ABSTRACT

JAMES B. WHITE. A Contrast and Comparison of Maximum Achievable Control Technology (MACT) and Life Cycle Assessment(LCA) as Strategies to Reduce Hazardous Air Pollutants(HAPS). (Under The Direction of Dr. ALVIS TURNER)

Maximum Achievable Control Technology (MACT) and Life Cycle Assessment (LCA) provide alternative methods for controlling Hazardous Air Pollutants (HAPs). This paper evaluates the application of MACT and LCA as general strategies to reduce HAP emissions within the specific context of the primary aluminum industry. MACT is a "end-of-pipe" control based approach. It is derived from the emissions baseline and the control technologies used by the top 12% of the best controlled sources within a given source category. LCA is a pollution prevention approach that focuses on the "cradle to cradle" multimedia environmental inputs, outputs, and impacts of a product or process. This technical paper concludes that MACT is the most effective immediate strategy to control HAPs. LCA is effective as a means of reducing HAPs, however, is limited by its tradeoff of data quality for data quantity, and its lack of environmental models to evaluate environmental impacts. A model for streamlining LCA using MACT data is demonstrated, and an overview is provided for MACT and LCA methods.

Key Word Index: Clean Air Act Amendments, Life Cycle Assessment, Maximum Achievable Control Technology, LCA, MACT

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1.0 INTRODUCTION

1.1 General Background

The mission of the US Environmental Protection Agency (EPA) is the protection of human health and the environment. Since its formation in December, 1970, the driving force underlying the accomplishment of the EPA's mission has been a "command-and-control" philosophy that prescribes "end-of-pipe" controls to reduce pollutant releases. This approach culminated in the 1990 Clean Air Act Amendments (CAAA) in which Congress legislated a technology based, top down approach to the issue of Hazardous Air Pollutants (HAPs).

Through the CAAA Congress created a list of these air toxics and placed the EPA on a stringent time schedule for developing standards to control the sources of these emissions. This approach, termed in the legislation as Maximum Achievable Control Technology (MACT), directed the evaluation of the control technologies in use by the top 12% of the best controlled sources within a given HAP source category. Having identified the technology and its control efficiency, EPA was to take this information and promulgate standards, which as a minimum, required the application of these controls to the source category as a whole (See Appendix A).

In the mid-1980s a new environmental protection philosophy began to emerge as an alternative to the "command-and-control" doctrine that had dominated the EPA's formative years. This philosophy involved non-coercive, incentive based approaches such as typified in the Pollution Prevention Act of 1990. Concurrent with the emergence of this pollution prevention focus, a holistic approach to environmental accounting began to re-emerge. This approach, called Life Cycle Assessment (LCA), offered EPA, as well as other agencies, institutions, and commercial entities, a broad based, multimedia method with which to implement and measure the successes of Pollution Prevention (See Appendix B).

In 1991, engineers in EPA's Office of Air Quality Planning and Standards (OAQPS), which is tasked with developing MACT Standards, began to consider Pollution Prevention in general, and LCA in particular, as potential tools for meeting MACT Standards and minimizing costly "end-of-pipe" retro-fits. They reasoned that the use of LCA might reveal opportunities to reduce the overall environmental burden of a source category, minimize cross media pollutant transfers, and meet MACT standards by providing opportunities for incremental changes distributed over the life of a HAP source.

These considerations eventually created two camps within OAQPS. One camp maintained that LCA, by taking a "cradle to cradle" perspective, offered the regulatory community a method of achieving and balancing source specific reductions and broader multimedia environmental benefits. The other camp supported the more traditional MACT approach, arguing that LCA lacked the specificity necessary for a regulatory method. Furthermore, they contended that key components of LCA, such as its multimedia focus, were considered within the core of the MACT approach.

In 1992, EPA's Air and Energy Engineering Research Laboratory (AEERL) joined with OAQPS in planning a study to facilitate a direct comparison of the two strategies. The study proposed to target a MACT source category scheduled for review and to develop a LCA for it. Each method would then be evaluated to determine their respective advantages in meeting the MACT emission standards for the target source. Unfortunately, budget constraints and programmatic priorities prevented the study from taking place, and the question was unresolved.

1.2 Technical Objective

The objective of this technical paper is to revisit the proposed EPA study, and to compare and contrast MACT and LCA with respect to their application as strategies to reduce HAP emissions from a MACT source. The following approached was taken to develop this paper's technical objective:

- Selection of a MACT source for evaluation;
- Review of the relevant regulatory background;
- Review of both MACT and LCA methodologies;
- Development of generic source models from the MACT and LCA perspectives;
- Collection and evaluation of relevant data; and,
- Comparison and contrast of each method with respect to its ability to reduce the target HAPs.

The background materials for both the MACT and LCA Methods which were reviewed for this paper have been summarized and are presented in Appendices A and B, respectively. The Congressional HAPs list which includes the HAPs that are the objective of this study are presented in Appendix C, and the MACT Source Categories list from which the Source Category was selected is presented in Appendix D. Appendix E presents a list of proposed and promulgated MACT Standards, and relates the prescribed MACT controls to other controls derived from CAAA control technologies standards.

1.3 Selection of a MACT Source Category

For purposes of this study, both proposed and promulgated MACT standards were reviewed, and the MACT Source Category of Primary Aluminum was selected. This Source Category contains two listed HAPs: Hydrogen Fluoride (HF) and Polycyclic Organic Matter (POM). Primary Aluminum is a draft MACT being developed by Research Triangle Institute, Research Triangle Park, NC, as a part of its contract support for OAQPS. In addition, components of the Aluminum industry have been previously reviewed by the Tellus Institute, Boston, MA, as a part of a larger LCA packaging study. These two efforts provide a starting point for this work.

2.0 HAZARDOUS AIR POLLUTANTS: A REGULATORY OVERVIEW

It has taken 23 years for HAPs to acquire their present status as a regulated pollutant. In the meanwhile, there have been five Congressional efforts to regulate ambient air pollution. These efforts embody the evolution of the "command and control" approach to reducing the level of contaminants in the ambient air. The following section presents a general overview of these efforts, highlighting the emergence of the HAPs issue, and focusing on the MACT solution contained in Title III, Section 112, of the 1990 CAAA.

2.1 The 1967 Clean Air Act

The first Clean Air Act, passed in 1967, provided the US Department of Health, Education, and Welfare with the authority to establish air quality standards. Under the Act, the Secretary of Health, Education, and Welfare was authorized to designate "atmospheric areas" and air quality control regions. In addition, the Secretary was directed to publish air quality criteria and control technology data to support the regulatory activities of the States (Quarles and Lewis, 1990).

Under the 1967 Act, the individual States were directed to formulate ambient air quality standards, as opposed to emissions standard, and to develop enforcement plans. Both State's plans and standards were to be based on air quality criteria and control technology data for specific air quality control regions within each States boundaries. The Act also provided that, in those cases where air pollution presented "an imminent and substantial endangerment to the health of persons," and neither state nor local authorities have acted to reduce the potential danger, the Secretary could request the US Attorney General to institute judicial action to enjoin the polluters (Moorman, 1970).

The 1967 Act proved to be ineffective in controlling ambient air pollution. It lacked the strength to compel the formation of the required plans and standards or to coordinate regulatory activities across state boundaries. Consequently, a great deal of variation occurred in the implementation of the Act. It became evident that a stronger Federal presence was needed.

2.2 The 1970 Clean Air Act

The Clean Air Act of 1970 was a major step toward protecting the Nation's air quality. Under the 1970 Act, two groups of pollutants were regulated: Criteria Pollutants and Air Toxics (See Table I). The first group, the Criteria Pollutants, contained six pollutants which are discharged into the atmosphere in large quantities from numerous sources. Due to the volume of these pollutants emitted and the dispersion of emission sources across the Nation, they pose environmental problems across broad regions. The National Ambient Air Quality Standards (NAAQS) under Subchapter I of the Act were the centerpiece of the strategy to control these regional sources.

Table I: The Component Titles of the 1970 Clean Air Act

Subchapter I	Air Pollution Prevention and Control
Section 1875c-7	National Emission Standards for Hazardous Air Pollutants
Subchapter II	Emissions Standards for Moving Sources
Subchapter III	General

(Sieve, Mary R., 1976)

The NAAQS were numerical standards intended to provide two levels, Primary and Secondary, of protection. The Primary Standards were developed to prevent adverse impact on human health; Secondary Standards were developed to prevent adverse impact on the environment. The Act required that these standards were to be based on scientific determination of threshold levels of air contamination below which no adverse health or environmental effects would be experienced. In specifying a threshold, the NAAQS approach accepted a minimum level of pollution.

NAAQS were intended under the regulation to be implemented at the State level through the development of State Implementation Plans (SIPs). The SIPs were legally binding and could be enforced by Federal and/or State authorities. Unfortunately, the SIPs had several weaknesses. SIPs required both air quality data and a complete inventory of emission sources prior to the imposition of controls. Correct estimates of the actual reductions that would actually be achieved were also needed. However, there were major deficiencies in the knowledge of the nature, the quantity, and quality of pollutant emissions. For example, the dynamics of pollutant dispersion, pollutant transformation in ambient air, or and the effectiveness of recommended control measures were largely unknown. These weaknesses impeded the implementation of the SIPs.

The ambient air quality standards also proved to be controversial. Opponents argued that they were too stringent because they were designed to reduce the risk with an adequate margin of safety for the most exposed and vulnerable part of society. On the other hand, it was argued that they were too weak, since they did not consider multiple exposures.

The second group of pollutants covered under the 1970 Act were those considered to be immediately hazardous to human health, and which are associated with specific health effects. Typically these were carcinogens, mutagens, or reproductive toxins which have as their source specific industries (Wegman, 1991). Consequently, unlike the national air quality concerns, the threat of exposure to these chemicals are highest to those people living adjacent to a site.

Congress gave EPA authority to regulate these Air Toxics under Subchapter I, Section 1875c-7 of the 1970s Act. This section defined Air Toxics or HAPs as air pollutants to which no ambient air quality standard were applicable and which, in the judgement of the Administrator, may cause or contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness. The Act required the Administrator to publish and, periodically revise, a list of HAPs for which he intended to establish an emission standard, and to, within 180 days after the inclusion of an air pollutant on the list, publish a proposed regulation establishing emission standards for such pollutants together with a notice of public hearing (Sieve, Mary R., 1976).

The EPA was only marginally successful in implementing the HAPs legislation, and between 1970 and 1990, only seven toxic pollutants were listed. In contrast to the EPA's achievements with air toxics, and in the same time period, the Occupational Safety and Health Administration regulated more than 500 work place toxic chemicals, and the States regulated approximately 700 air toxics (Durenberger, 1991). EPA's problem lay in the wording of the 1970 Act and its requirement that EPA provide an ample margin of safety to protect public health. An initial group of six standards were promulgated before the scientific issues underlying the concept of "an ample margin of safety" were well understood and subjected to litigation. Since these standards were not judicially challenged, they have remained in effect. However, standards adopted subsequently have been challenged.

2.3 The Energy Supply and Environmental Coordination Act of 1974

The Energy Supply and Environmental Coordination Act (PL-93-319) came about as a result of the Arab oil embargo. This Act modified certain air quality requirements to balance energy needs and environmental concerns following the embargo, but did impact the promulgation of HAP Standards (Quarles and Lewis, 1991).

The Act specifically exempted proposed actions under the Clean Air Act from NEPA requirements. According to Section 7 (c)(1), "no action taken under the Clean Air Act shall be deemed a major Federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969" (15 U.S.C. 793(c)(1)0) (Quarles and Lewis, 1991).

2.4 The 1977 Clean Air Act Amendments

In 1977, after only six HAP standards had been established by EPA under the 1970 CAAA, Congress amended the Act. The components of the 1977 Clean Air Act Amendments are shown in Table II.

Table II: The Component Titles of the 1977 Clean Air Act

Title I Air Pollution Prevention and Control

- Part A. Air Quality and Emission Limitations
  - Section 112 National Emission Standards for Hazardous Air Pollutants
- Part B. Ozone Protection
- Part C. Prevention of Significant Deterioration of Air Quality
- Part D. Plan Requirements for Non-Attainment Areas

Title II Emission Standards for Moving Sources

- Part A. Motor Vehicle Emission and Fuel Standards
- Part B. Aircraft Emission Standards

Title III - General

(GI, Inc., 1993)

The 1977 Amendments were primarily intended to correct the delays which had been encountered and to force EPA to meet the goals of the legislation. They directed a second round of SIPs which were designed to achieve attainment by 1982 or at least by 1987. The 1977 round of legislation also addressed the issue of HAPs with the objective of pushing EPA to move forward with its regulatory effort. The Act was only moderately successful in this goal, bringing the total number of HAPs under regulation to seven (Novello, 1991). Table III presents the list of HAPs Standards on the books by 1990.

The most recent HAPs standard promulgated under the 1977 CAAA occurred in 1989 and 1990 to regulate Benzene. The Benzene Standards are based on the D.C. Circuit Court's reasoning in the 1987 Vinyl Chloride decision, NRDC v. EPA, 824 F.2d 1146 (D.C. Cir. 1987). In establishing the standard for Benzene, EPA confronted the zero risk problem head-on, and set standards requiring the tightest level of controls which it had determined to be technologically and economically feasible, although not at zero risk. The Court of Appeals declared EPA's approach illegal and that decision halted the HAPs regulatory efforts. These standards were the only post-Vinyl Chloride standards adopted prior to the 1990 amendments (Quarles and Lewis, 1991).

Table III: Hazardous Air Pollutants (HAPs) Listed Under the Clean Air Act of 1970 and the Amendments of 1977

Mercury
Beryllium
Asbestos
Vinyl Chloride
Radionuclides
Inorganic Arsenic
Benzene

(Quarles and Lewis, 1994)

2.5 HAPs and the Toxic Release Inventory (TRI)

The focus on HAPs as a necessary subject of regulatory action increased dramatically during the late 1980's. This increase was directly linked to a heightened public awareness and concern over hazardous waste sites. The genesis of the public's concern was contained under Superfund Title III. Under Title III, manufacturers of 300 different chemicals were required to report to both State and Federal regulatory authorities the amounts of these chemicals released directly into the air, the water, or onto land. The law applied to facilities with 10 or more employees that manufactured or processed more than 25,000 pounds of these reportable chemicals, or that used more than 10,000 pounds of them. It required that the manufacturers file an annual report, the data from which would then be compiled by EPA, and released in an annual publication of the EPA's *Toxic Release Inventory (TRI)* (Bryer, 1994).

In 1989, the TRI reported that 5.7 billion pounds of toxic chemicals had been released to the air, water, land, or injected underground. Nearly one-half of the total mass of emissions were composed of only five chemicals: toluene, ammonia, methanol, acetone, and 1,1,1-trichloromethane. The TRI also brought to light that more toxic chemicals were released into the air than into any other medium. The top five sources of air toxics were chemical facilities, primary metals, transportation, paper and plastic industries. Table IV presents the general emission sources and the quantity of chemicals they emitted to the ambient air as identified in the 1989 TRI.

Table IV: Total Air Emissions of Toxic Chemicals by Industrial Category

Industry	Millions Pounds
Chemicals	766.5
Primary Metals	256.7
Transportation	219.4
Paper	216.2
Plastics	186.2
Fabrication of Metals	141.1
Electrical	102.7
Petroleum	70.5
Furniture	61.8
Machinery	50.8
Printing	57.2
Instruments	52.9
Lumber	38.1
Textiles	37.3
Miscellaneous Manufacturing	27.1
Stone/Clay	24.7
Food	23.1
Tobacco	13.9
Leather	12.8
Apparel	4.5
Total	2,382.5

(Bryer, 1993)

The TRI indicated that about two-thirds of all industrial emissions came from point sources, while the remainder were released from widely dispersed non-point or area sources. Table V contains a listing of the emission sources identified by the TRI and reorganized into point and areas source categories. The table also presents each source's percentage contribution to the total 1989 inventory. Table VI presents the top fifteen toxic chemicals identified in the TRI as emissions from these sources.

The TRI brought to the public's attention the fact that the sources of air toxic were not only diverse but widely dispersed as well. This information increased the public's concern and made legislators aware that regulation of these chemicals would be particularly difficult.

Table V: Major Area and Point Sources of Toxic Air Pollutants and Their Percentage Contribution to the Total TRI

Source	Percent of Total Emissions
Area	
Motor vehicles	56
Treatment, storage, and disposal works	5
Secondary formaldehyde, non-point	5
Wood burning smoke	4
Asbestos, demolition	4
Gasoline marketing	3
Solvent use/degreasing	1
Other/unspecified	2
Total	80
Point	
Electroplating	6
Cooling towers (power)	3
Chemical users/producers	2
Secondary formaldehyde, point	2
Iron and steel production	1
Coal and oil combustion	1
Other/unspecified	6
Total	20

(Bryer, 1993)

Table VI: The Fifteen Toxic Chemicals Released into the Air in Largest Amounts in 1989

Chemical	Millions Pounds
Toluene	255.4
Ammonia	244.5
Methanol	199.7
Acetone	199.2
1,1,1-Trichloroethane	168.6
Methyl Ethyl Ketone	127.6
Xylene (mixed isomers)	147.5
Chlorine	132.3
Dichloromethane	109.3
Carbon Disulfide	99.8
Freon 113	63.2
Hydrochloric Acid	60.7
Trichlorethylene	44.3
Glycol Ethers	47.7
Ethylene	41.4

(Bryer, 1993)

2.6 The 1990 Clean Air Act Amendments

The immensity of the air toxics problem in terms of the variety of chemicals, the potential chemical toxicity, and the dispersion of sources, coupled with the difficulty that EPA had encountered in the past, presented Congress with a seemingly intractable problem. This problem was how to deal with HAPs without becoming mired in the scientific, technical, and legal issues surrounding concepts such as "ample margins of safety." Public demand increased for the establishment of additional regulatory controls which would directly restrict emissions of those toxic substance not covered under the NAAQS. Under public pressure stemming the Union-Carbide Incident and nurtured by revelations from the 1986 Emergency Planning and Community Right-to-Know-Act, Congress moved to address the HAPs problem.

The basic regulatory framework of the amended Clean Air Act, which was built around NAAQS and applied to only a few common pollutants, appeared to offer a possible solution. Congress responded to the public concern in the 1990 CAAA. The components of the 1990 CAAA are shown in Table VII. As seen in Table VII, Congress emphasized the importance of HAPs as an issue and demonstrated its resolve to solve the HAPs problem by assigning it a Title in its own right.

Table VII: The Component Titles of the 1990 Clean Air Act Amendments

Title I	Attainment and Maintenance of National Ambient Air Quality Standards
Title II	Provisions Relating to Mobile Sources
Title III	Hazardous Air Pollutants
Title IV	Acid Deposition Control
Title V	Permits
Title VI	Stratospheric Ozone Protection
Title VII	Enforcement
Title VIII	Miscellaneous Provisions
Title IX	Clean Air Research
Title X	Disadvantaged Business Concerns
Title XI	Clean Air Employment Transition Assistance

(Quarles and Lewis, 1990)

In a major departure from the Clean Air Act of 1977, Section 112, Title III of the 1990 Act listed 189 chemicals from new and existing sources that were to be regulated. This effective denied their selection by the EPA, and effectively removed them from debate (See Appendix C). The Act further required EPA to take the list of 189 chemicals and to assign each to one or more source categories, such as chemical plants, oil refineries, steel plants, etc., known to emit the pollutant (See Appendix D). Upon completion of the source assignments, the Act required EPA to issue Maximum Achievable Control Technology (MACT) Standards for each source category by a specified deadlines, using as a basis for each Standard the minimum regulatory standards provided by under the Title.

This mandate was the first step of Congress' two tiered approach to solving the HAPs problem This tier focused on technology-based control options much like those that had been previously used in regulating criteria pollutants and other forms of air pollution. The second tier was a health-based approach that was to be issued if the technological controls did not reduce the residual risk from the source below a one in a million (1×10^{-6}) threshold by the year 2000 (Bryer, 1993).

2.6.1 MACT Source Definitions/MACT Standards

Under Title III, Section 112, Congress directed the EPA Administrator to promulgate control technology standards that required "the maximum degree of reduction in emissions of the hazardous air pollutants,...(I)ncluding a prohibition of such emissions, where achievable." The Act further authorized the Administrator to set emission standards so as to "distinguish among classes, types, and sizes of sources within a category or a subcategory" (Moyer and Francis, 1991).

2.6.1.1 New and Existing Sources

Under Section 112, existing sources were defined as those sources that were operating at the time of the passage of the Amendments; new sources are those sources that come into existence after the passage of the CAAA. The Act established that the emission standards for new sources could not be less stringent than the emission control achieved in practice by the best controlled similar sources in the same category or subcategory. The standards for existing, however may be less stringent than those for new sources in the same category or subcategory, but shall not be less stringent and may be more stringent than:

> 1) the average emissions limitation achieved by the best performing 12 percent of the existing sources (for which the Administrator has emissions information), excluding those sources that have, within 18 months before the emission standard is proposed or within 30 months before such standard is promulgated, whichever is later, first achieved a level of emission rate or emission reduction which complies, or would comply if the source is not subject to a standard with the lowest achievable emission rate (as defined by Section 171) applicable to the source category and prevailing at the time in the category or subcategory with 30 or more sources; or,
>
> 2) the average emission limitation achieved by the best performing five sources (for which the Administrator has or could reasonable obtain emissions) in the category or subcategory for categories or subcategories with fewer than 30 sources." (Quarles and Lewis, 1991).

The average of the best performing 12 percent of existing sources and the best performing five sources is called the "MACT Floor". The wording "...the average emission limitation..." was subjected to extensive debate, and several possible legal interpretations were proposed. The EPA's interpretation was base on grouping the words "average emissions limitation achieved by" together in a single phrase. The question then asked is: "What is the 'average emission limitation achieved by' the best performing 12 percent of the existing sources?" To understand the significance, assume that one has 100 sources and ranks them, top to bottom, with respect to their control efficiencies with the most efficient being number one (See Figure 1). The emissions from the top 12 sources, taken as a group, are then averaged. The resulting calculation sets the MACT Floor near the 94 percentile of the total group (Federal Register, 1994). After much debate the higher level of control (i.e., the 94 percentile) was selected as the acceptable interpretation for the MACT Floor (Federal Register, 1994).

2.6.1.2 Major Sources

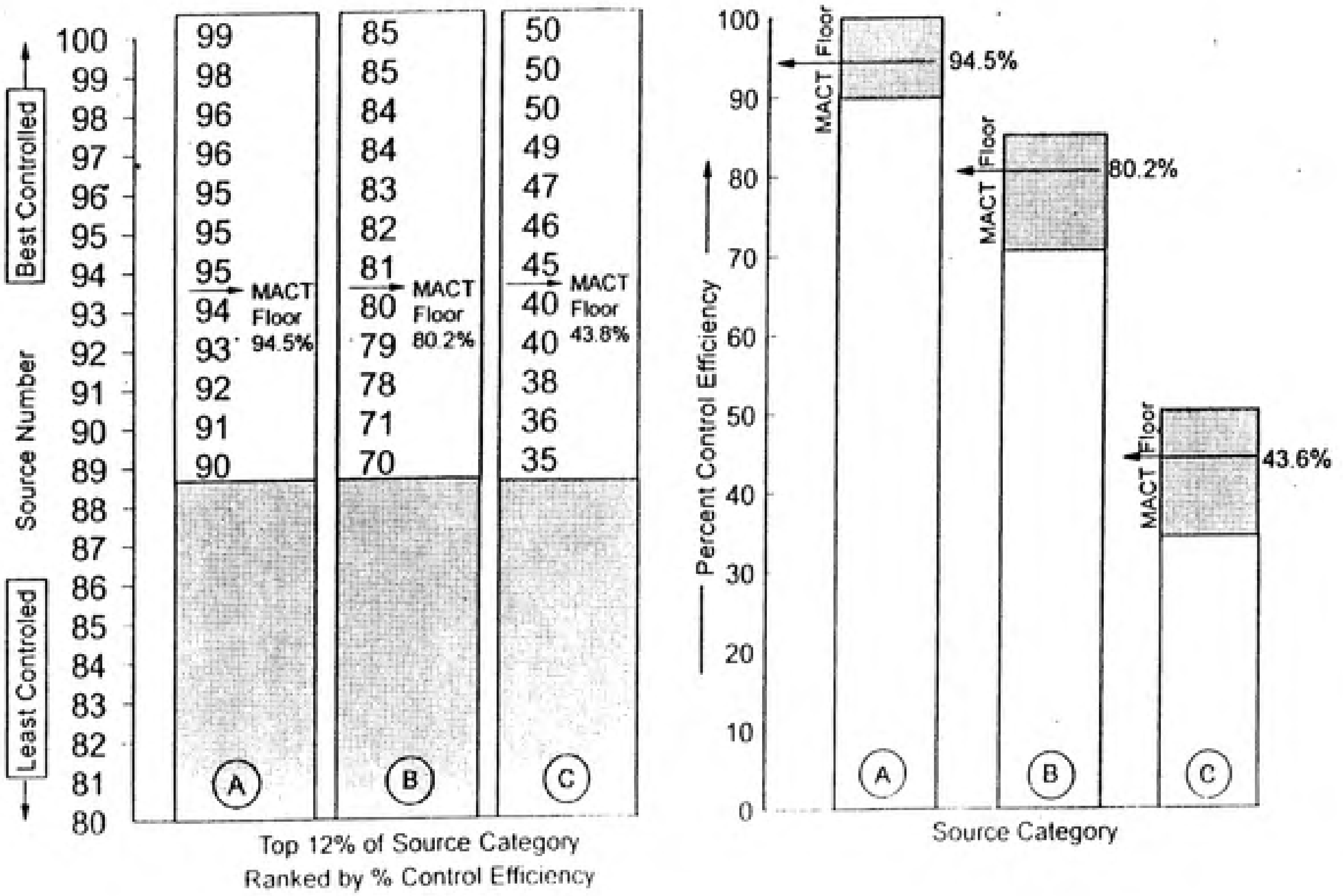
Only major sources of HAPs were intended by Congress for MACT regulation. Consequently, Congress defined a major source to be "... any stationary source or group of stationary sources located with a contiguous area under common control that emits or has the potential to emit considering controls, in the aggregate, 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants." The Administrator was also authorized to lower the emission threshold to distinguish between major and area sources, if that was determined to be desirable. The level of the new cutoff was to be base on the potency, persistence, or other characteristics of the HAP in question (Moyer and Francis, 1991).

The definition of major sources has become the topic of much debate. The emphasis of which has centered on the meaning of the word "potential" within the context of the definition. The debate focuses on whether "potential to emit" describes conditions before or after the installation of primary controls. Or, whether it means the "potential to emit" during some period of time that exceeds the anticipated operation of the controlled source. Or, whether it will necessitates a clause in a future air permit that specifies operational hours, etc. to limit the "potential to emit?" These issues are not yet resolved. Consequently, they can have a significant impact on the development of future state operating permits under Title V of the CAAA as well as negotiations of control limits under the "MACT Hammer."

