

# EPA Identification and

# Characterization of Five Non-Traditional Source Categories:

Catastrophic/Accidental  
Releases, Vehicle Repair  
Facilities, Recycling, Pesticide  
Application, and Agricultural  
Operations

**J**oint **E**missions **I**nventory **O**versight **G**roup

Prepared for Office of Air Quality Planning and Standards

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**IDENTIFICATION AND CHARACTERIZATION OF FIVE NON-TRADITIONAL SOURCE  
CATEGORIES: CATASTROPHIC/ACCIDENTAL RELEASES, VEHICLE REPAIR FACILITIES,  
RECYCLING, PESTICIDE APPLICATION, AND AGRICULTURAL OPERATIONS**

**FINAL REPORT**

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## **ABSTRACT**

This report presents the results of work completed under Work Assignment Nos. 2/220 and 3/304 under EPA Contract No. 68-D9-0173. This work is part of EPA's program to identify and characterize emissions sources not currently accounted for by either the existing AIRS or SIP area source methodologies and to develop appropriate emissions estimation methodologies and emission factors for a group of these source categories. Based on the results of the identification and characterization portions of this research, five source categories were selected for methodology and emission factor development: catastrophic/accidental releases, vehicle repair facilities, recycling, pesticide application and agricultural operations. This report presents emissions estimation methodologies and emission factor data for the selected source categories.

The discussions for each selected category include general background information, emissions generation activities, pollutants emitted, sources of activity and pollutant data, emissions estimation methodologies, issues to be considered and recommendations. The information used in these discussions was derived from various sources including available literature, industrial and trade association publications and contracts, experts on the category and activity, and knowledgeable federal and state personnel.



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## LIST OF ACRONYMS

ACGIH	Amer. Conference of Governmental Industrial Hygienists
ADP	Air-dried unbleached pulp
AFS	AIRS Facility Subsystem
AIRS	Aerometric Information Retrieval System
ASTM	American Society for Testing and Materials
BLEVEs	Boiling Liquid Expanding Vapor Explosions
CARB	California Air Resources Board
CAS	Chemical Abstract Service
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CHRIS	Chemical Hazard Response Information System
CO	carbon monoxide
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
ERNS	Emergency Response and Notification System
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
HTAHCAC	Handbook of Toxic and Hazardous Chemicals and Carcinogens
HDPE	high-density polyethylene
ITC	International Trade Commission
JEIOG	Joint Emission Inventory Oversight Group
LDPE	low-density polyethylene
MRFs	Material recovery facilities
MRI	Mediamark Research Incorporated
MSW	Municipal Solid Waste
NADB	U.S. EPA, National Air Data Branch
NAPAP	National Acid Precipitation Assessment Program
NEDS	National Emissions Data System
NLM	National Library of Medicine
NMR	Neilson Marketing Research
NO <sub>x</sub>	oxides of nitrogen
NRC	National Response Center
PCV	positive crankcase ventilation valve
PET	polyethylene terephthalate
PM	particulate matter
PM-10	particulate matter less than 10 µm in diameter
PP	polypropylene
PS	polystyrene
PVC	polyvinyl chloride
RCRA	Resources Conservation and Recovery Act
SAMI	Selling Area Marketing Index
SARA	SUPERFUND Amendments and Reauthorization Act of 1986
SCC	source classification code
SERC	State Emergency Response Commission
SIP	State implementation plan
SO <sub>2</sub>	sulfur dioxide



SOCMI	Synthetic and organic chemical manufacturing industry
SPI	Society of the Plastics Industry
TLV	Threshold Limit Values
TOG	Total organics
TOXNET	NLM's Toxicology Data Network
TPY	tons per year
TRI	Toxic Chemical Release Inventory
TRS	total reduced sulfur
TSP	total suspended particulate
TWA	ACGIH's Time-Weighted Average
USCG	U.S. Coast Guard
V	vinyl
VOC	volatile organic compound(s)
VMT	vehicle miles traveled

## CONVERSION FACTORS

To Convert From	To	Multiply By
Acre	Hectare (ha)	2.471
Acre	Square meter (m <sup>2</sup> )	4047
Barrel (bbl)	Liter (l)	159
Barrel (bbl) - petroleum*	Gallon (gal)	42
Board foot	Cubic meter (m <sup>3</sup> )	0.0024
British thermal unit (Btu)	Gram/calorie (g/cal)	251.98
British thermal unit/hour (Btu/hr)	Watt (W)	0.293
Centigrade	Fahrenheit	(°C+32) 9/5
Cord	Cubic meter (m <sup>3</sup> )	3.6224
Cubic foot (ft <sup>3</sup> )	Cubic meter (m <sup>3</sup> )	0.0283
Cubic foot (ft <sup>3</sup> )	Liter (l)	28.316
Cubic foot/minute (ft <sup>3</sup> /min)	Cubic centimeter/second (cm <sup>3</sup> /sec)	472.0
Cubic yard (yd <sup>3</sup> )	Cubic meter (m <sup>3</sup> )	0.77
Fahrenheit	Centigrade	(°F-32) 5/9
Foot (ft)	Meter (m)	0.3048
Gallon (gal)	Liter (l)	3.785
Inch (in)	Centimeter (cm)	2.54
Mile (mi)	Kilometer (km)	1.609
Pound steam/hour** (lb/hr)	British thermal unit/hour (Btu/hr)	1400.0
Pound (lb)	Kilogram (kg)	0.45
Pound/ton (lb/ton)	Gram/kilogram (g/kg)	0.496
Pound/square inch (psi)	Kilopascal (kPa)	6.894
Quart (qt)	Liter (l)	0.946
Square foot (ft <sup>2</sup> )	Square meter (m <sup>2</sup> )	0.0929
Ton	Kilogram (kg)	907.1

\*42 gal/bbl is the standard as used in the oil industry. For other industries, different gallons/bbl apply.

\*\*Typical value based on common boiler design parameters. Value will vary depending upon steam temperature and pressure.

## **SECTION 1.0**

### **INTRODUCTION**

#### **1.1 BACKGROUND**

Area source emissions of particulate matter (PM or TSP), sulfur dioxide (SO<sub>2</sub>), oxides of nitrogen (NO<sub>x</sub>), reactive volatile organic compounds (VOC) and carbon monoxide (CO) are estimated annually by the National Air Data Branch (NADB) of the U.S. Environmental Protection Agency (EPA). Area sources are typically aggregations of individual sources that are too small to be defined as point sources in a specific geographic area. Area sources usually include all mobile sources and any stationary sources that are too small, difficult, or numerous to be inventoried as point sources. The National Emissions Data System (NEDS) is the data management and processing system that has historically been used to maintain these annual emissions data. The statutory requirement for annual inventories defines an area source as an anthropogenic mobile or stationary source that emits less than 100 tons per year (TPY) of TSP, SO<sub>2</sub>, NO<sub>x</sub> or VOC, or 1,000 TPY of CO.

The original NEDS area source methodology and algorithms were developed in 1973 and 1974 using 1960 census data (*e.g.*, population, housing, manufacturing). The NEDS methodology has remained relatively unchanged over the past 17 years and forms the basis for the Aerometric Information Retrieval System/Area and Mobile Source Subsystem (AIRS/AMS) methods. The Joint Emissions Inventory Oversight Group (JEIOG) is currently updating and revising emission estimation and allocation methods using more recent data.

While emissions sources included in current inventory methodologies do cover a large portion of anthropogenic emissions, many small source categories are not included in the inventory. Identification, characterization and inclusion of these categories and their emissions in the inventory will result in a more thorough and complete emissions inventory.

## **1.2 PURPOSE OF WORK ASSIGNMENT**

The purpose of these work assignments is to more fully characterize the following five source categories not currently accounted for in the NEDS area source and AIRS/AMS methodologies: Catastrophic/Accidental Releases; Vehicle Repair Facilities; Recycling Processes; Farming Operations; and Crop Dusting/Pesticide Application. To the extent that data and information were available, the following topics are included in the categorization:

- Definition and description of the category and activity
- Process identification and definition
- Pollutants emitted from each identified process
- Estimate of the pollutant levels
- Source activity data availability
- Level of detail required by user
- Emission factors available/required for each identified process
- Regional, seasonal or other temporal characteristics
- Potential methodology
- Additional data requirements critical to methodology development

## **1.3 CONTENTS**

Sections 2 through 6 of this report describe the characterizations of the five source categories. Section 2 presents the results for catastrophic/accidental releases; Section 3 describes vehicle repair facilities; Section 4 includes recycling processes; Section 5 includes farming operations and Section 6 discusses crop dusting/pesticide application. An index of pollutant codes is provided as Appendix A. Appendix B presents a sample National Response Center (NRC) accident report.

## **SECTION 2.0**

### **CATASTROPHIC/ACCIDENTAL RELEASES - RAIL CAR, TANK TRUCK, AND INDUSTRIAL ACCIDENTS**

#### **2.1 DEFINITION/DESCRIPTION OF CATEGORY AND ACTIVITY**

Catastrophic releases, which often involve the release of large quantities of substances over a very short period of time, potentially represent a significant portion of an area's total emissions. However, these emissions are not represented in the current area source emissions inventory methodology.

For this discussion, catastrophic/accidental releases refer to the unintentional and unexpected, sudden release of pollutants to the atmosphere from rail cars, tank trucks, and industrial facilities. Naturally occurring releases like the Mount St. Helens Volcanic eruption in 1980 are not covered in this definition. The accident or catastrophe may be caused by equipment failure, roadway conditions, human error, or by natural conditions (*i.e.*, hurricane, lightning, earthquake, or flash flood).<sup>1</sup> These two types of releases differ in their severity. As defined here, an accident is an unintentional or unexpected happening that is undesirable or unfortunate, while a catastrophic event is a sudden and widespread calamitous event causing great damage or hardship. Because accidental releases are considered not as severe as a catastrophic release, minor accidental releases often go unreported. Examples of accidental releases are the overloading of an underground storage tank and chemical spill resulting from a highway truck accident. The Chernobyl disaster is an example of a catastrophic release.

Catastrophic releases from rail car, tank truck, and industrial accidents are usually chemical spills, with or without combustion. The types and quantities of emissions depend on factors such as the material released, remediation efforts, and weather conditions.



### **2.1.1 Rail Car**

According to recent statistics, about 80 million tons of hazardous materials are shipped annually by rail in the United States.<sup>2</sup> The majority of these shipments are in single tanks permanently mounted on rail cars. Exceptions include multi-tank cars (the units are usually ton containers), seamless steel cylinders (for very high-pressure service), and compartmented tank cars in which each compartment is treated as a separate tank. The sizes of these will range from a few hundred gallons in the case of a 1-ton container to 45,000 gallons in so-called jumbo tank cars. Since 1970, however, the capacity of new tank cars has been limited to 34,500 gallons.

Rail cars are usually classified as pressure tank cars, non-pressure tank cars, cryogenic liquid tank cars, or miscellaneous tank cars. Carbon steel is used to construct over 90 percent of the tanks, with aluminum used for most of the remainder. Nickel or nickel alloy is found in acid service, and there are a small number of stainless steel cars.<sup>3</sup> Safety relief valves (and vents) are required, unless otherwise specified. Tanks may be lined, insulated, and possibly fitted with heating coils. Some may have special thermal protection to prevent Boiling Liquid Expanding Vapor Explosions (BLEVES) or other explosions in the event of exposures to pool fires or flame jets. To help prevent punctures from occurring during derailment, shelf couplers and head shields are used.

In addition to bulk transportation, hazardous materials may be transported in small packages (*i.e.*, cylinders, drums, barrels, cans, bottles, and boxes). These containers are defined by the U.S. Department of Transportation as having a capacity of less than 110 gallons or 1000 pounds. Packaged hazardous materials may be moved by truck, van, or boxcar.

### **2.1.2 Tank Truck**

Tank trucks are usually tractor-semitrailer vehicles or smaller bobtail-type units. The tanks themselves are typically constructed of steel or an aluminum alloy, but may also be constructed of stainless steel, nickel and other materials. Capacities range from 3,000 to 10,000 gallons,

although slightly smaller and larger units are available. Internodal tanks, tanks within a protective rigid framework, one-ton tanks which are lifted on and off the transporting vehicle, and large gas cylinder bundles are also commonly used for bulk transport by highway.

### **2.1.3 Industrial Facilities**

A broad range of facilities may pose potential risks associated with the release of hazardous materials. These facilities can include large refineries, chemical plants, and storage terminals; more moderately sized industrial users, warehouses, and isolated storage tanks for water treatment; and small quantity users/storage areas as may be found in high school and college laboratories, florists, greenhouses, hardware and automotive stores, and paint stores.

## **2.2 PROCESS IDENTIFICATION AND DEFINITION**

Air pollutants from catastrophic and accidental releases may enter the atmosphere through evaporation of liquid releases, combustion of solid or liquid materials, or venting of gaseous or particulate materials.

### **2.2.1 Rail Car**

The release of hazardous materials from rail cars usually results from (1) collision or derailment, which typically involves the largest spills or discharges; and (2) fitting or seal leaks, relief valve leaks, and other releases associated with improper tightening of closures or defective equipment. It is estimated that most releases occur as a result of this second category.<sup>4</sup> Results from rail car accidents, like accidents involving tank trucks, can range from virtually no adverse consequences up to many deaths, depending on the materials involved and the circumstances of the accident.

### **2.2.2 Tank Truck**

Truck accidents on roadways, regardless of the cargo involved, are generally due to (1) collisions with other vehicles; (2) collisions with fixed objects such as bridges or overpass supports; or (3) loss of control and overturns due to excessive speed on curves. These four events are most likely to result in a release of large quantities of hazardous materials and are predominately the result of human error. Smaller releases may arise due to defective or loose valves, fittings or couplings; weld failures; and various other structural defects.<sup>1</sup>

### **2.2.3 Industrial Facilities**

Releases from industrial fixed facilities may arise from storage tank or container ruptures or leaks, piping ruptures or leaks, releases through safety and relief valves, fire-induced releases, other equipment failures, malicious or deliberate actions, overfills and overflows of storage tanks, human errors, open valves, failed loading hoses, or improper hose connections.<sup>1</sup>

Transfer areas include pipelines, pumps, valves, and control instrumentation needed to achieve the movement of material within a facility. The loading/unloading area involves the most handling operations and the largest potential for human error in most facilities. Because the greatest volume of materials are contained here, spills can be quite large.<sup>1</sup>

## **2.3 POLLUTANTS EMITTED FROM EACH IDENTIFIED SOURCE**

The nature of catastrophic releases makes precisely describing the released materials difficult. A material may be in one form for storage or transportation but may form a different substance when released. Appendix A is a compilation of common hazardous materials, from the National Response Center, that could be subject to accidental release. Many of these substances are included within EPA's List of Hazardous Substances, Section 302.4(a) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). VOC species emitted are dependent on the material released. VOC, NO<sub>x</sub>, and CO emissions are

possible if combustion takes place. Air toxics may also be emitted. Some examples of the different types of materials and emissions are described in the following paragraphs.

In Chicago, a bulk storage tank of silicon tetrachloride developed a leak. The escaping liquid, 150,000 gallons, reacted with the moisture in the air and formed hydrogen chloride, resulting in a dense, corrosive, choking plume that stretched 5-10 miles downwind.<sup>1</sup>

A train derailment transporting white phosphorus in Miamisburg, Ohio produced a white cloud of toxic smoke that towered a thousand feet over the community and covered an area about 1 mile wide and 10-15 miles long.<sup>1</sup>

In Houston, a tank truck carrying liquefied anhydrous ammonia collided with a car and fell from an elevated highway to a busy freeway. The truck exploded, releasing billowing clouds of ammonia covering a three mile radius.<sup>1</sup>

## **2.4 ESTIMATE OF THE POLLUTANT LEVELS**

Levels of pollutants vary widely from year to year and from area to area. Due to the nature of catastrophic/accidental releases, it is very difficult to estimate annual emissions for any particular hazardous material. Using national hazardous material databases, information on various spills can be collected. For instance, using information from the Emergency Response Notification System (ERNS), described in 2.6, estimates for the reported quantities of released hazardous substances was obtained. In 1989 there was an estimated 219.8 million pounds of catastrophic/accidental release of hazardous substances within the United States and its territories.<sup>5</sup> This number is low because it only covers reported occurrences. Employing a methodology similar to that developed for oil spills, emission rates could be estimated, provided that input data for the various factors in equations are available.<sup>6</sup>

Estimates on missing sources for an area emissions inventory could also be obtained by collecting data on the total gallons or pounds of material released in a specific area. Using some simplifying assumptions, such as 50 percent dispersion rate for particulate releases or

10 percent volatilization rate for liquids, rough emission estimates could be calculated from the available data.

## **2.5 POINT/AREA SOURCE CUTOFF**

Catastrophic releases are not specifically identified in current point or area source inventories. The reason for this is that Source Classification Codes (SCC) codes do not exist for these categories. Source Classification Codes are required for storing source and emissions data in EPA's Aerometric Information Retrieval System (AIRS) Facility Subsystem (AFS), and in states' computerized source files.<sup>7</sup> To include such emissions in an inventory, SCC codes would need to be developed.

## **2.6 LEVEL OF DETAIL OF SOURCE ACTIVITY DATA AVAILABILITY**

40 CFR Part 302.6 requires that releases of hazardous chemicals be reported to the National Response Center (NRC). The NRC, operated by the U.S. Coast Guard (USCG) and EPA, maintains a database on oil spills, hazardous materials, and other releases. Access to these data is guaranteed by the Freedom of Information Act.<sup>8</sup> Data reported for each accident include, but are not restricted to, the following:<sup>9</sup>

- Date of release
- Material released
- Media affected (water, air, etc.)
- Mode (train, ship, truck, etc.)
- Location
- Quantity released

Appendix B contains an example of an NRC accident report. The entries are fictitious and are only presented for example purposes.

Agencies requesting information from the NRC should send written requests to the following address:



National Response Center  
U.S. Coast Guard Headquarters  
Room 2611  
2100 2nd Street S.W.  
Washington, DC 20593

The NRC also operates a toll-free accident reporting service (1-800-424-8802).

Another source of information on catastrophic emissions is ERNS. ERNS is a national computer database and retrieval system that is run by the EPA and supported by the USCG. ERNS stores information on releases of oil and hazardous substances, and provides a direct source of easily-accessible data that can be used to analyze spills and to support emergency planning efforts by Federal, state, and local governments. The database contains the following types of information:

- Material released
- Amount released
- Source of release
- Incident location
- Response actions taken
- Environmental medium into which the release occurred

Information from ERNS is made available to the public in periodic reports published by EPA's Emergency Response Division. These reports can be obtained by calling the RCRA/Superfund Hotline at 1-800-424-9346 (in the Washington, D.C. metropolitan area, call 1-202-382-3000).<sup>10</sup>

All states are required by CERCLA to have a State Emergency Response Commission (SERC). It is the duty of the SERC to compile information on accidental/catastrophic releases occurring within the state. However, the quality of the information varies from state to state, and much of the information can be obtained from NRC or ERNS.<sup>11</sup>

A future source of information on accidental releases will be the Toxic Chemical Release Inventory (TRI). TRI contains files on the annual estimated releases of toxic chemicals to the environment from point sources complying with Title III of the SUPERFUND Amendments and Reauthorization Act (SARA) of 1986. EPA collects the information and it becomes accessible through the National Library of Medicine's (NLM) Toxicology Data Network (TOXNET). Data submitted to EPA include names and addresses of facilities which manufacture, process or otherwise use these chemicals, as well as amounts released to the environment or transferred to waste sites.<sup>12</sup> Beginning in 1992, a new section will be added to the data form and database for reporting facilities to fill in amount of material released accidentally.<sup>13</sup>

Contact the following source for further information about the TRI file and gaining access to it:

TRI Representative  
Specialized Information Services  
National Library of Medicine  
8600 Rockville Pike  
Bethesda, MD 20894  
Telephone (301) 496-6531

EPA also maintains the Emergency Planning and Community Right to Know Hot Line. This service provides additional information about the requirements of Title III of SARA and technical questions about TRI. The number of the hotline is 1-800-535-0202.

## **2.7 LEVEL OF DETAIL REQUIRED BY USERS**

Catastrophic releases should be inventoried on an area wide or county basis. NRC and ERNS contain area-specific release data (amount, type, remediation efforts, date of release, etc.) for the nation. NRC reports could be generated for all releases occurring in a particular area. To quantify catastrophic releases, the following information is required to estimate emissions:

- Area covered by the spill
- Quantity of spill
- Type of material released
- Time period of release
- Meteorological conditions
- Occurrence of combustion
- Release site demographics characteristics
- Media affected
- Remediation efforts
- The total number of releases occurring

## **2.8 EMISSION FACTOR REQUIREMENTS**

The releases reported to the NRC and ERNS should be examined individually to determine the volatility of material, and the effect of remediation and climate. Furthermore, the evaporative loss needs to be calculated along with the emission factor for any fire that may be associated with the release. Because there has been work toward developing a methodology for assessing the emissions from structural fires<sup>14</sup>, that aspect is not covered in this report.

Evaporation losses for liquid spills can be calculated by the following steps:

- Determine the spill area and spill material
- Determine the elapsed time
- Calculate mass transfer coefficient
- Calculate evaporative exposure
- Determine volume fraction evaporated
- Calculate mass evaporated

Atmospheric emissions as a result of fire can be calculated by the following steps:

- Determine burning velocity
- Determine spill area and spill material
- Determine elapsed time of fire
- Determine mass of fuel burned
- Determine mass of pollutant released

## **2.9 REGIONAL, SEASONAL OR TEMPORAL CHARACTERISTICS**

Seasonal climate variations could affect the likelihood of a spill and volatilized emissions, depending on regional or temporal conditions. Winter conditions in the northeast or west increase the potential for vehicular accidental releases because of ice and snow accumulation. Freezing temperatures would also decrease the volatilization of released material. In the southwest, dry hot conditions could lead to greater evaporation losses from a spill.

## **2.10 URBAN OR RURAL CHARACTERISTICS**

Point sources are just as likely to locate in rural as in urban areas. Therefore this probability of releases occurring would be equal for either of them. However, studies on truck transportation of hazardous substances have shown a higher probability of releases occurring in urban road areas compared to interstate or state highways.<sup>15</sup> Catastrophic or accidental releases are likely to happen in urban as well as rural areas.

## **2.11 POTENTIAL METHODOLOGY**

Due to the wide variety of factors and circumstances inherently associated with catastrophic/accidental releases, it is very difficult and resource intensive to accurately assess emissions. There are several ways to estimate emissions from releases, each of which result in estimates with varying degrees of uncertainty. The methodologies described in this section

cover current years. For releases from current years, two methods are proposed, although multiple variations of these are also possible. Emission estimates for each method could be based on a variation of the following general procedure, using data from databases containing historical records of catastrophic/accidental releases.

- Step 1        Determine the activity level from appropriate databases (*i.e.*, the number of releases, the pollutant and its physical state, and the amount of material released).
- Step 2        Determine emissions by multiplying the activity indicator by an emission factor (no emission factors are currently available), or determine emissions by use of appropriate equations which account for variables such as liquid spill area, gas-phase mass transfer coefficient, and volume and depth of the spill (these equations also need to be developed).

Future projections on the number of catastrophic/accidental releases could be calculated by applying statistical analysis to the number of yearly accidents over the past 20 years to obtain a projection of the number of releases for a given year.

In the first method, emissions from accidental releases would be estimated using existing NRC, ERNS, or state databases to obtain the type and amount of material released for any particular geographic area. This method would require that each accidental release be treated separately: emissions from each release would be calculated individually and then added together to provide an estimate of the total released emissions.

In the second method, activity indicators (number and type of release) would also be obtained from the NRC, ERNS, or state database. However, each release would not be treated separately. Instead, the total amount of pollutant would be summed and multiplied by an appropriate emission factor. The emission factor would be based on some gross assumptions concerning the factors that affect the emissions. Because of the use of assumptions, the emissions estimate for this method would have the highest level of uncertainty.

For future year emission estimates, probabilistic accident estimation is suggested. This techniques involves historical data summarization, trend direction procedures, and possibly one-to five-year forecasts.

## 2.12 REFERENCES

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## **SECTION 3.0**

### **VEHICLE REPAIR FACILITIES**

#### **3.1 DEFINITION AND DESCRIPTION OF THE CATEGORY AND ACTIVITY**

Vehicle repair facilities are defined as locations which service or repair light-duty vehicles with predominantly gasoline engines. This category includes the general service station or garage, as well as facilities offering more specialized services (*e.g.*, oil change, tune-up, muffler/exhaust repair, radiator repair, etc.). This category does not include exterior-related services such as car washing/detailing shops and paint and body repair shops. Many repair activities which generate emissions are also performed by individual vehicle owners. These do-it-yourselfers (DIYers) could account for a large percentage of the emissions related to this category. Due to the broad scope of this category, several subcategories were identified. The following subcategories represent the fluids or class of fluids identified as sources of emissions.

##### **Maintenance**

- Antifreeze/engine coolants
- Brake fluids
- Crankcase oils
- Lubricants & silicones
- Steering fluids
- Transmission fluids
- Windshield washer fluids

##### **Cleaning**

- Brake cleaners
- Carburetor and choke cleaners
- Engine/parts cleaners/degreasers

##### **Specialty**

- Belt dressings
- Engine starting fluids
- Tire repair products
- Windshield deicers

##### **Additives**

- Crankcase
- Fuel system

- Radiator
- Transmission

## 3.2 PROCESS IDENTIFICATION AND DEFINITION

Automotive repair products are used by professional mechanics and vehicle owners. VOC emissions from automotive fluids are associated with draining, refilling, overfilling, or replacing fluids and from running and standing losses. Vehicle repair facilities generate emissions through the use of products containing solvents and aerosol propellants. Propellants are used to propel aerosol products from containers, solubilize active ingredients, and serve as part of the diluting system. Solvents solubilize the product ingredients and affect the evaporation rate of the product. Many of these products are composed of volatile organic compounds (VOC). In addition, some of the compounds in automotive fluids are considered hazardous, composed of toxic and ignitable chemicals.

Some categories and product types were found to be more fully defined than others, particularly with regard to the specificity of the terminology for various discrete product types and the variability of formulations for a specific type of product. For example, the basic functional fluids used in vehicles (antifreeze, brake fluid, transmission fluid, etc.) tend to have the same basic formulation and principal ingredients. However, the term "carburetor cleaner" can apply to products designed to be sprayed into the carburetor as well as buckets of solvent used to soak partially-disassembled carburetors. There are also numerous other examples of multi-use products, such as dressings, and other product categories such as lubricants, where descriptions and designations may overlap. With the available information on product types and formulations, it can be difficult to distinguish between formulations for distinct product types (*i.e.*, products with different intended applications) and different formulations for products intended for the same basic use. In some cases, varying formulations may be due to differences in product form (*e.g.*, aerosol, liquid or solid), while some products in the same category may use different ingredients for the same function (*e.g.*, different solvents) or even operate on different basic principles (solvent versus alkaline cleaning).

Almost without exception, the products discussed here are designed and labeled for use in general automotive applications, which include cars, trucks and motorcycles. Specific products for trucks or motorcycles are mentioned where they have been identified.

The formulation data presented in Table 3-1 and the following discussions are derived mainly from product-specific and general formulations by product type listed in *Clinical Toxicology of Commercial Products*.<sup>1</sup> Except where another source is noted, all formulations summarized or cited in this section were found in this reference. Wherever possible, distinctions have been made between information from actual product formulations and general formulations compiled by the authors, since in some cases the two sets of data did not agree. Some additional information was also available in *Household and Automotive Cleaners and Polishes*,<sup>2</sup> but most of the formulations in this reference are from sources such as technical bulletins, and could not be verified as being related to any actual product currently on the market.

Most automotive fluids contain varying combinations of additives such as oxidation inhibitors, rust inhibitors, antiwear agents, detergents and dispersants, pour-point depressants, viscosity index improvers and foam inhibitors. Oxidation inhibitors are generally organic compounds containing sulfur, nitrogen and phosphorus, or alkyl phenols. Rust inhibitors are mildly polar organic acids such as alkyl succinic or organic amines. Antiwear agents are composed of fatty acids, esters, ketones, sulfur or sulfur dioxide mixtures, organic chlorine compounds (such as chlorinated wax), organic sulfur compounds (such as sulfurized fats and sulfurized olefins), chlorine-sulfur compounds, organic phosphorus compounds (such as tricresyl phosphate, thiophosphates and phosphites) and organic lead compounds.<sup>3</sup> Detergents and dispersants often make up 2 to 20 percent of automotive lubricants and are primarily composed of sulfonates, calcium/barium salts of petroleum mahogany sulfonic acids, phosphonates, thiophosphonates and polymers containing oxygen or nitrogen-bearing comonomers. Pour-point depressants are usually polymethacrylates or polymers formed by condensation of wax with naphthalene or phenols. Viscosity index improvers are linear polymers and foam inhibitors are methyl silicone polymers.<sup>3</sup>

**TABLE 3-1. FORMULATION PROFILES FOR AUTOMOTIVE FLUIDS USED IN VEHICLE REPAIR FACILITIES**

Species Name	Percent by Weight	Species Name	Percent by Weight
<b>Antifreeze/Engine Coolants</b>		<b>Lubricants</b>	
<u>Formulation 1</u>		<u>Formulation 1</u>	
Ethylene glycol	95	Naphtha (aliphatic)	64.5
Water	3	Oxygenated organic acids	20.0
Soluble inhibitors/dyes	2	Tricresyl phosphate (synthetic base)	10.0
<u>Formulation 2</u>		Colloidal graphite dispersion in aliphatic naphtha	5.0
Ethylene glycol	95.0	Nonylphenoxy acetic acid	0.5
Water	2.5	<u>Formulation 2</u>	
Soluble inhibitors/dyes	2.5	Mineral oil	95
<u>Formulation 3</u>		Additive, containing sulfur, chlorine, lead	5
Ethylene glycol	95.0	<u>Formulation 3</u>	
Alkaline metal earths	2.5	Mineral oil	99
Water	2.5	Additives, containing methacrylate copolymer	1
<b>Brake Fluids</b>		<u>Formulation 4</u>	
<u>Formulation 1</u>		Combined amount: Petroleum distillate, 2-butyl alcohol, glycerol mono-oleate, 1,1,1-trichloroethane	97.7
Mixed polyglycol ethers	79	Carbon dioxide	2.3
Polyalkylene glycol	20	<u>Formulation 5</u>	
Inhibitors	1	Mineral oil	100
<u>Formulation 2</u>		<u>Formulation 6</u>	
Mixed polyglycol ethers	73	Mineral spirits	70
Polyalkylene glycol	26	Mineral oil	21
Inhibitors	1	Petrolatum	6
<u>Formulation 3</u>		Emulsifiers	3
Mixture of glycol ethers (diethylene glycol monoethyl ether, triethylene glycol monoethyl ether, triethylene glycol monomethyl ether)	7	Carbon dioxide (aerosol)	
Polypropylene glycol	20	<u>Formulation 7</u>	
Propylene or dipropylene glycol	10	Trichloroethane	94
<u>Formulation 4</u>		Silicone fluid	4
Poly-oxy-alkylene glycols, tri-glycol-ethers	100	Vegetable oil	2
<b>Crankcase Oils (no entries)</b>		<u>Formulation 8</u>	
		Mineral oil	50
		Colloidal graphite dispersion in mineral oil	48
		Sorbitan fatty acid ester	2

(continued)

**TABLE 3-1. FORMULATION PROFILES FOR AUTOMOTIVE FLUIDS USED IN  
VEHICLE REPAIR FACILITIES (Continued)**

Species Name	Percent by Weight	Species Name	Percent by Weight
<b>Steering Fluids (no entries)</b>		<b>Brake Cleaners</b>	
<b>Transmission Fluids</b>		<u>Formulation 1</u>	
<u>Formulation 1</u>		Methanol	100
Mineral oil	92	<u>Formulation 2</u>	
Additive, containing zinc alkyl dithiophosphate, boron, nitrogen and sulfur compounds	8	Ethanol	100
<u>Formulation 2</u>		<u>Formulation 3</u>	
Mineral oil	91	Isopropanol	100
Additive, containing polymer, dye, boron, sulfur phosphorus compounds	9	<u>Formulation 4</u>	
		Aliphatic chlorinated solvents	100
<b>Windshield Washer Fluids</b>		<b>Carburetor and Choke Cleaners</b>	
<u>Formulation 1</u>		<u>Formulation 1</u>	
Methanol	64	Ethylene dichloride	63
Water	36	Cresol	25
		Butane	12
<u>Formulation 2</u>		<u>Formulation 2</u>	
Water	>59.97	Aliphatic hydrocarbons	88
Methanol	40.00	n-Butane	12
Detergent/dye	<0.03		
<u>Formulation 3</u>		<u>Formulation 3</u>	
Methanol	68	Cresol (o-,m-,p-)	35
Water	27	Ethylene dichloride	30
Ethylene glycol	5	n-Butane	24
		Ethanol	11
<u>Formulation 4</u>		<u>Formulation 4</u>	
Methanol	>95	Toluene	38.89
Polyether alcohol surfactant	1	Isomers of xylene	33.33
		Methanol	11.11
<u>Formulation 5</u>		Tetrahydrofurfuryl alcohol	11.11
Concentrate:		Acetone	5.56
Methanol	>70	<u>Formulation 5</u>	
Water	>10	Methylene chloride	42.10
Mercapto ethoxylate	<1	o-Dichlorobenzene	41.57
Premix:		Cresylic acid	15.80
Methanol	>40	Complex amines	0.53
Water	>50		
Mercapto ethoxylate	1-10		

(continued)

**TABLE 3-1. FORMULATION PROFILES FOR AUTOMOTIVE FLUIDS USED IN  
VEHICLE REPAIR FACILITIES (Continued)**

Species Name	Percent by Weight	Species Name	Percent by Weight
<b>Carburetor and Choke Cleaners, continued</b>		<b>Carburetor and Choke Cleaners, continued</b>	
<u>Formulation 6</u>		<u>Formulation 15</u>	
Xylol	>50	Polybutene amine inhibitor	<30
Mixture of petroleum distillates	>40	Mixed xylenes	<30
<u>Formulation 7</u>		<b>Engine/Parts Cleaners/Degreasers</b>	
Mineral oil	>60	<u>Formulation 1</u>	
Combination: high molecular weight esters, mixture of oxygenated unsaponifiable hydrocarbons, alkyl aryl phosphate, aromatic solvents	>30	Isopropanol	100
<u>Formulation 8</u>		<u>Formulation 2</u>	
Acetone	<50	Kerosene	100
Aromatic hydrocarbons	<35	<u>Formulation 3</u>	
Chlorinated hydrocarbons	<25	Aromatic 150 solvent	100
<u>Formulation 9</u>		<u>Formulation 4</u>	
Aromatic hydrocarbons	71	Mineral spirits	100
Ketone	29	<u>Formulation 5</u>	
<u>Formulation 10</u>		Heavy aromatic naphtha	100
Xylene	37	<u>Formulation 6</u>	
Methylene chloride	15	Kerosene	59.04
Orthodichlorobenzene	10	Pine oil	37.27
2-Butoxyethanol	5	Ethanolamine	3.69
<u>Formulation 11</u>		<u>Formulation 7</u>	
Chlorinated solvents	>50	Kerosene	87.03
Cresols	>20	Perchloroethylene	9.28
Soaps	1-10	Butyl cellosolve	2.22
<u>Formulation 12</u>		Ethanolamine	1.48
Xylene	35	<u>Formulation 8</u>	
Acetone	35	Kerosene	75
Diacetone alcohol	12	Butyl cellosolve	25
<u>Formulation 13</u>		<u>Formulation 9</u>	
Aromatic hydrocarbons	71	Butyl cellosolve	100
Ketones	29		
<u>Formulation 14</u>			
Mixed xylenes	64.7		
Diacetone alcohol	32.4		

(continued)

**TABLE 3-1. FORMULATION PROFILES FOR AUTOMOTIVE FLUIDS USED IN  
VEHICLE REPAIR FACILITIES (Continued)**

Species Name	Percent by Weight	Species Name	Percent by Weight
<b>Engine/Parts Cleaners/Degreasers, continued</b>		<b>Engine/Parts Cleaners/Degreasers, continued</b>	
<u>Formulation 10</u>		<u>Formulation 18</u>	
Petroleum distillates	80	Aromatic hydrocarbons	78.2
Pine oil	10	Nonionic surface active agents	6.8
Ethoxylated linear alcohol	10		
<u>Formulation 11</u>		<u>Formulation 19</u>	
Water	52	Aliphatic chlorinated solvents	45-52
Petroleum distillates	40	Phenolic compounds	16-19
Anionic surfactant	6	Water	14-25
Sodium metasilicate	2	Vegetable fatty acid soap	12-14
		Synthetic wetting agents	<1
		Soluble chromates	0.2
<u>Formulation 12</u>		<b>Belt Dressings</b>	
Coal tar distillates	<65		
Aliphatic chlorinated solvents	<40		
<u>Formulation 13</u>		<u>Formulation 1</u>	
Petroleum distillates	<90	Petroleum derived resins	42.5
Vegetable fatty acid soap	>5	Chlorinated solvent as methylene chloride	25.5
Synthetic wetting agents	<5	Petroleum distillate	17
Coupler	<3		
<u>Formulation 14</u>		<u>Formulation 2</u>	
Petroleum distillates	95	Combined amount: solid petroleum fraction	
Nonionic surfactants	5	of an asphaltic nature, heavy bodied	
		mineral oil fraction of crude, and	
		unrefined wool grease	70
		Petroleum distillates	30
<u>Formulation 15</u>		<u>Formulation 3</u>	
Water	86	Combined amount: petroleum distillates,	
Anionic surfactant	6	solid petroleum fraction of an asphaltic	
Glycol ether	5	nature, heavy bodied mineral oil	
Alkaline detergent builders	3	fraction of crude, and unrefined wool	
		grease	75
<u>Formulation 16</u>		<b>Engine Starting Fluids</b>	
Petroleum hydrocarbon	93		
Nonyl phenyl polyethylene glycol ether	7		
<u>Formulation 17</u>		<u>Formulation 1</u>	
Petroleum distillates	70	Ethyl ether	100
Vegetable fatty acid soap	>5		
Synthetic wetting agents	<5		
Water	<5		
Coupler	<4		

(continued)

**TABLE 3-1. FORMULATION PROFILES FOR AUTOMOTIVE FLUIDS USED IN  
VEHICLE REPAIR FACILITIES (Continued)**

Species Name	Percent by Weight	Species Name	Percent by Weight
<b>Engine Starting Fluids, continued</b>		<b>Crankcase Additives</b>	
<u>Formulation 2</u>		<u>Formulation 1</u>	
Ethyl ether	>90	Petroleum distillate	<90
Combined amount: high molecular weight esters, mixture of oxygenated unsaponifiable hydrocarbons	<1	Alcohol	>5
		Ester	>5
<u>Formulation 3</u>		<b>Crankcase Additives, continued</b>	
Unrefined ether	63	<u>Formulation 2</u>	
Aliphatic hydrocarbon	36	Naphthenic oil	90
Mineral oil	1	Mixture of solvents:	10
<u>Formulation 4</u>		Butyl carbitol	
Unrefined ethyl ether	80-90	Butyl cellosolve	
		Methyl isobutyl carbinol	
		Diacetone alcohol	
		Cyclohexanone	
<b>Tire Repair Products</b>		<u>Formulation 3</u>	
<u>Formulation 1</u>		Mineral oil	>60
Combined amount: rubber solvent, 1,1,1-Trichloroethane	100	Combined amount: high molecular weight esters, mixture of oxygenated unsaponifiable hydrocarbons, alkyl aryl phosphate	>30
<u>Formulation 2</u>		<b>Fuel System Additives</b>	
Combined amount: rubber solvent, 1,1,1-Trichloroethane	80	<u>Formulation 1</u>	
<u>Formulation 3</u>		Methanol	100
Toluol	>80		
<b>Windshield De-icers</b>		<b>Radiator Additives</b>	
<u>Formulation 1</u>		<u>Formulation 1</u>	
Water	50	Water	64-67
Methanol	35	Mineral oil	25-27
Ethylene glycol	15	Surfactants and emulsifiers	8-9
<u>Formulation 2</u>		<u>Formulation 2</u>	
Methanol	45	Oxalic acid	95
Water	40	Clay	4
Ethylene glycol	15	Nonionic surfactants	1

(continued)



**TABLE 3-1. FORMULATION PROFILES FOR AUTOMOTIVE FLUIDS USED IN  
VEHICLE REPAIR FACILITIES (Continued)**

<b>Species Name</b>	<b>Percent by Weight</b>	<b>Species Name</b>	<b>Percent by Weight</b>
<b>Radiator Additives, continued</b>		<b>Radiator Additives, continued</b>	
<u><b>Formulation 3</b></u>		<u><b>Formulation 7</b></u>	
Sodium carbonate	95	Water	78
Clay	4	Sodium citrate	10
Nonionic surfactants	1	Anionic and nonionic surfactants	7
		Isopropyl alcohol	5
<u><b>Formulation 4</b></u>		<b>Transmission Additives</b>	
Water	84-85	<u><b>Formulation 1</b></u>	
Sodium citrate	7	Refined mineral oil	100
Anionic and nonionic surfactants	5	<u><b>Formulation 2</b></u>	
Isopropyl alcohol	3-4	Mineral oil	>60
		Combined amount: amine salt of an acid, chlorinated hydrocarbons	>30
<u><b>Formulation 5</b></u>			
Petroleum distillates	74		
n-Butyl alcohol	18		
Nonionic surfactants	8		
<u><b>Formulation 6</b></u>			
Mineral spirits	>50		
n-Butanol	>20		
Alkyl phenol ethoxylate	>10		

### 3.2.1 Maintenance

#### 3.2.1.1 *Antifreeze/Engine Coolants*

The automotive engine cooling system controls metal temperatures within safe limits by removing excess heat generated by the engine. In liquid-cooled engines (which account for essentially all motor vehicles currently in use), this is accomplished by circulating a fluid coolant through channels in the engine block and then through the radiator to release the block-generated heat to the atmosphere. The coolant temperature in an engine varies from ambient to hot and then cools again to ambient temperature. These cyclic temperature changes can affect the stability of protective films at metal surfaces and can cause corrosion. Coolant typically consists of a mixture of water and "antifreeze" product designed to depress the freezing point, elevate the boiling point, and prevent corrosion of metal surfaces within the engine, water pump and other parts of the liquid circulation system.

