LIFE CYCLE ASSESSMENT FOR PC BLEND 2 AIRCRAFT RADOME DEPAINTER

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Notice

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Preface

The research effort described in this report was conducted under cooperating programs of both the Department of Defense (DoD) and the Environmental Protection Agency (EPA). Among the shared objectives of the cooperators is demonstrating the effectiveness of analytical tools and environmental techniques to reduce environmental impacts and costs of operations while maintaining performance standards. This project was sponsored by the DoD's Strategic Environmental Research and Development Program (SERDP) program and conducted by the EPA's Life Cycle Assessment (LCA) Research Team at the National Risk Management Research Laboratory (NRMRL).

Strategic Environmental Research And Development Program

DoD | EPA
DOE
SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness Through Environmental Research

SERDP was established to sponsor cooperative research, development and demonstration activities for environmental risk reduction. Funded with DoD resources, SERDP is an interagency initiative between DoD, the Department of Energy (DOE) and EPA. SERDP seeks to develop environmental solutions that improve mission readiness for Federal activities. In addition, it is expected that many techniques developed will have applications across the public and private sectors.

Life Cycle Assessment (LCA) Research Program

Since 1990, the NRMRL has been at the forefront in the development of LCA as a methodology for environmental assessment. In 1994, NRMRL established an LCA team to organize individual efforts into a comprehensive research program. The LCA Team coordinates work in both the public and private sectors with cooperators ranging from members of industry and academia to Federal Facility operators and commands. The team has published project reports and guidance manuals, including "Life Cycle Assessment: Inventory Guidelines and Principles," and "Life Cycle Design Guidance Manual." The work described in this report is part of an expanding program of research in LCA taking place under the direction of NRMRL in Cincinnati, Ohio.

Under these programs, NRMRL has researched and evaluated substitutes for methyl ethyl ketone (MEK) as cleaners and solvents in aircraft maintenance operations at Tinker Air Force

Base (TAFB) in Oklahoma. TAFB performs maintenance, including structural repair and refabrication of USAF aircraft, notably the B-1B and the B-52.

Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

This report describes the life cycle assessment on a potential replacement solvent blend for aircraft radome depainting at the Oklahoma City Air Logistics Center at Tinker Air Force Base. The life cycle assessment is composed of three separate but interrelated components: life cycle inventory, life cycle impact assessment, and life cycle improvement assessment. This study uses a comprehensive approach, encompassing all energy requirements, solid wastes, atmospheric emissions, and waterborne wastes associated with the production, use, and disposal of the depainting solvent. The life cycle inventory quantifies these values. The partial impact assessment uses a classification system to categorize the atmospheric and waterborne emissions into the relevant potential impact categories of ecosystem and human health. The improvement assessment uses results from the inventory and impact assessment along with a cost analysis to evaluate the improvement alternatives.

This report was submitted in fulfillment of Contract No. 68-C4-0020, WA 1-07, to Lockheed Environmental Systems & Technologies Company from Lockheed to Franklin Associates, Ltd., under sponsorship of the U.S. Environmental Protection Agency. This report covers a period from January 1995 to July 1996, and work was completed as of July 1996.

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Acronyms

BOD	biochemical oxygen demand
Btu	British thermal unit
CFC	chlorofluorohydrocarbons
CO	carbon monoxide
COD	chemical oxygen demand
DBE	dibasic ester
DO	dissolved oxygen
DoD	Department of Defense
EPA	Environmental Protection Agency
kwh	kilowatt-hours
LCA	Life Cycle Assessment
LCI	life cycle inventory
MEK	methyl ethyl ketone
MSDS	Material Safety Data Sheets
NMP	n-methyl-pyrrolidone
NO_2	nitrogen dioxide
NRMRL	National Risk Management Research Laboratory
OC-ALC	Oklahoma City Air Logistics Center
PC	propylene carbonate
PC2	PC Blend 2
REPA	resource and environmental profile analyses
Rfd	reference dose values
SERDP	Strategic Environmental Research and Development Program
SETAC	Society of Environmental Toxicology and Chemistry
TAFB	Tinker Air Force Base
TDS	total dissolved solids
TOD	total oxygen demand

Chapter 1
Executive Summary

Introduction

This executive summary highlights the Life Cycle Assessment (LCA) performed by Franklin Associates, Ltd. on a potential replacement solvent blend for aircraft radome depainting at the Oklahoma City Air Logistics Center (OC-ALC) at Tinker Air Force Base (TAFB). LCA, as defined by the Society of Environmental Toxicology and Chemistry (SETAC) and the Environmental Protection Agency (EPA), is composed of three separate but interrelated components: 1) life cycle inventory, 2) life cycle impact assessment, and 3) life cycle improvement analysis. This study completes all three components.

The study uses a comprehensive approach, encompassing all energy requirements, solid wastes, atmospheric emissions, and waterborne wastes associated with the production, use, and disposal of the depainting solvent. Each major processing step, from the extraction of raw material to final disposition of the spent solvent, is included in this cradle-to-grave assessment. The life cycle inventory (LCI) quantifies these values. The partial impact assessment uses a classification system to categorize the atmospheric and waterborne emissions into the relevant potential impact categories of ecosystem and human health. Then, a mass loading characterization model is used to compare the baseline impact results to the different improvement alternatives. The improvement assessment uses the results from the LCI and impact assessment along with a cost analysis to evaluate the improvement alternatives.

Background

Currently, TAFB uses methyl ethyl ketone (MEK) to depaint B-52 and KC-135 aircraft radomes. Because of the high volatility of MEK, significant evaporative losses to the atmosphere occur during each depainting session. Additionally, MEK has been targeted for elimination by the EPA's 33/50 Voluntary Reduction Program. The EPA and TAFB are currently evaluating solvent blends containing propylene carbonate as a nonvolatile and less toxic substitute for MEK. One propylene carbonate solvent blend currently being evaluated and the focus of this LCA, is known as PC Blend 2 (PC2). The PC Blend 2 is composed of 50 percent n-methyl-pyrrolidone (NMP), 25 percent dibasic ester (DBE), and 25 percent propylene carbonate (PC). Results of initial performance screening studies indicate acceptable performance of this solvent for depainting radomes.

Scope

This report presents a detailed life cycle assessment of the entire life cycle of the PC2 from raw material acquisition to final disposition. To enhance the utility of this report and to assist readers with relative perspective and comprehension, the results of this LCI are presented in detail in Chapters 3 and 4 on the following three bases: per 10 KC-135 aircraft radomes depainted (estimated to require 110 gallons of PC2); per 10 B-52 aircraft radomes depainted (estimated to require 180 gallons of PC2); and per annual PC2 usage at TAFB for depainting radomes (estimated to require approximately 1,820 gallons PC2). Because the KC-135 is the predominant radome processed at TAFB, it was selected as the "baseline scenario." The results presented in this Executive Summary are for the baseline scenario and represent depainting of 10 KC-135 radomes. The relative results for the baseline scenario are generally representative of the results for both the B-52 and for the annual usage of PC2. The conclusions drawn for the impact assessment and improvement analysis would also be quite similar for the other bases.

Because PC2 is not currently being used in aircraft radome depainting operations at TAFB, key assumptions were made based on limited knowledge of how PC2 would likely perform in use. These assumptions comprise the baseline PC2 use scenario presented in the LCI. However, because of the lack of experience in PC2 depainting performance, the parameters around the use of PC2 may be quite different than assumed in the baseline scenario. Therefore, a number of alternative PC2 use and waste management scenarios are also evaluated in this study. The baseline and alternative scenarios are described below.

- Baseline PC2 Use Scenario

  10 KC-135 radomes depainted
  110 gallons PC2 required for 10 radomes
  Each radome showered continuously for 2 hours
  Disposal of spent PC2 is by incineration (no energy recovery)

- Alternative Waste Management Scenario

  Recycling of spent PC2

- Alternative PC2 Use Scenarios

  Varying volume of PC2 required (plus or minus 20 percent)
  Varying yield of radomes per PC2 volume (five radomes to 20 radomes per 110 gallons)
  Varying time required (one hour to four hours per radome)

Life Cycle Inventory

Methodology

The life cycle inventory methodology is only very briefly described here. A thorough discussion of the LCI methodology can be found in Chapter 2 of this report. A life cycle inventory (LCI) quantifies the resource consumption (i.e., raw materials and energy) and environmental emissions (i.e., atmospheric emissions, waterborne wastes, and solid wastes) for a given product based upon the study boundaries established. The unique feature of this type of analysis is its focus on the entire life cycle of a product, from raw material acquisition to final disposition, rather than on a single manufacturing step or environmental emission.

As a first step in any LCI, the system boundaries must be defined and the individual processes identified that lead to the end product. This activity is usually summarized with process flow diagrams. The next step usually consists of developing a preliminary material balance around each process and eventually the entire system. This effort ensures that all raw materials are accounted for and no significant waste streams have been overlooked.

For each process identified in the LCI, average energy requirements are first quantified in terms of fuel or electricity units, such as cubic feet of natural gas, gallons of diesel fuel, or kilowatt-hours (kWh) of electricity. The fuel used to transport raw materials to each process is included as a part of the LCI energy requirements.