2.6.1.3 Area Sources

Area sources were defined under CAAA as "any stationary source of HAP that is not a major source." For HAP emissions arising from area sources, Title III provided that the Administrator may, but need not, "... elect to promulgate standards or requirements applicable to sources in such categories or subcategories which provide for the

Figure 1: The Determination of MACT Baseline as a Result of the Interpretation of the MACT Definition



use of generally available control technologies or management practices by such sources to reduce emissions" (Moyer and Francis, 1991).

Area source standards are collectively called Generally Available Control Technology (GACT) Standards. As of December, 1993, only two GACT Standards had been issued. These standards covered two different kinds of commercial dry cleaning facilities that used perchloroethylene. In each case, EPA issued both a MACT and GACT standard because some of the facilities were major and some were minor sources (Novello, 1994).

2.6.2 Pollution Prevention and MACT

Pollution Prevention principles have contributed to the implementation of the previous version of the CAAA, and have been the source of significant pollutant emission reductions. For example, the substitution of low sulfur coals for high sulfur coals in power plants provided power utilities with a raw material substitution option consistent with the Pollution Prevention Hierarchy. This substitution produced significant reductions in the emission of sulfur oxides (SOx).

Although HAP Standards are normally structure in terms of numerical emission limits, the Act recognized that alternative approaches, such as those embodied in the Pollution Prevention Act, are sometimes necessary and desirable. For example, in some cases physically measuring HAPs emissions from a source may be impossible, or at least impractical, due to technological and economic limitations. Consequently, Section 112 (h) of the Act allowed the Administrator to promulgate design, equipment, work practice, or operational standards, or combinations thereof, in those cases where it was deemed infeasible to prescribe or enforce an emissions standard.

The application of this type of approach is demonstrated in the control of the emissions of volatile organic compounds (VOCs) from storage vessels which constitutes both a MACT and LAER source. The occurrence of these emissions (high concentrations for short periods during filling and low concentrations for longer periods during storage) and the configuration of storage tanks make direct emission measurements impractical. Therefore, MACT standards incorporating equipment specifications and work practice modifications can be written so as to deliver a reasonably reliable level of control (Novello, 1994).

Section 112 (h) (30), also allowed the use of alternative equivalent technological systems for the control of HAPs. This section stated that if, after notice and opportunity for comment, the owners or operators of any source established to the satisfaction of the Administrator that an alternative means of emission limitation would reduce HAP emissions at lest as much as would be achieved under design, equipment, work practice, or operational standards, the Administrator could permit the use of the alternative (Novello, 1991). The Act's acceptance of Pollution Prevention and equivalent technological systems as a means to control HAPs provide MACT standards with the flexibility to accommodate non-technology based solutions, and establishes the basis for the consideration and evaluation of LCA as a HAP reduction strategy.

2.6.3 Residual Risks

The determination of residual risk is the trigger for the second tier of Congress' HAPs regulatory strategy. This approach is based on the previous NAAQS concept of providing an "ample margin of safety to protect public health." The CAAA required that within eight years of establishing MACT standards for the designated source categories, except for those standards established two years after enactment which then have nine years, standards to protect against the remaining residual health and environmental risks were to be promulgated. These standards would be triggered if more than one source in a category or subcategory exceeded a maximum individual cancer risk of one in a million.

Cognizant of the scientific and legal problems inherent in this approach, Congress also provided that the Administrator could also consider other relevant factors in making the determination of whether a more stringent standard was necessary to prevent adverse environmental effects. These factors included such as things as costs, energy, and safety. Furthermore, in the case of area sources controlled under GACT standards, the Administrator was not required to conduct a residual risk review (Quarles and Lewis, 1991).

2.6.4 MACT Hammer

Recognizing EPA's past difficulties in meeting regulatory schedules, the 1990 Amendments provided for the implementation of MACT standards regardless of whether EPA acted. If EPA fails to adopt MACT standards in a timely fashion this "MACT Hammer" comes into play, requiring case-by case determinations by the states for new major sources and modifications to such sources. These control standards are to be written into each state's Title V Operating Permit Program and become effective after EPA approves the permit. The MACT Hammer is intended to provide roughly the same degree of HAP control as the MACT Standards while shifting the developmental burden onto the State and the affected industry (Quarles and Lewis, 1991; Novello, 1994).

2.6.5 RACT, BACT, LAER, MACT

Lastly, in the discussion of MACT, it is important to note the inherent complexity of environmental chemistry and the inclusive nature of the past and present legislative definitions, result in an overlap of MACT and one or more of the criteria pollutants regulations: RACT, BACT, and LAER. RACT, BACT, and LAER represent increasing stringent control methods. These terms are defined as follows:

- Reasonably Available Control Technology (RACT) is the level of air pollutant emissions control required to be imposed on all existing sources in non-attainment areas. It consists of those device, systems, process modification, or other apparatus or techniques the application of which will permit attainment of the requisite NAAQS (Frick and Sullivan, 1990).

- Best Available Control Technology (BACT), as determined by EPA guidelines, is the best measure for controlling small dispersed sources of particulate matter. It is an emission limitation based on the maximum degree of reduction of each pollutant emitted from any major emitting facility subject to regulation under CAAA. The determination of BACT is made on a case by case basis, taking into account energy, environmental, economic impacts and other costs. It includes the application of control technologies, control system, or innovative fuel combustion techniques for the control of each pollutant (Frick and Sullivan, 1990).

- Lowest Achievable Emission Reduction (LAER)is the most stringent standard for emission control reflecting the highest degree of control attained by any relevant source. LAER is required of new sources built in areas that have not yet met the NAAQS (Moyer and Francis, 1991).

The question of how these technologies relate to one another is complex and is being resolved by the EPA on a case by case basis. The question arises when one considers that roughly half of the listed HAPs are VOCs and will be affected by the new non-attainment control requirements to which some facilities may be subjected. These requirements can reflect different levels of stringency and may establish differing schedules for compliance.

The question of the selection between RACT, BACT, LAER or MACT involves the physical and chemical properties of the pollutant and its location within the source. For example, consider the case in which the HAP is a VOC and subject to LAER. The CAAA defines VOCs as any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions (Quarles and Lewis, 1991). Typically, EPA regards VOC's as any organic chemical having a vapor pressure exceeding 0.1 millimeters of mercury (mm Hg) at standard conditions of 20° C and 760 mm Hg (Mukhopadhyay and Moretti, 1993). Several VOCs are contained in the 189 chemicals listed in the 1990 CAAA as HAPs.

In determining MACT for this VOC/HAP entity, a nation wide survey of emission controls for the specific source category would be conducted. The average of the top 12% best controlled sources would be determined and the MACT Floor established for the HAP. Because the survey includes VOC Non-Attainment areas and LAER sources, and because LAER is the most stringent VOC control technology, it is likely that the recommended MACT control would be a LAER technology. This recommendation would not affect the sources in the non-attainment area, but would compel an upgrade of control technologies for those major sources in other areas.

On the other hand, particulate matter, in certain situations, can be composed of one or more of the listed HAPs. If the HAP is a non-VOC, such as chromium, and it is in either the solid phase or attached to particulate matter at the time of collection, the nationwide survey of MACT sources would include BACT among the best 12% of the controlled sources. The MACT Floor would be established and the MACT recommendation would most likely be a BACT technology. However, if the HAP is a non-VOC, such as mercury, which is in equilibrium with particulate matter at the time of collection, but is not wholly attached to the particle, emissions testing would demonstrate the need for a better control technology. Consistent with the mandate of the CAAA, EPA would recommend a technology that is more stringent than the current control technology used by the best controlled 12%. In this case, all emission sources within the source category would be required to install as MACT new controls which are not covered under BACT.

Appendix E presents selected MACT Standards proposed or promulgated by December, 1994. The Appendix lists Source Category, HAPs, and control standards, and relates the latter to RACT, BACT, LAER control technologies as appropriate.

3.0 MACT AND LCA FOR THE PRIMARY ALUMINUM INDUSTRY

The utility of either MACT or LCA as a strategy in the reduction of HAP emissions can be best evaluated through the development of each approach with respect to a HAP source. As indicated in Section 1.2, the subcategory of Primary Aluminum Production in the HAP category of Non-Ferrous Metals Processing has been selected for this analysis. Primary Aluminum Production involves the refining, smelting, and casting of aluminum ingots for use in the production of aluminum products. The production of primary aluminum generates two listed HAPs: Hydrogen Fluoride (HF) and Polycyclic Organic Matter (POM), as well as several other criteria pollutants.

3.1 Aluminum: The LCA Perspective

The LCA for Primary Aluminum will be developed first because it provides the most comprehensive overview of the HAPs source category.

3.1.1 Life Cycle Assessment - Inventory Analysis

As indicated in Appendix B, by convention, the first step in a LCA Inventory Analysis is a screening step intended to establish specific study parameters. The first parameter to be addressed in the screening phase involves the establishment of the study's boundary conditions. The boundary conditions include the definition of the intended audience, the decision on which data is to be used, the acceptable data quality, and the determination of how the LCA results will be reviewed prior to use (Vigon, et. al.,1993).

For the purposes of this study, it will be assumed that the Primary Aluminum Industry is developing the LCA and that the audience is external (i.e., the EPA). This assumption is consistent with Title III, Section 112 of the CAAA that allows the EPA Administrator to consider recommendations for alternative technological systems developed by the owners or operators of a MACT source.

Due to costs constraints, the study will be handled as a streamlined or modified LCA. This type of LCA approach uses secondary and tertiary data coupled with the a minimal LCA Impact Analysis, instead of developing primary data for all life cycle stages. The modified LCA approach will cost the Primary Aluminum Industry approximately $20,000 to

$25,000 to develop versus the typical $150,000 to $300,000 to develop just the Inventory component of a full scale LCA (Todd, 1994). In addition, to emphasize the HAPs focus, the inventory data collected and reported in this study will focus air emissions. In an actual LCA, either full scale or modified, a full spectrum of data would be collected in order to evaluate the multimedia consequences of the improvement recommendation.

All 23 primary aluminum plants in the US already have primary control technology installed and operational in one form or another (i.e., wet scrubbers or dry scrubbers). Consequently, to make the methodologies more comparable, the inventory data to be collected during this LCA will target emissions from controlled processes. The data will be acquired from several sources including EPA peer reviewed publications, such as the Tellus packaging study and the *Environmental Resource Guide (ERG)*, various LCA and public emissions databases, and the general literature. Primary data derived from costly site specific emissions testing or other site specific measurements will be used only to the extent that it is available through these sources. It will also be assumed that the Primary Aluminum Industry does not have access to complete data on the full life cycle, upstream and downstream, of its product, but that it is willing to accept this incomplete data set in order to determine the existence of an opportunity. This assumption is consistent with the current state of LCA and current industry practice (Todd, 1994).

Most of the available data sources for this LCA have not been subjected to any formalized peer review. Consequently, the data quality is variable and generally unknown. For the industry, the main use of this data are to provide insight into potential opportunities to reduce HAPs through a Pollution Prevention style intervention. These opportunities will make up the core of the LCA Improvement Analysis, and will be the subject of an independent, non-LCA cost analysis prior to implementation. For the purpose of this technical paper, the main use of the data are to demonstrate the concepts underlying the LCA approach and to provide the basis for the contrast and comparison of the strategies under study.

The second question in the screening phase involves defining the system's boundary. LCA is by definition is a "cradle-to-cradle" methodology. The HAP source category, Primary Aluminum, is only one of several possible "gate-to-gate" mini-LCAs embedded in the "cradle-to-cradle" requirement. To meet the definition of LCA will require linking the several "gate-to-gate" LCAs into a single coherent system. The approach selected to resolve this problem is one of tracking a unit of aluminum from raw material acquisition through disposal/reuse for a generic aluminum product. This approach not only links the system, but provides a convenient unit of measure (i.e., emissions per unit of aluminum) for the Inventory and Improvement Analysis.

To place this unit of LCA measurement into context, it is necessary to determine a generic aluminum product for analysis and around which to establish the system's boundary. Consequently, it is necessary to review the uses of aluminum in the US. The principle uses of aluminum include: building, transportation, consumer products, electrical, packaging, structural engineering, and domestic wares. In 1983, approximately 22% of all aluminum consumed in the US went to construction, and 27% to 30% was used in packaging and containers, such as food and drink cans (Alexander and Greber, 1991). Further review of the literature indicates that in 1984 an estimated 112 billion cans were produced in the US (Stilwell et. al., 1991). Of the 112 billion, 84 billion (75%) were beer or soda cans representing a short lived use of an energy intensive resource. Table VIII presents a summary of the uses of aluminum packaging in the US.

Table VIII: Uses of Aluminum in Packaging Sector in the US

Application	Quantity (tons/year)
Container Sheet for Cans	1,780,000
Household and Industrial Foil	122,000
Other Sheet	93,500
Other Foil	91,000
Foil for Semi Rigid Containers	54,000
Sheet for Rigid Containers	8,6000

(Stilwell, et. al, 1991)

As seen in Table VIII, the largest US use of aluminum is in the production of packaging. Because aluminum cans comprise the largest component of the packaging market, this study shall focus on aluminum cans as the generic product of interest for the development of this LCA.

Consistent with LCA convention, to complete the life cycle of the target product, a recycle step must be included. This step involves the inclusion of the Secondary Aluminum Industry into the system's boundary. The Secondary

Aluminum Industry handles the collection, processing, and refining of salvable, non-virgin aluminum products into aluminum ingots for reuse. With the addition of the Secondary Aluminum Industry to the study, the system's boundary can be drawn to encompass the raw materials acquisition; preprocessing and processing of aluminum ore; the fabrication of cans; packaging of the product, wholesale and retail distribution, consumer use, disposal, and recycle. Figure 2 presents the LCA system template for the evaluation of LCA as a HAP reduction strategy.

3.1.1.1 Aluminum: Materials Acquisition and Preparation Stage

The actual development of the environmental input/output inventory begins after the system is defined. In this step all the flows through the many stages of the system under study are identified, quantified, and attributed as to source and receptor. This includes raw materials, intermediates, co-products, by-products, energy, effluents, emissions, and other discharges.

Consistent with the streamlining objective established in the definition of the study's boundary, the primary emphasis of this LCA will be on air emissions with the goal of identifying the target HAPs, HF and POM, and a few associated pollutants. The limited information on other environmental inputs and outputs will be provided to balance the LCA perspective, but will not be factored into the Impact or the Improvement analysis phase.

3.1.1.1.1 Bauxite

The first step in the LCA for aluminum commences with the acquisition of the primary raw material: bauxite. Bauxite ore is the sole source of the intermediate product, alumina, which is processed into aluminum. The acquisition of bauxite is labor intensive, and requires energy for mining, water and energy for benefication, and energy for transportation.

Bauxite is typically found near the earth's surface in subtropical or tropical regimes where warm weather and abundant rains leach the soil, removing soluble iron, sodium, potassium, calcium etc., and leaving insoluble silicates and aluminum. The composition of a high quality bauxite ores are shown in Table IX.

Figure 2: Life Cycle Assessment Template for an Aluminum Can

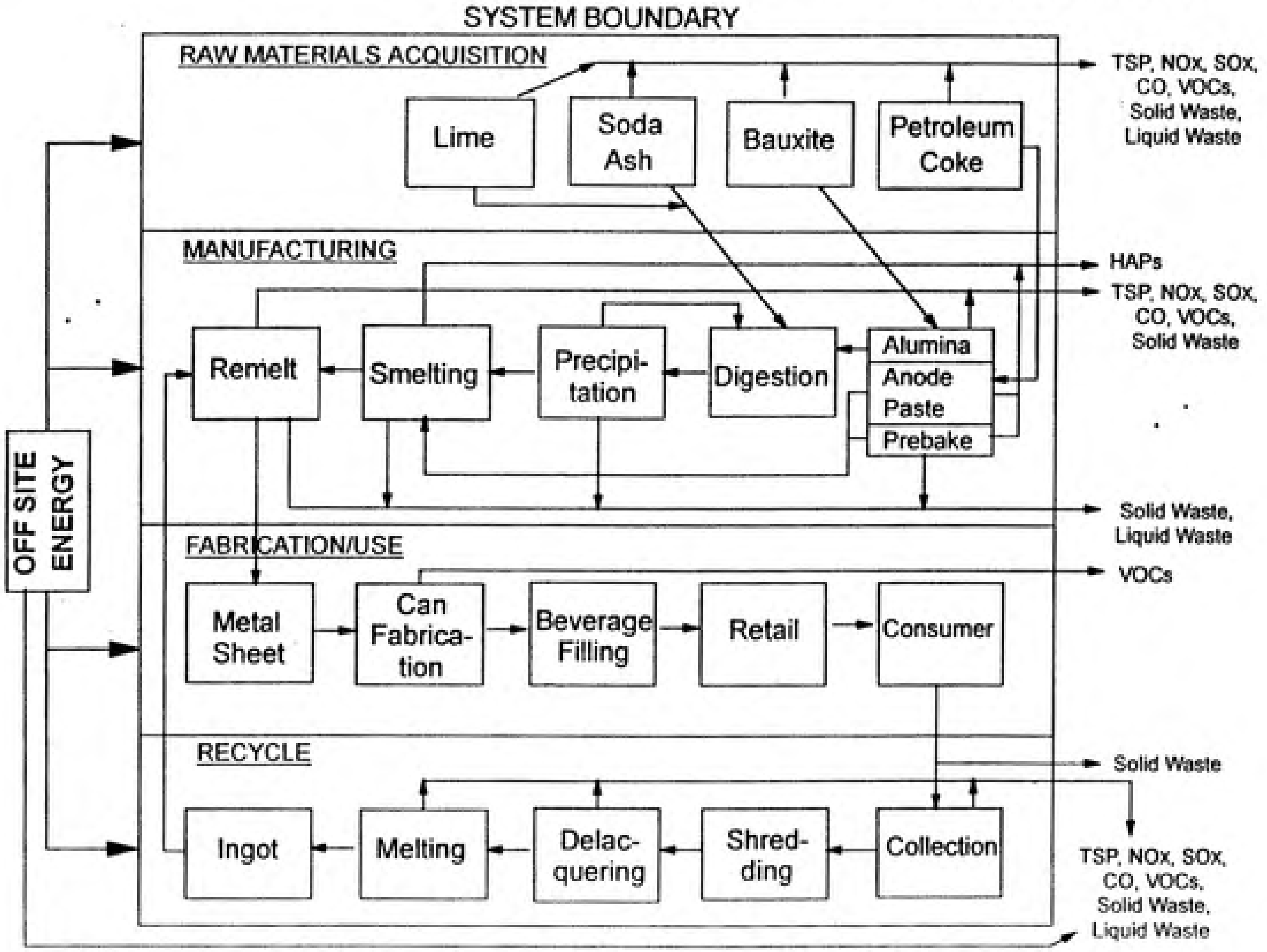


Table IX: The Composition of High Quality Bauxite Ores

Constituents	Percent(%)
Al_2O_3	40 to 60
Fe_2O_3	5 to 30
SiO_2	1 to 8
TiO_2	2 to 4
H_2O	12 to 30

(McKetter, 1981)

From the table it can be seen that bauxite (Al_2O_3) is the predominant component of a high quality ore. However, the composition varies from region to region, and this variation in quality impacts the energy consumption during the refining step. Most high grade bauxite ores deposits suitable for aluminum smelting occur in Jamaica, Guyana, Surinam, West Africa, India, Malaysia and Northern Australia (Groliers, 1994). In these countries, bauxite is stripped mined and processed for shipment to primary aluminum smelting plants to be refined.

The world production of primary aluminum in 1992 was 19,219,000 metric tons, and the United States and Canada were the two largest producers. During that year, the United States produced 6,709,000 metric tons of aluminum of which 4,042,000 metric tons were primary aluminum (World Almanac, 1994). The primary aluminum in the US and Canada is largely produced from these imported bauxite ores (World Almanac, 1994). The US imports about 85%-90% of its needs mainly from Surinam, Jamaica, and Guyana with approximately 30% coming from Jamaica. The remaining 10% to 15% is mined domestically in Arkansas (Alexander and Greber, 1991).

Bauxite deposits occur in three main forms: blanket, inter-layered and pocket deposits. Most of the tropical deposits are the blanket type, about 20 feet thick, and are mined with an open cast/open pit methods (McKetter, 1981). This form of mining accounts for most of the bauxite refined in the US.

During the open pit mining process the overburden of soil is removed and draglines are used to strip the bauxite deposit. Open pit mining has a major impact on vegetation (e.g., tropical rain forests), soil, and ground and surface waters. In addition, the handing and relocation of the solid wastes from the mining activities also pose an environmental problem (Tellus, Vol II, 1992). The rate of solid waste production increases annually as the depth of the ore bodies increase and the ore's grade decreases. It presently requires approximately 4 to 6 pounds of bauxite ore to produce 2 pounds of alumina, and approximately 2 pounds of alumina to produce 1 pound of high grade aluminum (Environmental Resource Guide, 1991). Or, as a general rule of thumb, 4 pounds of bauxite produce 1 pound of 99.5% pure aluminum (Groliers, 1994).

Usually the bauxite ore is crushed washed and screened near the mine site in a process known as benefication. This process requires the input of large quantities of water, but it eliminates clay, minerals, and dirt to improve the quality of the product. The ore is then kiln dried or calcined in a rotary kiln before being shipped. The drying of the ore is the greatest energy consumer in the mining processing step (Tellus, Vol II, 1992). Table X presents inventory of selected environmental inputs and outputs that associated with bauxite production. The outputs include heavy metals (HM), total suspended particulate (TSP), nitrogen oxides (NOx), sulfur oxides (SOx), and VOCs.

Table X: Selected Environmental Inputs and Outputs fro the LCA Raw Materials Acquisition Stage: Bauxite Production

LCA Stage	Input/Output	Total
Bauxite Mining Processing Production (Units/ton bauxite)	Energy (i)	0.51 MM Btu/ton
	HM(o)	0.003 lb/ton
	TSP (o)	1.5 lb/ton
	SOx (o)	0.033 lb/ton
	NOx (o)	0.36 lb/ton
	CO (o)	0.003 lb/ton
	VOCs (o)	0.003 lb/ton

(Tellus, Vol. II, 1992) (i)= input, (o)= output

Bauxite ore accounts for about 71% of the U.S. import, the remaining 29% is the aluminum intermediate, alumina. The transportation of these materials to the US is via seagoing cargo vessels and requires the input of energy in the form of fossil fuels and generates emissions of criteria pollutants from the combustion of these fuels.

3.1.1.1.2 Lime

Limestone for the production of lime is also quarried by open pit methods. During the mining process, overburden is removed and piled in containment areas. The raw ore is transported from the mine site to a crushing area where its size is reduced. The crushed ore is then conveyed to a second where its size is further reduced and screened. The open pit mining process produces large quantities of dust, but no water is used in the mining phase. It requires 2.88 tons of limestone ore to produce one ton of lime, and EPA has estimated that 180 pounds of solid wastes are produced for every short ton of lime produced via the open pit method (Tellus, Vol II, 1992).

After the raw limestone is crushed and screened, it is calcined in a rotary or vertical kiln. These calcining methods account for 90% and 10%, respectively, of the US's production of lime. Most of these air emissions occur during this process when the limestone is being processed into lime. As in the calcining of the bauxite ores, this step is energy intensive, and the combustion of fossil fuels is the source of several emissions. These emissions include TSP, acid gases, such as SOx and NOx, VOCs, and oxides of carbon. Table XI presents an inventory of selected inputs and outputs for lime production.

Table XI: Selected Environmental Inputs and Outputs for the LCA Raw Materials Acquisition Stage: Lime Production

LCA Stage	Input/Output	Total
Lime Mining/ Processing and Manufacture (Units/ton lime)	Energy (i)	4.91 MM Btu/ton
	TSP (o)	42.9 lb/ton
	SOx (o)	1.27 lb/ton
	NOx (o)	4.41 lb/ton
	CO (o)	2.19 lb/ton
	VOCs (o)	0.05 lb/ton
	HM (o)	0.001 lb/ton

(Tellus, Vol. II, 1992) (i) = input, (o)= output

3.1.1.1.3 Caustic Soda

Caustic soda, or sodium hydroxide (NaOH), is produced commercially from the electrolysis of salt. Approximately

80% of the US chlor-alkali industry use the diaphragm cell to produce this product and a chlorine co-product. The principle reagent of the diaphragm process is brine from salt mines. The brine is heated and treated with soda ash and caustic soda to remove impurities. It is then pumped into a electrolytic cell where a direct current decomposes the salt solution into chlorine, hydrogen, and a solution of sodium hydroxide. The dilute caustic soda is evaporated to produce a solution of 50% caustic soda (Tellus, Vol. II, 1992). Table XII presents a modified emissions inventory of air pollutant emissions generated during the production of caustic.

Table XII: Selected Environmental Inputs and Outputs for the LCA Raw Materials Acquisition Stage: Caustic Soda Production

LCA Stage	Input/Output	Total
Caustic Production (Unit/ton caustic)	Energy (i)	28.0 MM Btu/ton
	TSP (o)	0.55 lb/ton
	SOx (o)	9.05 lb/ton
	NOx (o)	10.3 lb/ton
	CO (o)	0.87 lb/ton
	VOCs (o)	0.29 lb/ton

(Tellus, Vol. II, 1992) (i)= input (o)= output

Although not shown in Table XII, chlorine gas is also emitted from the production process in at least two places. These are from the seals around the electrolytic cell and during the loading of tank cars with chlorine. In addition, several types of water borne wastes are produced, including an estimated 53 pounds of brine mud per ton of caustic produced. This mud contains magnesium hydroxide and calcium carbonate. Approximately 1.5 pounds of asbestos per ton of caustic is also generated during the process pounds (Tellus, Vol. II, 1992).

3.1.1.1.4 Cryolite

Cryolite, a double sodium aluminum fluoride salt, is a rare mineral, and the only known major deposit is in Ivigtut, Greenland (McKetta, 1981). Cryolite acts as a flux during the electrolytic smelting process (Oss, 1981). Approximately 0.025 tons of cryolite per ton of aluminum is required in the smelting step (McKetta, 1981).

World requirements for cryolite exceed demand, consequently most of the cryolite consumed is synthetic. In the US the standard synthetic product analyses as 95% NA_3AlF_6 and 4% other fluorides calculated as calcium fluoride (CaF) (Oss, 1981). Sources of synthetic cryolite include: 1) recovery from smelting pot linings or pot gases; 2) synthesis based on fluorspar (CaF_2); and, 3) the active scrubbing of fluoride emissions from the smelting operation with alumina and the return of the alumina to the system (Ours, 1994).

3.1.1.1.5 Petroleum Based Coke

Coke is the principle ingredient used in the fabrication of the electrodes that supply electric current to drive the electrolytic reduction of alumina to aluminum. Coke is produced off site through the thermal dehydrogenation of residual oil products. This "cracking" is followed by calcining to drive of volatile components. In addition to VOCs, a number of carcinogenic compounds, collectively known as POMs, are associated with the production coke. Table XIII presents data on selected inputs and outputs from this process.

