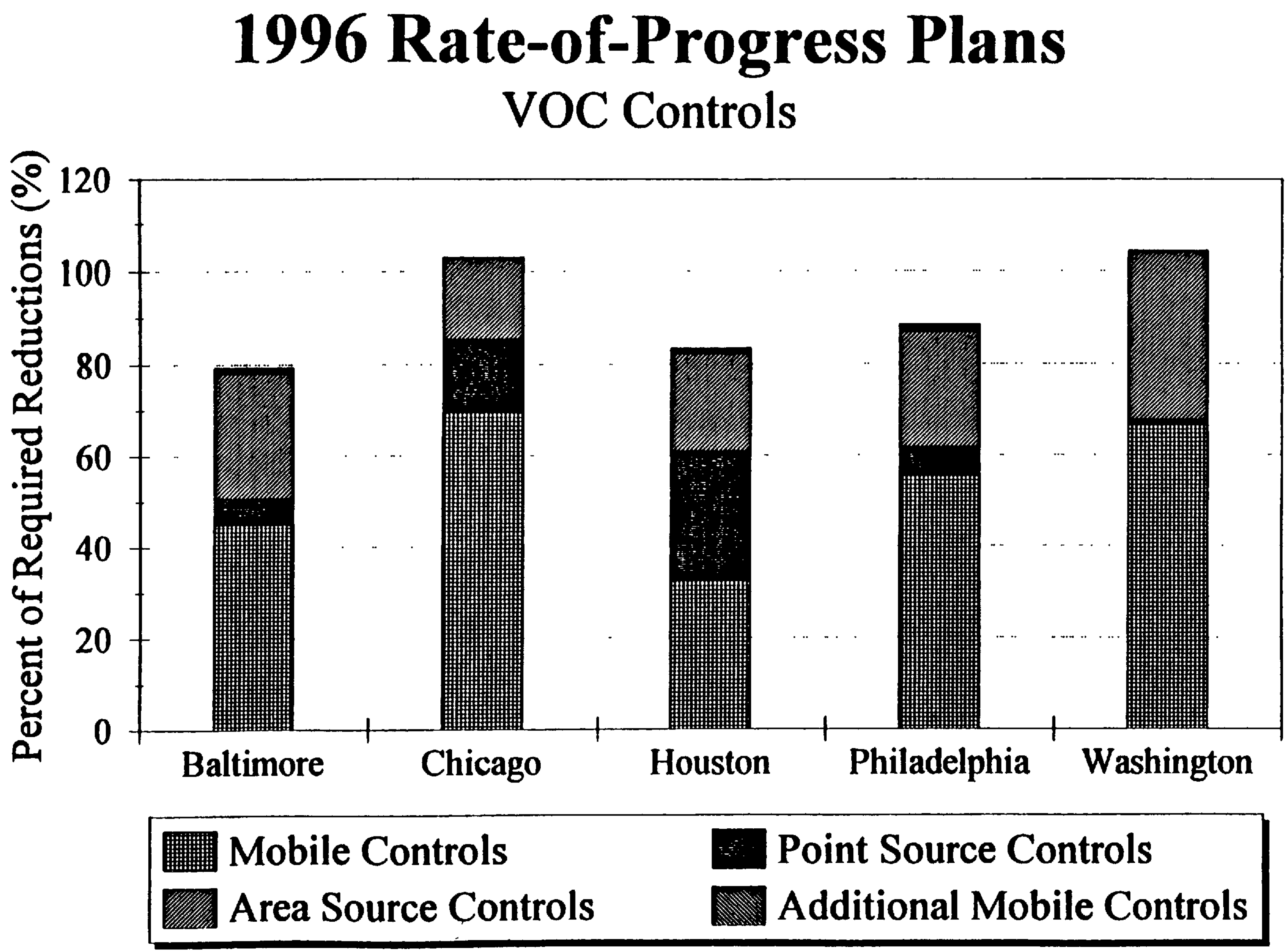

Figure 5-1. Rate-of-Progress Plans by City.

Radian calculated the potential NO_x emission reductions resulting from on and non-road mobile controls in the same fashion as for VOCs, estimating low, high, and average values. These values were estimated for the full menu of control options for on-road mobile sources, including California RFG, LEVs, and expanded Clean Fleet programs. Cost-effectiveness values typically ranged from about $5,000 - $10,000 per ton for (long-run) enhanced I/M, to over $100,000 for LEV programs. Non-road mobile source controls were much lower in cost, typically $1,000 to $2,000 per ton of NO_x, regardless of city.

Radian evaluated the potential reductions for utilities in a slightly different fashion. Given that most utility boilers in the five cities currently do not have NO_x controls, there are a wide variety of control options available to them, covering the full range of costs and efficiencies. Therefore Radian adopted a three-tiered control analysis for utility boiler NO_x controls, first evaluating relatively simple combustion modifications such as FGR, then more elaborate combustion modifications such as LNBs, and finally flue gas treatments including SCR. In general, the cost and cost-effectiveness of these options increase from the first to the last, with Level 1 controls typically in the $300 to $1,000 per ton range, Level 2 about $2,000 to $4,000, and Level 3 in the $5,000 to $15,000 range. This sequence follows the logical order in which these controls would be applied in the field. This approach allows the reader to evaluate the NO_x reduction potentials over the full range of cost-effectiveness values.

As with the other control strategies, Radian evaluated the boiler controls for low, high, and average control efficiencies. RP values were taken from the Acurex NESCAUM report, and ranged from 50 to 80 percent for the various combustion modifications (Acurex, 1992). Radian assumed an 80 percent RP value from FGT controls as well. Though a large percentage of FGT retrofits may be difficult, such difficulties are reflected in the wide cost range used in the cost-effectiveness analysis.

Though the potential emission reductions and control costs vary from city to city, a few generalizations can be made. First, the major NO_x sources do not experience the same level of future growth as do the major VOC sources. In fact, emissions are only projected to increase about 10 percent over the 1990 to 2010 period, in all cities. This is likely due to the slow growth in the utility sector, combined with stable emissions levels from on-road mobile sources. Therefore reductions achieved through controls are not quickly outstripped by growth as happens with VOCs. Second, potential reductions seem to increase steadily over time, typically rising to levels 20 percent or more of the total NO_x inventory by 2010. This increase primarily is due to increased rule penetration for non-road mobile controls due to equipment turnover, and to a lesser extent, improved on-road controls (e.g., Phase II Clean Fleet standards and California RFG after 2000).

The following sections provide a brief discussion of potential NO_x reductions and costs for each of the five cities. Emission reduction estimates are conservative, based upon the low-efficiency estimates from the literature.

Baltimore

NO_x reductions of up to 5.4 percent could be obtained from enhanced I/M and Level 1 utility boiler controls alone by 1996, and up to 17.3 percent with Level 3 controls. Much higher reductions are possible in future years, with the introduction of non-road mobile controls and more stringent on-road NO_x controls. By Radian's estimate total reductions could reach up to 38 percent by 2010.

As seen in Table 5-9, these potential emission reductions cover a very wide range of cost-effectiveness values, with non-road mobile controls at the low end ($1,000 to $2,000 per ton), and optional on-road mobile controls on the high end (up to $100,000 per ton). By and large, Level 1 utility boiler controls fall in the low range, while Levels 1 and 2 fall in the mid-range.

Chicago

The Chicago NO_x inventory was almost identical to Baltimore's in terms of the relative contributions of different source categories (See Figures 2-6 and 2-7). Therefore Chicago also has similar percentage reduction potentials. The only significant differences occurs in the utility category, where Chicago has a substantially lower percentage contribution to the inventory than Baltimore, a therefore has lower reduction potentials. (Note that the Power Generation category in Figure 2-7 -- Chicago -- also contains emissions from industrial boilers, raising its total, while Figure 2-6 -- Baltimore -- does not.) Total emission reductions range from 4.8 to 9.5 percent in 1996, and from 23.2 to 28.0 percent in 2010. Cost-effectiveness values are shown in Table 5-10, and are similar to those in all other cities.

Houston

Radian's analysis found Houston to have the lowest NO_x reduction potentials in the source categories evaluated of all the cities. This can be attributed to Houston having the lowest relative contribution from on-road mobile sources as well as power generation. In addition, most of the utility boilers operating in the Houston area are already using simple combustion modifications such as LEA and BOOS. Therefore the utility baseline emission level is much lower in Houston than in the other cities, resulting in a lower reduction potential. Overall, potential reductions range from 1.1 to 11.0 percent in 1996, and 12.8 to 22.3 percent of the total inventory in 2010.

Table 5-9. NO_x Control Strategies for Nonattainment Area -- Baltimore.

	1996 (TPD/% of Total)	1999 (TPD/% of Total)	2010 (TPD/% of Total)	Cost Effectiveness ($/ton) (Short/Long)
1. Mobile Source Controls				
Enhanced I/M Program	5.7	16.4	35.9	$19,184/5,670
RFG (2010 only)	—	—	11.4	$75,807/30,998
LEV Program	—	2.5	8.5	$134,550/55,158
NGV Program (2010 only)	—	—	1.3	NA/17,430
NGV Optional Program (2010 only)[a]	—	—	0.4	NA/17,430
California RFG (2010 only)[b]	—	—	10.8	$35,697/35,585
Total	**5.7 (1.3%)**	**18.9 (4.3%)**	**68.2 (15.5%)**	
2. Non-Road Mobile Source Controls				
Rail	—	0.6	1.9	$1,554
Vessels	—	0.3	0.6	$1,108
Agricultural Equipment	—	0.2	1.1	$146
Industrial Equipment	—	1.3	3.0	(Savings)
Heavy Construction Equipment	—	2.9	7.0	$3,748
Total	—	**5.3 (1.2%)**	**13.6 (3.1%)**	
3. Utility NO_x Controls[c]				
Level 1: LNB + OFA / BOOS	18.0	19.2	22.5	$613
Level 2: LNB + SCR / BOOS + FGR	64.7	69.0	80.8	$4,497
Level 3: LNB + SCR	70.5	75.1	87.9	$8,510
Total (Assuming Option 3)	**70.5 (16.0%)**	**75.1 (17.1%)**	**87.9 (20.0%)**	
Grand Total	**76.18 (17.3%)**	**99.3 (22.6%)**	**170.0 (38.6%)**	

[a] Benefits incremental to mandated NGV program.
[b] Benefits incremental to Federal RFG program.
[c] Utility NO_x control options correspond to PC-Fired/Oil & Gas Fired Boilers, respectively. No PC boiler controls for option 3.

Table 5-10. NO_x Control Strategies for Nonattainment Area – Chicago.

	1996	1999	2010	Cost Effectiveness
1. Mobile Source Controls				
Enhanced I/M Program	32.0	57.2	87.1	$15,307/6,615
RFG (2010 only)	—	—	38.2	$60,881/26,229
LEV Program	—	6.5	16.9	$141,204/86,677
NGV Program (2010 only)	—	—	3.5	NA/17,430
NGV Optional Program (2010 only)[a]	—	—	2.2	NA/17,430
California RFG (2010 only)[b]	—	—	36.2	$28,668/30,110
Total	**32.0 (3.2%)**	**63.7 (6.3%)**	**184.1 (18.2%)**	
2. Non-Road Mobile Source Controls				
Rail	—	1.4	4.1	$1,858
Vessels	—	0.3	0.5	$1,150
Agricultural Equipment	—	0.3	1.6	$146
Industrial Equipment	—	2.0	4.7	(Savings)
Heavy Construction Equipment	—	8.2	20.0	$3,756
Total	—	**12.2 (1.2%)**	**30.9 (3.1%)**	
3. Utility NO_x Controls[c]				
Level 1: LNB + OFA / BOOS	16.1	17.1	19.4	$631
Level 2: LNB + SCR / BOOS + FGR	61.2	64.6	73.7	$4,614
Level 3: LNB + SCR	64.1	67.6	77.3	$8,510
Total (Assuming Option 3)	**64.1 (6.3%)**	**67.6 (6.67%)**	**77.3**	
Grand Total	**96.1 (9.5%)**	**143.5 (14.2%)**	**292.5 (28.8%)**	

[a] Benefits incremental to mandated NGV program.
[b] Benefits incremental to Federal RFG program.
[c] Utility NO_x control options correspond to PC-Fired/Oil & Gas Fired Boilers, respectively. No PC boiler controls for option 3.

Table 5-11. NO_x Control Strategies for Nonattainment Area -- Houston.

	1996	1999	2010	Cost Effectiveness
1. Mobile Source Controls				
Enhanced I/M Program	23.5	38.3	51.4	$14,880/7,217
RFG (2010 only)	—	—	20.3	$73,335/32,168
LEV Program	3.7	4.2	9.6	$152,796/101,123
NGV Program (2010 only)	—	—	2.0	NA/17,430
NGV Optional Program (2010 only)[a]	—	—	0.6	NA/17,430
California RFG (2010 only)[b]	—	—	19.3	$34,533/36,928
Total	**27.2 (2.0%)**	**42.5 (3.0%)**	**103.2 (6.0%)**	
2. Non-Road Mobile Source Controls				
Rail	—	1.0	5.1	$1,530
Vessels	—	11.0	28.6	$1,090
Agricultural Equipment	—	0.5	4.1	$137
Industrial Equipment	—	0.0[d]	0.0	(Savings)
Heavy Construction Equipment	—	10.0	38.0	$3,830
Total	—	**22.5 (1.6%)**	**75.8 (4.9%)**	
3. Utility NO_x Controls[c]				
Level 1: LNB + OFA / NA[e]	15.5	16.8	20.5	$277
Level 2: LNB + SCR / BOOS + FGR	85.7	92.8	113.1	$3,942
Level 3: LNB + SCR	126.8	137.4	167.4	$8,510
Total (Assuming Option 3)	**126.8 (9.1%)**	**137.4 (9.6%)**	**167.4 (10.8%)**	
Grand Total	**154.0 (11.0%)**	**202.4 (14.2%)**	**346.4 (22.3%)**	

[a] Benefits incremental to mandated NGV program.
[b] Benefits incremental to Federal RFG program.
[c] Utility NO_x control options correspond to PC-Fired/Oil & Gas Fired Boilers, respectively. No PC boiler controls for option 3.
[d] No breakout of Industrial Equipment NO_x given in Houston inventory.
[e] Baseline oil/gas boilers already using LEA -- therefore BOOS is not applied.

Philadelphia

Philadelphia has the smallest baseline NO_x inventory, in absolute terms, of all five cities. This is due in large part to Philadelphia's low contribution from on-road mobile sources, as well as its reliance on nuclear power, minimizing its NO_x emissions from the utility sector. Therefore like Houston, emission reduction potentials are somewhat limited. Projections range from 4.4 to 6.2 percent in 1996, and from 23.1 to 25.2 percent in 2010.

D.C.

Unlike the other NO_x inventories evaluated, D.C.'s inventory is dominated by emissions from the utility sector (57%). This high value results from D.C.'s almost exclusive reliance on coal. This reliance, plus the high uncontrolled emission rates from PC-fired boilers offer ample opportunities for significant, low-cost NO_x reductions. In fact, a reduction of almost 7 percent could be obtained by 1996 just by adopting Level 1 boiler controls. Possible reductions in 1996 range from 8.7 to 38.5 percent in 1996, and from 19.5 to 55.0 percent in 2010. Large emissions from the on- and non-road mobile source categories also contribute to these high reduction levels.

Figures 5-2 to 5-6 illustrate the possible NO_x reductions resulting from mobile source controls, non-road mobile source controls, and utility NO_x controls. These figures shows the impact of NO_x controls for each of the nonattainment areas. Most of the reductions are a result of mobile source controls mandated by the CAAA as well as utility NO_x controls.

CONCLUSIONS

As is clearly seen in this study, the available controls for VOC and NO_x emissions have a wide range of cost-effectiveness values – anywhere from a cost savings to almost $500,000 per ton of pollutant. Even costs for a given type of control applied to a specific source category can be highly variable, dependant upon site-specific factors such as retrofit feasibility, local conditions, fuel cost, and a host of other factors. Nevertheless, a few general observations can still be made:

Table 5-12. NO_x Control Strategies for Nonattainment Area – Philadelphia.

	1996	1999	2010	Cost Effectiveness
1. Mobile Source Controls				
Enhanced I/M Program	15.0	24.7	37.0	$16,155/7,217
RFG (2010 only)	—	—	12.6	$87,868/36,797
LEV Program	—	3.0	8.9	$150,685/75,842
NGV Program (2010 only)	—	—	2.3	NA/17,430
NGV Optional Program (2010 only)[a]	—	—	0.7	NA/17,430
California RFG (2010 only)[b]	—	—	12.0	$41,376/42,241
Total	**15.0 (3.8%)**	**27.7 (7.1%)**	**73.5 (18.9%)**	
2. Non-Road Mobile Source Controls				
Rail	—	0.9	5.4	$1,530
Vessels	—	0.0	0.0	$966
Agricultural Equipment	—	0.1	0.3	$120
Industrial Equipment	—	0.8	1.9	(Savings)
Heavy Construction Equipment	—	2.5	6.0	$3,280
Total	—	**4.3 (1.1%)**	**13.4 (3.5%)**	
3. Utility NO_x Controls[c]				
Level 1: LNB + OFA / BOOS	2.5	2.6	3.0	$541
Level 2: LNB + SCR / BOOS + FGR	6.9	8.7	8.4	$4,060
Level 3: LNB + SCR	9.3	11	11.3	$8,510
Total (Assuming Option 3)	**9.3 (2.4%)**	**11.0 (2.8%)**	**11.3 (2.9%)**	
Grand Total	**24.3 (6.2%)**	**43.0 (11.1%)**	**98.2 (23.4%)**	

[a] Benefits incremental to mandated NGV program.
[b] Benefits incremental to Federal RFG program.
[c] Utility NO_x control options correspond to PC-Fired/Oil & Gas Fired Boilers, respectively. No PC boiler controls for option 3.

Table 5-13. NO_x Control Strategies for Nonattainment Area -- Washington D.C.

	1996	1999	2010	Cost Effectiveness
1. Mobile Source Controls				
Enhanced I/M Program	18.1	25.8	40.1	$20,555/9,160
RFG (2010 only)	—	—	11.4	$88,409/37,063
LEV Program	—	4.0	15.4	$120,166/37,063
NGV Program (2010 only)	—	—	2.3	NA/43,677
NGV Optional Program (2010 only)[a]	—	—	0.7	NA/43,677
California RFG (2010 only)[b]	—	—	16.5	$41,631/42,547
Total	**18.1 (2.0%)**	**29.8 (3.3%)**	**86.3 (9.5%)**	
2. Non-Road Mobile Source Controls				
Rail	—	0.4	1.3	$1,552
Vessels	—	0.0	0.0	NA
Agricultural Equipment	—	0.1	0.7	$173
Industrial Equipment	—	0.4	1.0	(Savings)
Heavy Construction Equipment	—	8.9	21.5	$3,748
Total	—	**9.9 (1.1%)**	**24.5 (2.7%)**	
3. Utility NO_x Controls[c]				
Level 1: LNB + OFA / BOOS	60.6	62.9	72.6	$652
Level 2: LNB + SCR / BOOS + FGR	245.6	255.1	292.2	$4,740
Level 3: LNB + SCR	331.9	345.4	394.8	$8,510
Total (Assuming Option 3)	**331.9 (36.5%)**	**345.4 (38.0%)**	**394.8 (43.4%)**	
Grand Total	**350.0 (38.5%)**	**385.1 (42.3%)**	**505.6 (55.6%)**	

[a] Benefits incremental to mandated NGV program.
[b] Benefits incremental to Federal RFG program.
[c] Utility NO_x control options correspond to PC-Fired/Oil & Gas Fired Boilers, respectively. No PC boiler controls for option 3.

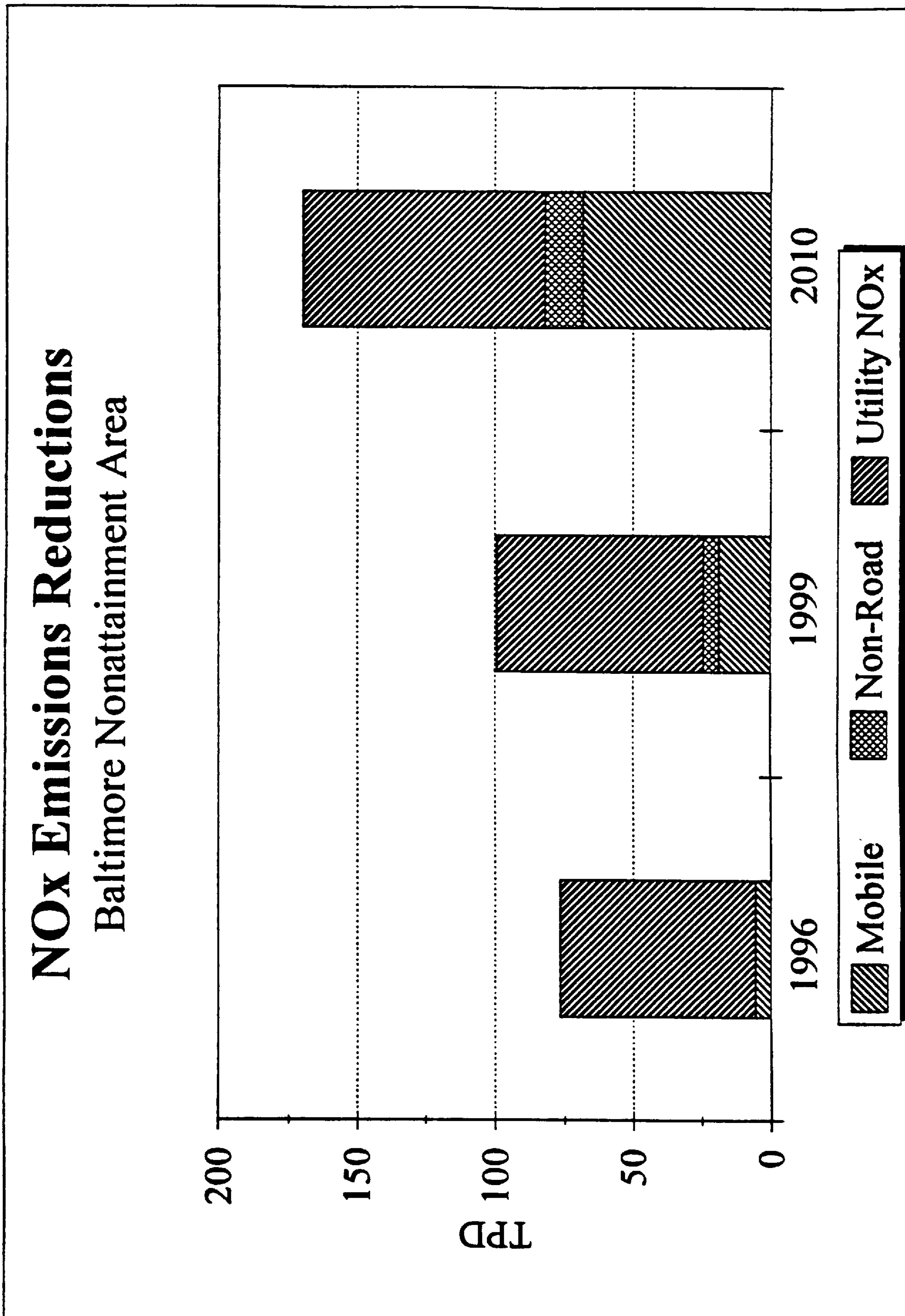

Figure 5-2. NOx Emissions Reductions in Baltimore.

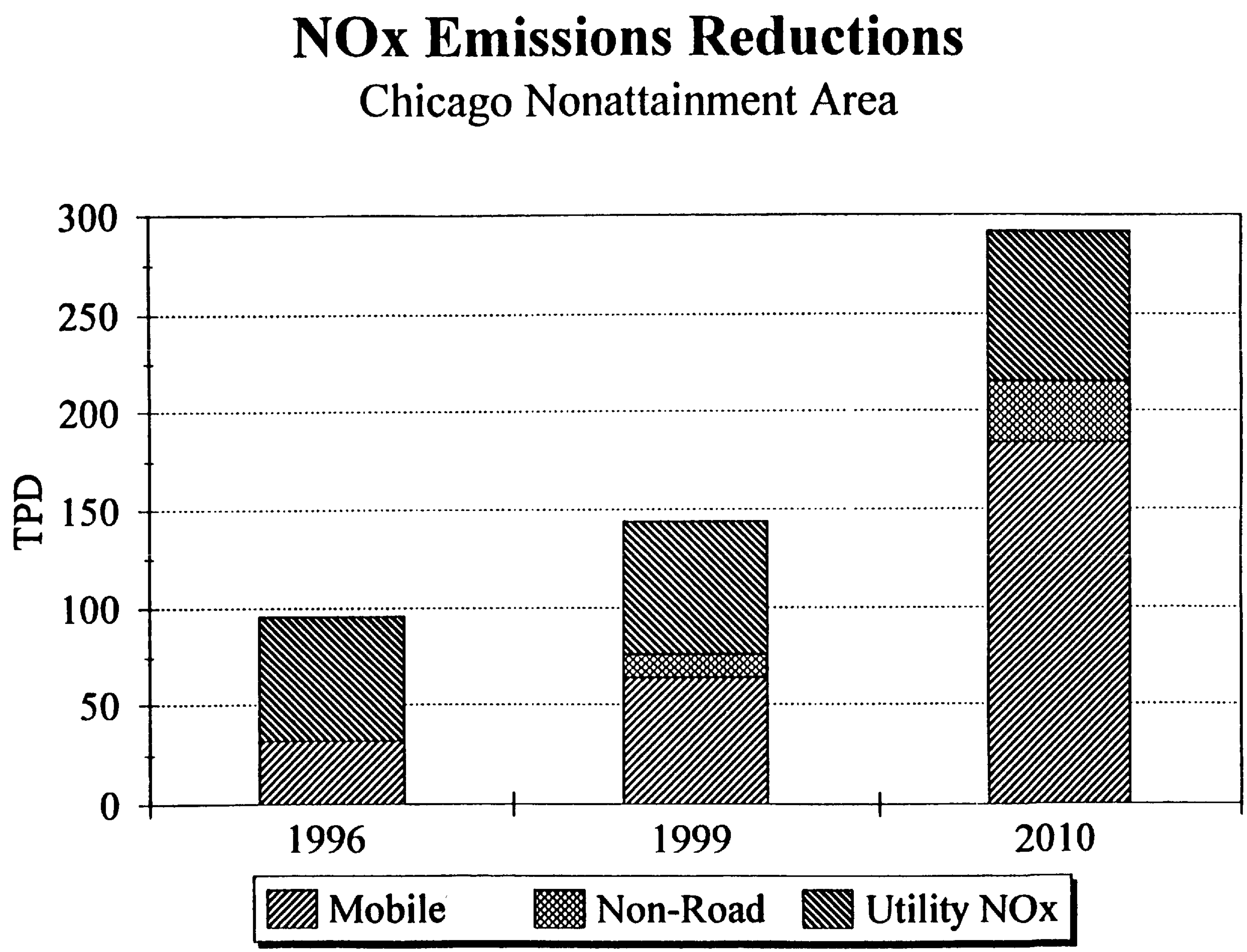

Figure 5-3. NOx Emissions Reductions in Chicago.

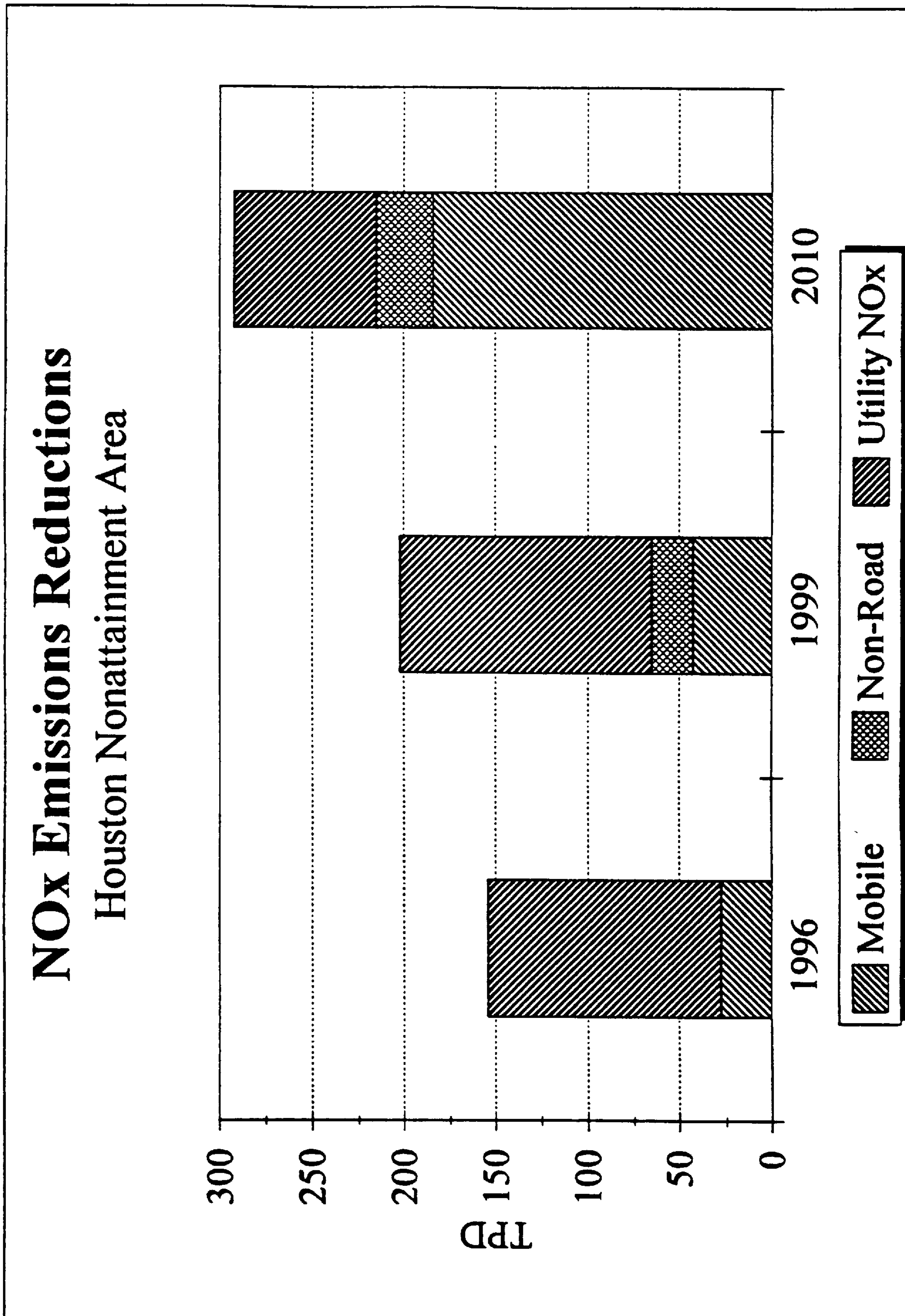

Figure 5-4. NOx Emissions Reductions in Houston.