Once the fuel consumption for each industrial process and transportation step is quantified, the fuel units are converted from their original units to an equivalent British thermal unit (Btu) based on standard conversion factors. The conversion factors have been developed to account for the energy required to extract, transport, and process the fuels and to account for the energy content of the fuels. The energy to extract, transport, and process fuels into a usable form is labeled precombustion energy. For electricity, precombustion energy calculations include adjustments for the average efficiency of conversion of fuel to electricity, and for transmission losses in power lines based on national averages.

The LCI methodology assigns a fuel-energy equivalent to raw materials that are derived from fossil fuels. Therefore, the total energy requirement for coal, natural gas, or petroleum based raw materials includes the fuel-energy of the material (called energy of material resource or inherent energy). In this study, this applies to the crude oil and natural gas used as raw materials to produce the raw materials comprising PC Blend 2.

Environmental emissions are categorized as atmospheric emissions, waterborne wastes, and solid wastes, and represent discharges into the environment after existing emission control devises. Similar to energy, environmental emissions associated with processing fuels into usable forms are also included in the inventory analysis. When efforts to obtain actual industry emissions

data fail, published emissions standards are used as the basis for determining environmental emissions.

Atmospheric emissions include substances classified by regulatory agencies as pollutants, as well as selected nonregulated emissions such as carbon dioxide. Atmospheric emissions associated with the combustion of fuel for process or transportation energy, as well as process emissions, are included in the LCI. The amounts reported represent actual discharges into the atmosphere after existing emission control devices.

As with atmospheric emissions, waterborne wastes include all substances classified as pollutants. The values reported are the average quantity of pollutants still present in the wastewater stream after wastewater treatment, and represent discharges into receiving waters. This includes both process-related and fuel-related waterborne wastes.

The solid wastes category includes solid wastes generated from all sources that are landfilled or disposed of in some other way. Also included is the ash from the combustion of materials at combustion facilities, such as an electric utility. It does not include materials that are recovered for reuse or recycling.

When performing an LCI analysis, typically both postconsumer and industrial wastes are considered. Postconsumer solid wastes are primarily packaging materials that are discarded by consumers after they have fulfilled their use. In this analysis, no postconsumer waste is considered and all solid waste generated is categorized as process-related or fuel-related industrial waste. Examples of industrial solid wastes are wastewater treatment sludge, solids collected in air pollution control devices, trim or waste materials from manufacturing operations that are not recycled, fuel combustion residues such as the ash generated by burning coal or wood, and mineral extraction wastes.

Baseline LCI Results and Discussion

A summary of the results of the life cycle inventory for the baseline scenario is presented in the following sections. More detailed results and discussion of the baseline scenario appear in Chapters 3, and 4 of this report. A discussion of reliability of results can be found in Chapter 2.

In this discussion, the use of the word "pollutant" is not meant to imply the chemical is harmful to the environment or to human health. It is used to refer to the chemicals released during the life cycle of PC2. Most of these chemicals represent regulated emissions.

Energy Requirements

Energy requirements are presented in this section on the basis of system component, energy category, and original fuel source. The energy requirements presented for the system components include: the production of the three chemical products comprising the PC Blend 2 (DBE, NMP, and PC), blending of the components to make PC2, use of PC2 at TAFB, and disposal by

incineration. Total energy is separated into the categories of process energy, transportation energy, and energy of material resource. Finally, energy requirements are broken down into original fuel source which consists of: natural gas, petroleum, nuclear, coal, and other energy (hydropower, and wood).

The energy contributions of each major component included in the LCI are illustrated in Figure 1-1. The total energy for depainting ten KC-135 radomes is approximately 43 million Btu. Raw materials acquisition and chemical processing associated with the production of NMP, DBE, and PC account for 56 percent, 23 percent, and 16 percent of the total energy requirements, respectively. Together, these three components of PC2 account for 95 percent of the total energy requirements. Blending, usage, and disposal of PC2 account for the remaining five percent of the total energy requirements.
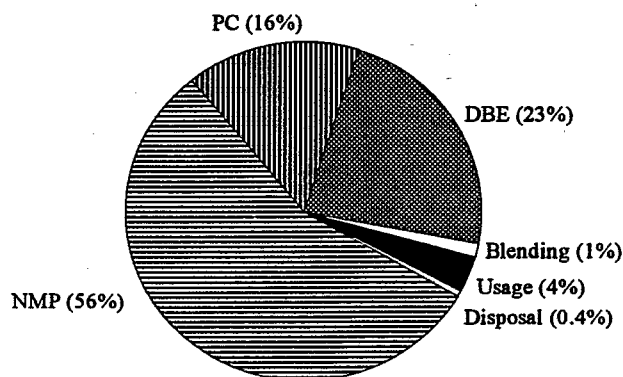
Source: Franklin Associates, Ltd.

Figure 1-1. LCI energy profile by component for PC Blend 2 radome depainting solvent (In percent).

The total energy requirements are separated by category in Figure 1-2. Energy categories in an LCI consist of process energy, transportation energy, and energy of material resource. Process energy is energy consumed by the various processes used to manufacture the PC2. It accounts for 44 percent of the total energy required for the production of the solvent. Transportation energy describes the energy used as fuel to transport the chemicals and materials to the next step in the manufacturing process. Transportation energy represents a small portion of the total energy, accounting for only three percent of the total energy requirements. The energy of material resource is the inherent energy of petroleum, natural gas, and coal when used as a raw material feedstock. Energy of material resource represents the largest single use of energy for this system at approximately 54 percent of the total energy requirements.

The total energy requirements for the production and use of PC2 for depainting radomes are reported by the source of energy in Figure 1-3. Energy requirements are categorized into five

Source: Franklin Associates, Ltd.
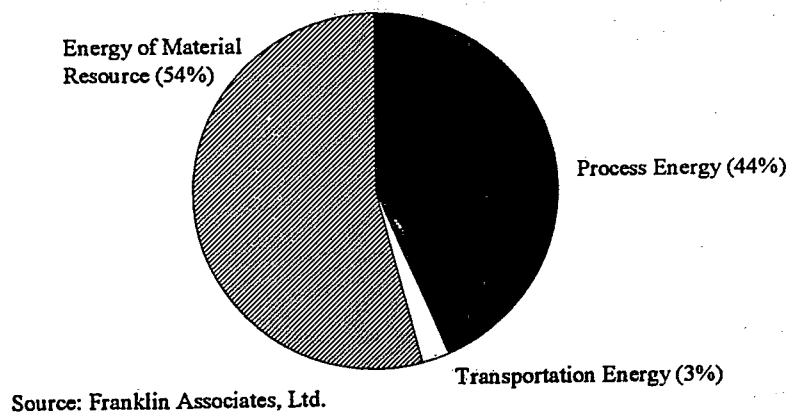
Figure 1-2. LCI energy profile by category for PC Blend 2 radome depainting solvent (In percent).

basic energy sources: natural gas, petroleum, coal, nuclear, and other energy (i.e., geothermal, lar, hydropower, etc.). The majority of the energy is derived from natural gas and petroleum which comprise 69 percent and 23 percent of the total energy, respectively. These values include the energy of material resource attributed to natural gas and petroleum when used as a raw material feedstock. The remaining eight percent of the energy needs for PC2 production and use are met by nuclear energy, coal and other energy sources.

Source: Franklin Associates, Ltd.
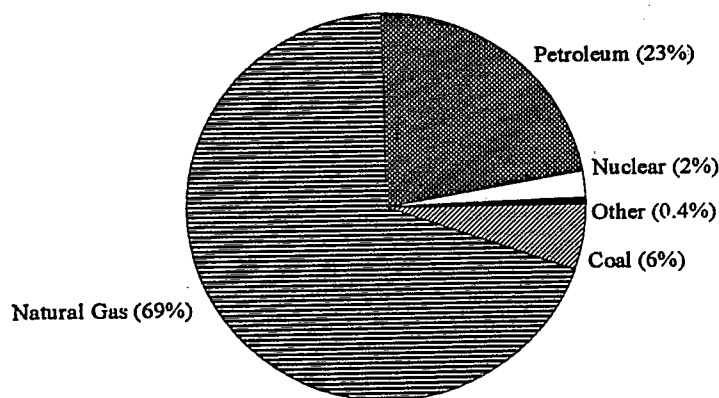
Figure 1-3. LCI energy profile by fuel type for PC Blend 2 radome depainting solvent (In percent).

Solid Waste

The solid waste category includes industrial solid waste generated from the individual processes in the manufacture, use, and disposal of the PC2 for depainting radomes. Industrial solid waste includes wastewater treatment sludges, solids resulting from air pollution control devices, trim or waste materials from manufacturing operations that are not recycled, fuel combustion residues, such as ash from burning wood or coal, and extraction wastes.