The corrosion protection afforded by antifreeze is dependent on the inhibitor effectiveness, the antifreeze concentration, and the quality of the water with which it is mixed. Various alcohols and glycols are effective freezing point depressants for water. However, because glycols, specifically ethylene glycol, raise the boiling point of water while alcohols lower it, alcohol antifreezes are no longer recommended by vehicle manufacturers. A minimum ethylene glycol concentration of 50 percent by volume is recommended to ensure freezing protection to -34°F (-37°C) and boiling protection to 227°F<sup>4</sup> (108°C).

According to the American Society for Testing and Materials (ASTM), car manufacturers recommend that the factory-filled coolant be used for one to two years because longer periods would show appreciable loss of freezing protection, loss of inhibitor reserve, and rust in solution.<sup>5</sup> Major antifreeze manufacturers recommend that their products be used for one year, preferably being replaced with fresh antifreeze each fall. A 1981 survey of antifreeze concluded that products packaged by original manufacturers accounted for 63 percent of total sales, secondary packaging for consumer sales accounted for 22 percent, and commercial and bulk users (*i.e.*, service stations and repair facilities) accounted for 5.5 percent of the sales of engine coolant.

The remainder (less than 10 percent) consisted of sales to original equipment manufacturers and the government.<sup>6</sup>

Generic components of antifreeze products include solvents, freezing point depressants, fluidifiers, and corrosion inhibitors/alkaline preservers. In current formulations, ethylene glycol serves the function of solvent, freezing point depressant and fluidifier. Concentrations of ethylene glycol in current formulations are more than 90 percent and commonly around 95 percent. About 3 percent water is typically included as a fluidifier. Corrosion inhibitors/alkaline preservers represent 2.5 to 4.5 percent of typical formulations and may include borax, caustic soda, sodium mercaptobenzothiazole, arsenites, or nitrates.

Air emissions of ethylene glycol can occur as evaporation of leaked or improperly disposed of coolant removed during servicing or regular replacement of spent coolant.

#### **3.2.1.2 *Brake Fluids***

Brake fluid is used as a pneumatic fluid to deliver pressure from the master brake cylinder to slave cylinders which apply brake shoes or pads to the drums or discs at each wheel. It also acts as a lubricant for the brake cylinder and seals.

Automobile manufacturers recommend that brake fluid should be changed "as needed." Some brake fluid manufacturers recommend that the brake fluid should be changed once a year, but to change it properly, the wheel cylinder should be taken apart, the whole system should be flushed with clean fluid, and the cylinder should be rebuilt. Due to the cost of this operation, it is common practice to add only enough fluid to raise the level in the master cylinder and replace what is lost due to leakage.<sup>7</sup> Thus, it is typical for brake fluid to be replaced only when major brake system maintenance (replacement or rebuilding of master or slave cylinders) is performed.

The U.S. Department of Transportation (DOT) has set standards and designations for brake fluids. DOT-2 is the designation for standard drum fluid. Fluids equally suited for both drum and disc systems are labeled DOT-3. An even higher-rated fluid (DOT-4) is for heavy-duty disc

applications.<sup>7</sup> Published formulations for brake fluids are typically based on a mixture of polyglycol ethers (70 to 80 percent), with the remainder being either polyalkylene glycol, propylene glycol, polypropylene glycol or a combination of these glycols and a small amount of additives (inhibitors, antioxidants or dyes).<sup>1</sup> A DOT-5 designation has been created for silicone-based brake fluids, which can prevent water absorption and provide a higher boiling point, but which may damage brake seals.<sup>8</sup> No published formulations have been located for silicone-based brake fluids.

Brake fluids may volatilize when exposed to the atmosphere following leakage or servicing and upon improper disposal.

#### **3.2.1.3 *Crankcase Oils***

Crankcase oils are well-fractionated and refined cuts from paraffin-base, mixed base or cycloparaffinic crude oils. The best grades of oils are derived from paraffinic or solvent-refined mixed base crudes. Crank case oils often contain one to two percent zincdithiophosphate or terpene.

Emissions occur with refilling and replacing, and through leaks, improper disposal and standing losses. These emissions are expected to be relatively low as compared to the other product categories due to the low volatility of crankcase oils.

#### **3.2.1.4 *Lubricants and Silicones***

Transmission and axle lubricants are generally well-refined heavy lubricating oils containing film-strength improvers or extreme pressure additives. They may contain between 0.5 and 1.0 percent phenolic and aromatic antioxidants. Antifriction bearing and chassis greases are usually derived from medium and high viscosity, well-refined lubrication oils, gelled by the addition of metallic soaps or other thickeners.<sup>3</sup>

Activities in this category are limited to lubrication or greasing. Lubrication is the application of a substance of low viscosity between two adjacent solid surfaces (one of which is in motion) to reduce friction, heat and wear between the surfaces.

A *lubricating grease* is a mixture of a mineral oil or oils with one or more soaps. The most common soaps are those of sodium, calcium, barium, aluminum, lead, lithium, potassium and zinc. Oils thickened with residuum, petrolatum or wax may be called greases. Some form of graphite may be added. Greases range in consistency from thin liquids to solid blocks and in color from transparent to black. Grease specifications are determined by the speed, load, temperature, environment and metals in the desired application.<sup>3,9</sup>

*Synthetic lubricants* are any of a number of organic fluids having specialized and effective properties that are required in cases where petroleum-derived lubricants are inadequate. Each type has at least one property not found in conventional lubricants. The major types are polyglycols (hydraulic and brake fluids), phosphate esters (fire-resistant), dibasic acid esters (aircraft turbine engines), chlorofluorocarbons (aerospace), silicone oils and greases (electric motors, antifriction bearings), silicate esters (heat transfer agents and hydraulic fluids), neopentyl polyol esters (turbine engines) and polyphenyl ethers (excellent heat and oxidation resistance, but poor low temperature performance).<sup>10</sup>

Specific automotive lubricant product types that do fall under the scope of this effort include general-purpose, dry film-type and silicone-based lubricant formulations, as well as rust preventive/remover, penetrant and nut-loosening products that often also function as lubricants. Published formulations for these products typically contain either 90 to 100 percent mineral oil or better than 65 percent mineral spirits or naphthas, with additional petroleum-base oils, graphite-containing components and proprietary ingredients. Some of these products also include chlorinated hydrocarbons, oxygenated organic acids and tricresol phosphate. There are a variety of both liquid and spray formulations, with hydrocarbons frequently mentioned as a propellant. One silicone lubricant spray is an exception to the mineral spirit/naphtha formulation mentioned above, with the liquid portion consisting of 94 percent trichloroethane (this percentage excludes the hydrocarbon propellant).

Air emissions from these types of products would include immediate or near-term volatilization of propellants and lighter solvents upon application to exposed parts, followed by slower evaporation of heavier constituents.

#### **3.2.1.5 *Steering Fluids***

Information on steering fluids was not readily available. However, in most vehicles transmission fluid may be used as a substitute.

#### **3.2.1.6 *Transmission Fluids***

Transmission fluids are used to cool and lubricate the gears and housing of automatic transmissions, and to protect against rust and corrosion of internal transmission parts. They are also used in manual transmissions, transaxles and power steering systems, although some specific makes of power steering systems are reported to require a specially-manufactured product.<sup>7,11</sup> Published formulations consist of over 90 percent mineral oil with the remainder a mixture of primarily inorganic additives.<sup>1</sup> It is recommended that the automatic transmission fluid and filter be replaced every 24,000 miles or two years.<sup>8</sup> Air emissions from transmission fluid may occur upon leakage and disposal, and may be fairly gradual due to the low volatility of mineral oil.

#### **3.2.1.7 *Windshield Washer Fluids***

The primary components of windshield washer fluids are alcohols and water. The purpose of alcohol in windshield washer fluid is to provide freeze protection for the fluid while in the vehicle windshield water reservoir, to avoid freezing of the fluid on the windshield while in use, and to assist in defrosting or deicing the exterior surface of the automotive windshield. The product is typically used full strength in the winter and diluted 50 percent by volume with water in the summer. The variability of use of windshield washer antifreeze precludes quantification of its operational lifetime. The amount used is entirely dependent upon climatic conditions and driver discretion. Some concentrated products are also labeled for direct use as windshield cleaners to be applied by hand.

Methanol, or occasionally isopropanol, is the basic ingredient acting as freezing point depressant in windshield washer fluid. A small volume of soluble inhibitors may be included (*i.e.*, less than 1 percent potassium phosphate) with the remainder being water, which acts as a solvent. Windshield washer antifreeze concentrates, generally requiring some dilution by the consumer, are packaged in metal cans or plastic containers. Pre-mix solutions are ready-to-use solutions requiring little or no dilution, and come in plastic containers. A 1974 survey of windshield washer fluids sales showed that pre-mix accounted for about 87 percent of national windshield washer sales volume while concentrates accounted for about 13 percent.<sup>12</sup>

A California Air Resources Board (CARB) shelf survey found pre-mix formulations with contents of 23 to 40 percent VOC by weight. Concentrated formulations were found to range from 35 to 80 percent.<sup>13</sup> Other published formulations of windshield washer antifreeze include 80 to 90 percent methanol for concentrates and 40 to 45 percent methanol for pre-mix. The balance is water (more than 10 percent for concentrates and more than 50 percent for pre-mix) and wetting agents and other additives such as mercapto ethoxylate, ammonia, or detergents (less than 1 percent). Some formulations using isopropanol are also mentioned briefly in the literature, but no further information is available on this alternative approach.<sup>1,13</sup>

The methanol in windshield washer fluid is the primary agent that prevents freezing. Thus, the percentage required varies with the temperatures that the vehicle is exposed to, which is a function of the region and the season. A concentration of 35 percent methanol will prevent freezing down to -25°F, and 10 percent methanol will prevent freezing down to 20°F.<sup>13</sup>

### **3.2.2 Cleaning**

#### **3.2.2.1 Brake Cleaners**

Brake cleaners are liquid or aerosol products used during servicing to remove contaminants from the mechanical and working surfaces of brakes. For conventional brakes, parts that can be cleaned include drums, linings, shoes, cylinders and spring sets. On disc brakes, the caliper units,

pads, discs and related parts can be cleaned. The product is applied liberally and then wiped off or allowed to air-dry.<sup>11</sup>

The major function of these products is to clean the desired parts without leaving any residue which might interfere with brake function. Published formulations mention perchloroethylene as the main ingredient of one brake cleaner and a liquid version consisting entirely of "aliphatic chlorinated hydrocarbon" (which may also be perchloroethylene). The volatile portion of these products will be released when the product is applied or shortly thereafter, with a smaller amount gradually leaving any sludge-type material removed from the parts.

### **3.2.2.2 Carburetor and Choke Cleaners**

Carburetor/choke/fuel injection system cleaners include a variety of specialized products designed for removal of dirt, gummy deposits, surface glaze and other contaminants from the exterior and interior working parts and passages in these three types of engine parts. Although they are labeled for single uses or in combinations (*i.e.*, "carburetor cleaner," "choke cleaner," "carburetor/choke cleaner," "carburetor and fuel system cleaner," etc.), the published formulations for these products are similar in that they consist entirely of various mixtures of VOCs. Other components such as water or detergents are inappropriate since these products are sprayed directly into the fuel/air system and any components that would leave deposits or condensation in the system must be avoided.

Labels on these products give instructions for the different types of uses as follows. Heavy spraying, soaking, and rinsing can be used for external cleaning of the carburetor linkages and automatic choke as well as the outside of the carburetor itself. Internal cleaning of the carburetor involves removing the air filter while the engine is running and spraying bursts of the product on the carburetor valve and the throttle plate as well as down the carburetor throat. The engine is revved to avoid stalling and to enhance air flow through the carburetor, which flushes loosened deposits through the system and into the cylinders to be burned. The engine should be run until it runs smoothly after this procedure. In addition, these products can be used to clean the positive crankcase ventilation (PCV) valve. This procedure involves disconnecting the PCV



valve on the crankcase side, spraying into the exposed valve, allowing it to soak and then starting the engine and repeating the spraying, after which the engine is stopped and the valve reconnected.<sup>11</sup> Procedures for using these products to clean fuel injectors have not been located.

Simpler products in this category consist of a majority of aromatic hydrocarbons (over 65 percent) with one additional ingredient (alcohol or ketone). Many other formulations have xylene as the largest-percentage component (35 to 65 percent) with alcohol or a combination of hydrocarbon and chlorinated solvents, ranging from glycol ethers to methylene chloride, orthodichlorobenzene, 2-butoxyethanol or diacetone alcohol and acetone. There are also some products that do not follow this basic formulation, including one based on mineral oil (65 percent) with the remainder a mixture of various organics (esters, hydrocarbons and solvents), and another based on equal amounts of xylenes and polybutene amine inhibitor.

Direct use of these products on external working parts is expected to result in immediate and disposal-type emissions similar to degreasers. Spraying into the carburetor will result in some direct emissions, but the fate of these products as they pass through the engine is not documented. If they have a significant effect on completeness of combustion, some components may not be burned or other compounds of concern may be formed.

### **3.2.2.3 *Engine/Parts Cleaners/Degreasers***

Cleaning vehicle engines involves a variety of distinct cleaning functions and several different types of products. For the purposes of this discussion, they will be divided into engine cleaner/degreasers, which are generally for use on external surfaces, and parts cleaners and related products which are used on internal surfaces and disassembled parts. For most of these products, emissions will occur as the products are applied, allowed to soak and removed. Use on a hot engine will encourage volatilization. In addition, components which are wiped off in sludge form or rinsed off with water may continue to volatilize from those media over time. Emissions from bucket-type carburetor cleaners would be an exception to this general pattern, and may include volatilization of solvents carried out of the bucket by cleaned parts, gradual evaporation through the water seal, and losses when the product is disposed of.

**3.2.2.3.1 Engine Cleaners/Degreasers** The general terms "engine or motor cleaner" and "degreaser" refer to products designed to remove grease, grime, oil and other contaminants from the external surfaces of engines and other mechanical parts. These products are generally used prior to or as part of a maintenance procedure, to provide a clean work area, or to clean parts to enhance their functioning. Engines and parts may also be cleaned for aesthetic purposes, as part of overall vehicle detailing, and thus these products might also be considered detailing products as well as maintenance and repair products.

These products may also be labeled as "engine shampoo," "motor wash," "engine scour," "grease eater" or other similar names. It should be noted that the term "degreaser" can be somewhat confusing in some contexts, since it is also used for organic solvent cleaners such as open-top vapor degreasers, which are not a consumer product but pieces of capital equipment used by industry and some large repair facilities to clean metal and other parts with specially formulated chlorinated solvent vapors, sprays or baths. Industrial degreasers are addressed by EPA via other regulatory programs.

Most of these products are aerosols or pump sprays which are sprayed on or foamed on a hot or cold engine, allowed to soak for 10 or 15 minutes and removed with a water spray. The engine is then started and allowed to idle for a period to ensure thorough drying. This process may be repeated if necessary.

Almost all published formulations for engine cleaner/degreasers are predominantly petroleum distillates/hydrocarbon solvent (80 to 95 percent), with additional volatile components such as pine oil, alcohols, glycol ether and chlorinated solvents which sometimes constitute essentially the rest of the product. Many products also include some surfactant, soap, wetting agent or water (trace to 5 percent). One of these typical products is labeled specifically for "motorcycle degreasing." There are some products designated "bulk" or "concentrated" which have lower solvent contents and are designed to be reduced with hydrocarbon solvents such as kerosene (one formulation cited a typical 1:9 dilution by volume).

There are also some products labeled as automotive cleaner/degreasers which contain considerably more water than the majority of these products (from 52 percent in a product also containing 40 percent petroleum distillates, to 86 percent in a product with 5 percent glycol ether and the remainder surfactants and detergent builders).<sup>1</sup> Finally, there are some newer products which are labeled as using d-limonene (a hydrocarbon chemical occurring in citrus oils and other botanical sources) as a cleaning agent, and not containing the typical ingredients of the other degreaser formulations previously discussed. These products are advertised as "environmentally safe."<sup>11</sup>

**3.2.2.3.2 *Parts Cleaners*** Other products in this category include several separate types of "parts cleaners." Depending on their formulations, these products may be used to remove grease and oil, carbon and other baked-on surface coatings, other contaminants and even paints. One product is a liquid that is brushed on small mechanical parts, and a similar product is an aerosol made to be sprayed on small parts. A bucket-type, solvent-based product, often known as a "carburetor cleaner," is formulated for immersing carburetors and other small disassembled parts. (These are not to be confused with spray-type products discussed in the following subheading which are also termed "carburetor cleaners" or "carburetor/choke cleaners.")

One published formulation for a brush-on parts cleaner includes over 60 percent petroleum distillates, less than 25 percent chlorinated solvents, over 5 percent phenolic compounds and additional soap and wetting agents. There are also several liquid degreaser formulations which are similar to the typical aerosol/spray formulations previously described, but which apparently could be used as brush-on cleaners or as fillers for spray bottles. One aerosol product intended for cleaning motorcycle plugs, points and chains, contains only chlorinated hydrocarbons. These appear to be more specialized, less common types of parts cleaners.

The bucket-type parts cleaners are generally di-phase (two layer) liquids which consist of a combination of chlorinated and non-chlorinated hydrocarbon solvents, with cresols/cresylic acid, water and soaps or other cleaning agents. The latter ingredients form a layer which floats on top of the solvent, reducing evaporation.

There are also other liquid products designed for use in parts cleaning tanks and a variety of tank/spray combinations which are used in commercial and industrial parts cleaning. The latter typically involves a commercial rental agreement under which a vendor supplies both the equipment and solvent, retrieving and reclaiming used solvent on a regular schedule. This type of product is not covered in this review, both because it is not detailed in the consumer/commercial literature and because it is a basically different product from the other products discussed. Only one published formulation which specified use in a parts-cleaning tank was located, containing over 50 percent aliphatic chlorinated solvents, almost 20 percent phenolics and the remainder water, soap and wetting agents.

### **3.2.3 Specialty**

#### **3.2.3.1 *Belt Dressings***

Belt dressings are aerosol or liquid products which are sprayed on engine drive belts to clean, lubricate and protect them, as well as to reduce noise such as squealing from belt/wheel contact points. Published formulations for aerosol products contain a combination of petroleum distillate and methylene chloride (17 and 25 percent, respectively, in one product), with the remainder consisting of "petroleum derived resins" or a combination of solid asphaltic petroleum fraction, mineral oil and wool grease. The one published formulation for a liquid product consists of 30 percent petroleum distillates and the same asphaltic/mineral oil/wool grease combination. The volatile ingredients will essentially evaporate upon use of the product.

#### **3.2.3.2 *Engine Starting Fluids***

Engine starting fluids are aerosol products which are sprayed into the carburetor to assist in starting engines which may be balky due to cold, dampness or undermaintenance. They typically consist of a large proportion of ethyl ether (80 to over 90 percent) with the remainder being other petroleum hydrocarbons. One published formulation contains only 63 percent ethyl ether, with the remainder being aliphatic hydrocarbons. If used correctly, most of the product may be drawn into the cylinders and combusted, but documentation of the fate of these products has not been

located. Two published formulations mentioned carbon dioxide as the propellant, but propellants are otherwise not specified.

### **3.2.3.3 *Tire Repair Products***

Tire repair products that have been identified include tire cement, tire sealant and tire inflators. Tire cements are used to glue in plugs and patches which are applied to tires or inner tubes. Available formulations include a large solvent content consisting of a combination of "rubber solvent" (probably naphtha) and 1,1,1-trichloroethane. These solvents would be emitted upon use.

Separate sealant and inflator products were not found, but combination "puncture seal" products have been located, consisting of an aerosol can with an attachment which fits a tire valve in the place of the regular spray valve. These products are made to inflate and temporarily seal tires with small punctures. When attached to a flat tire with a sufficiently small puncture, a sealant compound and pressurized gas are introduced into the tire. The sealant fills the leaking hole and the gas partially inflates the tire (to a pressure of about 20 psi). The vehicle should be driven slowly for several miles to distribute the remainder of the sealant. At least some products apparently use a hydrocarbon as the propellant/inflator gas, since the labels specify that the tire will be filled with an extremely flammable gas and care should be taken to avoid explosions on discharge of the inflator gas.<sup>11</sup> Only one formulation for a tire sealant was located, consisting of unspecified quantities of urethane, toluene, isopropyl alcohol, isopropyl acetate, tergitol (polyethylene glycol) and dichlorodifluoromethane (a chlorofluorocarbon which may no longer be used in this application). Solvents and propellant/inflators from these products would be emitted upon deflation of the repaired tire or during attempted inflation of a tire with too big a hole for the product to seal.

### **3.2.3.4 *Windshield Deicers***

Windshield deicers are used to remove frost or ice from windshields. They come in squeeze bottles or as manual or aerosol spray products. The active ingredient in most published

formulations is methanol, ranging from 35 to 70 percent, depending on the product (exclusive of propellant). Additional ingredients include up to 50 percent water and up to 15 percent ethylene glycol or a mixture of glycols. One published formulation uses isopropanol as the active ingredient.

When sprayed on, the methanol soaks into the frozen material and rapidly lowers the melting point of the ice to allow it to become a soft, slush-like mixture even at below-freezing temperatures. This mixture is then removed with windshield wipers or a windshield-cleaning tool.

### **3.2.4 Additives**

#### **3.2.4.1 *Crankcase Additives***

Motor flush/crankcase cleaner products are liquids which are added to crankcase oil just before an oil change and circulated briefly through the crankcase to remove accumulated deposits prior to draining and replacing the oil and filter. Published formulations consist of a dominant hydrocarbon ("naphthenic oil" or petroleum distillates, about 90 percent), with the remainder being a mixture of other solvents (such as glycol ethers and ketones, alcohol and esters and sometimes a combination of five organic solvents). These more volatile ingredients are likely to volatilize during removal and disposal of the old oil.

#### **3.2.4.2 *Fuel System Additives***

Fuel system antifreeze includes products sold for two related uses: gas-line antifreeze and fuel tank drier. The purpose of these products is to absorb condensation or accidentally-introduced water from the gasoline in the fuel tank, fuel lines and carburetor. This can prevent freezing of gas lines in cold weather, aid engine startup in freezing temperatures, help prevent stalling before the engine warms up and also prevent corrosion of the fuel tank and system due to the presence of water. The recommended concentration is 1 pint to 10 gallons of gasoline.

Generic components of a gas-line antifreeze/fuel tank drier include solvents and freezing point depressants. Published formulations consist almost exclusively of 100 percent methanol, which functions both as the solvent and the freezing point depressant. Some other unverified formulations include aliphatic alcohols, commonly methyl or isopropyl, with concentrations ranging from 30 to 90 percent, and solvents, commonly toluene, acetone, xylene, and isopropanol with concentrations ranging from 20 to 40 percent.

These products essentially become part of the fuel in the gas tank and are burned with the fuel. There is some possibility that more-volatile ingredients could evaporate from the fuel into the vapor space of the tank and then be preferentially emitted upon refueling. However, this has not been documented and it is not clear that these products actually contain anything other than methanol, which is less volatile than gasoline.

#### **3.2.4.3 Radiator Additives**

Radiator compounds and lubricants are products that are added to the vehicle's radiator fluid to perform a variety of functions related to the components of the cooling system. These products are different from the radiator cleaners discussed below in that they are meant to remain in the engine until the next regular change of coolant. Specific types include stop-leak products (for sealing small leaks in the radiator), anti-rust compounds (to stop or prevent corrosion in the radiator and other cooling system parts) and water pump lubricants. An individual product can often accomplish more than one of these functions. Several of these products appear to contain no volatile compounds, consisting of water, mineral oil, sealers and detergent-type products. Some other formulations contain compounds that may be of concern, including unspecified percentages of aromatic hydrocarbons/petroleum distillates.

Volatile components of these products would be emitted upon application to the radiator or as the coolant leaves the engine, either as leaks or upon waste disposal.

Radiator cleaners are products that are used on a one-time basis to clean the internal portions of a vehicle's cooling system, removing sludge, rust and other deposits that may form in the system.

Also known as "radiator flush," they are liquids which are added to the cooling system (by removing a small amount of coolant and replacing it with the product) and allowed to circulate throughout the system for about 10 minutes prior to complete draining and replacement of the coolant. These products are generally more concentrated than the radiator compounds discussed previously, and contain ingredients that would not be appropriate for longer-term use in the cooling system.

Published radiator cleaner formulations are divided between aqueous products which contain no volatile or a small percentage of isopropanol, and solvent-based products which can contain 80 to 90 percent volatile compounds (mostly mineral spirits/petroleum distillates). Volatile components of these products would be emitted as the coolant is removed from the engine or during proper or improper waste disposal.

#### **3.2.4.4 *Transmission Additives***

Transmission additives include sealer/leak-stop products, conditioners, treatments and flush-type products. Partial formulations have been located for all but the flush-type products, and indicate that while some of these products consist largely of mineral oil, they may contain other petroleum distillates, chlorinated hydrocarbons, and xylene, as well as phosphates, sulfonate and inorganics. The more volatile ingredients may volatilize quickly upon leakage or disposal of the transmission fluid, while the mineral oil will evaporate more slowly.

### **3.3 POLLUTANTS EMITTED FROM EACH IDENTIFIED PROCESS**

Reviewing the available product formulation data for automotive products resulted in a large database of compounds which have been mentioned as occurring in specific product types. This information is presented in Table 3-2. Table 3-2 provides a comprehensive overview of the chemicals found in automotive consumer products which have been identified as being of concern due to their apparent volatility and either their potential to participate in atmospheric photochemical reactions or potential toxic/hazardous properties. Table 3-2 also provides the Chemical Abstract Service (CAS) Registry Number and the American Conference of



**TABLE 3-2. VOLATILE ORGANIC COMPOUNDS IN AUTOMOTIVE PRODUCTS USED IN VEHICLE REPAIR FACILITIES**

PRODUCT COMPONENTS	Maintenance							Cleaning			Speciality				Additives				CAS	CAA	ACGIH	HTAHCAC
	A	B	C	L	S	T	W	B	C	E	B	E	T	W	C	F	R	T				
Acetone								X											67641		1780	X
Aliphatic Chlorinated Solvents	X							X	X													
Aliphatic Hydrocarbons				X					X		X											
Aliphatic Naptha				X																		
Aromatic Hydrocarbons									X													
Butyl Benzyl Phthalate																			85687			
Butyl Carbitol															X				71410			
Butyl Cellosolve				X				X							X				111762			X
Chlorinated Aromatic Hydrocarbon				X																		
Chlorinated Hydrocarbons								X	X								X					
Chlorinated Solvents	X			X																		
Cresol	X																		1319773	X	22	X
Cyclohexanone															X				108941		100	X
Diacetone Alcohol								X							X				123422		238	X
Dichlorodifluoromethane												X							75718		4950	X
Ethanol															X				64175		1880	X
Ethyl Ether		X									X								60297		1210	X
Ethyl Ether of Diethylene Glycol		X																				
Ethyl Ether of Ethylene Glycol		X																				
Ethylene Dichloride	X																		107062	X	40	X
Ethylene Glycol	X	X		X			X		X			X				X	X		107211	X	127	X
Formaldehyde																			50000	X	0.21	X
Glycol Ether		X						X	X						X					X	**	
Graphite in Aliphatic Naptha				X																		
Graphite in Mineral Oils				X																		
Hydrocarbons				X				X	X													
Hydrocarbon Radicals				X												X	X					
Isopropanol				X			X	X	X		X	X				X			67630		985	X
Isopropyl Acetate											X								108214		1040	X
Kerosene								X											8008206			X
Ketones															X							
Methanol							X					X			X				67561	X	262	X

Continued

**TABLE 3-2. VOLATILE ORGANIC COMPOUNDS IN AUTOMOTIVE PRODUCTS USED IN VEHICLE REPAIR FACILITIES (Continued)**

PRODUCT COMPONENTS	Maintenance						Cleaning			Speciality				Additives				CAS	CAA	ACGIH	HTAHCAC
	A	B	C	L	S	T	W	R	C	E	B	E	T	W	C	F	R	T			
Methyl Ethyl Ketone Peroxide																		1338234		1.5	X
Methyl Isobutyl Carbinol															X			108112		104	X
Methylene Chloride								X			X							75092	X	174	X
Mineral Spirits	X			X				X								X		8030306			
Morpholine																X		110918		71	X
Naphthenic Oil															X						
N-Butyl Alcohol				X												X		71363		152	X
Orthodichlorobenzene	X							X										95501			
Perchloroethylene								X										127184	X	339	X
Petroleum Distillates	X			X				X	X						X	X	X	8002059		890	
Petroleum Hydrocarbons	X			X					X		X										
Petroleum Oils				X																	
Petroleum Solvents									X												
Pine Oil									X									8002093			
Polyethylene Glycol													X			X		25322683			
Polypropylene Glycol		X																25322694			
Propane				X				X			X							74986			X
Propylene Glycol		X																57566			
Rubber Solvents													X								
Toluene													X					108883	X	377	X
Trichloroethane				X									X					71556	X	1910	X
Tricresyl Phosphate				X														78308		0.1	X
Urethan													X					51796	X		X
Xylene								X	X								X	1330207	X	434	X

Note: Descriptions of data items on this table are provided on the following page

## NOTES FOR TABLE 3-2

### Maintenance

- A. Antifreeze/engine coolants
- B. Brake fluids
- C. Crankcase oils
- L. Lubricants & silicones
- S. Steering fluids
- T. Transmission fluids
- W. Windshield washer fluids

### Cleaning

- B. Brake cleaners
- C. Carburetor and choke cleaners
- E. Engine/parts cleaners/degreasers

### Specialty

- B. Belt dressings
- E. Engine starting fluids
- T. Tire repair products
- W. Windshield deicers

### Additives

- C. Crankcase
- F. Fuel line
- R. Radiator
- T. Transmission

**CAS:** Chemical Abstract Service Registry number

**CAA:** These chemicals are listed in the 1990 Clean Air Act Amendments (Title III, Sec. 301) as hazardous air pollutants

**ACGIH:** American Conference of Governmental Industrial Hygienists, Time-Weighted Average (TWA) limits in mg/m<sup>3</sup> of air

**HTAHCAC:** These chemicals are listed in the Handbook of Toxic and Hazardous Chemicals and Carcinogens

See references and further discussion in text.

Governmental Industrial Hygienists' (ACGIH) Time-Weighted Average (TWA) workplace air concentration standard for the listed compounds. An "X" indicates whether the compound appears on the list of HAPs in Title III of the CAAA and/or in the *Handbook of Toxic and Hazardous Chemicals and Carcinogens* (HTAHCAC).<sup>14</sup>

ACGIH Threshold Limit Values (TLV) refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effect. The TWA is the weighted average concentration for a normal 8-hour workday and a 40-hour workweek to which nearly all workers may be repeatedly exposed without adverse effect. TWAs permit excursions above the TLV provided they are compensated by equivalent excursions below the TLV-TWA during the workday.<sup>15</sup>

The *Handbook of Toxic and Hazardous Chemicals and Carcinogens* is a document which includes EPA Priority Toxic Pollutants, substances with standards adopted by ACGIH, all substances considered in the National Institute for Occupational Safety and Health's Standards Completion Program, and most of the chemicals classified by EPA as hazardous wastes or hazardous substances.<sup>14</sup> The Handbook also includes chemicals which are listed as carcinogens, compounds with dangerous properties, and compounds of concern in industrial/workplace settings.

### 3.4 ESTIMATE OF THE POLLUTANT LEVELS

AP-42 contains national evaporative emissions and per capita emission factors for commercial/consumer solvent use.<sup>16</sup> The only automotive products categorized however, is windshield washing. The windshield washing per capita emission factor listed is 0.63 lb/yr. Use of this factor and assuming an annual growth rate of 1.8 percent results in a VOC emissions national total of 81,900 TPY for calendar year 1990. Other estimates of VOC emissions from the use of consumer products have been reported in References 17 and 18. National VOC estimates for solvents used in automotive repair in 1986 are 37,143 tons per year.<sup>17</sup> In a study of New York State emissions, the total annual tons of VOC for 49 consumer product categories is estimated as 26,979.<sup>19</sup> Of this total, 2,766 tons are attributed to the following seven automotive categories: auto antifreeze, carburetor and choke cleaners, brake cleaners, engine degreasers, engine starting

fluids, lubricants and silicones, and windshield deicers. In addition to these data, the California Air Resources Board has an extensive program underway to reduce VOC emission from consumer products. This effort includes data on average annual day VOC emissions from aerosol consumer products in California.<sup>20</sup> For the category automotive and industrial consumer products, CARB estimates a total of 3.96 VOC tons per day of propellant emissions and 27.37 tons per day of solvent emissions for a combined total of 31.33 tons per day.

Automotive product emissions may be apportioned on the basis of automobile-related activity.<sup>17</sup> There were approximately 135,671,000 automobiles and light-duty trucks registered in the United States in 1986. Per-vehicle emission factors were derived by dividing total VOC emissions by this number. National 1986 VOC emissions and per-vehicle emission factors are listed in Table 3-3.

**TABLE 3-3. VOC EMISSION FACTORS FOR AUTOMOTIVE PRODUCTS<sup>16</sup>**

<b>VOC Product</b>	<b>Nation VOC Emissions (tons/year)</b>	<b>LB/YR VOC Per Vehicle Registered</b>	<b>LB/YR Per Capita</b>
Carburetor and Choke Cleaners	13,093	0.193	0.109
Brake Cleaners	9,824	0.145	0.082
Engine Degreasers	5,192	0.077	0.043
Engine Starting Fluid	9,034	0.133	0.075

### **3.5 SOURCE ACTIVITY DATA AVAILABILITY**

The CAAA require EPA to prepare a report to Congress on VOC in consumer and commercial products and to promulgate regulations that would reduce VOC emissions from these products. EPA is currently working on the automotive consumer products portion of this report, which will be published in November, 1993. The Office of Air Quality Planning and Standards is developing a survey of consumer product manufacturers nationwide. This will eventually provide a comprehensive inventory of VOC in consumer and commercial products and activities. The following reports include information on comprehensive inventories of VOC from consumer and commercial products.

- *Photochemically Reactive Organic Compounds Emissions from Consumer and Commercial Products*<sup>19</sup>
- *Compilation and Speciation of National Emissions Factor for Consumer/Commercial Solvent Use*<sup>17</sup>
- *Analysis of Regulatory Alternatives for Controlling Volatile Organic Compounds (VOC) Emissions from Consumer and Commercial Products in the New York City Metropolitan Area (NYCMA)*<sup>21</sup>
- *Expansion of the New York Study: Evaluation of VOC Emission Reduction Alternatives from Selected Consumer and Commercial Products*<sup>22</sup>

Marketing data for automotive repair products, as well as many other categories, may be obtained from Mediamark Research Incorporated (MRI) and Simmons Market Research Bureau. However, these sources are based on consumer surveys of brands that the consumers report using and not on actual sales data.<sup>18</sup> Therefore it may not be an accurate representation of vehicle repair facilities' use of automotive fluids.

Sales volume data may be obtained from Nielsen Marketing Research (NMR) and the Selling Area Marketing Index (SAMI). NMR uses electronic checkout scanner data, while SAMI is based on warehouse withdrawal data. Although neither of these services provide data for the non-retail sector of the market, a possible source for such information may be Technomics, Incorporated in Chicago. Technomics reportedly estimates institutional usage of products from surveys of major buyers.<sup>18</sup>

Data on automotive fluid use can be derived from vehicular use data, such as those provided by references 23 and 24. In addition, statistics on the total number of registered vehicles by county are available from state Department of Motor Vehicle records. In 1990, approximately 143,550,000 passenger cars were registered in the United States.<sup>24</sup> Total 1990 vehicle miles traveled (VMT) for cars, in millions of vehicle-miles, were 151,370, for buses 5,728, and 616,831 for trucks.<sup>24</sup>

It is also necessary to determine usage rates for each automotive fluid per automobile. Simmons Market Research Bureau, Inc. reports that 34.4 percent of the U.S. population changes radiator coolant during any one-year period.<sup>25</sup> Two to four gallons of coolant are used per application.<sup>24</sup> The quantity of fluid used per application depends on the type of fluid. One and a half to three quarts of windshield washer fluid is used per application; product labels specify one pint of gas-line antifreeze per application.<sup>26</sup> For the 1 to 15 percent of car owners using gas-line antifreeze, gas-line antifreeze may be applied once every 8 to 10 gallons, 2 to 4 fill-ups or 1,000 miles.<sup>24</sup>

Alternatively, total usage can be calculated at a national level and then scaled to a per capita level. C.H. Kline reported 1.72 million gallons of gas-line antifreeze used or sold in 1981, extrapolating from 1974 data and assuming a two percent annual growth rate.<sup>27</sup> Similarly, C.H. Kline reported 18.4 million gallons of windshield washer fluid sold in 1981.<sup>27</sup> In 1988, Simmons reported that 86,698,000 gallons of antifreeze and 26,788,000 cans of gasoline additives had been purchased by consumers in the United States during the preceding year. Simmons also reported that 102,353,000 quarts of crankcase oil had been purchased during the preceding six months.<sup>28</sup> Specific data on use of the other automotive repair fluids are not readily available.

Emissions per volume of automotive fluid must be determined from field experiments, since few emission factors have yet been developed. EPA's *AP-42* provides a per capita emission factor estimate for VOC derived from windshield washing fluid.<sup>16</sup>

### **3.6 LEVEL OF DETAIL REQUIRED BY USERS**

The following data items are needed by users to estimate emissions from the use of automotive products during vehicle repair.