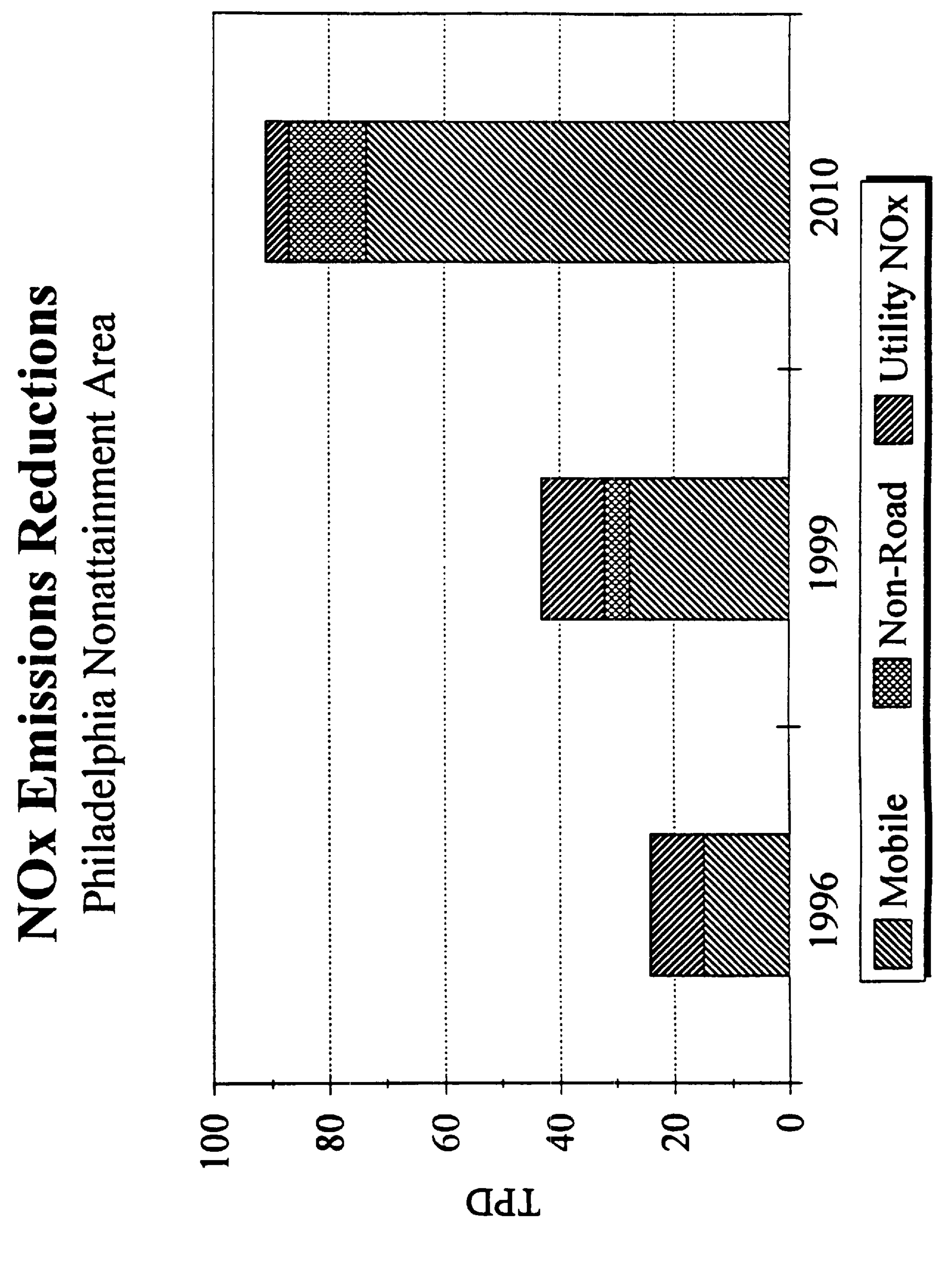

Figure 5-5. NOx Emissions Reductions in Philadelphia.

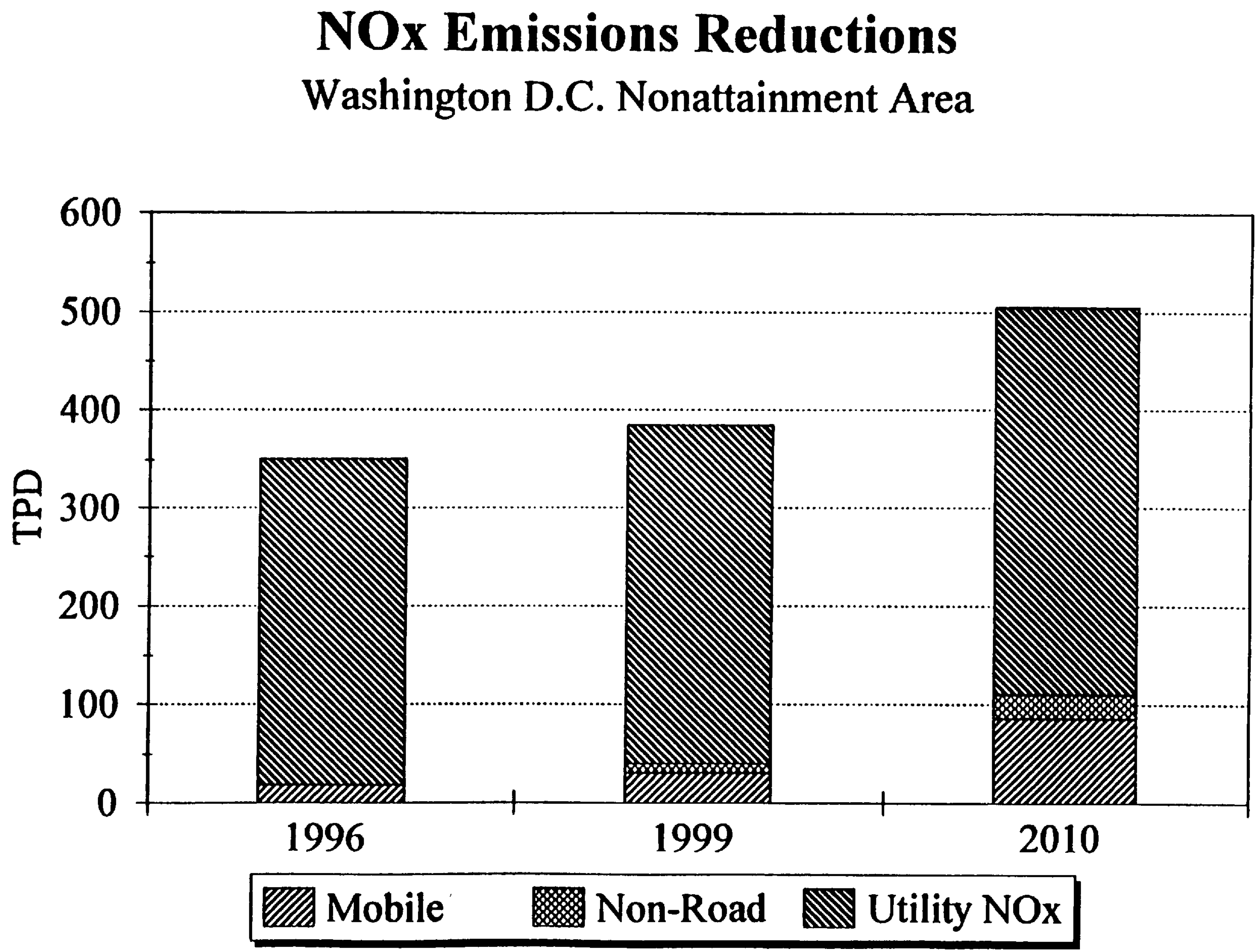

Figure 5-6. NOx Emissions Reductions in Washington D.C.

- For those cities with relatively high emissions from their vehicle fleet, RFP targets for 1996 may be met without resorting to extremely high cost-effectiveness controls. For those cities with large point source and non-road inventories, 1996 target attainment may require more stringent and expensive measures.

- By and large the mandated mobile source controls, Stage II, RFG, and enhanced I/M provided the greatest boost toward meeting the 1996 RFP targets. Other mobile source controls, such as Clean Fleets and LEVs, cannot generate significant reductions until after 1996.

- Without a downturn in economic growth, and barring major technological breakthroughs, most cities will not be able to meet their RFP targets for 1999 and thereafter only controlling VOCs. It is likely that some form of NO_x-for-VOC substitution will be needed to facilitate the process.

- As of this time, non-road mobile sources are one of the last major uncontrolled sources of VOC emissions. Therefore these sources must be addressed in the future in order to attain and maintain target emission levels.

- With the probable establishment of NO_x emission reduction targets in the near future, it is crucial to assess the feasibility of applying controls beyond the utility and on-road mobile categories. While Radian did find studies in the literature on controls for process heaters, IC engines, and other unregulated NO_x sources, Radian found little to no assessment of the potential application rates of these new controls. A comprehensive technological assessment of retrofit potentials should be undertaken in this regard.

GLOSSARY

ACG –	Automotive Consulting Group
ACT –	Alternative Control Techniques document
A/F –	Air/Fuel (Adjustment)
ATP –	Anti-Tampering Program
BAAQMD –	Bay Area Air Quality Management District (California)
BACT –	Best Available Control Technology
BID –	Background Information Document
BOOS –	Burners Out Of Service
CAAA –	Clean Air Act Amendments
CARB –	California Air Resources Board
CI –	Compression Ignition (diesel)
CMAQ –	Congestion Management/Air Quality (Federal Funds)
CO –	Carbon Monoxide
CTG –	Control Techniques Guideline
CVC –	Corporate Variable Costs
EGR –	Exhaust Gas Recirculation
EHC –	Electrically Heated Catalyst
FCC –	Fluid Catalytic Cracking units
FGR –	Flue Gas Recirculation
FGT –	Flue Gas Treatment
GPM –	Grams Per Mile
HAP –	Hazardous Air Pollutant
HC –	Hydrocarbon
HDGV –	Heavy-Duty Gas Vehicle
HON –	Hazardous Organic NESHAP
HOV –	High Occupancy Vehicle
HVLP –	High Volume/Low Pressure
IC –	Internal Combustion

I/M --	Inspection/Maintenance
ISTEA --	Intermodal Surface Transportation Efficiency Act (Federal funds)
IT --	Engine Timing (Retard)
LAER --	Lowest Achievable Emission Rate
LDT --	Light-Duty Truck
LDV --	Light-Duty Vehicle (car)
LEA --	Low Excess Air
LEV --	Low Emission Vehicle
LMOCP --	Lake Michigan Ozone Control Program
LNB --	Low NO_x Burner
MACT --	Maximum Achievable Control Technology
MMBtu --	Million British Thermal Units
MTBE --	Methyl-Tertiary Butyl Ether (oxygenate)
NAAQS --	National Ambient Air Quality Standards
NESHAP --	National Emission Standards for Hazardous Air Pollutants
NGR --	Natural Gas Reburn (Cofiring)
NGV --	Natural Gas Vehicle
NO_x --	Nitrogen Oxides
NPV --	Net Present Value
NSCR --	Non-Selective Catalytic Reductions
NSPS --	New Source Performance Standards
NSR --	New Source Review
OAQPS --	Office of Air Quality Planning and Standards (EPA)
OFA --	Overfire Air
OTVD --	Open Top Vapor Degreaser
PC --	Pulverized Coal
PM --	Particulate Matter
POTW --	Publicly Owned Treatment Works (wastewater)
PPM --	Parts Per Million
PTE --	Permanent Total Enclosure

P/V –	Pressure/Vacuum (relief valve)
RACT –	Reasonable Available Control Technology
RE –	Rule Effectiveness
RFG –	Reformulated Gasoline
RFP –	Reasonable Further Progress
ROG –	Reactive Organic Gases
ROP –	Rate Of Progress
RP –	Rule Penetration
RVP –	Reid Vapor Pressure (gasoline)
SANDAG –	San Diego Association of Governments
SCA –	Stage Combustion Air
SCAAQMD –	South Coast Air Quality Management District (California)
SCR –	Selective Catalytic Reduction
SI –	Spark Ignition (gasoline engine)
SNCR –	Selective Non-Catalytic Reduction
SOCMI –	Synthetic Organic Chemical Manufacture Industry
STAPPA –	State and Territorial Air Pollution Program Administrators
TCM –	Transportation Control Measure
TDM –	Transportation Demand Management
TLEV –	Transitional Low Emission Vehicle
TPD –	Tons Per Day
TPY –	Tons Per Year
TSM –	Transportation Systems Management
UAM –	Urban Airshed Model
ULEV –	Ultra Low Emission Vehicle
VMT –	Vehicle Miles Travelled
VOC –	Volatile Organic Compound
VOL –	Volatile Organic Liquid
VOM –	Volatile Organic Material
MWAQC –	Metropolitan Washington Air Quality Committee

WWTF -- Waste Water Treatment Facility

ZEV -- Zero Emission Vehicle

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Appendices

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APPENDIX A

1990 Emission Inventories

Baltimore

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above 2.60	Percent	Point	Area	Mobile	Total above 5.85	Percent
Oil & Gas Production										
Non Metallic Mining										
Natural Gas & Gasoline Processing										
Other Petroleum Processing										
Gasoline & Crude Oil Storage:										
Floating Roof Tanks										
All Other Tanks										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Volatile Organic Liquid Storage	0.58									
Volatile Organic Liquid Transfer:										
Ship & Barge		0.04								
Tanker Ballasting										
Total	0.02	0.04	0.00			0.00	0.00	0.00		
Barge and Tanker Cleaning										
Bulk Gasoline Terminals	5.46			5.46						
Bulk Gasoline Plants	0.13									
Service Station Loading (Stage I)		0.80								
Vehicle Refueling (Stage II)		13.20		13.20						
Gasoline Tank Truck Leaks		0.17								
Underground Storage Tank Breathing		1.05								
Aircraft Refueling		0.41								
Pipelines										
Petroleum Refineries:										
Vacuum Systems										
Fugitive Leaks										
Wastewater Collection-Process										
Wastewater Collection-Fugitive										
Subtotal	0.00	0.00	0.00			0.00	0.00	0.00		
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Lube Oil Manufacture										
Organic Chemical Manufacture:										
Polyethylene										
Propylene										
Styrene										
Others										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Chemical Manufacturing:										
Adipic Acid										
Nitric Acid										
Other Acid										
Other										
Total	0.00	0.00	0.00			0.00	0.00	0.00		

	Baltimore VOC (t/day) Point	VOC Area	VOC Mobile	VOC Total above 2.60	VOC Percent	NOx (t/day) Point	NOx Area	NOx Mobile	NOx Total above 5.85	NOx Percent
SOCMI:										
Fugitive Leaks										
Air Oxidation										
Others										
Total	0.00	0.00	0 00			0.00	0.00	0.00		
Inorganic Chemical Manufacture	0.38					2.24				
Fermentation Processes	1 22									
Vegetable Oil Processing										
Pharmaceutical Manufacture										
Plastic Products Manufacture	1 12					0.13				
Rubber Tire Manufacture										
SBR Rubber manufacture	0.49									
Textile, Polymers and Resins Manufacture										
Synthetic Fiber manufacture										
Iron and Steel Manufacture	1.98					28.61			28.61	
Fugitive										
Coke Ovens										
Fugitive										
Mineral Products:										
Cement						2.88				
Glass										
Other						0.40				
Total	0.00	0.00	0 00			3.28	0.00	0.00		
Lumber and Wood Products	0.07	0.30								
Printing and Publishing	5.66			5 66						
Non-Ferrous Metals										
Other Industrial Processes										
Heavy Construction (Ex Building)	0.04									
Large Appliances										
Magnet Wire										
Autos and Light trucks	4.01	1.78		5.79		0.25				
Industrial Machinery & Equipment										
Electronic & Electric Equipment										
Transportation Equipment										
Instruments & Related Products										
Construction and Mining Equipment	0.08									
Railroad Equipment	0.06									
Tire Retreading and Repair Shops	0.07									
Cans	2.88	3.69		6.57						
Metal Coils	1.46									
Paper	1.87					0.23				

Baltimore

	VOC (t/day) Point	Area	Mobile	Total above 2.60	Percent	NOx (t/day) Point	Area	Mobile	Total above 5.85	Percent
Fabric										
Metal and Wood Furniture										
Metal Furniture										
Wood Furniture	0 04									
Total	0.04	3.44	0.00	3.48		0.00	0.00	0.00		
Miscellaneous Wood Products										
Miscellaneous Metal Products	0.09	0.70								
Metal Coatings										
Flatwood Products										
Plastic Products										
Storage/Warehousing										
Large Ships	0 07									
Large Aircraft										
Others	1.15									
Architectural Coatings	0.61	19.23		19.84						
Auto Refinishing		10.39		10.39						
Others:										
Traffic/Maintenance Painting		0.61								
Degreasing:										
Carwashes	0.21									
Screw Machine Products	0.11									
Cold Cleaners		10.43								
Vapor/Conveyorized										
Total	0 31	10.43	0.00	10.74		0.00	0.00	0.00		
Dry Cleaning:										
Perchloroethylene	0.09									
Petroleum	0.31									
Total	0.40	5.29	0.00	5.69		0.00	0.00	0.00		
Graphic Arts		4.48		4.48						
Adhesives	0.89									
Emulsified Asphalt Paving	0.37	0.02				0.94				
Consumer and Commercial Solvents										
Personal Care Products	1.53					0.59				
Household Products										
Auto Aftermarket Products										
Adhesive Products										
Subtotal	1 53	0.00	0.00			0.59	0.00	0.00		
Pesticide products	4.11					0.68				
Miscellaneous Consumer Products	0.64									
Total	6.29	20.26	0.00	26.55		1.28	0.00	0.00		
Others										

Baltimore

	VOC (t/day) Point	Area	Mobile	Total above 2.60	Percent	NOx (t/day) Point	Area	Mobile	Total above 5.85	Percent
Municipal Waste:										
Incineration:										
Residential										
Commercial/Institutional										
Governmental										
Industrial										
Subtotal	0.00	0 04	0 00			0 00	0.26	0.00		
Landfills		2.51								
Municipal Waste Total	0.15	2.55	0 00	2.70		5.57	0.26	0.00		
Hazardous Wastes TSDFs										
POTWs		2.52								
Industrial WWTFs	0.42					0.21				
Pretreatment										
Subtotal	0.42	0.00	0.00			0.21	0.00	0.00		
Industrial Boiler Co-firing										
Others										
Fuel Combustion (external).										
Utilities	0.62					144.62			144.62	
Industrial										
Distillate Oils										
Residual Oil										
Natural Gas										
Subtotal	0.00	0 00	0.00			0.00	0.00	0.00		
Commercial/Institutional	0.20					2.29				
Distillate Oil										
Residual Oil										
Natural Gas										
Subtotal	0.20	0.00	0 00			2.29	0.00	0.00		
Residential										
Distillate Oil										
Natural Gas										
Subtotal	0.00	0.00	0.00			0.00	0.00	0.00		
Total	0.20	0.00	0.00			2.29	0.00	0.00		
Coal										
Total Natural Gas										
Open Burning:										
Structural Fires		0.05								
Forest/Agricultural		0.48								
Other										
Total	0.00	0.53	0.00			0.00	0.00	0.00		
[illegible]		[illegible]		[illegible]						

	Baltimore									
	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above 2.60	Percent	Point	Area	Mobile	Total above 5.85	Percent
Stationary Internal Combustion Engines:										
By Utilities	0.13					6.79				
By Others										
Total	0.13	0.00	0 00			6.79	0.00	0.00	6.79	
Miscellaneous Food Products						1.10				
Bakeries	0.72									
Cocoa Products										
Biogenic Sources										
Health Services										
Educational Services										
Engineering and Management Services										
Public Administration										
On-highway Vehicles:										
Light-duty Gasoline Cars (LDGV)										
Light-duty Gasoline Trucks (LDGT1&2)										
Heavy-duty Gasoline Trucks (HDGV)										
Heavy-duty Diesel Trucks (HDDV)										
Other Highway Vehicles:										
Motorcycles (MC)										
Light-duty Diesel Cars (LDDV)										
Light-duty Diesel Trucks (LDDT)										
Subtotal	0 00	0 00	0 00			0.00	0.00	0.00		
Inspection & Maintenance Credits										
TCMs Credits										
Total	0.00	0 00	132 00	132.00		0.00	0.00	161.00	161.00	
Non-highway Vehicles:										
Rail		0.49					10.85			
Aircraft										
Military		2.01					0.98			
Commercial		0.49					1.44			
Civil		0.22					0.02			
Subtotal	0.00	2.72	0 00			0.00	2.44	0.00		
Vessels:										
Commercial Vessels										
Distillate										
Residual										
Subtotal	0.00	0.41	0.00			0.00	2.78	0.00		
Pleasure Craft										
Inboard Diesel										
Inboard Gasoline										
Outboard Gasoline										

Baltimore

	VOC (t/day) Point	Area	Mobile	Total above 2.60	Percent	NOx (t/day) Point	Area	Mobile	Total above 5.85	Percent
Subtotal	0.00	7.72	0.00			0.00	0.92	0.00		
Vessels Subtotal	0.00	8.13	0.00			0.00	3.70	0.00		
Others:										
Recreational		0.84								
Agricultural										
Gasoline										
Diesel										
Subtotal	0 00	1 72	0.00			0.00	7.80	0.00		
Lawn & Garden		17.24					0.30			
Industrial Equipment		7.11					12.41			
Gasoline										
Diesel										
Subtotal	0.00	7.11	0.00			0.00	12.41	0.00		
Heavy Construction Equipment										
Gasoline										
Diesel										
Subtotal	0.00	3 74	0.00			0.00	28.83	0.00		
Others Subtotal		1.18					5.39			
Total Non-highway	0.00	42 33	0.00	42.33		0.00	71.72	0.00	71.72	
				301.28	0.93				412.74	0.95
Grand Total	40.01	150.63	132.00	322.64	0.93	200.82	71.98	161.00	433.80	

Chicago

	VOC (t/day) Point	Area	Mobile	Total above 4.60	Percent	NOx (t/day) Point	Area	Mobile	Total above 7.50	Percent
Oil & Gas Production										
Non Metallic Mining										
Natural Gas & Gasoline Processing										
Other Petroleum Processing										
Gasoline & Crude Oil Storage:										
Floating Roof Tanks	2.95									
All Other Tanks	5.16									
Total	8.11	0 00	0.00	8 11		0.00	0.00	0.00		
Volatile Organic Liquid Storage	6.41			6.41						
Volatile Organic Liquid Transfer:										
Ship & Barge	1.69	1.07								
Tanker Ballasting										
Total	1.69	1.07	0.00			0.00	0.00	0.00		
Barge and Tanker Cleaning		0.28								
Bulk Gasoline Terminals	5.08			5.08						
Bulk Gasoline Plants	0.17									
Service Station Loading (Stage I)		13.16		13.16						
Vehicle Refueling (Stage II)		34.87		34.87						
Gasoline Tank Truck Leaks		1.04								
Underground Storage Tank Breathing		5.13		5.13						
Aircraft Refueling		0.55								
Pipelines										
Petroleum Refineries:										
Vacuum Systems	4.85									
Fugitive Leaks	9.34									
Wastewater Collection-Process	0.42									
Wastewater Collection-Fugitive	4.69									
Subtotal	5.11	0 00	0.00			0.00	0 00	0.00		
Total	19.30	0.00	0.00	19.30		10.91	0.00	0.00	10.91	
Lube Oil Manufacture	0.12									
Organic Chemical Manufacture:										
Polyethylene	0.14									
Propylene										
Styrene	1.41									
Others	32.08									
Total	33.63	0.00	0.00	33.63		0.00	0.00	0.00		
Chemical Manufacturing:										
Adipic Acid										
Nitric Acid						0.44				
Other Acid										
Other						6.71				
Total	0.00	0.00	0 00			7.15	0.00	0.00		

Chicago

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above 4.60	Percent	Point	Area	Mobile	Total above 7.50	Percent
SOCMI:										
Fugitive Leaks	6.64									
Air Oxidation	4.54									
Others	13.35									
Total	24.53	0.00	0.00	24.53		0.00	0.00	0.00		
Inorganic Chemical Manufacture	0.23									
Fermentation Processes	0.06									
Vegetable Oil Processing	0.40									
Pharmaceutical Manufacture	4.47									
Plastic Products Manufacture	9.44			9.44						
Rubber Tire Manufacture	0.08									
SBR Rubber manufacture	0.83									
Textile, Polymers and Resins Manufacture	5.95			5.95						
Synthetic Fiber manufacture										
Iron and Steel Manufacture	2.28					7.53			7.53	
Fugitive	0.34									
Coke Ovens	12 60			12.60		1.79				
Fugitive	4.67			4.67		0.12				
Mineral Products:										
Cement										
Glass						10.84				
Other						7.81				
Total	0.00	0.00	0.00			18.65	0.00	0.00	18.65	
Lumber and Wood Products										
Printing and Publishing										
Non-Ferrous Metals										
Other Industrial Processes	21.73			21.73		9.75			9.75	
Heavy Construction (Ex. Building)										
Large Appliances	1.08									
Magnet Wire	1.44									
Autos and Light trucks	11.77			11.77						
Industrial Machinery & Equipment										
Electronic & Electric Equipment										
Transportation Equipment										
Instruments & Related Products										
Construction and Mining Equipment										
Railroad Equipment										
Tire Retreading and Repair Shops										
Cans	8.69			8.69						
Metal Coils	4.26									
[illegible]	22.50			22.50						

Chicago

	VOC (t/day) Point	Area	Mobile	Total above 4.60	Percent	NOx (t/day) Point	Area	Mobile	Total above 7.50	Percent
Fabric	2.99									
Metal and Wood Furniture										
Metal Furniture	6.84									
Wood Furniture	1.80									
Total	8.64	0.00	0.00	8.64		0.00	0.00	0.00		
Miscellaneous Wood Products										
Miscellaneous Metal Products	34.29			34.29						
Metal Coatings										
Flatwood Products	0.31									
Plastic Products	1.38									
Storage/Warehousing										
Large Ships										
Large Aircraft										
Others	6.98			6.98						
Architectural Coatings		51.25		51.25						
Auto Refinishing		22.25		22.25						
Others:										
Traffic/Maintenance Painting		5.87		5.87						
Degreasing:										
Carwashes										
Screw Machine Products										
Cold Cleaners	0.41	32.05								
Vapor/Conveyorized	4.63									
Total	5.04	32.05	0.00	37.09		0.00	0.00	0.00		
Dry Cleaning:										
Perchloroethylene										
Petroleum	1.22									
Total	1.22	0.00	0.00			0.00	0.00	0.00		
Graphic Arts	36.53	8.19		44.72						
Adhesives	3.38									
Emulsified Asphalt Paving		12.93		12.93						
Consumer and Commercial Solvents										
Personal Care Products		14.01								
Household Products		22.01								
Auto Aftermarket Products		5.99								
Adhesive Products		3.01								
Subtotal	0.00	45.02	0.00			0.00	0.00	0.00		
Pesticide products		1.00								
Miscellaneous Consumer Products		17.03								
Total	0.00	63.05	0.00	63.05		0.00	0.00	0.00		
Others										

Chicago

	VOC (t/day) Point	Area	Mobile	Total above 4.60	Percent	NOx (t/day) Point	Area	Mobile	Total above 7.50	Percent
Municipal Waste:										
Incineration:										
Residential		0.82					1.22			
Commercial/Institutional	0.09	1.63				2.40	0.54			
Governmental	1.20					0.60				
Industrial	0.33					0.56				
Subtotal	1.62	2 45	0.00			3.56	1 76	0.00		
Landfills	4.59									
Municipal Waste Total	6.21	2.45	0.00	8.66		3 56	1.76	0.00		
Hazardous Wastes TSDFs	2.46									
POTWs	9.95			9.95						
Industrial WWTFs	4.71			4.71						
Pretreatment		0.94								
Subtotal	4.71	0.94	0 00	5.65		0.00	0.00	0.00		
Industrial Boiler Co-firing										
Others										
Fuel Combustion (external):										
Utilities	0.72					131.37			131.37	
Industrial	3.38					68.45				
Distillate Oils		0 01					1.43			
Residual Oil							0.92			
Natural Gas		0.01								
Subtotal	3.38	0 02	0 00			68 45	2 35	0.00		
Commercial/Institutional	0.39					3.43				
Distillate Oil		0.03					2.04			
Residual Oil		0 01					0.63			
Natural Gas		0.06					3 06			
Subtotal	0 39	0 10	0 00			3 43	5 73	0.00		
Residential										
Distillate Oil		0.09					2.44			
Natural Gas		0 57					11.12			
Subtotal	0.00	0.66	0.00			0.00	13.56	0.00		
Total	3.77	0.78	0.00			71.88	21.64	0.00	93.52	
Coal										
Total Natural Gas										
Open Burning:										
Structural Fires		1.51					0.20			
Forest/Agricultural		0.13					0.02			
Other		1.10					0.21			
Total	0.00	2.74	0 00			0.00	0.43	0.00		
Pesticide Applications		9.41		[illegible]						