The industrial solid waste by weight for each scenario is displayed by system component in Figure 1-4. Over the entire life-cycle, about 80 pounds of industrial solid waste is produced for every ten KC-135 radomes that are depainted. The production of NMP, DBE, and PC each contribute 29, 18, and 11 percent, respectively, of the total industrial solid waste. Together, these three components comprise 58 percent of industrial solid waste produced. The blending operation contributes about 11 percent of the total solid waste. The PC2 use component includes solid wastes from electricity use at TAFB for the depainting operation and represents 32 percent of the total solid waste. The PC2 disposal component contributes less than one percent to the total industrial solid waste produced.
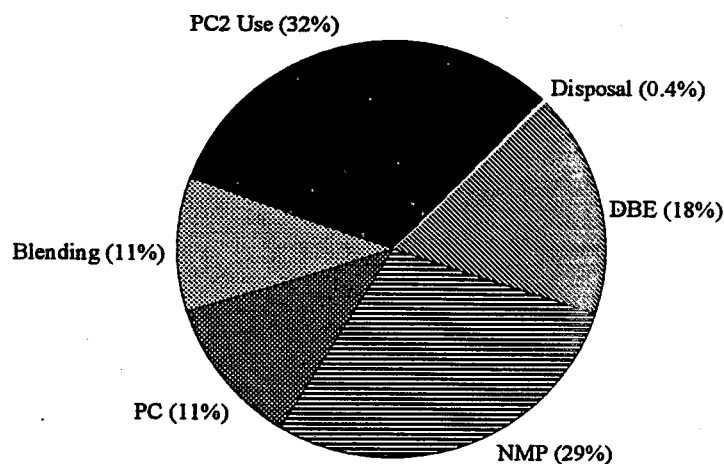
Source: Franklin Associates, Ltd.

Figure 1-4. LCI solid waste profile by component for PC Blend 2 radome depainting solvent (In percent).

Total solid wastes may also be disaggregated by the system categories: industrial process wastes and industrial fuel-related wastes. Process solid wastes are wastes produced as a result of the process steps within the product life cycle. Fuel-related solid wastes are solid wastes that result from the combustion of fuels. Fuel-related solid wastes, by far, make the greatest contribution to the overall system, representing 94 percent of the total industrial solid wastes produced. Process solid wastes comprise the remaining six percent of total solid waste.

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Atmospheric and Waterborne Emissions

The industrial atmospheric and waterborne emissions are shown by pollutant in Tables 1-1 and 1-2 for the baseline scenario with ten KC-135 radomes depainted. The industrial wastes are broken down into process, fuel-related, and total emissions in Table 1-1 and into system component in Table 1-2.

As shown in Table 1-1 for the industrial atmospheric emissions, both process- and fuel-related categories of emissions contribute significantly to the totals. Fuel acquisition and combustion is a source of atmospheric aldehydes, ammonia, carbon monoxide, fossil carbon dioxide, hydrocarbons, hydrogen chloride, kerosene, lead, methane, nitrogen oxides, other organics, particulate emissions, and sulfur oxides. Although not considered a pollutant, the amount of carbon dioxide that is emitted is also shown. Portions of these emissions categories may also come from process emissions. The majority of the carbon dioxide and nitrogen dioxide emissions are given off during incineration of the spent PC2. Process aldehyde emissions come from petroleum refining operations. Ammonia emissions are due to the manufacture of ammonia as an intermediate material, and also to the production of carbon dioxide. The carbon monoxide process emissions come primarily from formaldehyde production and also the operation to produce adipic acid. Hydrocarbon process emissions come primarily from natural gas and crudeoil production and processing. The production of propylene oxide results in process isobutane and propylene oxide emissions. Process sulfur oxide emissions are primarily the result of natural gas processing. Evaporative emissions for the PC2 are assumed to equal 0.5 percent of the total PC2 used, and are shown for each component of the blend.

Waterborne emissions are also shown in Table 1-1 by process and fuel related categories. Fuel acquisition and combustion is a source of waterborne acid, ammonia, BOD, chromium, COD, dissolved solids, iron, lead, metal ion, oil, phenol, sulfuric acid, suspended solids, and zinc emissions. Portions of these emissions categories may also come from process emissions. Process acid emissions come primarily from the process to make benzene, an intermediate for the DBE. Manufacture of ammonia, hydrogen, carbon dioxide, and petroleum refinery operations are all sources of process ammonia emissions. Process BOD emissions occur during the production of ammonia, methanol, and the nitric acid intermediates for DBE. Chromium, phenol, zinc, and COD process emissions come from petroleum refinery operations. The production of ammonia also produces COD emissions. Dissolved solids are produced primarily from the refined petroleum products, but some also come from the production of sodium hydroxide used in the manufacture of DBE. Sodium hydroxide production also results in mercury, zinc, and nickel emissions. Process metal ion emissions come from petroleum products refining. Process oil emissions are a result of crude oil and natural gas production and petroleum products refining. Sulfide process emissions are reported for benzene and sodium hydroxide production. The processes to make ammonia, methanol, and refinery operations are the sources of suspended solids emissions.

Table 1-1. Life Cycle Inventory of Atmospheric and Waterborne Emissions by Component for PC Blend 2 Radome Depainting Solvent*
(In pounds)

	Per Ten KC-135 Aircraft Radomes Depainted (1)		
	Process-Related	Fuel-Related	Total Emissions
Atmospheric Emissions			
Aldehydes	0.022	0.036	0.058
Ammonia	0.43	4.1E-04	0.43
Carbon Dioxide‡	1,986	2,429	4,415
Carbon Monoxide	18.4	2.8	21.2
Chlorine	8.3E-05	1.6E-05	9.9E-05
Dibasic Ester (DBE) †	1.2	-	1.2
Hydrocarbons	28.8	17.8	46.6
Hydrogen Chloride	6.0E-05	1.2E-05	7.2E-05
Isobutane	0.82	-	0.82
Kerosene	-	2.0E-04	2.0E-04
Lead	5.6E-07	1.9E-04	1.9E-04
Mercury	4.4E-05	-	4.4E-05
Methane	-	0.040	0.040
N-Methyl-Pyrrolidone (NMP) †	2.5	-	2.5
Nitrogen Oxides‡	229	6.0	235
Other Organics	-	0.53	0.53
Particulates	0.033	1.3	1.3
Propylene	0.080	-	0.080
Propylene Carbonate (PC) †	1.2	-	1.2
Propylene Oxide	0.039	-	0.039
Sulfur Oxides	1.2	6.8	8.0
Waterborne Wastes			
Acid	0.0026	9.0E-08	0.0026
Ammonia	0.026	1.4E-04	0.026
BOD	0.075	0.0011	0.076
Chromium	3.3E-05	3.6E-07	3.4E-05
COD	0.093	0.0052	0.098
Dissolved Solids	0.46	0.074	0.54
Iron	1.6E-04	0.11	0.11
Lead	8.0E-07	1.6E-07	9.6E-07
Mercury	2.2E-08	-	2.2E-08
Metal Ion	0.0094	0.0019	0.011
Nickel	1.2E-08	-	1.2E-08
Oil	0.065	0.0062	0.071
Phenol	4.6E-05	6.2E-06	5.2E-05
Sulfides	0.0011	-	0.0011
Sulfuric Acid	-	0.46	0.46
Suspended Solids	0.085	0.0010	0.086
Zinc	1.2E-05	2.3E-06	1.4E-05

* Includes all process and fuel related atmospheric emissions associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, and PC2 use at TAFB.

† Represents estimated atmospheric emissions at TAFB assuming 0.5 percent evaporative loss of PC2 blend during aircraft radome depainting.

‡ Includes emissions from incineration of spent PC2.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

The atmospheric and waterborne emissions in Table 1-2 show the total emissions broken into system components. The production of DBE, NMP, and PC, the PC2 components, include both process- and fuel-related emissions. The emissions for PC Blending 2 do not include any process emissions; only fuel-related emissions for utility requirements and transportation to TAFB are included. With the exception of DBE, NMP, and PC atmospheric emissions, the results shown for PC2 use at TAFB include only fuel-related emissions for the electricity used in the depainting operation. The results for the PC2 disposal include fuel-related emissions for transportation and atmospheric process emissions of nitrogen oxides and carbon dioxide from combustion of the spent PC2.

Results and Discussion of LCI Sensitivity Analyses

A summary of the results of the life cycle inventory for the alternative scenarios is presented in the following sections. More detailed results and a discussion of the alternative scenarios appear in Chapter 5 of this report. A discussion of reliability of results can be found in Chapter 2.

Sensitivities of the baseline energy and emissions results to changes in the major assumptions concerning the use and disposal of PC2 are examined here. As described earlier in the summary, the use of PC2 has been very limited thus far. Therefore, the parameters around the use of PC2 may be quite different than assumed in the baseline scenario. The scenarios in this section are chosen to illustrate the effects of changes in the major assumptions. As outlined in the scope of work in this summary, the alternative use and disposal scenarios are: recycling of the spent PC2, varying the volume required (± 20 percent), varying the yield (5 or 20 radomes per 110 gallons), and varying the time required for depainting (1 to 4 hours per depainting session).