- County, state or other geographic area information: number of registered vehicles and population
- Emissions per volume of fluid used by fluid type
- Fluid use per vehicle by fluid type
- Service stations per geographic area

- Vehicles serviced per station
- Class of vehicle serviced

### **3.7 REGIONAL, SEASONAL OR OTHER TEMPORAL CHARACTERISTICS**

Two of the product categories considered, windshield deicers and fuel system additives, are predominantly used in the winter and are therefore of less concern than the other categories, since winter is not an ozone season. Antifreeze is somewhat of a misnomer due to its alternative use as an antiboil agent. Because of this, engine coolants will show regional variation based on climatic differences, as well as a seasonal inclination toward summer and winter. All of the product categories will be used principally during the standard business week in accordance with the hours of operation for the repair facilities.

### **3.8 POTENTIAL METHODOLOGY**

Emissions from automotive vehicle repair and maintenance activities can be estimated using several different methodologies. Three methods for estimating emissions are presented here. The procedure in Method I calculates total annual emissions for individual automotive products based on automotive product sales. Method II estimates are based on the number of registered vehicles per specified location (state, county, or region). Method III suggests a procedure for estimating emissions by automotive fluid and vehicle class.

#### **Method 1**

- Compile a list of all the automotive repair products and their manufacturers.
- Determine sales volumes for each automotive repair product per area.
- Conduct laboratory testing, use existing emission factors to "generalize" VOC content by product assuming 100 percent volatilization, and determine emissions from each automotive product.
- Calculate total annual emissions for each automotive product by multiplying the appropriate emission factor by the annual product sales for the area.



## **Method 2**

- Compile a list of all the automotive repair products and their manufacturers.
- Determine sales volumes for each automotive repair product per area.
- Determine the number of vehicles registered in each area.
- Conduct laboratory testing or use existing VOC per-vehicle emission factors to determine automotive product emissions from each automobile in the area.
- Calculate total annual emissions for each area. Multiply per-vehicle emission factors by the number of registered vehicles in each area.

## **Method 3**

- Determine the number of service stations per area.
- Determine the number of vehicles serviced by vehicle class.
- Determine the amount of fluid used per vehicle, by fluid type and vehicle class.
- Develop emission factors through field studies to determine emissions per unit volume of fluid used broken down by fluid type.
- Compute pollutant emissions per area broken down by fluid type and vehicle class by multiplying the number of vehicles serviced by the appropriate emission factors.

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## **SECTION 4.0**

### **RECYCLING**

#### **4.1 INTRODUCTION**

Recycling may be defined as the reclamation of materials from waste. For purposes of this report, the definition includes all activities or processes related to the recycling effort, beginning with the removal of material from the waste stream and extending to the point where recycled material is essentially identical to products derived from virgin materials or may be acceptable as a substitute for virgin materials. This distinction is made to concentrate on the air emissions which are attributable to recycling processes up to the identified point. In reporting emissions however, care is needed to ensure that emissions associated with a recycling process are not double counted. For example vehicle emissions resulting from the collection of recyclable materials should be reported as part of a mobile source inventory and not as part of a recycling emissions inventory. Air emissions data are currently available from several information sources, such as *AP-42*<sup>1</sup> and EPA's Aerometric Information Retrieval System (AIRS), for a number of manufacturing processes which incorporate recycled materials. This section presents findings from research on the air emissions generated during recycling processes involving five materials: paper, plastic, glass, metals from Municipal Solid Waste (MSW) and solvents. Recycling of the first four materials involves one or more energy intensive steps. Emissions resulting from associated energy production however, are not addressed as part of this section. This section focuses on emissions from actual recycling processes.

The fifth category of materials researched for air emissions resulting from recycling was solvents. Unlike the other four recyclable material categories in this study which originate in homes or commercial establishments, spent solvents are generated primarily by industry. As the point of origination and the recycling path of spent solvents are significantly different from the other materials, the findings on this subject are presented separately.

A limited amount of statistical information is provided to describe the extent of recycling activities. Sections of the recycling industry are experiencing rapid changes. As evidence of this

change, pertinent historical data are provided along with projections. The flow of recyclable material is traced from the post-consumer waste stream through the production of materials suitable for secondary markets. Descriptions of the various collection and sorting methods are provided, followed by a detailed description of material-specific processing activities. Information which considers potential to emit air contaminants is presented for each of the four materials in the study.

## **4.2 BACKGROUND**

Historically, recycling has been practiced primarily by the manufacturing sector to reduce waste stream volumes, the resulting disposal costs, and also as a means of cost recovery by selling scrap materials. Recycling of post-consumer wastes was primarily limited to paper and rags until the 1970s. The environmental movement was partially responsible for educating the general population on the potential benefits of recycling, but markets for recycled materials remained limited. One of the driving forces behind an increased interest in recycling is the dwindling number of available landfills in the more densely populated areas of the United States. The Municipal Solid Waste Landfill Survey conducted by EPA projects that the number of landfills is expected to decrease from approximately 5500 in 1988 to about 1000 in 2013.<sup>2</sup>

The amount of MSW generated in 1988 was 180 million tons. MSW amounts are expected to rise to 200 million tons by 1995, and to 216 million tons by 2000.

Three disposal methods are used for MSW: landfilling, incineration, and recycling. Incineration and recycling are becoming increasingly popular. In 1984, 85 percent of MSW was disposed of in landfills, 5 percent was incinerated, and 10 percent was recycled. Statistics from 1988 show the incineration and recycling proportions to have grown to 14.2 and 13.1 percent, respectively, with 72.7 percent disposed of in landfills.

In 1986, 17 million tons of material were recycled, a 13 percent increase over the 1984 level. This amount is primarily due to voluntary efforts. However, most states have adopted recycling initiatives with recycling targets of 15 percent or higher. EPA has set a national recycling goal

of 25 percent of the MSW by 1995. It is estimated that 63 percent of MSW generated in 1988 was recyclable. Further, disposal of these materials accounted for 68 percent of landfill volume.

Recycling of post-consumer wastes will be an important factor in extending landfill lifetimes. The paths followed by post-consumer paper, plastic, glass and metals are initially quite similar, originating in homes and businesses and eventually arriving at resource recovery facilities. Table 4-1 presents statistics on the recovery of paper, plastic, metals, and steel from MSW in 1988. Recovery rates (by weight) for these materials in this study range from a high of 31.7 percent for aluminum to a low of 1.1 percent for plastic. The largest percentage of the ferrous metals category consists of "white goods," or household appliances, such as refrigerators, clothes washers, etc. The next largest ferrous metals subcategory represents steel containers, including cans. Overall, rigid containers (*i.e.*, bottles and cans) represent a considerable portion of the MSW weight. Glass is the most common material used in container manufacturing, representing 64 percent of the MSW rigid container weight. Other materials with respective MSW weight compositions are plastic (17 percent), steel (15 percent), and aluminum (4 percent).

The percentage of aluminum recycled from rigid containers was 53 percent in 1988. Corresponding percentages for other materials recycled from rigid containers were steel (15 percent), glass (15 percent), and plastic (6 percent).

### **4.3 RECYCLING PROGRAMS**

The passage of the Resource Recovery and Conservation Act (RCRA) in 1976 placed the management of municipal solid waste (MSW) on state and local governments. Several strategies have been developed in response to the need to reduce the volume of post-consumer wastes which are landfilled. Recycling is a key element of many of these plans.

**TABLE 4-1. MATERIALS RECOVERY FROM MUNICIPAL SOLID WASTE, 1988**

	<b>Weight Generated (in Millions of Tons)</b>	<b>Weight Recovered (in Millions of Tons)</b>	<b>Percent Recovered of Each Material</b>	<b>Discards (in Millions of Tons)</b>
Paper and Paperboard	71.8	18.4	25.6	53.4
Glass	12.5	1.5	12.0	11.0
Metals				
Ferrous	11.6	0.7	6.0	10.9
Aluminum	2.5	0.8	32.0	1.7
Other Nonferrous	1.1	0.7	63.6	0.4
<b>Total Metals</b>	<b>15.3</b>	<b>2.2</b>	<b>14.4</b>	<b>13.1</b>
Plastics	14.4	0.2	1.4	14.2
Rubber and Leather	4.6	0.1	2.2	4.5
Textiles	3.9	0.0	0.0	3.9
Wood	6.5	0.0	0.0	6.5
Other	3.1	0.7	22.6	3.1
<b>Total Nonfood Product Wastes</b>	<b>132.1</b>	<b>23.1</b>	<b>17.5</b>	<b>109.0</b>
Other Wastes				
Food Wastes	13.2	0.0	0.0	13.2
Yard Wastes	31.6	0.5	1.6	31.1
Miscellaneous Inorganic Wastes	2.7	0.0	0.0	2.7
<b>Total Other Wastes</b>	<b>47.5</b>	<b>0.5</b>	<b>1.1</b>	<b>47.0</b>
<b>Total MSW</b>	<b>179.5</b>	<b>23.6</b>	<b>13.2</b>	<b>155.9</b>

Source: Reference 2.



A number of recycling programs have been developed, both voluntary and mandatory. The type of program selected for a given area depends on a number of factors. Considerations include population density, current disposal methods, availability of funds, and marketability of recycled materials. The role of the consumer in a recycling program may also vary widely. A brief description of the more common programs follows in order of increasing consumer participation.

Two recycling program types require no consumer participation. For some solid waste facilities employing incinerators, recycling activity is limited to the removal of large ferrous-bearing items after incineration for sale to scrap dealers. Other facilities equipped with incinerators have front-end processing; materials to be recycled are removed from the waste stream prior to incineration. Removal of glass and metal components of the MSW stream prior to incineration has proven to be beneficial in the operation of the incinerator and associated equipment as it reduces downtime and produces a higher heat content for the remaining refuse.

Some programs allow recyclable materials to be commingled, with final separation to be performed at a central facility. For such programs, a separate pickup may be required as standard refuse vehicles may not be designed to store the commingled materials. Other mandatory recycling programs require that recyclables be separated by material type prior to curbside pickup. Specially designed trucks are equipped with bins to accept the material types. Refuse workers maintain the material type integrity by placing materials in the appropriate bins.

Many volunteer programs allow consumers to transport separated materials to a drop-off location during designated hours/days using their vehicles. Receptacles are provided for each material collected by the program. Volunteers are responsible for inserting materials in appropriate bins. Other voluntary programs provide curbside pickup of specified materials either in conjunction with the normal municipal refuse pickup or in a second pickup.

A number of states have implemented legislation requiring deposit on certain beverage containers. Consumers may retrieve their deposit upon returning the containers to specified return centers, often at the place of purchase.

One final option allows consumers to receive payment for recyclable materials brought to redemption centers. Payment to consumers is based on the weight and quality of the material being turned in, as opposed to the number of containers returned, which is the basis of the deposit system.

#### **4.3.1 Emissions Resulting from Collection of Recyclable Materials**

##### **4.3.1.1 *Characterization***

Several criteria pollutants would be released by vehicles involved in the collection and transportation of recyclable materials. Carbon monoxide, nitrogen dioxide, particulate matter and volatile organic compounds (VOCs) are emitted by vehicles. As noted in the introduction, however, such emissions should not be counted as part of an agency's recycling emissions inventory. Their proper place is the mobile source inventory.

##### **4.3.1.2 *Quantification***

When assessing emissions quantities, factors to be considered would include the type of recycling program and the extent of public participation. Many curbside recycling programs attempt to minimize additional vehicle (and manpower) requirements by performing collection of recyclable materials concurrently with non-recyclables. Given that many municipalities perform weekly refuse collection, vehicle miles travelled (VMT) by refuse collection vehicles should represent a negligible portion of total vehicle miles travelled in most areas.

Those programs which require a second pickup would result in additional vehicle miles travelled during collection. Some municipalities have gone from weekly pickup of MSW to biweekly alternating pickups of both MSW and recyclable materials. This approach was designed to minimize additional VMT. For programs resulting in increased VMT, emissions may be estimated by obtaining the VMT attributable to recycling and other vehicle information. Emission factors may then be obtained from AP-42, Volume II.<sup>1</sup>

Volunteer programs which involve dropoff centers would also result in an increase of vehicle emissions. Again, emissions quantification could be difficult as some individuals may make a separate trip while others may combine a number of activities with the dropoff. However, the number of vehicles involved in transporting the recyclable materials to the drop-off center would be much higher than for curbside pickup programs.

Possible approaches to quantifying vehicular emissions for programs involving drop-off centers could include assumptions or gathering actual data on both the level of participation and mean distance between the residence and the drop-off center. Information should also be obtained regarding vehicle types, models and ages to develop emission factors.

#### **4.3.2 Nonrecyclable Wastes**

Regardless of the type of recycling program, the result of waste segregation produces one or more reclaimed materials, and remaining wastes which require disposal by landfilling or incineration.

Incineration achieves significant waste volume reductions, lending to increased landfill lifetimes. As of 1988, nearly 160 municipal waste combustion facilities were on-line, accounting for approximately 320 incinerators.<sup>3</sup> Air emissions resulting from waste combustion must be addressed along with potential problems associated with the disposal of incinerator ash.

Over 95 percent of the municipal combustors brought on-line since 1980 have heat recovery boilers. These facilities represent 78 percent of the total incinerator capacity of 68,000 tons/day.<sup>3</sup> Although energy is "recovered" at some facilities, incineration is not considered to be a recycling process for the purposes of this report.

### **4.3.3 Emissions from Centralized Facilities**

#### **4.3.3.1 *Characterization***

Many recycling programs utilize a central facility for separation of recyclable materials. Two types of facilities have been developed: waste processing and material recovery. Waste processing facilities (WPFs) recover materials from raw MSW. Material recovery facilities (MRFs) perform final sorting of commingled recyclables. WPFs are more expensive to construct and are not widely used.

Automated systems are often employed in separating waste types in either of these facility types. A number of different processes may be employed to remove materials from the waste stream. Upon arriving at a processing facility, collection vehicles usually dump their contents on a tipping floor. Equipment, such as a front-end loader, is used to transfer the materials to a conveyor system. The waste moves between one or more stations within the facility where specific components are targeted for removal from the total stream. The waste is treated by a number of processes to achieve material-specific segregation. Some recyclables may also be subjected to compaction and/or baling prior to shipping.

The waste is exposed by breaking open plastic trash bags and other containers, and spreading the waste in a manner acceptable for the subsequent processing steps. Magnetic forces are often applied to the waste to remove ferrous-bearing items, such as steel cans. Other metals, such as aluminum, may be removed through the use of rare earth magnets or electrostatic separators. The latter method induces a charge on waste materials passing beneath. Materials capable of holding this induced charge are removed from the stream and are diverted for additional processing.

Air classification systems are used to separate waste items by density. Waste is exposed to a stream of high velocity air which removes the lighter fractions of the waste stream, such as loose papers and plastic items. Heavier components, such as glass containers, settle out of the air stream and are passed to the next processing station.

A number of facilities may use manual extraction of specific materials from the waste in place of any or all of the aforementioned mechanical means. This is more common in smaller scale facilities.

The methods of separation used by a given facility depend on a number of factors, including waste stream composition, throughput rates, worker's wages, health and safety considerations, alternate disposal methods, and secondary market material specifications and prices.

#### **4.3.3.2 *Quantification***

Airborne particulate concentrations are likely to be high in the tipping floor area.<sup>4</sup> Particulates are generated by the waste handling activities. One potential source of particulate matter may consist of waste paper in MSW which contacts the tipping floor, usually an indoor concrete pad. The pad surface's roughness abrades the paper when the waste is moved by equipment, such as a front-end loader. Additional dust could be created by waste abraded by the conveyor system, or by waste/waste contact. Tipping floors are often located in a structure which is not fully enclosed during operation. Doors are open to allow collection vehicles ingress and egress. This may allow particulate matter to escape the structure as fugitive emissions. Some tipping floors operate under negative pressure to reduce odors and fugitive emissions.

Air classification systems can produce particulate matter. Any fines in the waste stream reaching this stage may be separated from remaining waste by the air stream. A baghouse is often used to control emissions from this process. The composition of the fugitives would depend on the waste components and would be expected to be highly variable. Information on the characterization of particulate matter arising from this activity was not readily available.

Further, quantification of emissions may also prove difficult. The nature of activities in the structure containing the tipping floor may prevent attempts to measure the amount of dust escaping from the structure. Installation of a fan and baghouse could minimize dust and associated fugitives.

After separation and consolidation, paper, plastic, glass, and metals are all subject to a unique series of additional processes in preparation for sale in the secondary market. The pathway followed by each material will be presented separately.

#### **4.4 METALS RECYCLING**

This category may be divided into ferrous and nonferrous metals. Ferrous metals are partially or wholly composed of iron and are attracted by magnetic forces. Nonferrous metals include copper, lead, tin, zinc, brass, bronze, and aluminum.

Ferrous metal wastes comprised 11.6 million tons (76 percent) of the total metals waste in MSW in 1988.<sup>2</sup> Aluminum waste accounted for 2.5 million tons (16 percent), and other nonferrous metal waste contributed 1.1 million tons (7 percent). Of these three categories, recovery rates are lowest for ferrous metals (iron and steel) at 5.8 percent, rising to 31.7 percent for aluminum, and are highest for other nonferrous metals at 65.1 percent.

Several fractions of the nonferrous metals have high scrap value. Excluding aluminum, these metals only comprise around 1 percent of total MSW. This low composition has hindered efforts to recover these metals from MSW. Out of ten facilities designed to recover nonferrous fractions, a majority have abandoned the effort.<sup>5</sup>

Ferrous metals and aluminum accounted for more than 90 percent of the metals in MSW in 1988, therefore, research efforts focussed on recycling of these components.

##### **4.4.1 Steel**

Large household appliances, known as "white goods" or durables, and steel cans are the two largest categories of steel in MSW. White goods are usually collected separately from other MSW and are sent to automobile processing facilities for shredding.<sup>6</sup> Due to the different recovery path for these items, reclamation of steel from white goods was not investigated.

Steel cans may be constructed in a number of different ways and may include other materials. Bimetal cans are constructed of three components; a steel body with a seam and two aluminum end pieces. Cans may be constructed of steel components with the inner surfaces having been plated with tin, a chemically stable metal used to prevent reaction between the steel and the container contents. While this type of can is typically referred to as a "tin" can, the actual tin content is only about one percent of the total container weight, having been applied by electroplating. Other materials, such as epoxies and rosin esters, may be used in place of tin to line steel cans.

Three piece cans require the use of sealing compounds, such as synthetic rubber, between the end caps and can body, and also along the seam.

Two piece steel cans are a relatively new development, eliminating the seam. These cans are distinguishable from three piece cans not only by the lack of a seam, but also by the presence of a rounded edge between the can base and body. The only sealing required is between the top and can body, reducing the amount of sealing compound per container.

Organic materials may be applied to cans as components of interior and exterior coatings. Primer coatings are applied to the exterior of the can and may include epoxy, epoxy ester, acrylic vinyl, and polyester resin. Overvarnish coatings are the final application, and may contain polyesters, alkyds, and acrylics. Wide ranges of solvents are used in the coating process. Table 4-2 lists some of the organic compounds used in the coating and sealing of beverage cans. Many of the same compounds would be used for cans designed to contain products other than beverages.

Paper labels are affixed to cans by glue. Many recycling programs require that the labels be removed from cans, and that the interior be washed. However, some residual paper and glue may remain on the can exterior, and product residuals may also be found on interior surfaces.

**TABLE 4-2. TYPICAL ORGANIC COMPONENTS OF COATINGS APPLIED TO BEVERAGE CANS**

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**Interior Base Coat**

Butadienes  
Rosin esters  
Phenolics  
Epoxies  
Vinyls  
Organosols

**Overvarnish Coat**

Polyesters  
Alkyds  
Acrylics

**Primer (size) Coat**

Epoxy  
Epoxy ester  
Acrylic vinyl  
Polyester resin

**Solvents (used for interior and exterior base coats, overvarnish, and size coats)**

Mineral spirits	Ethylene glycol monoethyl ether acetate
Xylene	n-Butanol
Toluene	Isopropanol
Dicatone alcohol	Butyl carbinol
Methyl iso-butyl ketone	Paraffins
Methyl ethyl ketone	Propylene oxide
Isophorone	Resityl oxide
Solvesso 100 and 150 (TM)	Aliphatic petroleum hydrocarbons
Ethylene glycol monobutyl ether	Di-isobutyl ketone
Ethylene glycol monoethyl ether	Di-methyl formamide
Ethanol	Nitropropane
Cyclohexanone	

**End Sealing Compound**

Synthetic rubber

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Source: Reference 7.



Construction of the steel can has introduced sealing and coating compounds, and in the case of the bimetal can, different metals. Organic coatings may account for 1.8 percent of the container weight.<sup>8</sup> Residual waste may be present on the can interior. Each of these may be considered as contaminants with regard to recycling processes.

Scrap dealers will purchase only recycled materials fitting their specifications, such as accepting only cleaned cans stripped of label materials. The scrap will then be subject to additional processing, such as compaction and/or baling, in preparation for the secondary market.

Reclaimed steel may be marketed to three industries: iron/steel, detinning, and copper precipitate. The copper industry uses scrap steel to act as a precipitate in extracting copper. This process is not considered to be recycling in the context of this report and will not be covered.

The iron/steel and detinning industries have differing specifications for materials to be purchased. For example, less dense bales of scrap allow for more efficient removal of tin at detinning facilities. Iron/steel mills, however, prefer more dense scrap bales to minimize material handling.

#### **4.4.2 Detinning**

The detinning industry purchases scrap for purposes of recovering the tin content and, as a direct result, increasing the quality of the steel scrap. Detinned steel stock demands a higher price in the secondary market. The steel industry considers tin to be a contaminant, which when present in sufficient quantity, results in inferior product quality. Tin is removed from these materials through a chemical process called detinning. Detinning significantly lowers the amount of tin in the scrap and allows for increased usage.

A limited number of detinning facilities operate in this country. In 1968, 15 facilities were in operation, but by 1990, the number had decreased to around 6. In 1986, approximately 550,000 tons of tinplate scrap were detinned, yielding 1,250 tons of tin.<sup>6</sup> It should be noted that a portion of the stock which was detinned was scrap from container manufacturing facilities. An example

of such scrap would be tinsplate sheet stock remaining after can tops and/or bases had been punched out.

A number of factors can affect the viability of this industry. Detinning is intimately tied to activities within the steel container industry. The container market share for steel containers has experienced change in the last 15 years. In 1976, 46 pounds of tin cans were produced per capita; however, by 1983, this amount had dropped to 26 pounds.<sup>5</sup> Recently, the steel industry has been promoting the use and recyclability of steel cans to regain market share. The recycling rate for steel cans (including tinsplate cans) has been increasing, from a level of nearly 18 percent in 1989<sup>9</sup> to 34 percent in 1991.<sup>10</sup>

Further, the amount of tin per container has decreased due to technological changes. Tin content is currently at a level of around 0.4 percent of the container weight. The price of both scrap steel and tin are critical to profitability of detinning operations. A weakening in either or both the scrap steel and tin markets could result in a decrease in the number of detinning operations.

Transportation costs are significant for detinning. As a result, these facilities tend to be located near their source, populated areas with a high level of recycling activities or near steel mills. Industry wide detinning capacities are likely to increase in response to the number of state and local recycling initiatives, assuming favorable market conditions as previously discussed.

Detinned scrap steel stock is sold to the iron and steel industry. Information on this market is presented in the section on steel recycling.

The detinning industry is the only significant domestic source of tin metal in the United States.<sup>11</sup> The sources of tin are clean tinsplate scrap and tin-coated food and beverage cans. This section describes each of the steps involved in the overall process and the potential associated hazards. The detinning process includes the following steps:

- Unloading of ferrous metal scrap
- Shredding

- Air classification and magnetic separation
- Chemical detinning
- Separation
- Tin removal

The detinning and separation steps take place at all detinning facilities whereas other steps are not always required. The process at most detinning facilities is continuous, operating 24 hours per day, 5 days per week, although some older facilities use a batch process.

Continuous processes are more commonly utilized due to higher efficiencies and are present in most modern detinning facilities.

Tin cans must be shredded for two reasons. First, shredding loosens and separates most contaminants such as paper, glue, lacquer, plastic, and organics (food residues or dirt) from the cans. Shredding also separates aluminum ends from the bi-metal food and beverage cans. This step allows contaminants to be removed from the cans during subsequent magnetic separation and air classification. Second, shredding exposes a greater area of the tin cans to the tin-removing chemicals used. The area exposed may be up to one square acre per ton of tin cans.<sup>12</sup>

Shredding may result in airborne particulate matter. Other materials may be released by this process, such as contents of aerosol spray cans, and cans containing residual paints, solvents, fuels and cleaning compounds. In 1976, aerosol and paint cans accounted for 2.7 percent and 3.2 percent of total can shipments.<sup>8</sup> While recycling programs frequently do not permit many of these containers, they may arrive at a shredder from a facility which used magnetic separation to segregate the steel scrap.

#### ***4.4.2.1 Air Classification and Magnetic Separation***

After tin cans have been shredded, a conveyor system carries the cans to the air classification and magnetic separation step. In this step, most contaminants in the scrap (paper, glue, lacquer,

organics, aluminum, etc.) are removed. These contaminants, depending upon their properties, either fall (aluminum scrap not picked up by the magnetic separators), or are blown (less dense material pulled in by the air classifier) into disposal containers. While the tin cans remain attached to the magnet, the contaminants are transported to landfills for disposal. Industry sources have reported that the combination of shredding, magnetic separation, and air classification removes 98 percent of non-metallic contaminants and 99 percent of the aluminum.<sup>13</sup>

#### **4.4.2.2 Chemical Detinning**

After tin cans have passed through the shredder, magnetic separator, and air classifier, they are considered clean and have a large surface area exposed to increase the efficiency of the chemical detinning step. The actual detinning is accomplished by treating cans with a hot alkaline solution, usually caustic soda (sodium hydroxide), containing an oxidizing agent to dissolve the tin and precipitate it as sodium stannate.<sup>11</sup> This step would also remove any contaminants remaining on the scrap (*e.g.*, paints). The cans are placed in the detinning solution either through the use of steel baskets lowered into solution tanks (typical of batch processes) or a tube-like device that works like a screw conveyor.<sup>14</sup> The scrap works its way through the chemicals and into a wash. The screw conveyor is popular because it is a continuous process.

#### **4.4.2.3 Separation**

The detinned feedstock (cans) is separated from the detinning solution through the use of rinse trommels (a cylindrical rotating screen). The cans are rinsed with hot water that is recycled into the detinning tanks. The residual tin remaining on the surface of the detinned scrap is usually less than 0.06 percent.<sup>14</sup> The detinned scrap is baled and sold to iron and steel manufacturers for use in new products.

#### **4.4.2.4 Tin Removal**

Tin remaining in the detinning solution is removed through an electroplating process which utilizes electricity to turn the sodium stannate back into tin metal.<sup>14</sup> The tin is then melted off

the plates and cast into ingots that are sold. In older detinning plants, process residues, the spent caustic soda, and "detinner's mud" are recovered and used by other industries, while any rinse water is treated and reused.

Detinning also leads to recovery of aluminum and lead. For every ton of cans, the following yield may be typical: 5 pounds of tin, 34 pounds of aluminum, and 9 pounds of lead.<sup>15</sup>

In newer facilities, the spent caustic soda is also recycled through the system. The "detinner's mud," sludge that results from this process, is usually sold to tin smelters as a low-grade ore.<sup>16</sup>

#### **4.4.2.5 Air Emissions**

Modern detinning facilities produce small amounts of ammonia during the reduction of sodium nitrate. Process heating decreases the time required for detinning. The heat energy may be derived from the combustion of a number of fuels. Emissions associated with these facilities are produced by fuel combustion.<sup>17</sup> Such emissions, however, should already be reported in emission inventories.

#### **4.4.3 Iron and Steel Manufacturing**

The iron and steel manufacturing industries in the United States utilize two types of furnaces, the basic oxygen furnace and the electric arc furnace. The basic oxygen furnace produces about 60 percent of the steel in the United States, utilizing an average of 30 percent scrap while the electric arc furnace produces about 40 percent of the steel, using virtually 100 percent scrap.<sup>18</sup> The steps used to introduce ferrous metal scrap into each of the furnaces, at which point the scrap may be mixed with virgin materials, are slightly different for each type of furnace and will be discussed separately. Despite the differences in the charging steps, the equipment used and the ferrous scrap being charged to each of the furnaces are comparable.

#### **4.4.3.1 Basic Oxygen Process Furnace**

A basic oxygen process furnace is a large open-mouthed vessel lined with a refractory material. The furnace is mounted on trunnions that allow it to be rotated 360° in either direction. A typical vessel can be 12 to 14 feet across and 20 to 30 feet high. The basic oxygen furnace receives a charge composed of scrap and molten iron (produced in a blast furnace using iron ore and other materials) and converts it into molten steel. Steel is produced by introducing a jet of high purity oxygen into the furnace which oxidizes the carbon and the silicon in the molten iron, removes these oxidized products, and produces heat which melts the scrap.<sup>19</sup> The oxygen is injected into the furnace at supersonic velocities (Mach 2) through a water-cooled, copper tipped lance.<sup>20</sup> Emissions including metallic oxides, particles of slag, carbon monoxide, and fluoride are typically released from this process, however, the feedstock is composed primarily of virgin materials (at least 70 percent molten iron).<sup>20</sup>

The process steps to charge the basic oxygen furnace with ferrous metal scrap include loading the charge box and charging the furnace.

The ferrous metal scrap usually arrives at the facility's scrap yard in railroad cars. In the scrap yard, the scrap is transferred to the charge box (a container) by means of an overhead crane and electromagnet which are operated by a worker. The charge boxes are moved by special railed cars from the scrap yard into the charging aisle for the furnace.<sup>19</sup> The movement of the railed cars is controlled by workers at an operating panel.

When the furnace is ready to be charged, it is tilted toward the charging aisle, the charge box is lifted by mechanical means, and its contents deposited into the vessel.<sup>19</sup> Workers remotely control this equipment from an operating panel.

#### **4.4.3.2 Electric Arc Furnace**

Electric arc furnaces consist of a refractory-lined, cylindrical vessel made of heavy welded plates, a bowl-shaped hearth, and a dome-shaped roof. Three graphite or carbon electrodes are mounted

on a superstructure located above the furnace and can be lowered and raised through holes in the furnace roof. The electrodes convey the energy for melting the scrap charge. There are water-cooled bladders located at the holes in the furnace roof which cool the electrodes and also minimize the gap between the openings in the roof and the electrodes in order to reduce emissions, noise, heat losses and electrode oxidation. When the electrodes are raised, the furnace roof can be swung aside allowing charge materials to be deposited in the furnace. Any alloying agents that are required are added through the side or slag door of the furnace. Alloying agents used in the electric arc furnace include ferromanganese, ferrochrome, high carbon chrome, nickel, molybdenum oxide, aluminum, manganese-silicon, and others.<sup>20</sup> Charging of the furnace is easily accomplished in just a few minutes. The furnace is usually mounted on curved rocker trunnions. Hydraulic cylinders or an electromechanical means are utilized for tilting the furnace.<sup>21</sup>

Like the basic oxygen furnace, the process steps to charge the electric arc furnace with ferrous metal scrap include loading the charge bucket and charging the furnace.

Ferrous metal scrap is usually removed from railroad cars by a crane equipped with an electromagnet. The crane places the scrap into a drop-bottom (clam-shell type) charge bucket. The charge bucket is filled to a specified weight. The weight is checked on a scale having a digital display that is visible to the crane operator.<sup>21</sup> The charge bucket may be mounted on an overhead track system or attached to a crane.

Once the charge bucket has been filled with the specified weight of ferrous scrap, it is moved by the overhead track system or by a crane to the electric arc furnace. The furnace roof is swung open and the charge of scrap is deposited into the furnace. Charging the furnace in this manner results in uncontrolled emissions in most plants. During the charging process, the scrap must be introduced properly so that the refractory (lining of the furnace) is not damaged. When pieces of scrap remain above the parting line of the furnace roof (bezel ring), these pieces must be relocated so that the roof can be set in place. This relocation can be accomplished with the use of the charge bucket or some other large mass of metal suspended from the crane. Each of these actions are controlled remotely by operators at an operating panel and/or by the crane operator.<sup>21</sup>

At some facilities, the charge may be deposited directly into the furnace from the incoming transport by an electromagnet mounted on a crane. At facilities with smaller furnaces that do not have a removable roof, the charge is deposited in the furnace through doors.<sup>20</sup>

#### **4.4.3.3 Air Emissions**

For steel recycling, only those processes unique to or altered by the use of scrap steel which result in air emissions are addressed. Such emissions, however, are reported in the current inventories. The major source of emissions attributable to the recycling of steel is melting. Once this process is complete, the emissions resulting from the remaining processes are independent of the origin of the feedstock.

Melting processes include: (1) charging; (2) melting; (3) backcharging, or the addition of more feedstock or alloys; (4) refining, when the carbon level is adjusted; (5) oxygen lancing, to adjust the batch chemistry and loosen slag; (6) slag removal; and (7) drawing off the molten metal into a ladle or molds.

**4.4.3.3.1 Characterization** Contaminants such as paper labels, lacquer, glue, inks, and organics may be found in varying quantities in scrap purchased by iron and steel mills. Charging the furnace with this scrap may produce emissions of particulate matter, carbon monoxide, and hydrocarbon vapors. Lead, cadmium and other heavy metals may be present in pigments used in printed labels.<sup>6</sup> Inks used in coating cans may contain compounds which result in air contaminants when burned off during charging. Some of the compounds found in lithowhite ink include titanium dioxide, manganese naphthenate, drying alkyd, and aliphatic hydrocarbon solvent.<sup>22</sup>

Table 4-3 presents an emissions characterization summary for steel industry processes involving reclaimed steel. The range of pollutants is dependent on the type of contaminants within the scrap.



**TABLE 4-3. CHARACTERIZATION SUMMARY OF EMISSIONS FROM  
RECYCLING PROCESSES FOR STEEL PRODUCTION**

<b>Activity/Process</b>	<b>Emissions</b>
Scrap preparation	Hydrocarbons (degreasing process), smoke, organics, CO (heating process)
Charging, melting, refining, lancing, slag removal	Particulates, CO, organics, SO <sub>2</sub> , NO <sub>x</sub> , chlorides, fluorides

Source: Reference 1.

**4.4.3.3.2 Quantification** The quantity of air emissions released during steel production is dependent on the following parameters: percent of scrap in the charge; type and amount of contaminants in the scrap; and furnace type.

*AP-42* Volume I contains emission factors for processes involved with steel production using the three main furnace types: basic oxygen, electric arc, and open hearth. Table 4-4, extracted from *AP-42*, presents a range of emission factors for particulate emissions for melting. The low end of the range would be appropriate for clean scrap, such as rejects from an iron or steel mill. The upper end of this range would provide a better estimate of emissions where the scrap has a high level of contaminants, such as post-consumer tin cans.

Scrap purchased from detinning facilities should produce lower air emissions. Many contaminants, including paints, coatings, and residuals, are removed by the caustic solution.

#### **4.4.4 Aluminum**

Aluminum has numerous applications that may ultimately contribute to the MSW recyclable mix. Architectural uses include siding, window frames, awnings/canopies, and heating and ventilation.

**TABLE 4-4. EMISSION FACTORS FOR STEEL FOUNDRIES<sup>a</sup>**

Process	Particulates <sup>a</sup>		Nitrogen Oxides	
	kg/Mg	lb/ton	kg/Mg	lb/ton
<b>Melting</b>				
Electric arc <sup>b,c</sup>	6.5 (2 to 20)	13 (4 to 40)	0.1	0.2
Open hearth <sup>d,e</sup>	5.5 (1 to 10)	11 (2 to 20)	0.005	0.01
Open hearth oxygen lanced <sup>f,g</sup>	5 (4 to 5.5)	10 (8 to 11)	-	-
Electric induction <sup>h</sup>	0.05	0.1	-	-

<sup>a</sup> Reference 1.

<sup>b</sup> Expressed as units per unit weight of metal processed. If the scrap metal is very dirty or oily, or if increased oxygen lancing is employed, the emission factor should be chosen from the high side of the factor range.

<sup>c</sup> Electrostatic precipitator, 92–98 percent control efficiency; baghouse (fabric filter), 98–99 percent control efficiency; venturi scrubber, 94–98 percent control efficiency.

<sup>d</sup> Electrostatic precipitator, 95–98.5 percent control efficiency; baghouse, 99.9 percent control efficiency; venturi scrubber, 96–99 percent control efficiency.

<sup>e</sup> Electrostatic precipitator, 95–98 percent control efficiency; baghouse, 99 percent control efficiency; venturi scrubber, 95–98 percent control efficiency.

<sup>f</sup> Usually not controlled.

It is also used in the food and beverage industry in the form of cans, foils and closures. Table 4-5 presents a breakdown of aluminum waste from MSW. The elemental composition of recyclable material varies depending on the general type of material considered. Table 4-6 lists elements, with the exception of aluminum, which are present in different types of aluminum scrap.

**TABLE 4-5. GENERATION AND RECYCLING OF ALUMINUM PRODUCTS IN MSW**

Product Category	Weight Generated (in thousand tons)	Weight Recovered (in thousand tons)	Percent Recovered	Discards (in thousands tons)
Major Appliances	107		0	107
Furniture and Furnishings	89		0	89
Miscellaneous Durables	280		0	280
Miscellaneous Non-Durables	240		0	240
Beverage Cans	1,439	791	55	648
Other Cans	67		0	67
Foil and Closures	324	16	5	308
<b>Total</b>	<b>2,546</b>	<b>807</b>	<b>32</b>	<b>1,739</b>

Source: Reference 23.

**TABLE 4-6. TYPICAL ELEMENTAL COMPOSITION OF ALUMINUM SCRAP**

Source	Element Percent					
	Silicon	Iron	Copper	Manganese	Magnesium	Zinc
Used Beverage Containers (directly reclaimed)	0.2	0.6	0.15	0.9	1.1/1.3	
Municipal (mostly UBC)	0.8	0.5	2.4	0.6	0.1	2.0
Automotive (automobile shredder residue)	5.0	0.8	1.3	0.3	0.1	0.6

Source: Reference 24.

Aluminum used-beverage containers (UBC) constitute between 95 and 98 percent of all aluminum recycled from MSW. Aluminum UBCs, like containers made from ferrous metals, include either waterborne or solvent-borne surface coatings. Coatings are typically applied to both interior and exterior surfaces to isolate the can's contents from the metal body, improve appearance, protect lithography, and increase can mobility during the filling processes.<sup>19</sup> Together with inks and pigments used in exterior labeling, coatings contribute a variety of organic and inorganic chemicals to the recyclable material. Organic components typically used in surface coatings are similar to those used on steel cans as presented in Table 4-2.

#### **4.4.4.1 Secondary Aluminum Production**

Secondary aluminum production from scrap aluminum began shortly before World War I and has grown at a constant rate since World War II. The technology of aluminum recycling has remained essentially the same throughout the years, with changes primarily found in the method of casting ingots and the introduction of emission control devices.

Recyclable MSW aluminum can be obtained from several sources. A major source of aluminum is used aluminum beverage cans obtained from retailers who collect cans in states with deposit laws. Retailers presort the cans and usually sell them to a scrap dealer or directly to a secondary aluminum processor. Aluminum collected from municipal recycling programs can be a mixture of UBC, other aluminum cans, foil, and closures, though most is UBC.<sup>24</sup> Scrap dealers also

purchase aluminum in many forms directly from individuals, usually on a weight basis. Depending on the purchaser of the recycled aluminum, the scrap dealer may or may not separate or sort the various forms of aluminum. Large beverage can manufacturers like ALCOA and Reynolds require separated aluminum. Finally, it is possible to recover and recycle aluminum from incinerated MSW. However, the available information indicated that this source of recyclable aluminum is not considered significant.

Aside from separation/sorting, the processing steps are similar for all forms of aluminum. The recycling process described below emphasizes UBCs since they comprise the majority of aluminum recycled from MSW.