Table XIII: Selected Environmental Inputs and Outputs for the LCA Raw Mateials Acquisition Stage: Coke Production

LCA Stage	Input/Output	Total
Coke Production (Unit/ton coke)	Energy (i)	20 MM Btu/ton
	TSP (o)	0.09 lb/ton
	SOx (o)	0.69 lb/ton
	NOx (o)	0.29 lb/ton
	CO (o)	0.06 lb/ton
	VOCs (o)	0.10 lb/ton
	POMs (o)*	0.0000512 lb/ton

(Tellus, Vol. II, 1992) (i)= input (o)= outputs
*POMs are reported as naphthalene.

3.1.1.2 Aluminum: Manufacturing Stage

The production of aluminum is energy intensive. Due to this need for large quantities of energy, aluminum smelting is generally located near cheap power sources. In addition to energy, the manufacturing stage requires the input of bauxite, lime, caustic soda, cryolite (i.e., aluminum fluoride), and petroleum based coke acquired during the raw materials acquisition stage. These materials are use to produce the alumina intermediate and in its final reduction to Aluminum.

LCA's Manufacturing Stage for Aluminum in the US is set one of 23 reduction plants in 14 states. A typical reduction plant consists of one or more "pot lines" with each line consisting of up to 150 pots in series. The actual reduction of alumina to aluminum takes place in these pots on a continuous basis. In addition to the potlines, there are several ancillary processes on site for handling and processing intermediates materials, such as alumina production and electrode fabrication. The major components of a generic reduction plant are:

- shipping and receiving areas for raw materials and finished product;
- caustic slurry process for processing bauxite ore;
- a digester, filtration, calcining process for producing alumina;
- one or more potlines where alumina and cryolite are reduced to aluminum;
- a cast house where aluminum is reheated, purified, alloyed and cast into ingots;
- a rectifier for converting alternating current (AC) voltage into direct current voltage;
- an anode paste plant where coke and pitch are mixed to form the anode paste; and,
- an anode bake plant (located only at those facilities using a prebake process) (Ours, 1994).

Reduction plants are differentiated by the type of anode used, the method by which the pots are worked, and the method by which the anode is introduced into the pot during smelting. Each pot is a large steel box lined with carbon about 6 inches thick which forms a cathode. One or more carbon anodes dip into each pot to establish the electrical circuit. These anodes are either "prebaked" from petroleum coke and pitch, or are the "self-baking" Soderberg type. In the latter instance anode ingredients, coke and pitch, are continuously extruded as they are consumed from an electrode mold housed in the center of a pot (Oss, 1982).

The Prebake technology comprises 78% (18 out of 23) of the US industry (Ours, 1994). Each technology has two variations. In the Prebake technology the reducing anode is formed and hardened prior to introduction into the pot. Prebake plants are classified as center worked prebaked (CWP) or side worked prebake (SWP) depending on where the pot working crust breaking and alumina addition takes place. The Soderberg anode is a single continuous anode that is shaped and baked in place. The Soderberg pots, are differentiated by the positioning of the current carrying studs in the anodes. These anodes can be either inserted vertically as in the vertical stud Soderberg (VSS) or horizontally as in the horizontal stud Soderberg (HSS) (Ours, 1994).

3.1.1.2.1 Preprocessing and Production of Alumina: Bayer Process

Before it can be smelted, the incoming bauxite ore must be processed to produce the intermediate, alumina. The ore is crushed in a ball mill and digested in a steam heated, pressurized caustic solution of soda ash and lime (i.e., the Bayer Process). This digestion step results in the solubilization of the aluminum in the bauxite to form a "green liquor" consisting of sodium aluminate ($NaAlO_2$) in a caustic solution. The caustic solution is decanted, filtered, cooled, and hydrolyzed to precipitate the intermediate product, aluminum oxide trihydrate ($Al_2O_3.3H_2O$). The caustic solution is recycled to the digester, and the aluminum precipitate is filtered and either kiln dried or calcined to produce alumina. Table XIV presents selected inventory inputs and outputs for the alumina production process.

Table XIV: Selected Environmental Inputs and Outputs from the LCA Manufacturing Stage: Alumina Production

LCA Stage	Input/Output	Total
Alumina Production	Energy (i)	22.5 MM Btu/ton
(Units/ton alumina)	TSP (o)	41.6 lb/ton
	SOx (o)	10.4 lb/ton
	NOx (o)	6.2 lb/ton
	CO (o)	0.72 lb/ton
	VOCs (o)	0.08 lb/ton
	HM (o)	0.003 lb/ton

(Tellus, Vol. II, 1992) (i)= input (o)= output

The bottom residue from the Bayer process is a red or brown "mud" with a solids content of 35% to 75% and a pH >12 (Popovics, 1990). Typically one pound of this mud is produced for each pound of alumina processed in the Bayer Process (Environmental Resource Guide, 1991). The mud is largely water with clay, dirt, and trace amounts of hazardous substances, including heavy metals and organic compounds. The mud laden residual process water is routed out of the plant to a "mud lake" for containment. In the containment ponds evaporation and seepage compete against local precipitation to reduce the liquid volume. The settled effluent from the mud lake may discharged into receiving water, and some of the mud may be used for other industrial applications such as cement making (Popovics, 1990).

Other waste water from the alumina production includes spent liquor from the digester, condensates, and barometric condenser cooing water. The spent liquor is reused, and occasionally solids are removed from the recycle loop through "blow down." The blow down liquor is reduced in volume by evaporation, and the resultant slurry is land filled (Alexander and Greber, 1991).

3.1.1.1.2 Aluminum Smelting: Hall-Heroult Process

The dried alumina is transferred to a pot containing molten cryolite, or other forms of aluminum fluoride, where it is subjected to 50,000 to 150,000 amps of direct electrical current at 4-6 volts. This electrolysis process, known as the Hall-Heroult Process, accounts for approximately 1% of the US's annual energy production (Groliers, 1994). During electrolysis, alumina is decomposed into aluminum and oxygen. The oxygen combines with the carbon anode to produce CO_2 and the pure aluminum sinks to the bottom of the pot where it is siphoned off.

A single production pot operating continuously can produce one ton of 99.5% pure aluminum every 24 hours. The majority of the direct pollutant emissions from the Primary Aluminum Source Category occur during this stage of aluminum production. These emissions include air, water, and solid waste discharges. The air emissions include the HAPs, POM and HF, which are collected, treated, or destroyed through the use of baghouses, wet scrubbing, or incineration (Ours, 1994). Table XV presents selected air and energy inventory input and outputs from the smelting process.

The HF HAP is emitted from the cryolite/aluminum fluoride flux. However, standard measurement practices within the aluminum industry measure HF as aluminum fluoride and report it as total fluoride (TF). Consequently, there are no HF data readily available in the literature for this HAP. TF is collected by a closed system and, under optimum conditions, 95% of the fluoride is recovered (Ours, 1994). The POM emissions are associated with the heating of the coke-based anodes. In the Prebake Plant these emissions occur during anode fabrication and use. In the Soderberg Plants, the emissions occur through use as the anode is consumed during the electrolysis. The POMs are also

Table XV: Selected Environmental Inputs and Outputs for the LCA Manufacturing Stage: Aluminum Production

LCA Stage	Input/Output	Total
Aluminum Production (units/ton aluminum)	Energy (i)	189 MM Btu/ton
	TSP (o)	16.1 lb/ton
	SOx (o)	72.8 lb/ton
	NOx (o)	84.1 lb/ton
	CO (o)	7.21 lb/ton
	VOCs (o)	2.46 lb/ton
	TF (o)	7.41 lb/ton
	POMs (o)	0.000021 lb/ton*

(Tellus,Vol II, 1992) (i)= input (o)= output
* POMS are reported as naphthalene

collected and incinerated (Environmental Resource Guide, 1991). In addition to the air emissions, every pound of aluminum produced during electrolysis generates 0.02 pounds of spent potliner. The potliner wastes contain carbon, insulation material, and cyanide. It is mechanically removed and deposited in controlled sites because the cyanide content makes it a hazardous solid waste..

Molten aluminum from the pots is poured into molds prior to transfer to a remelt facility where it is further processed. At the remelt facility, the ingots are melted, degasified, purified, and combined with other metals to produce alloys as required. There are no discrete inventory data available for the remelt stage. However, with the exception of VOC emissions, they can be assumed to be similar to the emissions inventory for the secondary aluminum /recycle phase. In addition to air borne emissions, aluminum rich "skims" are produce during remelt as molten impurities float to the top of the vats. These impurities are skimmed off and disposed of as solid waste (Environmental Resource Guide, 1991).

The molten purified and alloyed metal is then recast into ingots, usually by a semi-continuous chilled mold process, for eventual rolling or extrusion. In addition to the remelt ingots, other aluminum forms include: sheet, flat or coiled, 0.01 to 0.25 inches thick; foil, <0.08 inches thick; plate, 1 to 6 inches thick; extruded sections, such as construction materials, wires and rods, and paste and powders. In these forms, aluminum is shipped to fabrication facilities where it is formed into products for consumer use

(Groliers, 1994). These shipments consume fossil fuel for energy and emit criteria pollutants as a result of the combustion.

3.1.1.3 Aluminum: Fabrication and Use Stage

Aluminum has become a vital component of the packaging industry, and the largest use within the industry is for cans. A typical can manufacturer receives rigid aluminum container sheet from the mill. The sheet is cleaned, molded, and subjected to either a lithographic or rotogravure printing process to imprint labels. The printing process generally involves a clear primer coat, a colored exterior, and decorative inks.

In the case of consumer beverages, the cans leave the fabrication process and are transported to a beverage manufacturer where they are sterilized and filled with a beverage. The filled cans are then "capped" for distribution. The filled containers are transferred by the wholesaler/distributer to a retail outlet for sale to the consumer. The consumer purchases the beverage and can, and eventually consumes the beverage and discards the can.

The main source of emissions from this life cycle stage are the VOCs from the printing process (Van Horn, 1967), and the criteria pollutants emitted by the combustion of fossil fuels. An accurate estimate of these emissions are not available.

3.1.1.4 Aluminum: Disposal/Recycle and Reuse Stage

At the end of its "useful" life, aluminum, particularly in the container form, is discarded. Estimates in 1991 put the weight of discarded aluminum of all types to be 600,000 to 900,000 tons annually, mostly in the form of containers and packaging (Stilwell, et. al, 1991). Consequently, aluminum recycle has emerged as a viable opportunity for the recovery useable materials, particularly for that aluminum used in cans. This recycled aluminum is the feedstock of the Secondary Aluminum Industry.

Secondary aluminum is the term used to distinguish between metals produced from ores and those produced from recovered metal scrap, such as sweepings, skimmings, drosses, and recycled metals (Anderson, 1931). Secondary aluminum production avoids the bauxite mining, alumina production, and aluminum refining steps in the aluminum life cycle. These steps are replaced by the following: primary screening with magnets, shredding to 1-inch sizes, pneumatic processing to remove paper, delacquering and melting of the recycled stock (Tellus, 1992; Selke, 1990).

The first step of returning aluminum containers to use via the Secondary Aluminum Industry begins with collection. Typically, this is accomplished through a "Drop Off Center" or curb side pickup. The cans are collected, transferred to a central site, smashed, baled, and transported to a Secondary Aluminum facility for processing. This facility may be co-located at a primary aluminum processing site. The collection, baling, and transfer require the inputs of fossil fuel energy and contribute to air emissions.

Prior to smelting, the collected aluminum cans go through a delacquering step. This step involves heating the metal to burn off any outer coatings, such as labels or sealants, which were added during the previous fabrication stage. The delacquering step is a potential VOC/HAP source. The delacquered cans are then remelted. The remelted aluminum is cast into ingots which are processed into aluminum sheet and returned to the fabrication plant to make new cans. The process can essentially operate as a closed loop with old cans being recycled to create new cans.

The remelting typically utilizes a gas fired furnace, and, therefore, consumes less energy than the smelting step in the primary production process. It has been estimated that it requires 8.32 MM Btu to produce one ton of new can sheet stock from used beverage cans versus the 208 MM Btu to produce a ton of aluminum from virgin stock (Tellus, 1992). Table XVI presents selected inventory items from the secondary aluminum industry's remelt/recycle step.

Table XVI: Selected Environmental Inputs and Outputs from the LCA Recycle/Reuse Stage: Secondary Aluminum Production

LCA Stage	Input/Output	Total
Recycled Aluminum (Units/ton recycled aluminum)	Energy (i)	8.32 MM BTU/ton
	TSP (o)	51.4 lb/ton
	SOx (o)	0.92 lb/ton
	NOx (o)	1.50 lb/ton
	CO (o)	0.001 lb/ton
	VOCs (o)	0.05 lb/ton

(Tellus, Vol. II, 1992) (i)= input (o)= output

3.1.2 Life Cycle Assessment - Impact Analysis

The LCA Impact Analysis step aggregates and assigns the environmental inputs and outputs identified in the Inventory Analysis into specific categories of environmental impacts. Impact Analysis is extremely complex, and no generally accepted methodology exists to date to address the full spectrum of emissions and impacts (Todd, 1994). This lack of completeness is due to two major methodological deficiencies. The first is the absence of environmental models that can predict the cumulative impacts of a product or process given the spatial and temporal separation of its inventory components over its life span of a product. The second deficiency is the lack of objective criteria for valuing the relative significance of the LCA impact categories.

For the purpose of this study, the Tier 1 - Inventory Evaluation Model presented in Appendix B will be used to aggregate and classify the inventory input/outputs components. This model is the simplest model in the five tier impact hierarchy currently being considered by the EPA and its associate, the Society for Environmental Toxicology and Chemistry (SETAC). Table XVII presents the previously presented LCA Inventory items aggregated and classified by impact category, according to this model.

Table XVII: The Impact Classification of the Aggregated LCA Inputs and Outputs Identified in the Inventory Analysis

LCA Stage	Inventory Input/Output		Aggregated Total		Impact Category
"Cradle to Cradle"	Energy	(i)	208 MM/Btu		Nat'l Res. Depletion
	Bauxite	(i)	1000	lb/ton	Nat'l Res. Depletion
	TSP	(o)	103	lb/ton	Ecosystem/Atmosphere
(Unit/ton aluminum)	SOx	(o)	93.1	lb/ton	Ecosystem/Atmosphere
	NOx	(o)	96.3	lb/ton	Ecosystem/Atmosphere
	CO	(o)	8.6	lb/ton	Human H'lth/Toxicity
	VOCs	(o)	2.63	lb/ton	Ecosystem/Atmosphere
	TF*	(o)	7.41	lb/ton	Human H'lth/Toxicity
	POMs	(o)	0.048	lb/ton	Human H'lth/Mutagen
	POMs*	(o)	0.000012	lb/ton	Human H'lth/Mutagen

(Tellus, Vol. II, 1992) (i)= input (o)= output
Nat'l Res. Depletion = Natural Resource Depletion; Human H'lth/Toxicity = Human Health/Toxicity; (*) = HAPs emission from Primary Aluminum Source Category

The impact classifications in Table XVII cover the four LCA stages established in the screening phase of the study: Raw Materials Acquisition, Manufacturing, Fabrication and Use, and Recycle. The Impact Categories presented in Table XVII are taken from Appendix B. In the next step of Impact Assessment, these classified in Table XVIII are quantified. Quantification is not required in Tier 1 Impact Model, however, a brief description of the impacts is generally presented.

The major impacts associated with the Raw Materials Acquisition Stage are attributable to the mining operations and the consumption of fossil fuels to produce energy. Open pit mining increases tropical deforestation and decreases biodiversity due to habitat alteration. In addition, bauxite mining causes a decrease in a non-renewable resource (i.e., bauxite), and an increase in erosion and runoff from the mining site which can also drive habitat alterations with a corresponding species loss.

The combustion of fossil fuel to produce energy for mining, transporting products, and for the benefication of bauxite ore emits several criteria pollutants. The emissions of TSP impact atmospheric visibility and deposits potentially acidic particulates onto vegetation and man made structures. Both SOx and the NOx contribute to an increase in other forms of acidic deposition, such as acid rain, leading to the acidification of land locked bodies of water and the damage to aquatic organism. In addition, acid precipitation increases the corrosion of materials and decreases the resistance of vegetation to secondary attacks from animal pests and diseases. The NOx emissions are also an ingredient in the creation of smog which can contribute to human health effects such increased pulmonary irritations. The CO emissions are toxic to human and animal life.

The environmental impacts associated with the LCA's Manufacturing Stage are also related to the use of energy, and to the acquisition of raw materials, such as lime and caustic for the production of alumina, petroleum for the production of the electrodes, and coal for the production of energy. The environmental impacts associated with the extraction of these raw materials include the depletion of non-renewable resources and potential habitat alteration. The latter impact can contribute to decreased biodiversity and species loss.

The fabrication and use of electrodes during the Manufacturing Stage for the alumina reduction process are sources of TSP, SOx, NOx, VOCs, and the HAPs: HF and POMs. The VOCs can contribute to the formation of smog, as well as, to potential ozone depletion. These LCA Impact Categories are intermediate steps that can eventually lead to both ecologic and human health impacts. The POMs emitted from this process are suspected carcinogens and have the potential to adversely impact human health. The HF, which is emitted during the electrolytic reduction of alumina, is also toxic and can have a direct human health impact.

The LCA Fabrication and Use Stage contributes to TSP, SOx, NOx, and VOCs. The TSP, SOx and NOx are associated with the production and use of energy. The VOC's emissions result from the lacquering and stenciling necessary to print labels on the cans prior to use.

The Recycle Stage also consumes energy and produces TSP, SOx, NOx, and VOCs. These criteria pollutants are associated with the production of process energy. The VOCs are a byproduct of a delacquering step prior to remelt.

The final step in Impact Assessment involves a valuation of the impact categories. In this step, the categories are weighted to facilitate a comparison for the purpose of ascertaining a potential improvement option. The category receiving the greatest weight is taken to offer the most return for a given intervention. The weights can be objective, derived from scientific study, or subjective, representing the practitioner's judgement or values. Due to the focus on HAPs, the weighing step was implicit in the establishment of the study boundary.

3.1.3 Life Cycle Assessment - Improvement Analysis

The LCA Improvement Analysis utilizes the outputs from both the Inventory and the Impact Analysis to identify and evaluate options for reducing the environmental impacts of the pollutants under study. The process typically consists of identifying a need, selecting an option, and determining the timing of the intervention (See Appendix B). The actual implementation of the selected option, including a formal cost/benefit analysis is not a part of the Improvement Assessment.

The identification of the desired improvement was established in the screening phase as the reduction of HAPs. The option to be evaluated is the impact of aluminum recycling on HAP emissions. Using summary data from the Tellus report and the 1992 production data for from the World Almanac, the benefits to the Primary Aluminum Industry in terms of the HF, POM, and other pollutants avoided can be estimated (Tellus, Vol. II, 1992; World Almanac, 1992). Table XVIII presents the results of that determination.

The estimation of the pollution avoided as presented in Table XVIII is determined as follows. The total aluminum production in the US 1992 was reported to be 6,709,000 metric tons of which 4,042,000 metric tons were primary aluminum (World Almanac, 1994). Using this production data and aggregating the pollutant input/output totals for controlled sources, the following calculation was made:

> Total Pollution Avoided (Tons) = ((Total Aluminum Production - Primary Aluminum Production) X 1.1 X (Primary Production Emissions - Secondary Production Emissions))/2000 lbs/ton

Table XVIII: LCA Improvement Analysis: Aggregated Pollution Avoided per Ton of Aluminum Recycled

Parameter	Primary Aluminum (A)	Secondary Aluminum (B)	(A-B)	Total Prevented
	MM Btu/ton	**MM Btu/ton**	**MM Btu/ton**	**MM Btu**
Energy	208	8.32	199.68	292,688
	lbs/ton	**lbs/ton**	**lbs/ton**	**Tons**
TSP	103	51.4	51.6	75,689
SOx	93.1	0.92	92.8	136,124
NOx	96.3	1.5	94.8	138,777
VOCs	2.63	0.05	2.58	3,784
CO	8.6	0.09	8.51	12,483
TF*	7.41	0	7.41	10,869
POMs**	0.0000512	0	0.0000512	0.11
POMs*	0.000021	0	0.000021	0.03

(Tellus, Vol. II, 1992; World Almanac, 1994, Ours, 1994)
(*) = HAP emissions at the Primary Aluminum Site; (**) = POMs off site; unaffected by recycle option.

Because recycled aluminum comprises approximately 40% of the US market, an initial estimate of the potential national HAP reduction at the plant site would have been 40% of the level that would be anticipated if all the aluminum production been met through primary production alone. This holds for TF, however, the HF component of TF is not known, so it can only be assumed to hold for HF. The 40% estimate also holds for POMs generated at the plant site during the smelting process. However, because the majority of POMs are produced during the production of coke, the LCA perspective indicates that the current level of recycle reduces the POMs by 21% of the level that they would have been at otherwise. In addition, there are concurrent reductions in other pollutants distributed over the life cycle of the aluminum industry. For example, TSP is reduced by approximately 20%, and SOx, NOx, and CO, by approximately 39%, of their potential total annual emissions.

Assuming the co-location of the primary and secondary aluminum facilities, the closed loop nature of the extended operation has significant implications for HAPs. The HAP reduction would be proportional to the amount of recycled aluminum handled by a given source within the source category. For example, a plant processing 100% recycled aluminum would have insignificant HF or POMs with which to contend; a plant with 50% recycled aluminum would have a 50% reduction in these HAPs.

Based on this LCA, the industry could consider recycle as an alternative technological system for the reduction of the HAPs. Consistent with Title III, Section 122,(h)(30) of the CAAA, the industry could initiate further analysis with the intent of accessing recycle's source specific impact on the pending MACT standard. Further analysis of this LCA as a potential strategy to reduce HAP emissions will be carried out in Section 5.0 MACT v LCA: A Contrast and Comparison of Strategies.

3.2 Aluminum: The MACT Perspective

From the MACT perspective, the 1990 CAAA designated the air toxics of concern, two of which, POM and HF, were identified by EPA as being produced and emitted by the Primary Aluminum Source Category. The designation of Primary Aluminum Production as a major MACT source was, subsequently, announced in the Federal Register along with the declared intent to promulgate regulations for this source by November 15, 1997. A generalized approach to meeting this and other MACT regulatory deadlines is presented in Appendix A.

The formal process of developing the MACT Standard for Primary Aluminum began with an intensive data gathering effort and the creation of a set of process models to describe the industry. The data survey revealed that there were two major technologies operational in the United States: Prebake and Soderberg. Figures 3 and 4 presents these two technologies, and a general description of each has been provided in Section 3.1.1.2.

3.2.1 Aluminum: MACT Model Plants

The survey further determined that the industry is made of 91 potlines in 23 plant, and that the sources of the HAP

Figure 3: Process Flow Diagram for a Primary Aluminum Soderberg Plant

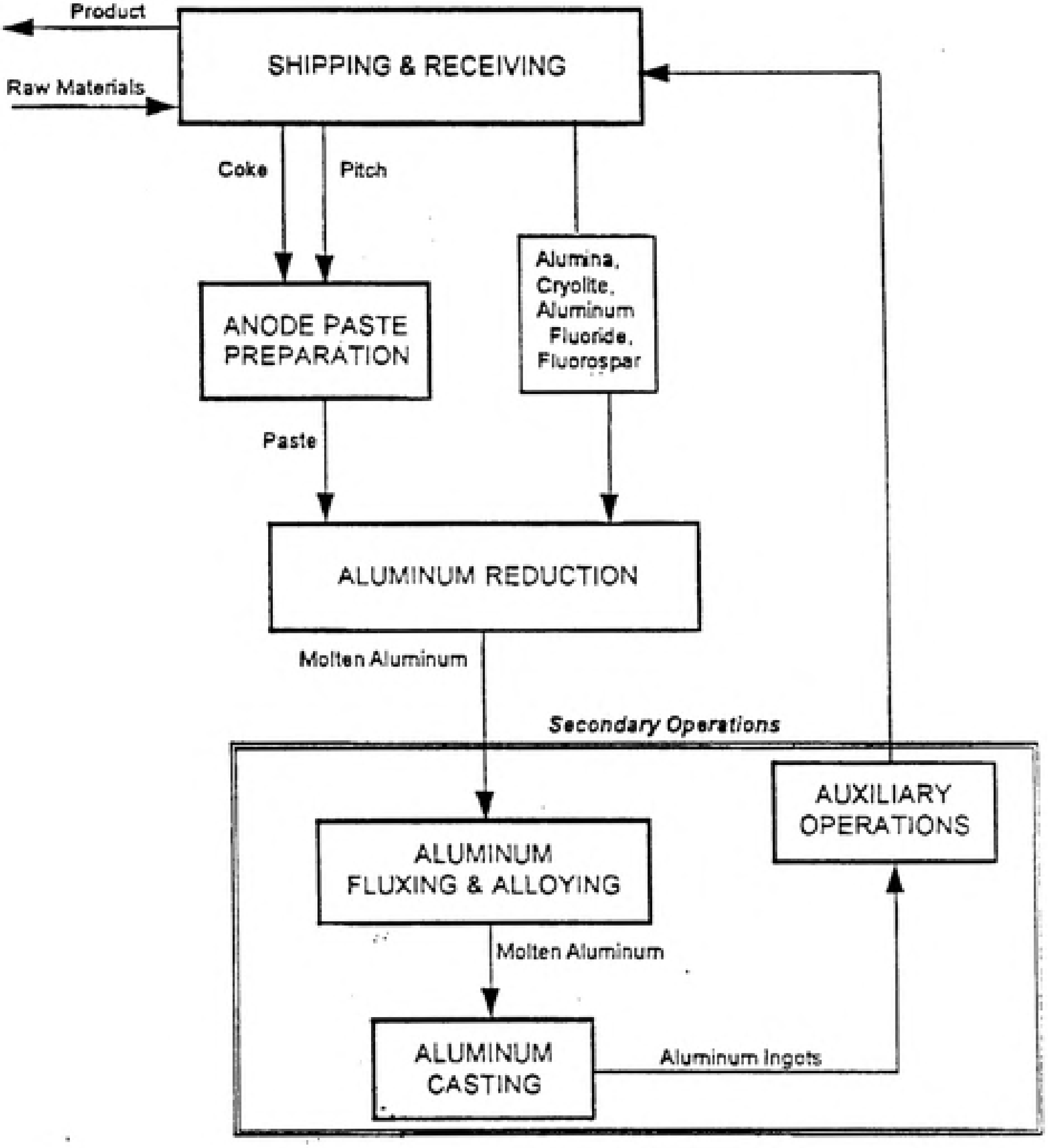
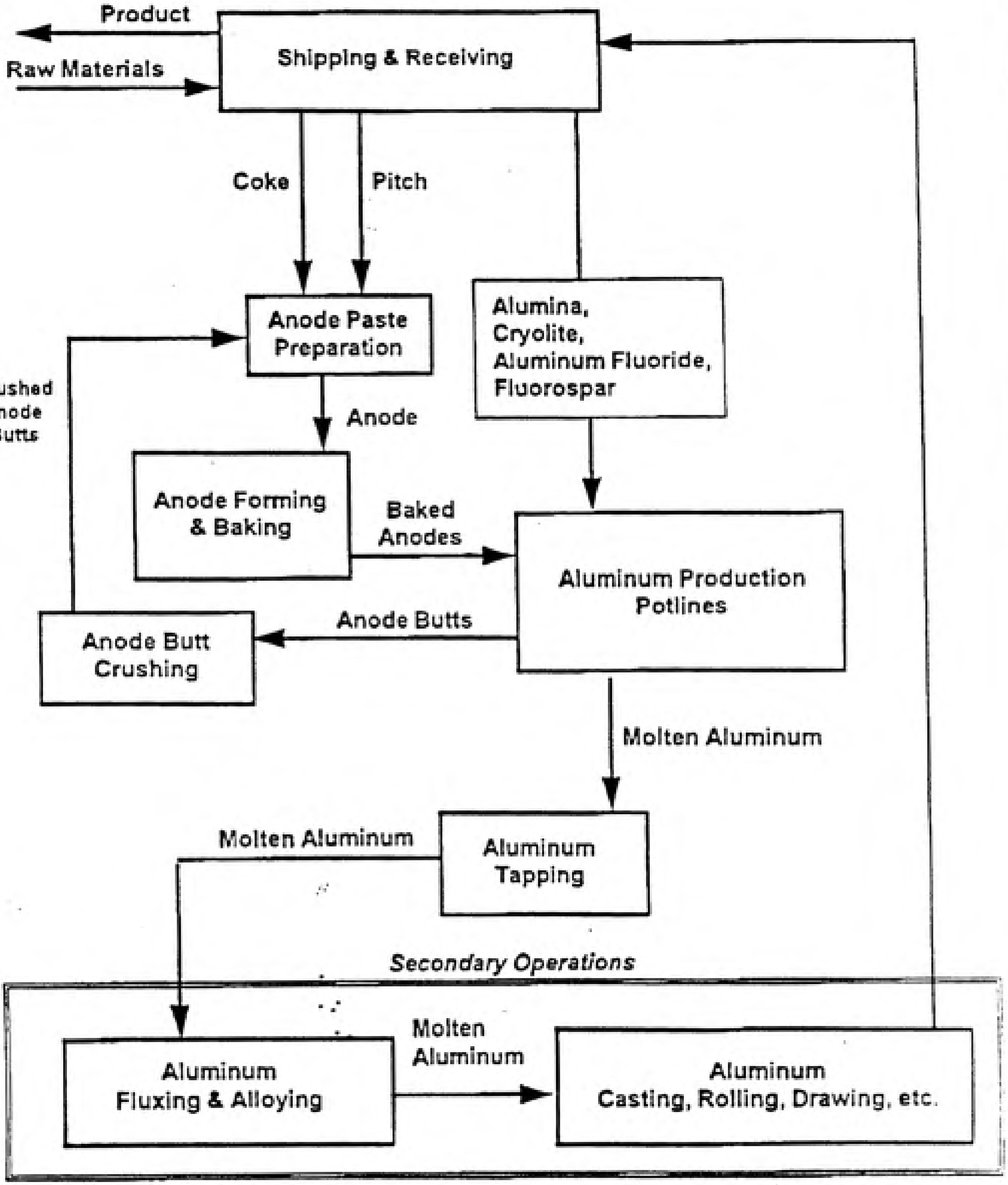


Figure 4: Process Flow Diagram for a Primary Aluminum Prebake Plants



emissions are aluminum smelting, paste production, and anode baking. The composition of the industry is presented in Table XIX. From this table it can be seen that the largest number of plants use the prebake technology in which the anode is formed and hardened prior to being inserted into the pot.