The results include all energy use and emissions associated with raw material acquisition, chemical processes for producing the three components comprising PC2 (i.e., DBE, NMP, PC), PC Blending 2 and PC2 use and disposal for depainting radomes at TAFB. For the recycled system, it is assumed that a recovery rate of approximately 85 percent can be achieved with the recycling process. The 15 percent lost could either be at TAFB (adhering to waste paint chips or absorbed in the cloth filter) or during distillation. The amount lost is assumed to be ultimately incinerated as hazardous waste. Virgin PC, DBE, and NMP must be used to make up for the 15 percent loss each time the spent PC2 is recycled and also the 0.5 percent evaporative loss assumed to occur during the use of PC2. The recycled system results also includes the energy requirements and emissions produced when transporting the spent PC2 to a theoretical recycling facility in Texas, distilling the waste solvent blend, re-blending the components, and transporting the recycled PC2 back to TAFB for another use.

Energy
The energy requirements for the different use scenarios are summarized in Figure 1-5. By recycling the spent PC2, the total energy requirements are reduced by about 70 percent. Most of the reduction comes from decreased process and energy of material resource requirements in the back-end steps for producing the DBE, PC, and NMP components of the blend. The energy for

Table 1-2. Life Cycle Inventory of Atmospheric and Waterborne Emissions by Process for PC Blend 2 Radome Depainting Solvent (In pounds)

	Per Ten KC-135 Aircraft Radomes Depainted (1)						
	Dibasic Ester * (DBE)	N-Methyl-Pyrrolidone * (NMP)	Propylene Carbonate * (PC)	PC2 Blending	PC2 Use at TAFB ^	PC2 Disposal	Total Emissions
Atmospheric Emissions							
Aldehydes	0.021	0.023	0.0070	0.0012	4.0E-04	0.0051	0.058
Ammonia	0.065	0.26	0.11	1.1E-05	1.4E-05	3.4E-05	0.43
Carbon Dioxide‡	589	1,148	381	77.6	215	2,005	4,415
Carbon Monoxide	1.8	18.5	0.42	0.11	0.22	0.19	21.2
Chlorine	4.3E-05	4.4E-05	9.6E-06	4.5E-07	5.3E-07	1.3E-06	9.9E-05
Dibasic Ester (DBE) †	-	-	-	-	1.2	-	1.2
Hydrocarbons	8.5	30.1	7.5	0.12	0.30	0.083	46.6
Hydrogen Chloride	3.0E-05	3.3E-05	7.2E-06	3.4E-07	4.0E-07	9.9E-07	7.2E-05
Isobutane	-	-	0.82	-	-	-	0.82
Kerosene	2.0E-05	6.0E-05	2.3E-05	2.4E-05	7.1E-05	9.5E-08	2.0E-04
Lead	3.5E-05	5.0E-05	3.3E-05	1.8E-05	5.3E-05	1.7E-07	1.9E-04
Mercury	4.4E-05	-	-	-	-	-	4.4E-05
Methane	0.011	0.022	0.0062	4.6E-04	0.0013	2.7E-05	0.040
N-Methyl-Pyrrolidone (NMP) †	-	-	-	-	2.5	-	2.5
Nitrogen Oxides‡	1.5	2.6	0.86	0.36	0.94	229	235
Other Organics	0.095	0.22	0.085	0.021	0.0023	0.10	0.53
Particulates	0.24	0.42	0.16	0.13	0.35	0.027	1.3
Propylene	-	-	0.080	-	-	-	0.080
Propylene Carbonate (PC) †	-	-	-	-	1.2	-	1.2
Propylene Oxide	-	-	0.039	-	-	-	0.039
Sulfur Oxides	1.4	3.0	1.1	0.63	1.8	0.037	8.0
Waterborne Wastes							
Acid	0.0026	2.4E-07	5.3E-08	2.5E-09	2.9E-09	7.3E-09	0.0026
Ammonia	0.0042	0.016	0.0065	4.0E-06	4.7E-06	1.2E-05	0.026
BOD	0.0097	0.065	6.5E-04	3.0E-05	3.6E-05	9.0E-05	0.076
Chromium	3.3E-05	9.7E-07	2.1E-07	9.8E-09	1.2E-08	2.9E-08	3.4E-05
COD	0.033	0.061	0.0031	1.4E-04	1.8E-04	4.2E-04	0.098
Dissolved Solids	0.28	0.20	0.044	0.0020	0.0024	0.0060	0.54
Iron	0.017	0.032	0.013	0.013	0.038	5.4E-05	0.11
Lead	4.0E-07	4.3E-07	1.0E-07	4.4E-09	5.2E-09	1.3E-08	9.6E-07
Mercury	1.2E-08	-	1.0E-08	-	-	-	2.2E-08
Metal Ion	0.0047	0.0052	0.0011	5.2E-05	6.2E-05	1.5E-04	0.011
Nickel	6.6E-09	-	5.8E-09	-	-	-	1.2E-08
Oil	0.050	0.018	0.0031	1.1E-04	1.5E-04	2.8E-04	0.071
Phenol	3.1E-05	1.7E-05	3.6E-06	1.7E-07	2.0E-07	5.0E-07	5.2E-05
Sulfides	0.0011	-	-	-	-	-	0.0011
Sulfuric Acid	0.069	0.13	0.051	0.052	0.15	2.0E-04	0.46
Suspended Solids	0.010	0.075	6.0E-04	2.8E-05	3.4E-05	8.2E-05	0.086
Zinc	5.8E-06	6.3E-06	1.4E-06	6.4E-08	7.6E-08	1.9E-07	1.4E-05

* Includes all process and fuel related atmospheric emissions associated with raw materials acquisition and chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC).

† Represents estimated atmospheric emissions at TAFB assuming 0.5 percent evaporative loss of PC2 blend during aircraft radome depainting.

^ Emissions associated with the generation of electricity used at TAFB for depainting aircraft radomes is also included.

‡ Includes emissions from incineration of spent PC2. 229 pounds of the carbon dioxide and 1,983 pounds of the nitrogen oxide emissions are calculated emissions for the incineration of the spent PC2 blend.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.
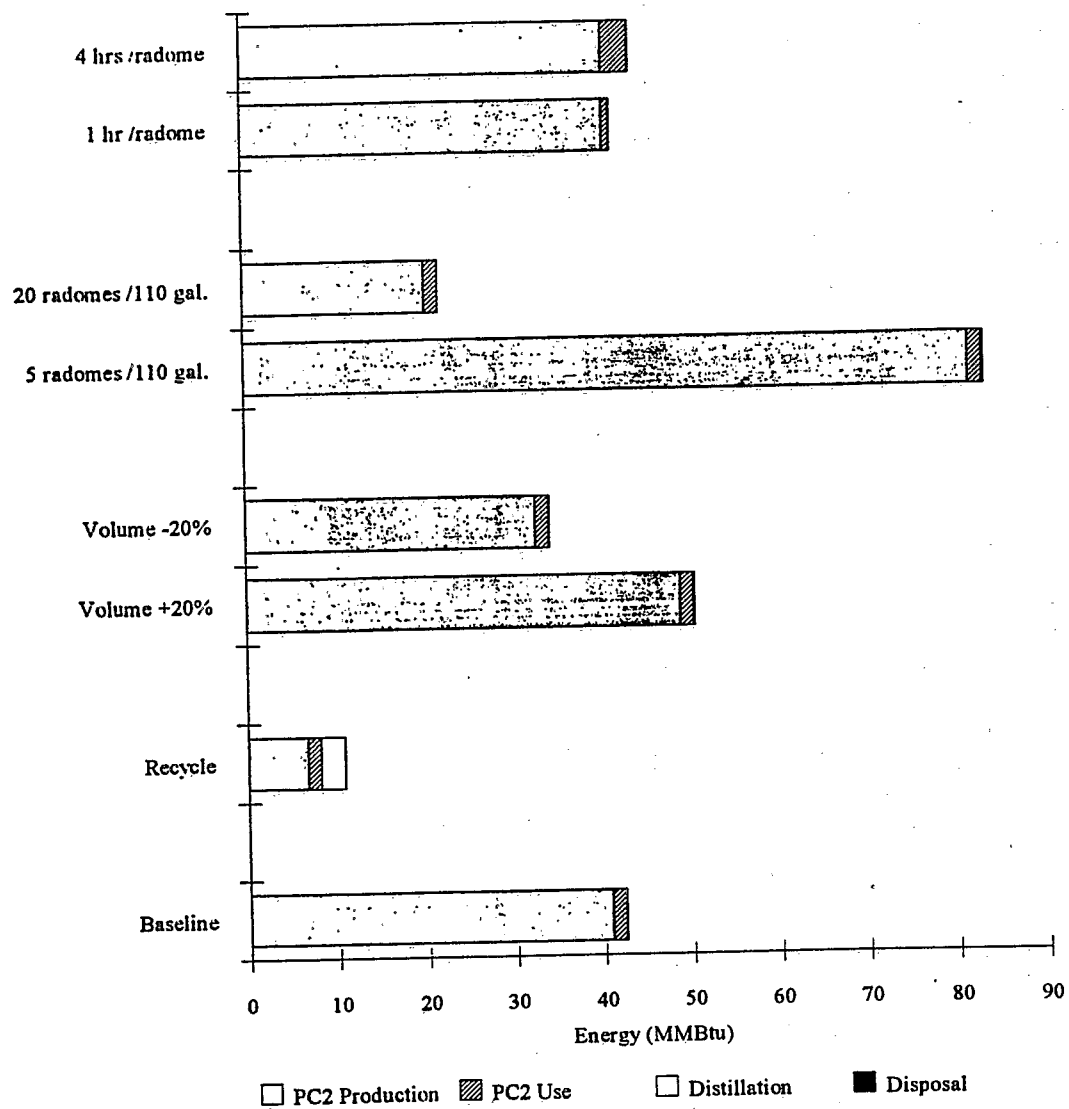
Figure 1-5. LCI energy usage by component showing sensitivity to improvement alternatives.