The actual process of aluminum recycling consists of several steps. If the scrap aluminum is to be transported over a long distance to the reclamation facility (secondary smelter), or if economic factors are a concern, the aluminum can be densified in order to reduce the volume of the scrap. Densification (compaction) is followed by shredding, which is then followed by a series of steps occurring at the secondary smelter. These include scrap drying or delacquering, smelting, and casting. Figure 4-1 presents an overview of the general aluminum recycling steps.

#### ***4.4.4.2 Compaction/Baling***

Sorted aluminum may be compacted in order to reduce the volume of scrap prior to being transported to the secondary smelter. Aluminum UBC typically arrives at the compactor in the form of loose, flattened cans. The "loose flats" are unloaded from the truck onto the floor, and with the use of a forklift or front-end loader, are loaded into high density balers. Balers are of two types, either vertical (loaded on the top) or horizontal (loaded on one side). These machines compact the aluminum into bales generally weighing 700 to 1,200 pounds each.<sup>25,26</sup> Alternatively, the aluminum can be compacted into 35-pound biscuits which are packaged into 2,500-pound bundles.<sup>25</sup>

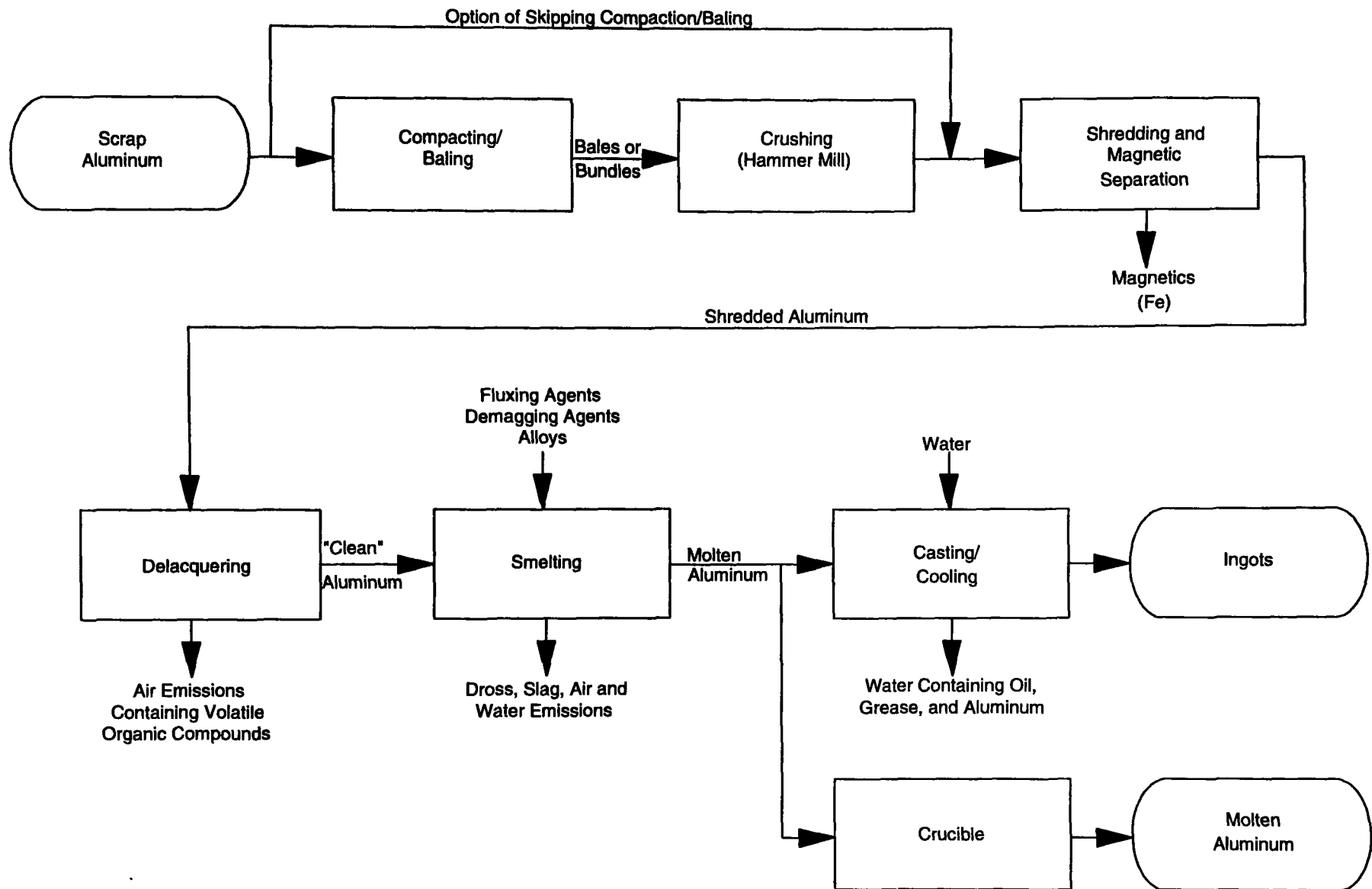


Figure 4-1. Overview of aluminum recycling.

The exact size of the bales or the choice between baling or biscuiting depends on economic factors (which form is less expensive to produce and transport) as well as operational limits (size of machinery, etc.) of both the facility producing the compacted aluminum and the customer buying it. As a final step, the bales or bundles are loaded by crane or forklift onto a truck or rail car.

#### **4.4.4.3 *Crushing***

A hammer mill is used to break up compacted or baled aluminum is broken up prior to processing. The aluminum is placed on a conveyor belt using a forklift or a crane with grapples (claws). The conveyor belt feeds the aluminum into the hammer mill which breaks the aluminum into fist-size pieces.<sup>27</sup> Further shredding is required by some facilities.

#### **4.4.4.4 *Shredding***

Whether the aluminum is transported to the secondary smelter in the form of bales, bundles, or as loose flats, it must be shredded into smaller pieces prior to smelting. Shredding permits removal of any remaining iron by magnetic separation and allows more efficient cleaning and melting of the aluminum.

In preparation for shredding, aluminum is loaded into a hopper by either a forklift or a front-end loader. The hopper can be fed directly or the aluminum can be pushed onto a conveyor belt (recessed into the floor) which then feeds the hopper. The hopper in turn feeds a steady flow of aluminum to a second conveyor belt. The aluminum travels along the conveyor belt, up an incline, to a conical-shaped weigh hopper with a door at the bottom. The weight of the aluminum within the weigh hopper is computer-monitored. When a pre-determined weight is attained, the conveyor belt feeding the weigh hopper is stopped and the door at the bottom is opened. The aluminum is then loaded onto another conveyor belt which feeds the shredding machinery. The weigh hopper discharges the aluminum onto the conveyor belt at a constant rate.

Within the shredding machine, the aluminum is sheared and cut into smaller pieces. The exact size of these pieces varies depending on the specifications of the machinery and the size desired by the customer purchasing the shredded aluminum. The shearing and cutting is performed by rotating blades, or by grinding action. Both methods involve high speed machinery. The shredded aluminum is then blown into the back of a trailer for transport to the secondary smelter.

#### **4.4.4.5 *Scrap Drying/Delacquering***

Before aluminum scrap can be melted for remanufacture, any impurities such as paints, coatings, container residues, or other contaminants must be removed. Impurities/contaminants are removed during a drying or delacquering phase. Drying is the general process of removing contaminants from the aluminum through heating. The scrap aluminum is heated in a gas- or oil-fired rotary furnace until the contaminants are burned off.

Drying is referred to as delacquering when recycling UBC. In this process, the shredded UBC is loaded onto a conveyor belt which feeds the delacquering kiln. The kiln is situated on a slight angle and rotates to allow the shredded UBC to travel, by gravity, through the kiln. As the paint and coatings burn off the aluminum, additional heat is produced which may be captured or reintroduced to the kiln. This produces a greater fuel efficiency in the kiln as well as more complete combustion of contaminants released from the aluminum.

The aluminum leaving the delacquering kiln is considered "clean", free of any paints, coatings, or residues. Aluminum is gravity fed from the delacquering kiln onto a conveyor belt moving toward the smelting furnace.

#### **4.4.4.6 *Smelting***

Generally, two types of charge furnaces are used in secondary aluminum smelting; reverberatory and rotary. Reverberatory furnaces are used for most medium to large secondary aluminum smelting operations.<sup>27</sup> These furnaces typically range in capacity from approximately 10 tons to 90 tons, operate by a continuous feed method, and can be either gas- or oil-fired. A charge well

is usually used to introduce pieces of aluminum below the liquid level of the already melted aluminum within the reverberatory furnace. The introduction of aluminum below the liquid level has two main advantages. First, fumes produced can be captured much more efficiently by using a submerged hood. Also, oxidation of aluminum is greatly reduced as the fresh molten aluminum surface is located below the molten aluminum/air interface. Oxidation of aluminum yields less aluminum product.

Rotary furnaces usually operate by a batch-type method. These furnaces have a relatively low capacity and are unsuitable for the addition of alloys and production of a homogeneous product. Thus, most rotary furnaces are used by smaller facilities that produce aluminum for use in products where the composition of the aluminum is not specific. Advantages of the rotary furnace include a controlled pouring rate and mechanical mixing action. Should an emergency arise during the pouring of molten aluminum, it is much easier to stop the flow from a rotary furnace than a reverberatory furnace.

For melting small quantities of aluminum (up to 1000 pounds), crucible or pot-type furnaces are used extensively. Most crucibles are made of silicon carbide or a similar refractory material.<sup>27</sup>

While aluminum is in its molten form, several different processes can be performed depending upon the scrap aluminum's characteristics and the desired composition of the recycled aluminum. These processes include the addition of fluxing or alloying agents, the removal of excess magnesium, and the removal of dross or slag which forms on the top of the molten aluminum.

**4.4.4.6.1 Additives** Fluxing agents are usually added to the furnace along with scrap. The addition of fluxing agents reduces losses of aluminum and removes extraneous contaminants. As aluminum reaches the molten stage, the fluxing agents react with leftover contaminants (inks, coatings, etc.) to form insoluble materials which float to the top of the melt. The accumulation of the flux (and contaminants) on top of the melt produces a layer on the surface known as slag. This layer reduces any losses of aluminum exposed to the surface due to oxidation. A flux may contain any one or combination of sodium chloride, potassium chloride, calcium chloride, calcium



fluoride, aluminum fluoride, or cryolite. A typical composition of a flux may be 47.5 percent sodium chloride, 47.5 percent potassium chloride, and 5 percent sodium fluoaluminate (cryolite).<sup>27</sup>

Alloys may also be added to the molten aluminum in order to achieve the desired composition of the recycled aluminum. Typical alloying agents include copper, silicon, manganese, magnesium, and zinc. Generally, in the case of UBC, aluminum is recycled for the purpose of producing new beverage cans. This end use obviates the need to add alloys as the aluminum already possesses its desired composition.

**4.4.4.6.2 Demagging** The covers of used beverage cans possess a higher concentration of magnesium than the rest of the can.<sup>28</sup> Therefore, it is necessary to remove some of the magnesium in order to produce a desirable, homogeneous aluminum metal product. Demagging is the process of removing excess magnesium from the aluminum. The process uses chlorine or chlorinating agents (*i.e.*, anhydrous aluminum chloride) or aluminum fluoride to react with the magnesium from the melt.<sup>29</sup>

Demagging through the use of chlorine is performed by introducing elemental chlorine gas, under pressure, through tubes at the bottom of the molten aluminum. As the chlorine bubbles upward it combines with the magnesium to form magnesium chloride. As the magnesium becomes scarce in the melt, aluminum chloride, a volatile compound, begins to form as fumes. Wet scrubbers are frequently used as an emission control method. Contaminated wastewater from the scrubbers may contain suspended solids, chlorides, and heavy metals.<sup>29</sup>

Fluoride may also be used for demagging in a process similar to chlorine demagging. Magnesium fluoride is produced which rises to the surface and combines with the flux on top of the melt. Gaseous fluorides and fluoride dusts are emitted from this process. Fluoride emissions may be controlled by either wet or dry methods. Dry methods produce a solid waste and wet methods produce both wastewater and solid waste. Other wastewater will have similar properties to that produced in chlorine demagging, with the exception of fluorides being present instead of chlorides.

**4.4.4.6.3 Skimming** Skimming is the procedure by which the dross (layer of oxidized aluminum) and/or slag (layer of flux and contaminant) are removed from the top of the molten aluminum. Cooled slag and dross are removed and stored for shipment to either a residue processor or recycler, or to be discarded (*i.e.*, landfilled).

**4.4.4.6.4 Pollution Control Methods** Emissions from the charge furnace can be controlled through the use of a scrubber or a scrubber-baghouse combination. If a charge well is employed and the aluminum scrap is introduced to the melt below the liquid level, a partially submerged hood may be installed. This increases the efficiency of emissions captured. The partially submerged hood is located above the charging area and below the liquid level, therefore emissions are captured prior to their dissipation into the air.

In a wet scrubber, the hot furnace gases are spray quenched with water. This produces steam which, in the case of chlorine demagging, reacts with the aluminum chloride to produce hydrated aluminum oxide and hydrochloric acid. These compounds are removed by the scrubber.

A coated baghouse may be used to increase the removal of emissions such as acid gases. In the coated baghouse, fabric filters are coated with a material which neutralizes acid gases from demagging and removes fines from loading and storage areas in one step. As the coating material becomes saturated or dirty, it is removed and a new batch of material is applied to the fabric filters. The baghouse may also be connected to hoods which extend over possible sources of dusts such as the loading and storage areas. Although most aluminum dust produced in these areas would be composed of large particles and settle almost immediately, these additional hoods may further reduce the presence of fine particulate.

Afterburners may also be used to reduce hydrocarbon emissions. These afterburners may be attached to the drying and/or delacquering kiln as well as the charge furnace. Temperatures used are on the order of 1500°F, which provides complete combustion and virtually no hydrocarbon emissions. However, due to the burning of fuel, nitric oxide and nitrogen dioxide may be produced.<sup>27</sup>

#### **4.4.4.7 Air Emissions**

**4.4.4.7.1 Characterization** As the paint and coatings burn during the delacquering/drying process, organic contaminants may be released due to incomplete combustion of the various compounds which make up these layers (see Table 4-2). Any one or combination of these chemical compounds may be present in the emissions from delacquering due to incomplete combustion. Also, lead, cadmium (a carcinogen) and other heavy metals may be present in particulate form in the emissions.<sup>30</sup> Wet scrubbers are usually employed to control emissions. Dry scrubbers are not favored due to the possible buildup of fines which can result in explosions.

Air emissions generated during smelting are typically controlled using submerged hoods connected to an air pollution control system. During the demagging process, hydrated aluminum oxide, hydrochloric acid, volatile aluminum chloride, magnesium fluoride, gaseous fluorides, or fluoride dusts can be formed. Table 4-7 presents processes and related emissions for the recycling of aluminum.

Afterburners are sometimes used to control hydrocarbon emissions. Afterburners are typically connected to both the delacquering and smelting furnaces. These can generate nitric oxide and nitrogen dioxide emissions.

**4.4.4.7.2 Quantification** Table 4-8 contains emission factors obtained from AP-42 for secondary aluminum production processes. Many contaminants are removed from aluminum scrap by the delacquering/drying process. Remaining contaminants are removed or driven off during smelting, resulting in air emissions. Emissions resulting from primary versus secondary processing vary and are difficult to compare directly.<sup>30</sup>

**TABLE 4-7. EMISSIONS CHARACTERIZATION SUMMARY OF RECYCLING PROCESSES' SECONDARY ALUMINUM OPERATIONS**

<b>Activity/Process</b>	<b>Emissions</b>
Crushing/screening	Metallic and nonmetallic particulate
Shredding/classifying	Metallic and nonmetallic particulate
Baling	Dirt, alumina dust
Burning/drying	Wide range of pollutants, including particulate matter, VOCs (chlorides, fluorides, sulfur oxides, oxidized alumina fines)
Hot dross processing	Dust
Sweating furnace	Products of incomplete combustion of rubber, oil and grease, plastics, paint, cardboard, paper, fumes from oxidation of magnesium and zinc contaminants
Smelting/refining (using chlorine or fluorine)	Chlorine, fluorine, HCl, metal chlorides of Zn, Mg, Al, aluminum oxide, others (depending on scrap composition)

Source: Reference 1

## **4.5 PAPER RECYCLING**

Paper is made from wood fibers, cotton, and other materials. Both hardwood and softwoods are used in a variety of paper and paperboard products. There are two primary paper manufacturing methods, mechanical and chemical. Mechanical papers are made from wood that has been physically reduced to fibers. Chemical papers are made using caustic soda, sodium sulfate, and various sulfides to reduce wood to fibers. In 1980, roughly 20 percent of the papers manufactured in the United States were mechanical papers and more than 50 percent were chemical.<sup>31</sup> Mechanical and chemical manufacturing techniques are chosen depending on the

**TABLE 4-8. PARTICULATE EMISSION FACTORS FOR  
SECONDARY ALUMINUM OPERATIONS<sup>a</sup>**

Operation	Uncontrolled		Baghouse		Electrostatic Precipitator		Emission factor rating
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	
Sweating furnace <sup>b</sup>	7.25	14.5	1.65	3.3	-	-	C
Smelting							
Crucible furnace <sup>b</sup>	0.95	1.9	-	-	-	-	C
Reverberatory furnace <sup>c</sup>	2.15	4.3	0.65 <sup>d</sup>	1.3 <sup>d</sup>	0.65	1.3	B
Chlorine demagging <sup>e</sup>							

<sup>a</sup> Reference 1. Emission factors for sweating and smelting furnaces expressed as units per unit weight of metal processed. For chlorine demagging, emission factor is kg/Mg (lb/ton) of chlorine used.

<sup>b</sup> Based on averages of two source tests.

<sup>c</sup> Uncontrolled, based on average of ten source tests. Standard deviation of uncontrolled emission factor is 1.75 kg/Mg (3.5 lb/ton), that of controlled factor is 0.15 kg/Mg (0.3 lb/ton).

<sup>d</sup> This factor may be lower if a coated baghouse is used.

<sup>e</sup> Based on average of ten source tests. Standard deviation of uncontrolled emission factor is 215 kg/Mg (430 lb/ton); of controlled factor, 18 kg/Mg (36 lb/ton).

quality requirements of the end product. The remainder of paper manufactured is recycled (25 percent) and additives (5 percent).

In addition to fiber, paper consists of numerous coatings, sizing agents, and colorants. In 1980, these additives constituted 3.5 percent of the components in paper made in the United States.<sup>31</sup> Coatings, used to make the paper strong and smooth, include clay, titanium oxide, calcium carbonate, zinc sulfide, talc, and synthetic silicates. Sizing agents make the paper water resistant and include rosin, hydrochemical and natural waxes, starches, glues, and cellulose derivatives. Colorants are primarily made of a wide range of inorganic elements. The most commonly used pigments are carbon black (black) and titanium oxide (white).

Inks are the other primary constituents of the paper. Inks consist of pigment and vehicle. Carbon-derived black pigments are the most common. Titanium oxide, zinc sulfide, and zinc oxide are also used in pigments. The vehicle is not actually applied to the paper as is the pigment, however, vehicle residues may remain in the paper. Printing vehicles include a variety of oils, waxes, and solvents. Letterpress and lithographic inks, which are commonly used on newsprint, use mineral oil, resin, and solvent vehicles. Xerographic, uv-cured, and laser printing inks use solvent, acrylic, and polyester-based vehicles.<sup>32</sup> Flexographic inks have wide applications and are gaining in popularity. These inks use numerous solvents as the printing vehicle.

#### **4.5.1 Primary Paper Recycling Technologies**

Plants that recycle wastepaper from MSW receive it from commercial collectors, wastepaper dealers, or directly from municipal collection programs. Table 4-9 presents an overview of the status of paper recycling. Once paper has arrived at the facility it is inspected and passed through a series of sorting stages (*i.e.*, magnets, trommel screens, manual sorting) that remove gross contaminants. Next the paper is pulped and the pulp is cleaned, deinked, and bleached. Technology used in wastepaper recycling plants varies depending on the paper grades accepted, as shown in Table 4-10. Facilities generating pulp for use in low-grade products (*e.g.*, brown paper bags and cardboard) use no deinking and little bleaching. Pulp used in higher-grade

**TABLE 4-9. GENERATION AND RECYCLING OF PAPER AND PAPERBOARD  
IN MSW, 1988**

	<b>Weight Generated (in Millions of Tons)</b>	<b>Weight Recovered (in Millions of Tons)</b>	<b>Percent Recycled</b>	<b>Discards (in Millions of Tons)</b>
<b>Nondurable Goods</b>				
Newspapers	13.3	4.4	33.3	8.9
Books and Magazines	5.3	0.7	13.2	4.6
Office Papers	7.3	1.6	22.5	5.7
Commercial Printing	4.1	0.6	14.6	3.5
Tissue Paper and Towels	3.0	Neg.	Neg.	Neg.
Paper Plates and Cups	0.7	Neg.	Neg.	Neg.
Other Nonpackaging Paper*	5.2	Neg.	Neg.	Neg.
<b>Total Paper and Paperboard Nondurable Goods</b>	<b>38.9</b>	<b>7.4</b>	<b>18.9</b>	<b>31.5</b>
<b>Containers and Packaging</b>				
Corrugated Boxes	23.1	10.5	45.4	12.6
Milk Cartons	0.5	Neg.	Neg.	Neg.
Folding Cartons	4.4	0.3	7.7	4.1
Other Paperboard Packaging	0.3	Neg.	Neg.	Neg.
Bags and Sacks	2.9	0.2	7.0	2.7
Wrapping Papers	0.1	Neg.	Neg.	Neg.
Other Paper Packaging	1.5	Neg.	Neg.	Neg.
<b>Total Paper and Paperboard Containers and Packaging</b>	<b>32.9</b>	<b>11.0</b>	<b>33.5</b>	<b>21.9</b>
<b>Total Paper and Paperboard</b>	<b>71.8</b>	<b>18.4</b>	<b>25.6</b>	<b>53.4</b>

\*Includes tissue in disposable diapers, paper in games and novelties, posters, tags, cards, etc.

Neg. = Negligible.

Source: Reference 23.

**TABLE 4-10. SPECIFIC PROCESSES ASSOCIATED WITH WASTEPAPER CATEGORIES**

<b>Wastepaper Category</b>	<b>Process</b>	<b>Finished Products</b>
Pulp substitutes	Pulping	Fine paper Tissue
Deinking grade paper	Pulping Screening Cleaning Deinking	Tissue Fine paper
Newspaper	Pulping Screening Cleaning Deinking	Newsprint Folding cartons
Mixed papers	Pulping Screening Cleaning	Packing Packaging Molded products
Corrugated	Pulping Screening Cleaning	Corrugating medium Linerboard Kraft towels

Source: Reference 33.

products must undergo more involved cleaning processes. Most facilities include some combination and configuration of the following types of steps and equipment.

- Material Inspection and Storage
- Conveyors
- Manual Sorting
- Magnetic Separators
- Trommel Screens
- Pulper
- Screens/Cleaners



- Separation
  - Flotation
  - Washing
- Clarification
- Bleaching
- Dewaterer/Thickener
- Effluent Treatment
- Sludge Disposal

Figure 4-2 depicts the generalized process flow of a paper recycling plant.

A number of chemical additives are vital to the processing of wastepaper. Table 4-11 lists chemical additives used in the deinking process. These chemicals are added at many points throughout the system, depending upon the technology used and the degree of pulp quality required for endproducts. Chemical additives remaining in washwater and sludge are handled by on site wastewater and sludge treatment systems. Many contaminants are found in the wastepaper stream that must be removed manually or by screens or filters throughout the process.

#### **4.5.1.1 *Material Inspection and Storage***

Wastepaper must be carefully inspected for quality before it can be used as a pulp supply. Aged or water-damaged papers are often discolored, which limits their use in high quality end products. Levels of contaminants, aging, and water damage must all be evaluated when the wastepaper arrives at the recycling facility. With current technology, roughly 70 percent of the mixed wastepaper that enters a facility can be used for recycled paper.<sup>34</sup> Twenty to 30 percent must be discarded, usually landfilled or incinerated. The inspection and storage area is generally arranged much like the tipping floor of a materials recovery facility. Trucks deliver loads of loose or baled wastepaper and dump them on a concrete receiving floor. Paper is stored in piles or in concrete bins or compartments. Bucket-loaders and forklifts are used to move the paper around the facility.

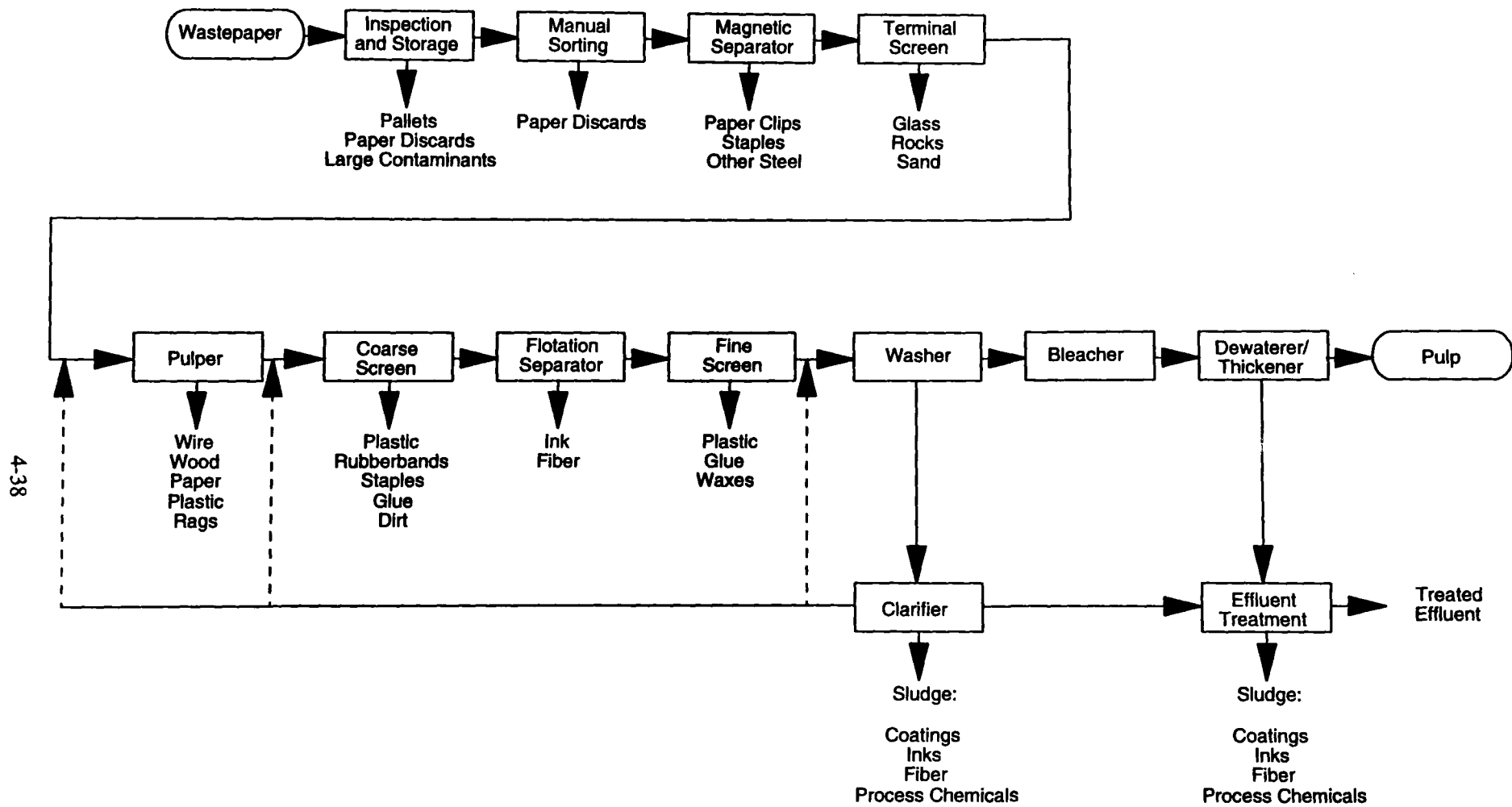


Figure 4-2. Paper recycling process flow.

**TABLE 4-11. DEINKING CHEMICALS**

<b>Deinking Chemical</b>	<b>Structure/Formula</b>	<b>Function</b>	<b>Dosage (% of Fiber)</b>
Sodium Hydroxide	NaOH	Fiber swelling Ink breakup Saponification Ink dispersion	3-5
Sodium Silicates	Na <sub>2</sub> SiO <sub>3</sub> (hydrated)	Wetting Peptization Ink dispersion Alkalinity ledger and buffering Peroxide stabilization	3-5
Sodium Carbonate	Na <sub>2</sub> CO <sub>3</sub>	Alkalinity Buffering Water softening	3-5
Sodium or Potassium	(NaPO <sub>3</sub> ) <sub>n</sub> , n=15 Hexametaphosphate Na <sub>5</sub> P <sub>3</sub> O <sub>10</sub> Tripolyphosphate Tetrasodium pyrophosphate	Metal ion sequestrant Ink dispersion Buffering Alkalinity Detergency Peptization	0.2-1.0
Nonionic Surfactants	Ethoxylated linear alcohol Ethoxylated alkyl phenols	Ink dispersion Wetting Emulsification Solubilizing Ink Removal	0.2-2.0
Solvents	C <sub>1</sub> -C <sub>14</sub> aliphatic saturated hydrocarbons	Ink softening Solvation	0.5-2.0
Hydrophilic	CH <sub>2</sub> CHC=OOH(Na) <sub>n</sub>	Ink dispersion	0.1-0.5
Polymers	Polyacrylates	Antiredeposition	0.1-0.5
Fatty Acid Soap	CH <sub>3</sub> (CH) <sub>16</sub> COOH Stearic acid	Ink flotation acid	0.5-5.0
Hydrogen Peroxide	H <sub>2</sub> O <sub>2</sub>	Bleach	1.0
Sodium Hydrosulfite	Na <sub>2</sub> S <sub>2</sub> O <sub>4</sub>	Bleach	0.5-1.0
Chlorine	CL <sub>2</sub> OCl <sup>-</sup>	Bleach	0.2-1.0

Source: Reference 35

#### **4.5.1.2 Conveyor Systems**

Conveyor belts frequently are used at the beginning of many paper recycling facilities as part of the sorting arrangement and to feed wastepaper to the pulper. Specialized conveyors are sometimes engineered to turn paper over or spread recyclables to a uniform depth to assist manual sorters.<sup>36</sup> In many facilities, conveyors are mounted at or below floor level on the tipping floor so that material may be pushed directly onto the belt.

#### **4.5.1.3 Manual Sorting**

Unless a consistently high quality wastepaper stream is available (*i.e.*, in-plant scrap), most plants perform some degree of sorting prior to pulping. Sorting wastepaper by quality, color, or grade is essentially a manual operation. The wastepaper stream is usually sorted as it passes workers on a conveyor belt. Both positive and negative sorting techniques are used. Negative sorting is the removal of contaminants from the recyclable stream. Negative sorting is marginally effective because sorters inevitably allow some contaminants to pass their station. Positive sorting removes the desired grade of paper from the mixed paper stream and results in lower contaminant levels. The Garden State Paper Company in Garfield, New Jersey uses both systems to sort different paper grades.<sup>37</sup>

Elevated sorting platforms and sunken conveyors are common design features at paper processing facilities. This reduces the number of times recyclables must be handled. Increasingly, plant designs place sorting stations directly over conveyor belts and/or processing equipment. This arrangement is efficient because it allows workers to drop sorted papers or waste into chutes that carry it to further processing.

#### **4.5.1.4 Magnetic Separators**

Magnetic separators are used in some wastepaper processing facilities to separate ferrous metals from highly-contaminated papers. In general, magnetic separators in paper plants employ a suspended magnet to remove ferrous metals from a conveyor belt passing beneath it.<sup>38</sup> Separated

material is then dropped into a bin for disposal. Metal contaminants commonly include paper clips, staples, and wire.

#### **4.5.1.5 *Trommel Screens***

Trommels are inclined screen cylinders that are used to sort fine materials (*i.e.*, glass fragments) from the wastepaper stream. Wastepaper is fed in one end of a rotating trommel screen by a conveyor and discharged to a conveyor or storage container at the other end. Fine material that falls through the trommel screen is collected by a trough that lines the outside of the screen and diverted to a conveyor or storage container.

#### **4.5.1.6 *Pulper***

After undergoing some combination of the sorting steps discussed, wastepaper is passed to the pulper. The pulper is the initial recycling step for most wastepaper recycling systems. Its function is to "fiberize" the paper and to break-down contaminants with a minimum amount of fiber degradation. The pulper is basically a large mixing vat that contains spinning paddles or blades that churn the paper in a water-based slurry. Wastepaper bales that have been broken apart are evenly fed to open pulping vats manually or by a conveyor belt. Some pulpers use metal rotors and discs to grind fibers, while others rely on fiber-to-fiber contact to break down the paper. Heated water (generally below 150 degrees Fahrenheit) and caustic chemicals, such as sodium hydroxide, are added to assist in the pulping process. The pH of pulper slurry is raised to between 10 and 12. The alkalinity swells fibers releasing inks into suspension. It also hydrolyzes ink vehicles and binders. Some screening of large contaminants takes place as the pulp is drained from the pulper. From the pulper the pulp slurry, or "stock," is carried by pipes to subsequent process steps.

Recently, high-consistency pulpers have gained popularity. These pulpers rely on a higher fiber concentration (roughly 15 percent) to break down the paper. High fiber concentrations are obtained by using less water. This method reduces the amount of chemicals and energy required.

This method also permits larger contaminant particles to remain unbroken in the pulp, which facilitates subsequent flotation separation.

#### **4.5.1.7 *Screening/Cleaning***

Most plants include a number of screening/cleaning steps throughout the system. Screens varying in coarseness are used to remove a range of progressively finer contaminants. Rotors are often used to press pulp through the screens.

#### **4.5.1.8 *Separators***

Separation is the step that removes the ink from the pulp. Flotation and washing are the primary deinking technologies used. Historically, flotation systems have been popular in Europe and washing systems have been common in the United States. At present, the flotation method is growing in popularity in the United States. Deinking systems separate ink by either floating large ink particles to the surface of the pulp or washing dissolved inks from the pulp. Both techniques generate ink-laden sludge in the form of a froth or wastewater. Most systems pass liquid wastes to the clarifier to remove ink, fiber, and other contaminants from the water.

**4.5.1.8.1 *Flotation Separators*** Flotation systems float inks to the top of the pulp slurry and then skim them from the surface. Small ink particles are agglomerated into larger clusters that are floated to the surface using dispersed and some dissolved air that is injected into the bottom of the flotation tank. The ink clusters attach themselves to the air bubbles and are floated to the surface. The resulting inky foam is mechanically skimmed from the surface of the slurry. The ink foam is usually dewatered prior to disposal.

For flotation to work effectively, ink must be stabilized as insoluble particles. Fatty acids are added to the pulp to form calcium soaps that act as stabilizers.<sup>39</sup> Fatty acid soaps (surfactants) and ethoxylates are commonly used along with calcium chloride, which assists in converting the fatty acid into insoluble soap. Typical concentrations are approximately 80 pounds of surfactant per ton of dry pulp produced.<sup>40</sup> In addition, clay enhances the process of ink removal, so it is

frequently added to flotation systems. This has created a potential demand for some heavily-coated magazine paper grades.

**4.5.1.8.2 Washing Separators** Washing separation systems operate by dispersing ink into tiny particles that can be washed from the pulp. Surfactants are necessary to stabilize the ink in solution and make it hydrophilic. Classes of alkylphenol ethoxylates and linear alcohol ethoxylates are commonly used as dispersants in washing systems.<sup>39</sup> Water is clarified and added to the pulp slurry before it enters the washer. There are a variety of washing systems available, and the most common types of washers are described below.<sup>41</sup>

*Sidehill screens* are basically inclined troughs lined with a screen. Pulp released at the top of the screen gradually tumbles to the bottom under its own weight. Water passes from the fiber and through the screen into a collection tank below. This equipment is generally an open-air arrangement.

*Gravity deckers* use spinning horizontal screen drums that accept a coating of pulp slurry. Water drains to the center of the drum and is removed. The pulp cake is scraped off as it dries.

*Inclined screw extractors* use a screw to pull the pulp slurry up through an inclined screen cylinder. Water drains away as the pulp rises in the cylinder.

*Vacuum filters* draw water from the slurry by sucking the pulp against screens.

*Screw Presses* extract water from the slurry by compacting the pulp in an enclosed chamber using a large screw. Water is forced from the pulp through perforations in the chamber walls.

All of these types of equipment are enclosed systems, except for the sidehill screen. Wastewater is drawn from the pulp and usually sent to the clarifier for treatment. Using clean water for washing is not practical for environmental reasons because of the required water volumes and

in terms of chemical use.<sup>41</sup> For these reasons, recycled wastewater streams are commonly used throughout the washing system. If necessary, pulp passes from the separation stage to a bleaching stage.

#### **4.5.1.9 Clarifier**

Process water is commonly treated and reused to conserve process chemicals. Water removed from washing and flotation is discharged to the clarifier where ink and other contaminants are removed. The clarified liquid is then recycled throughout the process to dilute the pulp. Most paper facilities pass unclarified water backward through the process. Cleaner water passes from the final washing stage to earlier and dirtier stages. The water is drained when it reaches the first washer and is then sent to the clarifier, treated, and recycled. A large percentage of liquid and solid plant effluents and emissions is generated at the clarifier.

Most clarifiers are designed as large vats or tanks; some are enclosed. A filter is often the first clarification stage, intended to reduce the loss of fiber and remove large contaminants. During washing, dispersants break the inks into tiny particles. Clarification reverses this process by adding flocculants to reaggregate the ink into larger particles that can then be floated or settled and removed. Low-molecular weight cationic liquid polymers and high-molecular-weight anionic polymers are used as flocculants depending on the wastewater makeup.<sup>39</sup> Dissolved air flotation is generally used to float the flocculated particles to the surface of the clarifier. The flocced particles are skimmed from the surface by a scoop mechanism that slowly rotates on an axis in the middle of the tank. A sediment sump draws heavy material from the bottom of the tank. Skimmed material and sludge are usually thickened and incinerated or landfilled. Wastewater is recycled through the plant or treated and released.

#### **4.5.1.10 Bleaching**

Once the deinking process has removed ink particles from the pulp, bleaching may be necessary to attain necessary brightness requirements for certain endproducts. A majority of paper recycling plants bleach the fibers to improve their brightness. Bleaching is accomplished by



adding bleaching agents to pulp before it enters a screw mixer. The fiber and bleach mixture is often allowed to soak and react in a holding tank or tower after mixing. The entire bleach process is usually enclosed. Water flowing from the reaction is clarified and reused or released to the plant's effluent control system.

Chlorine-based bleaches, such as hypochlorite, are commonly used throughout the paper industry. A 1987 survey by U.S. EPA Region V of paper mills revealed that 12 out of 14 deinking facilities surveyed used chlorine bleaching.<sup>42</sup> Concerns surrounding the use of chlorine-based bleaching agents have spurred the use of alternative bleaching agents. Hydrosulfite, peroxide, and oxygen-based bleaches are frequently used as alternatives when lower-quality brightness levels are acceptable.

#### **4.5.1.11 Dewatering Equipment/Thickener**

Some deinking facilities are directly connected to papermaking mills, allowing the bleached pulp to be sent directly to the paper mills. Sometimes, pulp must be stored or transported before being used in paper production. To reduce the volume and weight of the pulp, it is processed through a dewaterer. There are numerous dewaterer designs using screens, screws, presses, and vacuum systems to draw water from the pulp.

### **4.5.2 Air Emissions**

No information specifically pertaining to air emissions from pulping of recycled paper was available in AP-42 or AIRS. AP-42 Volume I contains data on the characterization of and emission factors for chemical wood pulping. This information is discussed in this section because reclaimed paper would be subject to the same or similar processes.