Chicago

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above 4.60	Percent	Point	Area	Mobile	Total above 7.50	Percent
Stationary Internal Combustion Engines:										
By Utilities	0.67					2 48				
By Others	3.22					25.98				
Total	3.89	0.00	0.00			28 46	0.00	0.00	28.46	
Miscellaneous Food Products										
Bakeries	3.22									
Cocoa Products										
Biogenic Sources										
Health Services										
Educational Services										
Engineering and Management Services										
Public Administration										
On-highway Vehicles:										
Light-duty Gasoline Cars (LDGV)			399.89					229.53		
Light-duty Gasoline Trucks (LDGT1&2)			70.54					37.33		
Heavy-duty Gasoline Trucks (HDGV)			16.73					9.28	9.28	
Heavy-duty Diesel Trucks (HDDV)			24.56					262.58		
Other Highway Vehicles:										
Motorcycles (MC)			9.98					1.49		
Light-duty Diesel Cars (LDDV)			0 61					1.98		
Light-duty Diesel Trucks (LDDT)			1.40					0.76		
Subtotal	0.00	0.00	11.99			0.00	0.00	4.23		
Inspection & Maintenance Credits			-32.49					-2.69		
TCMs Credits			0.00							
Total	0.00	0.00	491 22	491.22		0 00	0.00	540.26	540.26	
Non-highway Vehicles:										
Rail			5 83					23.41		
Aircraft										
Military			0.83					0.25		
Commercial			6.98					14.06		
Civil			0.39					0.06		
Subtotal	0.00	0.00	8.20			0.00	0.00	14.37		
Vessels:										
Commercial Vessels										
Distillate			0.39					2.04		
Residual										
Subtotal	0.00	0.00	0.39			0.00	0.00	2.04		
Pleasure Craft										
Inboard Diesel			0.05					0.38		
Inboard Gasoline								0.86		
Outboard Gasoline			23.62							

Chicago

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above 4.60	Percent	Point	Area	Mobile	Total above 7.50	Percent
Subtotal	0.00	0.00	23.67			0.00	0.00	1.24		
Vessels Subtotal	0.00	0.00	24.06			0.00	0.00	3.28		
Others:										
Recreational			3 19							
Agricultural										
Gasoline			0 26							
Diesel			2 26					11.66		
Subtotal	0.00	0.00	2 52			0.00	0.00	11.66		
Lawn & Garden			61 99					1.01		
Industrial Equipment										
Gasoline			21.76					6.93		
Diesel			1 42					12.30		
Subtotal	0.00	0 00	23 18			0.00	0.00	19.23		
Heavy Construction Equipment										
Gasoline			2 73					0.23		
Diesel			9 97					80.44		
Subtotal	0.00	0.00	12 70			0.00	0.00	80.67		
Others Subtotal										
Total Non-highway	0.00	0.00	138.48	138.48		0.00	0.00	153.63	153.63	
				1202.72	0.97				1003.36	0.98
Grand Total	347.55	268 01	623 70	1245.26		309.82	23.83	693 89	1027.54	

Houston

	VOC (t/day) Point	Area	Mobile	Total above 10.00	Percent	NOx (t/day) Point	Area	Mobile	Total above 20.00	Percent
SOCMI:										
Fugitive Leaks										
Air Oxidation										
Others										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Inorganic Chemical Manufacture	1.42					11.93				
Fermentation Processes	0.16					0.18				
Vegetable Oil Processing										
Pharmaceutical Manufacture										
Plastic Products Manufacture	19.19			19.19		7.33				
Rubber Tire Manufacture										
SBR Rubber manufacture										
Textile, Polymers and Resins Manufacture										
Synthetic Fiber manufacture										
Iron and Steel Manufacture										
Fugitive										
Coke Ovens										
Fugitive										
Mineral Products:										
Cement										
Glass										
Other										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Lumber and Wood Products										
Printing and Publishing	0.16					0.01				
Non-Ferrous Metals										
Other Industrial Processes										
Heavy Construction (Ex. Building)	0.25									
Large Appliances										
Magnet Wire										
Autos and Light trucks										
Industrial Machinery & Equipment										
Electronic & Electric Equipment										
Transportation Equipment										
Instruments & Related Products										
Construction and Mining Equipment										
Railroad Equipment										
Tire Retreading and Repair Shops										
Cans										
Metal Coils		5.58								
Paper	11.87			11.87		7.11				

Houston

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above 10.00	Percent	Point	Area	Mobile	Total above 20.00	Percent
Fabric										
Metal and Wood Furniture										
Metal Furniture										
Wood Furniture										
Total	0 00	0.00	0.00			0.00	0.00	0.00		
Miscellaneous Wood Products	0.06					0.32				
Miscellaneous Metal Products										
Metal Coatings										
Flatwood Products	5.15					0.12				
Plastic Products										
Storage/Warehousing	14.51			14 51		0.87				
Large Ships	2.94					0.01				
Large Aircraft										
Others										
Architectural Coatings		31.20		31.20						
Auto Refinishing		16.50		16.50						
Others:										
Traffic/Maintenance Painting		2.56								
Degreasing:										
Carwashes										
Screw Machine Products										
Cold Cleaners										
Vapor/Conveyorized										
Total	0.00	16.43	0.00	16 43		0.00	0.00	0.00		
Dry Cleaning:										
Perchloroethylene										
Petroleum										
Total	0.00	3.39	0.00			0.00	0.00	0.00		
Graphic Arts		8.73								
Adhesives										
Emulsified Asphalt Paving		0.82								
Consumer and Commercial Solvents										
Personal Care Products	0.01					0.16				
Household Products										
Auto Aftermarket Products										
Adhesive Products										
Subtotal	0.01	32.20	0.00			0.16	0.00	0.00		
Pesticide products										
Miscellaneous Consumer Products										
Total	0.01	32.20	0.00	32.21		0.16	0.00	0.00		

Houston

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above 10.00	Percent	Point	Area	Mobile	Total above 20.00	Percent
Municipal Waste:										
Incineration:										
Residential										
Commercial/Institutional										
Governmental										
Industrial										
Subtotal	0.00	0.04	0.00			0.00	0.00	0.00		
Landfills		0 49								
Municipal Waste Total	0.00	0.53	0.00			0.00	0.00	0 00		
Hazardous Wastes TSDFs										
POTWs										
Industrial WWTFs		26.33		26.33						
Pretreatment										
Subtotal	0.00	26.33	0.00	26.33		0.00	0.00	0.00		
Industrial Boiler Co-firing										
Others										
Fuel Combustion (external):										
Utilities	2.74					281.72			281.72	
Industrial										
Distillate Oils							4.59			
Residual Oil							0.62			
Natural Gas										
Subtotal	0.00	0.00	0 00			0.00	5.21	0.00		
Commercial/Institutional										
Distillate Oil		0 01					0.67			
Residual Oil							0.04			
Natural Gas										
Subtotal	0.00	0.01	0.00			0.00	0.71	0.00		
Residential										
Distillate Oil										
Natural Gas										
Subtotal	0.00	0.00	0.00			0.00	0.00	0.00		
Total	0.00	0 01	0.00			0.00	5.92	0.00		
Coal										
Total Natural Gas		0.35					5.85			
Open Burning:										
Structural Fires		2.29					0.30			
Forest/Agricultural		0.22					0.04			
Other		0.68								
Total	0.00	3.19	0.00			0.00	0.34	0.00		
Pesticide Applications		3.44								

Houston

	VOC (t/day) Point	Area	Mobile	Total above 10.00	Percent	NOx (t/day) Point	Area	Mobile	Total above 20.00	Percent
Stationary Internal Combustion Engines:										
By Utilities										
By Others										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Miscellaneous Food Products	0.06									
Bakeries	0.58	0 62				0.04				
Cocoa Products										
Biogenic Sources										
Health Services										
Educational Services										
Engineering and Management Services										
Public Administration										
On-highway Vehicles:										
Light-duty Gasoline Cars (LDGV)										
Light-duty Gasoline Trucks (LDGT1&2)										
Heavy-duty Gasoline Trucks (HDGV)										
Heavy-duty Diesel Trucks (HDDV)										
Other Highway Vehicles:										
Motorcycles (MC)										
Light-duty Diesel Cars (LDDV)										
Light-duty Diesel Trucks (LDDT)										
Subtotal	0 00	0 00	0.00			0.00	0 00	0.00		
Inspection & Maintenance Credits										
TCMs Credits										
Total	0.00	0 00	235.70	235 70		0.00	0 00	315.57	315 57	
Non-highway Vehicles										
Rail			0.50					17 64		
Aircraft										
Military			6.88					0.44		
Commercial			0.71					5.97		
Civil			1.50							
Subtotal	0.00	0.00	9.09			0.00	0.00	6.41		
Vessels:										
Commercial Vessels										
Distillate										
Residual										
Subtotal	0.00	0.00	10.22			0.00	0.00	79.95		
Pleasure Craft										
Inboard Diesel										
Inboard Gasoline										
Outboard Gasoline										

Houston

	VOC (t/day) Point	Area	Mobile	Total above 10.00	Percent	NOx (t/day) Point	Area	Mobile	Total above 20.00	Percent
Subtotal	0.00	0.00	68.21			0.00	0.00	2.71		
Vessels Subtotal	0.00	0.00	78.43			0.00	0.00	82.66		
Others:										
Recreational			6.52					0.00		
Agricultural										
Gasoline										
Diesel										
Subtotal	0 00	0.00	2.60			0.00	0.00	18.97		
Lawn & Garden			58 02							
Industrial Equipment										
Gasoline										
Diesel										
Subtotal	0.00	0.00	23.40			0.00	0.00	0.00		
Heavy Construction Equipment										
Gasoline										
Diesel										
Subtotal	0 00	0.00	16.48			0.00	0.00	98.34		
Others Subtotal			40.44					105.69		
Total Non-highway	0.00	0.00	228.96	228.96		0.00	0.00	312.07	312 07	

Philadelphia

	VOC (t/day) Point	VOC Area	VOC Mobile	VOC Total above	VOC Percent	NOx (t/day) Point	NOx Area	NOx Mobile	NOx Total above	NOx Percent
		0.34	0.38	10.00					7.00	
Oil & Gas Production										
Non Metallic Mining										
Natural Gas & Gasoline Processing										
Other Petroleum Processing	0.15			0.15		0.02				
Gasoline & Crude Oil Storage:										
Floating Roof Tanks										
All Other Tanks										
Total	0.00	0.00	0 00			0 00	0.00	0.00		
Volatile Organic Liquid Storage										
Volatile Organic Liquid Transfer:										
Ship & Barge										
Tanker Ballasting										
Total	0.00	0.00	0 00			0.00	0.00	0.00		
Barge and Tanker Cleaning										
Bulk Gasoline Terminals	3.44			3.44						
Bulk Gasoline Plants										
Service Station Loading (Stage I)		16.55		16.55						
Vehicle Refueling (Stage II)		25.33		25.33						
Gasoline Tank Truck Leaks		0.24		0.24						
Underground Storage Tank Breathing		2 17		2 17						
Aircraft Refueling										
Pipelines	0.09			0.09						
Petroleum Refineries:										
Vacuum Systems										
Fugitive Leaks										
Wastewater Collection-Process										
Wastewater Collection-Fugitive										
Subtotal	0.00	0.00	0.00			0.00	0.00	0.00		
Total	37 60	0.00	0 00	37.60		33.10	0.00	0 00	33 10	
Lube Oil Manufacture										
Organic Chemical Manufacture:										
Polyethylene										
Propylene										
Styrene										
Others	7.70									
Total	7.70	0.00	0.00	7.70		0.00	0.00	0.00		
Chemical Manufacturing:										
Adipic Acid										
Nitric Acid										
Other Acid										
Other	0.66					1.26				
Total	0.66	0.00	0 00	0.66		1.26	0.00	0.00		

	Philadelphia									
	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above	Percent	Point	Area	Mobile	Total above	Percent
		0 34	0.38	10.00					7.00	
SOCMI:										
Fugitive Leaks										
Air Oxidation										
Others										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Inorganic Chemical Manufacture	0.03			0.03		0.68				
Fermentation Processes										
Vegetable Oil Processing										
Pharmaceutical Manufacture	0.33			0.33		0 89				
Plastic Products Manufacture	1.76			1.76		0.30				
Rubber Tire Manufacture										
SBR Rubber manufacture										
Textile, Polymers and Resins Manufacture	0.08			0.08						
Synthetic Fiber manufacture										
Iron and Steel Manufacture	1.54			1.54		6.98				
Fugitive										
Coke Ovens										
Fugitive										
Mineral Products:										
Cement										
Glass	0.07					0.51				
Other	0 09					0.74				
Total	0.15	0.00	0.00	0.15		1.25	0.00	0.00		
Lumber and Wood Products										
Printing and Publishing	5 47			5.47		0.04				
Non-Ferrous Metals	0.05			0.05		0.06				
Other Industrial Processes	0.83			0.83		0.02				
Heavy Construction (Ex. Building)										
Large Appliances		0.24		0.24						
Magnet Wire										
Autos and Light trucks	0.10	7.41		7.51						
Industrial Machinery & Equipment	0.57	3.25		3.82		0.01				
Electronic & Electric Equipment	0.77	0.63		1.41		0.09				
Transportation Equipment	0.90			0.90		0.20				
Instruments & Related Products	0.48			0.48		0.04				
Construction and Mining Equipment										
Railroad Equipment										
Tire Retreading and Repair Shops										
Cans	0.06	7.09		7.15						
Metal Coils										
Paper	8.06			8.06		2.35				

	Philadelphia									
	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above	Percent	Point	Area	Mobile	Total above	Percent
		0.34	0.38	10.00					7.00	
Fabric										
Metal and Wood Furniture										
Metal Furniture	0.16	0.94								
Wood Furniture	0.36	0.16				0.01				
Total	0.53	1.10	0.00	1.62		0.01	0 00	0.00		
Miscellaneous Wood Products										
Miscellaneous Metal Products	0.58	2.19		2.77		0 02				
Metal Coatings	4.41			4.41						
Flatwood Products		1.04		1.04						
Plastic Products	0.75			0.75						
Storage/Warehousing										
Large Ships		0.66		0 66						
Large Aircraft		1.10		1.10						
Others	5.49	11 59		17 08		0 13				
Architectural Coatings		25.29		25 29						
Auto Refinishing		14.57		14 57						
Others:										
Traffic/Maintenance Painting		2.75		2 75						
Degreasing:										
Carwashes										
Screw Machine Products										
Cold Cleaners										
Vapor/Conveyorized										
Total	0 00	16.21	0.00	16.21		0.00	0.00	0.00		
Dry Cleaning:										
Perchloroethylene										
Petroleum										
Total	0 00	3.30	0.00	3 30		0.00	0.00	0.00		
Graphic Arts		7.15		7 15						
Adhesives										
Emulsified Asphalt Paving										
Consumer and Commercial Solvents										
Personal Care Products										
Household Products										
Auto Aftermarket Products										
Adhesive Products										
Subtotal	0 00	0.00	0.00			0.00	0.00	0.00		
Pesticide products										
Miscellaneous Consumer Products										
Total	0.00	43.29	0.00	43.29		0.00	0.00	0.00		

Philadelphia

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above	Percent	Point	Area	Mobile	Total above	Percent
		0 34	0.38	10.00					7.00	
Municipal Waste:										
Incineration:										
Residential										
Commercial/Institutional										
Governmental										
Industrial										
Subtotal	0.00	1.76	0.00			0.00	5.22	0.00		
Landfills										
Municipal Waste Total	0.00	1 76	0.00	1.76		0.00	5.22	0.00		
Hazardous Wastes TSDFs										
POTWs										
Industrial WWTFs										
Pretreatment										
Subtotal	0.00	0.00	0.00			0.00	0.00	0.00		
Industrial Boiler Co-firing										
Others	0.02			0.02		0.09				
Fuel Combustion (external).										
Utilities	0.21			0.21		21.03			21.03	
Industrial										
Distillate Oils										
Residual Oil										
Natural Gas										
Subtotal	0.00	0.02	0.00			0.00	3.12	0.00		
Commercial/Institutional										
Distillate Oil										
Residual Oil										
Natural Gas										
Subtotal	0.00	0.02	0.00			0.00	3.12	0.00		
Residential										
Distillate Oil										
Natural Gas										
Subtotal	0.00	0.31	0.00			0.00	65.08	0.00		
Total	0.00	0.34	0.00	0.34		0.00	71.32	0.00	71.32	
Coal										
Total Natural Gas	0.24			0.24		9.79			9.79	
Open Burning:										
Structural Fires		2.47					0.98			
Forest/Agricultural		1.88					0.93			
Other		2.33					7.85			
Total	0.00	6.69	0.00	6.69		0.00	9.76	0.00	9.76	
Pesticide Applications										

Philadelphia

	VOC (t/day) Point	VOC (t/day) Area	VOC (t/day) Mobile	VOC (t/day) Total above	VOC (t/day) Percent	NOx (t/day) Point	NOx (t/day) Area	NOx (t/day) Mobile	NOx (t/day) Total above	NOx (t/day) Percent
		0 34	0.38	10 00					7.00	
Stationary Internal Combustion Engines:										
By Utilities										
By Others										
Total	0.00	0.00	0 00			0.00	0.00	0.00		
Miscellaneous Food Products	0.72	1.92		2.64		0.19				
Bakeries	0.09			0.09		0.01				
Cocoa Products	0.06			0.06						
Biogenic Sources										
Health Services						0.42				
Educational Services						0.15				
Engineering and Management Services						0.05				
Public Administration						0.18				
On-highway Vehicles:										
Light-duty Gasoline Cars (LDGV)										
Light-duty Gasoline Trucks (LDGT1&2)										
Heavy-duty Gasoline Trucks (HDGV)										
Heavy-duty Diesel Trucks (HDDV)										
Other Highway Vehicles:										
Motorcycles (MC)										
Light-duty Diesel Cars (LDDV)										
Light-duty Diesel Trucks (LDDT)										
Subtotal	0 00	0.00	0.00			0.00	0 00	0.00		
Inspection & Maintenance Credits										
TCMs Credits										
Total	0.00	0.00	0.00			0 00	0.00	157.68	157.68	
Non-highway Vehicles:										
Rail			0 47					15.57		
Aircraft										
Military										
Commercial										
Civil										
Subtotal	0.00	0.00	7 89			0.00	0.00	7.98		
Vessels:										
Commercial Vessels										
Distillate										
Residual										
Subtotal	0.00	0.00	4.53			0.00	0.00	0.11		
Pleasure Craft										
Inboard Diesel										
Inboard Gasoline										
Outboard Gasoline										

Philadelphia

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above	Percent	Point	Area	Mobile	Total above	Percent
		0.34	0.38	10.00					7.00	
Subtotal	0.00	0.00	0.00			0.00	0.00	0.00		
Vessels Subtotal	0.00	0.00	4.53			0.00	0.00	15.72		
Others:										
Recreational			9.19					0.01		
Agricultural										
Gasoline										
Diesel										
Subtotal	0.00	0.00	6.04			0.00	0.00	2.11		
Lawn & Garden			35.31					0.29		
Industrial Equipment										
Gasoline										
Diesel										
Subtotal	0.00	0.00	20.28			0.00	0.00	7.78		
Heavy Construction Equipment										
Gasoline										
Diesel										
Subtotal	0.00	0.00	18.23			0.00	0.00	24.77		
Others Subtotal			0.00					0.00		
Total Non-highway	0.00	0.00	101.94	101.94		0.00	0.00	74.22	74.22	

Houston

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above 10.00	Percent	Point	Area	Mobile	Total above 20.00	Percent
Oil & Gas Production	35.37	4.79		40.16		70.10	1.62		71.72	
Non Metallic Mining	0.04					1.46				
Natural Gas & Gasoline Processing										
Other Petroleum Processing										
Gasoline & Crude Oil Storage:										
Floating Roof Tanks										
All Other Tanks		1.82								
Total	0.00	1.82	0.00			0.00	0.00	0.00		
Volatile Organic Liquid Storage										
Volatile Organic Liquid Transfer:										
Ship & Barge		18.01								
Tanker Ballasting										
Total	0.00	18 01	0.00	18.01		0.00	0.00	0.00		
Barge and Tanker Cleaning										
Bulk Gasoline Terminals	42.37			42.37						
Bulk Gasoline Plants										
Service Station Loading (Stage I)		6.77								
Vehicle Refueling (Stage II)		18.03		18.03						
Gasoline Tank Truck Leaks		0.16								
Underground Storage Tank Breathing		2.47								
Aircraft Refueling		0 03								
Pipelines	8.23					0.65				
Petroleum Refineries:										
Vacuum Systems										
Fugitive Leaks										
Wastewater Collection-Process										
Wastewater Collection-Fugitive										
Subtotal	0.00	0 00	0 00			0.00	0.00	0.00		
Total	169.02	0 00	0 00	169.02		184.88	0.00	0.00	184 88	
Lube Oil Manufacture										
Organic Chemical Manufacture:										
Polyethylene										
Propylene										
Styrene										
Others	113.86					121.26				
Total	113.86	0.00	0.00	113.86		121.26	0.00	0.00	121 26	
Chemical Manufacturing:										
Adipic Acid										
Nitric Acid										
Other Acid										
Other										
[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		

Washington D.C.

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above 8.00	Percent	Point	Area	Mobile	Total above 20.00	Percent
Oil & Gas Production										
Non Metallic Mining										
Natural Gas & Gasoline Processing										
Other Petroleum Processing										
Gasoline & Crude Oil Storage:										
Floating Roof Tanks										
All Other Tanks										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Volatile Organic Liquid Storage										
Volatile Organic Liquid Transfer:										
Ship & Barge										
Tanker Ballasting										
Total	0.00	0.03	0.00			0.00	0.00	0.00		
Barge and Tanker Cleaning										
Bulk Gasoline Terminals										
Bulk Gasoline Plants										
Service Station Loading (Stage I)		7.41								
Vehicle Refueling (Stage II)		26.81		26.81						
Gasoline Tank Truck Leaks		0.39								
Underground Storage Tank Breathing		1.17								
Aircraft Refueling		0.22								
Pipelines										
Petroleum Refineries:										
Vacuum Systems										
Fugitive Leaks										
Wastewater Collection-Process										
Wastewater Collection-Fugitive										
Subtotal	0.00	0.00	0.00			0.00	0.00	0.00		
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Lube Oil Manufacture										
Organic Chemical Manufacture:										
Polyethylene										
Propylene										
Styrene										
Others										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Chemical Manufacturing:										
Adipic Acid										
Nitric Acid										
Other Acid										
Other										
Total	0.00	0.00	0.00			0.00	0.00	0.00		

Washington D.C.

	VOC (t/day)					NOx (t/day)				
	Point	Area	Mobile	Total above 8.00	Percent	Point	Area	Mobile	Total above 20.00	Percent
SOCMI:										
Fugitive Leaks										
Air Oxidation										
Others										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Inorganic Chemical Manufacture										
Fermentation Processes										
Vegetable Oil Processing										
Pharmaceutical Manufacture										
Plastic Products Manufacture										
Rubber Tire Manufacture										
SBR Rubber manufacture										
Textile, Polymers and Resins Manufacture										
Synthetic Fiber manufacture										
Iron and Steel Manufacture										
Fugitive										
Coke Ovens										
Fugitive										
Mineral Products:										
Cement										
Glass										
Other										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Lumber and Wood Products										
Printing and Publishing										
Non-Ferrous Metals										
Other Industrial Processes										
Heavy Construction (Ex. Building)										
Large Appliances										
Magnet Wire										
Autos and Light trucks										
Industrial Machinery & Equipment										
Electronic & Electric Equipment										
Transportation Equipment										
Instruments & Related Products										
Construction and Mining Equipment										
Railroad Equipment										
Tire Retreading and Repair Shops										
Cans										
Metal Coils										
[illegible]										

Washington D.C.

	VOC (t/day) Point	Area	Mobile	Total above 8.00	Percent	NOx (t/day) Point	Area	Mobile	Total above 20.00	Percent
Fabric										
Metal and Wood Furniture										
Metal Furniture										
Wood Furniture										
Total	0.00	0.00	0.00			0.00	0.00	0.00		
Miscellaneous Wood Products										
Miscellaneous Metal Products		16.59		16.59						
Metal Coatings										
Flatwood Products										
Plastic Products										
Storage/Warehousing										
Large Ships										
Large Aircraft										
Others		3.80								
Architectural Coatings		32.14		32.14						
Auto Refinishing		16.38		16.38						
Others:										
Traffic/Maintenance Painting		3.77								
Degreasing:										
Carwashes										
Screw Machine Products										
Cold Cleaners										
Vapor/Conveyorized										
Total	0.00	16.76	0.00	16.76		0.00	0.00	0.00		
Dry Cleaning:										
Perchloroethylene										
Petroleum										
Total	0.00	9.49	0.00	9.49		0.00	0.00	0.00		
Graphic Arts		7.24								
Adhesives										
Emulsified Asphalt Paving		23.24		23.24						
Consumer and Commercial Solvents										
Personal Care Products										
Household Products										
Auto Aftermarket Products										
Adhesive Products										
Subtotal	0.00	33.86	0.00			0.00	0.00	0.00		
Pesticide products		6.58								
Miscellaneous Consumer Products		72.75								
Total	0.00	113.19	0.00	113.19		0.00	0.00	0.00		
Others										

Washington D.C.

	VOC (t/day) Point	VOC (t/day) Area	VOC (t/day) Mobile	VOC Total above 8.00	VOC Percent	NOx (t/day) Point	NOx (t/day) Area	NOx (t/day) Mobile	NOx Total above 20.00	NOx Percent
Municipal Waste:										
Incineration:										
Residential	0.02					0.42				
Commercial/Institutional	0.02					0.57				
Governmental										
Industrial	0.24					5.92				
Subtotal	0.26	0.00	0.00			6.54	0 00	0.00		
Landfills	2.95									
Municipal Waste Total	3.21	0.00	0.00			6.54	0.00	0.00		
Hazardous Wastes TSDFs										
POTWs	0 02									
Industrial WWTFs										
Pretreatment										
Subtotal	0.00	0.00	0.00			0.00	0.00	0.00		
Industrial Boiler Co-firing										
Others										
Fuel Combustion (external):										
Utilities										
Industrial										
Distillate Oils	0.01					0.89				
Residual Oil	0.01					2.45				
Natural Gas										
Subtotal	0.02	0.00	0 00			3 34	0 00	0.00		
Commercial/Institutional										
Distillate Oil	0.02					0.89				
Residual Oil	0.05					2.45				
Natural Gas										
Subtotal	0.07	0 00	0 00			3 34	0 00	0.00		
Residential										
Distillate Oil		0.03					0 80			
Natural Gas										
Subtotal	0.00	0.03	0.00			0.00	0.80	0.00		
Total	0.09	0.03	0.00			6.68	0.80	0.00		
Coal	0.23					468.16			468.16	
Total Natural Gas	0.52					15.69				
Open Burning:										
Structural Fires	0.74					0.09				
Forest/Agricultural	0.16	7.92				0.03	1.68			
Other										
Total	0.90	7.92	0.00	8.82		0.12	1.68	0.00		
Pesticide Applications										

Washington D.C.

	VOC (t/day) Point	Area	Mobile	Total above 8.00	Percent	NOx (t/day) Point	Area	Mobile	Total above 20.00	Percent
Stationary Internal Combustion Engines:										
By Utilities										
By Others										
Total	0.00	0 00	0.00			0.00	0.00	0.00		
Miscellaneous Food Products										
Bakeries	1.67									
Cocoa Products										
Biogenic Sources										
Health Services										
Educational Services										
Engineering and Management Services										
Public Administration										
On-highway Vehicles:										
Light-duty Gasoline Cars (LDGV)										
Light-duty Gasoline Trucks (LDGT1&2)										
Heavy-duty Gasoline Trucks (HDGV)										
Heavy-duty Diesel Trucks (HDDV)										
Other Highway Vehicles:										
Motorcycles (MC)										
Light-duty Diesel Cars (LDDV)										
Light-duty Diesel Trucks (LDDT)										
Subtotal	0.00	0.00	0.00			0.00	0.00	0.00		
Inspection & Maintenance Credits										
TCMs Credits										
Total	0.00	0.00	235.83	235.83		0.00	0.00	253.55	253.55	
Non-highway Vehicles:										
Rail		0.32					7.37			
Aircraft										
Military	0.10					0.01				
Commercial	2.02					5.58				
Civil	0.30					0.05				
Subtotal	2.42	0.00	0.00			5.64	0.00	0.00		
Vessels:										
Commercial Vessels										
Distillate										
Residual										
Subtotal	0.00	0.00	0.00			0.00	0.00	0.00		
Pleasure Craft										
Inboard Diesel										
Inboard Gasoline										
Outboard Gasoline										

Washington D.C.