Source: Tables 5-1 and 5-5.

producing the PC2 is to make up for the 15 percent recycling loss and plus the 0.5 percent evaporative emissions and for PC Blend 2. The energy for disposal of waste is also drastically reduced to about 15 percent of the baseline amount. The energy for distilling and transporting the spent PC2 is about 25 percent of the total energy for the recycled system. Source: Tables 5-1 and 5-5.

The energy results are also very sensitive to any changes in the volume and yield assumptions. An increase or decrease in the volume required brings about a proportional increase or decrease in the energy required to produce the PC2. Similarly, an increase or decrease in yield affects the volume required per radome. Again, the increase/decrease in total energy requirements is approximately proportional to the volume change.

Changes in the time required for depainting do not have as great an effect on the energy results. This is simply because varying the time only affects the PC2 use component; the use is only about three percent of the total energy in the baseline.

Solid Waste

The solid waste generation for the different use scenarios are summarized in Figure 1-6. Total solid waste generation is decreased by about 50 percent for the recycled system when compared to the baseline system. The reduction of fuel and process-related solid wastes associated with producing the three components of the PC2 is primarily responsible for this reduction. However, a small increase in fuel-related solid waste results from the recycling process and transportation to and from the recycling facility.

As with the energy results, the total solid waste is quite sensitive to assumptions regarding volume of PC2 required per radome. Because over 60 percent of the solid waste is due to the production of the components (DBE, PC, and NMP) and blending of the PC2, any change in the amount of PC2 required per radome has a substantial effect on the solid waste results. Changes in the volume required and the yield result in fairly proportionate changes in the PC2 production, distillation, and disposal components.

The process energy used at TAFB is electricity; therefore, changes in the processing time (thus, electricity requirements) result in substantial changes in electricity related fuel pollutants. The dramatic changes in solid waste which result from variations in process time are due primarily to solid waste from electricity generating plants (i.e. ash from coal).

Atmospheric and Waterborne Emissions

Tables 1-3 and 1-4 present atmospheric and waterborne emissions results for PC2 aircraft radome depainting solvent for the baseline and alternative scenarios.

All but four emissions categories show a dramatic reduction in emissions for the recycled system. The exceptions are the atmospheric emissions: dibasic ester, propylene carbonate, and
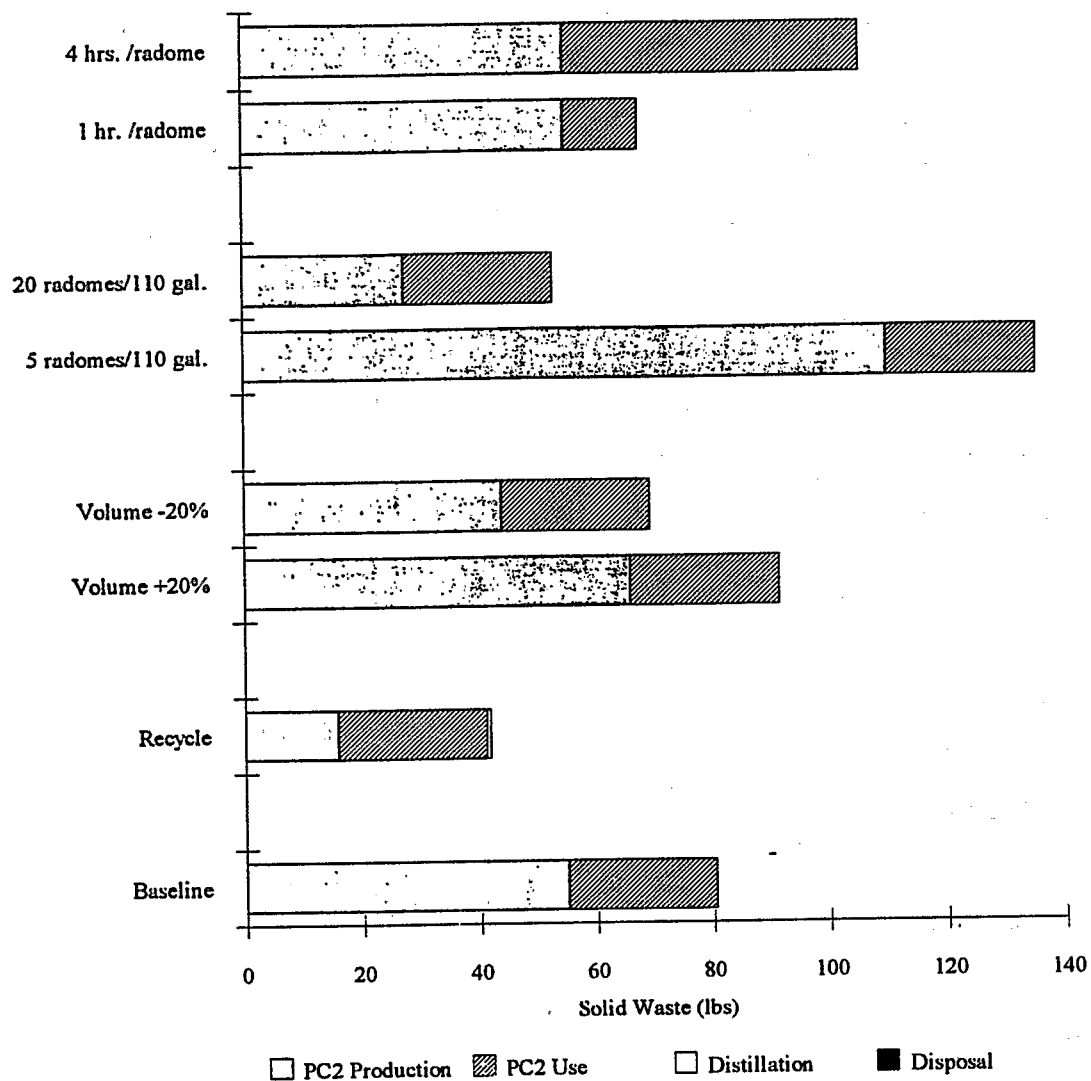
Figure 1-6. LCI solid wastes by component showing sensitivity to improvement alternatives.

Source: Tables 5-2 and 5-6

n-methyl-pyrrolidone (the three components of PC Blend 2), and other organics. The three PC2 components are the assumed atmospheric emissions during the PC2 use step at TAFB, and are assumed to remain unchanged with the use of recycled PC2. The other organics emissions increase for the recycled system because they are primarily related to additional transportation fuel pollutants produced when spent PC2 is transported to and from Texas for recovery. Source: Tables 5-2 and 5-6.

Increasing the volume of PC2 required results in increased emissions across the board, while decreasing the volume required results in decreased emissions. The decreases/increases in most cases are fairly proportionate to the change in PC2 required. This is because all the back-end steps have been changed proportionately. However, some emissions categories are less sensitive to the PC2 requirements. For example, sulfur oxides, particulate emissions, sulfuric acid, iron, kerosene, and airborne lead emissions change to a lesser degree than the other emissions. This is a reflection of their close tie to electricity consumption at TAFB which remains unchanged when the volume is varied.

Increasing the yield (less PC2 required) results in decreased emissions across the board, while decreasing the yield (more PC2 required) results in increased emissions. Again, most of the changes are fairly proportionate to the change in PC2 required, although some emissions categories are less sensitive to the PC2 requirements.

The results for varying the amount of time required per radome are shown in the last two columns. A baseline depainting time of two hours was assumed. For these analyses, the depainting time was halved and doubled. The comparison shows that decreasing the time to one hour results in decreased emissions in almost every category, while increasing the time results in increased emissions. The differences seen are fairly small for most categories of emissions. However, sulfur oxides, particulates, sulfuric acid, iron, kerosene, and airborne lead emissions change to a greater degree than the other emissions. This is entirely a reflection of their close tie to electricity consumption at TAFB.

Partial Impact Assessment

Methodology
Impact assessment, as defined by SETAC in **A Conceptual Framework for Life-Cycle Impact Assessment**, March 1993, consists of three steps: classification, characterization, and valuation. These steps are explained as follows:

Classification - The process of assigning and aggregating results from the inventory analysis into relatively homogenous potential impact categories and subcategories. For example, carbon monoxide and methane are assigned to greenhouse gas/global warming under ecosystem effects.

Table 1-3. Life Cycle Inventory of Atmospheric Emissions showing Sensitivity to PC2 use Assumptions* (In pounds per 10 KC-135 aircraft radomes depainted).