#### **4.5.2.1 Characterization**

Chlorophenols, chloroform, chloroethylene, chlorobenzene, methylene chloride, and carbon tetrachloride may be emitted during or after the bleaching process. The recovery furnace, lime

kiln, and smelt dissolving tank emit particulate matter composed primarily of sodium salts with some calcium salts from the lime kiln. A number of reduced sulfur compounds are emitted, including hydrogen sulfide, methyl mercaptan, dimethyl sulfide and dimethyl disulfide. Sulfur dioxide emissions result from the oxidation of reduced sulfur compounds in the recovery furnace. Carbon dioxide and nitrogen oxides are also emitted by the recovery furnace. Boilers used to provide heat and energy may also be a source of a number of the above pollutants, depending on the fuel being fired.

The pulping and papermaking processes produce significant amounts of wastewater. Many compounds found in wastewater may become airborne after release to treatment ponds.

#### **4.5.2.2 *Quantification***

Table 4-12 contains emission factors from *AP-42* for Kraft pulping. As stated earlier, emissions data for facilities using strictly reclaimed paper as a source of pulp were not discovered during this project. As a result, quantification of emissions for this scenario is not available at this time. The use of recycled paper is expected to increase significantly in the near future. One study shows a 53 percent increase in consumption by mills in the U.S. and Canada by 1995.<sup>43</sup>

## **4.6 GLASS RECYCLING**

Post-consumer glass can be classified into functional groups depending on the forming method used. Three groups, container glass (bottles and jars), flat glass (window glass, plate glass, float glass, tempered glass, and laminated glass), and pressed and blown glass (ornamental glass and stemware) constitute virtually all of glass produced.<sup>44</sup> As of 1988, 6.9 percent (12.5 million tons) of all MSW generated in the United States consisted of glass products, 92 percent of which was container glass, as shown in Table 4-13.

**TABLE 4-12. EMISSION FACTORS FOR KRAFT PULPING<sup>a</sup>**

**EMISSION FACTOR RATING: A**

Source	Type of control	Particulates		Sulfur dioxide (SO <sub>2</sub> )		Carbon monoxide (CO)		Hydrogen sulfide (S <sup>m</sup> )		RSH, RSR, RSSR (S <sup>m</sup> )	
		kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Digester relief and blow tank	Untreated <sup>b</sup>	-	-	-	-	-	-	0.02	0.03	0.6	1.2
Brown stock washer	Untreated <sup>b</sup>	-	-	-	-	-	-	0.01	0.02	0.2 <sup>e</sup>	0.4 <sup>e</sup>
Multiple effect evaporator	Untreated <sup>b</sup>	-	-	-	-	-	-	0.55	1.1	0.05	0.1
Recovery boiler and direct evaporator	Untreated <sup>d</sup>	90	180	3.5	7	5.5	11	6 <sup>e</sup>	12 <sup>e</sup>	1.5 <sup>e</sup>	3 <sup>e</sup>
	Venturi scrubber <sup>f</sup>	24	48	3.5	7	5.5	11	6 <sup>e</sup>	12 <sup>e</sup>	1.5 <sup>e</sup>	3 <sup>e</sup>
	ESP	1	2	3.5	7	5.5	11	6 <sup>e</sup>	12 <sup>e</sup>	1.5 <sup>e</sup>	3 <sup>e</sup>
	Auxiliary scrubber	1.5-7.5 <sup>g</sup>	3-15 <sup>g</sup>					6 <sup>e</sup>	12 <sup>e</sup>	1.5 <sup>e</sup>	3 <sup>e</sup>
Noncontact recovery boiler without direct contact evaporator	Untreated	115	230	-	-	5.5	11	0.05 <sup>h</sup>	0.1 <sup>h</sup>	-	-
	ESP	1	2	-	-	5.5	11	0.05 <sup>h</sup>	0.1 <sup>h</sup>	-	-
Smelt dissolving tank	Untreated	3.5	7	0.1	0.2	-	-	0.1 <sup>j</sup>	0.2 <sup>j</sup>	0.15 <sup>j</sup>	0.3 <sup>j</sup>
	Mesh pad	0.5	1	0.1	0.2	-	-	0.1 <sup>j</sup>	0.2 <sup>j</sup>	0.15 <sup>j</sup>	0.3 <sup>j</sup>
	Scrubber	0.1	0.2	-	-	-	-	0.1 <sup>j</sup>	0.2 <sup>j</sup>	0.15 <sup>j</sup>	0.3 <sup>j</sup>
Lime kiln	Untreated	28	56	0.15	0.15	0.05	0.1	0.25 <sup>m</sup>	0.5 <sup>m</sup>	0.1 <sup>m</sup>	0.2 <sup>m</sup>
	Scrubber or ESP	0.25	0.5	-	-	0.05	0.1	0.25 <sup>m</sup>	0.5 <sup>m</sup>	0.1 <sup>m</sup>	0.2 <sup>m</sup>
Turpentine condenser	Untreated	-	-	-	-	-	-	0.005	0.01	0.25	0.5
Miscellaneous <sup>b</sup>	Untreated	-	-	-	-	-	-	-	-	0.25	0.5

<sup>a</sup> Reference 1. Factors expressed in unit weight of air dried unbleached pulp (ADP). RSH = Methyl mercaptan. RSR = Dimethyl sulfide. RSSR = Dimethyl disulfide. ESP = Electrostatic precipitator. Dash = No data.

<sup>b</sup> If noncondensable gases from these sources are vented to lime kiln, recovery furnace or equivalent, the reduced sulfur compounds are destroyed.

<sup>c</sup> Apply with system using condensate as washing medium. When using fresh water, emissions are 0.5 (0.1).

<sup>d</sup> Apply when cyclonic scrubber or cascade evaporator is used to direct contact evaporation, with no further controls.

<sup>e</sup> Usually reduced by 50 percent with black liquor oxidation and can be cut 95 - 99 percent when oxidation is completed and recovery furnace is operated optimally.

<sup>f</sup> Apply when venturi scrubber is used for direct contact evaporation, with no further controls.

<sup>g</sup> Use 7.5 (15) when auxiliary scrubber follows venturi scrubber, and 1.5 (3) when it follows ESP.

<sup>h</sup> Apply when recovery furnace is operated optimally to control total reduced sulfur (TRS) compounds.

<sup>j</sup> Usually reduced to 0.01 g/kg (0.02 lb/ton) ADP when water low in sulfides is used in smelt dissolving tank and associated scrubber.

<sup>m</sup> Usually reduced to 0.015 g/kg (0.03 lb/ton) ADP with efficient mud washing, optimal kiln operation and added caustic in scrubbing water. With only efficient mud washing and optimal process control, TRS compounds reduced to 0.05 g/kg (0.08 lb/ton) ADP.

<sup>n</sup> Includes knotter vents, brownstock seal tanks, etc. When black liquor oxidation is included, emissions are 0.3 (0.6).

**TABLE 4-13. GENERATION AND RECYCLING OF GLASS IN MSW, 1988**

<b>Product Category</b>	<b>Weight Generated (in Millions of Tons)</b>	<b>Weight Recovered (in Millions of Tons)</b>	<b>Percent Recovered</b>	<b>Discards (in Millions of Tons)</b>
<b>Durable Goods*</b>	1.2	Neg.	Neg.	1.2
<b>Containers and Packaging</b>				
Beer and Soft Drink Bottles	5.4	1.1	20.0	4.3
Wine and Liquor Bottles	2.0	0.1	5.0	1.9
Food and Other Bottles and Jars	3.9	0.3	7.7	3.6
<b>Total Glass Containers</b>	11.3	1.5	13.3	9.8
<b>Total Glass</b>	12.5	1.5	12.0	11.0

\*Glass as a component of appliances, furniture, consumer electronics, etc.

Neg. = Negligible.

Source: Reference 23.

Nearly 100 percent of the glass recycled from MSW was container glass. Because of the intended longevity of the product, plate glass does not provide a consistent market for recyclers and little is recycled. Pressed and blown glass is also generally formed into items considered to be "durable goods." Because of the variety of methods used in its production, as well as the variety of raw materials used to produce it, pressed and blown glass is also seldom recycled.

The most common types of glass are soda-lime, borosilicate, lead silicate, and opal. Approximately 77 percent of all glass manufactured is soda-lime glass. Glass food and beverage containers are manufactured exclusively from this glass type. Borosilicate glass, a common example of which is Pyrex (produced by Owens-Corning Glassware), comprises approximately 11 percent of all glass produced. Lead silicate and opal glass comprise five percent and seven percent, respectively, of glass produced.<sup>44</sup> Other less common glass types are produced on a smaller scale for numerous markets; the production and recycling of these glass types can be considered negligible due to the low production volumes.

Soda-lime glass is used exclusively in the production of food and beverage containers because of the ease and efficiency with which it is produced. Three colors of soda-lime glass, clear (flint), green, and amber, are commonly produced and recycled. Green and amber glass are produced by adding minerals such as chromium trioxide, iron oxide, and cupric oxide for green glass and sodium sulfide for amber glass to a flint batch.<sup>45</sup> Recyclers generally segregate by color because clear glass can be used in any batch, whereas colored glass is generally used to produce recycled products in a specific color.

Borosilicate glass is used commonly in industry as well as in the commercial market. The formula for each type of borosilicate is so precise that cullet from different sources is not generally mixed, resulting in limited recycling potential. Lead silicate and opal glass constitute a minor portion of the glass industry. Because both glass types are considered to be "durable," very little is thrown away and therefore very little is recycled.<sup>44</sup>

#### **4.6.1 Glass Processing**

The basic method used to recycle glass waste varies only slightly nationwide.<sup>46</sup> In general, when separated glass arrives at a processing facility the following steps occur:

- Manual sorting
- Mechanical sorting
- Crushing and grinding
- Mechanical removal of metal, plastics, and any other small foreign materials
- Segregation of cullet by size and shipment to a manufacturer

Depending on the grade of cullet and its expected market, it may be rinsed with water following the above steps.

While numerous variations of this process are employed, approximately 90 to 95 percent of the glass processing facilities in the United States employ these methods.<sup>46</sup> Very few technologically

advanced separation methods are used, primarily because the price and profits associated with cullet are so low that most companies cannot afford expensive machinery.

The following sections discuss the most conventional process used to produce glass cullet. Figure 4-3 presents a schematic diagram of a typical glass recycling process.

Although the steps outlined below are used consistently in glass recycling facilities, the order that the steps are applied varies from facility to facility. For example, one facility may magnetically separate the waste before crushing, while another may do so after crushing. Others may use magnets before and after crushing. The operators of a facility rely upon trial and error to determine the most effective means of producing cullet for their facility. No single method has been proven to work most effectively under all circumstances.

#### **4.6.1.1 *Manual Sorting***

When glass arrives at a processing facility, it has usually been pre-sorted by color. At the processing facility, it is first emptied into a surge hopper which deposits the glass onto a conveyor belt. Generally, a facility will process different colored glass on different belts or at different times.<sup>47</sup> The glass passes along the conveyor where workers remove any large debris such as stones, branches, or other non-glass material.<sup>46</sup> Most facilities process glass at a rate that requires only two or three sorters per conveyor.

#### **4.6.1.2 *Magnetic Separation***

Magnetic separation of ferrous material typically follows hand sorting. The most common type of magnet used to remove ferrous waste is the cross-conveyor magnet.<sup>48</sup> Magnets are suspended over the conveyor belt at heights inversely proportional to the force of the magnets. A belt system, arranged perpendicular to the conveyor, surrounds the magnets and moves the attracted ferrous material off to the side. After the ferrous material moves over the edge of the conveyor and out of the magnetic field, it drops or is scraped into a waste chute.<sup>49</sup>

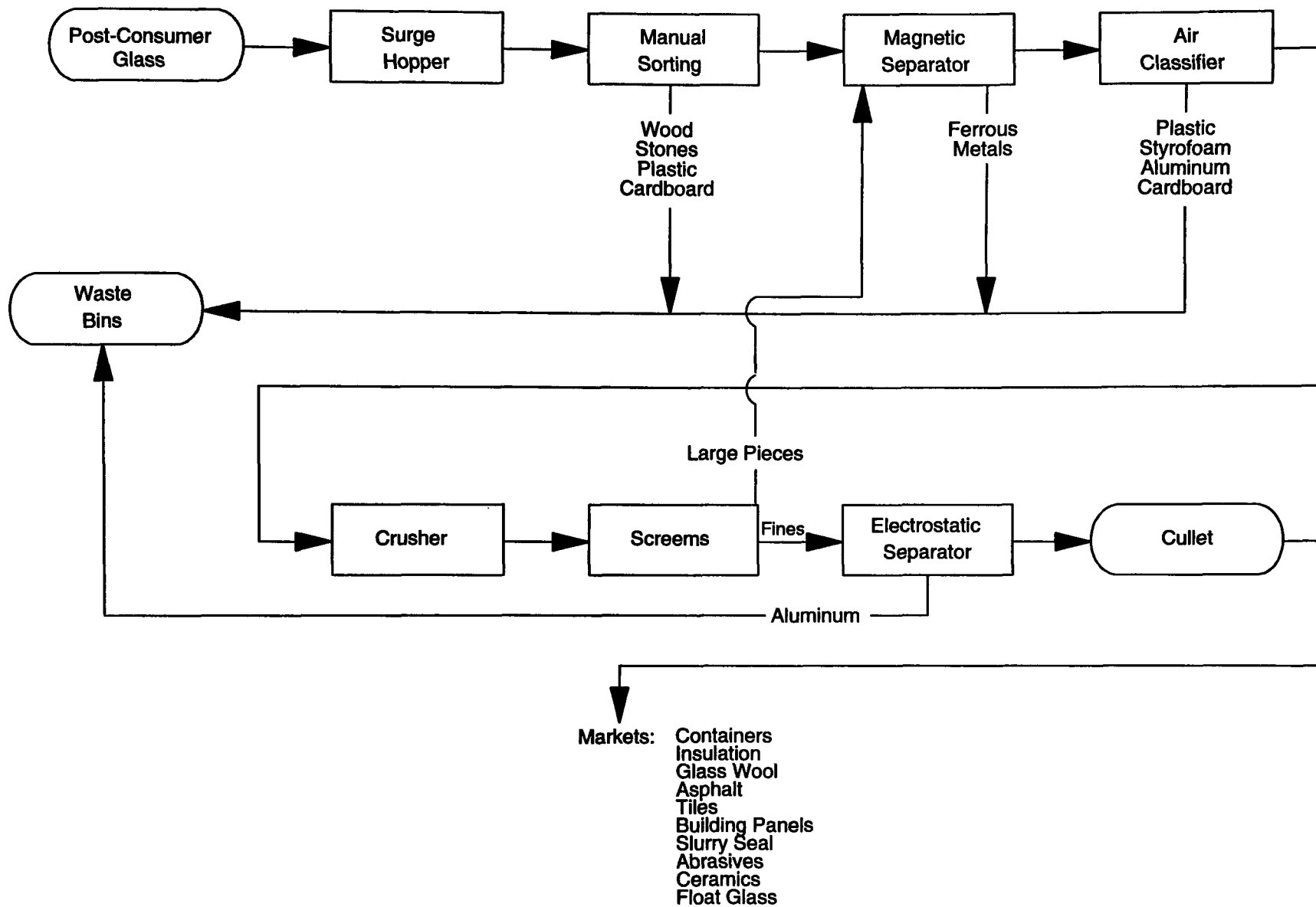


Figure 4-3. The glass recycling process.

Other types of magnets, such as drum magnets and pulley magnets, are occasionally used in this step. Drum magnets are encased within a revolving drum located over the conveyor. When ferrous metals are attracted to the magnet, they adhere to the drum surface, which rotates out of the magnetic field and into a waste bin. Pulley magnets are located at the end of a conveyor. When material passes over the end, non-ferrous material is carried onto another conveyor. Ferrous material adheres to the conveyor until it passes out of the magnetic field and into a waste bin.

#### **4.6.1.3 *Velocity Trap/Air Classifier***

After the glass material is passed through the magnetic separator, it is often passed through some type of air classifier or bag vacuum to remove the lighter organic material, paper, plastic, and styrofoam. A bag vacuum is simply a powerful vacuum or series of vacuums (up to 150) placed over the conveyor belts. Air is passed through a chute and bag system, similar to a common household vacuum. The chute is placed over the conveyor and the dust and fines are pulled up. The bags are semi-porous so air passes through but particulates do not. This system effectively removes the lighter material while allowing the heavier glass to remain on the conveyor.<sup>46</sup>

In a less common method, glass is passed across a vibrating screen. An upward air flow blows the light material away from the heavier glass. A similar system of air classification passes glass into a vertically oriented, hollow cylinder. The cylinder has a constant upward wind current that lifts the lighter material out but allows the heavier objects to fall.<sup>50</sup>

#### **4.6.1.4 *Crusher/Grinder***

After the glass is separated from the extraneous waste, it is ready to be crushed. Two types of crushers are commonly used. Many glass recycling facilities use impact crushers to produce cullet.<sup>47</sup> In this process, a conveyor deposits the glass into an inclined chute where the force of gravity breaks it against transverse steel rods or chains. The broken glass and debris is then deposited back onto a conveyor belt.



The second commonly used machine is a jaw crusher, which consists of two vertical steel plates into which glass is deposited. Initially, one of the two plates is positioned at an angle to form a housing to catch the glass. When glass is loaded, the two plates actively grind it into cullet, which is then redeposited onto a conveyor.<sup>48</sup> This technique is also commonly used to process glass into powder, but very few facilities powder glass.<sup>47</sup>

#### **4.6.1.5 Screening**

After glass is crushed, a conveyor moves it onto a vibrating screen or series of screens, which allow smaller glass shards to pass through to the next stage of the recycling process. The larger pieces, accompanied by any plastic and aluminum bottle caps, are conveyed back to the sorters or magnetic separators for reprocessing. Cullet that has not been crushed to a specified size passes through the separators and crushers until it meets the size specifications of the facility.<sup>47</sup> This process may be repeated three or four times before the cullet is crushed to an acceptable size. Most container manufacturers (one of the less stringent markets for cullet) require the cullet to be crushed to pieces smaller than 6 millimeters.<sup>51</sup>

#### **4.6.1.6 Aluminum Separation**

After being passed through each of the aforementioned processes, cullet may still contain waste aluminum. Most processing facilities use an electrostatic or eddy-current magnet to remove the aluminum after crushing and screening.<sup>48</sup> In both electrostatic and eddy-current separators, the process stream is charged by a high-voltage ion source. The charged material is then passed over the edge of a conveyor onto a rotating, electrically grounded drum. Highly conductive material (aluminum) rapidly dissipates its charge to the drum and falls into a waste bin. Non-conductive material (glass) remains adhered to the drum's surface for a greater distance and falls onto another conveyor.<sup>7</sup>

#### **4.6.2 Air Emissions**

Particulate is generated during crushing and grinding operations. Some facilities use air scrubbers to cleanse the air.<sup>7</sup> No information was readily available on the frequency of scrubber use for this process. Many individual processes contribute to the amount of glass dust in the air, but the airborne levels in recycling plants are difficult to quantify. No negative environmental effects have been attributed to glass recycling.<sup>50</sup>

#### **4.7 PLASTICS RECYCLING**

Plastics are broadly classified by their polymer structure as either thermoplastic or thermoset resins. Thermoplastics are recycled because they can be melted and reformed, while the cross-linked polymers of thermoset resins cannot. Table 4-14 lists U.S. sales figures, in pounds, of the six commonly recycled thermoplastic resins for 1990.

In the late 1980s, the Society of the Plastics Industry (SPI) voluntarily devised and implemented a system of seven codes to facilitate the identification and separation of common thermoplastic resins used in packaging applications. The symbols usually appear on the bottoms of containers and other disposable plastic items. The symbol consists of three arrows arranged head to tail in a triangular shape. The number appearing in the center of the triangle identifies the resin type. The common resins with their respective number identifiers are: (1) polyethylene terephthalate; (2) high density polyethylene; (3) vinyl; (4) low density polyethylene; (5) polypropylene; and (6) polystyrene. A "7" appearing within the symbol indicates "other" and may include mixtures or layers of resins.

Table 4-15 lists the various plastic goods recycled in 1988 and their contributions to recycling of plastics in general. At present, containers made from polyethylene terephthalate (PET) and high-density polyethylene (HDPE) are the only post-consumer plastics being recycled in significant quantities. These resins comprised one-half, or 0.1 million tons, of the plastic

**TABLE 4-14. NET U.S. RESIN SALES OF COMMONLY RECYCLED THERMOPLASTIC RESINS (1990)**

<b>Type</b>	<b>Million Lbs.</b>	<b>Example Products</b>
Low-density Polyethylene (LDPE)	10,859	Garbage bags Coated paper Clear film Wire coatings
Polyvinyl Chloride (PVC)	9,297	Construction pipe Blister packs Food wrap Cooking oil bottles Floor tiles
High-density Polyethylene (HDPE)	8,505	Milk and detergent bottles Heavy-duty films Wire and cable insulation
Polypropylene (PP)	8,132	Yogurt and margarine tubs Fishing nets Drinking straws Auto fenders Auto battery cases
Polystyrene (PS)	5,137	Disposable foam dishes and cups Egg cartons Cassette tape cases Foam insulation
Polyethylene Terephthalate (PET)	2,139	Soft drink bottles Synthetic textiles X-ray and photographic film Magnetic tape

Source: Reference 2, 52

**TABLE 4-15. GENERATION AND RECYCLING OF PLASTICS IN MSW, 1988**

<b>Product Category</b>	<b>Weight Generated (in Millions of Tons)</b>	<b>Weight Recovered (in Millions of tons)</b>	<b>Percent Recovered</b>	<b>Discards in (Millions of tons)</b>
<b>Durable Goods<sup>(a)</sup></b>	4.1	<0.1	1.5	4.1
<b>Nondurable Goods</b>				
Plastic Plates and Cups	0.4	Neg.	Neg.	0.4
Clothing and Footwear	0.2	Neg.	Neg.	0.2
Disposable Diapers(a)	0.3	Neg.	Neg.	0.3
Other Misc. Nondurables(b)	3.8	Neg.	Neg.	3.8
<b>Total Plastics Nondurable Goods</b>	4.6	Neg.	Neg.	4.6
<b>Containers and Packaging</b>				
Soft Drink Bottles	0.4	0.1	21.0	0.3
Milk Bottles	0.4	Neg.	<1.0	0.4
Other Containers	1.7	Neg.	Neg.	1.7
Bags and Sacks	0.8	Neg.	Neg.	0.8
Wraps	1.1	Neg.	Neg.	1.1
Other Plastic Packaging	1.2	Neg.	Neg.	1.2
<b>Total Plastics Containers and Packaging</b>	5.6	0.1	1.6	5.5
<b>Total Plastics</b>	14.4	0.2	1.1	14.3

(a) Appliances, toys, furniture, etc.

(b) Does not include non-plastic materials in diapers.

Neg. = Negligible.

Source: Reference 23.

recycled in 1988. Both resins are recycled at high rates because of their substantial use in packaging. Most PET is used to manufacture carbonated beverage containers, twenty-one percent of which were recycled in 1988. The high recycling rate is due to elevated collection levels in states with bottle bill legislation. HDPE is also used in base cups for PET bottles. HDPE is easily recyclable and is considered a resin of choice for numerous applications. However, less than one percent of HDPE milk bottles produced are currently recycled.

Limitations of collection systems and other factors have hindered reclamation of the other coded resins, which include: low-density polyethylene (LDPE), vinyl (V), polypropylene (PP), polystyrene (PS), and others. These resins appear in a range of products from building materials and luggage to egg cartons and garbage bags. In 1990, these resins together represented more than 34 billion pounds of potentially recyclable plastics, 8.9 billion pounds of which were used in packaging.<sup>52</sup>

Reclamation facilities acquire recyclable resins from various recycling programs. The resins are purchased as single resins (homogeneous) or mixed resins (heterogeneous). In general, recyclable plastics are separated into pure resin streams before being used as supplements to virgin feedstocks. The need for separation is primarily due to differences in melt characteristics. Commingled plastics recycling represents the significant exception to this rule. This technology allows a mixed stream of plastic wastes to be manufactured into dense products such as plastic lumber for outdoor applications.

#### **4.7.1 Processing**

This section presents an overview of the general processing steps to reclaim plastics, details resin-specific processes, and describes commingled resin processing.

Plastics reclamation systems vary widely depending upon the type of raw materials processed, the degree of processing, and the specific technology used. Regardless of the materials accepted at a reclamation facility, or the physical condition of the waste, plastics are generally processed using some combination of the following steps:

- Manual sorting
  - Shredding and grinding
  - Washing
- Separation (air classification, flotation, hydrocyclone)
- Drying
- Aluminum separation
- Extrusion

This section describes the general technologies associated with these steps. Reclamation of soft drink bottles, the most frequently recycled plastic product, generally follows the described process. Soft drink bottles are composed of three resins (PET, HDPE, PP), aluminum, and a paper label. Figure 4-4 presents an overview of a plastics recycling system with process inputs and outputs.

Due to their large volume, more and more plastics arrive at processing centers either shredded, in bales, or some in other compacted form. A hydraulic bale breaker can be used to break bales apart. Some facilities prefer to receive unaltered containers because of unique sorting and separation methods. At this point, the plastics are fed onto a conveyor or into a bin on the processing line and reclamation begins.

#### **4.7.1.1 *Manual Sorting***

The first processing step performed at a plastics recycling facility is hand sorting, except in cases where plastics are received preshredded. Since few reliable automated sorting technologies exist for separating plastics, most facilities integrate some type of hand sorting into their system. Recyclers that accept a heterogeneous resin stream may employ hand sorting as the primary method of resin separation. Any necessary separation by color must also be done by hand. Facilities accepting pre-sorted or homogeneous plastics may also use hand sorting to guarantee the quality of the material stream.

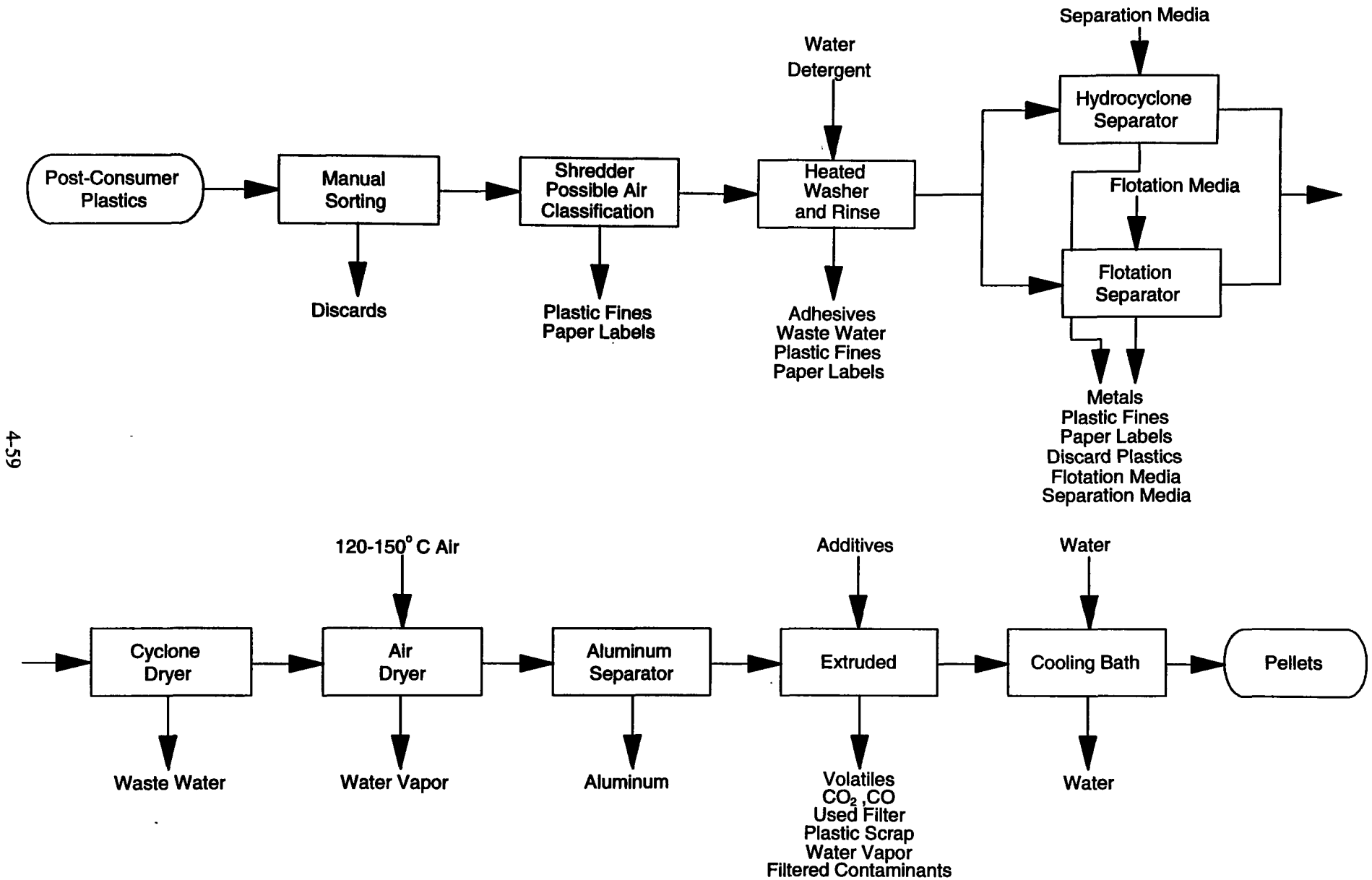


Figure 4-4. Overview of plastics recycling process with inputs and outputs.

#### **4.7.1.2 Shredding and Grinding**

Most processors of post-consumer plastic waste convert the raw plastic waste into a stream of plastic flakes of uniform size (1/4 to 1/2 inch on a side) that can be accepted by subsequent cleaning and separation equipment. Plastics are generally "flaked" using one of a large variety of grinders, shredders, or granulators currently available. These machines cut or shear the plastics with blades or sharp rotors. Shredding allows caps, labels, HDPE base cups, security closure rings, and other impurities to be separated from the bulk of the container during washing and automated separation. For processes requiring smaller particles, a second grinding stage may be employed after initial shredding.

Plastics are fed to the shredder or grinder by a gravity feed or conveyor system. Conveyor systems provide a more even introduction of material and allow for the material to be visually and magnetically inspected before processing.<sup>53</sup> Shredding and grinding are performed by a series of blades or rotating drums that either chop the plastic or draw it and tear it against a sharpened surface. When flakes are reduced to the target dimensions, they either fall through a screen or are blown from the shredder/grinder to transport ducts.

Some recently developed grinding systems, such as one designed by Herbold Granulators U.S.A., processes film scrap (*i.e.*, plastic bags and sheeting) and other particularly dirty plastic waste streams using a wet grinding method.<sup>54</sup> This technology uses a stream of water to wash film scrap as it is carried past cutting knives. The water not only washes impurities from the plastic flakes, but it also minimizes temperatures in the grinder chamber.

#### **4.7.1.3 Washing**

Once plastics have been shredded or ground, they are transferred to either a washing or separation process. Washing methods vary depending on the type of plastic being cleaned, the degree of contamination, and the specific machinery being used. However, most systems consist of a water bath, a mechanical or air agitator, and possibly a solvent rinse. To facilitate the



removal of labels and other impurities, washing usually occurs after the plastics have been shredded. Certain systems under development do some washing prior to shredding.<sup>54</sup>

As mentioned previously, washing is usually done in a water bath. Most facilities heat wash water to a temperature that effectively dissolves label adhesives and other contaminants. Temperatures can be as high as 160°F. In some cases, a mild caustic detergent is added to remove labels and kill bacteria. These detergents can be effective in concentrations as low as 1 percent. A vinyl recycling operation in Akron, OH, operated by BF Goodrich uses a one percent solution of Electrosol automatic dishwasher detergent agitated in hot water.<sup>55</sup> Mechanical paddles or air streams are used to accelerate cleaning. Washed plastics are frequently rinsed in one or more water rinse steps.

#### **4.7.1.4 Separation**

Separation is done to obtain a clean, single-resin feed material. One of three methods is typically used (*i.e.*, air classification, flotation, and hydrocyclone). In facilities using hydrocyclone or flotation tank systems to separate mixed resins, plastic containers must first be reduced to a single-resin chip or flake that can be skimmed from the surface or scraped from the bottom of a flotation tank.

**4.7.1.4.1 Air Classification** Air classification systems separate wastes using an air stream. This technology can be used to isolate a lightweight target material by removing it from the waste stream, or to remove lightweight impurities from a heavier resin. For example, polystyrene or plastic film wastes are often separated from heavier contaminants using air classification.

**4.7.1.4.2 Flotation** Flotation is an effective means of separation because of differences in resin densities. Flotation can also be used to separate contaminants from the target resin. Most flotation systems use water as the separation medium. A stream of mixed plastics is added to the flotation tank. Lighter fractions, polyethylene film for example, can be mechanically skimmed from the water surface, and heavier components scraped from the bottom. Solutions such as calcium nitrate can be used to adjust the specific gravities of the flotation bath to separate

the target material from the contaminant.<sup>55</sup> In some cases, a surfactant may also be added in low concentrations to prevent plastic flakes from adhering to the equipment or to each other.

Since materials separation represents one of the greatest hurdles to recycling the large variety of resins being manufactured, separation technology is constantly under development. Research is underway at Rochester Polytechnic Institute on a flotation system that uses a heated chemical bath to dissolve and separate mixed resins.<sup>56</sup> A batch of mixed resins is heated to the melting point of the most unstable resin. The molten resin is then removed from the bath. The bath temperature is raised to the next lowest melting point, and that resin removed. The process continues until all recoverable resins are isolated. This method requires a solvent filtration and recirculation system to process a waste stream consisting of solvents and various wastes.

**4.7.1.4.3 Hydrocyclone** Hydrocyclone technology, adapted from the mining industry, has recently been successfully applied to MSW handling. The equipment is essentially a centrifuge that separates plastic wastes and contaminants based on their specific gravities. Air, water, or oil is used to enhance the separation process. The separation medium can be filtered and reused. The fluid requirements are generally less than for flotation separation systems.

#### **4.7.1.5 Drying**

It is necessary to dry the cleaned plastic flakes before they are extruded into pellets or packaged for shipping. In the case of PET reprocessing, elevated water content in the resin can lower maximum processing temperatures, increasing the potential for decomposition during extrusion.<sup>57</sup> Cyclone driers are often used initially to dewater plastics. This is followed by some type of air drying system. Flakes dry as they pass under a stream of hot air on a conveyor. Air hopper dryers are also used. Heated air streams in the range of 120°C to 160°C range are common to most drying systems. Some systems also incorporate industrial dehumidifiers.

#### **4.7.1.6 Aluminum Separation**

Most PET reprocessing systems grind PET bottles together with aluminum caps and safety rings. The aluminum fragments must be removed from the plastic flakes to less than 100 ppm. Aluminum removal is commonly accomplished with an electrostatic separator. This technology utilizes a roller or disc to which an external electron field is applied. As the material stream contacts the charged roller, conductive materials quickly lose their charge and fall from the roller. Less conductive materials, such as PET, lose their charge more slowly, are pinned to the roller, and are dropped into a separate bin. A second system utilizes a combination of rare earth magnets and steel poles to create a magnetic field which can pull aluminum contaminants from the plastic stream.<sup>58</sup>

#### **4.7.1.7 Extrusion**

The form and composition of recycled resins required by endproduct processors varies widely. Plastics scrap processors commonly supply cleaned or separated resins in either a flake or pellet form depending on the needs of the buyer. While plastic flake can be added directly to virgin feedstocks, extruded pellets are generally preferred for the following reasons: 1) pellet extrusion involves additional filtration that results in a higher quality endproduct; 2) necessary compounding agents can be added during extrusion; and 3) extruded pellets can be tailored to match the size, density, and composition of virgin feedstocks to which they are to be added.

Typical extruder designs include a screw-shaped mechanism that uses friction to heat and melt the feedstock of recycled plastic flakes in a closed chamber. The plastic is softened and compounded with additives as it passes through the chamber.<sup>57</sup> The literature indicates that as the flakes or granules melt, they fuse together, trapping air and possible chemical degradation products. Such gases must be forced from the melt before it reaches a mold or pelletizer. Once pellets have been formed, they are commonly cooled in a recirculated water bath.

To improve the flexibility of recycled resins and the quality of endproducts, a range of compounds can be added to homogeneous, as well as heterogeneous, resin streams. These

additives represent many of the same compounds that are added to virgin feedstocks, including compatibilizers, impact modifiers, colorants, and antioxidants. Tables 4-16 and 4-17 list additives used in commonly recycled plastics.

#### **4.7.1.8 Air Emissions**

Dust is frequently cited as a significant problem associated with shredding and grinding plastics. Most operations incorporate some form of air filtration to minimize dust. In addition, a number of shredders/grinders have been introduced in recent years that operate at slower speeds, greatly reducing the amount of fines and dust generated.<sup>59</sup> In one study of dust levels in a plastics reclamation facility (Vermont Republic Industries), Vermont Department of Health inspectors measured concentrations of plastic dust in the vicinity of a PVC grinding operation that were below allowable levels for nuisance dusts.<sup>60</sup>

Heating plastics beyond resin-specific degradation and oxidation temperatures will result in resin degradation and air emissions. While oxidation may occur at normal process temperatures, degradation is usually the result of improper resin handling or equipment malfunction and misuse. It should be noted that many of the emissions from plastic melting are similar to those associated with the processing of virgin feedstock. Degradation and oxidation products from heated and melted plastics have been studied extensively, particularly as they pertain to the use of plastics in incinerators.

One study of Quantum Chemical Corporation,<sup>61</sup> evaluating the use of post-consumer HDPE in molding applications, used changes in melt temperatures to confirm that some resin degradation had occurred during reprocessing. This research also identified elevated smoke levels during the heating of some reprocessed resins. Smoke is believed to be generated by volatilized soap residues and other contaminants. This is a particular concern when extruders become jammed or clogged, causing temperatures to rise beyond the temperatures of thermal decomposition.

**TABLE 4-16. PRIMARY FEEDSTOCK CHEMICALS USED IN COMMONLY RECYCLED THERMOPLASTIC RESINS**

Resin	Feedstock Chemicals
Low-density polyethylene	Butane 1-Butane Ethylene Octane Propane Vinyl acetate
Polyvinyl Chloride	Acetylene Acrylic esters Acrylonitrile Butadiene Cety vinyl ether Chlorotrifluoroethylene Divinylbenzene Ethylene Methacrylic esters Propylene Vinyl chloride Vinylidene chloride
High-density polyethylene	Butane Ethylene Polypropylene
Polypropylene	Ethylene Propylene
Polystyrene	Acrylonitrile Acrylamide Acrylic acid Alkyl esters Aromatic acids Benzene Methacrylic acid Methyl acrylate N-vinyl-z-pyrrolidone Styrene Vinyl chloride
Polyethylene terephthalate	Dimethyl terephthalate Ethylene glycol Terephthalic acid Titanium oxide Triaryl phosphites Phenolic compounds

Sources: References 2, 62, 63.