	VOC (t/day) Point	Area	Mobile	Total above 8.00	Percent	NOx (t/day) Point	Area	Mobile	Total above 20.00	Percent
Subtotal	0.00	0.70	0.00			0.00	0.19	0.00		
Vessels Subtotal	0.00	0.70	0.00			0.00	0.19	0.00		
Others:										
Recreational		0.33					0 01			
Agricultural		2 23					5 07			
Gasoline										
Diesel										
Subtotal	0.00	2 23	0 00			0.00	5 07	0.00		
Lawn & Garden		7.06					0 67			
Industrial Equipment										
Gasoline										
Diesel										
Subtotal	0 00	1.54	0 00			0.00	4.23	0.00		
Heavy Construction Equipment										
Gasoline										
Diesel										
Subtotal	0.00	12.46	0.00			0.00	87.35	0.00		
Others Subtotal										
Total Non-highway	2.42	24.31	0 00	26 73		5.64	104.88	0.00	110.51	
				525.97	0.95				832.22	0.96
Grand Total	9 06	310.87	235 83	555.76		502.82	107.35	253.55	863.73	

APPENDIX B

Utility NO_x Cost-Effectiveness Calculations

CASH FLOW -- UTILITY NOx CONTROLS

Parameters (Based on Accurex NESCAUM Study)

Book Life	20	Catalyst Life (yrs)	4
CRF	0.119	Catalyst Cost ($/cf)	693
		NH3 Cost ($/ton)	152
Capacity Factor	.4 O&G, .65 Coal	Urea Cost ($/ton)	231
Rating (MW)	100 - 800		
Discount Rate	0.06	Electricity ($/kW-hr)	0.05
Inflation Rate	0.04	Coal ($/ton)	48.16
Nominal Interest	0.1024	Oil ($/bbl)	24.01
		Gas ($/1000cf)	2.74
Maintenance	0.02 (% cap)		
Maintenance - SCR	0.04 (% cap)	Percent Reburn	0.15
		Heat Rate (MMBtu/Mw-hr)	10.67
Real Wage Increase	0.02		
CPI 1991	1.05		

CONTROL-SPECIFIC PARAMETERS

PC-FIRED BOILERS		OIL & GAS BOILERS	
OFA / LNB + OFA:		BOOS:	
Coal (tons/MW-yr)	7	Oil (bbl/MW-yr)	12
		Gas (1000cf/MW-yr)	39
LNB:			
Coal (tons/MW-yr)	4	FGR:	
		Electricity (MW-hrs/MW-yr)	2
NGR:			
Coal (tons/MW-yr)	-207	BOOS + FGR + LNB:	
Gas (1000cf/MW-yr)	5608	Oil (bbl/MW-yr)	20
Electricity (MW-hrs/MW-yr)	-4.65	Gas (1000cf/MW-yr)	65
SNCR:		SNCR:	
Urea (tons/MW-yr)	17 (Uncontrolled Wall)	Urea (tons/MW-yr)	8 (Uncontrolled Wall)
	11 (Controlled Wall/Unc Tang)		5 (Controlled Wall/Unc Tang)
	8 (Controlled Tang)		4 (Controlled Tang)
Coal (tons/MW-yr)	1	Oil (bbl/MW-yr)	4
		Gas (1000cf/MW-yr)	13
SCR:			
Ammonia (tons/MW-yr)	7 (Uncontrolled Wall)	SCR:	
	4 (Controlled Wall/Unc Tang)	Ammonia (tons/MW-yr)	3 (Uncontrolled Wall)
	3 (Controlled Tang)		2 (Controlled Wall/Unc Tang)
Electricity (MW-hrs/MW-yr)	20		1 (Controlled Tang)
Gas (1000cf/MW-yr)	2100	Electricity (MW-hrs/MW-yr)	33
Catalyst (cf/MW)	20	Catalyst (cf/MW)	20

ACCUREX DATA

PC-FIRED BOILERS	Uncontrolled Em (lb/MMBtu)	Control Efficiency Low	High	Retrofit Penetration	Capital/Installation ($/1000)	Maintenance (000's/yr)	Op Labor (000's/yr
Wall-fired							
OFA	0.95	0.16	0.26	0.5	2837	23	2
LNB	0.95	0.37	0.53	0.8	2732	22	2
LNB + OFA	0.95	0.42	0.63	0.5	5568	45	4
NGR	0.95	0.47	0.58	0.7	5778	46	-1
SNCR	0.95	0.32	0.47	0.8	2627	21	2
SNCR + LNB	0.6	0.25	0.42	0.8	2627	21	2
SCR (cold)	0.95	0.74	0.84	0.8	26581	425	52
SCR + LNB	0.6	0.67	0.75	0.8	26581	425	52
Tangential-fired							
OFA	0.6			0.6			
LNB	0.6	0.25	0.33	0.8	3362	27	2
LNB + OFA	0.6	0.25	0.50	0.6	4097	33	3
NGR	0.6	0.42	0.58	0.7	5778	46	-1
SNCR	0.6	0.33	0.50	0.8	2627	21	2
SNCR + LNB	0.45	0.22	0.44	0.8	2627	21	2
SCR (cold)	0.6	0.75	0.83	0.8	26581	425	52
SCR + LNB	0.45	0.67	0.78	0.8	26581	425	52

OIL & GAS-FIRED	Uncontrolled Em (lb/MMBtu)	Control Efficiency Low	High	Retrofit Penetration	Capital/Installation ($/1000)	Maintenance (000's/yr)	Op Labor (000's/yr
Wall-fired							
BOOS	0.45	0.22	0.33	0.8		1	9
FGR	0.45	0.22	0.44	0.8	1376	11	11
LNB	0.45	0.33	0.44	0.6	3935	31	15
BOOS + FGR	0.45	0.33	0.44	0.8	1471	12	11
BOOS + FGR + LNB (incr)	0.325	0.23	0.69	0.5	7596	61	20
SNCR	0.45	0.33	0.44	0.8	1366	11	3
SNCR + BOOS + FGR	0.3	0.17	0.33	0.8	1366	11	3
SCR (cold)	0.45	0.67	0.78	0.8	18701	299	36
SCR + BOOS + FGR	0.3	0.67	0.83	0.8	18701	299	36
Tangential-fired							
BOOS	0.3	0.17	0.33	0.9	85	1	9
FGR	0.3	0.17	0.33	0.8	1376	11	11
LNB	0.3	0.17	0.50	0.6	3935	31	15
BOOS + FGR	0.3	0.33	0.50	0.8	1471	12	11
BOOS + FGR + LNB (incr)	0.225	0.11	0.56	0.5	7596	61	20
SNCR	0.3	0.33	0.50	0.8	1366	11	3
SNCR + LNB	0.2	0.25	0.50	0.6	1366	11	3
SCR (cold)	0.3	0.67	0.83	0.8	18701	299	36
SCR + LNB + FGR	0.2	0.50	0.75	0.5	18701	299	36

PC-FIRED BOILERS — Low Efficiency Case

Cap factor = 0.65
Rating (MW) = 100

Control	Wall % Control	Wall $/ton	Tangential % Control	Tangential $/ton
OFA	15.79%	1026	N/A	N/A
LNB	36.84%	390	25.00%	1101
LNB + OFA	42.11%	694	25.00%	1407
NGR	47.37%	1414	41.67%	2546
SNCR	31.58%	1394	33.33%	1549
SNCR + LNB	25.00%	2065	22.22%	2633
SCR (cold side)	73.68%	2987	75.00%	4587
SCR + LNB	66.67%	5160	66.67%	6880

PC-FIRED BOILERS **High Efficiency Case**

Cap factor = 0.65
Rating (MW) = 100

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
OFA	26.32%	615	N/A	N/A
LNB	52.63%	273	33.33%	825
LNB + OFA	63.16%	463	50.00%	704
NGR	57.89%	1157	58.33%	1818
SNCR	47.37%	929	50.00%	1033
SNCR + LNB	41.67%	1239	44.44%	1317
SCR (cold side)	84.21%	2614	83.33%	4128
SCR + LNB	75.00%	4587	77.78%	5898

PC-FIRED BOILERS

Low Efficiency Case

Cap factor = 0.65
Rating (MW) = 200

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
OFA	15.79%	846	N/A	N/A
LNB	36.84%	316	25.00%	887
LNB + OFA	42.11%	562	25.00%	1147
NGR	47.37%	1292	41.67%	2326
SNCR	31.58%	1311	33.33%	1424
SNCR + LNB	25.00%	1899	22.22%	2384
SCR (cold side)	73.68%	2626	75.00%	4025
SCR + LNB	66.67%	4528	66.67%	6037

PC-FIRED BOILERS

High Efficiency Case

Cap factor = 0.65
Rating (MW) = 200

Control	Wall % Control	Wall $/ton	Tangential % Control	Tangential $/ton
OFA	26.32%	507	N/A	N/A
LNB	52.63%	221	33.33%	666
LNB + OFA	63.16%	375	50.00%	574
NGR	57.89%	1057	58.33%	1661
SNCR	47.37%	874	50.00%	949
SNCR + LNB	41.67%	1139	44.44%	1192
SCR (cold side)	84.21%	2298	83.33%	3622
SCR + LNB	75.00%	4025	77.78%	5175

PC-FIRED BOILERS

Low Efficiency Case

Cap factor = 0.65
Rating (MW) = 500

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
OFA	15.79%	673	N/A	N/A
LNB	36.84%	244	25.00%	682
LNB + OFA	42.11%	435	25.00%	897
NGR	47.37%	1175	41.67%	2114
SNCR	31.58%	1231	33.33%	1304
SNCR + LNB	25.00%	1739	22.22%	2143
SCR (cold side)	73.68%	2279	75.00%	3485
SCR + LNB	66.67%	3921	66.67%	5227

PC-FIRED BOILERS

High Efficiency Case

Cap factor = 0.65
Rating (MW) = 500

Control	Wall % Control	Wall $/ton	Tangential % Control	Tangential $/ton
OFA	26.32%	404	N/A	N/A
LNB	52.63%	171	33.33%	512
LNB + OFA	63.16%	290	50.00%	449
NGR	57.89%	961	58.33%	1510
SNCR	47.37%	820	50.00%	869
SNCR + LNB	41.67%	1043	44.44%	1072
SCR (cold side)	84.21%	1994	83.33%	3136
SCR + LNB	75.00%	3485	77.78%	4481

PC-FIRED BOILERS

Low Efficiency Case

Cap factor = 0.65
Rating (MW) = 800

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
OFA	15.79%	606	N/A	N/A
LNB	36.84%	217	25.00%	603
LNB + OFA	42.11%	385	25.00%	801
NGR	47.37%	1129	41.67%	2033
SNCR	31.58%	1200	33.33%	1258
SNCR + LNB	25.00%	1677	22.22%	2051
SCR (cold side)	73.68%	2145	75.00%	3276
SCR + LNB	66.67%	3685	66.67%	4914

PC-FIRED BOILERS

High Efficiency Case

Cap factor = 0.65
Rating (MW) = 800

Control	Wall % Control	Wall $/ton	Tangential % Control	Tangential $/ton
OFA	26.32%	364	N/A	N/A
LNB	52.63%	152	33.33%	452
LNB + OFA	63.16%	257	50.00%	400
NGR	57.89%	924	58.33%	1452
SNCR	47.37%	800	50.00%	838
SNCR + LNB	41.67%	1006	44.44%	1025
SCR (cold side)	84.21%	1876	83.33%	2948
SCR + LNB	75.00%	3276	77.78%	4212

OIL & GAS-FIRED BOILERS   Low Efficiency   Cap factor = 0.4
Rating (MW) = 100

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
BOOS	22.22%	351	16.67%	812
FGR	22.22%	1027	16.67%	2054
LNB	33.33%	1885	16.67%	5655
BOOS + FGR (incr)	7.69%	5524	11.11%	5524
BOOS + FGR + LNB (incr)	11.11%	19536	-14.29%	-19536
SNCR	33.33%	1321	33.33%	1675
SNCR + LNB	N/A	N/A	25.00%	2942
SNCR + BOOS + FGR	16.67%	3350	N/A	N/A
SCR (cold side)	66.67%	6048	66.67%	7882
SCR + LNB + FGR	N/A	N/A	50.00%	15686
SCR + BOOS + FGR	66.67%	9015	N/A	N/A

OIL & GAS-FIRED BOILERS   High Efficiency

Cap factor = 0.4
Rating (MW) = 100

Control	Wall % Control	Wall $/ton	Tangential % Control	Tangential $/ton
BOOS	33.33%	234	33.33%	406
FGR	44.44%	514	33.33%	1027
LNB	44.44%	1414	50.00%	1885
BOOS + FGR (incr)	23.08%	1841	33.33%	1841
BOOS + FGR + LNB (incr)	55.56%	3907	42.86%	6512
SNCR	44.44%	990	50.00%	1117
SNCR + LNB	N/A	N/A	50.00%	1471
SNCR + BOOS + FGR	33.33%	1675	N/A	N/A
SCR (cold side)	77.78%	5184	83.33%	6306
SCR + LNB + FGR	N/A	N/A	75.00%	10457
SCR + BOOS + FGR	83.33%	7212	N/A	N/A

OIL & GAS-FIRED BOILERS Low Efficiency

Cap factor = 0.4
Rating (MW) = 200

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
BOOS	22.22%	351	16.67%	785
FGR	22.22%	814	16.67%	1628
LNB	33.33%	1479	16.67%	4438
BOOS + FGR (incr)	7.69%	4614	11.11%	4614
BOOS + FGR + LNB (incr)	11.11%	15728	-14.29%	-15728
SNCR	33.33%	1180	33.33%	1464
SNCR + LNB	N/A	N/A	25.00%	2519
SNCR + BOOS + FGR	16.67%	2928	N/A	N/A
SCR (cold side)	66.67%	5084	66.67%	6436
SCR + LNB + FGR	N/A	N/A	50.00%	12794
SCR + BOOS + FGR	66.67%	7569	N/A	N/A

OIL & GAS-FIRED BOILERS High Efficiency

Cap factor = 0.4
Rating (MW) = 200

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
BOOS	33.33%	234	33.33%	393
FGR	44.44%	407	33.33%	814
LNB	44.44%	1110	50.00%	1479
BOOS + FGR (incr)	23.08%	1538	33.33%	1538
BOOS + FGR + LNB (incr)	55.56%	3146	42.86%	5243
SNCR	44.44%	885	50.00%	976
SNCR + LNB	N/A	N/A	50.00%	1260
SNCR + BOOS + FGR	33.33%	1464	N/A	N/A
SCR (cold side)	77.78%	4358	83.33%	5149
SCR + LNB + FGR	N/A	N/A	75.00%	8529
SCR + BOOS + FGR	83.33%	6055	N/A	N/A

OIL & GAS-FIRED BOILERS Low Efficiency

Cap factor = 0.4
Rating (MW) = 500

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
BOOS	22.22%	351	16.67%	760
FGR	22.22%	610	16.67%	1220
LNB	33.33%	1090	16.67%	3270
BOOS + FGR (incr)	7.69%	3741	11.11%	3741
BOOS + FGR + LNB (incr)	11.11%	12070	-14.29%	-12070
SNCR	33.33%	1045	33.33%	1261
SNCR + LNB	N/A	N/A	25.00%	2114
SNCR + BOOS + FGR	16.67%	2522	N/A	N/A
SCR (cold side)	66.67%	4158	66.67%	5047
SCR + LNB + FGR	N/A	N/A	50.00%	10016
SCR + BOOS + FGR	66.67%	6180	N/A	N/A

OIL & GAS-FIRED BOILERS High Efficiency

Cap factor = 0.4
Rating (MW) = 500

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
BOOS	33.33%	234	33.33%	380
FGR	44.44%	305	33.33%	610
LNB	44.44%	817	50.00%	1090
BOOS + FGR (incr)	23.08%	1247	33.33%	1247
BOOS + FGR + LNB (incr)	55.56%	2414	42.86%	4023
SNCR	44.44%	783	50.00%	841
SNCR + LNB	N/A	N/A	50.00%	1057
SNCR + BOOS + FGR	33.33%	1261	N/A	N/A
SCR (cold side)	77.78%	3564	83.33%	4038
SCR + LNB + FGR	N/A	N/A	75.00%	6677
SCR + BOOS + FGR	83.33%	4944	N/A	N/A

OIL & GAS-FIRED BOILERS   Low Efficiency   Cap factor = 0.4
Rating (MW) = 800

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
BOOS	22.22%	351	16.67%	750
FGR	22.22%	531	16.67%	1061
LNB	33.33%	939	16.67%	2817
BOOS + FGR (incr)	7.69%	3402	11.11%	3402
BOOS + FGR + LNB (incr)	11.11%	10654	-14.29%	-10654
SNCR	33.33%	992	33.33%	1182
SNCR + LNB	N/A	N/A	25.00%	1956
SNCR + BOOS + FGR	16.67%	2365	N/A	N/A
SCR (cold side)	66.67%	3800	66.67%	4510
SCR + LNB + FGR	N/A	N/A	50.00%	8941
SCR + BOOS + FGR	66.67%	5642	N/A	N/A

OIL & GAS-FIRED BOILERS High Efficiency

Cap factor = 0.4
Rating (MW) = 800

Control	Wall		Tangential	
	% Control	$/ton	% Control	$/ton
BOOS	33.33%	234	33.33%	375
FGR	44.44%	265	33.33%	531
LNB	44.44%	704	50.00%	939
BOOS + FGR (incr)	23.08%	1134	33.33%	1134
BOOS + FGR + LNB (incr)	55.56%	2131	42.86%	3551
SNCR	44.44%	744	50.00%	788
SNCR + LNB	N/A	N/A	50.00%	978
SNCR + BOOS + FGR	33.33%	1182	N/A	N/A
SCR (cold side)	77.78%	3257	83.33%	3608
SCR + LNB + FGR	N/A	N/A	75.00%	5961
SCR + BOOS + FGR	83.33%	4514	N/A	N/A

APPENDIX C

VOC Control Measure Rankings

Baltimore

Source Category	Control Efficiency (%)		Cost Effectiveness ($/ton)		
	Low	High	Low	High	Average
Traffic/Maintenance Paints	40	53	(1,462)	(1,462)	(1,462)
Ind/Comm			0	0	0
Emulsified Asphalt	50	50	100	100	100
Underground Storage Tank Breathing	80	100	64	230	147
Degreasing	20	40	2	368	185
Ag. Equip			0	1,328	664
Landfills	79	79	500	930	715
Oil and Gas Production	69	100	750	1,300	1,025
Pleasure Craft			160	1,960	1,060
Lawn & Garden			160	1,960	1,060
Organic Chemical Mfg. - Others	20	20	800	2,000	1,400
Pesticide Application	30	45	1,600	1,600	1,600
Consumer and Commercial Products	28	28	(100)	3,400	1,650
Industrial WWTF	83	92	387	3,000	1,694
Graphic Arts	43	60	0	3,700	1,850
AIM Coatings	20	20	(8,600)	12,800	2,100
Misc. Metal Coatings	25	30	2,200	2,200	2,200
Can Coating	5	10	2,200	2,200	2,200
Industrial Machinery and Equipment Coatings	25	30	2,200	2,200	2,200
Bulk Gasoline Terminals	70	70	2,600	2,600	2,600
Textile, Resins and Polymers Mfg.	67	84	1,800	4,000	2,900
Petroleum Refineries	27	34	42	6,067	3,055
Automobile Refinishing	43	43	478	7,000	3,739
Vessel Loading - Marine	80	98	300	8,000	4,150
Paper Coatings	1	1	5,000	5,000	5,000
Organic Chemical Mfg. - Synthetic	77	85	210	10,032	5,121
VOL Storage	60	95	120	12,320	6,220
Storage and Warehousing	60	95	120	12,320	6,220
Scrappage -- Long					10,033
NGV -- Long					11,011
Expanded I/M -- Long					11,238
Scrappage -- Short					13,644
Expanded I/M -- Short					18,074
Auto and Light Truck Coating	20	30	17,400	19,000	18,200
NGV -- Short					25,842
Heavy Construction			0	57,128	28,564
Coke Oven Batteries	12	12	37,120	37,120	37,120
Tier II					98,274
CA LEV -- Long					144,461
CA LEV -- Short					423,440
Plastic Parts Mfg.	--	--	--	--	--
Service Station Loading (stage I)	--	--	--	--	--
Publically OwnedTreatment Works	--	--	--	--	--
Metal Furniture	--	--	--	--	--

Chicago

	Control Efficiency (%)		Cost Effectiveness ($/ton)		
	Low	High	Low	High	Average
Traffic/Maintenance Paints	40	53	(1.462)	(1,462)	-1462
Ind/Comm			0	0	0
Emulsified Asphalt	50	50	100	100	100
Underground Storage Tank Breathing	80	100	64	230	147
Degreasing	20	40	2	368	185
Ag. Equip			0	1,350	675
Landfills	79	79	500	930	715
Oil and Gas Production	69	100	750	1,300	1025
Pleasure Craft			160	1,960	1060
Lawn & Garden			160	1.960	1060
Organic Chemical Mfg. - Others	20	20	800	2,000	1400
Pesticide Application	30	45	1.600	1.600	1600
Consumer and Commercial Products	28	28	(100)	3.400	1650
Industrial WWTF	83	92	387	3,000	1693.5
Graphic Arts	43	60	0	3,700	1850
AIM Coatings	20	20	(8.600)	12.800	2100
Can Coating	5	10	2.200	2.200	2200
Misc. Metal Coatings	25	30	2.200	2.200	2200
Industrial Machinery and Equipment Coatings	25	30	2.200	2.200	2200
Bulk Gasoline Terminals	70	70	2.600	2.600	2600
Textile. Resins and Polymers Mfg.	67	84	1.800	4.000	2900
Petroleum Refineries	27	34	42	6.067	3054.5
Automobile Refinishing	43	43	478	7.000	3739
Vessel Loading - Marine	80	98	300	8.000	4150
Paper Coatings	1	1	5.000	5.000	5000
Organic Chemical Mfg. - Synthetic	77	85	210	10.032	5121
Storage and Warehousing	60	95	120	12.320	6220
VOL Storage	60	95	120	12.320	6220
NGV -- Long					7998
Expanded I/M -- Long					8193
Scrappage -- Long					10541
Scrappage -- Short					15621
Auto and Light Truck Coating	20	30	17.400	19.000	18200
Expanded I/M -- Short					19382
NGV -- Short					21027
Heavy Construction			0	48.228	24114
Coke Oven Batteries	12	12	37.120	37.120	37120
CA LEV -- Short					154642
Tier II					196547
CA LEV -- Long					202246
Service Station Loading (stage I)	--	--	--	--	--
Metal Furniture	--	--	--	--	--
Publically OwnedTreatment Works	50	90	--	--	--
Plastic Parts Mfg.	--	--	--	--	--

Houston

Source Category	Control Efficiency (%)		Cost Effectiveness ($/ton)		
	Low	High	Low	High	Average
Traffic/Maintenance Paints	40	53	(1.462)	(1.462)	(1.462)
Ind/Comm			0	0	0
Emulsified Asphalt	50	50	100	100	100
Underground Storage Tank Breathing	80	100	64	230	147
Degreasing	20	40	2	368	185
Landfills	79	79	500	930	715
Ag. Equip			0	1,991	996
Oil and Gas Production	69	100	750	1.300	1.025
Pleasure Craft			160	1,960	1.060
Lawn & Garden			160	1,960	1.060
Organic Chemical Mfg. - Others	20	20	800	2.000	1.400
Pesticide Application	30	45	1.600	1.600	1.600
Consumer and Commercial Products	28	28	(100)	3.400	1.650
Industrial WWTF	83	92	387	3.000	1.694
Graphic Arts	43	60	0	3,700	1.850
AIM Coatings	20	20	(8.600)	12.800	2.100
Industrial Machinery and Equipment Coatings	25	30	2.200	2.200	2.200
Can Coating	5	10	2.200	2.200	2,200
Misc. Metal Coatings	25	30	2.200	2.200	2,200
Bulk Gasoline Terminals	70	70	2.600	2.600	2.600
Textile, Resins and Polymers Mfg.	67	84	1.800	4.000	2.900
Petroleum Refineries	27	34	42	6,067	3.055
Automobile Refinishing	43	43	478	7.000	3.739
Vessel Loading - Marine	80	98	300	8.000	4.150
Paper Coatings	1	1	5.000	5.000	5.000
Organic Chemical Mfg. - Synthetic	77	85	210	10.032	5.121
Storage and Warehousing	60	95	120	12.320	6.220
VOL Storage	60	95	120	12.320	6.220
Expanded I/M -- Long					9.073
Scrappage -- Long					10.070
NGV -- Long					10.701
Scrappage -- Short					12.444
Expanded I/M -- Short					14.234
Auto and Light Truck Coating	20	30	17.400	19.000	18.200
Heavy Construction			0	45.705	22.853
NGV -- Short					30.779
Coke Oven Batteries	12	12	37.120	37.120	37.120
Tier II					196.547
CA LEV -- Long					303.368
CA LEV -- Short					466.361
Plastic Parts Mfg.	--	--	--	--	--
Service Station Loading (stage I)	--	--	--	--	--
Publically OwnedTreatment Works	--	--	--	--	--
Metal Furniture	--	--	--	--	--

Philadelphia

Source Category	Control Efficiency (%)		Cost Effectiveness ($/ton)		
	Low	High	Low	High	Average
Traffic/Maintenance Paints	40	53	(1,462)	(1,462)	(1,462)
Ind/Comm			0	0	0
Emulsified Asphalt	50	50	100	100	100
Underground Storage Tank Breathing	80	100	64	230	147
Degreasing	20	40	2	368	185
Landfills	79	79	500	930	715
Oil and Gas Production	69	100	750	1,300	1,025
Pleasure Craft			160	1,960	1,060
Lawn & Garden			160	1,960	1,060
Organic Chemical Mfg. - Others	20	20	800	2,000	1,400
Pesticide Application	30	45	1,600	1,600	1,600
Consumer and Commercial Products	28	28	(100)	3,400	1,650
Industrial WWTF	83	92	387	3,000	1,694
Graphic Arts	43	60	0	3,700	1,850
AIM Coatings	20	20	(8,600)	12,800	2,100
Industrial Machinery and Equipment Coatings	25	30	2,200	2,200	2,200
Can Coating	5	10	2,200	2,200	2,200
Misc. Metal Coatings	25	30	2,200	2,200	2,200
Bulk Gasoline Terminals	70	70	2,600	2,600	2,600
Textile, Resins and Polymers Mfg.	67	84	1,800	4,000	2,900
Petroleum Refineries	27	34	42	6,067	3,055
Automobile Refinishing	43	43	478	7,000	3,739
Expanded I/M -- Long					3,937
Vessel Loading - Marine	80	98	300	8,000	4,150
Paper Coatings	1	1	5,000	5,000	5,000
Organic Chemical Mfg. - Synthetic	77	85	210	10,032	5,121
VOL Storage	60	95	120	12,320	6,220
Storage and Warehousing	60	95	120	12,320	6,220
NGV -- Long					7,236
Expanded I/M -- Short					7,376
Scrappage -- Long					10,750
Scrappage -- Short					16,600
Auto and Light Truck Coating	20	30	17,400	19,000	18,200
NGV -- Short					18,566
Coke Oven Batteries	12	12	37,120	37,120	37,120
CA LEV -- Long					121,347
Tier II					131,031
CA LEV -- Short					373,484
Plastic Parts Mfg.	--	--	--	--	--
Service Station Loading (stage I)	--	--	--	--	--
Publically OwnedTreatment Works	--	--	--	--	--
Metal Furniture	--	--	--	--	--

Washington

	Control Efficiency (%)		Cost Effectiveness ($/ton)		
	Low	High	Low	High	Average
Traffic/Maintenance Paints	40	53	(1,462)	(1,462)	(1,462)
Ind/Comm			0	0	0
Emulsified Asphalt	50	50	100	100	100
Underground Storage Tank Breathing	80	100	64	230	147
Degreasing	20	40	2	368	185
Ag. Equip			0	785	393
Landfills	79	79	500	930	715
Oil and Gas Production	69	100	750	1,300	1,025
Pleasure Craft			160	1,960	1,060
Lawn & Garden			160	1,960	1,060
Organic Chemical Mfg - Others	20	20	800	2,000	1,400
Pesticide Application	30	45	1,600	1,600	1,600
Consumer and Commercial Products	28	28	(100)	3,400	1,650
Industrial WWTF	83	92	387	3,000	1,694
Graphic Arts	43	60	0	3,700	1,850
AIM Coatings	20	20	(8,600)	12,800	2,100
Industrial Machinery and Equipment Coatings	25	30	2,200	2,200	2,200
Can Coating	5	10	2,200	2,200	2,200
Misc. Metal Coatings	25	30	2,200	2,200	2,200
Bulk Gasoline Terminals	70	70	2,600	2,600	2,600
Textile, Resins and Polymers Mfg.	67	84	1,800	4,000	2,900
Petroleum Refineries	27	34	42	6,067	3,055
Automobile Refinishing	43	43	478	7,000	3,739
Vessel Loading - Marine	80	98	300	8,000	4,150
Paper Coatings	1	1	5,000	5,000	5,000
Organic Chemical Mfg. - Synthetic	77	85	210	10,032	5,121
Storage and Warehousing	60	95	120	12,320	6,220
VOL Storage	60	95	120	12,320	6,220
NGV -- Long					7,236
Expanded I/M -- Long					7,470
Scrappage -- Long					10,108
Scrappage -- Short					12,455
Expanded I/M -- Short					14,451
Auto and Light Truck Coating	20	30	17,400	19,000	18,200
NGV -- Short					18,566
Heavy Construction			0	52,548	26,274
Coke Oven Batteries	12	12	37,120	37,120	37,120
CA LEV -- Long					151,684
CA LEV -- Short					384,151
Tier II					393,094
Plastic Parts Mfg.	--	--	--	--	--
Service Station Loading (stage I)	--	--	--	--	--
Publically OwnedTreatment Works	--	--	--	--	--
Metal Furniture	--	--	--	--	--

APPENDIX D

Stationary Source VOC Control Measures

SOURCE CATEGORY: Architectural and Industrial Maintenance (AIM) Coatings

RELATIVE SOURCE SIZE:

- Baltimore, MD: 6.1%
- Chicago, IL: 4.1%
- Washington, DC: 5.8%
- Houston, TX: 2.8%
- Philadelphia, PA: 4.4%

BASELINE CONTROLS: Varies by state -- mostly uncontrolled.

Further Control Options	Efficiency	$/ton from Lit.
- Adopt the 1989 CARB model rule which sets VOC content limits for individual AIM coatings.	20%	$(8600)-12,800

DISCUSSION:

Architectural surface coatings are used by contractors, industry, and homeowners to coat both the inside and outside of buildings, houses, and their appurtenances. The various types of architectural surface coatings include flat and non-flat paints and about 35 categories of specialty coatings. Volatile organic compound emissions occur primarily from the evaporation of organic solvents from the coating during application and drying.