Atmospheric Emission	Baseline results (1)	Results with 100 percent closed-loop recycling (1)	Varying volume required		Varying radome yield		Varying depainting time	
			plus 20%	minus 20%	5 per 110 gallons	20 per 110 gallons	1 hour per radome	4 hours per radome
Aldehydes	0.058	0.039	0.070	0.047	0.116	0.029	0.058	0.059
Ammonia	0.43	0.066	0.51	0.34	0.85	0.21	0.43	0.43
Carbon Dioxide ‡	4,415	1,251	5,255	3,575	8,615	2,315	4,308	4,630
Carbon Monoxide	21.2	4.7	25.4	17.0	42.2	10.7	21.1	21.4
Chlorine	9.9E-05	2.4E-05	1.2E-04	7.9E-05	2.0E-04	5.0E-05	9.9E-05	9.9E-05
Dibasic Ester (DBE) †	1.2	1.2	1.5	1.0	2.5	0.62	1.24	1.24
Hydrocarbons	46.6	10.1	55.9	37.4	92.9	23.5	46.5	46.9
Hydrogen Chloride	7.2E-05	1.7E-05	8.7E-05	5.8E-05	1.4E-04	3.6E-05	7.2E-05	7.3E-05
Isobutane	0.82	0.13	0.98	0.65	1.6	0.41	0.82	0.82
Kerosene	2.0E-04	1.1E-04	2.2E-04	1.7E-04	3.3E-04	1.4E-04	1.6E-04	2.7E-04
Lead	1.9E-04	9.1E-05	2.2E-04	1.6E-04	3.3E-04	1.2E-04	1.6E-04	2.4E-04
Mercury	4.4E-05	6.8E-06	5.3E-05	3.5E-05	8.8E-05	2.2E-05	4.4E-05	4.4E-05
Methane	0.040	0.013	0.048	0.033	0.080	0.021	0.040	0.042
N-Methyl-Pyrrolidone (NMP) †	2.5	2.5	3.0	2.0	5.0	1.2	2.5	2.5
Nitrogen Oxides ‡	235.1	37.7	282.0	188.3	469.3	118.0	234.7	236.1
Other Organics	0.53	0.68	0.63	0.42	1.06	0.27	0.53	0.53
Particulates	1.3	0.78	1.5	1.1	2.3	0.84	1.16	1.68
Propylene	0.080	0.012	0.097	0.064	0.16	0.040	0.080	0.080
Propylene Carbonate (PC) †	1.2	1.2	1.5	1.0	2.5	0.62	1.24	1.24
Propylene Oxide	0.039	0.0060	0.047	0.031	0.078	0.020	0.039	0.039
Sulfur Oxides	8.0	3.7	9.2	6.8	14.2	4.9	7.1	9.8

* Includes all process and fuel related atmospheric emissions associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, PC2 use at TAFB, and disposal of spent PC2 by incineration.

† Represents estimated atmospheric emissions at TAFB assuming 0.5 percent evaporative loss of PC2 blend during aircraft radome depainting.

‡ Includes emissions from incineration of spent PC2.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

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Table 1-4. Life cycle Inventory of Waterborne Wastes showing Sensitivity to PC2 use Assumptions* (In pounds per 10 KC-135 aircraft radomes depainted).

Waterborne Wastes	Baseline results (1)	Results with 100 percent closed-loop recycling (1)	Varying volume required		Varying radome yield		Varying depainting time	
			plus 20%	minus 20%	5 per 110 gallons	20 per 110 gallons	1 hour per radome	4 hours per radome
Acid	0.0026	3.9E-04	0.0031	0.0020	0.0051	0.0013	0.0026	0.0026
Ammonia	0.026	0.0041	0.032	0.021	0.053	0.013	0.026	0.026
BOD	0.076	0.012	0.091	0.061	0.15	0.038	0.076	0.076
Chromium	3.4E-05	5.4E-06	4.1E-05	2.7E-05	6.8E-05	1.7E-05	3.4E-05	3.4E-05
COD	0.098	0.018	0.12	0.079	0.20	0.049	0.098	0.098
Dissolved Solids	0.54	0.12	0.64	0.43	1.1	0.27	0.53	0.54
Iron	0.11	0.062	0.13	0.099	0.19	0.076	0.095	0.15
Lead	9.6E-07	2.3E-07	1.1E-06	7.7E-07	1.9E-06	4.8E-07	9.5E-07	9.6E-07
Mercury	2.2E-08	3.5E-09	2.7E-08	1.8E-08	4.5E-08	1.1E-08	2.2E-08	2.2E-08
Metal Ion	0.011	0.0027	0.014	0.0090	0.022	0.0057	0.011	0.011
Nickel	1.2E-08	1.9E-09	1.5E-08	9.9E-09	2.5E-08	6.2E-09	1.2E-08	1.2E-08
Oil	0.071	0.013	0.085	0.057	0.14	0.036	0.071	0.071
Phenol	5.2E-05	1.1E-05	6.3E-05	4.2E-05	1.0E-04	2.6E-05	5.2E-05	5.3E-05
Sulfides	0.0011	1.6E-04	0.0013	8.4E-04	0.0021	5.3E-04	0.0011	0.0011
Sulfuric Acid	0.46	0.25	0.52	0.40	0.76	0.30	0.38	0.61
Suspended Solids	0.086	0.014	0.10	0.069	0.17	0.043	0.086	0.086
Zinc	1.4E-05	3.3E-06	1.7E-05	1.1E-05	2.8E-05	7.0E-06	1.4E-05	1.4E-05

* Includes all process and fuel related waterborne wastes associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, PC2 use at TAFB, and disposal of spent PC2 by incineration.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

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Characterization - The process of equating the pollutants in each impact category using the magnitude of potential impact. For example, under visibility alterations, the goal is to develop a method of equating X pounds of nitrogen oxide emissions to Y pounds of particulate emissions.

Valuation - The process of integrating the various impact categories by assigning a relative value or weight to each category.

The emissions identified by the inventory are classified into ecosystem and human health impact categories based on their potential impact within a category. The classification categories for ecosystem quality and human health are listed below.

Ecosystem Quality
- Greenhouse Gas/Global Warming
- Ozone Depleting Gas/ Stratospheric Ozone Depletion
- Acid Rain Precursor/Acid Rain
- Smog Precursor/Photochemical Smog/ Tropospheric Ozone
- Air Dispersion/Aging/Transport
- Aquatic Life
- Eutrophication/Plant Life
- Visibility Alterations (air or water)
- Weather Alterations
- Thermal Changes
- pH Alterations
- Chemical/Biological Content Alteration
- Oxygen Depletion
- Aquifer Contamination

Human Health
- Human Carcinogen (Class A)
- Irritant (Eye, Lung, Skin, GI Tract)/Corrosive
- Respiratory System Effects
- Central Nervous System Effects
- Allergenicity/Sensitization
- Blood Dyscrasias (Methemoglobinemia or Hematopoietic Effects)
- Odors
- Cardiovascular System Effects
- Reproductive Effects
- Behavioral Effects
- Bone Effects
- Renal Effects

Definitions of the classification categories and chemicals assigned to each are included in the discussion in Chapter 6 and Appendix B.

Without critical exposure or daily intake information, most characterization methods for establishing equivalence between pollutants in each classification category do not give conclusive results. However, the mass loading characterization model is utilized for this analysis to obtain meaningful results.

The loading technique assesses the inventory chemical emissions data on quantity only, using the assumptions that less quantity produces less *potential* impact. This model is not a measure of environmental impact. It is best used in a comparative analysis for two or more systems or two or

more process steps within one system. Quantities of a specific emission within a potential impact category are compared for each product system and the system that generates the least is considered to result in the least potential harm to ecosystem quality or human health.

There are several limitations to the use of the loading technique described above. First, it does not determine if a quantity of emission poses a significant threat and what the severity of that threat is. Also, emissions within a potential impact category cannot be compared. For example, if suspended solids and acid both have a potential impact on the category of aquatic life, there is no guidance on how to determine which produces the greater potential impact.

Valuation is not attempted for this study because it is highly subjective, and there is no scientific method for accurately completing it. Accepted procedures for conducting valuation are still being formulated.

Partial Impact Assessment Results and Discussion
Detailed results and discussion of the impact classification and partial characterization of atmospheric and waterborne environmental releases are presented in Chapter 6 and Appendix C of this report. The tables in Appendix C show each pollutant that is classified as having a potential impact on ecosystem quality and human health. The total atmospheric and waterborne emissions calculated for the inventory phase of this study form the basis for the partial impact assessment. Inventory releases for the baseline and alternative PC2 usage scenarios are presented earlier in Tables 1-3 and 1-4.

The partial impact assessment results for the atmospheric and waterborne emissions from the use of PC2 aircraft radome depainting solvent are summarized in Table 1-5 for all scenarios. In this table, "less potential impact" means that, in a given subcategory, the system had *no* emissions that were considered higher than the other system's emissions, while *at least 1* emission was higher for the other system. If neither system had any emissions higher than the other, the results for that subcategory were inconclusive. Results for a subcategory were also inconclusive if each system had at least one emission higher than the other. For example, for the first line in Table 1-5, the recycled system has significantly less potential impact in 20 subcategories. However, the results for ozone depletion are considered inconclusive, as are the results for the human health categories of irritant and allergenicity/sensitivity because each system is higher than the other for at least one emission in these subcategories.