**TABLE 4-17. CATEGORIES OF ADDITIVES USED IN PLASTICS, USE CONCENTRATIONS, AND MAJOR POLYMER APPLICATIONS (1987)**

Additive		Additive Concentration in Plastic Products <sup>(a)</sup> (lb additive/100 lb resin)	Largest Polymer Markets
<b>Fillers</b>		High, 10-50	PVC
Inorganics	Mica		
Minerals	Other minerals		
Calcium carbonate	Other inorganic		
Kaolin & other	Natural		
Talc			
<b>Plasticizers</b>		High, 20-60	PVC
Phthalates	Phosphates		
Dioctyl (DOP)	Polymeric		
Diisodecyl	Dialkyl adipates		
Diethyl	Trimellates		
Dimethyl	Others		
Others	Oleates		
	Palitates		
Epoxidized oils	Stearates		
Soya oil			
Others			
<b>Reinforcing Agents</b>		High, 10-40	Various
Fiberglass	Cellulose		
Asbestos	Carbon		
<b>Flame Retardants</b>		High, 10-20	Various
Additive Flame Retardants	Others		
Aluminum trihydrate	Reactive Flame Retardants		
Phosphorous compounds	Epoxy reactive		
Antimony oxide	Polyester		
Bromine compounds	Urethanes		
Chlorinated compounds	Polycarbonate		
Boron compounds	Others		

(continued)

**TABLE 4-17. CATEGORIES OF ADDITIVES USED IN PLASTICS, USE CONCENTRATIONS, AND MAJOR POLYMER APPLICATIONS (1987) (Continued)**

Additive		Additive Concentration in Plastic Products <sup>(a)</sup> (lb additive/100 lb resin)	Largest Polymer Markets
<b>Colorants</b>		Low, 1-2	Numerous
Inorganics	Organic reds		
Titanium dioxide	Organic yellows		
Iron oxides	Phthalo greens		
Cadmium	Others		
Chrome yellows (includes lead)	Dyes		
Molybdate orange	Nigrosines		
Others	Oil solubles		
Organic pigments	Anthroquinones		
Carbon black	Others		
Phthalo blues			
<b>Impact modifiers</b>		High, 10-20	PVC
Acrylics	CPE		
MBS	Ethylene-vinyl acetate copolymers		
ABS	Others		
<b>Lubricants</b>		Low, <1	PVC, PS
Metallic stearates	Fatty acid esters		
Fatty acid amides	Polyethylene waxes		
Petroleum waxes			
<b>Heat stabilizers</b>		Moderate, 1-5	PVC
Barium-cadmium	Calcium-zinc		
Tin	Antimony		
Lead			

(continued)

**TABLE 4-17. CATEGORIES OF ADDITIVES USED IN PLASTICS, USE CONCENTRATIONS, AND MAJOR POLYMER APPLICATIONS (1987) (Continued)**

Additive		Additive Concentration in Plastic Products <sup>(a)</sup> (lb additive/100 lb resin)	Largest Polymer Markets
<b>Free radical initiators<sup>(b)</sup></b>		Low, <1	LDPE, PS, PVC, PE
<b>Antioxidants</b>		Low, <1	PS
Hindered phenols	Others		
<b>Chemical blowing agents</b>		Moderate, 1-5	PVC, PP, PS
Azodicarbonides	High temperature CBS's		
Oxibisulfonylhydrazide	Inorganic		
<b>Antimicrobial agents</b>		Low, <1	PVC, PE
<b>Antistatic agents</b>		Low, <1	PVC
Quaternary ammonium compounds	Fatty acid ester derivatives		
Fatty acid amides & amines	Others		
Phosphate esters			
<b>UV stabilizers</b>		Low, <1	PE, PP, PS, PVC
Benzotriazoles	Malonates		
Benzophenones	Benzilidenes		
Salicylate esters	Others		
Cyanoacrylates			
<b>Catalysts<sup>(c)</sup></b>		Low, <1	Numerous
<b>Others</b>		Low, <1	

<sup>(a)</sup>Estimates refer to concentrations in those products where the additive is used.

<sup>(b)</sup>Includes organic peroxides only, as reported by source.

<sup>(c)</sup>Includes urethane catalysts only, as reported by source.

Source: Reference 2.



Emissions collection and treatment systems are employed on extruders throughout the industry to collect released gases. Incineration, fixed carbon-bed adsorbers, electrostatic precipitators, distilling equipment, and fractionalizers can all be used effectively to control air emissions.

The degradation of some resins, (*e.g.*, PVC) can result in the formation of acidic byproducts. These emissions can be neutralized using the appropriate neutralizing agents. Innovative Plastic Products Incorporated (IPPI) of Greensboro, GA sprays a sodium hydroxide mist to neutralize elevated hydrochloric acid levels.<sup>64</sup>

#### **4.7.2 Resin Specific Processing**

Process methods in plastics reclamation vary depending upon the type of resin being processed. Reclamation process steps for the seven post-consumer plastics defined previously generally incorporate some combination of the technologies discussed above. Some resins may require distinctive process technologies. These resin-specific issues are discussed below.

##### **4.7.2.1 *Polyethylene Terephthalate (PET)***

Polyethylene terephthalate is currently the most recycled resin in the United States. Reclaimed PET is used as either a pelletized feedstock supplement for mold applications or as an extruded fiber. The fiber is used in such products as carpeting and clothing insulation.

PET is liable to degrade if overheated above 300°C. It should not be held above temperatures approaching 300°C for longer than a few seconds. In addition PET will degrade more readily if it is not thoroughly dried before processing.<sup>57</sup>

PET vapor and particulate emissions are expected to be released during pellet extrusion.<sup>62</sup> However, the PET polymer is chemically stable except for the release of carbon dioxide, and it is generally considered to be free of toxic byproducts.

#### **4.7.2.2 High-Density Polyethylene (HDPE)**

High-density polyethylene is currently used as a recycled feedstock supplement for a wide variety of products ranging from oil and detergent bottles to extruded piping and other thick-walled items. HDPE is considered to be a nontoxic compound. It is used extensively in packaging and medical industries, as well as in the manufacture of pipe to carry potable water.

HDPE can be extruded between 170°C and 220°C<sup>57</sup> and decomposes at roughly 400°C.<sup>65</sup> When ignited, polyethylene burns easily with a very smoky flame.<sup>57</sup>

Vapor emissions from pelletizing operations may consist of ethylene, polyethylene polymer fines, and smoke. Extruder vents have been found to release 0.63 kg of volatile organic compounds/Mg of product processed.<sup>62</sup> This release consisted primarily of steam and air, with 0.05 percent by volume of cyclohexane. Significant oxidation byproducts of HDPE at 150°C are water, carbon dioxide, carbon monoxide, and acids.<sup>65</sup> In addition a variety of additives and solvents (e.g., chromium oxide and cyclohexane) may be released.

#### **4.7.2.3 Vinyl (V)**

PVC is the primary post-consumer vinyl currently being recycled and showing potential to produce significant volumes of reclaimed scrap. Post-consumer PVC appears in bottles of cooking oil and water, as well as perishable food shrink wrap. Recycled PVC is used as a feedstock supplement in pipe, siding, and other building materials.

Although electronic and flotation separation systems are sometimes used to sort PVC containers, most sorting is done manually. PVC processing plants generally incorporate the basic process steps indicated in Figure 4-4. Due to the similar densities of PVC and PET, separating them remains a technical challenge. More sophisticated separation systems are under development that involve the use of flotation baths adjusted to specific gravities, and X-ray and other electronic sorting systems.<sup>55,66</sup>

EPA's Industrial Process Profiles for the Plastics Industry describes polyvinyl chloride as chemically inert and nontoxic.<sup>62</sup> The release of residual vinyl chloride monomer, a human carcinogen, is sometimes cited as a concern when reprocessing PVC. However, industry sources generally believe that the tightly-bound PVC yields little monomer during reheating.<sup>67</sup> Maximum extrusion processing temperatures are around 170°C. The polymer will degrade rapidly if processed slowly at temperatures well above 170°C. Hydrochloric acid is produced during processing due to the release of chlorine. All metal surfaces designed to contact melted PVC should resist strong acids. Solvents commonly used with vinyl include cyclohexane, dichloroethane, and nitrobenzene.<sup>57</sup>

The use of cadmium and lead in PVC has long produced health concerns. Both are being replaced by safer alternatives, but recovered scrap may still contain heavy metals. PVC-coated wire scrap, traditionally compounded with lead additives, represents a significant source of contamination in plastics waste.

#### **4.7.2.4 *Low-Density Polyethylene (LDPE)***

Low-density polyethylene is used primarily in bags and other film applications. Due to its flexibility, it is a desirable reclamation feedstock. It is particularly beneficial when used as a matrix resin in the manufacture of commingled plastic products (see below).

The processing of LDPE is similar to the steps indicated in Figure 4-4 except that a wet grinder may be used. LDPE can be extruded between 120°C and 160°C. LDPE oxidizes at 150°C and decomposes at roughly 400°C.

Significant oxidation byproducts of LDPE are water, carbon dioxide, carbon monoxide, and acids.<sup>65</sup> The manufacture of virgin polyethylene requires the use of ethylene, considered to be highly explosive, but little or no unreacted ethylene should remain in recycled LDPE. Additional process and exposure information is similar to that listed for HDPE.

#### **4.7.2.5 Polypropylene (PP)**

Polypropylene is used in a variety of products from drinking straws to battery cases. Its high decomposition temperatures make it a desirable resin for commingled plastics products. PP can be extruded without decomposition below 240°C. Thermal stability of PP in the absence of oxygen is high.<sup>57</sup>

Degradation gases produced between 360°C and 400°C include primarily pentane, propylene, and methane, with increasing amounts of 2,4-dimethyl-1-heptene at higher temperatures. Additional byproducts include ethane, propane, isobutylene 2-methylpentane, and 4-methylheptane. Significant oxidation byproducts of PP at 150°C are water, carbon dioxide, carbon monoxide, and acids.<sup>65</sup>

#### **4.7.2.6 Polystyrene (PS)**

Polystyrene finds applications in both rigid and expanded foam forms. Rigid PS appears in durable products such as furniture and appliances, while the foam form is used in plates, cups, and egg cartons. Foam products have been the focus of considerable environmental criticism due to the release of chlorofluorocarbon blowing agents during manufacture. However, in 1988, the U.S. food packaging industry voluntarily discontinued the use of CFCs in their products.

PS reclamation includes standard shredding, washing, drying, and extrusion processes. Due to the low density of expanded PS, air classification is commonly employed to segregate it from the rest of the waste stream. It is sometimes necessary to densify or degasify bulky PS waste prior to pelletizing. Specialized equipment is available to crush and compress PS waste; other systems use high temperatures to release gases and densify the expanded foam. PS can be extruded between 150°C and 220°C. It will ignite and decompose between 245°C and 300°C depending upon the percentage of oxygen present.<sup>57</sup>

Between roughly 110°C and the ignition temperature (including the range of standard densifying and extrusion temperatures), polystyrene absorbs oxygen while releasing carbon monoxide, carbon

dioxide, acetone, and benzaldehyde. As temperatures approach 280°C, degradation products include approximately 40 percent styrene monomer. Other releases include fillers and compounding agents, including tetramer, toluene, and carbon monoxide.<sup>68</sup> Jerry Johnson of the Polystyrene Packaging Council estimates that styrene monomer emissions usually measure less than 2 ppm during extrusion.<sup>69</sup> A variety of solvents can be used to dissolve polystyrene, including a number of chlorinated and non-chlorinated hydrocarbons.

#### **4.7.2.7 *Commingled Plastics***

Commingled plastics recycling offers a relatively simple and flexible reprocessing alternative to sorting and cleaning mixed plastics. While most municipal solid waste programs that collect plastics for recycling concentrate their efforts on one or two resins, the opportunity to collect large quantities of multi-resin waste exists. However, separating the growing variety of plastics in the waste stream represents a significant technical challenge.

A number of ventures have successfully applied extruder and compression mold technology to the reprocessing of unsorted, mixed plastics into dense products such as lumber, automobile curbstops, and playground equipment. Generally, higher solid contaminant levels and decreased tensile strengths restrict this process to the manufacture of thick-walled endproducts.

There are several commingled plastics processing systems currently used in the United States. Most facilities use extruder technology that incorporates the same basic features discussed in 4.7.1.7. These systems are generally capable of handling a wide range of unsorted and uncleaned scrap. Most systems require the waste stream to be shredded to provide a more uniform feedstock. Most systems also use one segregated resin, preferably polyethylene, as a base or matrix to which the unsorted, even rigid, scrap is added as filler.

Since commingled recycling systems simultaneously melt a combination of resins, it is difficult to ensure that none of the resins is heated beyond its degradation temperature, releasing thermal degradation products. Thermal degradation temperatures vary depending upon the feedstock resins. Although it is difficult to precisely control feedstock components when utilizing a mixed

waste stream, it is important to carefully maintain process temperatures within the range of material decomposition temperatures.

Doty reports the generation of hydrochloric acid from chlorine released while melting PVC scrap in commingled plastics processing.<sup>64</sup> In one instance, gases severely corroded stainless steel air ducts. The plant no longer processes PVC due to these emissions. The plant is equipped to collect vapors or dust particles released during processing. Vapors are collected using vacuum hoods and are separated and disposed of in a gas washer. The system includes cross-current water spray chambers, pH meters that trigger an automated sodium hydroxide spray, a conductivity meter that triggers water recirculation to activated carbon adsorption reactors, and flocculation and filtration equipment.

#### **4.7.2.8 Air Emissions**

Generally, reclamation of plastics takes place in fully enclosed processing facilities equipped with emission and effluent control devices. Emissions hazards in plastics processing can result from residues in the recyclable plastics, chemicals used during reclamation, fugitive particulates generated during processing, organic chemicals absorbed in the plastic resins, and the degradation of plastic resins themselves.

Concern is often raised about the potential release of chemical compounds from plastics during processing. Actual polymer degradation can occur during extrusion and thermal oxidation of resins can occur during both drying and extrusion. While degradation is usually the result of improper resin handling or equipment malfunction, oxidation may occur at normal process temperatures.

Thermal oxidation byproducts include carbon monoxide, carbon dioxide, acids, peroxides, esters, and aldehydes. Degradation byproducts can encompass a number of toxic and carcinogenic chemicals including hydrochloric acid and vinyl chloride (from PVC) and styrene (from polystyrene). Other chemicals that can be released during processing include additives (chromium oxide) and solvents (cyclohexane and dichloroethane). Heavy metals including

cadmium and lead are being phased out in materials such as PVC, but may still be present in existing scrap.

Control technologies are used widely to prevent significant emissions from plastics drying and extrusion operations. Extruders may have shut-off devices that are triggered when normal operating temperatures are exceeded. Facilities are also equipped with systems to monitor, filter, neutralize, and/or vent emissions that are produced.

Both carbon dioxide and acids are generated from thermal oxidation of plastics during drying and extrusion. The quantities of these chemicals released from reclamation facilities have not been characterized.

## **4.8 SOLVENT RECYCLING**

### **4.8.1 Category Definition and Description**

Solvent recycling may take place in many forms. The ultimate goal is to make further use of the solvent material after it has been contaminated or modified by its initial use. Many firms participate in solvent recycling activities because of the economic incentive. A recycling program may reduce the cost of purchasing new raw materials and reduce the amount of waste generated. Reduction of waste results in decreased disposal costs and less exposure to liability associated with off-site shipments.<sup>70</sup>

### **4.8.2 Process Definition and Description**

Solvents may be recycled on-site or sent to a commercial off-site facility. On-site recycling operations may be performed with in-house staff or a commercial recycler may set up and operate fixed or mobile recycling equipment on the generators property. Commercial operations most often use distillation for solvent recovery, although solvent extraction is also commonly used. Many commercial operations accept solvent waste to be burned for heat recovery, although this is not universally considered to be a form of recycling. Another alternative is participation

in a waste-exchange program; however, relatively pure uniform wastes are typically more easily transferred through waste exchange programs than mixed wastes.<sup>70</sup>

Because of economies of scale, it may be more cost effective for very small quantity generators to make use of off-site recycling. However, a 1988 study of the economics of solvent recycling equipment showed that on-site solvent recycling is feasible, even for small-scale waste generators. Using the most conservative available assumptions, the study showed that an investment in small scale recycling should pay for itself in less than two years. In many circumstances, the investment will pay for itself in less than one year.<sup>71</sup>

On-site recycling has the following advantages over off-site recycling.

- Less waste leaving the facility and hence reduced liability and cost of transporting waste off-site
- Owner's control over reclaimed solvent's purity
- Reduced paperwork and reporting in the form of manifesting
- Potential lower unit cost for reclaimed solvent

Off-site recycling has the following advantages over on-site recycling.

- Reduce capital for recycling equipment and possible cost of operator training
- Reduced operating costs
- Fewer liabilities for worker health and potential events associated with improper operation of solvent recovery equipment such as fires, explosions, leaks, and spills.

Most recycling and solvent recovery operations involve employing similar technologies in varying sequences. The design of the recovery system must be considered on a case-by-case basis, accounting for material properties, purity requirements, process capacity, worker health and safety, and economics. Solvent recycling occurs across a wide variety of industries. Some examples of well known and common formalized recycling practices are listed below.<sup>70</sup>



- Recovery, by adsorption, of mixed solvents used for fabric coating
- Recovery of acetone from cellulose acetate spinning using water scrubbing and adsorption, and subsequent recycling within this process
- Recovery of diluent in solvent refining of oil using vaporization and recompression
- Recovery of hexane in vegetable oil extraction
- Recovery of furfural in butadiene purification
- Batch recovery, by evaporation and condensation, of perchloroethylene in dry cleaning
- Distillation for recovery of mixed solvents (typically ethyl alcohol and triethylamine) in antibiotic and pharmaceutical manufacture

Less formalized recycling which does not require special equipment is also being implemented through use of more passive measures such as process modifications and changes in handling procedures. Many firms have implemented these changes in procedures because of economic incentives.

#### **4.8.3 Pollutant and Activity Levels**

Although it is known that the majority of recycling emissions are likely to be VOC, actual levels of recycling emissions are difficult to document. Because procedural changes made to implement recycling often do not require a permit, a considerable amount of recycling occurs which is not publically documented or reported. The additional emissions resulting from such recycling activities when integrated with a process operation may be negligible or zero. For example, at a paint manufacturing plant, the waste cleaning solvent from each solvent-based paint batch is collected individually and stored. When the same type of paint is produced again, the waste cleaning solvent from the previous batch is used instead of new solvent. The paint manufacturing facility reduced waste solvent by 98.4 percent with essentially no increase in emissions.<sup>72</sup>

#### 4.8.4 Emission Factors and Available Literature

The emissions associated with recycling activities do not appear to be well documented in readily available literature. Section 4.7 of *AP-42*<sup>1</sup> provides documentation of particulate and VOC emission factors for waste solvent reclamation. Table 4-18 provides these emission factor data as they are tabulated in *AP-42*. A review of the references for this *AP-42* section indicates that all of the supporting references are dated in the 1970s. As a result, the applicability of these data to current recycling operations is questionable.

**TABLE 4-18. EMISSION FACTORS FOR SOLVENT RECLAIMING<sup>a</sup>**

**EMISSION FACTOR RATING: D**

Source	Criteria pollutant	Emission factor average	
		lb/ton	kg/MT
Storage tank vent <sup>b</sup>	Volatile organics	0.02 (0.004-0.09)	0.01 (0.002-0.04)
Condenser vent	Volatile organics	3.30 (0.52-8.34)	1.65 (0.26-4.17)
Incinerator stack <sup>c</sup>	Volatile organics	0.02	0.01
Incinerator stack	Particulates	1.44 (1.1-2.0)	0.72 (0.55-1.0)
Fugitive emissions			
Spillage <sup>c</sup>	Volatile organics	0.20	0.10
Loading	Volatile organics	0.72 (0.00024-1.42)	0.36 (0.00012-0.71)
Leaks	Volatile organics	NA	NA
Open sources	Volatile organics	NA	NA

<sup>a</sup> Reference 1. Data obtained from state air pollution control agencies and presurvey sampling. All emission factors are for uncontrolled process equipment, except those for the incinerator stack. Average factors are derived from the range of data points available. Factors for these sources are given in terms of pounds per ton and kilograms per metric tons of reclaimed solvent. Ranges in parentheses.

<sup>b</sup> Storage tank is of fixed roof design.

<sup>c</sup> Only one value available.

NA - not available.

The U.S. EPA has published a number of control technology guidance documents associated with some of the individual industry processes previously listed including fabric coating, vegetable oil production, dry cleaning operations, and the synthetic and organic chemical manufacturing industry (SOCMI). While these documents provide recommended or required emission rates, industry specific emission factors associated with recycling practices of specific industries are not provided.

The Industrial Technology Division of the EPA has been conducting a study of the solvent recycling industry as a result of findings that the quantity of hazardous wastes discharged by the recycling industry to publicly-owned treatment works is unknown.<sup>73</sup> Information-gathering efforts for this study have shown that not all solvent recyclers are RCRA-permitted facilities and that generators of spent solvents are shipping wastes to these unpermitted facilities. Approximately eighty percent of the recycling industry achieves zero discharge of solvent waste in wastewater due to the practices of contract hauling off-site, fuel blending, and incineration. Of those facilities which discharge wastes, only half treat the wastewater.

The U.S. Department of Energy has created a Chlorinated Solvent Substitution Program to minimize hazardous wastes by identifying recycle/recovery techniques for proposed substitute solvents.<sup>74</sup> This program has gathered information to support a preliminary screening of potentially feasible solvent recycling technologies and has performed some distillation tests on subject solvents. The distillation of testing has shown that for commercial grade solvents, distillation can accomplish recovery of key components, but not necessarily in the percentages reported by the manufacturer. The program has also identified some emerging membrane technologies such as pervaporation that may be feasible for some solvents. The program has recommended extensive literature review for promising technologies; further laboratory investigation; contact with vendors, researchers, and industrial experts; and creation of pilot recycling units.

#### **4.8.5 Potential for Additional Data**

It is very possible that local and state agencies possess a considerable amount of data concerning emissions resulting from solvent recycling activities. A review of permits for specific solvent recycling industries such as those previously listed may yield data which would allow calculation of process emission factors. Similarly, this information should also be available for those industries which specialize in commercial waste recycling.

#### **4.9 RECYCLING ACTIVITY SUMMARY**

Due to the number of recycling initiatives at federal, state and local levels, recycling materials from MSW will increase significantly. It is estimated that over 3,000 curbside pickup programs are currently in operation in the United States; this number is expected to increase rapidly. Collecting and sorting materials cause air emissions during handling and transportation. The suggested methodology to address vehicular pollution has been presented. Emissions from centralized processing facilities are not well documented and could represent an area requiring additional effort.

Of the four materials recovered from MSW covered in this section, plastics are undergoing the most rapid change. The recovery rates are increasing significantly due to the plastics industry's expanded recycling efforts and historically low recovery rates for this type of material. Further, several recovery processes are being developed to facilitate economical recovery of plastics.

The number of facilities which could potentially use recovered resins is estimated to be 14,000 in the top 10 states.<sup>75</sup> Data on emissions resulting from using reclaimed resins are not readily available and may prove difficult to derive due to the variety of resins and mixtures, facilities, and respective source configurations. The following two methods used in conjunction may be useful in developing the needed data. Reviewing state air permit files may provide some preliminary information, and an industry survey requesting detailed information on control devices, operating procedures, material throughput, and associated data could supplement data from state files.

Recycling rates of paper, steel and aluminum will also increase. However, the process technologies for recovery of these materials are generally well established. Research is being conducted in a number of areas to improve the recovery process. The improvements may be in a number of different areas, including cost reduction, lower environmental impacts, or increased material yields. Emissions data are available in *AP-42* and AIRS for steel and aluminum recycling processes. Specific information concerning paper recycling process emissions is not readily available. An industry survey and air permit file search may also prove to be a viable approach in developing this information.

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## SECTION 5.0

### PESTICIDE APPLICATION

#### 5.1 BACKGROUND

Under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), a pesticide (or economic poison) includes any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest, and any substance or mixture of substances intended for use as a plant regulator, defoliant or desiccant. The general category of pesticide can be further defined by the following terms which identify the *target* of the pesticide.

- *Acaricide (miticide)* - used to control plant-feeding mites (acarids)
- *Algicide* - used to control algae
- *Aphicide* - used to control aphids (plant lice)
- *Avicide* - used to control pest birds
- *Bactericide* - used to control bacteria
- *Biocide* - when absorbed by eating, drinking, breathing or other means in relatively small quantities, may cause illness or death, or even retardation of growth or shortening of life
- *Fungicide* - used to protect against fungi
- *Gametocide* - used to prevent pollination
- *Herbicide* - used to control weeds
- *Insecticide* - used to control insects
- *Larvicide* - used to kill insect larvae
- *Molluscicide* - used to control slugs and snails (mollusks)
- *Nematicide* - used to control nematodes
- *Ovicide* - used to kill eggs of insects and mites
- *Piscicide* - used to control fish
- *Predacide* - used to control vertebrates
- *Rodenticide* - used to control rodents (rats, mice, *etc.*) and related animals (such as rabbits)
- *Slimicide* - used to control slime and molds

Of the total pesticides currently used in the United States, approximately 60 percent are herbicides, 25 to 30 percent are insecticides and 10 to 15 percent are fungicides.<sup>1</sup>

Several additional terms are used to describe the *actions* or *purposes*, rather than the target, of certain pesticides.<sup>2</sup>

- *Defoliant* - a preparation intended for causing leaves to drop from crop plants such as cotton, soybeans or tomatoes, usually to facilitate harvest
- *Fumigant* - a substance or mixture of substances which produce gas, vapor, fume or smoke intended to destroy insects, bacteria or rodents
- *Plant growth regulator* - a preparation which, in minute amounts, alters the behavior of ornamental or crop plants or the produce thereof through physiological (hormonal) rather than physical action
- *Repellant* - a material used primarily for the control of insects, birds and other vertebrates

Pesticides fall into three basic chemical categories: synthetics, nonsynthetics (petroleum products) and inorganics. Formulations are commonly made by combining synthetic materials with various petroleum products. The synthetic pest-killing compounds in such formulations are labeled as *active* ingredients; the petroleum product solvents acting as carriers or diluents for the active ingredients are labeled *inert*. Pesticides are regulated primarily on the basis of active ingredients.<sup>2</sup> (The terms *active* and *inert* in this application refer to toxicological action in pesticides and are not to be confused with the common use of these terms to indicate photochemical activity.<sup>3</sup>)

Carriers are inert materials added to a technical (or, economic) poison to facilitate later dilution to field strength in simple blending equipment. (A technical poison or technical material is defined as the pesticide chemical in pure form, usually 95 to 100 percent active ingredient, as it is manufactured by a chemical company prior to being formulated into wettable powders, dusts, emulsifiable concentrates, granules, *etc.*) Certain kaolin clays, attapulgites, diatomites and several highly-absorbent synthetic pigments are used as carriers. Diluents are material liquids or solids

serving to dilute the technical material to field strength for adequate plant coverage, maximum effectiveness and economy. They may be used directly with technical materials to dilute to field strength sprays or dusts, but usually are blended with wettable powders and dust concentrates previously prepared with carriers. The most widely used solid diluents are kaolin clays, pyrophyllites and talcs, although attapulgites and diatomites, local clays, limestone products and other minerals are also used. Although solid carriers and diluents are generally considered to be inert, certain attapulgites, kaolin clays and diatomites aid in increasing toxic effectiveness, probably due to physical properties which induce starvation, desiccation and abrasion. Most formulations of dusts and sprays contain from 80 to 99 percent carrier-diluent.<sup>2</sup>

Adjuvants are materials which are added to a pesticide mixture in the spray tank to improve mixing and application or enhance pesticide performance. An adjuvant customizes the formulation to meet specific needs or to compensate for local conditions. By using the proper adjuvant, it is often possible to use certain chemical pesticides in a tank mixture that otherwise would present compatibility problems. (A tank mix is a mixture of two or more pesticides in the spray tank at the time of application. Non-compatibility of the ingredients can be a problem.) The term includes such materials as buffers, defoaming agents, spreaders, stickers, surfactants and others, as defined below (these definitions are taken from Reference 2). Often, a single adjuvant will accomplish more than one adjuvant function, such as a spreader-sticker, spreader-sticker-drift retardant, *etc.*

- ***Acidifiers*** - acids that can be added to spray mixtures to neutralize alkaline solutions and lower pH
- ***Attractants*** - food or bait, such as sugar, molasses, protein hydrolates or insect pheromones, which attract specific pests. Attractants allow pesticides to be applied to localized parts of the treatment area
- ***Buffers*** - substances capable of changing the pH of a water solution to a prescribed level
- ***Correctives (safeners)*** - substances which prevent objectionable changes when two or more substances must be mixed which otherwise would not be compatible
- ***Defoaming agents (foam suppressants)*** - materials which eliminate the foam produced in the spray tank from the action of the hydraulic or mechanical agitators

- *Deposition aids* - adjuvants that improve the ability of pesticide sprays to reach surfaces in the treatment area. Different types of products can be used with differing effects, such as drift control agents that affect droplet size
- *Dispersants* - materials that reduce the cohesiveness of like particles, either solid or liquid. Dispersing and suspending agents are added during the preparation of emulsifiable and wettable powders to facilitate dispersion and suspension of the ingredients
- *Emulsifiers* - surface-active substances which stabilize (reduce the tendency to separate) a suspension of droplets of one liquid in another liquid which otherwise would not mix with the first one
- *Extenders* - chemicals that enhance the effectiveness or effective life of a pesticide. Some extenders function by screening out ultraviolet light that decomposes many pesticides; others slow down pesticide volatilization
- *Foaming adjuvants* - surface-active substances that form a fast-draining foam to provide maximum contact of the spray with the plant surface, to insulate the surface and to reduce rate of evaporation. Used to enhance herbicide action, reduce drift of sprays and mark spray swath widths
- *Penetrants* - wetting agents, oils or oil concentrates that enhance the ability of a liquid to enter into pores of a substrate, to penetrate the surface
- *Spray colorants* - dyes that can be added to the spray tank so an applicator can see the areas that have been treated
- *Spreader-sticker* - a mixture of surfactant and latex or other adhesive sticker
- *Stickers (adhesives)* - substances such as latex or other adhesives that improve pesticide attachment to sprayed surfaces. They protect pesticides from washing off due to rainfall, heavy dew or irrigation, and help prevent pesticide loss from wind or leaf abrasion
- *Surfactants* - surface-active agents, also known as spreaders (film extenders) or wetting agents. They enhance spray coverage by reducing the surface tension of spray droplets and can be either nonionic, anionic or cationic
- *Thickeners (suspending agents)* - materials which make spray mixtures more viscous. They are often required as drift control agents with certain herbicides. They are used to prevent settling out and hard packing of pesticide chemicals in water systems
- *Viscosity adjuvants* - materials which stabilize herbicide sprays by increasing droplet size, reducing off-target movement (drift) of spray particles

## **5.2 PROCESS BREAKDOWN**

The "process breakdown" depends on several factors including the user, the pesticide formulation, the type of equipment, the crop or area to be treated, and the application and treatment. These factors are discussed in more detail below. These factors are often closely inter-related and not easily separated from one another. For example, while the formulation of the pesticide helps to determine the type of equipment to be used, the type of equipment available determines the type of formulation that can be used. The specific pest to be controlled determines the type of pesticides used. Particular pesticides may not be available in all formulations.

### **5.2.1 User Categories**

Pesticide application may be broken down into several user categories: consumer, agricultural, commercial, municipal and industrial. Consumer application refers to individual home and garden pesticide use. These products are generally applied as sprays or baits and include disinfectants, fungicides, insecticides, molluscicides, rodenticides, herbicides and repellents. Agricultural pesticide application refers to farm chemical usage, other than fertilizers, for soil and site preparation, pest control and harvesting aids. Agricultural pesticides can be applied in a variety of formulations (sprays, dusts, pellets, fogs, *etc.*) from the ground or from the air (aerial application).

Commercial pesticide application includes professional treatment of homes, buildings and lawns for fleas, cockroaches, termites, nematodes, crabgrass *etc.* Municipal pesticide application refers to governmental use of pesticides for mosquito control, roadsides, aquatic pests, *etc.*, and includes both ground and aerial applications. Industrial application refers to use for power line and gas line right-of-ways, *etc.*

Approximately 68 to 75 percent of pesticides used in the United States are applied to agricultural lands, both cropland and pasture.<sup>1,4</sup> Of the remaining 32 to 25 percent, 8 to 17 percent is used used privately for home and garden pests, and the remaining 24 to 8 percent, are used for industrial, commercial and governmental purposes.<sup>1</sup>



The essentials of good pesticide application are correct timing of application; proper chemicals and rates; and proper equipment, correctly used.<sup>5</sup>

### 5.2.2 Formulations

A single active ingredient is often sold in several different formulations. In choosing the formulation for a particular use, the user must consider the following: the plant, animal or surface to be protected; application machinery available and best suited for the job; hazard of drift and runoff; safety to applicator, helpers and other humans and pets likely to be exposed; habits or growth patterns of the pest; cost; and type of environment in which the application must be made (agricultural, aquatic, *etc.*). These formulations and their descriptions are listed below:<sup>2</sup>

- *Emulsifiable Concentrate* - A liquid formulation containing the active ingredient, one or more solvents and an emulsifier which allows mixing with water. Little agitation is required
- *Solution* - Used for those active ingredients which dissolve readily in water. The formulation is a liquid and usually consists of the active ingredient and additives. When mixed with water, a solution will not settle out or separate
- *Flowable* - A liquid formulation consisting of finely ground active ingredient suspended in a liquid. Flowables are mixed with water for application
- *Wettable Powder* - Dry, finely ground formulations which look like dusts. The active ingredient is combined with a finely ground dry carrier, usually mineral clay, along with other ingredients that enhance the ability of the powder to suspend in water. Wettable powders can be mixed with water for application as a spray and are one of the most widely used pesticide formulations
- *Dry Flowable* - Also known as water-dispersible granules, dry flowables are like wettable powders except that the active ingredient is formulated on a granule instead of a powder. Dry flowables require agitation, but are easier to pour and mix than wettable powders because there is less dust
- *Soluble Powder* - A dry formulation which, when mixed with water, dissolves readily and forms a true solution. When thoroughly mixed, no agitation is necessary. Not many formulations of this type are available because few active ingredients are soluble in water
- *Ultra Low Volume Concentrate* - A liquid formulation which may be applied with specialized equipment as is or diluted with a small quantity of specified carrier. These formulations are designed to be applied at rates of only ounces per acre

- *Low Concentrate Solution* - Small amounts of active ingredient (one percent or less) used without dilution for structural pests, space sprays in barns, mosquito control, *etc*
- *Aerosol* - A system of particles dispersed in a gas. Liquid particles make up a fog and solid particles form a smoke. In formulations, there are ready-to-use types such as household sprays. The commercial type holds five to ten pounds of formulation and can be refillable. In addition, aerosols formulations can be used for smoke or fog generators which break the liquid formulation into a fine mist or fog using a rapidly whirling disc or a heater surface
- *Invert Emulsion* - A water soluble pesticide dispersed in an oil carrier. Forms large droplets which do not drift easily
- *Dust* - Low percentage of active ingredient on a very fine dry inert carrier like talc, chalk or clay. Most are ready to use. Danger of drift
- *Bait* - Active ingredient mixed with food or another attractive substance
- *Granule* - Most often used for soil applications. The active ingredient is coated or absorbed onto coarse particles like clay, ground walnut shells or ground corncobs
- *Pellets* - Very similar to granules, although pellets are usually more uniform - or a specific weight or shape
- *Micro Encapsulation* - Particles of a pesticide, either liquid or dry, surrounded by a plastic coating. Mixed with water and applied as a spray. Encapsulation makes timed release possible
- *Water-Soluble Packets* - Water-soluble packets are used to reduce the mixing and handling hazards of some highly toxic pesticides. Pre-weighed amounts of wettable powder or soluble powder formulations are packaged in water-soluble plastic bags. When the bags are dropped into a filled spray tank, they dissolve and release their contents to mix with the water. There are no risks of inhaling or contracting the undiluted pesticide during mixing as long as the packets are not opened. Once mixed with water, pesticides packaged in water-soluble packets are no safer than other mixtures
- *Impregnates* - Pesticides that are incorporated into household and commercial products. Pet collars, livestock ear tags, adhesive tapes and plastic pest strips contain pesticides that volatilize over a period of time and provide control of nearby pests

### 5.2.3 Equipment

The type of formulation determines, in part, the type of equipment used to apply the pesticides. Various dusters, sprayers and blowers are used, with their corresponding tanks, nozzles, pumps and hoses. Several types of equipment are described in the following pages (descriptions are taken primarily from Reference 2).

### **5.2.3.1 *Dusters*<sup>2</sup>**

Duster types include hand dusters, rotary-type hand dusters, knapsack dusters and power dusters. In a hand duster, a plunger expels a blast of dust-laden air. The dust chamber may be at the end of the plunger tube itself, or an enlargement at the end, or it may be located below the plunger tube. A rotary-type hand duster is carried by a neck strap on the lower chest of the operator. A hand crank revolves a fan to provide feed from the dust chamber to the delivery tube ahead of the operator. Unlike the rotary-type hand duster, the knapsack duster is carried on the back. It is operated by a bellows on top of a cylindrical dust container. The bellows are operated by a hand lever at the side of the operator.

Power dusters can deliver dust in two ways: through a horizontal boom with a large number of delivery pipes, often terminating in a fishtail nozzle; and through a single large orifice or circular nozzle. A fan or a turbine blower delivers the dust-carrying air stream. The equipment can be modified to meet the requirements of different field conditions. A nozzle air velocity of approximately 5,000 feet per minute will allow good flotation with sufficient drive to carry dust through the foliage of the plant and rebound, to some extent, from the ground.<sup>5</sup>

### **5.2.3.2 *Sprayers*<sup>2,5</sup>**

The majority of field sprayers in use today are hydraulic sprayers in which the spray pressure is built up by direct action of the pump on the spray mixture. They range from low-pressure sprayers to high-pressure sprayers and can be mounted, pulled or self-propelled. The basic sprayer components are the tank, pump, agitator, hoses, valves and fittings, and nozzles.

Compressed air sprayers, power sprayers, hand sprayers, knapsack sprayers and mist blowers are examples of various sprayer types. Compressed air sprayers usually have a one- to three-gallon capacity. They are equipped with an air pump to develop pressure and often have a shoulder strap for carrying. They are generally not suitable for spraying at heights over six to ten feet.

In hand sprayers (often called Flit guns), the liquid pesticide is aspirated by a rapid flow of air over the open end of a vertical tube. The other end of the tube is immersed in the liquid in a container attached to a piston cylinder. The air flow is produced by the hand-operated piston, with its outlet at a right angle to and in approximate contact with the open end of the aspirator tube. A knapsack sprayer is a light-weight sprayer designed to be carried on the back of the operator. Unlike the compressed air sprayer, the knapsack sprayer is fitted with a hydraulic pump operated by a hand lever. This sprayer type is used for spraying small gardens and other similar areas.

A power sprayer is a plunger-pump sprayer operated by a gasoline or an electric motor. The equipment includes small, hand-drawn sprayers and larger trailer-type sprayers which use their own engines or can draw power from the tractor. Power sprayers have been adapted for orchard use with equipment arranged for spray coverage at considerable heights and for treating row and field crops with nozzles spaced appropriately on a horizontal boom.

In a mist blower, hydraulic atomization of the liquid in the nozzle is added by an air blast past the spray source. The air blast from the blower aims and carries the mist to the target. Mist blowers can evenly apply much less liquid per acre than was possible with the older, heavy plunger-pumps.

#### **5.2.4 Area to be Treated/Type of Application and Treatment**

Pesticides are used in and around homes and other structures; on gardens, lawns, field crops, orchards, right-of-ways, roadsides, wetlands; and in water. The type of area (both in general, *e.g.*, field crops, and specifically, *e.g.*, corn), the location, the pest to be controlled, and the size of the area are important considerations in determining the application and treatment strategy. Types of applications and treatments include band, basal, broadcast, directed, sequential, serial and spot. These terms are defined as follows.<sup>2</sup>

- *Band application* - application of herbicide in a narrow band on each side of a row crop as a saving over treatment of the entire field area between rows. The remainder of the area between rows may then be machine cultivated
- *Basal application* - application of pesticide on plant stems or tree trunks just above the soil line
- *Basal treatment* - herbicidal treatment, with minimal foliage contact, to stems of woody plants at and just above ground level so as to encircle just the stem
- *Broadcast application* - application of a pesticide uniformly over the area to be treated without regard to arrangement of crop (as in rows)
- *Directed application* - precise application to a specific area, such as to a row or bed, or to a plant organ, such as the lower leaves and stems
- *Sequential treatment* - succeeding or consecutive actions or operations. Sequential treatments in weed control as those of an herbicide as a pre-emergence overlying following preplant application of a different herbicide. The latter is applied before planting, the sequential treatment after seeding and before emergence of crop plants
- *Serial application* - the use of one pesticide immediately or shortly after the use of another
- *Spot treatment* - a treatment directed at specific plants or areas rather than a general application

### **5.3 POLLUTANTS EMITTED**

VOC, PM and air toxics can be emitted from pesticide application activities. Emissions can occur initially when technical material is mixed with other materials to field strength by the applicator. Emissions can also occur from the following activities.