Table XIX: A MACT Description of the Composition of the United States' Primary Aluminum Industry

Plant Type	Number of Plants	Number of Potlines
Center Work Prebake (CWPB)	15	64
Side Work Prebake (SWPB)	2	5
Horizontal Stud Soderberg (HSS)	3	12
Vertical Stud Soderberg (VSS)	3	10

(Ours, 1994)

Based on the number of plants and the variety of processes, 13 possible models representing the 91 potlines within the primary Aluminum Source category were created. These models were developed by dividing the industry into the four different types of potlines. Each potline type was further divided into categories by type of primary and secondary emission controls and their similarity in production rates (See Table XX).

3.2.2 Aluminum: MACT Baseline

With the plant models established, the next step in the MACT process focused on the evaluation of the existing control technologies and the establishment of the control baseline or MACT floor for the various emission sources (See Appendix A.). Within the Primary Aluminum Category, all 23 plants have primary emission control systems. A typical primary control system for a pot room consists of a pot hood, necessary ducting, and a primary pollution control device or series of devices. This system is designed primarily to remove HF gas, particulates containing fluoride, POMs, and in some cases sulfur dioxide (SO_2).

The MACT analysis determined that the most effective control device for fluoride currently in use is the dry alumina scrubber with a baghouse. When operating properly, this system has a control efficiency for total fluoride in excess of 99% (Ours, 1994). Wet scrubbers in series with the dry scrubbers provide little reduction for the fluoride HAP and are there primarily to control the SO_2 emissions.

Table XX: MACT Model Plants for the Primary Aluminum Industry

Model	Type	Potlines Represented	Control Devices	Production (tons/year)
1	SWPB	5	Dry alumina scrubbers for primary control and wet roof scrubbers for fugitives	100,000
2	CWPB	26	Dry alumina scrubbers for primary control	28,000
3	CWPB	20	Dry alumina scrubbers for primary control	60,000
4	CWPB	8	Dry alumna scrubbers for primary control	100,000
5	CWPB	8	Multicyclone, wet scrubbers & ESP for primary control	46,000
6	CWPB	1	Wet scrubbers and ESP for primary control	40,500
7	VSS	5	Dry alumina scrubbers followed by wet scrubbers for primary control and wet roof scrubbers for fugitive emissions	50,000
8	VSS	5	Dry alumina scrubbers for primary control	37,000
9	HSS	2	Dry alumina scrubbers for primary control	20,000
10	HSS	1	Dry alumina scrubbers for primary control	39,000
11	HSS	3	Wet scrubbers for primary control	45,600
12	HSS	3	Wet prescrubbers and wet ESP for primary control	26,000
13	HSS	3	Wet prescrubbers and wet ESP for primary control	51,000

(Ours, 1994)

For MACT purposes, the emission of a criteria pollutant such as SO_2 is not considered.

Consequently, the control option selected as the MACT baseline for the primary smelting emissions is the replacement of the existing wet systems for primary control with a dry alumina scrubber/baghouse system. This selection reflects the additional emission control achieved by most of the plants that have already installed dry alumina scrubbers. Not only does the dry alumina scrubber/baghouse system capture fluorides, but it enables the facility to return these captured fluoride back to the production process as makeup materials for the flux agent. The recycled particulate bearing fluoride are consumed leaving no residue and providing recovery of the resource. Model process 5, 6, 11, 12, and 13 are directly impacted by this MACT recommendation.

For the secondary emissions that escape through the pot room roof monitors, the MACT floor technology was determined to be improved operations and maintenance of existing systems and equipment repair. The equipment maintenance and work practice procedures improve the capture efficiency of the hooding associated with the primary collection systems and reduced the quantity of emissions that escape from the pots.

The MACT floor for POMs originating from the anode paste production process was based on the six possible models that were created to describe this process (See Table XXI). The analysis of these models resulted in only one control option for paste production. This option involves the installation of dry coke scrubbers to replace the existing controls on those plants without dry coke scrubbers. The dry coke scrubber use coke as an absorbent followed by a baghouse to collect POMs and other particulate. This technology was determined to be more efficient than an air filter or baghouse alone. Models 2, 3, 4, 5, and 6 are directly impacted by this MACT technology and require an upgrade of the existing facility to achieve compliance.

Table XXI: MACT Models for Anode Paste Production

Model	No of Plants	Control Device
1	5	Dry coke scrubber
2	1	Dry alumina scrubber
3	12	Bag house
4	2	High efficiency air filter (HEAF)
5	2	Wet Scrubber
6	1	Electrostatic precipitator

(Ours, 1994)

As with the anode paste process, there are six possible models that describe POM generation sources from the anode baking plants. These models are presented in Table XXII. An analysis of these models concluded that the combination of dry alumina scrubber and baghouse is also the most effective control technology currently used for the control of emission of both fluorides and POM from the anode bake furnace. This captured particulate can also be returned to the system and destroyed. A shift to this technology would directly effect models plants 3 and 4.

Table XXII: MACT Models for Anode Baking

Model	No of Plants	Control Devices	Anode Production (tons/yr)
1	8	Dry alumina scrubber	98,500
2	4	Dry alumina scrubber	160,500
3	2	Electrostatic precipitator	133,000
4	3	No emission controls	112,000

(Ours, 1994)

Due to the fact that the technologies that comprised the MACT floor provide such high levels of control for the target HAPs (i.e., >95%), alternative controls options were not considered necessary (Bransocme, 1995). Consequently, the MACT step requiring the determination of additional control options more stringent than baseline not pursued. This decision allowed the development of the MACT Standard to proceed with the evaluation of the energy and environmental impacts associated with the implementation of the MACT floor.

3.2.3 Aluminum: MACT Environmental Impact Analysis

The Environmental Impact Analysis showed that the recommended MACT controls for the smelters, prebake, and anode paste processes would reduce the HAP emissions, but would also have an impact on water and solid wastes streams. The overall impact on the waste water was determined to be potentially positive. A net decrease in water borne fluorides and suspended solids is anticipated because these pollutants will be recovered in the dry scrubbers prior to any wet scrubbing. Estimates for the reductions of these waste water fluorides and suspended solids are 38.9 tons/year and 77.7 tons/year, respectively (Ours, 1994).

The recommended controls are also expected to have positive benefits for the solid waste stream. This is due to the fact that with the proposed MACT technology, all fluoride laden solids are returned to the process and utilized for their potential value as fluxing agent. The potential reduction of solid wastes is estimated to be on the order of 6,000 to 15,000 tons/year (Ours, 1994).

The implementation of the MACT controls are also anticipated to reduce deposition of fluorides and POMs onto adjacent bodies of water not directly connected to a source by an effluent discharge. This benefit is due to the anticipated HAP reductions of approximately 50% or better in the ambient air releases from many of the aluminum plants. These plants include those located near the Great Lakes and in the Midwest which are known to contribute to the long-distance air transport of pollutants. Table XXIII presents nation wide model plant specific emission reduction estimates for HF, TF (total fluoride), and POM, resulting from the implementation of the proposed MACT Standard (Branscome, 1994). These reductions included: 3,373 tons/yr TF; 1,616 tons/yr HF; and 1,246 tons/yr POM for reductions of 53%, 56%, and 46%, respectively.

The Energy Impact Analysis identifies the amount and type of energy required by each regulatory alternative. The MACT requires retrofit of model plants 6, 11, 12, and 13 with dry alumina scrubbers is estimated to increase the total energy consumption by approximately 2 MM Btu/ton aluminum or an average of 0.5 MM Btu/ton per plant (Branscome, 1995). This estimated increase is slightly more than one percent over the current consumption of 189 MM Btu/ton of aluminum. No significant effects on energy consumption were projected for the anode baking and paste production process where existing controls are respectively replaced by a dry alumina scrubber or dry coke scrubber. However, energy consumption will increase in those plants that currently have no controls and have to install this technology. There are three model plants that are effected by this measure. These plants are anticipated to increase their gas consumption by an energy equivalent of approximately 0.07 Btu/ton of aluminum produced.

3.2.4 Aluminum: MACT Cost and Economic Analyses

The final steps in the MACT process involve the development of a Cost Impact Analysis and an Economic Impact Analysis for the proposed controls. The cost estimation procedure includes consideration of capital costs, direct and indirect operating costs, annual work practice costs, and monitoring costs. These costs were converted to 1994 dollars and subjected to a curvilinear cost regression analysis to develop a set of cost functions. Based on these derived cost functions, the total industry wide capital cost

Table XXIII: Emissions of Total Fluoride (TF), Hydrogen Fluoride (HF), and Polycyclic Organic Matter (POM) from Aluminum Smelting

Model Plant	Plant Type	Total TF Baseline Emissions (tons/year)	Total TF Emissions After Control (tons/year)	Total TF Emissions Reduction (tons/year)	Total Estimated HF Baseline Emissions (tons/year)	Total Estimated HF Emissions After Control (tons/year)	Estimated HF Emissions Reduction (tons / year)	Total Estimated POM Baseline Emissions (tons/year)	Total Estimated POM Emissions After Control (tons/year)	Estimated POM Emissions Reduction (tons/year)
1	CWPB2	450	300	150	225	150	75	113	75	38
2	CWPB1	131	131	0	61	61	0	30	30	0
3	CWPB2	236	224	12	118	112	6	59	56	3
4	CWPB1	488	101	386	244	51	193	122	25	97
5	CWPB1	83	83	0	42	42	0	21	21	0
6	CWPB1	117	99	18	59	50	9	39	35	5
7	CWPB2	140	140	0	70	70	0	35	35	0
8	CWPB2	379	140	239	165	70	95	83	36	47
9	CWPB2	196	112	84	98	56	42	49	28	21
10	CWPB1	954	123	831	477	62	415	239	31	208
	CWPB1	270	99	171	135	50	86	68	25	43
11	CWPB1	430	110	320	215	55	160	108	28	80
12	CWPB1	795	165	630	398	83	315	199	41	158
13	CWPB1	126	66	60	63	33	30	32	17	15
14	CWPB1	106	55	50	53	28	25	26	14	13
15	CWPB1	315	165	150	158	83	75	79	41	38
16	SWPB	165	165	0	83	83	0	41	41	0
17	SWPB	110	110	0	55	55	0	28	28	0
18	HSS	289	196	92	87	58	29	476	324	152
19	HSS	234	116	118	82	35	47	452	192	260
20	HSS	75	67	8	23	20	3	134	111	23
21	VSS	157	130	28	42	36	6	140	115	25
22	VSS	145	105	40	29	21	8	127	93	33
23	VSS	17	17	0	7	7	0	33	33	0
Industry Total		6,391	3,010	3,371	2,989	1,371	1,616	2,707	1,461	1,246
			Percent Reduction in TF Emissions	51%		Percent Reduction in HF Emissions	56%		Percent Reduction in POM Emissions	46%

for the implementation of MACT controls was estimated to be $158 million and the total annualized cost of $40 million (Branscome, 1994).

A break out of the cost estimate for the total and annualized cost, respectively, of site specific MACT upgrades includes: 1) the addition of dry alumina scrubbers for primary controls in the smelting process: $104 million, $23 million; 2) upgrading the paste production controls through the addition of dry coke scrubbers: $26 million, $6.1 million; 3) the addition of dry alumina scrubber systems onto the anode baking process: $20.6 millions, $6.2 million; and, 4) increased monitoring: $7 millions, $4.5 million. In addition, the direct operating costs in 1994 dollars for the anode process were estimated to be $1.16 per ton of paste and $4.81 per ton of anode. (Branscome, 1994).

Using the cost estimates from the cost analysis, an Economic Impact Analysis (EIA) was conducted to estimate the market's response to the proposed control recommendations. The EIA is use to determine whether adverse economic impacts are anticipated and whether further study is warranted (See Appendix A). This analysis is handled in-house by EPA through the application of one or more economic models. These models use the anticipated market price increase and price elasticity to gauge the overall economic impact of a proposed standard.

To arrive at the market price increase, the control costs for the entire Primary Aluminum Source Category were summed and divided by the sum of the industry revenues to derive an average price increase. This analysis indicated that the implementation of the MACT Standard would increase the market price of aluminum by less than one percent (Branscome, 1995). This increase did not exceed the 5% threshold trigger for a Regulatory Flexibility Analysis, consequently, it was not required.

After deriving an estimate of the market price increase, the anticipated reduction in aluminum output and its impact on the industry's employment were determine. A market analysis had previously determined that the demand for aluminum was inelastic. The combination of the low market price increase and the inelastic demand indicated that any negative changes in primary aluminum output would be small. Using additional information coupled with the assumption that employment in the Primary Aluminum industry is proportional to output, the analysis indicated that the impact on employment would also be small (Ours, 1994; Branscome, 1995).

The economic analysis concluded that the effect of the proposed MACT Standard on the market prices, outputs, unemployment, and total revenues of the Primary Aluminum Industry would all be less than one percent (Branscome, 1994). Because the recommended control options were not more stringent than the MACT floor, and because the estimated economic impact did not exceed the Regulatory Impact Analysis threshold of a $100 million increase in annual costs, further analysis not required. The MACT standard was drafted and sent to EPA for internal review and comment pending its listing in the Federal Register.

4.0 MACT v LCA: A Comparison and Contrast of Strategies

The objective of this section is to evaluate MACT and LCA with regard to their effectiveness in controlling the target HAPs: HF and POMs. To accomplish this objective, the results of the previous LCA and MACT studies will be compared and contrasted in the following manner:

- On a step by step basis to determine similarities and differences in their approach and to evaluate how these aspects impact the control of HAPs; and,
- As individual approaches with their respect to their effectiveness in controlling HAPs.

4.1 Comparison and Contrast: An Evaluation of the MACT and LCA Processes

To compare and contrast LCA and MACT as strategies in the control HAPs, it is necessary to review the components of each method, determine similarities and differences in approaches, and to evaluate how these methodological aspects impact the control of HAPs. As a first step in this process, it is desirable to review certain characteristics of HAPs and to consider how these characteristics can influence the selection of a particular strategy.

HAPs are a category of air pollutant, which in the judgement of Congress, are capable of causing or contributing to increased mortality or serious irreversible, or incapacitating reversible illnesses. These illnesses include specific health effects, such as carcinogenicity, mutagenicity, or reproductive toxicity. A HAP is specifically identified by its inclusion in a list of 189 chemicals in Title III, Section 112, of the 1990 CAAA. HAPs have as their origin specific industries and industrial processes, and, unlike pollutants regulated under the NAAQS, the threat of exposure to these chemicals are highest to those people living in close proximity to the emission source.

Due to their inherent toxicity and the localized nature of their effects, a successful strategy for reducing HAPs must be capable of identifying the HAP emissions source, characterizing the emissions, reducing or eliminating the emission, and assuring long term continued compliance with the reduced emissions level. Figure 5 presents the format that will be used for contrasting and comparing the capability of each method to meet these requirements. In this Figure, the steps that comprise each method are summarized and allocated on the basis of their similarity in function, input requirements, and outputs. This table is derived Appendices A and B which present a detailed description of the MACT and LCA methodologies.

Figure 5: A Guideline for the Comparison and Contrast of MACT and LCA as Strategies to Reduce HAPs

LCA	MACT
Step I	
Screening	Section 112, CAAA
Study Boundary	HAPs List
System Boundary	EPA Source List
Data Issues	Legal Requirements
Step II	
Inventory Analysis	Information Gathering LCA
Template	Model Plant Development
Data Collection	Data Collection
Inventory Inputs	Control Efficiency
Inventory Outputs	Primary Emissions
	Cost and Economic Data
Step III	
Impact Analysis	Control Option Development Impact
Classification	Environmental Impact Analysis
Impact Characterization	Air Pollution Analysis
Impact Valuation	Waste Water Analysis
LCA Recommendation	Solid Waste Analysis
	Energy Analysis
	Cost Analysis
	Economic Analysis
	Regulatory Impact Analysis
	Regulatory Alternatives
Step IV	
Improvement Analysis	Regulatory Recommendation
Improvement Recommendation	Draft MACT Standard

4.1.1 Step I: LCA Screening v MACT Congressional Mandate

Step I in Figure 5 compares the LCA Screening step to the MACT legislative directive established in Title III, Section 112, of the 1990 CAAA. The components of this step are similar in that they address issues involving the delinnation of the respective method's study boundaries, the systems boundaries, and data requirements.

Within the context of this technical paper, the study boundaries for each method are basically comparable. For example, LCA and MACT share a common objective in the control of the HAPs HF and POMs. The target audiences are also similar, although reciprocal in both methods. For LCA, the target audience can be either internal or external, but in this case it is external to the entity developing the study. The MACT audience is always external as the MACT goal is to develop and present a defensible standard to the regulated community.

MACT and LCA contrast, however, in the manner in which their respective study boundaries are established. The study boundary for LCA is typically determined by private considerations, in this case, the desire to recommend an alternative to MACT Standards. The MACT study boundary are set by legislative debate, and are defined through a series of determinations (e.g., Source Category Assignments and Source Rankings) performed independently of the individual study.

The resolution of data and data quality issues in establishment the study boundary also provide a major contrast between the two methods. The questions central to this issue concern what data will be used, and how stringent will be data quality goals in terms of completeness and accuracy. To achieve its "cradle to cradle objective" in a reasonably cost effective manner, LCA typically accepts a diverse set data from a wide range of sources. Consequently, its data will necessarily have a wide variation in quality. MACT, however, requires a high quality data set that can withstand litigation. This translates into a relatively small, but complete, set of quantitative data that complies with stringent data quality goals.

Following the data issues, the largest contrast in Step I occurs in the establishment of the LCA and MACT system boundaries. The methods contrast sharply in their flexibility in defining the system boundary and in their resulting perspectives of the problem. MACT's study boundary is imposed externally by the assignment of the HAP to a source, and the source to source category. This constrains the definition of the system boundary to a specific plant and process. The MACT objective is to locate the specific emission source, characterize it with respect to a fixed set of parameters (e.g., emission rates and existing control efficiency), and generate a solution (e.g., control technologies, work practice modification, etc.) from a limited set of options.

The effect of this source specific focus is to initially limit MACT's considerations to a set of technological alternatives co-incident with the emissions source. If these controls cannot provide the desired HAP reductions, MACT's consideration extends to set of technological alternatives derived from sources with similiar emissions. However, regardless of the orgin of the solution, the application of the solution and its effects are limited to a specific site of the HAP source.

The creation of the LCA system boundary offers greater flexibility in achieving a solution. Although, the HAPs are fixed by mandate, LCA views HAPs as one of many environmental issues in an interconnected multimedia "cradle-to-cradle" process. LCA undertakes to characterize the components of this larger system, and to work within the system boundary to affect a change. This change can involve a variety of technical and non-techical pollution prevention opportunities that ultimately reduce the target HAPs, as well as, the system's overall environmental impact. Also in contrast to MACT, the site of application for the recommended change may be physically and temporally distant from the emission source, and not directly tied to the source category. For example, in the foregoing study, the recycle option involves a segment of the aluminum industry not considered in the MACT approach. However, the inclusion of the secondary industry offers a means of meeting the market demand and while avoiding the production of some portion of the HAP emissions.

In summary, the first step for both methods has a potentially positive impact on each's ability to achieve the objective of reducing HAPs emissions. Each method is able to adequately define a system boundary that encompasses the HAP emissions source and facilitates the characterization of the factors that effect the target emissions. Major contrasts occur in how each study boundary is defined and in the relative flexibility each method has in defining its system's boundary. However, these contrasts are consistent with the philosophies underlying each method: MACT's Command and Control directives and LCA's Pollution Prevention incentives.

Step I also impacts the accuracy with which each method can characterize the HAP emissions and the extend to which projections can be made on the effectiveness of the recommended solution. As seen in the previous study, the LCA approach was unable to quantify the HAP, HF, because the LCA data sources were based on existing measurement practices did not report it. Because the emission rate of HF is unknown, the effectiveness of the recycle recommendation in reducing HF can only be estimated. Consequently, additional characterization is required before there is any chance of EPA accepting the LCA recommendation for inclusion into a discharge permit. MACT's stringent data quality requirements set the stage for the development of a legally defensible standard.

4.1.2 Step II: LCA Inventory v MACT Information Gathering

Step II covers the development of process models and the data gathering activities of the respective methods. The models that are developed in both methods (i.e., LCA templates v MACT Model Plants) are comparable in that define the system boundaries and serve as the basis of the analyses. These models clarify the system under study and show the relationship between the component parts. However, consistent with the definition of the system boundaries, the models contrast in their scope and detail. The LCA template covers the full "cradle to the cradle" life cycle of the product under study (i.e., aluminum) and is, therefore, more expansive. The MACT model covers a narrower scope and is analogous to a subsystem within the LCA model. It is focused on the specific process that is the source of the emissions and describes that within the limited context of the plant site.

The individual models serve to illustrate the contrast in each method's informational requirements as defined by their study and system boundaries. The range and a cross section of the typical data collected for each method is presented in Figure 6. As seen in the figure, the consequence of LCA's system boundary drawn to inventory all upstream and downstream inputs and outputs is that it has more extensive data requirements than MACT. As previously discussed, this extensive data requirement compels LCA to use a wide range of data from numerous sources. The data is largely taken from secondary (i.e., peer reviewed literature and databases), and tertiary sources (i.e., non-peer reviewed sources of unknown quality). It may also include primary (i.e., direct measurements), however, this is relatively rare and, when it occurs, it comprises only a small percentage of the total data set. The LCA data consist of quantitative(e.g., measurements of known confidence), semi-quantitative (e.g., engineering or science based estimates), and qualitative values (e.g., rankings, scoring, etc.).

In contrast, MACT requires in terms of volume quantitatively less data than LCA to attain its objective. However, MACT's data requirement are more intensive. They focus on a specific emission point within the source category and undertake to develop a limited, high quality data set on the inputs and outputs around that point. Because MACT data is required to withstand possible litigation, the data set is carefully screened and augmented

Figure 6: A Summary of Selected Environmental and Energy Inputs and Outputs for the Aluminum Industry

Raw Materials	Parameter	LCA	MACT
<u>Mining</u>			
Bauxite	Energy (i)	0.51 MM Btu/ton ore	N/D*
	TSP (o)	1.5 lbs/ton ore	N/D
Lime	Energy (i)	4.91 MM Btu/ton lime	N/D
	TSP (o)	42.8 lbs/ton lime	N/D
Caustic	Energy (i)	45.2 MM Btu/ton Caustic	N/D
	Chlorine (o)	2.5 lbs/ton caustic	N/D
<u>Manufacturing</u>			
Bayer Process			
	Bauxite (i)	4663 lbs/ton alumina	N/D
	Lime (i)	74 lbs/ton alumina	N/D
	Caustic (i)	126 lbs/ton alumina	N/D
	Energy (i)	22.5 MM Btu/ton	N/D
	TSP (o)	38.5 lb/ton	N/D
Anode Production			
	Coke (i)	850 lbs/ton aluminum	N/D
	Pitch (i)	233 lbs/ton aluminum	N/D
	Energy (i)	18.7 MM Btu/ton aluminum	N/D
Reduction			
	Alumina (i)	3860 lbs/ton aluminum	N/D
	Al. Fluoride(i)	40 lbs/ton aluminum	N/D
	Energy (i)	187.8 MM Btu/ton aluminum	N/D
	Fluoride (o)	7.4 lbs/ton aluminum	0.89 to 1.53 lbs/ton Prebake 1.0 to 1.07 lbs/ton Soderberg
<u>Recycle/Reuse</u>			
Shredding			
	Can Scrap (I)	2000 lbs/ton aluminum	N/D
	Energy (o)	1.8 MM Btu/ton aluminum	N/D
Delacquering and Melting	Can scrap (I)	2000 lbs/ton aluminum	N/D
	Energy (I)	6.52 MM Btu/ton aluminum	N/D
	TSP (o)	50 lbs/ton aluminum	N/D

(Tellus, Vol II.,1992; Ours, 1994) *N/D = Not Determined in Study

(o)= output; (i) = input

as necessary with primary emission measurements based on standardized emissions testing methods.