Only four states currently have regulations limiting the content of architectural surface coatings, California, New York, Texas, and Maryland. The USEPA is conducting a negotiated rulemaking to develop a national rule that reduces VOC emissions from this source category. Regulatory negotiations between industry, environmentalists, States, and the USEPA are progressing with a proposed rule expected by late in 1993. It is likely that the final agreement will yield a 45-percent reduction in VOC emissions. The national rule is being developed as a 3-tier standard. The first tier provides for a 25 percent reduction by 1996, the second and third tiers each requires an additional 10 percent reduction in emission by 2000 and 2003, respectively.

The publication of the 1996 Table of Standards is not yet available therefore the proposed method of control is the adoption of the 1989 California Air Resources Board (CARB) model rule. The limitations contained with the CARB rule are technologically feasible and have been in place in California since 1989. The available control methods are product reformulation, product substitution and consumer education. The CARB rule could achieve VOC reductions approaching those expected from the first phase of the regulatory negotiation, providing a conservative estimate of a 20 percent reduction.

The large cost effectiveness differential can be accounted for by the large category diversity of AIM coatings. Reformulation has been shown to be an effective way controlling organic emissions from coatings. Uncertainty about the necessary equipment modifications and research and development requirements of product reformulation accounts for much of the board range. Replacement of noncomplying coatings with existing complying coating is often more cost effective than reformulation.

A CARB technical support document presented the cost effectiveness of the model rule ranging from a credit of $8,600 per ton of VOCs reduced to a cost of $12,800 per ton and varied according to the coating category in question (STAPPA, 1993).

SOURCES:

1. SCAQMD, 1991.
2. STAPPA, 1993.
3. LMOCP, 1993.
4. BAAQMD, 1991.

SOURCE CATEGORY: Auto and Light Truck Surface Coating

RELATIVE SOURCE SIZE:

- Baltimore, MD: 1.8%
- Chicago, IL: 0.9%
- Washington, DC: 0.0%
- Houston, TX: 0.0%
- Philadelphia, PA: 1.3%

BASELINE CONTROLS: CTG - Surface Coatings of Cans, Coils, Paper, Fabric, Auto and Light Trucks.

VOC limits (lbs VOC/gallon coating (minus water)):
1.2 - primer application
2.8 - primer surface coat
2.8 - topcoat application
4.8 - final repair application

Further Control Options	Efficiency	$/ton from Lit.
Abatement of spray booth with add-on controls.	20-30%	$17,400-19,000

DISCUSSION:

Several types of control techniques are used in the automobile and light-duty truck manufacturing industry. These methods can be broadly categorized as either add-on control devices or new coatings application systems. Add-on devices that reduce emissions by recovering or destroying the solvents before they are discharged into the ambient air include thermal and catalytic incinerators and carbon adsorbers. The proposed control would requirement installation of exhaust controls on sources that do not have any substantial existing controls.

The Bay Area AQMD studied the New United Motor Manufacturing, Inc. (NUMMI) automobile assembly plant located in the their district. Currently, the NUMMI controls emissions from their drying ovens with thermal and catalytic incineration. Other than the ovens, there are no additional add-on controls on the coating operations in the existing facility. The South Coast AQMD found similar results at a General Motors plant in their region. Both studies concluded that the spray booth abatement was the next level of control available.

In a phone conversation with a Chrysler Corporation plant engineer, a similar control scenario was determined for their facility. The plant is currently controlling their VOC emissions with add-on controls on their drying ovens, water-wash systems in their paint spray booths, transfer efficiency requirements for the coating application, and compliance coatings with regulated levels of solvent content. The area of the operations available for additional controls is in the spray booth. The engineer at Chrysler said that they did not believe that add-on controls for this source has been proven reliable for the low-concentration, high flow rate exhaust streams.

Further research is being conducted with additional product reformulation and refinement of application methods. At this time, no credible reference was available to validate the reduction possibilities.

Studies have been done by Radian recently to determine feasible methods of controlling VOC emission from paint spray booths. A detailed technical and economic evaluation of the control technologies resulted in the final selection of a rotary zeolite preconcentrator (RZP) combined with a recuperative catalytic oxidation (RCO) unit. The preconcentrator increased the concentration of the exhaust stream allowing for more efficient oxidation of the stream. Costs and control efficiencies seem to be site-specific for this category.

Since cleanup solvents and sealers are not regulated in most areas, reformulation of these materials may provide the potential for additional reductions.

SOURCES:

1. BAAQMD, 1991.
2. Personal communication. Sandra Lopez @ Chrysler.
3. STAPPA, 1993.
4. CTG – EPA-450/2-77-008, 1977.

SOURCE CATEGORY: Automobile Refinishing

RELATIVE SOURCE SIZE:

- Baltimore, MD: 3.2%
- Chicago, IL: 1.8%
- Washington, DC: 2.9%
- Houston, TX: 1.5%
- Philadelphia, PA: 2.5%

BASELINE CONTROLS: None

Further Control Options		Efficiency	$/ton from Lit.
3%	Vehicle Preparation: Low-VOC surface preparation.	73%	$1,250
88%	Coating application: VOC limits based on current technology and rely on the use of higher-solids solvent borne coatings.	43%	$4,200-4,725 (CARB) $7,000 (SCAQMD)
9%	Gun-cleaning: Use of automated gun-cleaning systems.	28%	$478

DISCUSSION:

Autobody refinishing facilities are located throughout the United States. The shops may be independently owned and operated or operated by dealerships and franchises. The steps involved in automobile refinishing include surface preparation, surface coating application, and equipment cleaning.

Several districts in California currently regulate automobile refinishers, setting limits on VOC contents of coatings and surface preparation solvents. The USEPA is also developing a federal rule for auto refinishing.

The three approaches available to reduce VOC emissions from autobody refinishing are to lower the VOC content of the products used, improve the application technique and control the use of clean-up solvents.

The most effective method of reducing VOC emissions is to lower the VOC content of the products used. Limitations in the VOC content of surface preparation products as well as topcoats and primers has shown to provide reductions in the Bay Area and South Coast

AQMD districts. Waterborne primer surfacers are in use and high-solids primers are also available.

Another technique for reducing emissions is to use high transfer efficiency spray equipment, especially high-volume, low-pressure (HVLP) spray systems. This technology has been shown to reduce emissions and save money by decreasing coating use, hazardous waste generation, and spray booth maintenance costs.

Finally, emissions can also be reduced during the equipment cleaning phase. With the use of an automatic cleaning device or solvent recycling systems, emission reductions are possible.

The application of add-on controls for the abatement of VOC emissions has been determined to cost prohibitive by the EPA and private industry. In a study done for the State of New Jersey, it was calculated that the annual cost effectiveness of add-on controls for the autobody refinishing industry would be in the range of $64,300 to 180,000 per ton VOC removed. This is well above the BACT level control cap of $17,000 per ton.

Since approximately six major coating manufacturers account for more than 90-percent of the coating sales to, and the large majority of VOC emissions from the autobody refinishing industry, regulation of the producers appears to be more feasible than regulation of the users.

The EPA is currently developing a federal rule for the auto refinishing industry. The focus is with coating reformulation targeting the coating manufacturers rather than the product users. Although work has been done towards developing this rule, the project was cut by the EPA and therefore, estimates may not be available until next year. A project engineer, who has provided technical support to the EPA on the federal rule development project, suggests that our cost effectiveness figures for both the coating reformulation and gun cleaning may be high.

Users have commented that reformulation to lower solvent coatings increases the drying time of the paints and therefore decreases productivity.

SOURCES:

1. LMOCP, 1993.
2. STAPPA, 1993.
3. Radian Corp., 1987.

SOURCE CATEGORY: Bulk Gasoline Terminals

RELATIVE SOURCE SIZE:

- Baltimore, MD: 1.7%
- Chicago, IL: 0.4%
- Washington, DC: 0.0%
- Houston, TX: 3.9%
- Philadelphia, PA: 0.6%

BASELINE CONTROLS: CTG - Hydrocarbon Emissions from Tank Gasoline Loading Terminals.

A bulk gasoline terminal shall equip the loading system with a vapor control system given operating requirements.

Further Control Options	Efficiency	$/ton from Lit.
Improved vapor recovery system: - Application of carbon adsorption, refrigeration, or incineration.	70%	$2,600

DISCUSSION:

Bulk gasoline terminals serve as the major distribution point for gasoline produced at refineries. Gasoline is delivered to bulk terminals through pipelines, and is stored in large above-ground storage tanks. Gasoline is then pumped through metered loading areas, called loading racks, into delivery tank trucks which serve various wholesale and retail gasoline dispensing facilities. VOC emissions occur during loading of the delivery tank trucks, as the entering gasoline displaces the vapors into a collection system. The collected vapors are then routed to a vapor processing system (SQAQMD, 1991).

VOC emissions from gasoline bulk terminals can be controlled through the use of available control technologies such as carbon adsorption vapor recovery systems.

Carbon adsorption vapor recovery systems operate based on dual carbon beds to remove organic compounds from the air-vapor mixture. During gasoline tank truck loading, one carbon bed is in the adsorbing mode while the other bed is regenerated by vacuum stripping. The displaced gasoline vapors from the tank truck are introduced at the bottom of the on-line carbon and are adsorbed onto the activated carbon as the vapors ascend. At the same time, the second bed is subjected to a vacuum to desorb the hydrocarbons. The recovered hydrocarbons are then adsorbed by a liquid gasoline stream which circulates between the processing unit and the storage tank (BAAQMD, 1987).

This control measure proposes to reduce the current VOC emission level by 70 percent. Available test data indicate that the proposed emission limit can be achieved based on the above control technologies.

SOURCES:

1. BAAQMD, 1991.
2. SCAQMD, 1991.
3. CTG -- EPA-450/2-77-026, 1977.

SOURCE CATEGORY: Can Coating

RELATIVE SOURCE SIZE:

- Baltimore, MD: 2.0%
- Chicago, IL: 0.7%
- Washington, DC: 0.0%
- Houston, TX: 0.0%
- Philadelphia, PA: 1.2%

BASELINE CONTROLS: 1977 CTG - Surface Coatings of Cans, Coils, Paper, Fabric, Auto and Light Trucks.

VOC limits (lbs VOC/gallon coating (minus water)):
2.8 - sheet basecoat & overvarnish
2.8 - two-piece can exterior
4.2 - two- & three-piece can interior, two-piece can exterior end
5.5 - three-piece can side-seam spray
3.7 - end sealing compound

Further Control Options	Efficiency	$/ton from Lit.
Control technologies such as radiation curable, powder systems, water-borne, and high-solid coatings.	5-10%	$2,200

DISCUSSION:

Surface coatings are applied to cans to serve as liners and sealers, and to provide a protective and decorative finish. Organic emissions from can coating operations occur in the application and flashoff areas, and in the baking ovens. The majority of the emissions occur before the coated can enters the ovens.

Coating technologies such as radiation curable, powder systems, water-borne, and high solids have the potential for further reducing VOC emissions from some can coating operations. Radiation curable coatings are high solids formulations which contain little or no organic solvents. These coatings use ultraviolet or electron beam energy to initiate the reaction to form a polymer surface coating. Radiation curable coatings, because of their high viscosity and need for control of coating thickness, are most amenable to flat application of radiation curable coatings on a three dimensional basis. Ultraviolet curable (UV) coatings systems are currently used by several companies in the Bay Area.

Powder coatings may also represent an acceptable alternative to conventional, organic solvent based coating systems in certain applications. Some water-borne and high solids coatings that have VOC levels below existing standards may be suitable for can coating operations.

Radian performed a study for a can manufacturing client in the California Valley. This plant was using water-borne compliance coating for their coating operations. An attempt was made to use the powder coating, side-seam adhesive to meet the BACT requirements in their district. The study concluded that the powder coating was an ineffective method of sealing the can. The same study approximated the cost effectiveness of add-on controls at $22,635 per ton of VOC removed. This amount is well above the BACT level of control and therefore it is not a economically feasible control method.

SOURCES:

1. CTG -- EPA-450/2-77-008, 1977.
2. BAAQMD, 1991.
3. Personal communication. Leon Leonard.

SOURCE CATEGORY: Coke Oven Batteries

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 1.1%
- Washington, DC: 0.0%
- Houston, TX: 0.0%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: Varying baseline control levels.

Further Control Options	Efficiency	$/ton from Lit.
Implement the recently proposed benzene NESHAP.	12%	$37,120

DISCUSSION:

A coke oven battery is a series of 10 to 100 coke ovens operated together. Prepared coal is "coked," or heated in an oxygen-free atmosphere until the volatile components in the coal are evaporated. Coke oven gas is the most commonly used fuel for underfiring coke ovens. Approximately 40-percent of coke oven gas is used to heat the coke ovens.

Emissions of volatile organic materials originate from several coking operations, including coke oven charging, oven leakage during the coking period, coke removal, and hot coke quenching.

During the coking cycle, VOM emissions from the thermal distillation process can occur through poorly sealed doors, charge lids, off-take caps, collecting main duct, and through cracks that may develop in oven brick work.

The primary control strategy for controlling emissions during coal charging is to conduct staged charging to prevent overloading scrubber systems. Oven leakage during the coking period can be minimized by maintaining oven seals and by following proper operating and maintenance procedures.

To control coke removal emissions, many facilities use mobile scrubber cars with hoods, shed enclosure evacuated to a gas cleaning device or traveling hoods with affixed duct leading to a stationary gas cleaner.

Few data exist on the potential national VOC emissions reductions from coke batteries. However, targeted performance levels set by USEPA in the proposed National Emission

Standard for Hazardous Air Pollutants (NESHAP) for coke batteries would require additional emissions reductions of 1.3 percent for doors, 2.3 percent for lids, 4.5 percent for offtake caps and 4 percent during charging, above the current estimated control efficiency of 90 percent (LMOCP, 1993).

Current controls, consisting of modified coke battery hardware, installed pollution control devices and production practices are estimated to control 90 percent of potential emissions from charging operations, door leaks and topside leaks.

SOURCES:

1. Personal communication. Gail Lacy, Amanda Agnu, Ed Warcowski @ Region V EPA.
2. STAPPA, 1993.
3. LMOCP, 1993.

SOURCE CATEGORY: Consumer and Commercial Products

RELATIVE SOURCE SIZE:

- Baltimore, MD: 8.3%
- Chicago, IL: 5.1%
- Washington, DC: 20.4%
- Houston, TX: 2.9%
- Philadelphia, PA: 7.5%

BASELINE CONTROLS: None

Further Control Options	Efficiency	$/ton from Lit.
Adopt the California (CARB) consumer products regulations: - Phase I - Phase II - Deodorants and Antiperspirants	28%	$(100)-3,400

DISCUSSION:

Consumer and commercial products are those items sold to retail customers for household, personal or automotive use, along with the products marketed by wholesale distributors for use in commercial or institutional settings, such as beauty shops, schools and hospitals. VOC emissions from these products are the result of the evaporation of propellant and organic solvents during use.

Consumer and commercial products represent a diverse area source and include personal care products, household maintenance products, pesticide products and aerosol paints.

Reductions in VOC emissions from consumer products can be achieved in several ways, including reformulation of the product, alternative and modified dispensing or delivery systems or product substitution.

By adopting CARB's "Consumer Products" rule, reductions in emissions are possible for the 28 products regulated under the California rule, in addition to the deodorant and antiperspirant rule. The CARB committee speculated that the implementation of these rules would result in a 28 percent reduction overall for consumer and commercial products.

SOURCES:

1. CARB, 1990.

2. CARB, 1991.
3. STAPPA, 1993.
4. SCAQMD, 1991.
5. E.H. Pechan, 1991.

SOURCE CATEGORY: Degreasing/Solvent Cleaning

RELATIVE SOURCE SIZE:

- Baltimore, MD: 3.2%
- Chicago, IL: 2.9%
- Washington, DC: 3.0%
- Houston, TX: 1.5%
- Philadelphia, PA: 2.8%

BASELINE CONTROLS: RACT: CTG - Solvent Metal Cleaning Operations

Further Control Options	Efficiency	$/ton from Lit.
Implement standards similar to SCAQMD's Rule 1122, use alternative solutions (e.g. semi-aqueous & aqueous solutions), operating requirements, and install control devices.	42% 20-40%	$2-368 (SCAQMD) $130-320 (LMOCP)

DISCUSSION:

Surface cleaning, or degreasing, includes the solvent cleaning or conditioning of metal surfaces and parts, fabricated plastics, electronic and electrical components. The cleaning processes are designed to remove foreign materials such as oils, grease, waxes and moisture in preparation for further treatment.

The CTG for solvent metal cleaning covers three categories of cleaners: cold cleaners, which remove soils from a metal surface by brushing, flushing or immersion while maintaining the solvent below its boiling point; open-top vapor degreaser (OTVD), which use hot solvent vapor to clean and remove soils from batch metal parts; and conveyorized degreasers, which clean and remove soils from metal parts using either cold or vaporized solvents in a continuous process (LMOCP, 1993).

In most areas, current level of control is consistent with the "System A" RACT level, as defined by the CTG. A model rule guideline, published by the USEPA in June 1992, included a section on solvent metal cleaning and this time the model rule contained the additional requirements previously included under "system B" in the CTG for each equipment type. Additional provisions in the model rule included requirements for record keeping, equipment maintenance, and compliance test reporting (STAPPA, 1993).

Most recently, solvent metal cleaners are a source category affected by the requirements of Title III of the Clean Air Act Amendments of 1990 which require the development of

Maximum Achievable Control Technology (MACT) standards for hazardous air pollutants (HAPs). The USEPA is in the process of developing specific control requirements and standards for vapor degreasers which use low reactive solvents such as trichloroethane, perchloroethylene, trichloroethylene, and methylene chloride.

The EPA expects the degreasing NESHAP to be proposed in November 1993. This new standard will result in reductions of 60 percent for vapor degreasers at a cost savings. The proposed rule will also focus on the use of halogenated solvent (e.g. carberator cleaners) in cold cleaning operations. In Illinois, conveyorized and open-top vapor degreasers have permit restrictions and therefore fall under more strict state regulations. Cold cleaners, because of their large numbers, are difficult to account for and enforce the mandated level of controls.

Strategies implemented by companies in Michigan consist of changing to aqueous or semi-aqueous solutions, increasing reclamation, and installing equipment such as water cooled finned tubes, as opposed to flat tubes, to condense vapors, secondary cooling collars, power covers, and increased freeboard ratios. The South Coast AQMD has revised Rule 1122 to further reduce emissions from degreasing by minimizing workload requirements, specifying maximum draft rates and proper handling procedures, and requiring the installation of control devices (LMOCP,1993).

Two companies in a Michigan survey reported control costs of $120-318 per ton for the installation of water-cooled finned condensing tubes and a centrifuge system. The South Coast AQMD estimated the cost of control to be between $96-368 per ton. And finally, USEPA's 1990 FIP for Chicago estimated $20 per ton to eliminate the emission size exemptions still in effect.

SOURCES:

1. CTG – EPA 450/2-77-022, 1977.
2. STAPPA, 1993.
3. LMOCP, 1993.
4. Radian, 1993.

SOURCE CATEGORY: Emulsified Asphalt

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.2%
- Chicago, IL: 1.0%
- Washington, DC: 4.1%
- Houston, TX: 0.1%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: CTG - Use of Cutback Asphalt
- Seasonal Restrictions/Content Limits

Further Control Options	Efficiency	$/ton from Lit.
Reduce the oil distillate content to 3.5 percent by volume and further limit the seasonal restrictions	50%	Estimated $100

DISCUSSION:

Many states have regulations prohibiting the use of cutback asphalt (petroleum based) asphalt during the ozone season. In addition, other states also have distillate oil content restrictions mandating the level of oil allowed.

The proposed method of control for this category is to reduce the oil distillate content of the emulsion. If it is technically feasible to reduce the content to 3.5 percent or lower, 50 percent reduction in VOC emissions could be achieved (IEPA, 1993). Another method of controlling emissions, would be to prohibit the use of cutback asphalt all together. A cost effectiveness estimate of $100 per ton has been made to account for process modifications or reformulation costs. In the E.H. Pechan report, they estimated no increase of cost for this control measure.

SOURCE:

1. CTG -- EPA-450/2-77-037, 1977.
2. IEPA, 1993.

SOURCE CATEGORY: Graphic Arts

RELATIVE SOURCE SIZE:

- Baltimore, MD: 1.4%
- Chicago, IL: 3.6%
- Washington, DC: 1.3%
- Houston, TX: 0.8%
- Philadelphia, PA: 1.2%

BASELINE CONTROLS: RACT: CTG - Graphic Arts (Flexography and Rotogravure)

Further Control Options	Efficiency	$/ton from Lit.
36% Rotogravure and Flexography: Add-on controls with permanent total enclosure (PTE). - Also establish VOC limits for inks no less stringent than 300 g/l. - Use low-VOC clean-up solvents.	95%	Add-on: $120-4,800 + PTE: $9,000-20,000
64% Offset Lithography: Adopt the draft CTG RACT regulations	67-90%	Savings-3,700

DISCUSSION:

The graphic arts industry includes operations that are involved in the printing of newspapers, magazines, books, general packaging materials, and other printed materials. There are six basic operations or applications used in graphic arts. These are lithography, rotogravure, letterpress, flexography, screen printing, and metal decorating. The three main operations are flexography, lithography, and rotogravure.

Lithography is generally the most used printing process in the graphic arts industry, and is used in printing books, pamphlets, newspapers, magazines, and artwork. This is either done using a substrate in a continuous roll (web) or as a sheet-fed system either heat or non-heat setting. VOC emissions come from the ink fountains, dampening system, plate and blanket cylinders, dryers, chill rolls, final products, and cleaning solution.

The rotogravure process is used mainly in large volume, high-speed printing of general publications, including catalogues, magazines, advertising brochures, and others. This operation is especially used in the application of glossy film inks. VOC emissions come from the ink fountain, press, dryer (only for heatset), chill rolls, and cleaning solution.

Flexography, which is a form of letterpress application that uses a flexible plastic or rubber plate in a rotary web press, is used in the printing of flexible packaging, milk cartons, folding cartons, paperboard, and labels and tapes. The VOC emission sources for flexography are similar to the other two processes.

Rotogravure and flexography printing are both covered under the 1978 CTG addressing the graphic arts industry. A draft CTG document on offset lithography, which is due for finalization in late 1993, discusses ink vapor control and cleaning solution reformulation. In addition, cleaning solutions used in all three industries do not seem to be covered by these rules and it may be possible to regulate the VOC content, thus, reducing emissions from these sources.

The actual percent reduction will vary depending upon the type of process, inks used, control method selected, and size of the facility. It appears that the primary candidate for controls are offset lithography printers, which would have reductions between 67 percent and 90 percent according to use of the draft CTG (LMOCP, 1993).

VOC limits for inks should be established no less stringent that 300 g/l, less water and solvent. In addition, the industry should consider using low-solvent cleanup-up solutions.

From previous conversations with industry representatives, the cost of a permanent total enclosure (PTE) for a typical graphic arts facility would be approximately $400,000 per facility. Incorporating a PTE would require add-on controls to process the abated emissions, at a minimum cost effectiveness estimate of $9,120-24,800 per ton VOC removed. These cost effectiveness values are Radian estimates based on engineering judgement.

The USEPA is developing a NESHAP for the printing/publishing industry and is currently gathering background information on the various printing applications used in the industry, including offset lithography.

Also, the Office of Air Quality is developing two more projects that effect the printing industry: Hazardous Air Pollutant (HAP) standards for printing and publishing and an Alternate Control Technology (ACT) for small gravure and flexographic printers. In addition, a project entitled Design for Environment, being developed through the Office of Pollution Prevention and Water Control, is working with the printing industry to reduce the VOC content of cleaning solutions.

SOURCE:

1. CTG -- EPA 450/2-78-033, 1978.
2. Draft CTG - Offset Lithography, 1991.
3. LMOCP, 1993.
4. STAPPA, 1993.
5. Personal communication. RR Donnelly.

SOURCE CATEGORY: Industrial Machinery and Equipment -- Surface Coating

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 0.0%
- Washington, DC: 0.0%
- Houston, TX: 0.0%
- Philadelphia, PA: 0.6%

BASELINE CONTROLS: CTG - Misc. Metal Parts Coating

VOC limits (lbs VOC/gallon coating (minus water)):
4.3 - clear coating
3.5 - air dried coating
3.5 - extreme performance coating
3.0 - all other coating

Further Control Options	Efficiency	$/ton from Lit.
-Improved transfer efficiency requirements. - Lowering VOC limits	25-35%	$2,200

DISCUSSION:

A large variety of metal parts are coated both to prevent corrosion and to enhance appearance. Industrial equipment and machinery are a subsection of the miscellaneous metal parts and products category and therefore candidate control measures will be similar. The coatings are applied either as part of the original equipment manufacturing process or by special coating applicators whose sole business is the coating of a variety of parts.

Spraying is the most common application method of applying primers, single coats, and topcoats. It provides a transfer efficiency typically ranging from 20 to 70 percent. For flow coating, metal parts are moved by conveyor through an enclosed booth. Inside, a series of nozzles shoot streams of coating, which flow over the part. Dip coating involves manual or automated immersion of the parts into a tank of coating. Both the flow and dip methods achieve transfer efficiencies in excess of 90 percent. In electrodeposition, parts are grounded and immersed in a bath of coating. Electrical potential causes the solids in the coating to adhere to the substrate. Powder coating is applied to parts by spraying. There is virtually no solvent in powder coatings. The parts are then moved to an oven where the paint particles melt and then flow over the part forming a continuous film.

VOC emission from the coating of metal parts occur from the application, flashoff, and drying process. Generally, large industrial parts are air dried because of their size or because they contain heat sensitive materials. Small parts and assembly line types of parts are more likely to be force dried in ovens.

The use of transfer efficient equipment is proposed for metal parts coating operations. A minimum transfer efficiency standard in the metal parts rule would require most applicators to modify or replace their current spraying equipment with one or more of the spraying techniques discussed above.

Transfer efficiency requirements will result in the modification or replacement of conventional spray equipment. Studies show that the new equipment costs should be completely offset by a savings in paint consumption.

SOURCE:

1. CTG -- EPA 450/2-78-015, June 1978.
2. BAAQMD, 1991.

SOURCE CATEGORY: Industrial Wastewater Treatment

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.1%
- Chicago, IL: 0.4%
- Washington, DC: 0.0%
- Houston, TX: 2.4%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: There is some penetration of the HON NESHAP and the Benzene Waste Operations NESHAP on industrial wastewater treatment facilities but not enough to form a MACT source.

Further Control Options	Efficiency	$/ton from Lit.
Implementing the EPA draft RACT for industrial wastewater which requires that wastewater streams exceeding a threshold flow and concentration cutoff be controlled. The basis for RACT for this category is steam stripping.	83-92% (EPA estimates) 69-89% (STAPPA)	$387-1,351 (STAPPA) $500-3,000 (LMOCP)

DISCUSSION:

VOC emissions occur when industrial wastewaters are collected and/or treated to remove contaminants prior to final wastewater discharge. Units used to treat industrial wastewaters include tanks, equalization basins, oil-water separators, and biological treatment units. VOC emissions occur where the VOC containing wastewater is exposed to ambient air. Emissions vary with types of VOC removal devices used, (air strippers, steam strippers, etc.), types of tanks (fixed roof, floating roofs), the surface areas of exposed wastewaters at surface impoundments and whether or not the tank or impoundment is heated, aerated, or agitated (LMOCP, 1993).

A preliminary draft CTG for industrial wastewater treatment facilities has been developed by the USEPA. In the draft CTG, industrial wastewater exceeding a VOC concentration of 500 ppmw and a flow rate of 1 liter/min would be regulated under a proposed rule for hazardous waste treatment, storage and disposal facilities.

Industrial wastewater will also be regulated by the Hazardous Organic National Emission Standard for Hazardous Air Pollutants (HON) proposed by EPA in December 1992. As proposed, the HON regulates wastewater streams with a organic hazardous air pollutant concentration of 5 ppmv or greater and a flow rate of 0.02 liters per minute or greater.

Three approaches are being considered in the draft CTG in deciding which wastewater streams should be controlled: one based on VOC concentration; one based on flow rate cutoff; and one based on a combination of VOC concentration and flow rate. Identified wastestreams may be required to remove VOCs with a removal technique, such as steam stripping. The emissions from a steam stripper system must be controlled using a recovery device such as a carbon adsorption or combustion device. The system should remain closed so that at no time does the wastewater come into contact with the ambient air. The proposed method of controlling tanks involves covering open tanks with fixed roofs and installing an internal floating roof or venting vapors to a control device. The proposed method of control for surface impoundments uses covers and control devices. Types of surface impoundments covers being considered include floating membrane covers, air supported covers, and rigid membrane covers.

The costs vary significantly depending on the type and size of the unit being controlled, the concentration cutoff and flow rate cutoff. The higher the VOC concentration in the wastewater, the lower the cost-effectiveness and emission reduction available.

SOURCE:

1. Draft CTG. IWWTF
2. Personal communication, Chris Bagley.
3. LMOCP, 1993.
4. STAPPA, 1993.

SOURCE CATEGORY: Landfills

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.8%
- Chicago, IL: 0.4%
- Washington, DC: 0.5%
- Houston, TX: 0.0%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: Some states are requiring capture controls.

Further Control Options	Efficiency	$/ton from Lit.
Install gas collection system with a control device capable of reducing VOCs in the collected gas by at least 98 percent.	79%	$500-930

DISCUSSION:

Landfill gas is generated naturally by the aerobic and anaerobic decomposition of waste. Such gas consists primarily of methane and carbon dioxide, with VOCs making up less than 1 percent of emissions.

EPA has proposed regulations for new and existing municipal landfills, requiring landfills emitting greater than 167 tons per year of VOCs to design and install gas collection systems and combust captured gases. A final rule is expected to be promulgated in the fall of 1993.

The only available control strategy for reducing landfill gas emissions is a well-designed and well-operated gas collection system with a control device capable of reducing VOCs in the collected gas by at least 98 weigh-percent. Energy recovery systems have also been demonstrated to achieve 98 percent emission control at landfills where their use is feasible.