- During application
- After application as the pesticide (including carriers and other additives) evaporates
- During farming operations such as field preparation and harvesting when organic materials and soils are disturbed, allowing for additional pesticide evaporation and movement of dust particles
- During mowing operations along treated roadsides and rights-of-way

## 5.4 ESTIMATE OF POLLUTANT LEVELS

Figures available from the U.S. International Trade Commission (ITC) indicate that U.S. production of pesticides and related products in 1987 amounted to about 1.04 billion pounds.<sup>6</sup> According to Reference 1, these figures are probably underestimates and do not differentiate between the amounts actually used in the United States and those that are exported. Other estimates suggest that between 0.9 and 1.1 billion pounds of active ingredients are used each year in the United States.<sup>1</sup> The U.S. EPA has also estimated pesticide usage in the United States during recent years at 1.1 billion pounds of active ingredients.<sup>4</sup>

Reference 4 provides two per capita factors representing 1989 pesticide usage in terms of pounds of active ingredient (a.i. stands for active ingredient):

Non-agricultural usage (active ingredient): 1.1 lbs per capita

All usage (active ingredient): 4.28 lbs per capita

Reference 3 provides the following assumptions about pesticides.

- The amount of solvent carrier is about 1.45 times the amount of active ingredient
- The total potential VOC emissions are 2.45 times the amount of active ingredient

Combining these assumptions with the per capita factors from Reference 4, potential VOC emissions from all pesticide use can be calculated as follows:

$$(4.28 \text{ lbs a.i./capita})(2.45)(250,000,000)(1 \text{ ton}/2,000 \text{ lbs}) = 1,310,750 \text{ tons}$$

The nonagricultural portion of potential VOC emissions would be

$$(1.1 \text{ lbs a.i./capita})(2.45)(250,000,000)(1 \text{ ton}/2,000 \text{ lbs}) = 336,875 \text{ tons}$$

The agricultural portion of potential VOC emissions would be

$$(3.18 \text{ lbs a.i./capita})(2.45)(250,000,000)(1 \text{ ton}/2,000 \text{ lbs}) = 973,875 \text{ tons}$$

Actual VOC emissions would be less since not all of the VOC will evaporate. Some of the pesticide may be leached into the soil and water, may be broken down by various organisms into other substances, or may remain in landfilled containers.

Other national, state and regional per capita factors and emissions estimates are available from References 7 through 11. These estimates are briefly summarized in Tables 5-1 and 5-2.

No data were readily available to estimate PM emissions from pesticide application activity.

## **5.5 SOURCE ACTIVITY DATA AVAILABILITY**

Many sources of data are available to estimate pesticide application activity. These sources are identified under the appropriate user category (consumer, agricultural, commercial, municipal, industrial).

### **5.5.1 Consumer**

EPA's Office of Pesticides and Toxic Substances has recently made available results of its national home and garden pesticide use survey.<sup>12</sup> The following types of data were collected from households surveyed about their pesticide use.

- Types of pesticides used
- What they were used for
- How often they were used
- How they were applied, including safety precautions
- How unused portions were stored and/or disposed of

**TABLE 5-1. PER CAPITA FACTORS FOR PESTICIDE EMISSIONS**

REFERENCE NUMBER	REGION	EMISSION FACTOR (lbs VOC/capita)	USE/PRODUCT	COMMENTS
7	CA	0.67	Consumer/commercial insecticides	average
7	CA	0.15	Consumer/commercial herbicides and fungicides	average
7	NJ	0.56	Consumer/commercial insecticides	average
7	NJ	0.12	Consumer/commercial herbicides and fungicides	average
7	NY	0.64	Consumer/commercial insecticides	average
7	NY	0.14	Consumer/commercial herbicides and fungicides	average
8	New England	0.041/0.428/0.815	Consumer/commercial insecticides	low/mid/high
8	Mid Atlantic	0.041/0.428/0.815	Consumer/commercial insecticides	low/mid/high
8	E.N. Central	0.038/0.404/0.769	Consumer/commercial insecticides	low/mid/high
8	W.N. Central	0.038/0.404/0.769	Consumer/commercial insecticides	low/mid/high
8	S. Atlantic	0.059/0.622/1.186	Consumer/commercial insecticides	low/mid/high
8	E.S. Central	0.059/0.622/1.186	Consumer/commercial insecticides	low/mid/high
8	W.S. Central	0.059/0.622/1.186	Consumer/commercial insecticides	low/mid/high
8	Mountain	0.040/0.418/0.797	Consumer/commercial insecticides	low/mid/high
8	Pacific	0.040/0.418/0.797	Consumer/commercial insecticides	low/mid/high
8	U.S.	0.180/0.184/0.188	Consumer/commercial moth control	low/mid/high
8	U.S.	0.000/0.156/0.313	Consumer/commercial herbicides and fungicides	low/mid/high



**TABLE 5-2. PESTICIDE EMISSIONS ESTIMATES**

REFERENCE NUMBER	REGION	EMISSIONS (tons VOC/year)	USE/PRODUCT	COMMENTS
7	CA	3,000.41 - 13,613.93	Consumer/commercial insecticides	low - high
7	CA	3,605.25	Consumer/commercial herbicides and fungicides	high
7	NJ	845.57 - 3,836.65	Consumer/commercial insecticides	low - high
7	NJ	1,016.02	Consumer/commercial herbicides and fungicides	high
7	NY	1,254.72 - 5,693.1	Consumer/commercial insecticides	low - high
7	NY	1,507.65	Consumer/commercial herbicides and fungicides	high
9	NYCMA	5/32	Pet insecticides	household/commercial
9	NYCMA	33/15	Insect repellents	household/commercial
9	NYCMA	413/619	Other insecticides	household/commercial
9	NY	12/70	Pet insecticides	household/commercial
9	NY	69/30	Insect repellents	household/commercial
9	NY	717/1,064	Other insecticides	household/commercial
10	CA	27,008.98	Agricultural 47092 pesticide	total organics (TOG)
10	CA	1,818.87	Domestic 47100 pesticide	TOG
10	CA	1,369.78	Unspecified 47118 pesticide	TOG
10	CA	63,507.54	Agricultural 47126 pesticide	TOG
10	CA	2,997.19	Domestic 47134 pesticide	TOG
10	CA	96,702.36	All pesticides	TOG - total of 5 above
11	CA	182,019,000	Formula 10 pesticides	TOG - lbs/yr

- How product containers were disposed of
- How child resistant packaging was used
- How effective the pesticides were judged to be
- Which pests were major problems (either treated or untreated)

The summary data are reported primarily in thousands and percents of households with specific pesticide-related statistics. Rates of application and amounts of pesticides applied are not reported in the summary.

Reference 1 provides various statistics in consumer pesticide use, such as the following.

- Between 8 and 17 percent of pesticides used in the United States are used privately to control household and home garden pests
- About 90 percent of all U.S. households use pesticides

Reference 4 estimates that the following volumes of pesticide active ingredients are used in the home and garden sector.

- 25 million lbs herbicides (includes plant growth regulators)
- 30 million lbs insecticides (includes miticides and contact nematicides)
- 11 million lbs fungicides (does not include wood preservatives)
- 3 million lbs other (includes rodenticides, fumigants and molluscicides)
- 69 million lbs total (34,500 tons)

Other consumer pesticide usage data are available from References 7, 8, 9, 10, 11 and 13. Some of these data are national, state or regional in their coverage and may report commercial and consumer use together.

### 5.5.2 Agricultural

The *Census of Agriculture* contains information on the number of acres of various crops harvested and the number of farms and number of acres on which agricultural chemicals are used.<sup>14</sup> These data are reported on the national, state and county level under the following headings.

- Sprays, dusts, granules, fumigants, *etc.*, to control: insects on hay and other crops; nematodes in crops; diseases in crops and orchards; weeds, grass or brush in crops and pasture
- Chemicals used for defoliation or for growth control of crops or thinning of fruit

State and county agricultural statistics are available from state Departments of Agriculture and state and national Agricultural Statistics Services. These publications contain state and county statistics on crops harvested and crop-specific information on percent of acres treated with various herbicides and insecticides. Reference 15 is an example of these state publications.

References 16 and 17 provide crop-specific agricultural chemical usage for field crops in 1991 and vegetables in 1990, respectively. In Reference 16, data include the crop, the name of the agricultural chemicals applied, the area or acres applied (percent), the number of applications, the rate per application and rate per crop per year (pounds per acre) and the total applied (pounds) by major producing state. Similar data items for vegetables are reported in Reference 17.

Many states regularly produce agricultural chemicals manuals. The *1991 North Carolina Agricultural Chemicals Manual* includes sections covering safety, application, specimen identification, insect control, disease control, fruit disease, chemical weed control, plant growth regulators, fertilizer use, and animal control.<sup>5</sup> Crop-specific data by pest may include pesticide name and available formulations, amount of formulation per acre, active ingredient per acre, minimum interval between application and harvest, and precautions and remarks.

The *Farm Chemicals Handbook* and Thompson's *Agricultural Chemicals* provide compound-specific information.<sup>2,18</sup> For example, the pesticide index in Reference 2 includes definitions of various pesticide activity-related terms, as well as detailed information on pesticides by brand name and/or common name. Information that may be provided for a pesticide by brand name includes: *identification* - common name, other name, code number, discontinued names; *chemistry* - composition, family, properties, structure; *action/use* - action, use, formulations, combinations; *registration notes*; *environmental guidelines* - signal word, toxicity class, toxicity, protective clothing, handling and storage cautions; and *emergency guidelines* - flashpoint, combustion products; fire extinguishing media, antidote, first aid, emergency telephone number, basic producer.

Usage statistics for agricultural purposes are compiled in the National Pesticide Usage Database, developed by Leonard Gianessi of Resources for the Future.<sup>19,20</sup> This database is disaggregated into county use for 25 widely used agricultural pesticides, but statistical significance may be limited to the state level.

References 10, 11, 21 and 22 also provide some agricultural pesticide usage information. References 10, 11 and 21 reflect activity in California and include emissions estimation methodologies.

### **5.5.3 Commercial/Municipal/Industrial**

Reference 1 estimates that 8 to 24 percent of the pesticides used in the United States are used for industrial, commercial and government purposes. The *National Home and Garden Pesticide Use Survey - Final Report* provides the following statistics:<sup>12</sup>

"About 15 percent of the 66.8 million households that have a private lawn (about 10 million households) had pesticides applied in the past year by someone other than a member of the household, usually by a commercial lawn care company. Also, about 20 percent of all households (about 16 million) had their homes commercially treated for indoor pests, such as cockroaches, ants or fleas."

Most trade associations contacted either do not collect information on pesticide usage (amounts in different user categories) or may only collect data on certain products, not on the scale needed to make emissions estimates.<sup>23,24</sup> State officials contacted indicate that while there are recordkeeping requirements for pesticide applicators, the requirements may differ depending on the pesticide use (agricultural, structural, *etc.*) and may or may not include the name of pesticide or the amount or concentration.<sup>25,26</sup> The experts contacted suggested other potential sources of information, including the Chemical Specialty Manufacturers Association, the Chemical Manufacturers Association and other manufacturers and distributors.<sup>24,26</sup> Individual municipalities may keep records of amounts and types of pesticides applied by the municipality.

## **5.6 LEVEL OF DETAIL REQUIRED BY USERS**

### **5.6.1 Consumer**

The following information is needed to estimate use by consumers.

- Total amount of consumer pesticides used per county, state or region. This information can then be used to estimate average consumer indoor pesticide use (per capita or per household) by county, state or region; average consumer outdoor pesticide use (per capita or per household) by county, state or region
- Percent of pesticide used that is volatile and is likely to evaporate
- PM emission rate per unit (gallon or pound) of pesticide used, developed into a per capita or per household emission factor

### **5.6.2 Agricultural**

The following information is needed to estimate use by agriculture.

- Amount of pesticide used per acre, by crop
- Acres harvested, by crop, and percent of harvested crop that is treated with pesticides
- Percent of total pesticides used applied aerially and percent of total pesticides used applied from the ground

- Percent of pesticide used that is volatile and is likely to evaporate, by application type (ground or aerial)
- PM emission rate per unit (gallon or pound) of pesticide used, developed into a per acre emission factor

### **5.6.3 Commercial/Municipal/Industrial**

The following information is needed to estimate commercial/municipal/industrial use.

- Commercial, municipal and industrial pesticide use by county and medium (terrestrial or aquatic)
- Percent applied aerially and percent applied from the ground by county and medium for each user type
- Percent of pesticide used that is volatile and is likely to evaporate, by application type (ground or aerial), by county and by medium for each user type
- PM emission rate per unit (gallon or pound) of pesticide used

## **5.7 EMISSION FACTORS AVAILABLE/REQUIRED**

Table 5-1 provides the per capita VOC emission factors available from References 7 and 8. These emission factors only address consumer/commercial use of insecticides, herbicides and fungicides and are state- (California, New Jersey and New York) and region-specific. Reference 3 provides a general VOC emission factor for agricultural pesticide use.

VOC and PM emission factors need to be developed for all user categories. These emission factors may include, but are not limited to, the following:

- *Consumer* - national, regional or state per capita or per household emission factors
- *Agricultural* - national, regional or state crop-specific emission factors for ground and aerial application
- *Commercial* - national, regional or state per household emission factors
- *General* - herbicide/insecticide per acre emission factors

## **5.8 REGIONAL, SEASONAL AND OTHER TEMPORAL CHARACTERISTICS**

Most household pesticides are used during spring and summer months when pest infestations are greatest. Warmer weather may also increase volatilization of termiticides. Since insect populations are generally larger in more moderate climates, pesticide usage and corresponding emissions should be greater in the southern states.<sup>1</sup> However, high density population areas such as center-city areas may show a higher per capita usage rate than other parts of the same city.

In general, greater consumption, and therefore, greater emissions, occur during the growing season for all pesticide user categories. Rural areas may have greater emissions due to intensive agricultural pesticide use.

## **5.9 POTENTIAL METHODOLOGIES**

The following paragraphs present conceptual methodologies for estimating emissions from each user category.

### **5.9.1 Consumer**

To estimate consumer emissions from pesticide use, total pesticide use must be broken down into the various user categories. Total consumer pesticide use should be allocated to specific regions in order to develop regional per capita or per household VOC and PM emission factors. County population and housing data are available from the *Census of Housing* and the *Census of Population*.<sup>27,28</sup>

### **5.9.2 Agricultural**

Data from Reference 16 can be used to determine the pounds of various agricultural chemicals used per acre by crop by state. Although data from all states are not available from this reference, it may be possible to infer regional patterns from the existing data. Additional application rate information may be taken from publications like Reference 5. Data on acres

harvested by crop are available from the *Census of Agriculture*.<sup>14</sup> Reference 16 also provides data on percent of total area planted that is treated with herbicides, insecticides, fungicides and other chemicals and number of applications per year, by crop and state. These data can be used to adjust total county acreage to county acreage treated. This can be represented by the following equation.

$$\begin{array}{ccccccc} \text{Number of acres} & & \text{Percent of acres} & & \text{Lbs applied per} & & \text{Number of} & & \text{Total lbs} \\ \text{(county, crop)} & \times & \text{treated (crop)} & \times & \text{acre (crop)} & \times & \text{applications} & = & \text{applied} \end{array}$$

Next, the VOC portion of the pesticide and the amount of VOC likely to evaporate must be estimated. VOC emissions would be estimated by the following equation.

$$\text{Total lbs applied} \times \text{weight percent VOC in pesticide} \times \text{percent VOC evaporates} = \text{lbs VOC emissions}$$

Additional considerations in these equations are the percentage of pesticides applied aerially and the percentage of pesticides applied from the ground. Harold Collins of the National Agricultural Aviation Association stated that 30 percent of all agricultural pesticides are applied aerially. In addition, the exact same formulations and levels of active ingredients are used aerially as are used during ground applications. The quantity of diluent may vary with the application method, but quantities do not exceed the manufacturer's recommendations. (Reference 18 contains manufacturer's recommendations.) It is reasonable to expect that a greater proportion of pesticides evaporates when applied aerially.<sup>29</sup>

To determine PM emissions, agencies may need to know more specific information on the types and formulations of the pesticides applied in the area and the application or treatment activities. If these data are unknown, many assumptions will need to be made regarding PM emissions per acre treated or pounds applied.



### 5.9.3 Commercial/Municipal/Industrial

Very few data have been located on commercial pesticide usage. Reference 1 estimates that 8 to 24 percent of the pesticides used in the United States are used for industrial, commercial and government purposes. An inventorying agency should be careful not to double-count residential use of commercially applied pesticides. If this lawn and home use (pesticides being applied by someone other than a member of the household) is being accounted for under the consumer use category, it should not be included here.

Total commercial pesticide usage would be divided by number of households having lawn treatment and number of households having home treatment to estimate pounds of pesticides applied per lawn-treated household and pounds per home-treated household, respectively. The *Census of Housing* can be used to identify the number of households with lawns and total number of households. These figures are then multiplied by 0.15 and 0.20, respectively, to determine the number of treated households in each category.

As with the other user categories, the percent of VOC in the pesticide and the percent that evaporates needs to be determined to estimate the VOC emission factor. General assumptions will need to be made concerning types, formulations and treatment activities as input to the emission factor determination. These assumptions will also be needed to determine the PM emission factor. The VOC and PM emission factors can then be applied to the number of treated households in each category to estimate VOC and PM emissions.

Municipal pesticide use can be determined by contacting the local and state government agencies to determine the pesticide amount, type and treatment in the area being inventoried. In addition, these agencies may also have information on industrial pesticide application. VOC percent and percent evaporation needs to be determined to estimate the VOC emission factor.

If the detailed information on municipal and industrial pesticide use is not available, the agency may consider "scaling up" the inventory to account for this pesticide use. This scaling up activity

assumes that the pesticides used in these applications are used in the same relative amount and have the same characteristics as those used in other user applications.

## 5.10 REFERENCES

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## SECTION 6.0

### AGRICULTURAL OPERATIONS

#### 6.1 BACKGROUND

Agricultural (farming) operations include plowing, disking, fertilizing, applying pesticides, preparing seed beds, planting, cultivating and harvesting.<sup>1</sup> All these operations can be generically classified as soil preparation, soil maintenance and crop harvesting operations.<sup>2</sup> For the purposes of this discussion, agricultural operations have been divided into two major categories: tilling and harvesting. Tillage operations include plowing, disking, fertilizing, pesticide application, seed bed preparation, planting and cultivating activities, *i.e.*, soil/site preparation and soil maintenance. (Cultivation is defined as shallow tillage operations performed to create soil conditions conducive to improved aeration, infiltration and water conservation, or to control weeds.<sup>2</sup>

Tilling and harvesting activities can result in emissions of PM, as well as VOC and air toxics from the disturbed soil and organic matter (weeds, crop residue). Dust emissions from tilling are greatest during periods of dry soil and during final seedbed preparation, and depend on surface soil texture, surface soil moisture content and other conditions of a particular field being tilled.<sup>3</sup> In addition, PM emissions are also generated by wind erosion of bare or partially vegetated soil.<sup>2</sup>

This discussion addresses only the dust and associated emissions from agricultural operations. Fuel combustion emissions from the agricultural equipment are addressed in the off-highway or non-road mobile sources portion of national and SIP inventories.

#### 6.2 PROCESS BREAKDOWN

Tilling and harvesting activities can be broken down by crop (*e.g.*, sugar cane, cotton, wheat, *etc.*), soil type (*e.g.*, clay, silt, loam, *etc.*) and site characteristics, and activity type (*e.g.*, manual harvesting versus machine harvesting).

## **6.2.1 Tilling**

### **6.2.1.1 Crop**

Tilling to prepare the seedbed is needed when planting small and/or high cost seed, such as lettuce, tomatoes, sugar beets, alfalfa and clovers. It is not as important for vigorous large-seeded plants such as corn, small grains, soybeans, dry beans and sorghum.<sup>1</sup>

Plowing under crop residues helps to control certain insects in certain crops. Examples include the following:<sup>1</sup>

- *Wheat* - The Hessian fly can be controlled by plowing under infested wheat stubble and volunteer wheat. The wheat jointworm is held in check by destroying all volunteer grain
- *Corn* - Plowing under corn stalks reduces the next year's crop of European corn borers
- *Cotton* - The cotton boll weevil and pink boll worm can be controlled by early destruction and plowing under of cotton stalks

Also, timely cultivation can reduce grasshopper infestations by drying out their eggs.

Periodic tillage can also help maintain the open furrows needed to channel the water for surface-flow irrigation; helps break up soil crusts; and covers over the roots of crops such as sugar beets and potato tubers.

### **6.2.1.2 Soil Type/Site Characteristics**

Tilling can improve plant growth by improving aeration, water movement and root penetration in the soil profile. The physical condition of soil as related to its ease of tillage, fitness as a seedbed and impedance to seedling emergence and root penetration is known as tilth. Coarse-textured soils usually exhibit good physical condition, but have a small capacity for supplying enough water and plant nutrients. Fine-textured soils normally have a satisfactory nutrient and water reserve, but often inhibit soil aeration because the fine particles pack closely together, thus

slowing air exchange. Plowing and cultivating coarse-textured soils do not seem to make them a better medium for plant growth; tilling most fine-textured soils improves the air-water relations immediately following the tillage operations, which result in better plant growth.<sup>1</sup>

Tillage operations should be conducted sparingly since tillage can lead to soil surface smoothing and clod pulverization. Soil moisture at the time of tillage affects cloddiness. Different soils have differing moisture contents at which soil pulverization is most severe. More clods are produced if the soil is either extremely dry or moist than if it contains an intermediate moisture content.<sup>4</sup>

#### **6.2.1.3 *Equipment Type***

Tillage methods are widely different, ranging from the conventional (*e.g.*, moldboard plowing, disking, harrowing or dragging) to those of special sizing and bed shaping, deep chiseling, strip tillage and zero tillage.<sup>1</sup> Equipment used for tilling can vary depending on the tillage operation to be performed. In addition, the type of tillage implement used influences the soil cloddiness and surface roughness.<sup>4</sup> Major types of planters available for small grains include hoes, single and double disks, deep furrow drills and seeding attachments on one-ways and cultivators. Implements used to provide a rough, clodding soil surface may include listers, duckfoot cultivators and narrow-tooth chisel cultivators.<sup>2</sup>

### **6.2.2 Harvesting**

Emissions from harvesting activities are dependent primarily on the crop and the equipment used. Emissions from cotton harvesting are related to machine speed, basket and trailer capacity, lint cotton yield, free silica content and transport speed. Emissions from grain harvesting are related to combine speed, combine swath width, field transport speed, truck loading time, truck capacity and truck travel time.<sup>5</sup>



#### **6.2.2.1 Crop**

Crops vary in the manner in which they are harvested. In some harvesting operations, only a portion of the plant is harvested, such as in harvesting of cotton. In other harvesting operations, such as mowing and baling hay, almost the entire plant is harvested. In addition, some crops are "dustier" than others.

#### **6.2.2.2 Equipment**

The crop to be harvested determines the type of harvesting equipment to be used. For example, types of harvesters used for cotton include pickers and strippers. However, these harvesters are not appropriate for harvesting grain crops.

#### **6.2.3 Wind Erosion**

Emissions from wind erosion depend on several factors, including soil erodibility, surface roughness, vegetative cover and other site-specific factors.

### **6.3 POLLUTANTS EMITTED**

All tilling and harvesting operations can result in PM, VOC and air toxics emissions. The type of tilling operation affects the rate of emissions. In addition, the crop being harvested and the crop residue that is tilled under after harvest can also add organic particles to the dust emissions. PM emissions also result from wind erosion of the tilled soil.

### **6.4 ESTIMATE OF POLLUTANT LEVELS**

The following national PM-10 emissions have been calculated using emission factors presented in *Gap Filling PM<sub>10</sub> Emission Factors for Selected Open Area Dust Sources*.<sup>5</sup>

The emission factor for all wheat harvesting activities (harvest machine, truck loading and field transport) is 1.68 pounds per square mile. The emission factor for all sorghum harvesting activities (harvest machine, truck loading and field transport) is 7.83 pounds per square mile. The emission factor for harvesting cotton, assuming the weighted values for a stripper, is 26 pounds per square mile. Using a default value for silt content, the PM-10 emission factor for tilling is 5.7 pounds per acre. These emission factors have been applied to national statistics on acres of crops harvested from the *1987 Census of Agriculture*.<sup>6</sup>

Harvesting wheat:

$$53,224,174 \text{ acres} \times 1.68 \text{ lbs/mi}^2 \times 0.0015625 \text{ mi}^2/\text{acre} = 139,713 \text{ lbs or } 69.9 \text{ tons}$$

Harvesting sorghum:

$$9,760,574 \text{ acres} \times 7.83 \text{ lbs/mi}^2 \times 0.0015625 \text{ mi}^2/\text{acre} = 119,415 \text{ lbs or } 59.7 \text{ tons}$$

Harvesting cotton:

$$9,826,081 \text{ acres} \times 26 \text{ lbs/mi}^2 \times 0.0015625 \text{ mi}^2/\text{acre} = 399,185 \text{ lbs or } 199.6 \text{ tons}$$

Tilling (assuming one operation per harvested acre):

$$282,223,880 \text{ acres} \times 5.7 \text{ lbs/acre} = 1,608,600,000 \text{ lbs or } 804,338 \text{ tons}$$

Tilling (assuming that the average farm size in the United States is 462 acres and one operation per acre):

$$462 \text{ acres/farm} \times 5.7 \text{ lbs/acre} = 2,633 \text{ lbs/farm or } 1.3 \text{ tons/farm}$$

The National Acid Precipitation Assessment Program (NAPAP) developed estimates of wind erosion from natural and agricultural lands. National TSP emissions from this category for 1985 were estimated at 4,711,540 tons. PM-10 emissions were estimated to be 1,130,769 tons.<sup>7</sup>

No estimates of VOC or air toxics emissions from tilling and harvesting operations are available.

## **6.5 SOURCE ACTIVITY DATA AVAILABILITY**

County-level data on acres harvested by crop and populations of equipment on farms are available in the *Census of Agriculture*. Reference 8 contains data on number of tillings per year by crop. Number of fertilizer and pesticide applications per year by crop by state are available from Reference 9.

## **6.6 LEVEL OF DETAIL REQUIRED BY USERS**

### **6.6.1 Tilling**

The following data items are needed by users to estimate tilling emissions.

- Number of harvested acres, by crop
- Number of pesticide and fertilizer applications, by crop
- Local tilling practices and activity, by crop
- Generic emission factors for tilling activity or specific emission factors for each type of tilling activity

### **6.6.2 Harvesting**

The following data items are needed by users to estimate harvesting emissions.

- Number of harvested acres, by crop
- Harvesting equipment used, by crop (especially cotton)
- Emission factors by crop and equipment

### **6.6.3 Wind Erosion**

The following data items are needed by users to estimate emissions from wind erosion.

- Number of tilled acres, by crop
- Soil-site characteristics including soil type, soil erodibility, *etc.*
- Local climate information

## **6.7 EMISSION FACTORS AVAILABLE/REQUIRED**

Emission factors are available from References 2, 3 and 5. Specifically, Reference 2 provides emission factor equations for tilling and wind erosion. Area-specific data are needed for these equations. The emission factor equation in Reference 2 is based on *AP-42* (Reference 3). Reference 5 provides emission factors for agricultural tilling, harvesting of cotton by various types of harvesters, and harvesting of wheat and sorghum.

## **6.8 REGIONAL, SEASONAL AND OTHER TEMPORAL CHARACTERISTICS**

Most emissions from agricultural operations occur in rural areas. Seasonally, tilling emissions will occur primarily in the spring, especially around final seedbed preparation time. Harvesting emissions occur primarily at the end of the growing season, in the fall. Wind erosion emissions occur primarily when soils are dry and not protected by a vegetative cover, primarily during the winter and spring.

## **6.9 POTENTIAL METHODOLOGIES**

The following methodology approaches are derived from References 2, 3 and 5. Most of the data items needed for these methodologies are readily available.

### 6.9.1 Tilling

The PM emission factor for agricultural tilling can be described by the following equation.<sup>2,3,5</sup>

$$E = k(4.80)(s)^{0.6} \text{ lbs/acre}$$

where:  $k$  = particle size multiplier (dimensionless)

$s$  = silt content (percent) of surface soil

The particle size multiplier,  $k$ , is 0.21 for PM-10. Thus the emission factor equation (with an *AP-42* rating of B) for PM-10 is

$$\begin{aligned} E_{10} &= (0.21)(4.80)(s)^{0.6} \text{ lbs/acre} \\ &= 1.1(s)^{0.6} \text{ lbs/acre} \end{aligned}$$

Silt content can be determined from soil survey maps. Soil Conservation Service personnel and local Agriculture Extension Service personnel may also have these data. If silt content is unknown, a default value of 18 percent can be used.<sup>2,5</sup> Using the default silt content, the PM-10 emission factor equation (with a C rating) is

$$\begin{aligned} E_{10} &= (0.21)(4.80)(18)^{0.6} \text{ lbs/acre} \\ &= 5.7 \text{ lbs/acre} \end{aligned}$$

The number of acres tilled depends on the amount of acres planted and harvested and the number of times per season that the land is tilled. Reference 8 provides the following information on number of tillings per year by crop:

Crop	Tillings per year
Barley	3
Corn	3
Cotton	4 - East, 3 - West

Oats	3
Sorghum	2 - East, 3 - West
Soybeans	3
Wheat	3 - East, 2 - West

Number of acres harvested by crop is available from the *Census of Agriculture* and/or state Departments of Agriculture.

The emissions estimation equation for PM-10 emissions from tilling (assuming 18 percent silt) is

$$\text{Emissions (lbs/year)} = (\text{acres of crop harvested/year})(\text{tillings per crop})(5.7 \text{ lbs/acre})$$

### 6.9.2 Harvesting

PM emission factors for harvesting cotton, wheat and sorghum are available in Reference 5. For cotton, the emission factors are given for different harvester types and for several harvesting activities, including harvesting itself, trailer loading and transport. Specific equipment types are not indicated for the wheat and sorghum emission rates and factors. Emission factors are given for the harvest machine (generic), truck loading and field transport. Number of acres harvested by crop is available from the *Census of Agriculture* and/or state Departments of Agriculture.

The generic emissions estimation equation for harvesting activity is

$$\text{Emissions (lbs/year)} = (\text{acres of crop harvested/year})(\text{emission factor, lbs/mi}^2)(0.0015625 \text{ mi}^2/\text{acre})$$

### 6.9.3 Wind Erosion<sup>2</sup>

Wind erosion has the following emission factor equation:

$$E = kaIKCL'V'$$

where:	E	=	PM-10 wind erosion losses of tilled fields, tons/acre/yr
	k	=	0.5, the estimated fraction of TSP which is PM-10
	a	=	portion of total wind erosion losses that would be measured as suspended particulate, estimated to be 0.025
	I	=	soil erodibility, tons/acre/yr
	K	=	surface roughness factor, dimensionless
	C	=	climatic factor, dimensionless
	L'	=	unsheltered field width factor, dimensionless
	V'	=	vegetative cover factor, dimensionless

"I" may be thought of as the basic erodibility of a flat, very large, bare field in a climate highly conducive to wind erosion. K, C, L' and V' are reduction factors for a ridged surface, a climate less conducive to wind erosion, smaller-sized fields and vegetative cover, respectively. This same equation can be used to estimate emissions from a single field, a county or an entire state. As more generalized input data are used for the larger land areas, the accuracy of the resulting estimates decreases.

Reference 2 provides tables and figures to aid in quantifying the variables in the above equation. Additional sources of information include the following: the Soil Conservation Service for soil maps for determining "I" and National Weather Service data for determining "C." "I" and "C" values can be determined for individual jurisdiction, with the remaining three variables being quantified as functions of crop type. Number of acres harvested by crop is available from the *Census of Agriculture* and/or state Departments of Agriculture.

The general emissions estimation equation for agricultural wind erosion emissions is

$$\text{Emissions by crop (tons/yr)} = (\text{acres of crop harvested/year})(\text{emission factor, tons/acre})$$

The calculated emissions from each crop are then summed to obtain agricultural wind erosion emissions by county, state or other jurisdiction.



## 6.10 REFERENCES

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## **SECTION 7.0**

### **ISSUES AND RECOMMENDATIONS**

#### **7.1 INTRODUCTION**

This section describes various issues and recommendations for each of the missing sources categories discussed in this report. The discussion includes additional work which may improve methodologies and develop new or more accurate input data and emission factors. Issues and recommendations are included for Catastrophic/Accidental Releases (7.2), Vehicle Repair Facilities (7.3), Recycling (7.4), Pesticide Application (7.5), and Agricultural Operations (7.6).

#### **7.2 CATASTROPHIC/ACCIDENTAL RELEASES**

A number of issues require further attention before practical methods for estimating activity levels and emission factors associated with catastrophic/accidental releases can be generated. Although the NRC and ERNS databases provide estimates of the number of reported catastrophic/accidental incidents and the quantity and type of material spilled, other pertinent information and data are lacking. For example, data on the type of cleanup, area of the spill, and quantity of spilled material recovered are generally not available. Some additional effort should be expended to investigate the availability of other sources or approaches for obtaining this information. In addition, these databases do not generally include small spills, therefore, statistical extrapolation methodologies are needed to more accurately estimate total emissions. Finally, considering the complexity of calculating emissions from catastrophic or accidental releases, experts on volatilization and combustion of spilled materials should be contacted for their input on the practicality of developing simple but meaningful estimates of air pollutant emissions from catastrophic/accidental incidents.

#### **7.3 VEHICLE REPAIR FACILITIES**

The three potential methodologies for vehicle repair facilities presented in Section 3 were based on product sales volumes, vehicle registrations, and service operations performed, respectively.

Each of these methodologies requires basic information that includes the current formulation of products used in service stations; the relative use of products by service stations, other vehicle repair facilities, and consumers; and the distribution of product use or repair activities over time and geographic regions. Recent interaction between EPA and automotive product industry representatives (Chemical Specialties Manufacturers Association and Motor Equipment Manufacturers Association) has indicated that industry is willing to assist in the development of information that would facilitate any of the three potential approaches. In particular, cooperation should be obtained on the determination of formulations, VOC releases, sales by geographic area, type of product form, and end user. In addition, industry representatives should be able to provide valuable perspective in determining appropriate methodologies for estimating emissions from vehicle servicing.

Before further work on the three potential methodologies is conducted, an initial screening phase is recommended to provide both structure and prioritization. This preliminary screening phase should consist of an assessment of the three potential methodologies and existing data resources; consultation with industry on appropriateness of specific methodologies, readily-available information, and potential future contributions to these methodologies; and preparation of a proposed set of methodology development efforts and a plan for carrying them out.

## **7.4 RECYCLING**

Emissions from recycling activities in general are difficult to quantify due to the variability of recycling programs. This variability can arise from the materials included in the recycling program, the collection method, the sorting/segregation step, or processing. The existence or extent of program activity in a particular area is at least partially dependent on available waste disposal alternatives, participation rates, and state and local regulations. Therefore, emissions estimation from recycling programs may be most accurate if performed on a city by city basis.

Due to the lack of quantitative emissions data available for many recycling processes, a series of emissions tests should be conducted to develop emission factors. For example, PM-10 emission factors could be developed from a properly designed particulate sampling procedure for

a variety of commercially available glass crushers. These factors could then be applied to glass crushing activities at a given facility to quantify emissions. Emissions tests should also be performed for other common recycling processes, such as shredding/grinding, air classification, loading/unloading/conveying, delacquering/melting, compaction, and extruding.

## **7.5 PESTICIDE APPLICATION**

Important data are still missing from the methodologies developed for pesticide applications and were not located when researching Section 5. These data items include the VOC portion of the pesticide that evaporates and the emission rates (VOC and PM-10) for various pesticides and formulations by user categories (consumer, agricultural, commercial, and general). In addition, national- or state-level statistics on commercial, municipal, and industrial pesticide usage were not found and are necessary for methodology development.

A separate issue that could be dealt with involves developing emission factors that account for geographic variability effects on VOC and PM-10. Various geographical effects including temperature and soil water content, can affect emissions, however, a great amount of effort would be needed to develop this data. Also, the effect on an overall emissions inventory for a particular area would probably be minimal. The more important issue would probably be from an air toxics standpoint.

## **7.6 AGRICULTURAL OPERATIONS**

Several data items are still needed for the methodologies developed to estimate emissions from agricultural operations. Most importantly, harvesting emission factors are needed for crops other than cotton, wheat, and sorghum. Also, due to the lack of quantitative emissions data available for many agricultural operations, a series of emissions tests should be conducted to develop emission factors. For example, PM-10 emission factors could be developed from a properly designed particulate sampling procedure for a variety of harvester types. These factors could then be applied to harvested acres in a particular area to quantify emissions. Emissions tests should also be performed for other common agricultural operations including plowing, fertilizing, seed bed preparation, planting, and cultivating.

## APPENDIX A

### INDEX OF CODES

(Source: National Response Center, U.S. Coast Guard, Washington D.C.)