There is an additional contrast in the data requirements of the two methods. This contrast is a direct consequence of the analytical requirements in the subsequent analysis step of each method. Although, extensive in scope, LCA's data inventory effort is relatively homogenous as it focuses on environmental inputs and outputs. MACT's data requirements, however, are more heterogenous in nature. In addition to inputs and emissions, MACT collects data on technology, control efficiencies, costs, and economics.

In summary, Step II for both methods generates system models that have an overall positive contribution to each's ability to deal with the HAPs issue. However, in the data collection component of Step II, a major contrast occurs which impacts the ability of each method to control HAPs. The quantity of data collected, under the LCA system template enables LCA to locate emission source and define its relationship to other system parameters. However, the diversity of LCA data sources and data quality constraints LCA to at best an order of magnitude estimates of the inventory components. This limits LCA's predictive ability in the subsequent steps of the LCA methodology. The diversity of data quality also reduces LCA's ability to accurately gauge the effective of a recommended prevention action, or to determine it long term compliance without additional testing beyond the scope of the study.

The data needs defined by the MACT models is more focused. It facilitates the identification and characterization of the HAP emission source in terms of emission rates, baseline controls, etc., while keeping the data collection effort relatively small. The result is that MACT provides emission estimates within an error range of acceptable engineering practice. This enables, MACT to effectively predict the outcome of a control technology and to predict long term compliance with the Standard.

4.1.3 Step III: LCA Impact Analysis v MACT Environmental Impact Analysis

Step III in Figure 5 contains the data analysis step for both LCA and MACT. In this step both methods analyze collected data to describe the existing situation and, by using the tools available to the method, manipulate the data to obtain a set of recommendations for future action. This step in each method is comparable in terms of their objectives to generate a recommendation on how to reduce HAPs. However, it in this step that the greatest contrast between the two methods occurs in terms of process, completeness of process, depth of analyses, and utility of output.

During the Impact Analysis step, LCA undertakes to determine the LCA system's overall environmental burden, apportion the burden to specific impact categories, and to develop and apply a weighting system that ranks the impacts to determine where the optimum improvement can be made. To accomplish this the aggregated inventory data is plugged into one of five conversion models to develop impact descriptors. The outputs of these models are then weighted according to their environmental consequence by either objective or subjective criteria. The impacts determined to have the greatest positive significance and the recommendation to reduce that impact is passed on to the next step. Because the subject LCA already has its objective established (i.e., the reduction of HAPs), the impact categories of interest and their weight are explicitly determined. The questions remaining are how to arrive at a recommendation and what is the strength of the recommendation

The MACT analog to LCA Impact Analysis is the Environmental Impact Analysis (EIA). The EIA quantifies the anticipated control efficiency of each proposed regulatory alternative for HAP control, and examines their impact in terms of increases or decreases in energy demand, air emissions, water pollution, and solid waste disposal. These loading are not directly linked to environmental impacts, per se. However, they are quantified in terms of increased costs for handling and disposal and the impact this has on the source category and the nation.

An important contrast occurs between the LCA and the MACT approach at the outset of Step III in terms of process. This contrast involves a shift in focus within the system under analysis. The LCA process continues sequentially to derive one or more recommendations. These recommendation are then evaluated by passing them back through the impact analysis stage to determine the magnitude and direction of any system changes. MACT, however proceeds on parallel paths. At the outset of the analysis step, MACT generates a series of regulatory controls options based on the control data derived in Step II. These options become the focus of the impact analysis with the most acceptable option becoming the basis for the final recommendation.

There is a major contrast between the two methods with regards to the degree of completeness of this analysis step, and it is here that the methods significantly diverge with respect to their ability to control HAPs. LCA's environmental classification models are extremely complex conceptually and, generally, do not exist in a state that is readily applicable for analysis. Consequently, the LCA Impact Analysis is unable to provide the depth of analysis necessary to yield a definitive solution for reducing HAPs. To work around this limitation, LCA typically omits the characterization and valuation steps and relies on the simplest of the environmental impact models: the "Less-is-Best" Model. In this model, recommendations are made that reduce the overall output of the pollutant under consideration, with the assumption, that increases or decreases in absolute quantity of pollutant correspond to an increase or decrease in the environmental impact. This form of modeling is roughly comparable to MACT's EIA approach of determining quantitative increases or decrease in waste with respect to burdens on treatment systems. However, it does not have the same foundation or, consequently, the same utility as the MACT analog. Because it is derived from suspect data, the LCA recommendation cannot be used for definitive or legally defensible decisionmaking purposes; it can only point to trends.

In contrast, MACT is a complete system fully capable of implementing its environmental analysis. Using system inputs and data on control efficiency for the set of regulatory alternatives, MACT defines a baseline and estimates, with a high degree of accuracy, quantitative and directional changes of waste loading on water, air, solid waste, and energy as surrogates on environmental impact. Furthermore, these estimates give MACT analytical depth as they become inputs to a subsequent suite of analyses that have no corresponding analog in LCA. These analyses include Cost Analysis, Economic Analysis, Regulatory Impact Analysis, and Regulatory Flexibility Analysis. The MACT cost/benefit analysis provides an estimate of the increase costs for each regulatory option. This analysis, in turn, drives an economic analysis which determines the impact on the economy as a whole, which in turn triggers an in-depth regulatory analysis if a $100 million threshold is exceeded. MACT's analytsis culminates in a fuctional recommendation for a HAP control standard that can provide quantitative reductions in HF and POMs and has an opportunity to withstand scrunity and challenge from the outside.

In summary, the lack of development of the LCA Impact Analysis undermines its holistic approach and prevents it from being a rich, fully integrated environmental management tool. In its current stage of development, LCA is not capable of analyzing the full complement of data generated by the Step II inventory. Having identified the HAPs emissions source (Step I), estimated HAP emissions (Step II and Step III), and assigned the emissions to impact categories (Step III), LCA is reduced to simplistic assumptions and order of magnitude estimates of HAP reduction and environmental impact. Even with these constraints, LCA can make a pollution prevention style recommendation with a degree of confidence that it reduces HAPs and the environmental burden of the overall system. However, having accepted a compromise on data quality to acquire the requisite broad spectrum of data, LCA is not in a position to make its recommendation with the same degree of confidence as MACT. In contrast, MACT works on a narrower front with a defined set of data and analytical tools to perform a traditional analyis. Consequently, it is capable of compeleting its objective and delivering a recommendation for HAP control that is both technically and legally defensible.

4.1.4 Step IV: LCA Recommendations v MACT Standards

This step, as shown in Figure 5, is comparable for both methods in that it is here that both LCA and MACT make recommendations for reducing or eliminating the target HAPs. The contrast between the methods occurs in the type of recommendation made and in its ability to effectively control the HAPs. This section will address the substance of the respective recommendations; a detailed evaluation of the approval procedures for implementing the respective recommendations once they are developed is outside the bounds of this evaluation.

In this final step, the LCA methodology receives an output from the impact analysis, develops a critical review of the study's methods, evaluates the output from the impact analysis, and generates a pollution prevention oriented improvement recommendation. The strength of the LCA recommendation with respect to its ability to reduce HAP emissions is directly related to the data on which it is based. As discussed in Step III, trade offs in data quality for data quantity, typically reduces the accuracy of the estimates of environmental benefits to orders of magnitude. However, in this study, avoidance clearly has positive benefits in terms of reducing HAPs, energy consumption, and the generation of other pollutants. In fact, as seen in Table XVIII, each ton of aluminum recycled avoids the cumulative environmental impacts of ton of aluminum produced from raw materials over the life cycle of product up to the point at which the recycled material enters the system. Consequently, the LCA recommendation can effect a reduction in the total HAP emissions at a specific site in direct proportion to the amount of recycled aluminum used to meet its production demands. The exact amout of this reduction is not known.

Having reveiwed the recommendation, critiqued the study, and perhaps requested some additional information to clarify a point, a LCA recommendation is made. This recommendation constitutes the output of the LCA process, and LCA terminates with the recommendation. However, prior to receiving approval for implementation, the LCA recommendation must under go further analysis outside of the LCA methodology. This analysis involves costing the recommendations in terms of either traditional cost/benefit analysis or its Life Cycle Costs (LCC). The cost/benefit is comparable to the MACT cost analysis. The LCC analysis, however, is substantively different. Like LCA, it has a cradle to cradle framework, however, it attempts to identify all the cost bearing activities associated with a system over this time frame. The key variables in LCC include: procurement costs, delivery and installation, annual operating costs, annualized maintenance cost, taxes, life span in years, and a discount rate (Bailey, 1990/91). There are no environmental considerations in either cost method; it is assumed that the environmental issues have been resolved in the LCA and the new issue is whether the recommendation is affordable.

In contrast to LCA, the central focus of this step for MACT is the translation of the preceding analysis into a draft standard with all supporting documentation. MACT received a recommended emissions limit from the preceding analysis step and regulatory option that can meet the emissions limitation. The control option is typically in the form of a control technology, work practice standard, or equipment specification that has survived passage through the various MACT impact analyses. The regulatory alternative is quantitative with regards to its estimated ability to control the HAPs and the environmental and economic impacts associated with this control.

In summary, Step IV of the process focuses on the ability of the individual methods to present recommendations to reduce HAPs. The cumulative LCA and MACT processes are in sharp contrast in this stage. LCA's recommendation, driven by its "less is best" assumption, is subject to extensive internal review and further analysis through the LCA process. When passed out of the LCA process, it is subject to an additional set of analysis, prior to receiving a formal decision to proceed. If implemented, the LCA recommendaton typically takes the form of internal company initiative, rather than as a substantive industry directive. In contrast, the MACT development process terminates and the emissions standard and control technology recommendation are ready for public review prior to implementation.

4.2 Comparison and Contrast: The Effectiveness of LCA and MACT in Reducing HAPs

The previous sections compared and contrasted MACT and LCA in terms of their methodology for deriving a recommendation that could reduce HAPs emissions from the Primary Aluminum Source Category. This analysis indicated that LCA was the least effective in terms of its ability to measure the quantity of HAPs emitted before and after the implementation of a option. However, the LCA was able to make a pollution prevention recommdation, based on its systems approach, that appeared to have merit.

The objective of this section is to, first, quantitatively compare and contrast the ability of the respective methods to draw similar conclusions on HAP emissions from the source category. Second, compare and contrast each recommendation (i.e., recycle v control technology) in terms of their application as a HAP reduction strategy in the Primary Aluminum Source Category. Because of the inherent weakness of the LCA data set, this analyis will combine elements from each study as needed in the second evaluation step to provide an evaluation of the LCA recommendation.

The first step in this evaluation is to compare the ability of MACT and LCA to draw similiar conclusions on emissions levels prior to a control recommendation (i.e., baseline) and the emission levels after controls. Table XXIV presents estimates of HAP emission rates derived from the previous studies. The MACT emission rates represent average over the 23 MACT model plants developed in the MACT study. It is determined by taking the total baseline and controlled HAPs presented in Table XXIII and dividing them by the total aluminum production (tons/yr) of the MACT model plants. The LCA emission rates are taken directly from Table XVIII, and represent the best estimates of the Tellus packaging study as to the emissions of the specific HAPs (See Table XXIV).

Table XXIV: A Contrast and Comparison of Baseline and Controlled HAP Emission Rates for Aluminum Smelting

	MACT			LCA		
	Baseline (lb/ton Al)	Controlled (lb/ton Al)	(%)	Baseline (lb/ton Al)	Controlled (lb/ton Al)	(%)
HF	1.3	0.57	44	ND	ND	ND
TF	2.8	1.3	46	7.4	0	100
POMs	1.2	0.6	50	0.000029	0	100

(%) = Percentage Reduction; ND = Not Determined

Table XXIV appears to demonstrate a clear environmental benefit in terms of percentage reduction between control based and avoidance based recommendations. It also demonstrates the significant difference in the predictive capabilities of the data. For example, no estimates are available for HF. As discussed previously, this is because fluoride data has been reported for TF in the open literature.

More importantly, Table XXIV demonstrates a distinct contrast in the emissions rates developed by each study. Beyond the relative difference in the values of the emission rates, there is no apparent relationship in the direction of the variation of the difference. The MACT emissions are not generally higher or lower than their LCA counterpart.

Given that MACT develops a primary data set to can withstand potential litigation, the variations in the estimates of the emission rate are indicative of the variability inherent in the LCA data set. This variability is a consequence of LCA's extensive focus as opposed to MACT intensive focus on data collection.

The impact of this emphasis on data can be more readily seen in a comparison of HAP baseline emissions developed from these emission rates. Using these emission rates from Table XXIV and the total 1992 US aluminum production of 7,379,900 tons, the total baseline emissions are calculated and presented in Table XXV.

Table XXV: HAP Baseline Emissions for Aluminum Smelting Using MACT and LCA Emission Rates

Pollutant	MACT	LCA	% Variance (LCA/MACT)X100)
HF	4,797	ND	ND
TF	10,332	27,306	264.3
POMs	4,428	0.11	0.002

Table XXV indicates a major contrast in the baseline HAPs estimate. In addition to failing to directly estimate HF and treating it as a component of TF, LCA overestimates the TF baseline by approximately 264% and under estimates POMs by 99.998% when compared to MACT.

Given that, in this case, the LCA data do not provide a reliable starting point, or HAPs baseline, estimate, it is obvious that they are equally faulty in estimating the actual amount of pollutant reduced. Although, unable to generate a reliable estimate of the HAP baseline, the LCA study does identify and characterize potential HAP emission points for the over all system. From the LCA it can be seen that POM generation occurs off-site in the preparation of petroleum coke and onsite during anode preparation and smelting steps. HF is emitted onsite during anode baking and the smelting operations. Consequently, recycled aluminum which enters the production line at the remelt stage has the potential to reduce a primary plant's HAP emissions.

If one uses the MACT data for HAP emission rates, assumes co-location and/or inter-changeability of melting processes, and holds a given plant's annual production rate constant, increasing the percentage recycled aluminum content has the effect of reducing HAP emissions per ton of aluminum produced. Using these assumptions the quantity of recycle aluminum to obtain a MACT control limit for a specific plant has been determined (See Figure 7).

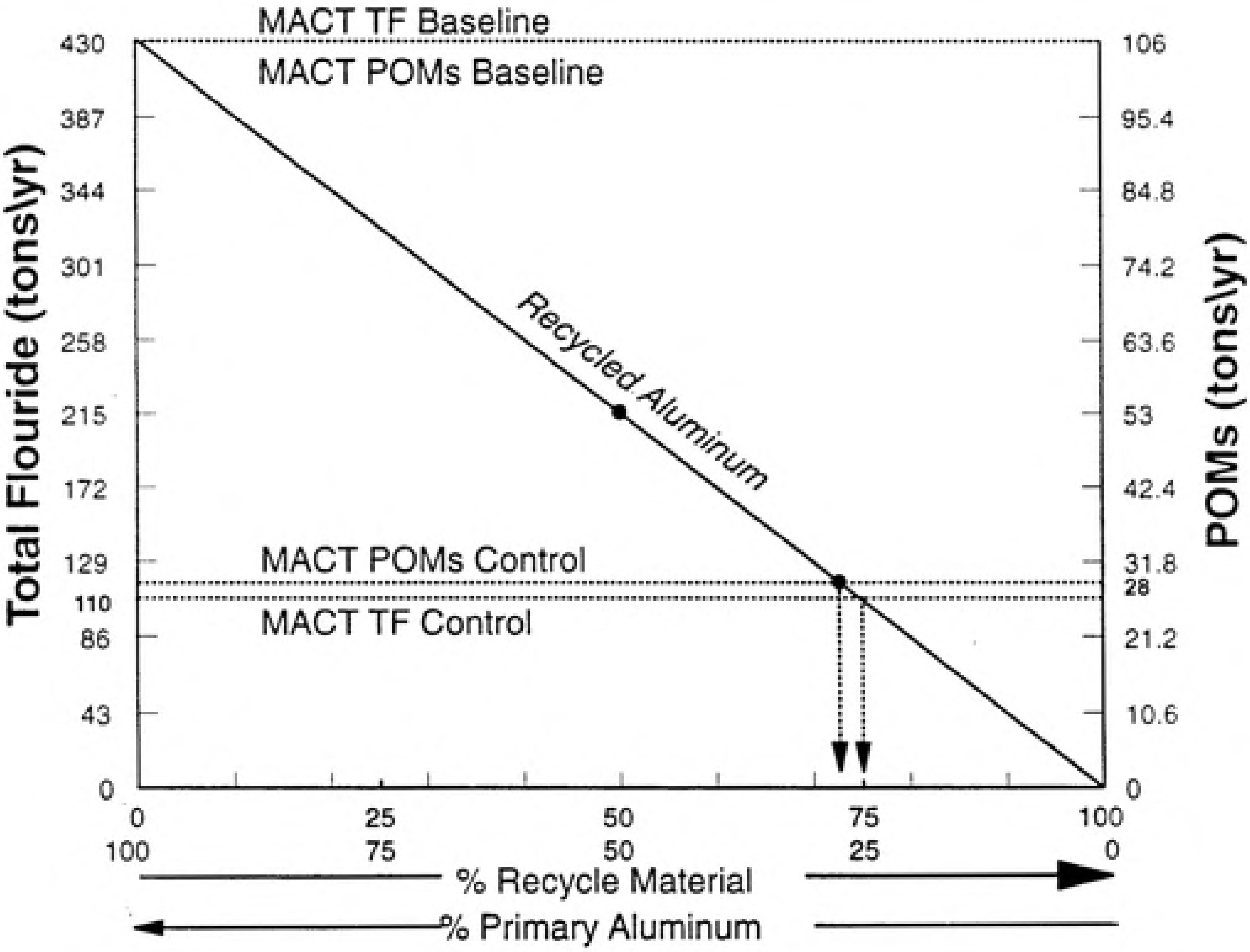
Figure 7 presents is a Center Worked Prebaked Plant taken from the MACT model plant analysis. The plant's annual production is 200,000 tons/yr aluminum. For baseline controls, it uses a dry alumina fluidized bed to collect and destroy POMs and HF, TF. The baseline emissions for this plant as derived from the MACT assumptions are 430 tons/yr TF and 106 ton/yr POMs. After the control options are implemented under the proposed MACT standard, the implemented, these levels decline to 110 tons/yr TF and 28 tons/yr POM or 75% and 75% respectively (Branscome, 1994).

The figure presents the assumption that, at zero percent recycle, the plant meets in production capacity through the use of 100% virgin ore and emits TF and POM equivalent to the baseline. At the smelter site, each ton of production met through another source, such as recycle, avoids the equivalent production of HAPs, consequently, at 100% recycle or 200,000 tons/yr recycled aluminum, produces no HAPs.

From Figure 7, it can be seen that in order to meet the MACT control level in tons/yr of HAP emitted, the plant would have to handle approximately 146,000 to 150,000 tons/yr recycled aluminum or approximately 73% to 75% of its total annual aluminum production. This would constitute a major shift in the plant's business and would not be practical from a business or cost/benefit approach.

Combining components of the two methods, specifically MACT data set and LCA system's view, provides LCA with an increased capability to make a viable pollution prevention.

Figure 7: The Use of LCA to Attain MACT Baseline for HAP Emissions (tons/yr) for A Typical MACT Model Plant



Although Figure 7 is a site specific example and the requirement for 73% recycle to achieve HAP emission rates equivalent MACT control levels is not practical, it can be seen that the percentage recycle is roughly equivalent to the percentage of MACT control. Using the percentage HAP reductions presented in Table XXV, and the Model Plant annual production rates, a table of the minimum recycle requirements to meet the MACT control levels recommended in the MACT analysis can be created (See Table XXVI).

Table XXVI: Minimum Recycle Requirements to Meet MACT Control Levels

Plant No.	Plant Production (tons/yr)	Reduction %			Minimum Recycle (tons/yr)
		TF	HF	POM	
1	300,000	33	33	34	102,000
2	230,000	0	0	0	0
3	224,000	7	5	5	15,680
4	184,000	79	79	80	147,200
5	200,000	0	0	0	0
6	180,000	15	15	17	30,600
7	140,000	0	0	0	0
8	140,000	57	56	57	79,800
9	112,000	43	43	43	48,160
10	224,500	87	87	87	195,315
10a	180,000	63	63	63	113,400
11	200,000	74	74	75	150,000
12	300,000	79	79	79	237,000
13	120,000	48	48	47	57,600
14	100,000	47	47	50	50,000
15	300,000	48	47	48	144,000
16	300,000	0	0	0	0
17	200,000	0	0	0	0
18	231,000	32	32	32	73,920
19	137,000	48	57	58	79,460
20	79,000	11	13	10	10,270
21	186,000	18	16	18	33,480
22	100,000	27	28	26	28,000
23	100,000	0	0	0	0
National Total	4,506,500	53	56	46	2,523,640

In Table XXVI the column labeled “Minimum Recycle (tons/yr)" is estimated as the maximum MACT derived reduction of any one of the three pollutants (i.e, TF, HF, POM) multiplied by each model plant's production rate. The choice of the maximum percentage HAP reduction provides a conservative estimator, and ensures that the other pollutants are covered.

Using the production data from the 1994 World Almanac, it can be estimated that approximately 40% of the US total aluminum production is secondary aluminum (World Almanac, 1994). Using this figure as an arbitrary upper estimate of a theoretical maximum percentage recycle to attain equivalent MACT emission rates, it can be seen from the table that MACT Model Plants 1,3,6,20,21, and 22 fall with in the range of considering the LCA recommendation. In addition, Plants 3,6,20, and 21 would have recycle requirement less than 20% of each plant's annual production, consequently, implementing the LCA recommendation not necessarily require a total change in the plant's character.

Based on this analysis, LCA would recommend that plant specific increases in recycled aluminum be considered as a means of meeting the MACT control levels, and that plants 3,6,20, and 21 would be likely candidates for an initial study to determine the feasibility of implementing the recommendation.

This recommendation would terminate the LCA activity. The LCA recommendation and its supporting documentation would then become the subject of further analysis. In addition to cost/benefit issues underlying facility and process modifications to accommodate the implementation of the recommendation, the final analysis would also have to resolve issues concerning the CAAA's position on permissible HAP swapping and emissions averaging, as well as, procedures for developing and implementing the recommendation in the Title V air permit.

In summary, given the potential health and environmental impacts of HAPs, the CAAA time line for achieving HAP reductions, the specificity of each method, and the relative difficulty in implementing the two approaches, it can be concluded that MACT provides the most effective strategy to control HAP emissions in the near term. In contrast to MACT, LCA is not readily available to play an immediate role in reducing HAPs. However, LCA's avoidance recommendation, through eliminating the HAPs, eliminates the necessity of MACT's residual risk determinations and the eventuality of additional controls. The LCA approach minimizes the over all environmental burden for other pollutants and provides additional positive environmental benefits. Consequently, it is evident that some combination of the MACT/LCA approaches which uses LCA perspective and MACT's intensity could provide and effective HAP management tool.

5.0 CONCLUSIONS AND RECOMMENDATIONS

In conclusion, it is evident from the previous study that MACT and LCA represent opposite ends of the spectrum in environmental management. MACT is the latest version of EPA's traditional "command and control" philosophy. It a is narrowly focused, tactical approach, to a controlling a target set of pollutants from a specific source. Due to the fact that it is unencumbered of the need to immediately consider ample margins of safety, and that its minimum goal is the identification and imposition of the control technology of the best controlled 12% of a source category on the category as a whole, MACT provides a efficient tool for HAPs control. It can readily acquire the necessary data, develop an emissions baseline, evaluate alternative control technologies, evaluate the impact of these technologies on a set of well define parameters, and use the authority of the CAAA impose a standard.

In contrast, LCA is a representative of the "pollution prevention/incentive base" environmental management philosophy. It a strategic tool, broad in scope and general in focus. It works across the life cycle of a product or process to resolve a specific problem (e.g., HAPs) within the context of the overall environmental benefits. Although the LCA inventory component is well defined, its data needs are so extensive that if compels tradeoffs between cost and data quality. This diversity of data sources and the impact on data quality precludes an accurate estimate of a pollutant's baseline emissions. The central component of the LCA method, the Impact Analysis models, are under development and are not available to contribute to a technically based reduction recommendation or to gauge impacts of that recommendation. Consequently, LCA is reduced to simplistic "less is best" assumptions without the data quality to fully comprehend their effectiveness. The cumulative result is that LCA cannot currently be considered as an effective strategy for reducing HAPs within the legal and time constraints of the CAAA.

There are three recommendations that are evident from the course of this study. The first is that there is a potential synergy between LCA and MACT that should be further researched. This synergy can bring the strengths of each method to bear on the HAPs issue, if not as an immediate answer, but in the context of the residual risk reduction. This research should focus on developing a streamlined or modified LCA which can use MACT inputs and

MACT and analysis capabilities. Figure 8 presents the overlap of LCA and MACT and indicates a way in which a streamlined LCA approach to MACT might be accomplished.

The modified LCA would maintain its life cycle context but restricts its data needs to a few pollutants such as done in the body of the previous work. The cradle to cradle approach would provide the opportunity to identify and evaluate pollution prevention opportunities, and the focused data set coupled with MACT analytical tools would provide a major increase in the utility of the LCA system. In addition, the modified LCA offers a methods of linking the outputs of multiple MACT source into a coherent database and evaluation the impacts and costs in a comprehensive way.

Additional opportunities for research occur within the framework of LCA's Impact Analysis. One of the major differences in the effectiveness of the two methods occurs in how they each handle costs. MACT uses standard cost/benefit analysis focusing on identifying and projecting costs associated with the general categories of installing, operating, and monitoring a control technology. Traditional LCA concentrates its effort in evaluating the environmental impacts of the system under analysis and treats costs as external to the method.

A major improvement in the utility of the LCA method could be made if environmental costs were incorporated into the Impact Analysis hierarchy. The nearest analog to MACT's cost benefit analysis available to LCA are Life Cycle Costing (LCC) and Full Cost Accounting (FCA). Both subscribe to a life cycle frame work, but only FCA focuses on valuing the environment.