In Illinois, municipal waste landfills are regulated by Waste Disposal Rules and Regulations issued by the Illinois Pollution Control Board. The operator of a landfill is required to install a gas management system based on the methane concentration detected or if the malodors caused by the unit are detected beyond the property boundary (STAPPA, 1993).

SOURCE:

1. STAPPA, 1993.

SOURCE CATEGORY: Metal Furniture

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 0.6%
- Washington, DC: 0.0%
- Houston, TX: 0.0%
- Philadelphia, PA: 0.2%

BASELINE CONTROLS: CTG -- Surface Coating of Metal Furniture

VOC limits (lbs VOC/gallon coating (minus water)):
3.0 - metal furniture coating

DISCUSSION:

No sources have been found to validate further control methods. Control measures consistence with several of the coating operations may apply for this source category, but no assumptions have been made.

SOURCE CATEGORY: Miscellaneous Metal Parts Coatings

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.2%
- Chicago, IL: 2.7%
- Washington, DC: 2.9%
- Houston, TX: 0.0%
- Philadelphia, PA: 0.5%

BASELINE CONTROLS: 1978 CTG - Misc. Metal Parts Coating

VOC limits (lbs VOC/gallon coating (minus water)):
4.3 - clear coating
3.5 - air dried coating
3.5 - extreme performance coating
3.0 - all other coating

Further Control Options	Efficiency	$/ton from Lit.
- Improved transfer efficiency requirements. - Lowering VOC limits	25-35%	$2,200

DISCUSSION:

A large variety of metal parts are coated both to prevent corrosion and to enhance appearance. Metal parts and products include, but are not limited to, farm machinery, small appliances, industrial machinery, and fabricated metal components. The coatings are applied either as part of the original equipment manufacturing process or by special coating applicators whose sloe business is the coating of a variety of parts.

Spraying is the most common application method of applying primers, single coats, and topcoats. It provides a transfer efficiency typically ranging from 20 to 70 percent. For flow coating, metal parts are moved by conveyor through an enclosed booth. Inside, a series of nozzles shoot streams of coating, which flow over the part. Dip coating involves manual or automated immersion of the parts into a tank of coating. Both the flow and dip methods achieve transfer efficiencies in excess of 90 percent. In electrodeposition, parts are grounded and immersed in a bath of coating. Electrical potential causes the solids in the coating to adhere to the substrate. Powder coating is applied to parts by spraying. There is virtually no solvent in powder coatings. The parts are then moved to an oven where the paint particles melt and then flow over the part forming a continuous film.

VOC emission from the coating of metal parts occur from the application, flashoff, and drying process. Generally, large industrial parts are air dried because of their size or because they contain heat sensitive materials. Small parts and assembly line types of parts are more likely to be force dried in ovens.

The use of transfer efficient equipment is proposed for metal parts coating operations. A minimum transfer efficiency standard in the metal parts rule would require most applicators to modify or replace their current spraying equipment with one or more of the spraying techniques discussed above.

Transfer efficiency requirements will result in the modification or replacement of conventional spray equipment. Studies show that the new equipment costs should be completely offset by a savings in paint consumption (BAAQMD, 1991.)

SOURCE:

1. CTG -- EPA 450/2-78-015, 1978.
2. BAAQMD, 1991.

SOURCE CATEGORY: Oil and Gas Production

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 0.0%
- Washington, DC: 0.0%
- Houston, TX: 3.6%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS:

After further review of the Oil and Gas Production source category we have found that the 40.16 TPD value can be broken down into the following sub-sources:

- 6.45 - Crude Petroleum and Gas Extraction
- 27.17 - Natural Gas Liquids
- 6.5 - other small sources, individually, not accounting for much of the emission inventory.

The first two categories makeup a large portion of the oil and gas source. We have had difficulties determining the processes within these industries because the SIC codes do not correspond with any SCC codes which would provide further source descriptions.

Further Control Options		Efficiency	$/ton from Lit.
50%	Tanks: convert from fixed roof tanks to internal floating roof tanks or install a vapor recovery unit.	69 - 98%	$1,300
30%	Dehydrators: use of condensation control technology such as R-BTEX or Aromatic Recovery Unit.	95%	---
12%	Fugitive: develop a inspection/maintenance program similar to the petroleum industry.	8-24%	---

6%	Pneumatic: convert to a compressed air actuated system.	100%	Estimated $750

DISCUSSION:

The oil and gas production industry is very large and diverse. Extraction of crude oil and gas from wells is the primary function of the industry.

The Houston inventory is the only non-attainment region that registered an emission level for this source category. Apparently, this value was derived using the EPA prescribed method taking the total number of well-heads in a region and multiplying that number by an emission factor. The persons responsible for the development of the inventory were not able to give further disaggregation of this source category, therefore Radian was required to make board assumptions to perform our analysis.

The relative source breakdown was achieved by taking the total number of oil wells and gas wells and multiplying times an assumed source distribution. The major sources of VOC emissions in the oil production industry include: fugitive leaks from pipe, compressors, and valves; pneumatics exhaust of pressurized gas; heater-treaters used to evaporate the moisture from the mixture; and storage tanks (fixed roof) used for storing the product before further processing.

The sources of organic emissions from the gas production industry include: gas well and equipment fugitive leaks; exhaust from compressor engines; pneumatic devices vented expelled gases into the air; and glycol dehydrators that separate the VOC from the glycol medium.

For the purpose of our analysis, 263,000 gas wells and 560,000 oil wells were used to determine the source breakdown. We assumed that none of the oil wells cross-produced gas as well (We are aware that this does not hold true in industry practices, but it simplifies our investigation.)

SOURCE CATEGORY: Publicly Owned Treatment Works (POTWs)

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.7%
- Chicago, IL: 0.8%
- Washington, DC: 0.0%
- Houston, TX: 0.0%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: None

Further Control Options	Efficiency	$/ton from Lit.
1. Develop and implement emission reduction control programs including enclosures, add-on controls, and/or process modifications. 2. Develop and implement a pollution prevention effort by establishing more stringent discharge limits on SPDES permits at both the industries discharging to the POTW and the POTW.	50-90%	Not available

DISCUSSION:

Publicly owned treatment works (POTWs), commonly know as sewage treatment plants, treat domestic sewage and industrial and commercial wastes received primarily through underground sewers. There are many different types of wastewater systems, reflecting a diversity of wastewater sources, environmental conditions, and treatment needs.

VOCs may be emitted both when the wastewaters are transported and when they are treated to remove contaminants. Emissions vary according to the type of treatment process or operation; the amount of turbulence associated with flow into, through and/or out of the unit; the surface area of exposed wastewaters; and whether or not the treatment unit is heated, aerated/agitated or covered/enclosed.

Emissions from POTWs may be stack emissions or fugitive emissions. Stack emissions sources may include combustion exhaust vents, and other ducted wastewater treatment equipment such as scrubbers, activated sludge reactors, and sludge handling building blower vents. Fugitive emission sources include large uncovered wastewater or solids areas such as settling basins, clarifiers, weirs, compost piles, channels and impoundments.

Although sources of VOC emissions may be known, relatively little information has been published on the extent and effects of air emission from POTWs.

The proposed methods of control for POTWs include the development and implementation of emission reduction control programs at POTWs, including enclosures, add-on controls and/or process modification.

A second approach for controlling VOC emissions is to implement sewer use/discharge regulations, applicable to all users, that emphasize waste minimization. In particular, industrial pretreatment regulations can reduce levels of VOCs in the wastewater stream by requiring changes in raw materials used, modification of operating practices and processes, preventive maintenance, and recycling or segregation of waste streams.

Control costs for the available approaches have not been documented. The costs will vary significantly by site-specific parameters.

An EPA study is underway to identify and characterize hazardous air pollutant emissions sources and the need for MACT standards for POTWs. The results of the study are expected to be available in the late fall of 1993.

SOURCE:

1. LMOCP, 1993.
2. STAPPA, 1993.

SOURCE CATEGORY: Paper Coating

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.5%
- Chicago, IL: 1.8%
- Washington, DC: 0.0%
- Houston, TX: 1.1%
- Philadelphia, PA: 1.4%

BASELINE CONTROLS: CTG - Surface Coating of Cans, Coils, Paper, Fabric, Autos & Light Duty Trucks

VOC limits (lbs VOC/gallon coating (minus water)):
2.8 - paper coatings

Further Control Options	Efficiency	$/ton from Lit.
Use of low-solvent coatings and recordkeeping.	1%	$5,000

DISCUSSION:

Paper coating includes the coating of adhesive tapes and labels, book covers, post cards, office copier paper, pressure sensitive tape and other forms of paper. In paper coating operations, resins are dissolved in an organic solvent or solvent mixture, and then this solution is applied to a continuous roll of paper. As the coating dries, solvent evaporates and the coating cures. These coatings are applied for a variety of decorative and protective purposes.

Generally, in paper coating operations VOC emissions occur in the coating area, the preheat and baking zones, and as the coated surface dries.

SOURCE:

1. CTG -- EPA 450/2-77-008, 1977.
2. SCAQMD, 1991.

SOURCE CATEGORY: Pesticide Application

RELATIVE SOURCE SIZE:

- Baltimore, MD: 1.9%
- Chicago, IL: 0.7%
- Washington, DC: 0.0%
- Houston, TX: 0.3%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: All states regulate pesticide use to some degree.

Further Control Options	Efficiency	$/ton from Lit.
- Changes in pesticide formulation. - Changes in pesticide application. - Alternative methods to control pests.	30-45%	$1,600

DISCUSSION:

Pesticides are widely used by agricultural and commercial enterprises to control insects, fungus, animal pests, weeds and other undesirable plant growth, and many other types of pests.

Pesticide formulations consist of synthetic or nonsynthetic materials which contain reactive organic compounds. Synthetic organic materials contain the toxic material used to control or mitigate the pest. Nonsynthetic organic materials are used as synergists, inhibitors, solvents, emulsifiers, wetting agents, spreaders, stickers, perfumes and adjuvants. Petroleum are also applied directly for the control of insects and mites on fruit trees, weed, and fungus on produce.

Techniques for reducing VOC emissions from the application of agricultural pesticides include: formulating organic-solvent containing pesticide formulations; using alternative application methods; and using integrated pest management (IPM) to reduce the use of pesticides.

Changes in pesticide formulations include: minimizing the use of petroleum-borne formulations and substituting with waterborne or dry formulations; adding thickening agents to increase particle size to reduce spray drift; and substituting lower vapor pressure solvents to reduce evaporation.

Changes in application techniques include: dusting the soil with pesticides rather than spraying; modifying the design of the spray device to prevent the formation of fine droplets during application; lowering the spray nozzle height; and incorporating the pesticide in the soil immediately following, or in place of, spraying.

Although EPA is not now developing any regulations to limit VOC emissions from pesticide application, the agency is considering including pesticide VOC control in the Federal Implementation Plan for several district in California. In March 1993, EPA published an Alternative Control Technology (ACT) document for the control of VOC emission from the application of agricultural pesticides.

SOURCE:

1. SCAQMD, 1991.
2. STAPPA, 1993.

SOURCE CATEGORY: Petroleum Refineries

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 1.5%
- Washington, DC: 0.0%
- Houston, TX: 15.3%
- Philadelphia, PA: 6.5%

BASELINE CONTROLS: Possible Regulatory Requirements Affecting Baseline:

- CTG: Storage Tanks
- NSPS: Petroleum Refinery Wastewater
- NSPS: VOL Liquid Storage
- NSPS: Fugitive Emissions from Petroleum Refineries
- Benzene NESHAP
- Benzene Waste Operations NESHAP
- Hazardous Organic NESHAP

Further Control Options			Efficiency	$/ton from Lit.
35%	Tanks: Vapor recovery system, External/internal floating roof tanks, Primary/secondary seals.		77%	$120 - 12,320
30%	Fugitives:	Alternative II (baseline)	0%	
		Alternative III	8%	$(30)-94
		Alternative IV	10%	$280-380
		Alternative V	13%	$320-450
		Alternative VI	24%	$5,380-5,850
20%	Wastewater Treatment: Nothing further.		--	--
15%	Process Vents: Flaring, venting to existing device or incineration for all cases.		---	---

DISCUSSION:

The petroleum industry, due to its size and complexity, is difficult to summarize as a singular source category. This industry has been a large point source emitter for many years and the regulatory grasp is fairly tight. With the recently proposed benzene NESHAP and the benzene wastewater NESHAP, the probable further control levels are not well defined. We have had difficulty determining the baseline level of controls because of uncertain rule penetration.

Tanks:

Previous studies performed by Radian have shown tank emissions as a significant contributor to the industries emission counts. For a detailed description of baseline levels and control alternative, see Volatile Organic Liquid Storage.

Fugitive Leaks:

Alternative II: is a leak detection and repair program as well as equipment specifications. The requirements of this alternative are based upon the recommendations of the refinery VOC leak CTG document. This alternative entails: yearly monitoring for valves in light liquid service and pump seals in light liquid service; quarterly monitoring for leaks from valves, pressure relief devices, and compressors; weekly visual inspection of pump seals; and capping of open-ended lines.

Alternative III: increases the frequency of equipment inspections and by specifying additional equipment requirements. This alternative requires: quarterly and monthly inspection of light liquid valves and light liquid pump seals, respectively; installation of rupture disks for safety/relief valves and by mechanical contact seals with controlled degassing reservoirs for compressors and other requirements as in Alterative II.

Alternative IV: reductions achieved by installing dual mechanical seals with a barrier fluid system and degassing reservoir vents on light liquid pumps. Other controls remain as in Alternative III.

Alternative V: increases emission control by requiring more frequent inspections on gas/vapor and light liquid valves. Valve monitoring is required on a monthly basis. All other specifications remain as in Alternative IV.

Alternative VI: offers the highest level of emission reduction of the regulatory alternatives. This alternative controls fugitive VOC emissions through stringent equipment specifications. Alternative VI employs the equipment specifications required in Alt. V with the addition of sealed bellows valves on gas/vapor and light liquid service valves.

Wastewater:

Nearly all the refineries in the Houston/Galveston area have reported that they come under Benzene Waste Operations NESHAP regulations. Therefore, it could be substantiated that a large fraction of the total reported VOC emissions in the emission inventory may already be controlled through this NESHAP. Also, additional controls from other regulations, such as the Hazardous Organic NESHAP, will further reduce this number. It is clear from the current inventory that a substantial emission reduction has most likely occurred from the synergy with the Benzene Waste Operations NESHAP (and other regulations).

Several oil and gas associations are looking at minimizing the regulatory impact of the RFP SIP on their industry. One opportunity is to take credit for the emission reductions that will occur after 1990 but prior to 1996 as a result of the implementation of existing federal regulation. The benzene wastewater NESHAP regulations are a primary example. These associations believe that this NESHAP compliance efforts will satisfy a significant portion of the RFP SIP emission reduction goal and will negate the need to implement additional regulatory requirements on their industry.

SOURCE:

1. HRM, 1987
2. CTGs, NSPS, NESHAP

SOURCE CATEGORY: Plastic Parts Manufacturing

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.3%
- Chicago, IL: 0.8%
- Washington, DC: 0.0%
- Houston, TX: 1.8%
- Philadelphia, PA: 0.3%

DISCUSSION:

Radian has had difficulty determining possible control measures for this source category. Studies have been done by the Michigan EPA and the Wisconsin EPA looking into the sources of VOC emissions from plastic parts manufacturing.

The manufacturing process uses extrusion of plastic feedstock to produce the final product. The plastic material is melted and the molten mixture is either poured into a mold or blown to create the product. Flashoff from the melting ovens and fugitive emissions during the drying process provides the largest sources of organic emissions.

Radian has not developed a control strategy for this source due to uncertainties with the industry. Control technologies similar to the SOCMI and polymer industries may be applicable for plastic parts manufacturing, but without further information, an analysis is not possible.

SOURCE CATEGORY: Synthetic Organic Chemical Manufacturing (SOCMI)

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 2.0%
- Washington, DC: 0.0%
- Houston, TX: 0.0%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: The following regulations have an impact on the SOCMI industry:
- NSPS for: Fugitive Emissions, Air Oxidation, Distillation, Reactor Processes, and Volatile Organic Liquid Storage
- Draft CTG for distillation and air oxidation.
- CTG for Air Oxidation
- SOCMI NESHAP

Further Control Options		Efficiency	$/ton from Lit.
53%	WW Collection and Treatment: Steam Stripping	83-92%	$387-3,000
41%	Process Vents: RACT level of control for reactor and distillation process vents @ 98% control efficiency.	80%	$10-20,000
6%	Equipment Leaks:		
	Alternative I (baseline-required)	0%	$(75)-1,404
	Alternative II	13%	$(77)-1,065
	Alternative III	32%	$477-1,610
	Alternative IV	42%	$956-1,989
1%	Tanks:	60-95%	$120-12,320

DISCUSSION:

The synthetic organic chemical manufacturing industry (SOCMI) is a large and diverse industry manufacturing hundreds of major chemicals through a variety of chemical processes. The overall SOCMI can be described as a series of production stages. The first stage consists of the collection and separation of naturally occurring organic materials into their usable chemical components. Second stage facilities use the industrial products from the first stage plants as raw materials and are characterized by medium-sized plants that make a variety of final products in medium-sized volumes The third stage consists of facilities that produce specialty chemicals and have a low volume of production and high unit manufacturing costs.

The SOCMI category relative breakdown used is based on the national primary air pollution impacts developed as part of the SOCMI NESHAP. This highlights the wastewater treatment and process vents as the major VOC emission sources.

Wastewater: The effect of the benzene NESHAP on the wastewater collection and treatment operations is unknown. Under the SOCMI hazardous organic NESHAP (HON), the required removal efficiencies are based on steam stripping. Whether units comply with the draft CTG for Industrial WW or the HON NESHAP regulations, it appears that the level of control is similar. For the purposes of our analysis, we are assuming that the application of RACT level controls, steam stripping, will be the recommended control option. A further description of this category can be seen in the Industrial WWTF section.

Process Vents: The major processing steps involved in SOCMI plants can be classified into two broad categories: conversion and separation. Conversion processes comprise the reactor processes segment of the industry. Separation processes includes distillation operations which is the predominant separation technique used in large scale organic chemical manufacturing plants.

VOC emission points from reactor process include process vent streams from reactors and product recovery systems such as condensers, absorbers, and adsorbers. For distillation operations, the common emission points for several types of distillation units, include condensers, accumulators, vacuum pumps and pressure relief valves.

The draft CTG prepared by the EPA for SOCMI reactors and distillation processes describes controls, such as thermal incinerators and flares, that are applicable to all SOCMI reactor and distillation processes and can reduce VOC emissions by about 98 percent. A CTG for air oxidation units exists requiring similar levels of control.

The proposed HON also requires 98 percent control of reactor, air oxidation, and distillation vents that meet certain applicability criteria.

Lastly, the NSPS standards developed for air oxidation operations, distillation operations, and reactor processes affect facilities constructed or reconstructed since the early 1980's. These regulations provide similar levels of control as those previously discussed.

Fugitive Leaks: Fugitive leaks come from a variety of sources within the SOCMI industry, these sources include: valves, pumps, connectors, compressors, pressure relief devices, open-ended lines, sampling connection systems, instrumentation systems, and closed-vent systems and control devices.

The CTG for VOC leaks from the SOCMI industry defines several alternative levels of control:

Alternative I: is a leak detection and repair program with an action level of 10,000 ppm and the following monitoring requirements: quarterly monitoring of vapor valves, compressor seals, and pressure relief valves; yearly monitoring of light liquid pump seals and light liquid valves.

Alternative II: is a leak detection and repair program with an action level of 10,000 ppm and the following monitoring requirements: quarterly monitoring of light liquid pump seals, vapor and light liquid valves, compressor seals, and vapor relief valves.

Alternative III: is the same as Alternative II but with the retrofit of rupture disks on vapor relief valves and the deletion of vapor relief valve detection and repair.

Alternative IV: is the same as Alternative III but with the retrofit of dual seals (with barrier fluid and degassing systems) to light liquid pumps, the retrofit of degassing vents to compressors, and the deletion of pump and compressor leak detection and repair.

The control of fugitive leaks is also covered under the HON regulations, requiring inspection and repair standards, test methods and procedures, recordkeeping, and reporting requirements. The proposed HON would require some additional equipment relative to the CTG requirements, and has lower leak definitions. The HON will affect many of the same processes as the CTG; however, the HON only affects equipment containing >5% volatile HAP.

Tanks: (See Volatile Organic Liquid Storage)

SOURCE:

1. STAPPA, 1993.
2. LMOCP, 1993
3. HON FR Notice 12/31/92 FR
4. CTGs, NSPS, NESHAP

SOURCE CATEGORY: Organic Chemical Manufacture - Others (Chicago)

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 2.6%
- Washington, DC: 0.0%
- Houston, TX: 10.3%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS:

Further Control Options	Efficiency	$/ton from Lit.
Add-on controls: Afterburners and condensers.	20%	$800-2,000

DISCUSSION:

The Lake Michigan Ozone Control Program did a site-specific analysis of this category in for the Chicago non-attainment area, the following information details their proposed control strategy.

Synthetic organic chemicals are manufactured in a multi-level system of processes that are based on about ten feedstock or building-block chemicals which are principally produced in petroleum refineries. These chemicals are the feedstock or ingredients for many of the miscellaneous organic chemical manufacturing industries that produce polymers, resins, plastic products, gasoline and oil additives, fibers, dyes, synthetic rubber and rubber additives, pesticides, herbicides, soap, detergent, food flavoring, etc.

In the Illinois inventory, Organic Chemical Manufacturing is divided into four segments: polyethylene, polyproplylene, polystrene, and others. The "Others" category is also distinguished from synthetic organic chemical manufacturing, which produce any of the 365 chemicals listed as SOCMI products.

In this source category, there are 64 plants with over 450 emission units. For 40 of the plants, actual VOC emissions are less than 25 TPY. There are 12 plants with actual emissions greater than 100 TPY.

In the Chicago nonattainment area, Illinois regulates VOC emissions which are not covered by CTG's with a set of generic non-CTG rules. Whereas other states regulate on a source-specific basis, Illinois regulates on the basis of five generic rules. These rules require, as RACT, an 81 percent reduction of uncontrolled emissions.

The generally available technologies for the control of VOC emissions from miscellaneous organic chemical manufacturing are add-on controls, e.g. condensation, adsorption, and thermal oxidation. These emission control technologies have been widely applied at MOCMI plants for many years. Condensation is particularly attractive due to the conservation of expensive material which are used in most operations. Source by source analysis and evaluation was required to ascertain the most reasonable add-on control for each situation.

Of the emissions in this category in Illinois, 70 percent are from plants whose emissions are greater than 100 TPY. These sources are regulated by Illinois rules. No further emissions reduction are anticipated from these plants. The remainder of the emissions are from those plants whose annual emissions are less than 25 TPY. If an 81 percent reduction of emissions is technically feasible and economically reasonable, additional reductions may be achievable from this category.

SOURCE:

1. LMOCP, 1993.

SOURCE CATEGORY: Service Station Loading (Stage I)

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.2%
- Chicago, IL: 1.1%
- Washington, DC: 1.4%
- Houston, TX: 0.6%
- Philadelphia, PA: 2.9%

BASELINE CONTROLS: CTG - Stage I Vapor Control System, Gasoline Service Stations

Further Control Options	Efficiency	$/ton from Lit.
Use of a fail-safe, stage I vapor recovery system with automatic shut-off of the system if it is not functioning properly.	Not Available	Not Available

DISCUSSION:

Gasoline service stations receive their gasoline from tank trucks. The Stage I vapor recovery systems route the gasoline vapors displaced from the stationary storage tank by the incoming fuel to the delivery truck. The delivery truck stores the vapors in its on-board tank and later transfers the vapors to the terminal or bulk plant for processing into liquid fuel or disposal by and acceptable emission control technique.

Stage I systems have been used for more than 10 years in the U.S. to reduce VOC emissions. These systems reduce vapor-filling losses by at least 96 percent when operating at design efficiency. System performance in practice may be significantly less than the design efficiency because of human errors in operating the system.

The South Coast AQMD is proposing to require the use of fail-safe equipment in all stage I fuel transfer systems. Under this measure, existing designs will be modified for reliable, automatic shutdown of gasoline flow at any time the system is not functioning properly.

A fail-safe system is not commercially available at this time, therefore cost information and control efficiency estimates are not yet available.

SOURCE:

1. SCAQMD, 1991.

SOURCE CATEGORY: Marine Vessel Loading (Ship & Barge Transfer)

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 0.2%
- Washington, DC: 0.0%
- Houston, TX: 1.6%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: Possibly the Benzene NESHAP and U.S. Coast Guard regulations.

Further Control Options	Efficiency	$/ton from Lit.
Application of vapor balancing, vapor collection or vapor combustion devices.	80-98%	$300-8,000 (LMOCP) $550-6,800 (STAPPA)

DISCUSSION:

Marine vessel loading refers to the loading of tank ships and barges with volatile liquids. Evaporate emissions from marine vessel loading occur primarily as a result of loading losses which occur when organic vapors in an empty vessel are displaced by the incoming liquid.

Vapor balancing, refrigeration, carbon adsorption, incineration or a combination of these methods can be used to reduce VOC vapor emissions from marine vessel loading. The emissions control equipment can be located either on the vessel itself or onshore at the terminal. The control methods require a shipboard vapor collection system, a ship-to-shore connection, a shoreside vapor transfer system and a final control device.

Presently, some terminals are using inert gases to displace the organic vapors evaporate during loading. These displaced gases are collected and routed to a vapor control device.

In May 1992, EPA issued a technical support document for proposed standards for marine vessel loading operations. Currently, marine vessel loading volatile liquids containing more than 70 weight-percent benzene are regulated under the Benzene Transfer Operations standard requiring a vapor collection system and control device capable of reducing benzene emissions by 98 weight-percent. Although there has not been federal requirements, several states have adopted rules. SCAQMD, BAAQMD, Louisiana and New Jersey have adopted marine vapor recovery requirements. Texas, Washington, Alaska, and Pennsylvania have considered adopting similar regulations.

SOURCE:

1. CTG
2. STAPPA, 1993.
3. LMOCP, 1993.
4. Personal communication. Lynn McGuire.

SOURCE CATEGORY: Storage and Warehousing

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 0.0%
- Washington, DC: 0.0%
- Houston, TX: 1.4%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: Possible baseline penetration by VOL NSPS, Benzene NESHAP, and CTGs.

Further Control Options	Efficiency	$/ton from Lit.
- Vapor recovery systems. - External/internal floating roof tanks. - Primary/secondary seals.	60-95%	$120-12,320

DISCUSSION:

Volatile organic liquids are typically stored in vertical or horizontal tanks. VOCs are emitted through tank breathing or diffusional losses, which result from changes in ambient air temperature and barometric pressure, and through liquid working losses, which result from the displacement of vapors as the tanks are filled. Storage and warehousing differs from the volatile organic liquid storage category because with storage and warehousing facilities, the liquids being stored in the tanks are not owned by the facility operators.

The USEPA has published two control technique guideline documents (CTG) and promulgated three New Source Performance Standards (NSPS) which establish the major components of the regulatory baseline. This history of regulatory action makes the baseline control scenario complex. Due to the fixed-roof tank CTG, it is reasonable to assume that all fixed-roof tanks with volumes of 40,000 gallons and greater storing liquids with true vapor pressures of 1.5 psia or greater were converted to internal floating roof tanks in nonattainment areas. This conversion occurred because the majority of the States did not distinguish between petroleum liquids and other VOL's in implementing the CTG. Because the control cutoffs of the petroleum NSPS are also 40,000 gal and 1.5 psia, and compliance for all three regulatory actions could be achieved with a low-cost, noncontact internal floating roof with a vapor-mounted primary seal only and uncontrolled fittings, it is reasonable to assume this type of internal floating roof tanks as the baseline, as opposed to other, higher-cost control options. Below 40,000 gal or 1.5 psia, few States require controls. Therefore, it is reasonable for the purposes of RACT analysis to assume only fixed-roof tanks exist with volumes less that 40,000 gal or volumes above 40,000 gal storing liquids less than 1.5 psia (LMOCP, 1993).

The external floating roof baseline cases are more complex because of previous regulatory actions affecting these tanks. First, as a result of the CTG and the NSPS, it is reasonable to assume riveted external floating roof tanks in nonattainment areas are controlled with rim-mounted secondary seals at vapor pressures of 1.5 psia or greater. For these riveted tanks, it is reasonable to assume a shoe seal as the primary seal. Second, some welded tanks are equipped with vapor-mounted primary seals. These are divided into a controlled (rim-mounted secondary seal) subgroup, which can be defined as having liquid vapor pressures of 1.5 psia and greater, and an uncontrolled subgroup, with vapor pressures less than 1.5 psia. Third, the populations of external floating roofs with liquid-mounted or shoe seals may be categorized as: tanks uncontrolled by both the NSPS and the CTG; tanks controlled by both the NSPS and the CTG; and tanks controlled by the NSPS but not controlled by the CTG (LMOCP, 1993).

USEPA has issued a draft CTG in September 1991 which gives guidelines to control organic emissions further from VOC storage in floating and fixed roof tanks.

The draft CTG includes control options under consideration as potential RACT for controlling volatile organic compound emissions from fixed roof, internal floating roof and external floating roof tanks containing 40,000 gallons or greater volume of VOL with vapor pressure less than 11.1 psia (optional vapor pressure cutoff value of 0.5, 0.75, 1.0, and 1.5 psia) in ozone non-attainment areas. Control options for fixed roof and internal floating roof are: (1) installation of internal roof, vapor mounted primary seal with uncontrolled deck fittings, (2) internal floating roof, vapor mounted primary seal only with controlled deck fitting, (3) internal floating roof, vapor mounted primary and secondary seals with controlled deck fitting, (4) internal floating roof, liquid mounted primary and secondary seals, with controlled deck fittings, (5) internal floating roof tank, welded construction, liquid mounted primary and secondary seals, with controlled deck fitting (LMOCP, 1993).