AAC	ACETIC ACID	AMF	AMMONIUM SULFITE
AAD	ACETALDEHYDE	AMH	AMMONIUM HYDROXIDE
AAM	ACRAYLAMIDE	AMK	n-AMYL METHYL KETONE
AAN	n-AMYL ALCOHOL	AML	AMYL ACETATE
AAS	sec-AMYL ACETATE	AMM	n-AMYL MERCAPTAN
AAT	AMMONIUM ACETATE	AMN	AMMONIUM NITRATE
ABC	AMMONIUM BICARBONATE	AMP	AMMONIUM PERCHLORATE
ABF	AMMONIUM BIFLUORIDE	AMR	AMMONIUM STEARATE
ABM	ACETYL BROMIDE	AMS	AMMONIUM SULFATE
ABR	ALLYL BROMIDE	AMT	AMMONIUM THIOCYANATE
ABS	ALKYLBENZENESULFONIC ACIDS	AMY	n-AMYL CHLORIDE
ABZ	AMMONIUM BENZOATE	ANB	AMMONIUM BROMIDE
ACA	ACETIC ANHYDRIDE	ANI	iso-AMYL NITRILE
ACB	AMMONIUM CARBONATE	ANL	ANILINE
ACC	ACETYL CHLORIDE	ANP	AMMONIUM NITRATE-PHOSPHATE MIXTURE
ACD	ACRIDINE	ANS	AMMONIUM NITRATE-SULFATE MIXTURE
ACE	ACETYLENE	ANT	n-AMYL NITRATE
ACF	ALLYL CHLORAFORMATE	ANU	AMMONIUM NITRATE-UREA SOLUTION
ACH	AMMONIUM CHROMATE	AOL	AMMONIUM OLEATE
ACI	AMMONIUM CITRATE	AOX	AMMONIUM OXALATE
ACL	ALUMINUM CHLORIDE	APB	AMMONIUM PENTABORATE
ACM	AMMONIUM CARBAMATE	APC	ANTIMONY PENTACHLORIDE
ACN	ACRYLONITRILE	APE	AMMONIUM PERSULFATE
ACP	ACETOPHENONE	APF	ANTIMONY PENTAFLUORIDE
ACR	ACRYLIC ACID	APO	ARSENIC PENTAOXIDE
ACT	ACETONE	APP	AMMONIUM PHOSPHATE
ACY	ACETONE CYANOHYDRIN	APS	ACETYL PEROXIDE SOLUTION
ADA	ADIPIC ACID	APT	ANTIMONY POTASSIUM TARTRATE
ADN	ADIPONITRILE	ARD	ARSENIC DISULFIDE
AEE	AMINOETHYLETHANOLAMINE	ARF	ASPHALT BLENDING STOCKS: ROOFERS FLUX
AEX	2-(2-AMINOETHOXY) ETHANOL	ARL	ACROLEIN
AFB	AMMONIUM FLUOBORATE	ART	ARSENIC TRISULFIDE
AFM	AMMONIUM FORMATE	ASA	ARSENIC ACID
AFR	AMMONIUM FLUORIDE	ASC	ANISOYL CHLORIDE
AGC	AMMONIUM GLUCONATE	ASF	AMMONIUM SULFIDE
AHP	AMMONIUM HYPOPHOSPHITE	ASL	AMMONIUM SILICOFUORIDE
AID	AMMONIUM IODIDE	ASM	AMMONIUM SULFAMATE
ALA	ALLYL ALCOHOL	ASP	ASPHALT
ALC	ALLYL CHLORIDE	ASR	ASPHALT BLENDING STOCKS: STRAIGHT RUN RESIDUE
ALD	ALDRIN	AST	ARSENIC TRICHLORIDE
ALF	ALUMINUM FLUORIDE	ASU	AMMONIUM BISULFITE
ALM	ALUMINUM SULFATE	ATA	ACETYLACETONE
ALN	ALUMINUM NITRATE	ATB	ANTIMONY TRIBROMIDE
ALS	AMMONIUM LAURYL SULFATE	ATC	ALLYLTRICHLOROSILANE
ALT	AMMONIUM LACTATE	ATF	AMMONIUM THIOSULFATE
AMA	AMMONIA, anhydrous	ATH	ANTHRACENE
AMB	AMMONIUM MOLYBDATE		
AMC	AMMONIUM CHLORIDE		
AMD	AMMONIUM DICHROMATE		

ATM	ANTIMONY TRICHLORIDE	BRX	BROMINE
ATN	ACETONITRILE	BTA	sec-BUTYL ACETATE
ATO	ARSENIC TRIOXIDE	BTB	BORON TRIBROMIDE
ATR	AMMONIUM THIOSULFATE	BTC	n-BUTYL ACRYLATE
ATS	n-AMYLTRICHLOROSILANE	BTD	1,4-BUTYNE DIOL
ATT	ANTIMONY TRIFLUORIDE	BTf	BROMINE TRIFLUORIDE
ATX	ANTIMONY TRIOXIDE	BTL	sec-BUTYLAMINE
ATZ	ATRAZINE	BTM	n-BUTYL MERCAPTAN
AYA	tert-AMYL ACETATE	BTN	BUTYLENE
AZM	AZINPHOSMETHYL	BTO	1,2-BUTYLENE OXIDE
BAC	BORIC ACID	BTP	p-tert-BUTYLPHENOL
BAD	iso-BUTYRALDEHYDE	BTR	n-BUTYRALDEHYDE
BAI	iso-BUTYL ACRYLATE	BUA	tert-BUTYLAMINE
BAL	BENZYL ALCOHOL	BUD	1,4-BUTENEDIOL
BAM	n-BUTYLAMINE	BUT	BUTANE
BAN	n-BUTYL ALCOHOL	BYA	tert-BUTYL ACETATE
BAS	sec-BUTYL ALCOHOL	BZA	BENZOIC ACID
BAT	tert-BUTYL ALCOHOL	BZC	BENZOYL CHLORIDE
BBR	BENZYL BROMIDE	BZD	BENZALDEHYDE
BBZ	BROMOBENZENE	BZM	BENZYLAMINE
BCF	BENZYL CHLOROFORMATE	BZN	BENZONITRILE
BCL	BENZYL CHLORIDE	BZO	BENZYL DIMETHYLOCTADECYL- LAMMONIUM CHLORIDE
BCN	n-BUTYL ACETATE	BZP	BENZOPHENONE
BCP	BOILER COMPOUND	CAA	COPPER ACETOARSENITE
BCR	BARIUM CHLORATE	CAC	CHLOROACETYL CHLORIDE
BCS	BUTYLTRICHLOROSILANE	CAF	CALCIUM FLUORIDE
BCY	BARIUM CHLORATE	CAH	CALCIUM HYDROXIDE
BDE	BISPHENOL A DIGLYCIDYL ETHER	CAL	CALCIUM PHOSPHATE
BDI	BUTADIENE	CAM	CALCIUM
BDO	1,4-BUTANEDIOL	CAO	CALCIUM OXIDE
BEC	BERYLLIUM CHLORIDE	CAP	p-CHLOROANILINE
BEF	BERYLLIUM FLUORIDE	CAR	CARENE
BEM	BERYLLIUM	CAS	CALSIUM ARSENITE
BEN	BERYLLIUM NITRATE	CAT	CADMIUM ACETATE
BEO	BERYLLIUM OXIDE	CBA	COBALT ACETATE
BES	BERYLLIUM SULFATE	CBB	CARBON BISULFIDE
BHC	BENZENE HEXACHLORIDE	CBC	COBALT CHLORIDE
BHP	tert-BUTYL HYDROPEROXIDE	CBD	COPPER BROMIDE (OUS)
BMA	BENZYLTRIMETHYLAMMONIUM CHLORIDE	CBF	CARBOFURAN
BMN	n-BUTYL METHACRYLATE	CBN	4-CHLOROBUTYRONITRILE
BNT	BARIUM NITRATE	CBO	CARBOLIC OIL
BNZ	BENZENE	CBR	CYANOGEN BROMIDE
BOC	BISMUTH OXYCHLORIDE	CBS	COBALT SULFATE
BPA	BISPHENOL A	CBT	CARBON TETRACHLORIDE
BPC	BARIUM PERCHLORATE	CBY	CARBARYL
BPD	BENZENE PHOSPHORUS DICHLORIDE	CCA	CALCIUM ARSENATE
BPF	BROMINE PENTAFLUORIDE	CCB	CALCIUM CARBIDE
BPH	BUTYL BENZYL PHTHALATE	CCC	CALCIUM CHLORATE
BPM	BARIUM PERMANGANATE	CCH	CYCLOHEXANONE
BPO	BARIUM PEROXIDE	CCL	CYANOGEN CHLORIDE
BPT	BENZENE PHOSPHORUS THIODICHLORIDE	CCN	CALCIUM CYANIDE
BRA	n-BUTYRIC ACID	CCP	CALCIUM PEROXIDE
BRC	BARIUM CARBONATE	CCR	CALCIUM CHROMATE
BRT	BORON TRICHLORIDE	CCT	CREOSOTE, COAL TAR
BRU	BRUCINE		

CCY	COPPER CYANIDE (OUS)	CPR	CYCLOPROPANE
CDA	CACODYLIC ACID	CPS	CAUSTIC POTASH SOLUTION
CDC	CADMIUM CHLORIDE	CPT	CAPTAN
CDN	CHLORDANE	CRA	CHLOROACETOPHENONE
CDO	CARBON DIOXIDE	CRB	CHLOROBENZENE
CES	CUPRIETHYLENE DIAMINE SOLUTION	CRC	CHROMOUS CHLORIDE
CFB	CADMIUM FLUOROBORATE	CRE	CALCIUM RESINATE
CFM	COBALT FORMATE (OUS)	CRF	CHLOROFORM
CGE	CRESYL GLYCIDYL ETHER	CRL	m-CRESOL
CHA	CYCLOHEXYLAMINE	CRN	p-CHLOROTOLUENE
CHC	CHARCOAL	CRO	o-CRESOL
CHD	CHLOROHYDRINS	CRP	CHLOROPRENE
CHN	CYCLOHEXANOL	CRS	CRESOLS
CHP	CYCLOHEXANONE PEROXIDE	CRT	CHROMIC ACETATE
CHS	CHROMIC SULFATE	CSA	CHLOROSULFONIC ACID
CHT	CYCLOHEXENYLTRICHLORO-SILANE	CSF	COPPER SULFATE
CHX	CYCLOHEXANE	CSN	COPPER SULFATE,AMMONIATED
CHY	CALCIUM HYPOCHLORITE	CSO	p-CRESOL
CID	COPPER IODIDE	CSS	CAUSTIC SODA SOLUTION
CIT	CITRIC ACID	CST	COPPER SUBACETATE
CLC	CALCIUM CHLORIDE	CSY	CORN SYRUP
CLD	COLLODION	CTA	CROTONALDEHYDE
CLS	CAPROLACTAM	CTC	CATECHOL
CLT	COPPER LACTATE	CTD	4-CHLORO-o-TOLUIDINE
CLX	CHLORINE	CTF	CHLORINE TRIFLUORIDE
CMA	CHROMIC ANHYDRIDE	CTT	COPPER TARTRATE
CMB	CADMIUM BROMIDE	CUF	COPPER FORMATE
CMC	CHROMYL CHLORIDE	CUM	CUMENE
CME	CHLOROMETHYL METHYL ETHER	CYA	CYANOACETIC ACID
CMH	CUMENE HYDROPEROXIDE	CYG	CYANOGEN
CMN	CADMIUM NITRATE	CYP	CYCLOPENTANE
CMO	CARBON MONOXIDE	DAA	DIACETONE ALCOHOL
CMP	p-CYMENE	DAC	DIMETHYLACETAMIDE
CMS	CADMIUM SULFATE	DAE	DIETHYLETHANOLAMINE
CNI	COPPER NITRATE	DAI	DODECYLBENZENESULFONIC ACID, ISOPROPYLAMINE SALT
CNN	COPPER NAPHTHENATE	DAL	DECALDEHYDE
CNO	o-CHLORONITROBENZENE	DAM	DIPHENYLAMINE
CNT	CALCIUM NITRATE	DAN	n-DECYL ALCOHOL
COB	COBALT BROMIDE (OUS)	DAP	Di-n-AMYL PHTHALATE
COF	COBALT FLUORIDE	DAS	DODECYL BENZENE SULFONIC ACID, SODIUM SALT
COL	COPPER OXALATE	DBA	Di-n-BUTYLAMINE
CON	COBALT NITRATE	DBC	DIISOBUTYL CARBINOL
COP	COPPER ACETATE	DBE	DI-n-BUTYL ETHER
COU	COUMAPHOS	DBK	Di-n-BUTYL KETONE
COX	CADMIUM OXIDE	DBL	DIISOBUTYLENE
CPA	COPPER ARSENITE	DBM	m-DICHLOROBENZENE
CPB	COPPER BROMIDE	DBO	o-DICHLOROBENZENE
CPC	COPPER CHLORIDE	DBP	p-DICHLOROBENZENE
CPF	COPPER FLUOROBORATE	DBR	DECABORANE
CPG	COPPER GLYCINATE	DBS	DODECYLBENZENESULFONIC ACID, TRIETHANOLAMINE SALT
CPH	CAMPHENE	DBT	DIBUTYLPHENOL
CPL	CHLOROPICRIN	DBZ	n-DECYLBENZENE
CPN	p-CHLOROPHENOL		
CPO	CAMPOR OIL		
CPP	CALCIUM PHOSPHIDE		

DCA	2,4-DICHLOROPHENOXYACETIC ACID	DMP	DIMETHYLPOLYSILOXANE
DCB	DICHLOROBUTENE	DMS	DIMETHYL SULFOXIDE
DCE	1-DECENE	DMT	DIMETHYL TEREPHTHALATE
DCF	DICHLORODIFLUOROMETHANE	DMZ	DIMETHYLZINC
DCH	1,1-DICHLOROETHANE	DNA	DI-n-PROPYLAMINE
DCL	DICHLONE	DNB	m-DINITROBENZENE
DCM	DICHLOROMETHANE	DNC	DINITROCRESOLS
DCP	2,4-DICHLOROPHENOL	DNE	2,5-DINITROPHENOL
DCS	DODECYLBENZENESULFONIC ACID, CALCIUM SALT	DNH	2,6-DINITROPHENOL
DCV	DICHLORVOS	DNL	2,6-DINITROTOLUENE
DDB	DODECYLBENZENE	DNO	o-DINITROBENZENE
DDC	1,DODECENE	DNP	2,4-DINITROPHENOL
DDD	DDD	DNT	2,4-DINITROANILINE
DDN	DODECANOL	DNU	3,4-DINITROTOLUENE
DDS	DODECYL SULFATE, SODIUM SALT	DNZ	p-DINITROBENZENE
DDT	DDT	DOA	DIOCTYL ADIPATE
DDW	DIMETHYLHEXANE DIHYDRO PEROXIDE	DOD	DODECENE
DEA	DIETHANOLAMINE	DOP	DIOCTYL PHTHALATE
DEB	DIETHYLBENZENE	DOX	1,4-DIOXANE
DEC	DIETHYL CARBONATE	DPA	DIBUTYL PHTHALATE
DED	DIELDRIN	DPB	1,1-DICHLOROPROPANE
DEE	2,2-DICHLOROETHYL ETHER	DGM	DIETHYLENE GLYCOL MONOMETHYL ETHER
DEG	DIETHYLENE GLYCOL	DPC	1,3-DICHLOROPROPANE
DEL	1,2-DICHLOROETHYLENE	DPD	DIPHENYLDICHLOROSILANE
DEM	DIETHYLENE GLYCOL MONOBUTYL ETHER ACETATE DEN DIETHYLAMINE	DPE	DIPHENYL ETHER
DEP	DI(2-ETHYLHEXYL)PHOSPHORIC ACID	DPF	2,3-DICHLOROPROPENE
DES	2,4-D ESTERS	DPG	DIPROPYLENE GLYCOL
DET	DIETHYLENETRIAMINE	DPH	DIETHYL PHTHALATE
DEZ	DIETHYLZINC	DPM	DIPHENYLMETHANE DIISOCYANATE
DFA	DIFLUOROPHOSPHORIC ACID	DPN	DIPENTENE
DFE	1,1-DIFLUOROETHANE	DPO	DIBENZOYL PEROXIDE
DFP	DI(2-ETHYLHEXYL)PHOSPHORIC ACID	DPP	1,2-DICHLOROPROPANE
DGD	DIETHYLENE GLYCOL DIMETHYL ETHER	DPT	DICYCLOPENTADIENE
DGE	DIETHYLENE GLYCOL MONOETHYL ETHER	DPU	1,3-DICHLOROPROPENE
DHN	DECAHYDRONAPHTHALENE	DSA	DODECYL BENZENE SULFONIC ACID
DHP	DIHEPTYL PHTHALATE	DSD	DODECYL SULFATE, DIETHANOL-AMINE SALT
DIA	DIISOPROPYLAMINE	DSF	DIMETHYL SULFATE
DIB	DICHOENIL	DSL	DIMETHYL SULFIDE
DIC	DICAMBA	DSM	DODECYL SULFATE, MAGNESIUM SALT
DID	DIISODECYL PHTHALATE	DSR	DISTILLATES: STRAIGHT RUN
DIH	DIISOPROPYLBENZENE HYDRO-PEROXIDE	DSS	DIOCTYL SODIUM SULFOSUCCINATE
DIK	DIISOBUTYL KETONE	DST	DODECYL SULFATE, TRIETHANOLAMINE SALT
DIM	DIMETHYL ETHER	DTC	DODECYLTRICHLOROSILANE
DIP	DIISOPROPANOLAMINE	DTH	DOWTHERM
DIQ	DIQUAT	DTM	4,4-DICHLORO-alpha-TRICHLOROMETHYL BENZHYDROL
DIS	DISULFON	DTN	DEMETON
DIU	DIURON	DTS	DEXTROSE SOLUTION
DLP	DALAPON	DTT	2,4-DINITROTOLUENE
DMA	DIMETHYLAMINE	DUR	DURBAN
DMD	DIMETHYLDICHLOROSILANE	DZN	DIAZINON
DME	DIETHYLENEGLYCOL MONOBUTYL		
DMF	DIMETHYLFORMAMIDE		
DMH	1,1-DIMETHYLHYDRAZINE		



DZP	DI-(p-CHLOROBENZOYL) EAA ETHYL	ETC	ETHYLENE CYANOHYDRIN
EAC	ACETOACETATE	ETD	ETHOXYLATED TRIDECANOL
EAD	ETHYL ACRYLATE	ETG	ETHOXY TRIGLYCOL
EAI	ETHYLALUMINUM DICHLORIDE	ETH	ETHANE
EAL	2-ETHYLHEXYL ACRYLATE	ETI	ETHYLENEIMINE
EAM	ETHYL ALCOHOL	ETL	ETHYLENE
EAS	ETHYLAMINE	ETM	ETHYL METHACRYLATE
EBA	ETHYLALUMINUM SESQUI-CHLORIDE	ETN	ETHYL NITRITE
EBA	n-ETHYL-n-BUTYLAMINE	ETO	ETHION
EBR	ETHYL BUTYRATE	ETS	ETHYLTRICHLOROSILANE
EBT	ETHYL BUTANOL	EVO	EPOXIDIZED VEGETABLE OILS
ECA	ETHYL CHLOROACETATE	FAC	FERRIC AMMONIUM CITRATE
ECF	ETHYL CHLOROFORMATE	FAL	FURFURYL ALCOHOL
ECH	ETHYL CHLOROHYDRIN	FAO	FERRIC AMMONIUM OXALATE
ECL	ETHYL CHLORIDE	FAS	FERROUS AMMONIUM SULFATE
ECS	ETHYLDICHLOROSILANE	FCL	FERRIC CHLORIDE
EDA	ETHYLENEDIAMINE	FCP	FERRIC GLYCEROPHOSPHATE
EDB	ETHYLENE DIBROMIDE	FEC	FERROUS CHLORIDE
EDC	ETHYLENE DICHLORIDE	FFA	FURFURAL
EDR	ENDRIN	FFB	FERROUS FLUOROBORATE
EDT	ETHYLENEDIAMINE TETRACETIC ACID	FFX	FERRIC FLUORIDE
EEE	ETHYLENE GLYCOL DIETHYL ETHER	FMA	FORMIC ACID
EET	ETHYL ETHER	FMS	FORMALDEHYDE SOLUTION
EFM	ETHYL FORMATE	FNT	FERRIC NITRATE
EGA	ETHYLENE GLYCOL MONO-ETHYL ETHER	FOX	FERROUS OXALATE
	ACETATE	FRS	FERROUS SULFATE
EGD	ETHYLENE GLYCOL DIMETHYL ETHER	FSA	FLUOSULFONIC ACID
EGE	ETHYLENE GLYCOL MONO-ETHYL ETHER	FSF	FERRIC SULFATE
EGL	ETHYLENE GLYCOL	FSL	FLUOSILICIC ACID
EGM	ETHYLENE GLYCOL MONO-BUTYL ETHER	FUM	FUMARIC ACID
EGY	ETHYLENE GLYCOL DIACETATE	FXX	FLUORINE
EHA	ETHYLHEXALDEHYDE	GAK	GASOLINE BLENDING STOCKS:
EHP	ETHOXYDIHYDROPYRAN		ALKYLATES
EHT	ETHYL HEXYL TALLATE	GAT	GASOLINES: AUTOMOTIVE (<4.23g lead/gal)
EHX	2-ETHYL HEXANOL	GAV	GASOLINES: AVIATION (<4.86g lead/gal)
ELT	ETHYL LACTATE	GCM	GLYCIDYL METHACRYLATE
EMA	ETHYLENE GLYCOL MONOBUTYL ETHER	GCR	GLYCERINE
	ACETATE	GCS	GASOLINES: CASINGHEAD
EMC	ETHYL MERCAPTAN	GLA	GALLIC ACID
EME	ETHYLENE GLYCOL MONO-METHYL ETHER	GOC	GAS OIL: CRACKED
ENB	ETHYLIDENE NORBORNENE	GOS	GLYOXAL
ENP	ETHOXYLATED NONYLPHENOL	GPL	GASOLINES: POLYMER
EOD	ETHOXYLATED DODECANOL	GRF	GASOLINE BLENDING STOCKS:
EOP	ETHOXYLATED PENTADECANOL		REFORMATES
EOT	ETHOXYLATED TETRADECANOL	GSR	GASOLINES: STRAIGHT RUN
EOX	ETHYLENE OXIDE	GTA	GLUTARALDEHYDE SOLUTION
EPA	2-ETHYL-3-PROPYLACROLEIN	HAC	HEXADECYLTRIMETHYL-AMMONIUM
EPC	EPICHLOROHYDRIN		CHLORIDE
EPD	ETHYL PHOSPHONOTHIOIC DICHLORIDE	HAI	2-HYDROXYETHYL ACRYLATE
EPP	ETHYL PHOSPHORODICHLORIDATE	HAL	n-HEXALDEHYDE
EPS	ETHYLPHENYLDICHLOROSILANE	HAS	HYDROXYLAMINE SULFATE
ESC	ETHYL SILICATE	HBR	HYDROGEN BROMIDE
ESF	ENDOSULFAN	HCC	HEXACHLOROCYCLOPENTADIENE
ETA	ETHYL ACETATE	HCL	HYDROCHLORIC ACID
ETB	ETHYLBENZENE	HCN	HYDROGEN CYANIDE

HDA	HYDROXYLAMINE	LAC	LEAD ACETATE
HDC	HYDROGEN CHLORIDE	LAH	LITHIUM ALUMINUM HYDRIDE
HDQ	HYDROQUINONE	NOX	NITROGEN TETROXIDE
HDS	HYDROGEN SULFIDE	NPH	4-NITROPHENOL
HDZ	HYDRAZINE	NPP	2-NITROPROPANE
HFA	HYDROFLUORIC ACID	NSS	NAPHTHA: STODDARD SOLVENT
HFX	HYDROGEN FLUORIDE	NSV	NAPHTHA: SOLVENT
HMD	HEXAMETHYLENEDIAMINE	NTA	2-NITROANILINE
HMI	HEXAMETHYLENIMINE	NTB	NITROBENZENE
HMT	HEXAMETHYLENETETRAMINE	NTC	NITROSYL CHLORIDE
HPA	HYDROXYPROPYL ACRYLATE	NTE	NITROETHANE
HPM	HYDROXYPROPYL METHA-CRYLATE	NTI	NAPHTHENIC ACIDS
HPO	HYDROGEN PEROXIDE	NTL	NITRALIN
HPT	HEPTANE	NTM	NAPHTHALENE
HSS	HEXADECYL SULFATE, SODIUM SALT	NTO	NITROUS OXIDE
HTC	HEPTACHLOR	NTP	2-NITROPHENOL
HTE	1-HEPTENE	NTR	m-NITROTOLUENE
HTN	HEPTANOL	NTT	p-NITROTOLUENE
HXA	n-HEXANE	NTX	NITRIC OXIDE
HXE	1-HEXENE	NVM	NAPHTHA: VM & P
HXG	HEXYLENE GLYCOL	NXX	NITROGEN
HXN	n-HEXANOL	OAC	OLEIC ACID, SODIUM SALT
HXX	HYDROGEN	OAN	OCTANE
IAA	ISOAMYL ALCOHOL	OAP	OLEIC ACID, POTASSIUM SALT
IAC	ISOPROPYL ACETATE	OAS	OILS, MISC.: ABSORPTION
IAI	ISODECYL ACRYLATE	OCA	OILS, EDIBLE: CASTOR
IAL	ISOBUTYL ALCOHOL	OCC	OILS, EDIBLE: COCONUT
IAM	ISOBUTYLAMINE	OCF	OILS: CLARIFIED
IAT	ISOAMYLACETATE	OCR	OILS, MISC.: CROTON
IBA	ISOBUTYL ACETATE	OCS	OILS, EDIBLE: COTTONSEED
IBL	ISOBUTYLENE	OCT	OILS, MISC.: COAL TAR
IBN	ISOBUTYRONITRILE	ODS	OILS: DIESEL
IBR	ISOBUTYRIC ACID	OET	OCTYL EPOXY TALLATE
IBT	ISOBUTANE	OFR	OILS, FUEL: 4
IDA	ISODECALDEHYDE	OFS	OILS, EDIBLE: FISH
IHA	ISOHEXANE	OFV	OILS, FUEL: 5
IOA	ISOOCTYL ALCOHOL	OIL	OILS: CRUDE
IOC	ISOOCTALDEHYDE	OLA	OLEIC ACID
IPA	ISOPROPYL ALCOHOL	OLB	OILS, MISC.: LUBRICATING
IPC	ISOPROPYL PERCARBONATE	OLD	OILS, EDIBLE: LARD
IPE	ISOPROPYL ETHER	OLM	OLEUM
IPH	ISOPHORONE	OLS	OILS, MISC.: LINSEED
IPL	ISOPHTHALIC ACID	OMN	OILS, MISC.: MINERAL
IPM	ISOPROPYL MERCAPTAN	OMS	OILS, MISC.: MINERAL SEAL
IPP	ISOPROPYLAMINE	OMT	OILS, MISC.: MOTOR
IPR	ISOPRENE	ONF	OILS, MISC.: NEATSFOOT
IPT	ISOPENTANE	OOD	OILS, FUEL: 1-D
ISA	ISODECYL ALCOHOL	OOL	OLS, EDIBLE: OLIVE
IVA	ISOVALERALDEHYDE	OON	OILS, FUEL: NO. 1
JPF	JET FUELS: JP-4	OPM	OILS, EDIBLE: PALM
JPO	JET FUELS: JP-1	OPN	OILS, EDIBLE: PEANUT
JPT	JET FUELS: JP-3	OPT	OILS, MISC.: PENETRATING
JPV	JET FUELS: JP-5	ORD	OILS, MISC.: ROAD
KPE	KEPONE	ORG	OILS, MISC.: RANGE
KRS	KEROSENE	ORN	OILS, MISC.: ROSIN

ORS	OILS, MISC.: RESIN	PNA	PROPIONIC ACID
OSB	OILS, EDIBLE: SOYA BEAN	POA	POTASSIUM ARSENITE
OSD	OILS, MISC.: SPINDLE	POP	POTASSIUM PEROXIDE
OSF	OILS, EDIBLE: SAFFLOWER	POX	PROPYLENE OXIDE
OSP	OILS, MISCELLANEOUS: SPERM	PPA	POLYPHOSPHORIC ACID
OSX	OILS, FUEL: 6	PPB	PHOSPHORUS BLACK
OSY	OILS, MISC.: SPRAY	PPG	PROPYLENE GLYCOL
OTA	OCTANOL	PPI	POLYMETHYLENE POLYPHENYL ISOCYANATE
OTB	OILS, MISC.: TURBINE	PPL	PROPYLENE
OTC	OILS, EDIBLE: TUCUM	PPO	PHOSPHORUS OXYCHLORIDE
OTD	OILS, FUEL: 2-D	PPP	PHOSPHORUS PENTASULFIDE
OTE	1-OCTENE	PPR	PHOSPHORUS, RED
OTF	OILS, MISC.: TRANSFORMER	PPT	PHOSPHORUS TRICHLORIDE
OTL	OILS, MISC.: TALL	PPW	PHOSPHORUS, WHITE
OTN	OILS, MISC.: TANNER'S	PPZ	PIPERAZINE
OTW	OILS, FUEL: 2	PRA	n-PROPYLAMINE
OVG	OILS, EDIBLE: VEGETABLE	PRD	PYRIDINE
OXA	OXALIC ACID	PRG	PROPARGITE
OXY	OXYGEN	PRP	PROPANE
PAA	PERACETIC ACID	PRR	PYRETHRINS
PAC	PHOSPHORIC ACID	PTA	PENTANE
PAD	PROPIONALDEHYDE	PTB	PENTABORANE
PAH	PROPIONIC ANHYDRIDE	PTC	POTASSIUM CYANIDE
PAL	n-PROPYL ALCOHOL	PTD	POTASSIUM DICHROMATE
PAN	PHTHALIC ANHYDRIDE	PTE	1-PENTENE
PAS	POTASSIUM ARSENATE	PTH	POTASSIUM HYDROXIDE
PAT	n-PROPYL ACETATE	PTI	POTASSIUM IODIDE
PBO	POTASSIUM BINOXALATE	PTL	PETROLATUM
PBP	PROPYLENE BUTYLENE POLYMER	PTM	POTASSIUM
PBR	PHOSPHORUS TROBROMIDE	PTN	PETROLEUM NAPHTHA
PCB	POLYCHLORINATED BIPHENYL	PTO	PARATHION
PCH	POTASSIUM CHROMATE	PTP	POTASSIUM PERMANGANATE
PCL	PERCHLORIC ACID	PTS	POTASSIUM OXALATE
PCM	PERCHLOROMETHYL MERCAPTAN	PTT	PROPYLENE TETRAMER
PCP	PENTACHLOROPHENOL	QNL	QUINOLINE
PCR	POTASSIUM CHLORATE	RSC	RESORCINOL
PDC	PENTADECANOL	SAB	SODIUM ALKYL BENENESULFONATES
PDH	PARALDEHYDE	SAC	SULFURIC ACID, SPENT
PDL	PHENYLDICHLOROARSINE	SAL	SALICYLALDEHYDE
PDT	POTASSIUM DICHLORO-s-TRIAZINETRIONE	SAM	SODIUM AMIDE
PET	PENTAERYTHRITOL	SAR	SODIUM ARSENITE
PFA	PARAFORMALDEHYDE	SAS	SODIUM ALKYL SULFATES
PGA	PYROGALLIC ACID	SAZ	SODIUM AZIDE
PGC	POLYPROPYLENE GLYCOL	SBF	SODIUM BIFLUORIDE
PGM	POLYPROPYLENE GLYCOL METHYL ETHER	SBH	SODIUM BOROHYDRIDE
PHD	PHOSDRIN	SBS	SODIUM BISULFITE
PHG	PHOSGENE	SBT	SORBITOL
PHH	PHENYLHYDRAZINE HYDROCHLORIDE	SCD	SODIUM CACODYLATE
PHN	PHENOL	SCH	SODIUM CHROMATE
PII	PROPYLENEIMINE	SCL	SULFURYL CHLORIDE
PLB	POLYBUTENE	SCM	STRONTIUM CHROMATE
PLP	POLYPROPYLENE	SCN	SODIUM CYANIDE
PLT	beta-PROPIOLACTONE	SCR	SODIUM DICHROMATE
PME	PROPYLENE GLYCOL METHYL ETHER	SCY	SODIUM THIOCYANATE
PMN	n-PROPYL MERCAPTAN		

SDA	SODIUM ARSENATE	TDB	TETRADECYL BENZENE
SDB	SODIUM BORATE	TDC	t-TRIDECENE
SDC	SODIUM CHLORATE	TDI	TOLUENE 2,4-DIISOCYANATE
SDF	SODIUM FLUORIDE	TDN	TRIDECANOL
SDH	SODIUM HYDRIDE	TEA	TRIETHANOLAMINE
SDN	SODIUM NITRATE	TEB	TRIETHYLBENZENE
SDS	SODIUM SULFIDE	TEC	TETRACHLOROETHANE
SDT	SODIUM DICHLORO-s-TRIAZINETRIONE	TED	TETRAETHYL DITHIOPYROPHOSPHATE
SDU	SODIUM	TEG	TRIETHYLENE GLYCOL
SFA	SULFURIC ACID	TEL	TETRAETHYL LEAD
SFC	SODIUM FERROCYANIDE	TEN	TRIETHYLAMINE
SFD	SULFUR DIOXIDE	TEP	TETRAETHYL PYROPHOSPHATE
SFL	SULFOLANE	TES	2,4,5-T ESTERS
SFM	SULFUR MONOCHLORIDE	TET	TRIETHYLENETETRAMINE
SFR	SODIUM SILICOFLUORIDE	TFA	TALLOW FATTY ALCOHOL
SHC	SODIUM HYDROCHLORITE	TFC	TRIFLUOROCHLOROETHYLENE
SHD	SODIUM HYDROXIDE	TFE	TETRAFLUROETHYLENE
SHR	SODIUM HYDROSULFIDE SOLUTION	TFR	TRIFLURALIN
SLA	SALICYLIC ACID	TGC	TRIPOPYLENE GLYCOL
SLD	SELENIUM DIOXIDE	THF	TETRAHYDROFURAN
SML	SODIUM METHYLATE	THN	TETRAHYDRONAPHTHALENE
SNT	SODIUM NITRITE	THR	THIRAM
SOX	SODIUM OXALATE	TIA	TRIISOBUTYLALUMINUM
SPH	SODIUM PHOSPHATE tribasic	TLI	o-TOLUIDINE
SPP	SODIUM PHOSPHATE	TLO	TALLOW
SRA	STEARIC ACID	TMA	TRIMETHYLAMINE
SRS	SUCROSE	TMC	TRIMETHYLCHLOROSILANE
SSC	SODIUM SILICATE	TML	TETRAMETHYL LEAD
SSE	SODIUM SELINITE	TNA	TANNIC ACID
SSF	SODIUM SULFITE	TOL	TOLUENE
STC	SILICON TETRACHLORIDE	TPA	2-(2,4,5-TRICHLOROPHENYOXY)
STF	STANNOUS FLUORIDE		PROPANOIC ACID
STO	SELENIUM TRIOXIDE	TPE	2-(2,4,5-TRICHLOROPHENYOXY) PROPANOI
STR	STRYCHNINE		ACID, ISOCTYL ESTER
STY	STYRENE	TPG	THIOPHOSGENE
SVA	SILVER ACETATE	TPH	TRICHLOROPHENOL
SVC	SILVER CARBONATE	TPO	TRIS(AZIRIDINYL)PHOSPHINE OXIDE
SVF	SILVER FLUORIDE	TPT	TURPENTINE
SVI	SILVER IODATE	TRC	TRICHLORFON
SVN	SILVER NITRATE	TRN	THORIUM NITRATE
SVO	SILVER OXIDE	TSU	THALLIUM SULFATE
SVS	SILVER SULFATE	TTD	1-TETRADECENE
SXX	SULFUR	TTE	TETRACHLOROETHYLENE
TAL	TRIETHYLALUMINUM	TTG	TETRAETHYLENE GLYCOL
TAP	p-TOLUENESULFONIC ACID	TTN	TETRADECANOL
TAS	2,4,5-TRICHLOROPHENOXYACETIC ACID, SODIUM SALT	TTP	TETRAETHYLENEPENTAMINE
TBT	TETRABUTYL TITANATE	TTT	TITANIUM TETRACHLORIDE
TCA	2,4,5-TRICHLOROPHENOXY ACETIC ACID	TXP	TOXAPHENE
TCE	TRICHLOROETHANE	UAN	URANYL NITRATE
TCF	TRICHLOROFLUOROMETHANE	UDB	n-UNDECYLBENZENE
TCL	TRICHLORETHYLENE	UDC	1-UNDECENE
TCP	TRICHLOROSILYL PHOSPHATE	UND	UNDECANOL
TCS	TRICHLOROSILANE	UPO	UREA PEROXIDE
TCT	TRICHLORO-s-TRIAZINETRIONE	URA	URANYL ACETATE
		URE	UREA

URP	URANIUM PEROXIDE
URS	URANYL SULFATE
VAL	VALERALDEHYDE
VAM	VINYL ACETATE
VCI	VINYLDENE CHLORIDE
VCM	VINYL CHLORIDE
VEE	VINYL ETHYL ETHER
VFI	VINYL FLUORIDE
VME	VINYL METHYL ETHER
VNT	VINYLTOLUENE
VOT	VANADIUM OXYTRICHLORIDE
VOX	VANADIUM PENTOXIDE
VSF	VANADYL SULFATE
VTs	VINYLTRICHLOROSILANE
WCA	WAXES: CARNAUBA
WPF	WAXES: PARAFFIN
XLM	m-XYLENE
XLO	o-XYLENE
XLP	p-XYLENE
XYL	XYLENE
ZAC	ZINC AMMONIUM CHLORIDE
ZAR	ZINC ARSENATE
ZBC	ZINC BICHROMATE
ZBO	ZINC BORATE
ZBR	ZINC BROMIDE
ZCA	ZIRCONIUM ACETATE
ZCB	ZINC CARBONATE
ZCL	ZINC CHLORIDE
ZCN	ZINC CYANIDE
ZCO	ZIRCONIUM OXYCHLORIDE
ZCR	ZINC CHROMATE
ZCS	ZIRCONIUM SULFATE
ZCT	ZIRCONIUM TETRACHLORIDE
ZDP	ZINC DIALKYLDITHIOPHOSPHATE
ZEC	ZECTRAN
ZFB	ZINC FLUOROBORATE
ZFM	ZINC FORMATE
ZFX	ZINC FLUORIDE
ZHS	ZINC HYDROSULFITE
ZIR	ZIRCONIUM NITRATE
ZNA	ZINC ACETATE
ZNT	ZINC NITRATE
ZPC	ZINC POTASSIUM CHROMATE
ZPF	ZIRCONIUM POTASSIUM FLUORIDE
ZPP	ZINC PHOSPHIDE
ZPS	ZINC PHENOLSULFONATE
ZSF	ZINC SULFATE
ZSL	ZINC SILICOFLUORIDE

## APPENDIX B

### HYPOTHETICAL EXAMPLE OF AN NRC ACCIDENT REPORT

**Date:** 01/01/92  
**Report#** 1

**Time:** 1020

**D.O.** SJS

**(A) Reporting Company:** ABC Trucking CO.  
**Spiller?** T

**Type:** PE

**Address:** P.O Box 100

**City:** Anytowne

**State:** NC    **Zip:** 11111

**(B) Suspected Discharger:**

**Type:**

**Address:**

**City:**

**State:**

**Zip:**

**Spill Date:** 12/31/91

**Spill Time:** 1420

**Location:**

**City:** Noname

**County:** Hambone

**State:** NC

**Description:** Intersection of hwy 1 and hwy 2

**CHRIS Code**  
ACR

**Material Name**  
Acrylic Acid

Total Qty	Units	In Water	Units
2,500.00	GAL	0.00	NONE

**Source/Cause:** Tanker truck struck by train.

**Transportation Mode:** Highway

**Affected Medium:** Land

**Medium description:** Soil and Pavement

**Injuries:**

**Fatalities:**

**Evacuation:**

**Damage?**

**Amount:**

**Caller Notified:**

#### Remedial Action / Additional Information

Unknown railroad company

#### National Response Center Notifications

**Time**

**Agency**

1048

EPA Region 4

**TECHNICAL REPORT DATA**  
(Please read instructions on the reverse before completing)

1. REPORT NO. <b>EPA-600/R-93-045</b>		2.		3. RECIPIENT'S ACCESSION NO.	
4. TITLE AND SUBTITLE <b>Identification and Characterization of Five Non-traditional Source Categories: Catastrophic/Accidental Releases, Vehicle Repair Facilities, Recycling, Pesticide Application, and Agricultural Operations</b>				5. REPORT DATE <b>March 1993</b>	
				6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) <b>S. Sleva, J. Pendola, J. McCutcheon, and K. Jones (TRC); and S. Kersteter (SAI)</b>				8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS <b>TRC Environmental Corp., 100 Europa Dr., Suite 150, Chapel Hill, NC 27514; and Science Applications International Corp., 206 University Tower, 3101 Petty Rd., Durham, NC 27707</b>				10. PROGRAM ELEMENT NO.	
				11. CONTRACT/GRANT NO. <b>68-D9-0173, Tasks 2/220 and 3/304</b>	
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15. SUPPLEMENTARY NOTES <b>AEERL project officer is E. Sue Kimbrough, MD-62, 919/541-2612.</b>					
16. ABSTRACT <b>The report gives results of work that is part of EPA's program to identify and characterize emissions sources not currently accounted for by either the existing Aerometric Information Retrieval System (AIRS) or State Implementation Plan (SIP) area source methodologies and to develop appropriate emissions estimation methodologies and emission factors for a group of these source categories. Based on the results of the identification and characterization portions of this research, five source categories were selected for methodology and emission factor development: catastrophic/accidental releases, vehicle repair facilities, recycling, pesticide application, and agricultural operations. The report gives emissions estimation methodologies and emission factor data for these source categories. The discussions of each category include general background information, emissions generation activities, pollutants emitted, sources of activity and pollutant data, emissions estimation methodologies, issues to be considered, and recommendations. The information used in these discussions was derived from various sources including available literature, industrial and trade association publications and contracts, experts on the category and activity, and knowledgeable federal and state personnel.</b>					
17. KEY WORDS AND DOCUMENT ANALYSIS					
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS		c. COSATI Field/Group	
Pollution	Accidents	Pollution Control	13B	13L	
Emission	Vehicles	Stationary Sources	14G		
Estimating	Repair Shops	Characterization		15E	
Identifying	Circulation	Accidental Releases			
Properties	Pesticides	Recycling	14B	06F	
Analyzing	Agriculture	Pesticide Application		02	
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