LCC seeks to develop the standard cost parameters over the life of the product and not just for the immediate application. FCA, however, uses a life cycle frame work and requires that natural resources be carried as assets on a company's books. Treating the environment as a asset compels the company to factor environmental costs into product costs. This translates into increased consumer awareness and enables the factoring of environmental impacts into the calculations of the country's gross domestic product (Popoff, P., 1993). FCA is currently being debated. It poses several difficult questions such as the development of environmental discount rates. However, it offers the opportunity for development of a compatible cost component for LCA.

The last recommendation for further research is also in the area of LCA Impact Analysis. The current suite of impact tools work around a set of issue based impact

Figure 8: Potential MACT Standards Contained Within the Life Cycle of Aluminum

Source Category	Source
A. Raw Materials Acquisition Stage	
Petroleum and Natural Gas	Oil and Natural Gas Production Petroleum Refineries
Liquids Distribution	Gasoline Distribution (Stage 1)
B. Primary Manufacturing Stage	
Fuel Combustion	Industrial Boilers Process Heaters Stationary Turbines
Mineral Products Processing	Alumina Processing
Non-Ferrous Metal Processing	Primary Aluminum Production
C. Secondary Manufacturing Stage	
Surface Coating Processes	Aerospace Industries Auto and Light Duty Truck Large Appliances Metal Can Surface
Coatings	Shipbuilding and Repair Miscellaneous Metal Parts and Products
Miscellaneous Processes	Aerosol Can-Filling Facilities Industrial Process Cooling Towers
Area Sources	Commercial Sterilization Facilities
D. Disposal Stage	
Waste Treatment and Disposal	Municipal Landfills Solid Waste Treatment, Storage and Disposal Facilities
E. Recycle/Reuse Stage	
Non-Ferrous Metal Processing Production	Secondary Aluminum

categories. These categories represent aggregations of endpoints assembled under policy issues. The result is a tendency to double count impacts, and to ignore the spatial and temporal significance of a given inventory item. For example, a unit of VOCs emitted in the mid-west is not equivalent in impact to the same unit of VOCs emitted in Los Angeles. In addition, there is the tendency to become entangled in trying to place objective defensible values on the loss of biodiversity though Global Warming as compared to the loss of biodiversity through Acid Deposition.

There are two potential area here for further research. The first is the development of endpoint/receptor based impact categories. This would involve the development of impact networks, similar to ecological food chains, that would facilitate the tracking of a unit of pollution throughout the network to its ultimate receptors. This "inventory to impact mapping" is extremely complex, but once developed the network mapping would lend themselves to Fuzzy Logic or Neural Network analytical approaches. This would resolve the issue of double counting and require the valuing of endpoints, such as death or disability, instead of the larger policy issues.

The second area of research is less technical, but promises immediate rewards. There appears to be significant overlap in the Risk Assessment (RA) and LCA. A simplistic view of the two methods is that LCA is composed of multiple RAs chained together, beginning at the acquisition of raw materials and continuing thought the disposal/reuse of a product. To date, LCA has developed without significant input from the RA community. This is largely due to LCA's past involvement with defining and resolving the inventory issues. As a result, there is a divergence in terminology used to describe commonly shared concepts, and a general parochial attitude that prevents the flow of ideas. A synthesis of LCA and RA concepts could enable LCA to address important issues, such as the those associated with the spatial and temporal nature of the inventory and impacts, or in RA terms, transport, transformation, and fate. In addition, the linking of the two could provide an important new tool for thinking about environmental impacts and managing their consequences.

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APPENDIX A:

MAXIMUM ACHIEVABLE CONTROL TECHNOLOGY (MACT)

APPENDIX A: THE MAXIMUM ACHIEVABLE CONTROL TECHNOLOGY PROCESS

The purpose of this appendix is to present the steps in the development of a generic MACT standard. This overview is presented as background and provides the MACT perspective for the contrast and comparison of MACT and LCA strategies. Figure A.1 lays out the basic steps in the MACT process.

A.1 Phase I: Legislative Authorization

The MACT process began with the Congressional directive in the 1990 Clean Air Act Amendments to develop control standards for a designated set of 189 air pollutants identified as Hazardous Air Pollutants (HAPs). Upon the passage of the Act, EPA took the list and assigned each HAP on the list to a specific source category. This list was then prioritize, and a schedule for standards development for each source category was determined.

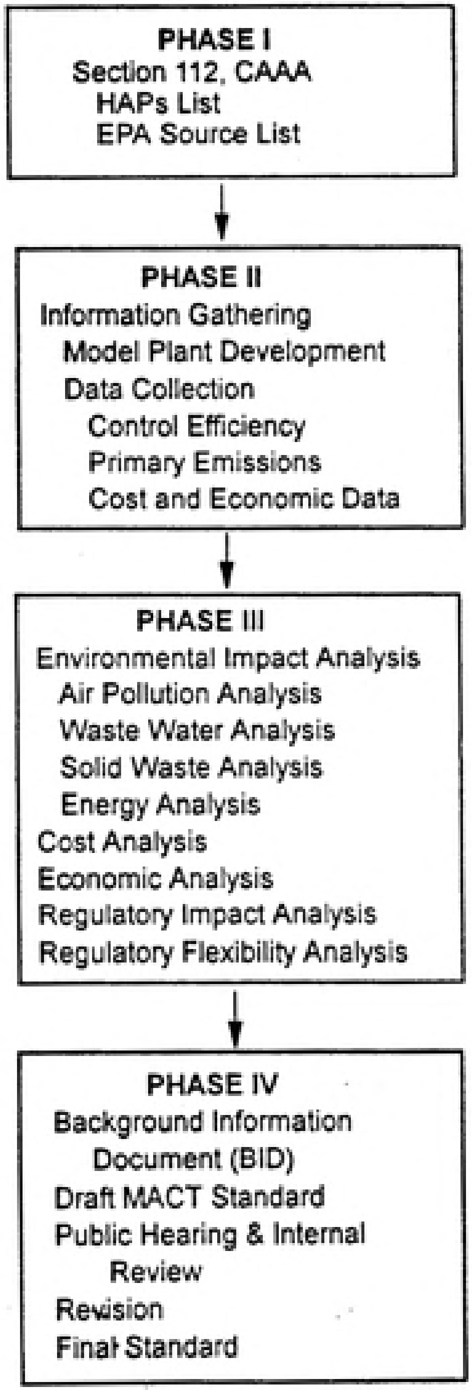
The following criteria were considered in ranking of the source categories and in the development of the regulatory schedule: a) the known or anticipated adverse effect of each HAP on the public health and on the environment; b) the quantity and location of each emission, or reasonably anticipated emission, with respect to each source category or subcategory; and, c) the efficiency of grouping categories or subcategories according to the pollutants emitted, or the process or technologies used for control purposes. The HAP list, organized by Chemical Abstract Numbers, are presented in Appendix C. Appendix D presents the source category list.

A.2 Phase II: Information Gathering Phase

Formal MACT development begins with the assignment of one or more source categories to an EPA Project Officer who is charged with overseeing the development of the MACT Standard and meeting the regulatory deadline. The Project Officer is supported by one or more contractors, typically an engineering research organization, which provides data gathering, modeling, and data analysis support.

The first technical step in the MACT process is an intensive effort to develop background data on each source category and its related emissions. In this phase, industries are interviewed through a variety of sources including telephone surveys, SF-84 Forms, letters of

Figure A.1: An Overview of the MACT Process



inquiry, and plant visits by EPA or its representatives. Supporting information is also gathered from other sources, such as literature searches, trade associations, vendors, and state regulatory agencies. As the data are assembled, they are screened and compiled into a docket by the contractor. The docket is a legal entity which chronicles the development of specific MACT standard.

Based on a review of the acquired information, EPA tentatively selects certain plants within the source category for emissions testing. Either the EPA or its representative then negotiates with the plant management for access to perform emissions testing. This emissions testing provides necessary data to fill data gaps and a reliable data set from with to characterizes HAP emissions from well-controlled facilities.

A.3 Phase II: Analytical Phase

The Analytical Phase overlaps the Information Gathering Phase. In this Phase three items critical to the MACT process are established: model plant parameters; control options, including baseline controls; and, regulatory alternative.

A.3.1 Definition of a Model Plant

Model plants are developed as an engineering tool for determining the impacts of the proposed control regulation. A comprehensive analysis of a model plant is intended to answer four basic questions:

- What are the emission sources within a category and/or what pollutants will be regulated;
- How effective are existing Federal, state and local regulations in controlling the source (i.e., MACT Floor);
- What additional control beyond the floor is feasible on a National scale; and,
- What emission level should be allowed?

Each model plant is defined in terms of the process, production rate, capacity, raw materials, products, equipment, baseline pollution controls, and other parameters that describe the source category. They are constructed so as to accurately represent the HAP source in the source category. For existing sources, model plants represent the facilities as they exist or as they would be constructed or modified for installations of new or improved control equipment. For new sources under the New Source Performance Standard (NSPS), they describe plants that are likely to be built. Typical parameters considered in the development of the plant models are listed in Table A.1.

Ideally, model plants are tied to a common set of nameplate capacities. However, more than one model plant can be defined to facilitate the accurate description of the various types and size ranges of plants commonly found within a source category. For example, source categories that contain several emission points, such as vents, equipment leaks, etc., usually have a different set of model plants for each emission source. In the case of the Halogenated Solvent Cleaning/Degreasing Source, five model cleaners were developed.

Table A.1: Typical Parameters Considered in the Development of MACT Model Plant

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- Type of plant or affected facility
- Plant size ranges expressed in production capacity
- Typical annual production expressed as hours per year of operation at specified capacity utilization rate
- Raw materials, products, co-products, and by-products
- Hours per year of operation (actual and at full name plate capacity
- Relevant pollutants and their physical and chemical properties
- Corrosive or toxic properties of materials that require special handling, such as waste and process materials, or of special materials for control process equipment
- Uncontrolled emission rates
- Type of pollution control equipment used
- Controlled emission rates for each plant site and each control system
- Baseline control from SIP's or permit conditions;
- Exhaust gas temperatures into and our of the control systems
- Exhaust gas velocity and exhaust gas flow rate
- Moisture content of effluent stream
- Pressure drop across pollution control systems
- Stack height and distance to fence line if dispersion modeling is required
- Quantity of lost product recycle to process stream;
- Solid waste disposal requirement for waste products;
- Possible retrofit considerations
- Water pollution control requirements

(ESD, 1992)

This included four batch solvent cleaners differing only by size: small, medium, large, very large, and one in-line cleaner. (ESD, 1992).

After emission source test data are obtained and most information about the industry has been gathered, a final model is defined. The final model serves as the basis for calculations about the environmental and economic impact of a proposed MACT standard.

A.3.2 Baseline/MACT Floor

The term "baseline emissions" is used to describe the level of HAP control achieved by the affected industry in the absence of any additional EPA standard. The determination of the "baseline" enables the evaluation of the impact of a given regulatory alternative on air quality, and facilitates the comparison of the economic, energy and environmental impacts of the regulatory alternatives. This impact is typically expressed as an incremental impact.

Baseline control is defined on a case-by-case basis. The facilities within a source category and covered by an existing regulation are assumed to emit pollutants at the limits specified therein. Generally, the regulations of interest in these determinations are those contained in the State Implementation Plans (SIP) and other local air pollution codes. Table A.2 contains a listing of potential sources of Baseline information.

Table A.2: Sources of Information for the Determination of the MACT Baseline

Existing State regulation
National databases
Questionnaires sent to users
Questionnaires sent to manufactures/vendors

Other sources of baseline determinations include the use of data such as the average of state/local regulations, the weighted average of regulation based on number of facilities per state, or the average emissions or performance of currently installed controls. For example, at baseline for the Halogenate Solvent Cleaning/ Degreasing source there is a mixture of controlled and uncontrolled cleaners due to State and local regulations.

In some cases, regulatory activities other than air regulations can be the primary factors affecting the baseline control level. For example the Occupational Health and Safety Administration (OSHA) or Consumer Product Safety Commission may have issued standards that cover a source. Or, as in the Source Category that covers landfills, the Resource Conservation and Recovery Act (RCRA), Subtitle D affects the baseline control level. Whenever other regulatory sources are used in the baseline determination there are potential interpretational problems with determining the level of control required by the other regulations. The MACT process must reconcile these difficulties and incorporate them into the baseline.

A.3.3 Development of Control Options

Control options are the building blocks used to develop regulatory alternatives. Each alternative is based on a combination of different control options deemed appropriate for each facility class and emission source identified during the preliminary model plant analysis.

The development of control options establishes the potential emission reduction techniques applicable to the industry and the specific source category. They further identify, in an increasing order of stringency, those combinations of assorted techniques and associated emission reductions anticipated from each option. A typical listing of control options is shown in
Table A.3.

Table A.3: Typical Controls Options for a MACT Source Category

- Baseline level of control
- Add-on controls for each pollutant individually, or for groups of pollutants)
- Pollution prevention (product substitution, source reduction)
- Work practices
- Combinations, individually effective on certain pollutants but not others, that may be individually but not collectively, currently used in practice

(ESD, 1992)

It is important to note in Table A.3 that the control options are not limited to add-on devices, but also include process modifications or changes in operating practices, such as combustion controls, changes in raw materials, or the installation of more efficient equipment. In case where the source category is uncontrolled, or where new controls are available but have not been demonstrated in the source category, technology transfer may be the option's basis.

A.3.4 Development of Regulatory Alternatives

Each regulatory alternative is analyzed for each model plant to establish a range of economic, environmental, and energy impacts across the source category for a emission limitations. Based on the analysis, the alternative can be used to further refine the subcategories and to establish a "cut-off" based on size production below which the impacts are unacceptable. Figure A.2 presents an example of the regulatory alternatives derived for a hypothetical source.

Figure A.2: Example of Potential Regulatory Alternatives (RAs) for a MACT Source

New	Existing
Baseline: Cyclone	Cyclone
Available Control Options:	
Low pressure drop wet scrubber	same
Venturi scrubber	same
Fabric filter	
Wet FGD with/venturi	
Carbon injection	
MACT Floor: FF w/wet FGD	Venturi Scrubber
Regulatory alternatives:	
RA1: Floor	RA1: Floor
RA2: Floor + carbon injections	RA2: Fabric filter
	RA3: Wet FGD w/venturi
	RA4: Fabric filter w/wet FGD
	RA5: FF w/wet FGD + carbon injection

FF = Fabric Filtration; FGD = Flue Gas Desulfurization

MACT is select after the regulatory alternatives are established and the control option analysis is complete. For the MACT standard, the MACT Floor is the first alternative with subsequent alternative being increasingly more stringent. In the event that the source is composed of one or more subcategories, these subcategories are defined, and the regulatory alternatives including technology transfer options are evaluated. A separate MACT is then selected for each subcategory.

There are no legislated bounds on the number of regulatory alternatives developed during the analysis phase. Realistically, however, there is a limit to the funds available to analyze alternative/model plant combinations, and some alternatives must be set aside. The decision to set aside an alternative is typically based on engineering experience, reality checks, common sense, policy, commonality to another alternative, etc.

A.3.5 Environmental Impact Analysis (EIA)

Section 102(2)(C) of the National Environmental Policy Act (NEPA) of 1969 requires Federal agencies to prepare detailed Environmental Impact Statement (EIS) on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment. NEPA seeks to build into the Federal decision-making process a careful consideration of all environmental aspects of proposed actions.

However, in a number of legal challenges to standards for various industries, the US Court of Appeals for the District of Columbia Circuit has held that an EIS need not be prepared by EPA for proposed actions under the Clean Air Act. Nevertheless, EPA has concluded that preparing an EIS could have beneficial effects on certain regulatory actions such as MACT. Consequently, although not legally required to do so by NEPA Section 102(2) (c), EPA has adopted a policy requiring that a variant of an EIS be prepared for all NESHAPs developed under Section 112 of the CAAA. To implement this policy, a separate Environmental Impact Analysis (EIA) is conducted. The MACT EIA is devoted solely to the determination of the potential environmental impacts associated with a proposed standard.

Under this approach both adverse and beneficial impacts on air and water pollution, increased solid waste disposal, increased energy consumption, etc., are discussed. The beneficial and adverse environmental impacts are expressed in terms of primary impacts (i.e., those attributed directly to each control system, such as reduced levels of specific pollutants) and secondary impacts (i.e., indirect or induced impact such as emission of another pollutant through utilization of a control system). The environmental impacts of new and existing sources are determined separately. Impact for existing source are calculated based on the existing population of sources, where as impact for new sources are calculated based on growth projection over 5 years from the expected proposal date.

Included in the EIA are two additional analysis. The first is an analysis of the impact of irreversible and irretrievable commitment of resources. The analysis is concerned with how the regulatory alternative may foreclose further options, or curtail the diversity of beneficial uses of the environment. The commitment of resources is generally stated in terms of the energy resource required by pollution control systems and is usually negligible. The second analysis provides an estimate of the effects that delaying a standard would have on the other environmental impacts. If the negative environmental impacts are small and there does not appear to be any emerging emission control technology that achieves equal or greater emission reductions at less cost, the standard may be recommended for delay.

A.3.5.1 Air Pollution Impact

The effect of each regulatory alternative or MACT on ambient air pollutant concentration levels is an important component of a MACT EIA. In this section of the EIA, the quantities of air pollutants emitted from the model plants are estimated. These quantities include estimates of excess emissions from start-up, shutdown, and unavoidable process upsets and control system failures. Secondary air pollutants generated by the emission control techniques are also identified.

Atmospheric dispersion modeling under various anticipated weather conditions is an important tool in this analysis. These models project the average and maximum annual HAP concentrations for a given control scenario. The impact on air quality is evaluated by comparing anticipated ambient air pollutant concentration levels for sources controlled under each regulatory alternative. These impacts are summarized and discussed as a part of the analysis.

A.3.5.2 Water Pollution Impact

The potential effects of the control recommendations on water quality are also an important factor in the EIA. Any potential unavoidable adverse impacts on water quality are clearly presented during this stage. For new and existing sources, the quantity and quality of the water effluents discharged under each regulatory alternative or MACT are identified. The impacts of these anticipated pollutant discharges are characterized, discussed, and compared to those of already existing effluent discharges.

State, local, or Federal government regulations establishing minimum acceptable water quality standards for the anticipated effluents are also discussed at this point, as are the application of various techniques to reduce adverse water pollution impacts. Projections based on the model plants coupled with industry growth estimates are used to ascertain the national water quality impact of the standard in the fifth year after its proposal.

A.3.5.3 Solid Waste Impact

The potential impact of solid waste disposal of each control scenario is also considered during the course of the EIA. This analysis characterizes the potential quantities and types of solid wastes anticipated from each regulatory alternative, and compares these wastes to those generated by a typical uncontrolled plant. The application and effectiveness of various techniques to dispose of these solid wastes with minimum environmental impact are discussed and evaluated, and potential unavoidable adverse impacts from disposal of these solid wastes are identified. Lastly, estimates of the national solid waste burden in the fifth year after the proposed standard is in place are made to facilitate comparison among the regulatory alternatives..

A.3.5.4 Energy Impacts

The amount and type of energy (e.g., electric, fossil-fuel, etc.,) required by each regulatory alternative are identified during the energy impact analysis. Measures to reduce the overall energy consumption for the regulatory alternatives are discussed as appropriate. These measures can include fuel switching (e.g., gas to oil or coal, or oil to coal), switching from fuel energy to electrical energy, access to nuclear energy, etc. Use estimates are made for the various scenarios to determine their potential impact on national energy demand in the fifth year after the proposal of the standard.

A.3.6 Cost Analysis

An important component of the MACT process is the Cost Analysis. The purpose of this analysis is to estimate the out-of-pocket costs to the regulated community of the various regulatory alternatives over a specific time period (i.e., 5 years). In order to make the results of the analysis meaningful and comparable, specific criteria are imposed on the analysis. The criteria for the development of a MACT cost analysis are listed in Table A.4.

Table A.4: Criteria for Development of Cost Information

- All cost information should be for one point in time
- Appropriate cost indices
- Standardized interest and discount rates
- Uniform base year
- Realistic capacity utilization rates
- Viable analysis period

(ESD, 1992)

Also during the cost analysis, both process and control costs are developed and presented, although the emphasis is on the incremental control costs above an assumed baseline level or the "no control" regulatory alternative. The costs components considered in the analysis are shown in Table A.5.

Table A.5: Typical Costs Evaluated in a MACT Cost Analysis

- Capital costs of equipment, installation, process modification
- Annualized costs of operating and maintaining the technique including recovery credits, etc.
- Annualized costs of monitoring compliance with control option
- Associated costs related to compliance with other environmental regulations (e.g., hazardous waste)

(ESD, 1992)

Other cost considerations include items such as the cost new emissions monitoring or compliance testing requirements which might appreciably raise the cost of the regulatory alternative. If one or more of the regulatory alternatives leads to increased water pollution or solid waste disposal, the cost associated with reducing the potential water pollution to acceptable levels, or with disposing of any solid wastes in an environmentally acceptable manner, are identified and included in the overall costs.

Also included in the cost analysis are those costs currently being imposed on the industry in response to other regulations, such as the Clean Water Act, RCRA, and OSHA. Where future costs of impending regulation are available, they are also estimated and factored into the analysis. In addition, if the promulgation of the MACT standards have the potential to impose major resource requirements on regulatory and enforcement agencies, the impact of these requirements on the agencies are accessed to extent feasible and included in the analysis.

Costs analysis are performed separately for new facilities and for modified or reconstructed facilities. Cost effectiveness values, such as dollars per unit of emissions reduced, are developed for each model plant and control option. These values, the emission reductions achieved, and the cost of each regulatory alternative is then compared against the MACT baseline. If the cost of the preferred option is greater than the MACT Floor, an economic analysis is performed.

A.3.7 Economic Impact Analysis

The objective of the economic analysis is to identify the incremental economic impact associated with regulatory compliance and compare that impact against the MACT baseline. The format of the analysis varies according to the economic nature of the industry and whether it is a new or existing source. Generally, however, the economic impacts are examined in terms of their effects on capital availability, profitability, prices, product substitution, closures, trade balances, domestic employment, and other appropriated indicators.

For the economic impact analysis, a composite scenario or profile of exiting facilities plus their 5-year projections are developed. A typical profile is shown Figure A.3. The profile presents a static view of the industry based on the most up-to-date information. Concurrent with the development of these profiles, a time series is developed to illustrate the dynamics of the source category in terms of economic and financial performance. The profile and the time series are used to highlight factors and trends that may be important in determination of economic impacts.

A central part of the economic analysis methodology is the evaluation of the potential market responses to the regulation, and the determination of the costs and effects of the regulation. These market responses include the potential socioeconomic and inflationary impacts that might result from application of standards. For example, any

Figure A.3: An Outline of the Parameters for the Development of an Industrial Profile for a MACT Economic Analysis

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I. Profile

- A. Source Category
  1. Ownership
  2. Market share by capacity
  3. Vertical integration
     - a. Backward to suppliers
     - b. Forward to final product markets
  4. Horizontal integration - product diversification
  5. Total Capacity
     - a. Total output expressed as value of shipments or sales

- B. Plants
  1. Size, capacity and utilization
  2. Age, location, employment

- C. Markets
  1. Substitutes
  2. Imports and exports
  3. Product differentiation
  4. Elasticity of demand
  5. Supply and demand determinants
  6. Transportation constraints

II. Time Series Information

- A. Historical data (5 to 10 years)
  1. Capacity data
  2. Production data
  3. Prices
  4. Financial data
     - a. Revenues, capital formation, income statements
  5. Expansion path
  6. Economies of scale
  7. Geographic location

- B. Five year projection
  1. Product demand
  2. Capacity demand
  3. Raw Material or process changes
  4. New sources - growth and replacement
  5. Other forms of growth
  6. Price projections
  7. Plant size projection
  8. Imports and exports

(ESD, 1992)

potential social disruption caused to the communities surrounding the source of interest are considered. This includes such things as potential impacts on factory employment, plant closing, curtailment of expansions, and relocation of plants. Potential inflationary impacts are also identified and presented. These impacts include such factors as: identification of who will be directly impacted by the costs; the potential direct effect on prices of goods; possible productivity effects; and, the potential for the location of new plants outside the US.

At the conclusion of the economic analysis, the fifth year's annualized costs for the subject profile, and the potential price increase are developed for comparison against EPA's trigger criteria for regulatory analysis. If these criteria are exceeded, a Regulatory Impact Analysis (RIA) is required (Federal Register, 1981). To facilitate this determination, the items addressed in the economic analysis are those items specified for "significant" regulations in Federal Register. Due to the number of variables involved, a typical analysis can be complex and resource intensive. Consequently, the necessity for an analysis is assessed for each individual project, and only those projects which recommend a regulatory alternative more stringent than MACT are analyzed.

A.3.8 Regulatory Impact Analysis

RIAs are required for proposed regulatory actions that have the potential to produce an annual effect on the Nation's economy of $100 million or more. Other factors that can trigger a RIA include major projected increases in prices for consumers, individual industries, Federal, State, or local government agencies or geographic regions. The determination of a potentially significant adverse effect on competition, employment, investment, productivity, innovation or on the ability of the US based enterprise to compete with foreign based enterprises in domestic or export markets can also trigger a RIA.

In addition to the RIA, EPA is required to comply with PL96-354, the Regulatory Flexibility Act (RFA). This act specifies that a flexibility analysis must be prepared if the proposed regulations will have significant economic impact on a substantial number of small entities, such as small businesses, small organizations, and small governmental units. A criterion of significance that EPA has used specifies that economic impact are significant when ever compliance costs will increase production costs by more than 5%. Other criteria used by EPA relate to the availability of capital for small entities, possible closures among small entities, and compliance cost which as a percent of sales for small entities are at least 10% higher than the same costs for large entities.

A.4 Phase IV: Development of the Standard

Based on the aggregated analysis, a control technology is selected for recommendation as the MACT Standard. The selected regulatory alternative is translated into regulatory language and written up in the form of a Federal regulation. The relevant information acquired over the course of the project is simultaneously summarized in the Background Information Document (BID). The contents and layout of a typical BID package are shown in Figure A.4. The BID, the proposed standard, and the preamble explaining the standard are then widely circulated to the industry being considered for control for comment. The point of view of these "expert" is taken into consideration as the final documentation is prepared.

A final proposal package is assembled and passed through the Office of EPA's Assistant Administrator for concurrence prior to being officially endorsed by the EPA Administrator. In this step the draft standard is distributed internally for comment from other EPA offices, such as the Office of Solid Waste Management or the Office of Pollution Prevention and Toxics, which may be impacted by its adoption. After an internal review and reconciliation of comments, the draft standard is sent to the EPA Administrator for concurrence and signature.

After the Administrator's concurrence, all information and data generated and reviewed during the MACT analysis is made available to the public in a docket on file at EPA Headquarters, Washington, DC. To promote public comment, the preamble and the proposed draft regulation are published in the Federal Register. This Federal Register announcement is a formal invitation to the public to participate in the standard setting process. This invitation includes both written comments and oral responses, the latter of which are taken during public hearings that have been scheduled to discuss the proposed standards with interested parties.