For external floating roof tank the control options are: (1) external floating roof, riveted construction with mechanical shoe primary seal and secondary seal with controlled fittings, (2) external floating roof, with vapor-mounted primary and secondary seals with controlled fitting, (3) external floating roof with liquid-mounted primary and secondary seals with controlled fittings (LMOCP, 1993).

Add-on controls are also an effective method of controlling vapors displaced by the incoming liquid in fixed roof tanks. VOC emissions can be controlled by carbon adsorption or by thermal or catalytic oxidation.

The costs involved to equip fixed roof, internal floating roof, and external floating roof tanks with control equipments depends on the control option and tank size and type. For this reason, the cost of control varies significantly.

SOURCE:

1. CTG
2. LMOCP, 1993.
3. STAPPA, 1993.

SOURCE CATEGORY: Textile, Resins and Polymers Manufacturing

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 0.5%
- Washington, DC: 0.0%
- Houston, TX: 0.0%
- Philadelphia, PA: 0.0%

DISCUSSION:

We have encountered difficulties determining the baseline control for this source category. The draft CTG for Batch Processes refers to operations used on a noncontinuous basis to manufacture products. Batch process are used in manufacturing polymers (resins), pharmaceutical products, pesticides, and synthetic organic chemicals. The draft Batch CTG is a grab-bag that can contain all process vents. In the Lake Michigan Ozone Control Program study, they also made references to the polymer (resin) manufacturing industry within the Organic Chemical Manufacturing - Others. We are assuming that this category does not fall under the requirements mandated for the synthetic organic chemical manufacturing industry, including the CTG and draft CTGs for process vents, equipment leaks, and industrial wastewater as well as the new hazardous organic NESHAP (HON) requirements. The SOCMI regulations were targeted at continuous production processes.

Independent of the category, most of the regulations for these industries consider setting limits of 98 percent control efficiency for all process streams, as achieved by current technologies.

Control techniques available for batch processing are condensation, absorption, adsorption, oxidation, and vapor containment. Because of the intermittent nature of flows in batch processing, control techniques should be capable of effectively processing emissions from both peak periods and no-flow periods.

EPA's draft CTG presents three control options: Option 1 would provide 98 percent control of process vents; Option 2 would provide 95 percent control; and Option 3 would provide 90 percent control.

SOURCE:

1. Draft CTG
2. STAPPA, 1993.
3. LMOCP, 1993.

SOURCE CATEGORY: Traffic/Maintenance Paints

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.2%
- Chicago, IL: 0.5%
- Washington, DC: 0.7%
- Houston, TX: 0.2%
- Philadelphia, PA: 0.5%

BASELINE CONTROLS: None (Except New York and California)

Further Control Options	Efficiency	$/ton from Lit.
- Develop rule limiting the VOC content to 250 grams VOC/liter. - Use low- or no-solvent markings	40-53%	$(1,462) savings

DISCUSSION:

Traffic/maintenance paints are used by State or local highway maintenance crews or by contractors to mark pavement roadways and bridges. These markings include traffic lane center lines and edge stripes, parking space markings, crosswalks, arrows, and other directional markings. The VOC emissions occur from the evaporation of organic solvents during and shortly after the paint is applied.

The California Air Resources Board (CARB) developed a model rule for architectural coatings that regulates traffic paints. The model rule prohibits the sale, or manufacture for sale, of any traffic paint containing more than 250 grams VOC/liter of coating.

Traditional containment devices or add-on controls are not applicable to this source category. Emissions of VOCs can be reduced by using lower VOC-emitting paints. Alternative markings include water-based paints, thermoplastics, preformed tapes, field-reacted materials and permanent markers.

The adoption of a rule similar to the CARB model rule, requiring a VOC limit of 250 g/l has could reduce emissions by 40 to 53 percent.

EPA is developing regulations as part of a regulatory negotiation for Architectural and Industrial Maintenance coatings, of which highway paints are a part.

SOURCE:

1. LMOCP, 1993.
2. STAPPA, 1993.

SOURCE CATEGORY: Underground Storage Tank Breathing

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.3%
- Chicago, IL: 0.4%
- Washington, DC: 0.2%
- Houston, TX: 0.3%
- Philadelphia, PA: 0.7%

BASELINE CONTROLS: Stage I vapor balance systems.

Further Control Options	Efficiency	$/ton from Lit.
Pressure/Vacuum Relief Valves for Vent Pipes.	80%	$64-230

DISCUSSION:

Underground storage tanks at service stations are passively vented to the atmosphere via a vent pipe. Emissions from the vent pipe occur when vehicles are being fueled at the pump, when fuel is being dropped from a gasoline transport using a Stage I vapor balance system and from diurnal temperature changes. Stage I controls were intended to control emissions from vents during tank loading operations by channeling displacement vapors into the delivery truck through pipes and hoses.

Even with the Stage I controls, gasoline vapor losses still occur. One uncontrolled source of gasoline vapor losses is through the underground gasoline tank vent pipe. The vent pipe emissions result from breathing losses which are caused by vapor and liquid expansion and contraction due to diurnal temperature changes. Currently, service stations equipped with the Balance-type systems are not required to have pressure relief valves.

The control measure proposes that all open vent pipes be equipped with a low pressure/vacuum (P/V) relief valve. P/V valves can be installed to maintain pressure within the tank. An ideal pressure setting for the P/V relief valves will need to be determined in order to achieve optimum emission reductions, therefore some source testing may be required.

The Bay Area AQMD is conducting additional testing to determine if P/V vents could also increase the efficiency of Stage I and Stage II vapor recovery systems.

The LMOCP expected a 90 to 100 percent control efficiency in its service station tank breathing source category as well as further emissions reduction in its Stage I and Stage II source categories. Assuming a rule effectiveness of 80 percent and a 100 percent rule penetration, an emission reduction estimate of 80 percent was made.

SOURCE:

1. LMOCP, 1993.
2. STAPPA, 1993.
3. SCAQMD, 1991.
4. BAAQMD, 1991.

SOURCE CATEGORY: Volatile Organic Liquid Storage

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 0.9%
- Washington, DC: 0.0%
- Houston, TX: 0.0%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: Possible baseline penetration by VOL NSPS, Benzene NESHAP, and CTGs.

Further Control Options	Efficiency	$/ton from Lit.
- Vapor recovery systems. - External/internal floating roof tanks. - Primary/secondary seals.	60-95%	$120-12,320

DISCUSSION:

Volatile organic liquids are typically stored in vertical or horizontal tanks. VOCs are emitted through tank breathing or diffusional losses, which result from changes in ambient air temperature and barometric pressure, and through liquid working losses, which result from the displacement of vapors as the tanks are filled.

The USEPA has published two control technique guideline documents (CTG) and promulgated three New Source Performance Standards (NSPS) which establish the major components of the regulatory baseline. This history of regulatory action makes the baseline control scenario complex. Due to the fixed-roof tank CTG, it is reasonable to assume that all fixed-roof tanks with volumes of 40,000 gallons and greater storing liquids with true vapor pressures of 1.5 psia or greater were converted to internal floating roof tanks in nonattainment areas. This conversion occurred because the majority of the States did not distinguish between petroleum liquids and other VOL's in implementing the CTG. Because the control cutoffs of the petroleum NSPS are also 40,000 gal and 1.5 psia, and compliance for all three regulatory actions could be achieved with a low-cost, noncontact internal floating roof with a vapor-mounted primary seal only and uncontrolled fittings, it is reasonable to assume this type of internal floating roof tanks as the baseline, as opposed to other, higher-cost control options. Below 40,000 gal or 1.5 psia, few States require controls. Therefore, it is reasonable for the purposes of RACT analysis to assume only fixed-roof tanks exist with volumes less that 40,000 gal or volumes above 40,000 gal storing liquids less than 1.5 psia (LMOCP, 1993).

The external floating roof baseline cases are more complex because of previous regulatory actions affecting these tanks. First, as a result of the CTG and the NSPS, it is reasonable to assume riveted external floating roof tanks in nonattainment areas are controlled with rim-mounted secondary seals at vapor pressures of 1.5 psia or greater. For these riveted tanks, it is reasonable to assume a shoe seal as the primary seal. Second, some welded tanks are equipped with vapor-mounted primary seals. These are divided into a controlled (rim-mounted secondary seal) subgroup, which can be defined as having liquid vapor pressures of 1.5 psia and greater, and an uncontrolled subgroup, with vapor pressures less than 1.5 psia. Third, the populations of external floating roofs with liquid-mounted or shoe seals may be categorized as: tanks uncontrolled by both the NSPS and the CTG; tanks controlled by both the NSPS and the CTG; and tanks controlled by the NSPS but not controlled by the CTG.

USEPA has issued a draft CTG in September 1991 which gives guidelines to control organic emissions further from VOC storage in floating and fixed roof tanks.

The draft CTG includes control options under consideration as potential RACT for controlling volatile organic compound emissions from fixed roof, internal floating roof and external floating roof tanks containing 40,000 gallons or greater volume of VOL with vapor pressure less than 11.1 psia (optional vapor pressure cutoff value of 0.5, 0.75, 1.0, and 1.5 psia) in ozone non-attainment areas. Control options for fixed roof and internal floating roof are: (1) installation of internal roof, vapor mounted primary seal with uncontrolled deck fittings, (2) internal floating roof, vapor mounted primary seal only with controlled deck fitting, (3) internal floating roof, vapor mounted primary and secondary seals with controlled deck fitting, (4) internal floating roof, liquid mounted primary and secondary seals, with controlled deck fittings, (5) internal floating roof tank, welded construction, liquid mounted primary and secondary seals, with controlled deck fitting.

For external floating roof tank the control options are: (1) external floating roof, riveted construction with mechanical shoe primary seal and secondary seal with controlled fittings, (2) external floating roof, with vapor-mounted primary and secondary seals with controlled fitting, (3) external floating roof with liquid-mounted primary and secondary seals with controlled fittings (LMOCP, 1993).

Add-on controls are also an effective method of controlling vapors displaced by the incoming liquid in fixed roof tanks. VOC emissions can be controlled by carbon adsorption or by thermal or catalytic oxidation.

The costs involved to equip fixed roof, internal floating roof, and external floating roof tanks with control equipments depends on the control option and tank size and type. For this reason, the cost of control varies greatly.

SOURCE:

1. CTG

2. LMOCP, 1993.
3. STAPPA, 1993.
4. CTG
5. Draft CTG

Rule Effectiveness Improvement

Rule effectiveness (RE) improvement refers to an improvement in the implementation of a regulation. An RE improvement may take several forms, ranging from more frequent and in-depth training of inspectors to larger fines for sources that do not comply with a given rule. RE improvements are an important issue in areas that have already adopted reasonable available control technology for many of their sources.

The purpose of an RE improvement is to give state and local agencies additional means for achieving actual reductions for the State Implementation Plans (SIP). Title I of the Clean Air Act identifies RE improvements as one of the measures that can be used to meet the 15-percent VOC reduction requirements by November 15, 1996.

The establishment of the original RE can be accomplished by three methods in accordance with EPA guidelines. These three methods include the 80 percent default, the questionnaire approach, and the Stationary Source Compliance Division (SSCD) protocol approach.

For controlled sources, a default value of 80 percent is used. This reflects the fact that not all sources comply with regulatory requirements and those sources that have complied with the requirements often operate in a non-compliant manner. USEPA allows creditable reductions for programs instituted by the States which increase rule effectiveness.

APPENDIX E

Stationary Source NO_x Control Measures

SOURCE CATEGORY: Cement Kilns

RELATIVE SOURCE SIZE:

- Baltimore, MD:
- Chicago, IL: 0%
- Washington, DC: 0%
- Houston, TX: 0%
- Philadelphia, PA:

BASELINE CONTROLS: Uncontrolled emissions 3.3 - 5.3 lb/ton clinker (coal), 10.3 - 16.7 lb/ton (natural gas). No controls required outside of California. ACT documents to be developed for all sources over the 25 TPY limit.

Further Control Options	Efficiency	$/ton from Lit.
LEA -- Sintering operations. Wet process, gas fired kilns.	14% (Rad 3,4)	N/A
LEA -- Sintering operations. Long dry / precalciner kilns.	0 - 20% (CIEC)	Low cost
LNB -- Sintering operations. Long dry / precalciner kilns.	10 - 30% (CIEC)	Low cost
Staged Combustion -- Calcining operations. Precalciner retrofit easier than long dry.	20 - 50% (CIEC)	Low cost
SNCR -- Calcining operations. Precalciner retrofit easier than long dry.	40 - 70% (CIEC)	Medium cost
SC + SNCR -- Calcining operations. Precalciner retrofit easier than long dry.	40 - 90% (CIEC)	Medium cost
SCR -- Preheater, long dry process, and precalciner kilns. Unproven feasibility.	70 - 90% (CIEC) 80% (SCAQMD)	High cost 1,600 (SCAQMD)
Wet Scrubbing -- Limited application to exhaust streams around 10,000 ppm.	90% (SCAQMD)	1,600 (SCAQMD)

DISCUSSION: NO_x emissions from cement kilns vary depending upon kiln configuration as well as fuel type. Kilns can be of wet process, preheater, precalciner, or long dry configurations. Of these kiln types, preheater and precalciner units have lower uncontrolled NO_x emissions than do long dry and wet systems, a result of higher fuel efficiencies and lower firing rates in the burner zone. Surprisingly, coal-fired units exhibit lower NO_x emissions than do natural gas units, because thermal NO_x formation tends to dominate over fuel NO_x.

The control option chosen for a kiln should consider the fuel types used. Many kilns burn oil, gas, and/or coal, depending upon spot market prices and short term fuel availability. Therefore the control technology approach should be compatible with these changing operating conditions if possible. However, it is difficult to predict the ultimate effectiveness of the controls noted above, given the very limited number of control applications to date (a few pilot scale trails and retrofits in California and Europe). The efficacy of wet scrubbing and final cost-effectiveness values for these options is yet to be determined.

SOURCE:

SCAQMD
Radian, CIEC presentation
Radian, Sustainable Materials Project
Radian, Misc

SOURCE CATEGORY: Chemical Manufacturing (SOCMI and Other)

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0%
- Chicago, IL: 0.4%
- Washington, DC: 0%
- Houston, TX: 10.6%
- Philadelphia, PA: 0.3%

BASELINE CONTROLS: Uncontrolled emissions about 0.3 lb/MMBtu for process heaters; up to 0.8 lb/MMBtu (typically 0.3-0.4) for oil/gas-fired boilers. No current controls outside of California (heaters and boilers regulated). LNBs beginning to penetrate heater market in other states. RACT to be adopted by states. Draft ACT available for heaters and industrial boilers.

Further Control Options	Efficiency	$/ton from Lit.
PROCESS HEATERS:		
SCA -- For natural draft systems.	45% (Pechan)	130-430 savings (Pechan)
LNB -- Largest reductions for oil-fired and forced-draft burners.	27% (Nat. Draft)* 58% (Forced Dr.)*	1,200-3,800* 805-2,640*
LNB + FGR --	55% (Gas)* 70% (Oil)*	2,000-5,000* 600-2,600*
Ultra-LNBs -- With internal FGR and/or steam injection.	75% (ACT)	300-2,000 (ACT)
SNCR --	60% (ACT)	12,700-14,400 (gas)* 3,000-7,000 (oil)*
SNCR + LNB --	70% (ACT)	12,000-15,700 (gas)* 900-8,000 (oil)*
SCR -- Best applied to large, forced draft, box types requiring frequent service.	80% (LMOS) 85% (w/ LNB)	9,800-14,300 (Rad) 17,500-22,500 (for small heaters) 11,000-17,000 (gas)* 2,600-11,600 (oil)*
BOILERS -- See industrial boiler section.		

*From ACT: 90% capacity factor, 80-250 MMBtu/hr for gas, 72 MMBtu/hr for oil.

DISCUSSION:

This section assumes that chemical manufacturing facilities have the same type of NO_x sources as do petroleum refineries, namely boilers and process heaters. Therefore this discussion closely parallels that section. However, CO boilers are most likely unique to petroleum refineries, and will not be discussed here.

Process heaters are used extensively to facilitate chemical reactions requiring heat inputs. Typical ratings range from 30 to 100 MMBtu/hr, though the largest units may be in the 500 MMBtu/hr range. Process heaters operate almost exclusively on oil or natural gas. The burners themselves use either forced or natural draft configurations. The air intake configuration has a direct impact on the emissions reductions achievable from these systems. On the whole, natural draft systems are more difficult to modify than forced draft systems, and costs will vary accordingly. Also, as with other retrofit strategies, post-combustion controls become very expensive on a dollar per ton basis for smaller heaters.

Boilers used in chemical manufacturing most likely use oil and/or natural gas for fuel. Of all oil/gas-fired boilers, approximately 90% use natural gas. These boilers are intrinsically cleaner than comparable coal-fired units, due to the lower nitrogen content of the fuels. Of these two fuels, gas produces somewhat lower NO_x emissions than oil units. Because of their lower emissions levels, oil/gas-fired systems may become the favored choice of ICI boiler operators in the future, wherever oil and/or gas is readily available. However, because of the lower baseline emissions from these units, fewer emissions reductions are achievable than from similar coal-fired systems.

Of oil and gas boilers, tangential-fired units are more expensive to retrofit with CMs than wall-fired units. Because T-fired units also have lower uncontrolled emissions than wall-fired ones, the resulting dollars per ton value becomes even higher. Similarly, distillate oil boilers are intrinsically cleaner than residual oil units. Accordingly, the dollars per ton values for controls applied to distillate oil burners are about twice as high as those for residual oil systems.

Because of the economies of scale associated with post-combustion controls, SNCR and SCR may only be cost-effective for larger industrial boilers. In addition, flue gas treatments operate effectively only within specific temperature windows. The unsteady loads encountered with smaller boilers may make for unstable temperature profiles and limit the effectiveness of SNCR and SCR in these cases. In any case, dollar per ton values for FGTs are much higher than for CMs. (For example, SCR systems are typically five times as expensive per ton controlled than LNBs.)

The addition of methanol to natural gas burners may prove to be another promising control. There have been no commercial applications of this process to date, however, and the cost-effectiveness is uncertain.

Finally, note that the controls noted above may also be used in combination to achieve lower emissions levels, as with utility boilers. Though control experience is limited with boilers of this size, potentially cost-effective controls are available. However, costs per ton increase dramatically as boiler sizes decrease to the 10 MMBtu/hr range, and few controls may be cost-effective for this size range.

SOURCE:

Hans Buening
Bay
Radian CO Boilers
Radian BIDS
Pechan
ACT

SOURCE CATEGORY: Glass Melting Furnaces

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0%
- Chicago, IL: 0.9%
- Washington, DC: 0%
- Houston, TX: 0%
- Philadelphia, PA: 0.1%

BASELINE CONTROLS: Uncontrolled emissions 5.6 - 23.6 lb/ton of glass, 8.0 from AP-42. No controls required currently. ACT guidance to be developed.

Further Control Options	Efficiency	$/ton from Lit.
LNB -- Variable applicability based on site-specific factors.	15-65% (30-50% typical) (Rad)	1,220-3,670 (Rad)
CMs (Various) -- Includes varying burner tilt, fuel injection rate, excess air.	5-36% (Rad)	570-1,500 (Rad)
Electrical Boosting -- Possibly only for container glass. Dependant on percent of boost.	5-35% (Rad)	4,200-21,000 (Rad)
Increased cullet use --	< 15% (Rad)	N/A
SNCR -- From California furnaces.	20-80% (40-65% typical) (Rad)	1,000-3,690 (Rad)
SCR -- No field data, very speculative.	75-90% (Rad)	1,260-6,420 (Rad)
Oxy-firing -- > 90% oxygen replaces combustion air.	85-90% (Rad)	3,150-9,280 (Rad)
Increase cullet charge, electrical boost, furnace insulation, reduce excess air, LNBs -- Control package from Bay Area Plan.	45-55% (Bay)	4,400 (Bay)
All-electric melting, advanced furnace designs, SNCR, alternative fuels -- Control package from SCAQMD.	95% (SC)	22,800 (SCAQMD)

DISCUSSION:

Glass melting furnaces are used in the manufacture of container glass, flat glass, pressed and blown glass, and fiberglass, with container glass facilities being the most common. These furnaces can be significant sources of NO_x due to the very high combustion temperatures required for the process. However, there is little to no experience in the U.S with controlling these emissions, with the exception of California (where there are 4 SNCR systems operating). Thus the numbers presented in the table above are very speculative. Emissions rates vary widely among differing boiler sizes and configurations, which in turn creates a wide range of potential cost-effectiveness estimates.

SOURCE:

Radian
LMOS
Bay
SC

SOURCE CATEGORY: Industrial/Commercial/Institutional Boilers -- Coal-Fired

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0% (Possibly under other categories)
- Chicago, IL: 8.5% (Coal, Oil & Gas)
- Washington, DC: 0.8% (Coal, Oil & Gas)
- Houston, TX: 0.0% (Possibly under other categories)
- Philadelphia, PA: 0.0% (Possibly under other categories)

BASELINE CONTROLS: Uncontrolled emissions 0.5 - 1.0 lb/MMBtu. NSPS standards for boilers >100 MMBtu/hr constructed after June 1984 (to 0.5-0.8 levels). No current regulations for older, or smaller boilers. RACT standards yet to be promulgated for sources > 25 TPY.

Further Control Options*	Efficiency	$/ton from Lit.
LEA -- Applicable to forced-air burners.	4 - 31%	N/A - (Savings ?)
SCA -- BOOS + OFA. For boilers > 25 MMBtu/hr. OFA not for largest units.	10 - 32% 36% (Pechan)	250 - 500 (Pech)
FGR -- Most boiler configurations.	20 - 45%	N/A
NGR -- Not applicable to small cyclones.	30 - 65%	N/A
LNB -- For boilers > 25 MMBtu/hr.	18 - 67%	1,600 - 2,100**
SNCR -- For larger boilers with steady loads.	33 - 46% 50 - 80% (Acurex) 40 - 80%	5,100 - 6,600**
SCR -- For larger boilers with steady loads.	80% (Pechan) 50 - 90% (Acurex)	3,400 - 9,200 (Pech)
Fuel Switching -- Seasonal use of natural gas.	70% (GRI)	N/A

* Unless noted, values taken from Lake Michigan Ozone Control Program Report, Apr 93

** For boilers rated at 250 MMBtu/hr

DISCUSSION:

Industrial/Commercial/Institutional boilers are used for a variety of applications, including steam and hot water production, small-scale electrical generation, and miscellaneous process needs. Industrial boilers typically are 30 - 150 MMBtu/hr, though units up to 850 MMBtu/hr can be found. These larger boilers are essentially the same as coal-fired utility boilers, and can use similar controls (see section on utility boilers). Unlike utility boilers, however, application of NO_x controls has been very limited, and many of the efficiency and cost numbers are based upon previous experience in the utility sector.

Coal-fired boilers are pulverized coal (PC), stoker, or cyclone configurations. By and large cyclone units are older boilers which are not amenable to combustion modifications, and may have to rely on flue gas treatment alone. Combustion modifications may be successfully applied to other boiler types. Of PC boilers, tangential-fired units are more expensive to retrofit with CMs than wall-fired units. Because T-fired units also have lower uncontrolled emissions than wall-fired ones, the resulting dollars per ton value becomes even higher.

Because of the economies of scale associated with post-combustion controls. SNCR and SCR may only be cost-effective for larger industrial boilers. In addition, flue gas treatments operate effectively only within specific temperature windows. The unsteady loads encountered with smaller boilers may make for unstable temperature profiles and limit the effectiveness of SNCR and SCR in these cases.

Seasonal fuel switching from coal to natural gas may also prove to be a cost-effective NO_x control strategy. Based on estimates from utility boilers, NO_x reductions may be on the order of 70%. However, the cost of retrofitting smaller boilers for dual-fuel capabilities is not known at this time. (See the section on utility boiler controls for a further discussion.)

Finally, note that the controls noted above may also be used in combination to achieve lower emissions levels, as with utility boilers. Though control experience is limited with boilers of this size, potentially cost-effective controls are available, especially when compared to oil and gas-fired boilers of similar capacity. (Oil & gas boilers typically have much lower baseline emissions than coal-fired units, thereby raising dollars per ton values even for similar percentage reductions.)

SOURCE:

LMOS
EPA
Acurex
Pechan
GRI

SOURCE CATEGORY: Industrial/Commercial/Institutional Boilers -- Oil/Gas-Fired

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0% (Possibly under other categories)
- Chicago, IL: 8.5% (Coal, Oil & Gas)
- Washington, DC: 0.8% (Coal, Oil & Gas)
- Houston, TX: 0.0% (Possibly under other categories)
- Philadelphia, PA: 0.0% (Possibly under other categories)

BASELINE CONTROLS: Uncontrolled emissions 0.1 - 0.8 lb/MMBtu, typically 0.3 - 0.4. No NSPS in place. RACT standards yet to be promulgated for sources > 25 TPY; draft ACT available.

Further Control Options*	Efficiency	$/ton from Lit.
LEA -- Values for oil-fired units.	36%	(5,900)
FGR -- Most boiler configurations. Values for natural gas units.	50% (Buening)	1,300 - 6,200
LNB + FGR --	70% (Buening)	--
SCR -- Only for larger boilers with steady loads.	80%	2,600 - 24,000
Combustion Modifications -- Overall.	5 - 75%**	
Flue Gas Treatment -- Overall.	50 - 90%**	
All controls -- CMs and/or FGTs.	30%**	Small/Med: 2,300 - 6,000 Med/Large: 500 - 5,000

* Unless noted, all values taken from Pechan, 1991.
** From the Lake Michigan Ozone Control Program Report, April 1993.

DISCUSSION:

Industrial/Commercial/Institutional boilers are used for a variety of applications, including steam and hot water production, small-scale electrical generation, and miscellaneous process needs. Industrial boilers typically are 30 - 150 MMBtu/hr, though units up to 850 MMBtu/hr can be found. These larger boilers are essentially the same as utility boilers, and can use similar controls (see previous section on utility boilers). Unlike utility boilers, however, application of NO_x controls has been very limited, and many of the efficiency and cost numbers are based upon previous experience in the utility sector.

Of all oil/gas-fired boilers, approximately 90% use natural gas. These boilers are intrinsically cleaner than comparable coal-fired units, due to the lower nitrogen content of the fuels. Of these two fuels, gas produces somewhat lower NO_x emissions than oil units. Because of their lower emissions levels, oil/gas-fired systems may become the favored choice of ICI boiler operators in the future, wherever oil and/or gas is readily available. However, because of the lower baseline emissions from these units, fewer emissions reductions are achievable than from similar coal-fired systems.

Of oil and gas boilers, tangential-fired units are more expensive to retrofit with CMs than wall-fired units. Because T-fired units also have lower uncontrolled emissions than wall-fired ones, the resulting dollars per ton value becomes even higher. Similarly, distillate oil boilers are intrinsically cleaner than residual oil units. Accordingly, the dollars per ton values for controls applied to distillate oil burners are about twice as high as those for residual oil systems.

Because of the economies of scale associated with post-combustion controls. SNCR and SCR may only be cost-effective for larger industrial boilers. In addition, flue gas treatments operate effectively only within specific temperature windows. The unsteady loads encountered with smaller boilers may make for unstable temperature profiles and limit the effectiveness of SNCR and SCR in these cases. In any case, dollar per ton values for FGTs are much higher than for CMs. (For example, SCR systems are typically five times as expensive per ton controlled than LNBs.)

The addition of methanol to natural gas burners may prove to be another promising control. There have been no commercial applications of this process to date, however, and the cost-effectiveness is uncertain.

Finally, note that the controls noted above may also be used in combination to achieve lower emissions levels, as with utility boilers. Though control experience is limited with boilers of this size, potentially cost-effective controls are available. However, costs per ton increase dramatically as boiler sizes decrease to the 10 MMBtu/hr range, and few controls may be cost-effective for this size range.

SOURCE:

EPA
Acurex
Pechan

SOURCE CATEGORY: Iron and Steel Manufacture

RELATIVE SOURCE SIZE:

- Baltimore, MD: 6.1%
- Chicago, IL: 0.6%
- Washington, DC: 0.0%
- Houston, TX: 0.0%
- Philadelphia, PA: 1.8%

BASELINE CONTROLS: Uncontrolled emissions from iron and steel manufacturing is highly variable, 0.02 - 0.8 lb/ton of steel, depending upon process, fuel, and cycling period. NSPS is in place for coal-fired industrial boilers. No other processes are regulated for NO_x. RACT requirements to be promulgated.

Further Control Options*	Efficiency	$/ton from Lit.
LEA -- Reheat furnace. Limited data for 15 to 30 MW loads.	24-43% (EPA)	N/A
LEA - Soaking pits. Limited data for about a 2 MW load.	< = 69% (EPA)	N/A
BOOS -- Reheat furnace. Limited data.	< = 43% (EPA)	N/A
FGR -- Rehaet furnace. Limited data.	50% (GRI)	N/A
LNB -- Metal melting furnaces.	50% (SCAQMD)	9,300 (SCAQMD)
Furnace overhaul -- specifics undefined.	40% (LMOCP)	N/A
SCR -- Processes not specified.	40-60% (LMOCP)	N/A
SNCR/NSCR -- Processes not specified.	80-90% (LMOCP)	N/A
Unspecified boiler controls	20-80% (LMOCP)	230-5,200 (20%) 1,700-7,400 (80%) (LMOCP)

*All test results based on gas-fired units.

DISCUSSION:

Iron and steel manufacturing consists of several different NO_x-producing sources, including:

- Electric arc furnaces
- Open hearth furnaces
- Blast furnaces
- Reheat/heat treat furnaces
- Annealing furnaces
- Basic oxygen process furnaces
- Pelletizing
- Soaking pits
- Sintering operations
- Coating operations

Both baseline emissions and potential reductions vary with the particular source in question. In addition, NO_x control tests have been run on only reheat and annealing furnaces, and soaking pits, and this information is sparse. (Most research in this area has involved control of PM emissions.) Applicability of CMs to these processes may be limited by the need to have strict control of process temperatures at all times. Therefore few conclusions can be made regarding the feasability and overall cost-effectiveness of controls for this source category.