Figure 1-7 provides some additional insight as to the magnitude of change in emissions amounts for the various alternatives. The figure summarizes the average percent difference (shown by the shaded bars) between the alternative scenario and the baseline. The range of the percent difference is also shown by the dotted lines. It is important to note that while the recycling scenario results in the greatest reduction in emissions as measured by the average percent difference, one emission increases (other organics with an increase from baseline of 28

percent) for the recycling scenario. The other organics emissions are found in three different potential impact subcategories and cause the "inconclusive" results in Table 1-5.

Table 1-5. Summary of Impact Assessment Results with Comparison of Improvement Alternatives to Baseline

Alternative System Compared to Baseline	Number of Impact Subcategories with Less Potential Impact	Number of Potential Impact Subcategories with Inconclusive Results
100% closed loop recycling of PC2	20	3
20% increase in volume of PC2	0	0
20% decrease in volume of PC2	23	0
Decrease yield to 5 per 110 gallons	0	0
Increase yield to 20 per 110 gallons	23	0
Increase depaint time to four hours per radome	0	0
Decrease depaint time to one hour per radome	23	0

Source: Appendix C, Tables C-1 to C-4.

Improvement Analysis

So far, the improvement alternatives have been compared by their energy requirements, produced emissions, and relative potential impact. In addition, an economic evaluation is provided to estimate the cost to supply the new solvent (PC2), and the cost of disposal or recovery of the used solvent for each of the improvement alternatives. This analysis is not a life cycle cost analysis, but instead analyzes the cost to TAFB for the various improvement alternatives. The analysis assumes that no new capital equipment will be required for the change-over from MEK to PC2. Thus no capital expenditures are required. Also, for the three year and five year recycling scenarios, the cost estimates are on a constant basis and do not include any factor for escalation of material and disposal costs over time. The cost estimates for the various PC2 use/disposal alternatives are summarized in Table 1-6.

In the baseline scenario, it is assumed that new PC2 would be purchased each year, and the spent solvent would be disposed of at the Coffeyville, KS hazardous waste incinerator. The total supply and disposal cost would be about $38,951 per year.

The first recycling scenario assumes a three year program of PC2 usage and recycling, after which all used solvent would be incinerated. For this scenario, new PC2 must be purchased the first year of operation. In the years following, 85 percent of the new supply would be comprised
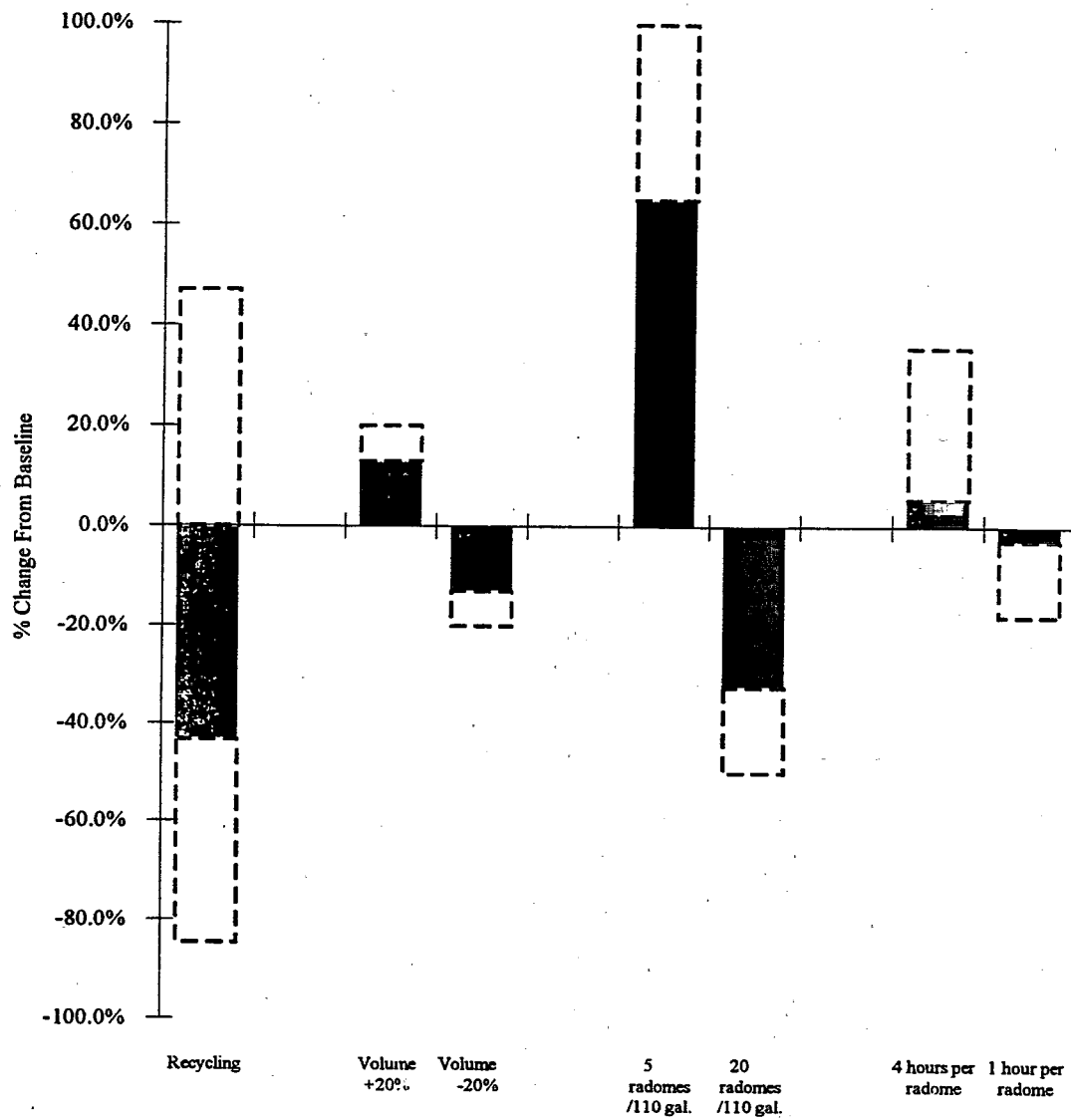
Figure 1-7. Summary of impact analysis average percent difference from baseline over all potential impact categories.

Shaded area shows average percent change from baseline and dotted lines show the range.
Source: Tables C-1 through C-4.

Table 1-6. Sensitivity of PC Blend 2 Costs to Demand

	Dollars/year (1)			
	New PC2	Disposal (2)	Recovery/ Distillation	Total
Baseline (1,815 gallons/yr)	31,218	7,623	-	38,841
Baseline w/ Recycling (3 yr. usage)	13,528	2,724 (3)	19,973	36,225
Baseline w/ Recycling (5 yr. usage)	9,990	1,635 (4)	23,968	35,592
Baseline w/+20% volume	37,462	9,148	-	46,609
Baseline w/-20% volume	24,974	6,098	-	31,073
Baseline w/+100% volume	62,436	15,246	-	77,682
Baseline w/-50% volume	15,609	3,812	-	19,421

Summarized from Tables 6-3 and 6-4.

(1) All costs are in constant dollars, escalation of costs are not included in these estimates.
(2) Disposal by incineration in a hazardous waste incinerator.
(3) Represents a one-time disposal of PC2 averaged over three years.
(4) Represents a one-time disposal of PC2 averaged over five years.

of recycled PC2 and 15 percent would be new PC2 makeup. The average three year cost is estimated at $36,225 which is about $2,800 per year less than the base case scenario.

The second recycling scenario is similar to the first with the exception of a five year usage and recycling program instead of a three year program. For this scenario, the average annual cost is $35,952 or $3,359 per year lower than the baseline scenario.

As seen in Table 1-6, the relative increases/decreases in the usage constraints are fairly proportionate to their resulting change in the costs. Increasing/decreasing the volume required by 20 percent results in an increased/decreased cost of approximately 20 percent. Halving and doubling the yield of PC2 has the effect of doubling/halving the total costs, respectively.

Conclusions

The following conclusions are reached regarding the life cycle inventory, partial impact assessment, and improvement analysis of PC2 radome depainting solvent. All changes are stated as results of each alternative scenario are compared to the baseline scenario.

- For the recycling scenario:
  - total energy requirements decrease by about 70 percent.
  - total solid waste is reduced by about 50 percent.

- total atmospheric and waterborne emissions show an average reduction of about 65 percent. However, the other organics atmospheric emissions increase by 28 percent.
- recycling PC2 results in less potential impact, except for the ecosystem potential impact category of ozone depletion and the human health categories of irritant/corrosive and allergenicity.
- total costs for a three year recycling program show an average of seven percent reduction in costs.
- total costs for a five year recycling program show an average of nine percent reduction in costs.