After the public comment period is completed, all significant public comments, as well as, EPA's position on any relevant issues that were raised, are included in the preamble of a promulgation package along with a draft of the revised regulation. The revision is then subjected to another round of internal EPA reviews. This internal review process continues until either variances and uncertainties in the revised draft are reconciled or until internal

Figure A.4: The MACT Background Information Document (BID) Format

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Chapter 1. Summary
Summary of statutory authority, regulatory alternative or MACT, environmental and economic impact, and RIA

Chapter 2. Introduction
Purpose of document, statutory authority, source category selection, and regulatory analysis

Chapter 3. Processes and Pollutant Emissions
Source Category descriptions, emission source descriptions, and baseline emissions

Chapter 4. Emission Control Techniques
Summary of emission control techniques and source test data, technology transfer issues

Chapter 5. Modifications and Reconstructions
Definition of potential modifications and reconstructions

Chapter 6. Model Plants and Regulatory/MACT Alternatives
Definition of model plants, regulatory alternatives or MACT

Chapter 7. Environmental Impacts
Presentation of environmental impacts of regulatory alternatives or MACT and impacts of delayed standards

Chapter 8. Costs
Presentation of control costs of regulatory alternatives or MACT applied to new and modified/reconstruction facilities and other cost considerations

Chapter 9 Economic Impact
Source Category characterization, economic impact of regulatory alternatives including MACT and potential socioeconomic and inflationary impacts

Appendix A. Chronological History of the Development

Appendix B. Index to Environmental Impact Considerations
Cross referenced index impact discussion in the BID

Appendix C. Emission Source Test Data
Summary of all emission source data gathered during development of proposed standards

Appendix D. Emission Measurement and Continuous Monitoring
Presentation of emission measurement methods, monitoring systems and devices, and performance test methods

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(ESD, 1992)

deadlines are met. Upon completion of this round of reviews, the draft standard receives a final approval from the EPA Administrator and the Administrator's signature. The MACT standard is then published as a final rule in the Federal Register.

APPENDIX B:

LIFE CYCLE ASSESSMENT METHODOLOGY (LCA)

APPENDIX B. LIFE CYCLE ASSESSMENT METHODOLOGY

Life Cycle Assessment (LCA) is an environmental management tool currently under development through cooperative work between the Society for Environmental Toxicology (SETAC) and the US EPA. LCA is primarily a means of accounting and aggregating environmental inputs and outputs, and assessing their associated environmental impacts for a product, process, or technology over its life time. This appendix presents an overview of LCA to facilitate the contrast and comparison against MACT procedures.

B.1 Life Cycle Assessment - Overview

LCA has been used in one or more forms by industries, governmental agencies, and other organizations over the past several years. Table B.1 presents an overview of the history of LCA development in the US.

Table B.1: An Overview of LCA Development in the United States

Sponsor	Product	Year
Coca Cola	Beverage Containers	1969
EPA	Beverage Containers	1974
SPI	Plastics	1974
Unknown	Beer Containers	1974
Goodyear	Soft Drink Containers	1978
Proctor & Gamble	Laundry Detergent Packaging	1988
Proctor & Gamble	Surfactants	1989
Council for Solid Waste Solutions	Formed Polystyrene and Bleached Paperboard	1990
American Paper Institute	Cloth and Disposable Diapers	1990
Council for Solid Waste Solutions	Grocery Sacks	1990
Proctor & Gamble	Cloth and Disposable Diapers	1990
Vinyl Institute	Vinyl Packaging	1991
National Ass. of Diaper Services	Diapers	1991
Council of State Governments	Packaging	1991
Proctor & Gamble	Hard Surface Cleaners	1992

(Curran, 1993)

By convention, a standard or "classic" full-scale LCA consists of three phases: Inventory Analysis, Impact Analysis, and Improvement Analysis. These phases are subdivided into smaller components and are preceded by an optional Screening Phase. Because of the relative newness of LCA, the methodologies underlying these phases are in various stages of development. Figure B.1 presents the current status of LCA's component parts with respect to their developmental stage and potential applications.

Figure B.1: The Developmental Status of LCA Procedures

End Uses	LCA Concept	Goal Scoping	Inv	Impacts			Impv
				Class	Char	Val	
Perf. Eval.	2	1	1	1	.	.	1
Env. Label	3	2	2	2	.	.	1
Prod. Inf.	3	2	2	2	.	.	1
Prod. Des.	3	3	3	2	.	.	1
Prod. Opt.	3	3	3	2	.	.	1
Education	2	2	2	2	.	.	1
Purchase	2	1	1	1	.	.	1
Specific	2	1	1	1	.	.	1
Regulatory	2	1	1	1	.	.	1
Public Pol.	2	1	1	1	.	.	1

(Fava, 1992) Perf.Eval. = Performance Evaluation; Env. = Environmental; Prod. Inf.= Product Information; Prod. Des. = Production Description; Prod. Opt. = Product Optimization; Public Pol. = Public Policy; Inv = Inventory; Char = Characterization; Val = Valuation. 1-Not yet documented; 2-Limited written procedures; 3-Written procedures exist; (.) = Not Defined

In its current state of development, LCA involves a sequential process which requires the User to step though each of the three components in order to arrive at a solution. This process can also be iterative, requiring multiple passes though the method in order to obtain an optimal solution.

As seen in Figure B.1, the concepts underlying theoretical LCA and LCA's applications as a scoping tool are well discussed in the literature. In a scoping role, the LCA may be constrained, typically focusing on the inventory component alone, and conducted with a limited use in mind, for example, for product improvement or marketing. The LCA

Inventory Analysis stage is also relatively well developed. The most intensive efforts in the this area are a series of EPA reports prescribing a rigorous engineering approach to developing the environmental input/output parameters. However, as seen in the Table, both the Impact and Improvement Analyses, are less well understood. The decrease in literature dramatically indicates the complexity and uncertainty underlying the basic issues and the developmental nature of these methods.

Due to the extreme variation in the developmental state of its component parts, a LCA study conducted for a specific purpose or target audience may not be generally applicable for another use. For example, a LCA to develop a product improvement option may not be entirely appropriate for public education or marketing. However, the successful application of LCA can result in the reduction of the environmental consequences of a product's development, use, and disposal. Because it has a multimedia focus and looks both up and down stream over a products life (i.e., cradle-to-cradle), LCA provides the User with the opportunity to actually reduce environmental burdens, and not simply transfer the problem from one media to another, as is typically done with the application of the standard end-of-pipe control approaches (Curran, 1993).

Full cradle-to-cradle evaluations are extremely costly and, because of the difficulties and uncertainties, extremely rare. Consequently, over the past four years several entities, both public and private, have attempted to streamline or modify the LCA process (Todd, 1994). These LCA modification efforts typically takes the following form: 1) a general inventory using a wide range of quantitative and qualitative data; 2) an impact analysis that focuses on small group of impact categories; 3) the use of a "less is best" model for the analysis of the environmental consequences; and 4, a general improvement recommendation (Todd, 1994).

B.2 Life Cycle Assessment - Inventory Analysis

Life Cycle Inventory Analysis is the best defined and most readily applied component of the LCA process. This is largely due to its longevity and to the relatively ease of the environmental input/output accounting. The foundation for modern Inventory Analysis was laid in 1969 when Midwest Research Institute, Kansas City, Mo, conducted a seminal study for Coca Cola, Inc. The process was called Resource and Environmental Profile Analysis (REPA). Since that time Inventory Analysis has undergone successive refinements that have culminated in the current methodology.

B.2.1 Inventory Analysis - Screening

The first step in the Inventory Analysis is typically a screening step. This preliminary step establishes the project's definition, sets the boundary conditions for the analysis, and establishes the objectives of the study.

The screening step distinguishes between the study boundary and the boundaries of the system to be studied. The study's boundary includes the identification of the target audience, the sources of data and types of data (e.g., quantitative, semi-quantitative, qualitative) to be used, acceptable data quality and completeness, and the final review process. In general the goal of a LCA can be characterized as either being internal or external with respect to the entity developing the study and the target audience. Figure B.2 illustrates potential uses of LCA dependent on the target audience.

Figure B.2: Potential Internal and External Applications for LCA

Internal Applications	External Applications
▪ Reduce future regulatory liability ▪ Compare impacts of generic raw materials ▪ Identify materials, processes, or systems that create significant impacts ▪ Help develop long-term corporate policy regarding overall material use, resource conservation, and reduction of environmental impacts and risks ▪ Forecast potential impacts of new products or processes ▪ Compare alternative with an objective of minimizing impacts ▪ Aid in training designers in use of lower impact product materials ▪ Internally evaluate impacts associated with source reduction. and waste management techniques	▪ Provide information that allows consumers or institutional buyers to evaluate and differentiate between products ▪ Provide information to policy makers and the public about the environmental impacts of a product, the use and fate of the product and potential impacts avoided by Pollution Prevention/ management techniques ▪ Help develop policy on on overall material use, waste managment and resource resource conservation, reduction of environmental impacts

(SETAC, 1990)

The system boundary refers to a delineation of the physical system under study. It includes all the sources of environmental input and outputs, from raw materials acquisition through recycle and ultimate disposal, that contribute to the development of the product or process understudy. To make the LCA more tractable, large systems must be divided into subsystems. The choice of subsystems is usually determined by the availability of data, and the overall system is analyzed only to a level of detail that corresponds to the data available.

All subsystems must be carefully described and related to the larger system. For example, the boundary conditions for an industrial subsystem can be defined as the collection of unit processes which, when acting together, perform the operation which is the target of the study. Because this is a physical system, it must obey the laws of conservation of mass and the laws of thermodynamics. These laws provide a useful check on the validity of any boundary description. On the other hand, the boundary may not be so readily identified. Consequently, it is imperative to define the system with some precision. The system's function and other pertinent factors must be fully specified to allow interested parties to duplicate system.

B.2.2 Inventory Analysis - Templates

The development of process flow schematics called Life Cycle Inventory Templates to represent the linkage and flows through the system and between the subsystems are critical to LCA. These flow charts are structured to cover the four basic compartments in the life cycle:

> Raw Materials Acquisitions - Raw Materials Acquisitions include all the activities required to obtain raw materials or energy from the natural environment. This includes transportation of the raw materials to a processing point.
>
> Manufacturing - Manufacturing activities include materials manufacture, product fabrication, and filling, packaging,and distribution. Materials manufacture describes those steps which take raw material into a form that can be used to fabricate a particular product. This includes the production of intermediates and their transportation to other sites. Product fabrication describes the steps that take a raw material or an intermediate product and creates a product. Filling/packaging/distribution describes those steps that prepare a final product for shipment and the transportation to a retail outlet.

> Use/Reuse/Maintenance - This step includes those activities in which a product is consumed or otherwise utilized. It includes activities which serve to recondition, maintain, or extend the useful life of the product.
>
> Recycle/Waste Management - This step begins after the product or material under study has served its intended purpose and either re-enters the system through recycling or is disposed of as waste. The template treats recycling as a subsystem within the main system. Closed loop recycling is included as a part of the main system; open looped recycling which refers to a products or component going from one system to another for use as a raw material in the second system, is treated as an output.

A generic LCA template is shown in Figure B.3. As previously indicated, in developing the LCA template complex systems must be broken down into subsystems. Allocation procedures have been developed as a means of attributing inputs and outputs to products and processes within these subsystems (Vigon, et. al., 1993). These allocation procedures are particularly useful in attributing waste water treatment, solid waste disposal, and air pollution control so that the products under study carry their proper share of overall environmental burden.

B.2.3 Life Cycle Inventory - Inventory

The actual development of the input/output inventory begins after the system's boundary is defined. In this step all flows through subsystems or processes contained within the system boundary, including co-products, by-products, and open and closed loop recycling, etc., are identified, quantified, attributed. This process involves intensive and detailed data collection. Ideally the necessary data is obtained from upstream and downstream companies operating specific processes included in the LCA boundary. Generic sources of LCA data are shown in Figure B.4.

Secondary data sources, however, can also be used, and are often the only sources of the needed data. These secondary sources include process designers, engineering calculations based on process chemistry and technology, estimations from similar operations, published sources and commercially available databases, and the market place.

Data collection must be based on a relevant period of time. This interval must be long enough to smooth out any atypical behavior in the system, while being sufficiently short so that genuine improvements options are discernable.

Figure B.3: A Generic Template of the LCA Process

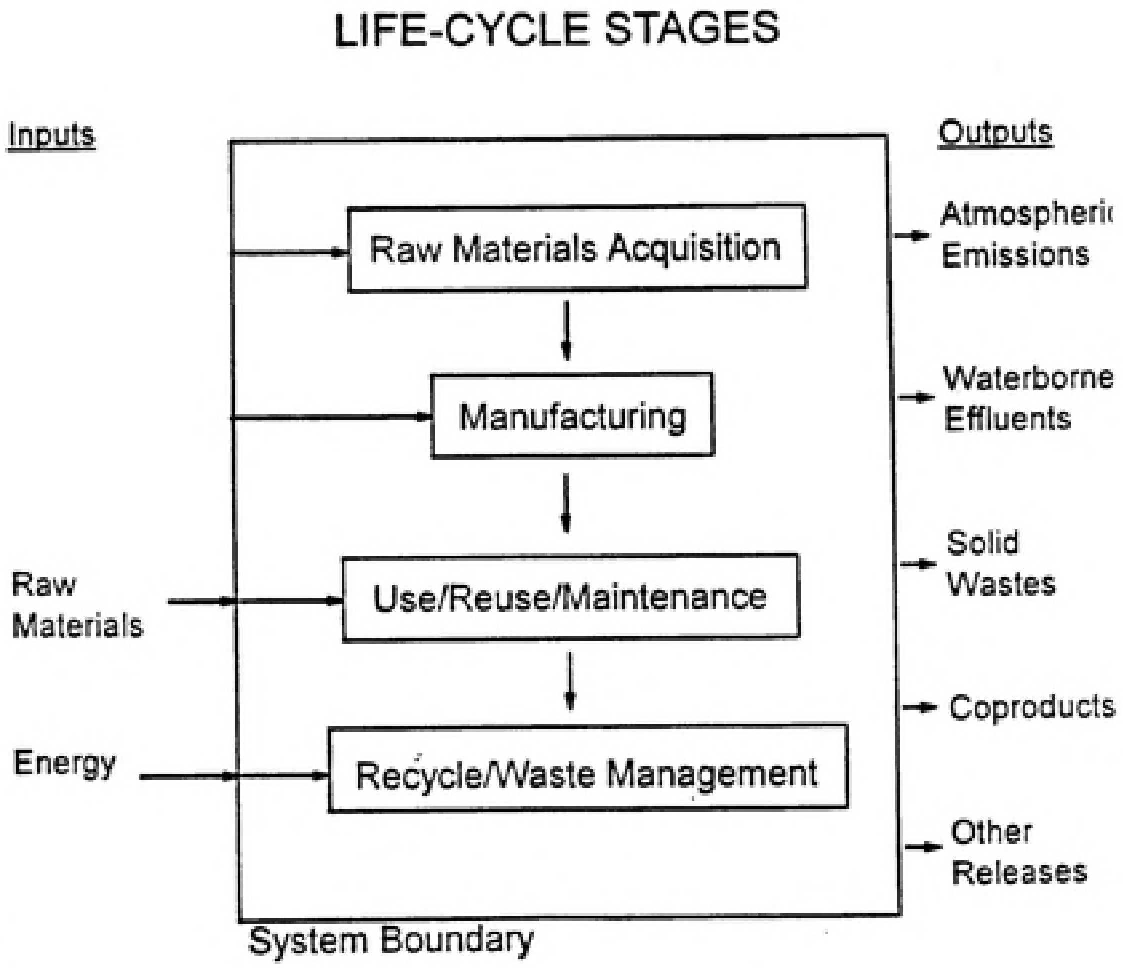

Figure B.4: Potential Sources of LCA Data and Their Relationship to the LCA Process

Stage	Data Source	LCA Scope
Before -Raw Materials Acquisition	Suppliers	Cradle to Gate
During -Production	Plant	Gate to Gate
After -Use -Disposal	State and Federal	Gate to Cradle

(Fava, 1992)

The basis of all the inventory data, such as their source, geographic and temporal relevance should be well documented, and any averaging and/or weighing techniques should be reported when multiple data sources are selected.

The data set collected for the Inventory will have some variability, uncertainty, and gaps associated with it. These limitations should be evaluated within the context of the study. Sensitivity analyses should be performed to assess their impacts and the potential limits placed on the LCA's conclusions.

B.3 Life Cycle Assessment - Impacts Analysis

Impact Analysis is the quantitative/qualitative component of LCA that characterizes, assesses, and attributes the environmental impacts of the flows to and from the system identified in the Inventory Analysis. Impact Analysis provides the User with guidance on the relative importance of the different emissions, and suggests courses of action to improve existing conditions. Figure B.5 contains a typical listing of LCA Impact Categories.

As seen in Figure B.5, the central component of Impact Analysis is the Impact Categories list. Each category in this list defines an area in which the environmental burden identified in the inventory is anticipated to have an impact.

Figure B.5: Examples of LCA Impact Categories

Ecosystem	Human Health	Natural Resources
Atmosphere ▪ Toxicity impacts ▪ ozone depletion ▪ greenhouse effects ▪ visibility changes ▪ smog/fog ▪ ground-level ozone build-up ▪ climatic change - micro - macro	**Chronic Effects** ▪ carcinogenic ▪ mutagenic ▪ teratogenic ▪ neurological ▪ major organ diseases - heart - lung - liver - kidney ▪ physiological ▪ anemia	**Stock** ▪ fossil fuels ▪ minerals ▪ atomic power ▪ wind power ▪ precipit ▪ tidal power ▪ solar power ▪ hydrosphere ▪ aesthetics
Water ▪ toxicity impacts ▪ contamination ▪ depletion - surface - ground ▪ thermal changes ▪ turbidity changes ▪ acidification ▪ nutrification ▪ eutrophication ▪ chemical alterations	**Acute Effects** ▪ accidents - occupational - nonoccupational ▪ radiation - ionized - ultra violet - heat ▪ noise ▪ odor, taste, etc.	**Flows** ▪ water resource ▪ soil fertile ▪ forest prod ▪ agricultural products ▪ fresh water products ▪ salt water products ▪ flora and fauna ▪ land (space)
Soil ▪ toxicity impacts ▪ salinity ▪ leterization ▪ podzolization ▪ acidification ▪ fertilization		**Other** ▪ geomorphology impacts ▪ biodiversity impacts ▪ habitat alterations

(Fava, 1992)

These categories can be general, such as Global Warming, Ozone Depletion, Ecologic, Acid Rain, etc., which largely describe the potential for an impact to occur. Or they can be more detailed attempting to identify a specific endpoint, such as cancer, acidification, habitat destruction, etc.

In its current form, Impact Analysis is divided into three components: Classification, Characterization, and Valuation. Classification involves the grouping of the elements of the Inventory Analysis into impact categories. This grouping is done in such a way that one entry from the inventory table may be included into more than one category. An example of the classification of Impacts is shown in Figure B.6. After grouping inventory items into the appropriate impact category, the Practitioner must decide which, if any, of the impacts lie outside the scope of the Impact Analysis. There are no rules for determining which impacts should be included as an assessment endpoint.

The second step in the Impact Analysis is Impact characterization. Impact Characterization seeks to describe and/or estimate the contribution of individual inventory items to its designated category. Characterization includes: determining assessment points, selecting measurement endpoints, and applying conversion models to develop impact descriptors.

Figure B.6: Example Classification System of Inventory Items Under Impact Categories

Ecosystem Impacts		Natural Resource Impacts	
Impact Category	Inventory Item	Impact Category	Inventory Item
Greenhouse Effect	CO2 CFC Particulate	Fossil Fuel Depletion	Crude Oil Fossil Fuel
Ozone Depletion	CFC NO2 CO2	Renewable Energy Use	Renewable Fuels
Acidification	SO2 NO2		
Water Contamination	Oil Phenol Organic C Solid Waste		

Assessment endpoints are those study endpoints that are consistent with and lie within the scope of the LCA. In some cases an assessment endpoint cannot be directly measured. The Practitioner must then select a measurable endpoint to act as a quantitative or qualitative surrogate. Criteria for selecting a measurement endpoint include: the relevance of the measurement endpoint to the goals and scope of the study; the consistency of the endpoint with the scope and boundary of the Inventory; the intended application of the Impact Analysis' results; data limitations; the availability of an impact assessment model, and the ease of characterizing potential impacts.

Conversion models may be used to develop specific impacts descriptors to characterize measurement endpoints. A set of typical conversion models are presented in Figure B.7. These models have been arranged in descending order from the most to the least complex according to the data requirements for driving the models. The Tier 1 Model, Inventory Evaluation, is the most frequently used of the models listed. The simple "less is best" assumption that lies at its core avoids the complex scientific and policy issues, as well as the costs, associated with the models further up in the hierarchy.

The Valuation stage of the Impact Analysis is a value-bound procedure based on an assessment of relative environmental harm. It occurs when the different impact categories are weighted so that they can be compared among themselves to assess and rank their respective importance. The purpose of this step is to arrive at a further interpretation and/or aggregation of the data to facilitate the determination of the most desirable improvement intervention. The weighing involves objective and/or subjective assignments of relative values to the individual categories.

Typically valuation incudes: identification of the underlying values of the Decision Maker/Practitioner; determination of weights to place on the impacts; and the application of these weights to impact descriptors. Valuation should be made as explicit as possible and should be capable of representing the information contained in the typical mixture of quantitative/qualitative data. One tool for making valuation explicit is contained in the use of Decision Analysis Theory. Other potential valuation techniques include: Multi-Attribute Utility Theory; Impact Valuation Matrices; a Leopold Interaction Matrix; Analytic Hierarchy Process; and Modified Delphi Techniques (Weitz, 1994).

Figure B.7: Impact Analysis Conversion Model Hierarchy

Tier 5. Site-Specific Impact Assessment Methods

Models determine the actual impacts of the Inventory data based on site-specific fate, transportation, and impact information.

Tier 4. Generic Impact Assessment Methods

Models estimate potential impacts on the basis of generic environmental and human health information. Generic environmental information may consist of generic fate, transport, and impact data for potential individual, population, or ecosystem impacts.

Tier 3. Impact Ranking Models

Models aggregate inventory data on the basis of inherent chemical properties, such as toxicity, persistence, and bioaccumulation. Categories of inherent chemical properties may then be used to determine relative impact potentials.

Tier 2. Impact Equivalency Assessment

Models use derived equivalency factors as the basis for which to aggregate Inventory data. Aggregated equivalency factors may then be used to estimate relative homogenous measures of potential impacts.

Tier 1. Inventory Evaluation

Models asses Inventory data on the basis of quantity, with the assumption that less of an input or output produces less impact.

(Weitz, 1994)

Impact Analysis is the least developed concept in LCA. This is largely due to the fact that the existing category do not take into consideration temporal or geographic dimensions of the LCA inputs and outputs. In addition, there is a general lack of environmental models that can handle the complexity of the emissions spectrum and the temporal and spatial separations.

B.4 Life Cycle Analysis - Improvements Analysis

At the conclusion of the Impact Analysis, the Practitioner has on hand a complete listing of the system's environmental inputs and outputs that has been assigned to relevant impact categories, assessed, and ranked according to their respective impacts. At this point the final step in LCA begins. The LCA Improvement Analysis utilizes the previous analyses to identify and evaluate the potential technical options for reducing the environmental impacts of the system or systems under study.

The Improvement Analysis is divided into three main steps: identification of a need for improvement; selection of an improvement option; and the timing of the improvement intervention. Identification of the improvement opportunity is a direct output of the Impact Analysis. The actual identification may involve a range of environmental issues and opportunities, such as the possibility of decreasing one or more pollutant emissions or effluents, decreasing solid waste disposal, or the opportunity to reduce the consumption of some natural resources through substitution.

Typically, most improvement options involve the opportunity for the elimination and/or substitution of one or more inventory items within the system boundary. For example, this can involve the choice of a single chemical, material, product, or process. Or it can involve improvements in working procedures over the whole life cycle of the system, the installation of control technologies, or closed production lines. The improvement option could also reach upstream of the plant, and well within the life cycle of the system, attempt to change consumer preference or use habits.

The final selection of an improvement option, in the situations not driven by regulatory mandate, is typically decided upon by an assessment of the economic cost/benefit that underlie the options under consideration. It is important to note that, although environmentally desirable, an indicated improvement option may not always be economically feasible. An improvement would have to be considered relatively important to be introduced, and a cost/benefit analysis is often the deciding factor.

The final component of the Improvement Analysis is the establishment of the time horizon for the implementation of the selected improvement option. It should be noted that the actual redesign or a product or process is not technically part of the LCA process. The User must select an appropriate time horizon consistent with the goals of the LCA.

When the Improvement Analysis is complete, the Practitioner is ready to develop the final report. The style and format of the report will depend on the target audience as determined in initial LCA screening steps. In any case, the reporting should be objective and transparent. In particular there should be a clear indication of what has, and what has not, been included in the study. This should specifically address such areas as methodology, data gaps, and assumptions. The contents of a full report are presented in Figure B.8.

Figure B.8: Contents of a Full LCA Report

Objectives of study
Scope of the Study
System Boundaries
Flow Diagram
Methodology
Data and Data Quality Indicators
Data Presentation
Conclusions
Summary Report
Peer Review
Qualifications of the Practitioner

(SETAC, 1990)

B.4 Life Cycle Analysis - Data Quality

The term "data quality" is used to describe a systematic approach undertaken by the Practitioner to measure the suitability of LCA data for the intended purpose. Data quality is inseparable from the LCA methodology. It determines the degree of confidence the User has in the individual input data, in the data set as a whole, and ultimately in the decision made using the data.

The Data Quality Assessment (DQA) exists because LCA data are diverse and require assessment through a logical formalized and repeatable method. DQA is defined so as to consist of three stages: definition of the study purpose and system; data collection and integration; and the study results and analysis.

Important considerations underlying the definition of the study's purpose, including the development of the system's boundary and boundary conditions, were presented in Section B.2.1.

Data collection is preceded by the development of a set of Data Quality Goals (DQG). The DQGs specify the completeness and accuracy desired in the data set based on the study's goal definition, study scope, and predetermined applicable data quality indicators (DQI). DQI are quantitative or qualitative characteristics of data such as accuracy or credibility. Quantitative DQI's include: precision, completeness, distribution, homogeneity, correlation, and uncertainty.

After the DQG and DQI are selected and approved, formal data collection begins. The determining factor for the level of quality achieved in the data collection is dependent on the level of effort allocated to the study. The level of effort is limited by the study purpose; budgetary and time constraints; data availability; and the need to maintain scientific integrity. Periodic checks against the DQG is required as the data collections proceeds in order to keep the study on track. If the quality of data meets the DQG, the LCA can proceed through analysis and publication. To meet the requirements of openness and transparency as outlined in Figure B.8, a write-up of the DQA/DQI are included in the final LCA report.