SOURCE:

SCAQMD
LMOCP
EPA
GRI

SOURCE CATEGORY: Oil and Gas Production (IC Engines and Gas Turbines)

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 0.0%
- Washington, DC: 0.0%
- Houston, TX: 6.3%
- Philadelphia, PA: 0.0%

BASELINE CONTROLS: Uncontrolled emissions from IC engines 5 - 20 g/hp-hr; gas-fired turbines 1.4 - 2.4 g/hp-hr, distillate oil turbines 2.1 - 3.8 g/hp-hr. No current regulations for stationary IC engines. NSPS for turbines > 10 MMBtu/hr (75 - 150 ppm). NESCAUM area recommending 42/65 ppm for 1-10 MW turbines, 9 ppm for 10 + MW. ACT available for engines and turbines. RACT to follow.

Further Control Options*	Efficiency	$/ton from Lit.
IC ENGINES: (NSCR, PSC, CMs, EGR, SCR) See section on IC Engines.		
TURBINES:		
Water/Steam Injection -- Potential retrofit for all turbines. Operational constraints. Unproven in field.	50-70% (Acurex) 50-95% (Radian) 70% (Pechan)	3,700-7,500 (Acu) 415-2,300 (Radian) 1,300-2,200 (Pech)
Dry Low NO_x -- R&D stage. Unproven in field.	70-80% (Acurex) < = 94% (Radian)	N/A 60-1,100 (Radian)
SCR -- Applied to large cogeneration units, but unproven on simple cycle.	70-80% (Acurex)	2,500-6,500 (Ac/Rad)
SCR + Dry Low NO_x or W/S Injection - Unproven in field.	N/A 70-90% (Radian) 94% (Pechan)	5,000-14,000 (Acu) 3,800-11,900 (Rad) 3,100 - 5,200 (Pech)

*Acurex values for 11,000 hp units

DISCUSSION:

Gas turbines and IC engines located at compressor stations are the most significant sources of NO_x from oil and gas production. A small percentage of emissions also comes from heaters, reboilers, and flaring. Controls will not be evaluated for these smaller sources. Note that most of the information presented here is based on gas production systems. Radian assumes that the control options discussed will be equally applicable to the oil production sector.

Gas pipeline engines range from 50 to 10,000 hp (2 and 4-cycle rich and lean-burn), while turbines range from 1,000 to 30,000 hp. Nationwide, total hp is split evenly between engines and turbines. Ages are also variable for these units, with the oldest engines being 50 years old, and the oldest turbines around 30 years old. By and large, the newer engines and turbines have much lower emissions than their older counterparts. This is especially true for new engines employing lean combustion technology.

Of the control options evaluated in the report, two are unique to gas turbines. Water/steam injection is used to lower the temperature in the combustion canister, thereby lowering thermal NO_x formation. However, increases in CO and HC emissions may result. In addition, appliction of this technology may be limited by the lack of water delivery systems at remote locations. Lean combustion, or dry low NO_x, modifications also lower temperatures in the canister by premixing the fuel charge with air. This later control option is still in the R&D stage.

In general, most of the control technologies noted for engines and turbines can be installed on the newer units, though retrofits for older systems can be problematic. Only NSCR, PSC and lean combustion have been successfully demonstrated for engines in the field. While SCR has been successfully applied to large utility cogeneration turbines, it has not been field-tested on simple cycle units like those found at compressor stations, or on any oil-fired units. In addition, SCR may have limited applications in this area because of decreased effectiveness under variable loads.

SOURCE:

Acurex
Radian
Pechan

SOURCE CATEGORY: Petroleum Refineries

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0%
- Chicago, IL: 6.5%
- Washington, DC: 0.0%
- Houston, TX: 16.1%
- Philadelphia, PA: 8.3%

BASELINE CONTROLS: Uncontrolled emissions about 0.3 lb/MMBtu for process heaters; up to 1.0 lb/MMBtu for CO boilers. No current controls outside of California (heaters regulated; CO boilers exempt). LNBs beginning to penetrate heater market in other states. RACT to be adopted by states. Draft ACT available for heaters.

Further Control Options	Efficiency	$/ton from Lit.
PROCESS HEATERS:		
SCA -- For natural draft systems.	45% (Pechan)	130-430 savings (Pechan)
LNB -- Largest reductions for oil-fired and forced-draft burners.	27% (Nat Dr)* 58% (Forcd Dr)*	1,200-3,800* 805-2,640*
LNB + FGR --	55% (Gas)* 70% (Oil)*	2,000-5,000* 600-2,600*
Ultra-LNBs -- With internal FGR and/or steam injection.	75% (Draft ACT)	300-2,000 (Draft ACT)
SNCR --	60% (Draft ACT)	12,700-14,400 (gas)* 3,000-7,000 (oil)*
SNCR + LNB --	70% (Draft ACT)	12,000-15,700 (gas)* 900-8,000 (oil)*
SCR -- Best applied to large, forced draft, box types requiring frequent service.	80% (LMOP)	9,800-14,300 (Radian, 1993a) 17,500-22,500 (for small heaters)
	85% (w/ LNB) (LMOP)	11,000-17,000 (gas)* 2,600-11,600 (oil)*

Further Control Options	Efficiency	$/ton from Lit.
CO BOILERS:		
Divert CO stream -- Problem with no heat recovery, increased CO and NH_3 emissions.	?	?
SNCR -- Feasibility uncertain.	?	?
SCR -- Expensive, difficult retrofit. Possible catalyst fouling.	?	?

*From Draft ACT: 90% capacity factor, 80-250 MMBtu/hr for gas, 72 MMBtu/hr for oil.

DISCUSSION:

The majority of NO_x emissions from petroleum refineries originate from process heater operation. Process heaters are used extensively in refineries to facilitate chemical reactions requiring heat inputs. Typical ratings range from 30 to 100 MMBtu/hr, though the largest units may be in the 500 MMBtu/hr range. Approximately 90% of heaters in this sector are natural draft.

Process heaters operate almost exclusively on oil or natural gas. The burners themselves use either forced or natural draft configurations. the air intake configuration has a direct impact on the emissions reductions achievable from these systems. On the whole natural draft systems are more difficult to modify than forced draft systems, and costs will vary accordingly. Also, as with other retrofit strategies, post-combustion controls become very expensive on a dollar per ton basis for smaller heaters.

CO boilers are another significant source of NO_x emissions from petroleum refineries. These boilers operate as part of fluid catalytic cracking (FCC) units. FCC units use the off-gas from the "cracking" process to burn off coke deposited on the catalyst during cracking. CO boilers have unusually high uncontrolled NO_x emissions per unit heat input. These high levels are caused by both the high temperatures of the inlet gas stream and the presence of NO_x and NH_3 within the stream.

There has been little to no experience with controlling NO_x emissions from CO boilers in the U.S. to date, so efficiency and cost-effectiveness numbers are not available. However, engineering judgement leads us to believe that CO boilers will be very difficult to retrofit with LNBs, due to their unique burner requirements. In addition, particulate and sulfur concentrations in the CO stream may limit the applicability of SCR treatment. However, SNCR may prove to be a viable option.

SOURCE:

EPA, July 1992 (Draft ACT)
Buening, 1993
Radian, 1993a
Pechan, 1991

SOURCE CATEGORY: Residential Heating

RELATIVE SOURCE SIZE:

- Baltimore, MD: 0.0% (Not provided in inventory)
- Chicago, IL: 1.0%
- Washington, DC: < 0.1%
- Houston, TX: 0.0% (Not provided in inventory)
- Philadelphia, PA: ?

BASELINE CONTROLS: Uncontrolled emissions from residential heating systems range from 0.06 - 0.10 lb/MMBtu for natural gas-fired units, and 0.08 - 0.19 lb/MMBtu for distillate oil-fired units. There are currently no controls required for these units, and no RACT planned.

Further Control Options	Efficiency	$/ton from Lit.
LNBs -- Applied to new water heaters.	40 - 50% (Bay)	< = 2,000 (Bay)
Solar water heater -- Retrofit in-use units.	100%	63,000 (SCAQMD)
GAS-FIRED UNITS:		
Radiant Screens -- Requires careful installation. HC/CO may go up.	49 - 57% (EPA)	N/A
Secondary air baffles -- Requires careful installation. Single port burners.	38% (EPA)	N/A
Surface combustion burner -- R&D stage.	79% (EPA)	N/A
Perforated burner -- Commercially available.	78% (EPA)	N/A
Modulating furnace -- Derating furnace. Longer heating periods.	29% (EPA)	N/A
Pulse combustor -- R&D stage.	43 - 71% (EPA)	N/A
Catalytic combuster -- R&D stage.	> 91% (EPA)	N/A

Further Control Options	Efficiency	$/ton from Lit.
DISTILLATE OIL-FIRED UNITS:		
Flame retention burner head --	- 57% to + 144% (EPA)	N/A
Controlled mixed burner head --	44% (EPA)	N/A
Integrated furnace system -- No retrofits.	69% (EPA)	N/A
"Blue Flame" burner/furnace system -- No retrofits. Commercially available.	84% (EPA)	N/A
Internal recirculation -- Retrofit OR new installation. Not commercially available in U.S.	59 - 84% (EPA)	N/A

DISCUSSION:

Residential heating systems consist of space heaters, warm air furnaces, and water heaters. These systems typically use either natural gas or distillate fuel oil. These units are a difficult source category to regulate due to their large number, lack of regular maintenance, and slow turnover time (a SCAQMD source indicates a 10 year turnover time). Because of their small contribution to the total inventory on and individual basis, residential heating systems will not meet the 25 TPY cut-off limit required for Federal NO_x RACT. Indeed little control information has been compiled for this source category, and our study found no cost-effectiveness values outside of California. In addition, many of the control efficiency values are speculative.

Burner tuning may be the lowest cost control for in-use heating systems. However, EPA data indicate that tuning only reduces PM, CO, and HC, rather than NO_x emissions. Most other controls may have high retrofit costs, where retrofits are even feasible. Another option is to wait for the replacement of an old heater with a new, cleaner technology. Several of these emerging technologies are noted in the table above. We note the commercial status of these technologies when given. The reliance of these controls on regular maintenance was not provided in the literature, however.

If heater systems are retired and replaced with any of these control technologies, then cost-effectiveness values will rise, with the remaining useful life of the old unit. These costs might be subsidized by the local utility/PUC. If the adoption of a control technology is postponed until unit retirement, emissions reductions will be slower in coming about.

SOURCE:
EPA
SCAQMD
Bay

SOURCE CATEGORY: Stationary Internal Combustion (IC) Engines

RELATIVE SOURCE SIZE:

- Baltimore, MD: 2.5%
- Chicago, IL: 2.2%
- Washington, DC: 0.0% (Possibly under other categories)
- Houston, TX: 0.0% (Possibly under other categories)
- Philadelphia, PA: 0.0% (Possibly under other categories)

BASELINE CONTROLS: Uncontrolled emissions 5 - 20 g/hp-hr, (typically 11 - 12). No current regulations. RACT standards under development, with ACT currently available.

Further Control Options	Efficiency	$/ton from Lit.
RICH BURN ENGINES:		
Pre-stratified charge -- restricted to 4-cycle, naturally aspirated, carburated engines capable of turbocharging.	80% (LMOS) 87% (ACT)	150-7,400 (ACT)
Air-Fuel (A/F) adjustment -- Fuel-injected engines, no turbochargers. Possible CO/HC increase. <= 5% fuel penalty.	25% (LMOS) 10-40% (ACT)	350-650 (LMOS)* 430-2,900 (ACT)
Ignition Timing (IT) Retard -- Misfire possible. Up to 7% fuel penalty.	35% (LMOS) 0-40% (ACT)	250-500 (LMOS)* 360-2,900 (ACT)
A/F + IT Retard -- Allows for better performance with significant emissions reductions.	10-40% (ACT)	410-2,900 (ACT) 300-600 (LMOS)*
NSCR -- Engines with tight A/F control. Up to 10% fuel penalty possible.	80% (LMOS) 80-90% (Rad) 90-98% (ACT)	200-2,600 (LMOS)* 125-210 (Rad) 240-6,900 (ACT) 1,000-9,000 (Bay)

Further Control Options	Efficiency	$/ton from Lit.
LEAN BURN ENGINES:		
A/F adjustment -- Fuel-injected engines, no turbochargers. <= 5% fuel penalty.	30-40% (LMOS) 5-30% (ACT)	300-1,000 (LMOS)* 330-3,700 (ACT)
IT Retard -- Misfire possible. Up to 5% fuel penalty.	20-25% (LMOS) 0-20% (ACT)	250-700 (LMOS)* 500-2,400 (ACT)
A/F + IT Retard -- Allows for better performance with significant emissions reductions.	40% (LMOS) 20-40% (ACT)	250-850 (LMOS)* 400-3,500 (ACT)
Lean burn combustion -- 2 & 4-cycle, lean burn gas-fired engines. Proven in field. Best for base-load applications.	80-90% (Acurex) 87% (ACT)	520-630 (Acurex)** 650-3,600 (ACT)
EGR -- 2 & 4-cycle lean burn engines. Unproven in field.	40-60% (Acurex)	300-650 (Acurex)**
SCR -- 2 & 4-cycle engines. Best for steady loads. Catalyst poisoning possible. Unproven in field.	70-90% (Acurex) 80-90% (LMOS) 90% (ACT)	800-1,300 (Acu)** 550-9,000 (LMOS)* 490-6,800 (ACT) 2,600-16,000 (Bay)
SCR + lean combustion -- 2 & 4-cycle engines. Best for steady loads. Catalyst poisoning possible. Unproven in field.	< 90% (Acurex)	6,700-10,000 (Ac)**
COMPRESSION IGNITION (DIESEL): IT Retard -- Up to 5% fuel penalty.	20-34% (LMOS) 20-30% (ACT)	350-550 (LMOS)* 370-2,900 (ACT)
SCR -- Best for steady loads. Diesel must contain < 0.5% sulfur or catalyst becomes poisoned.	80-90% (LMOS)	700-8,500 (LMOS)* 800-1,300 (Rad)
Electrification -- All engine types.	100%	23,000 (Bay)

*Values for 8000 and 200 hp engines, respectively.
**Acurex values for 2000 hp engine.

DISCUSSION:

Stationary IC engines are used in a variety of applications, including electricity generation (typically as standby), oil and gas pumping and transportation, agriculture, and refrigerator compression. These engines burn gasoline, natural gas, diesel, or diesel/gas mixtures.

The control strategy chosen for a particular engine is usually determined by its air/fuel ratio (A/F) -- all engines can be classified as either rich burn or lean burn (including diesels and most 4-cycle turbocharge), depending on the exhaust O_2 content. Potential process modifications for spark ignition engines include A/F adjustment and ignition timing (IT) retard. For rich burn engines, A/F adjustment decreases the ratio further, limiting the amount of O_2 available for conversion into NO_x. The operating A/F for lean burn engines can be adjusted to a leaner setting to achieve similar results. However, HC and CO emissions may increase as a result. IT retard delays the timing of ignition, thereby decreasing combustion chamber volume and temperature. This change also decreases NO_x formation. Both of these CMs have an associated fuel penalty of about 5%. However, use of IT retard in conjunction with A/F adjustment can lower emissions while minimizing operational impacts.

Post-combustion controls for rich burn engines require the use of non-selective catalytic reduction (NSCR). NSCR typically employs a three-way catalyst for the simultaneous control of HC, CO and NO_x. Three-way catalysts are a commercially available technology with a proven record of performance on mobile sources, and may be easily applied to stationary engines. Because of the lower CO and HC emissions, SCR may be employed with lean-burn engines. Overall, only NSCR and pre-stratified charge (PSC) controls have been successfully applied in the field.

The cost-effectiveness values reported for post-combustion treatment span a wide range. The dollar per ton values are quite sensitive to load, and this factor may be responsible for the wide range in the values reported in the literature. The values reported in the LMOS reference were based upon continuous-load situations, and may therefore be somewhat low.

Finally note that electrification of smaller engines may be a viable NO_x control option in certain restrictive situations. Although cost-effectiveness values are extremely high (> $20,000/ton), emissions reductions reach 100%. Use of alternative fuels may prove to be another control option in the future, though no firm cost or reduction numbers were found in the literature.

SOURCE:

LMOS
ACT
Bay
Acurex

SOURCE CATEGORY: Utility Boilers -- Oil/Gas-Fired

RELATIVE SOURCE SIZE:

- Baltimore, MD: 6.4%
- Chicago, IL: 3.9%
- Washington, DC: 1.8%
- Houston, TX: 12.3%
- Philadelphia, PA: 2.6%

BASELINE CONTROLS: Uncontrolled emissions from oil and gas boilers vary with boiler capacity, firing configuration, and fuel quality. For boilers in the northeast, uncontrolled levels are about 0.45 lb/MMBtu for wall-fired units, and 0.30 lb/MMBtu for tangential-fired units. Boilers constructed after 1971 are subject to NSPS standards, from 0.2 - 0.3 lb/MMBtu. However, the majority of utility boilers in operation today were constructed before this date, and have no controls applied. Figures below are for uncontrolled boilers. ACT guidelines and NO_x RACT regulations are under development.

Further Control Options	Efficiency	$/ton (Rad or lit)*
COMBUSTION MODIFICATIONS:		
<u>Wall-fired units (100-800 MW):</u>		
BOOS --	22 - 33% (Acurex)	234 - 351 (Rad.)
FGR -- Up to 15% recirculation.	22 - 44% (Acurex) 31% (Pechan) 40 - 50% (Bay)	265 - 1,027 (Rad) 1,284-1,323 (Pec)** 447 - 559 (Bay)***
LNB -- Broad application possible. Good field results.	33 - 44% (Acurex) 30 - 50% (Bay)	704 - 1,885 (Rad) 1,271 - 2,119 (Bay)
OFA --	25 - 35% (Bay)	415 - 582 (Bay)
BOOS + FGR -- Not incremental.	33 - 44% (Acurex)	425 - 921 (Rad)
BOOS+FGR+LNB -- Not incremental.	44 - 78% (Acurex)	898 - 2,942 (Rad)

Further Control Options	Efficiency	$/ton (Rad or lit)*
<u>Tangential-fired units (100-800MW):</u>		
BOOS --	17 - 33% (Acurex)	375 - 812 (Rad.)
FGR -- Up to 15% recirculation.	17 - 33% (Acurex) 31% (Pechan) 40 - 50% (Bay)	531 - 2,045 (Rad) 2,568-2,645 (Pec)** 447 - 559 (Bay)***
LNB -- Broad application possible. Good field results.	17 - 50% (Acurex) 30 - 50% (Bay)	939 - 5,655 (Rad) 1,271 - 2,119 (Bay)
OFA --	25 - 35% (Bay)	415 - 582 (Bay)
BOOS + FGR -- Not incremental.	33 - 50% (Acurex)	567 - 1,381 (Rad)
BOOS+FGR+LNB -- Not incremental.	33 - 67% (Acurex)	1,572 - 5,884 (Rad)
FLUE GAS TREATMENT:		
<u>Wall-fired units (100-800 MW):</u>		
SNCR -- Demonstrations ongoing. Ammonia slip a concern.	33 - 44% (Acurex) 35% (Bay)	744 - 1,321 (Rad)* 959 - 1,370 (Bay)***
SNCR (Incremental to BOOS/FGR)	17 - 33% (Acurex)	1,182 - 3,350 (Rad)*
SCR (cold side) -- Demonstrations ongoing.	67 - 78% (Acurex) 80% (Pechan) 80% (Bay)	3,257 - 6,084 (Rad)* 2,866 - 4,396 (Pech)** 2,450 - 2,757 (Bay)***
SCR (Incremental to BOOS/FRG)	67 - 83% (Acurex)	4,515 - 9,015 (Rad)*

Tangential-fired units (100-800 MW):		
SNCR -- Demonstrations ongoing. Ammonia slip a concern.	33 - 50% (Acurex) 35% (Bay)	788 - 1,675 (Rad)* 959 - 1,370 (Bay)***
SNCR (Incremental to LNB) --	25 - 50% (Acurex)	978 - 2,942 (Rad)*
SCR (cold side) -- Demonstrations ongoing.	67 - 83% (Acurex) 80% (Pechan) 80% (Bay)	3,608 - 7,882 (Rad)* 5,363 - 7,497 (Pech)** 2,450 - 2,757 (Bay)***
SCR (Incremental to LNB/FGR)	50 - 75% (Acurex)	5,961 - 15,686 (Rad)*

* All Radian and Acurex values for 40% capacity factor.
** Pechan values for 50 - 940 MW range.
*** Using BAAQMD capital cost numbers, Radian cash flow model.

DISCUSSION:

Utility boilers have a rated capacity of >= 250 MMBtu/hr, or 25 MW. Boilers may approach 1000 MW at their largest. PC-fired boilers, oil/gas-fired units and gas turbines make up the vast majority of electric generating capacity in the U.S. Oil and gas-fired boilers tend to have lower uncontrolled emissions than PC boilers, but higher emissions than turbines (see section on Oil and Gas production for a discussion of turbine controls).

Oil and gas-fired units themselves utilize either wall or tangential firing configurations. Wall-fired boilers have significantly higher uncontrolled emissions levels than tangential units. Accordingly, controls for wall-fired systems generally have lower cost-effectiveness values than for tangential systems. For this reason the table above reports these values separately. Similarly, combustion modifications are separated from flue gas treatments to emphasize the cost differential between these two control approaches.

As seen in the table, CMs are less expensive on a dollar per ton basis than FGTs. In addition, due to economies of scale, cost-effectiveness values are lower for the larger capacity units. These economies of scale are particularly apparent with the capital intensive FGTs. There is also a significant spread in the estimated efficiency values. This variation is do to the influence of site-specific factors (e.g., boiler age, fuel quality, etc.).

The cost-effectiveness figures generated by Radian use data from a December 1992 Acurex report on boilers in the northeast as its basis. The primary inputs were uncontrolled and controlled emissions rates, capital and consumables costs. Radian used these values in a cash flow model to determine net present costs and emissions reductions, and from these, a dollar per ton value for each control option. The model allows Radian to investigate the sensitivity of the cost-effectiveness values to changes in installed capital, operating, and consumables costs, as well as capacity factors, MW rating, and equipment book life.

Radian's values consistently were within five to twenty percent of Acurex's calculations. In addition, our values compare fairly well with the values from Pechan for SCR, though Radian's estimates for FGR are somewhat lower than Pechan's, especially for tangential-fired units. Values from the BAAQMD for capital costs, used in Radian's cash flow model, also generated comparable for figures.

The controls themselves cannot be applied to all boilers in service, however. Retrofit potential may be limited by boiler age, type of windbox (NGR), space availability, sulfur in fuel (SCR), or a number of other factors. (Potential penetration of these controls is considered in Task 5.) In addition to these limitations, CM applications may have a number of side effects, depending on the application, including:

- increased CO emissions;
- unstable flame formation;
- increased unburned carbon emissions;
- loss of boiler turndown capability;
- reduced boiler efficiency/fuel economy;
- loss of generating capacity;
- back-end corrosion; and,
- boiler vibrations.
- flame impingement on water walls

SOURCE:

Acurex
Pechan
GRI
John Zink Inc.
LMOCP

SOURCE CATEGORY: Utility Boilers -- PC-Fired

RELATIVE SOURCE SIZE:

- Baltimore, MD: 24.5%
- Chicago, IL: 29.5%
- Washington, DC: 54.2%
- Houston, TX: 8.9%
- Philadelphia, PA: 2.6%

BASELINE CONTROLS: Uncontrolled emissions from pulverized coal (PC) boilers vary with boiler capacity, firing configuration, and fuel quality. For boilers in the northeast, uncontrolled levels are about 0.95 lb/MMBtu for wall-fired units, and 0.60 lb/MMBtu for tangential-fired units. Boilers constructed after 1971 are subject to NSPS standards, from 0.5 - 0.7 lb/MMBtu. However, the majority of utility boilers in operation today were constructed before this date, and have no controls applied. Figures below are for uncontrolled boilers. ACT guidelines and NO_x RACT regulations are under development.

Further Control Options	Efficiency	$/ton (Rad or lit)*
COMBUSTION MODIFICATIONS:		
Wall-fired units (100-800 MW):		
OFA -- Limited experience	16 - 26% (Acurex)	364 - 1,026 (Rad.)
LNB -- Broad application possible. Good field results.	37 - 53% (Acurex) 50% (Pechan)	152 - 390 (Rad) 94 - 206 (Pechan)**
LNB + OFA -- Not incremental.	42 - 63% (Acurex)	257 - 694 (Rad)
NGR -- About 15% gas. Costs assume coal at $48/ton, gas at $2.74/1000 scf. Retrofits require OFA.	47 - 58% (Acurex)	924 - 1,414 (Rad)
Tangential-fired units (100-800MW):		
LNB --	25 - 33% (Acurex) 50% (Pechan)	452 - 1,101 (Rad) 204 - 1085 (Pech)**
LNB + OFA -- Not incremental.	25 - 50% (Acurex)	400 - 1,407 (Rad)
NGR -- About 15% gas. Costs assume coal at $48/ton, gas at $2.74/1000 scf.	42 - 58% (Acurex)	1,452 - 2,546 (Rad)

Further Control Options	Efficiency	$/ton (Rad of lit)*
FLUE GAS TREATMENT:		
Wall-fired units (100-800MW):		
SNCR -- Demonstrations ongoing. Ammonia slip a concern.	32 - 47% (Acurex)	800 - 1,394 (Rad)*
SNCR (Incremental to LNB) --	25 - 42% (Acurex)	1,006 - 2,065 (Rad)*
SCR (cold side) -- Demonstrations ongoing. Only with low-sulfur coal.	74 - 84% (Acurex) 80% (Pechan)	1,876 - 2,987 (Rad)* 3,671 - 4,627 (Pech)**
SCR (Incremental to LNB) --	66 - 75% (Acurex)	3,276 - 5,160 (Rad)*
Tangential-fired units (100-800MW):		
SNCR -- Demonstrations ongoing. Ammonia slip a concern.	33 - 50% (Acurex)	838 - 1,549 (Rad)*
SNCR (Incremental to LNB) --	22 - 44% (Acurex)	1,025 - 2,633 (Rad)*
SCR (cold side) -- Demonstrations ongoing. Only with low-sulfur coal.	75 - 83% (Acurex) 80% (Pechan)	2,948 - 4,587 (Rad)* 5,139 - 6,478 (Pech)**
SCR (Incremental to LNB) --	67 - 78% (Acurex)	4,212 - 6,880 (Rad)*
GAS SUBSTITUTION:		
Seasonal control approach using 100% gas. SO_2 credits obtainable. Highly variable with gas prices.	80% (GRI)	3,489 (Radian)***

* All Radian and Acurex values for 65% capacity factor.
** Pechan values for 60 - 975 MW range.
*** Assuming $48/ton coal, $2.74/1000 scf gas.

DISCUSSION:

Utility boilers have a rated capacity of >= 250 MMBtu/hr, or 25 MW. Boilers may approach 1000 MW at their largest. PC-fired boilers, along with oil/gas-fired units and gas turbines, make up the vast majority of electric generating capacity in the U.S. PC boilers tend to have higher uncontrolled emissions than either oil/gas boilers or turbines.

PC units themselves utilize either wall or tangential firing configurations. Wall-fired boilers have significantly higher uncontrolled emissions levels than tangential units. Accordingly, controls for wall-fired systems generally have lower cost-effectiveness values than for tangential systems. For this reason the table above reports these values separately. Similarly, combustion modifications are separated from flue gas treatments to emphasize the cost differential between these two control approaches.

As seen in the table, CMs are less expensive on a dollar per ton basis than FGTs. In addition, due to economies of scale, cost-effectiveness values are lower for the larger capacity units. These economies of scale are particularly apparent with the capital intensive FGTs. There is also a significant spread in the estimated efficiency values. This variation is do to the influence of site-specific factors (e.g., boiler age, fuel quality, etc.).

The cost-effectiveness figures generated by Radian use data from a December 1992 Acurex report on boilers in the northeast as its basis. The primary inputs were uncontrolled and controlled emissions rates, capital and consumables costs. Radian used these values in a cash flow model to determine net present costs and emissions reductions, and from these, a dollar per ton value for each control option. The model allows Radian to investigate the sensitivity of the cost-effectiveness values to changes in installed capital, operating, and consumables costs, as well as capacity factors, MW rating, and equipment book life. Radian's values consistently were within five to twenty percent of Acurex's calculations. In addition, our values compare fairly well with the values from Pechan for LNBs, though Radian's estimates for SCR are somewhat lower than Pechan's.

The controls themselves cannot be applied to all boilers in service, however. Retrofit potential may be limited by boiler age, type of windbox (NGR), space availability, sulfur in fuel (SCR), or a number of other factors. (Potential penetration of these controls is considered in Task 5.) In addition to these limitations, CM applications may have a number of side effects, depending on the application, including:

- increased CO emissions;
- unstable flame formation;
- increased unburned carbon emissions;
- loss of boiler turndown capability;
- reduced boiler efficiency/fuel economy;
- loss of generating capacity;
- back-end corrosion; and,
- boiler vibrations.
- flame impingement

A final control option recently receiving attention is seasonal fuel switching. This control approach allows the boiler operator to burn natural gas in place of coal during the summer months (ozone season). Because of natural gas' inherently lower NO_x emissions, this strategy can lower emissions by up to 80%. While the retrofit cost may not be high ($30,000 for a LNB retrofit of a 200 MW boiler -- John Zink, Inc), the fuel cost differential between gas and coal may make the overall cost-effectiveness quite high. Based on Acurex's assumptions concerning coal and gas costs, emissions reductions may cost close to $4,000/ton. These costs may be even higher if a gas pipeline must be installed on-site. The high costs may be offset somewhat by SO_2 credits resulting from the conversion.

SOURCE:

Acurex
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