APPENDIX C:

LIST OF HAZARDOUS AIR POLLUTANTS (HAPs)

Table C.1: Pollutants Subject to Regulation Under the CAAA Title III, Section 112

Chemical Abstract Service (CAS) Number	Chemical Name
75070	Acetaldehyde
60355	Acetamide
75058	Acetonitrile
98862	Acetophenone
53963	2-Acetylaminofluorene
107028	Acrolein
79061	Acrylamide
107131	Acrylonitrile
107051	Allyl chloride
92671	4-Aminobiphenyl
62533	Aniline
90040	o-Anisidine
1332214	Asbestos
71432	Benzene (including benzene from gasoline)
92875	Benzidine
98077	Benzotrichloride
100447	Benzyl chloride
92524	Biphenyl
117817	Bis (2-ethylhexyl) phthalate (DEHP)
542881	Bis (chloromethyl)ether
75252	Bromoform
106990	1,3-Butadiene
156627	Calcium cyanamide
105602	Caprolactam
133062	Captan
63252	Carbaryl
75150	Carbon disulfide
56235	Carbon tetrachloride
463581	Carbonyl sulfide
120809	Catechol
133904	Chloramben
57749	Chlordane
7782505	Chlorine
79118	Chloroacetic acid
532274	2-Chloroacetophenone
108907	Chlorobenzene
510156	Chlorobenzilate
67663	Chloroform
107302	Chloromethyl methyl ether
126998	Chloroprene*
1319773	Cresols/Cresylic acid (isomers and mixture)
95487	o-Cresol

Table C.1: Pollutants Subject to Regulation Under the CAAA Title III, Section 112 (Continued)

Chemical Abstract Service (CAS) Number	Chemical Name
108394	m-Cresol
106445	p-Cresol
98828	Cumene
94757	2,4-D (2,4-chlorophenoxyacetic acid, including salts and esters)
	DDE* {recommended technical correction: CAS number 72559] (1,1-dichloro-2, 2-bis (-chlorophenyl)ethylene)
334883	Diazomethane
132649	Dibenzofurans [recommended technical correction: Dibenzofuran]
96128	1,2,-Dibromo-3-chloropropane
84742	Dibutylphthalate
106467	1,4-Dichlorobenzene(p) [recommended technical correction: 1,4-Dichlorobenzene]
91941	3,3,-Dichlorobenzidene [recommended technical correction: 3,3,'-Dichlorobenzidine]
111444	Dichloroethyl ether (Bis(2-chloroethyl)ether)
542756	1,3,-Dichloropropene
62737	Dichlorvos
111422	Diethanolamine
121697	N,N-Diethyl aniline (N,N-Dimethylaniline) [recommended technical correction: N,N--Dimethylaniline]
64675	Diethyl sulfate

Table C.1: Pollutants Subject to Regulation Under the CAAA Title III, Section 112 (Continued)

Chemical Abstract Service (CAS) Number	Chemical Name
119904	3,3-Dimethoxybenzidine [recommended technical correction: 3,3,'-Dimethoxybenziidine]
60117	Dimethyl aminoazobenzene
119937	3,3' ,-Dimethyl benzidine [recommended technical correction: 3,3'-Dimethoxybenzidine]
79447	Dimethyl carbamoyl chloride[recommended technical correction: Dimethylcarbamoyl chloride]
68122	Dimethyl formamide [recommended technical correction: N,N-Dimethylformamide]
57147	1,1-Dimethyl hydrazine[recommended technical Correction: 1,1-Dimethylhydrazine]
131113	Dimethyl phthalate
77781	Dimethyl sulfate
	4,6-Dinitro-o-cresol, and salts" [recommended technical correction to remove CAS number]
51285	2,4-Dinitrophenol
121142	2,4-Dinitrotoluene
123911	1,4-Dioxane (1,4-Diethyleneoxide)
122667	1,2-Diphenylhydrazine
106898	Epichlorohydrin (1-Chloro-2,3-epoxypropane)
106887	1,2-Epoxybutane
140885	Ethyl acrylate
100414	Ethyl benzene [recommended technical correction: ethylbenzene]
51796	Ethyl carbamate (Urethane)
75003	Ethyl chloride

Table C.1: Pollutants Subject to Regulation Under the CAAA Title III, Section 112 (Continued)

Chemical Abstract Service (CAS) Number	Chemical Name
106934	Ethylene dibromide (Dibromoethane)
107062	Ethylene dichloride (1,2-Dichloroethane)
107211	Ethylene glycol
75218	Ethylene oxide
96457	Ethylene thiourea
75343	Ethylidene dichloride (1,1-Dichloroethane)
50000	Formaldehyde
76448	Heptachlor
118741	Hexachlorobenzene
87683	Hexachlorobutadiene
77474	Hexachlorocyclopentadiene
67721	Hexachloroethane
822060	Hexamethylene-1,6 - diisocyanate
680319	Hexamethylphosphoramide
110543	Hexane
302012	Hydrazine
7647010	Hydrochloric acid [recommended technical correction: Hydrochloric acid (Hydrogen Chloride) gas only)]
7664393	Hydrogen fluoride (Hydrofluoric acid)
123319	Hydroquinone
78591	Isophorone
	Lindane (all isomers) [recommended technical correction: 1,2,3, 4, 5,6-hexachlorocyclohexane (all stereo isomers, including lindane)]
108316	Maleic anhydride
67561	Methanol
72435	Methoxychlor
74839	Methyl bromide (Bromomethane)

Table C.1: Pollutants Subject to Regulation Under the CAAA Title III, Section 112 (Continued)

Chemical Abstract Service (CAS) Number	Chemical Name
74873	Methyl chloride (Chloromethane)
71556	Methyl chloroform (1,1,1-Trichloroethane)
78933	Methyl ethyl ketone
60344	Methyl hydrazine [recommended technical correction: Methylhydrazine]
74884	Methyl iodide (Iodomethane)
1008101	Methyl isobutyl ketone (Hexone)
624839	Methyl isocyanate
80626	Methyl methacrylate
1634044	Methyl tert butyl ether [recommended technical correction: Methyl tert-butyl ether]
101144	4,4-Methylene bis(2-chloroaniline) [recommended technical correction: 4,4'-Methylene bis (2-chloroaniline]
75092	Methylene chloride (Dichloromethane)
101688	Methylene diphenyl diisocyanate (MDI) [recommended techncial correction: 4-4' Methylenediphenyl diisocyanate (MDI)]
101779	4-4'-Methylenedianiline
91203	Naphthalene
98953	Nitrobenzene
92933	4-Nitrophenol
100027	4-Nitrophenol
79469	2-Nitropropane
684935	N-Nitroso-N-methylurea
62759	N-Nitrosodimethylamine
59892	N-Nitrosomorpholine

Table C.1: Pollutants Subject to Regulation Under the CAAA Title III, Section 112 (Continued)

Chemical Abstract Service (CAS) Number	Chemical Name
56382	Parathion
82688	Pentachloronitrobenzene (Quintobenzene)
87865	Pentachlorophenol
108952	Phenol
106503	p-Phenylenediamine
75445	Phosgene
7803512	Phosphine
7723140	Phosphorus
85449	Phthalic anhydride
336363	Polychlorinated biphenyls (Aroclors)
1120714	1,3-Propane sultone
57578	beta-Propiolactone
123386	Propionaldehyde
114261	Propoxur (Baygon)
78875	Propylene dichloride (1,2-Dichloropropane)
75569	Propylene oxide
75558	1,2-Propylenimine (2-Methyl aziridine)
91225	Quinoline
106514	Quinone
100425	Styrene
96093	Styrene oxide
1746016	2,3,7,8-Tetrachlorodibenzo-p-dioxin
79345	1,1,2,2-Tetrachloroethane
127184	Tetrachloroethylene (Perchloroethylene)
7550450	Titanium tetrachloride
108883	Toluene
95807	2,4-Toluene diamine [recommended technical correction: 2,4-toulenedimine)]
584849	2,4-Toluene diisocyanate
95534	o-Toluidine
8001352	Toxaphene (chlorinated camphene)
120821	1,2,4-Trichlorobenzene

Table C.1: Pollutants Subject to Regulation Under the CAAA Title III, Section 112 (Continued)

Chemical Abstract Service (CAS) Number	Chemical Name
79005	1,1,2-Trichloroethane
79016	Trichloroethylene
95954	2,4,5-Trichlorophenol
88062	2,4,6-Trichlorophenol
121448	Triethylamine
1582098	Trifluralin
540841	2,2,4-Trimethylpentane
108054	Vinyl acetate
593602	Vinyl bromide
75014	Vinyl chloride
75354	Vinylidene chloride (1,1-Dichloroethylene)
1330207	Xylenes (isomers and mixture)
95476	o-Xylenes* [recommended technical correction: o-Xylene
108383	M-Xylenes [recommended technical correction: m-Xylene]
106423	p-Xylenes* [recommended technical correction: p-Xylene]
0	Antimony compounds
0	Arsenic compounds (inorganic including arsine)
0	Beryllium Compounds
0	Cadmium Compounds
0	Chromium Compounds
0	Cobalt Compounds
0	Coke Oven Emissions
0	Cyanide Compounds [1]
0	Glycol ethers' [2]
0	Lead Componds
0	Manganese Compounds
0	Mercury Compounds
0	Fine mineral fibers [3]
0	Nickel Compounds
0	Polycylic Organic Matter
0	Radionuclides (including radon) [5]
0	Selenim Compounds

APPENDIX D:

LIST OF HAZARDOUS AIR POLLUTANT SOURCES

Table D.1: Hazardous Air Pollutants (HAPs) Source Catgories

FUEL COMBUSTION

- Engine Test Facilities
- Industrial Boilers
- Institutional/Commercial Boilers
- Process Heaters
- Stationary Internal Combustion Engines
- Stationary Turbines

NON-FERROUS METALS PROCESSING

- Primary Aluminum Production
- Secondary Aluminum Production
- Primary Cooper Smelting
- Primary Lead Smelting
- Secondary Lead Smelting
- Lead Acid Battery Manufacturing
- Primary Magnesium Refining

FERROUS METALS PROCESSING

- Coke By-Product Plants
- Coke Ovens: Charging, Top Side, and Door Leaks
- Coke Ovens: Pushing, Quenching, and Battery Stacks
- Ferroalloys Production
- Integrated Iron and Steel Manufacturing
- Non-Stainless Steel Manufacturing - Electric Arc Furnace (EAF) Operation
- Stainless Steel Manufacturing - Electric Arc Furnace (IEAF) Operation
- Iron Foundries
- Steel Foundries
- Steel Pickling - HCl Process

MINERAL PRODUCTS PROCESSING

- Alumina Processing
- Asphalt/Coal Tar Application - Metal Pipes
- Asphalt Concrete Manufacturing
- Asphalt Processing
- Asphalt Roofing Manufacturing
- Chromium Refractories Production
- Clay Products Manufacturing
- Lime Manufacturing
- Mineral Wool Production
- Portland Cement Manufacturing
- Taconite Iron Ore Processing
- Wool Fiberglass Manufacturing

Table D.1: Hazardous Air Pollutants (HAPs) Source Catgories (Continued)

PETROLEUM AND NATURAL GAS PRODUCTION AND REFINING

- Oil and Natural Gas Production
- Petroleum Refineries - Catalytic Cracking (Fluid and other) Units, Catalytic Reforming Units, and Sulfur Plant Units
- Petroleum Refineries - Other Sources Not Distinctly Listed

LIQUIDS DISTRIBUTION

- Gasoline Distribution (Stage 1)
- Organic Liquids Distribution (Non-Gasoline)

SURFACE COATING PROCESSES

- Aerospace Industries
- Auto and Light Duty Truck (Surface Coating)
- Flat Wood Paneling (Surface Coating)
- Large Appliance (Surface Coating)
- Magnetic Tapes (Surface Coating)
- Manufacture of Paints, Coatings, and Adhesives
- Metal Can (Surface Coating)
- Metal Coil (Surface Coating)
- Metal Furniture (Surface Coating)
- Miscellaneous Metal Parts and Products (Surface Coating)
- Paper and Other Webs (Surface Coating)
- Plastic Parts and Products (Surface Coating)
- Printing, Coating, and Dyeing of Fabrics
- Printing/Publishing (Surface Coating)
- Shipbuilding and Ship Repair (Surface Coating)
- Wood Furniture (Surface Coating)

WASTE TREATMENT AND DISPOSAL

- Hazardous Waste Incineration
- Municipal Landfills
- Publicly Owned Treatment Works (POTW) Emissions
- Sewage Sludge Incineration
- Site Remediation
- Solid Waste Treatment, Storage and Disposal Facilities (TSDF)

Table D.1: Hazardous Air Pollutants (HAPs) Source Catgories

Table D.1: Hazardous Air Pollutants (HAPs) Source Catgories (Continued)

AGRICULTURAL CHEMICALS PRODUCTION

2, 4-D Salts and Esters Production
4-Chloro-2-Methylphenoxyacetic Acid Production
4,6-Dinitro-o-Cresol Production
Captafol Production
Captan Production
Chloroneb Production
Chlorothalonil Production
Dacthal (tm) Production
Sodium Pentachlorophenate Production
Tordon (tm) Acid Production

FIBERS PRODUCTION PROCESSES

Acrylic Fibers/Modacrylic Fibers Production
Rayon Production
Spandex Production

FOOD AND AGRICULTURE PROCESSES

Baker's Yeast Manufacturing
Cellulose Food Casing Manufacturing
Vegetable Oil Production

PHARMACEUTICAL PRODUCTION PROCESSES

Pharmaceuticals Production

POLYMERS AND RESINS PRODUCTION

Acetal Resins Production
Acrylonitrile-Butadiene-Styrene Production
Alykd Resins Production
Amino Resins Production
Boat Manufacturing
Butadiene-Furfural Cotrimer (R-11)
Butyl Rubber Production
Carboxymethylcellulose Production
Cellophane Production
Cellulose Ethers Production
Epichlorohydrin Elastomers Production
Epoxy Resins Production
Ethylene-Propylene Rubber Production
Flexible Polyurethane Foam Production
Hypalon (tm) Production
Maleic Anhydride Copolymers Production

Table D.1: Hazardous Air Pollutants (HAPs) Source Catgories (Continued)

POLYMERS AND RESINS PRODUCTION (continued)

Methylcellulose Production
Methyl Methacrylate-Acrylonitrile-Butadiene-Styrene Production
Neoprene Production
Nitrile Butadiene Rubber Production
Non-Nylon Polyamides Production
Nylon 6 Production
Phenolic Resins Production
Polybutadiene Rubber Production
Polycarbonates Production
Polyester Resins Production
Polyethylene Terephthalate Production
Polymerized Vinylidene Chloride Production
Polymethyl Methacrylate Resins Production
Polystyrene Production
Polysulfide Rubber Production
Polyvinyl Acetate Emulsions Production
Polyvinyl Alcohol Production
Polyvinyl Butyral Production
Polyvinyl Chloride and Copolymers Production
Reinforced Plastic Composites Production
Styrene-Acrylonitrile Production
Styrene-Butadiene Rubber and Latex Production

PRODUCTION OF INORGANIC CHEMICALS

Ammonium Sulfate Production - Caprolactam by-Product Plants
Antimony Oxides Manufacturing
Chlorine Production
Chromium Chemicals Manufacturing
Cyanuric Chloride Production
Fume Silica Production
Hydrochloric Acid Production
Hydrogen Cyanide Production
Hydrogen Fluoride Production
Phosphate Fertilizers Production
Phosphoric Acid Manufacturing
Quaternary Ammonium Compounds Production
Sodium Cyanide Production
Uranium Hexafluoride Production

Table D.1: Hazardous Air Pollutants (HAPs) Source Catgories (Continued)

PRODUCTION OF ORGANIC CHEMICALS

Synthetic Organic Chemical Manufacturing

MISCELLANEOUS PROCESSES

Aerosol Can-Filling Facilities
Benzytrimethylammonium Chloride Production
Butadiene Dimers Production
Carbonyl Sulfide Production
Chelating Agents Production
Chlorinated Paraffins Production
Chromic Acid Anodizing
Commercial Dry Cleaning (Perchloroethylene)
  - Transfer Machines
Commercial Sterilization Facilities
Decorative Chromium Electroplating
Dodecanedioic Acid Production
Dry Cleaners (Petroleum Solvent)
Ethylidene Norbornene Production
Explosives Production
Halogenated Solvent Cleaners
Hard Chromium Electroplating
Hydrazine Production
Industrial Cleaning (Perchloroethylene)
  - Dry-to-dry machines
Industrial Dry Cleaning (Perchloroethylene)
  - Transfer Machines
Industrial Process Cooling Towers
OBPA/1,3-Diisocyanate Production
Paint Stripper Users
Photographic Chemicals Production
Phthalate Plasticizers Production
Plywood/Particle Board Manufacturing
Polyether Polyols Production
Pulp and Paper Production
Rocket Engine Test Firing
Rubber Chemicals Manufacturing
Semiconductor Manufacturing
Symmetrical Tetrachloropyridine Production
Tire Production
Wood Treatment

CATEGORIES OF AREA SOURCES

Asbestos Processing

Table D.1: Hazardous Air Pollutants (HAPs) Source Catgories (Continued)

CATEGORIES OF AREA SOURCES (continued)

- Chromic Acid Anodizing
- Commercial Dry Cleaning (Perchloroethylene) - Transfer Machines
- Commercial Dry Cleaning (Perchloroethylene) - Dry-to-Dry Machines
- Commercial Sterilization Facilities
- Decorative Chromium Electroplating
- Halogenated Solvent Cleaners
- Hard Chromium Electroplating

APPENDIX E:

SELECTED MACT STANDARDS AND THEIR RELATIONSHIP TO OTHER CAAA STANDARDS

Table E.1: A List of MACT Standards Currently Proposed Or Promulgated

Source	Affected Facility
Constr., Reconstr. or Modified major Sources 112(g)	Major Sources of HAPs
State Programs & Deleg. of Fed. Authority 112(1)	Major Sources of HAPs
HON	Process vents storage vessels, transfer racks, wastewater streams, and equipment leaks used to produce one or more of 396 SOCMI chemicals.
Coke Oven Batteries & Source Categories	Coke Oven Batteries
Dry Cleaning	Dry Cleaning machines (at major and area sources)
Cadimium	Electroplating or Anodizing Tank Electroplating
Ethylene Oxide Sterilizers	Ethylene Oxide Sterilizers & Fumigators
Industrial Process Cooling	Ind. Process Cooling Towers using Chromium
Gasoline Distribution	Total Bulk Terminal & Breakout Station
Pulp & Paper	Pulp & Paper & paperboard
Halogenated Solvent Cleaning	Hal. Solvent Cleaning machines at major and area sources
Polymers & Resins	Existing & new facilities that manufacture Group 1 elastomers

Table E.1: A List of MACT Standards Currently Proposed Or Promulgated (Continued)

Source	Affected Facility
Polymers & Resins Group IV	Existing & new facilities that manufacture one or more Group IV polymers & resins
Epoxy Resins Production	Existing & new facilities that Manufacture & Non-Nylon Polyamides polymers & resins
Secondary Lead Smelters	New & existing secondary Lead smelters
Marine Tank Vessel Loading	New & existing marine tank vessel& unloading operations
TSDF & Disposal Facilities and Haz. Waste Generators: HAP Sandards for Tanks, Surface Impoundments & Containers	Hazardous Waste Treatment Facilities
Petroleum Refineries	Petroleum Refinery Processes
Off-Site Waste Operations	Off-site Waste & Recovery Operations
Magnetic Tape Mfg. & Operations	Magnetic Tape Products
Aerospace Mfg. and Rework	New & Existing commercial civil & military aerospace OEM & rework facilities that are major sources of HAPs
Shipbuilding & Ship Repair	HAP-Surface Coating Operations from new or existing shipbuilding or ship repair facilities
Wood Furniture	Exist. & new wood furniture manufacturing operations

MACT CONTROL TECHNOLOGY SUMMARY SHEET

SOURCE: Cadmium Electroplating

AFFECTED FACILITY: Electroplating and Anodizing Tank

HAP: Chromium

PROPOSAL DATE: 12/16/93 PROMULGATION DATE:
58FR65767

A. NEW SOURCES

Source	Small (<60 MM Ah/yr)	Large (>60 MM Ah/yr)
Hard Chromium Plating	Chemical Fume Suppressant	Packed Bed Scrubber
Decorative Chromium Plating Chromic Acid Bath	Chemical Fume Suppressant	
Decorative Chromium Plating Trivalent Chromium Bath	No Control	
Chromium Anodizing	Chemical Fume Suppressant	

B. EXISTING SOURCES

Source	Small (<60 MM Ah/yr)	Large (>60 MM Ah/yr)
Hard Chromium Plating	Chemical Fume Suppressant	Composite Mesh Pads
Decorative Chromium Plating Chromic Acid Bath	Chemical Fume Suppressant	
Decorative Chromium Plating Trivalent Chromium Bath	No Control	
Chromium Anodizing	Chemical Fume Suppressant	

NOTES:

1. No overlap with other CAA Standards

MACT CONTROL TECHNOLOGY SUMMARY SHEET

SOURCE: Coke Oven Batteries

AFFECTED FACILITY: Coke Oven Batteries

HAP: Polycyclic Organic Matter (POM)

PROPOSAL DATE: 12/04/92 57FR575534

PROMULGATION DATE: 10/27/93 58FR57898 1/13/94 59FR1992

Corr.

Source	MACT Track 12/31/95	MACT Track 01/01/03	LAER Track 01/15/93	LAER Track 01/01/98	LAER Track 01/01/01
Tall Doors	6.0	5.5	7.0	4.3	4.0
Foundry Doors	5.5	5.0	7.0	4.3	4.0
All Other Doors	5.5	5.0	7.0	3.8	3.3
Lids	0.6	0.6	0.83	0.4	0.4
Off take	3.0	3.0	4.2	2.5	2.5
Charging, s/charge	12	12	12	12	12

NOTES:

1. Owner/Manager has choice of MACT or LAER Track. MACT is initially less stringent, but requires the determination of Residual Risk and possibility of further control. LAER is more stringent and more costly up front, but avoids Residual Risk determination.

2. Emission limits for tall doors, foundry doors, all other door lids, of takes are visibility standards based on 30 run average using EPA Method 303 and 303A as measurment method; charging is in seconds of visible of emissions per charge.

3. Additional standards require specific sealants and caulks for doors; work practice standards require written plans and training.

MACT CONTROL TECHNOLOGY SUMMARY SHEET

SOURCE: Marine Tank Vessel Loading and Unloading Operations

AFFECTED FACILITY: New and Existing Marine Tanks, Vessels, and Unloading Operations

HAP: 53 Assorted HAP/VOCs

PROPOSAL DATE: 05/13/94 PROMULGATION DATE:
59FR25004
8/31/94
59FR44954-notice
03/08/95
60FR12723-revision

Terminal Type Throughput MM BBL/yr	RACT	MACT
Gasoline > 10.0 Crude Oil > 100	Required	
Gasoline > 5.0 Crude Oil > 100	Required	
Gasoline > 1.0 Crude Oil > 10.0		>1.1 Mg/yr uncontrolled HAP
Gasoline > 5.0 Crude > 1.5 Toluene > 10.0		>1.1 Mg/yr uncontrolled HAP
All		>1.1 Mg/yr uncontrolled HAP

NOTES:

1. RACT requires vapor tight tanks and vessels , collection equipment, and control device. Control technology must be capable of 95% recovery and 98% thermal destruction. MACT requires same equipment with 95% recovery and 93% thermal destruction.

2. MACT Standard extends existing practice to a greater range of sources. One of few situations in which RACT is more stringent than MACT.

MACT CONTROL TECHNOLOGY SUMMARY SHEET

SOURCE: Ethylene Oxide Sterilizers

AFFECTED FACILITY: Facility Ethylene Oxide Sterilizers and Fumigators

HAP: Ethylene Oxide

PROPOSAL DATE: 03/07/94 59FR10591
PROMULGATION DATE: 12/06/94 59FR62585

Vent Type	EO Cut off Kg/Yr	Standard
Sterilizer Vent	907	98%
Chamber Exhaust	907	5,300 ppmv max. conc.
Aeration Room	9,070	1 ppmv max. conc

NOTES:

1.Sterilizer Chambers vents and other exhausts are to be connected to catalytic oxidizers and/or acid wash scrubbers.

2.Chamber Exhausts and Aeration Room have no technology recommendations. Measurement Methods are prescribe for compliance determination.

MACT CONTROL TECHNOLOGY SUMMARY SHEET

SOURCE: Epoxy Resins Production and Non Nylon Polyamide Production

AFFECTED FACILITY: New and Existing Sources Engaging in the Manufacturer of Polymers and Resins

HAP: HAPs from Basic Liquid Resin and Wet Strength Resin Production

PROPOSAL DATE: 05/16/94 59FR25387   PROMULGATION DATE: 03/08/95 60FR12670

EXISTING		Wet Strength	Resin
Emission Source	Basic Liquid Resin		Equivalent Standard
Process Vents, Storage Tanks, and Waste Water	HAP Emission Limit 130 lb/MM lb Product	HAP Emission Limit 10 lb/MM lb Product	No Requirement
Equipment Leaks	Requirements of 40CFR63 (H)	No Requirement	Requirement of 40CFR63 (H)
NEW			
Process Vents, Storage Tanks, and Waste Water	98% Reduction of HAPs from Uncontrolled Sources or Limit HAPs to 5,000 lb/yr	HAP Emission Limit 7 lb/MM lb Product	No Requirement
Equipment Leaks	Requirements of 40CFR63 (H)	No RRequirement	Requirement of 40CFR63 (H)

NOTES:

1. 40CFR63 (H) provides anegotiated method that addresses leak controls by implementing leak detection and repair (LDAR)

MACT CONTROL TECHNOLOGY SUMMARY SHEET

SOURCE: Secondary Lead Smelters

AFFECTED FACILITY: New and Existing Sources

HAP: HAPs including Lead

PROPOSAL DATE: 06/09/94
59FR29750
04/19/95
60FR19556 - amendment

PROMULGATION DATE: 06/23/95
60FR32585

Furnace	Lead Compounds (mg/dscm)	THC (ppmv)	Total HCL and Chlorine (mg/dscm)	Fugitive Emissions
Reverberating/Blast	2 Baghouse	20 No Control	15 Monitoring of Soda Ash and Limestone, Scrubbers	Standard Operating Practices
Blast: Existing	2 Baghouse	360 After Burner at 700C	15	Standard Operating Practices
Blast: New	2 Baghouse	70 After Burner at 870 C	15	Standard Operating Practices
Reverberating and Rotary	2 Baghouse	None No Control	15	Standard Operating Practices
Electric	2 Baghouse	None No Control	None No control	Standard Operating Practices

NOTES:

1. Process fugitive sources include smelting furnaces and dyer charging hoppers and chutes, lead taps and molds, slag taps and molds, refining and alloying kettle, dryer transition, and dust agglomerating furnace taps and molds.

2. Baghouses constitute BACT technology