- By increasing the PC2 volume required per radome by 20 percent:
  - total energy requirements increase about 19 percent.
  - total solid waste increases about 14 percent.
  - total atmospheric and waterborne emissions show an average increase of about 19 percent.
  - the overall potential impact on ecosystem quality and human health is increased.
  - total cost shows an increase of 20 percent.

- By decreasing the PC2 volume required per radome by 20 percent:
  - total energy requirements are reduced by about 19 percent.
  - total solid waste decreases about 14 percent.
  - total atmospheric and waterborne emissions show an average decrease of about 19 percent.
  - the overall potential impact on ecosystem quality and human health is decreased.
  - total cost shows an decrease of 20 percent.

- By halving the yield from 10 to 5 radomes per 110 gallons:
  - total energy requirements increase by about 96 percent.
  - total solid waste increase by about 69 percent.
  - total atmospheric and waterborne emissions increase by an average of 95 percent.
  - the overall potential impact on ecosystem quality and human health is increased.
  - total costs increase 100 percent.

- By doubling the yield from 10 to 20 radomes per 110 gallons:
  - total energy requirements are reduced by 48 percent.
  - total solid waste is reduced by about 34 percent.
  - total atmospheric and waterborne emissions are reduced by an average of 47 percent.
  - the overall potential impact on ecosystem quality and human health is decreased.
  - total costs are reduced by 50 percent.

- By halving the time required for depainting from two to one hour per radome:
  - total energy requirements are reduced by only two percent

- total solid waste is reduced by 16 percent.
- atmospheric and waterborne emissions are reduced an average of three percent.
- the overall potential impact on ecosystem quality and human health is decreased.
- total costs were not calculated for this scenario due to relatively small differences.

- By doubling the time required for depainting from two to four hours per radome:
  - total energy requirements show an increase of four percent.
  - total solids waste shows an increase of 32 percent.
  - total atmospheric and waterborne emissions increase by an average of five percent.
  - the overall potential impact on ecosystem quality and human health is increased.
  - total costs were not calculated for this scenario due to relatively small differences.

- Based on an estimate of air emissions with a process screening model, direct emission of PC2 solvent vapors from the TAFB does not result in a significant known health problem as defined within the scope of this study to anyone outside the immediate working area.

Chapter 2
Study Approach And Methodology

Introduction

Life cycle assessment (LCA) is an analytical planning tool used by environmental professionals to quantify and understand (and to ultimately reduce) the resource consumption and environmental emissions associated with a product or process along its entire life cycle – from raw materials acquisition through final disposition. LCA is defined by the Society of Environmental Toxicology and Chemistry (SETAC) and the United States Environmental Protection Agency (EPA) as being composed of three separate but interrelated elements: life cycle inventory, life cycle impact assessment, and life cycle improvement assessment.

A life cycle inventory (LCI) quantifies the resource consumption (i.e., raw materials and energy) and environmental emissions (i.e., atmospheric emissions, waterborne wastes, and solid wastes) for a given product based upon the study boundaries established. The unique feature of this type of analysis is its focus on the entire life cycle of a product, from raw material acquisition to final disposition, rather than on a single manufacturing step or environmental emission. Figure 2-1 illustrates the general approach used in an LCI analysis.

The information from this type of analysis can be used as the basis for further study of the potential improvement of resource use and environmental emissions associated with a given product. It can also pinpoint areas in the life cycle of a product or process where changes would be most beneficial in terms of reduced energy use or environmental emissions.

Purpose

The purpose of this study is to provide an LCI that quantifies the energy use and environmental emissions associated with a potential replacement solvent blend for aircraft radome depainting at the Oklahoma City Air Logistics Center (OC-ALC) at Tinker Air Force Base (TAFB). A radome is the plastic housing sheltering the antenna assembly of an airplane's radar set. Currently, TAFB uses methyl ethyl ketone (MEK) to depaint B-52 and KC-135 aircraft radomes in a ventilated booth. Because of the high volatility of MEK, significant evaporative losses to the atmosphere occur during each depainting session. The large evaporative losses associated with using MEK limit the potential to reuse the solvent for depainting more than one radome, as well as cause difficulties in complying with applicable local, state, and federal air quality standards. Additionally, MEK has been targeted for elimination by the United States Environmental Protection Agency's (EPA) 33/50 Voluntary Reduction Program (also known as the EPA 17 list).
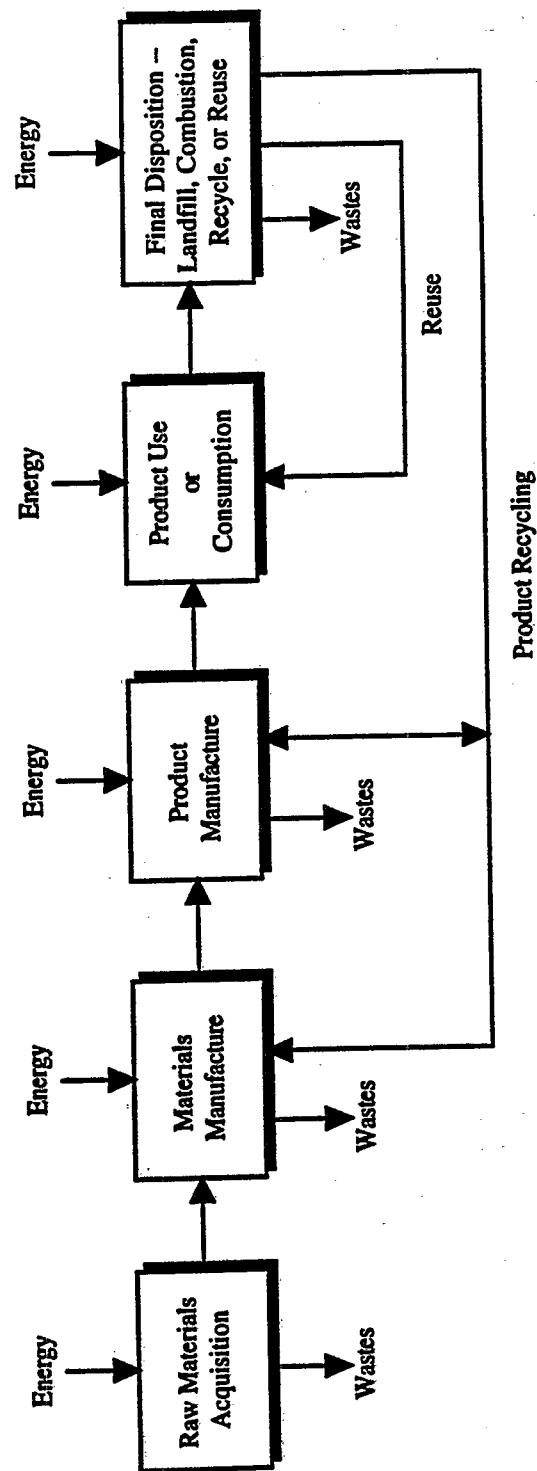
Figure 2-1. General materials flow for "cradle-to-grave" analysis of a product system.

Currently, the U.S. EPA and TAFB are evaluating solvent blends containing propylene carbonate as a nonvolatile, less toxic substitute for MEK. One propylene carbonate solvent blend currently being evaluated, and the focus of this LCI, is known as PC2 Blend (PC2). Results of initial performance screening studies indicate acceptable performance of this solvent for depainting radomes. The PC2 is comprised of 50 percent n-methyl-pyrrolidone (NMP), 25 percent dibasic ester (DBE), and 25 percent propylene carbonate (PC). The PC2 depainting process is not expected to require any change in existing capital equipment.

The focus of this LCI study will only be on the use of PC2 for depainting aircraft radomes. Often LCI is used as a comparative analysis between alternative products or processes, but in this case no comparison of PC2 to MEK was made because regulations are precluding the use of MEK. Results of the life cycle impact assessment and improvement assessment for the PC2 are presented in separate chapters which are a part of this study.

Study Boundaries

An LCI encompasses the entire life cycle of a product, from raw material acquisition to final disposition, rather than a single manufacturing step or environmental emission. Accordingly, the study boundaries of this LCI for use of PC2 include the following elements:

- raw materials acquisition
- production of intermediate chemicals and materials
- production of the three primary components of PC2: DBE, NMP, and PC
- use of PC2 at TAFB for depainting aircraft radomes
- disposal of PC2 by incineration as hazardous waste

Additional alternatives for off-site waste management of spent PC2 will be identified and analyzed in the improvement assessment phase of this study.

The LCI study boundaries for the analysis of PC2 are illustrated in Figure 2-2. Detailed process flow diagrams, along with a brief description of the production requirements for the three primary components of PC2, can be found in Appendix A located at the end of this report.

Life Cycle Inventory Methodology

Key elements of the LCI methodology include the study boundaries, resource inventory (raw materials and energy), emissions inventory (atmospheric, waterborne, and solid waste), and usage and disposal practices. Additional discussion on the methodology used to calculate product life cycle resource and environmental emissions is presented inthe following section of this report. The LCI study boundary for PC2 was discussed in the previous section of this report. Assumed PC2 usage practices for depainting aircraft radomes at TAFB are presented in Appendix A at the end of this report.
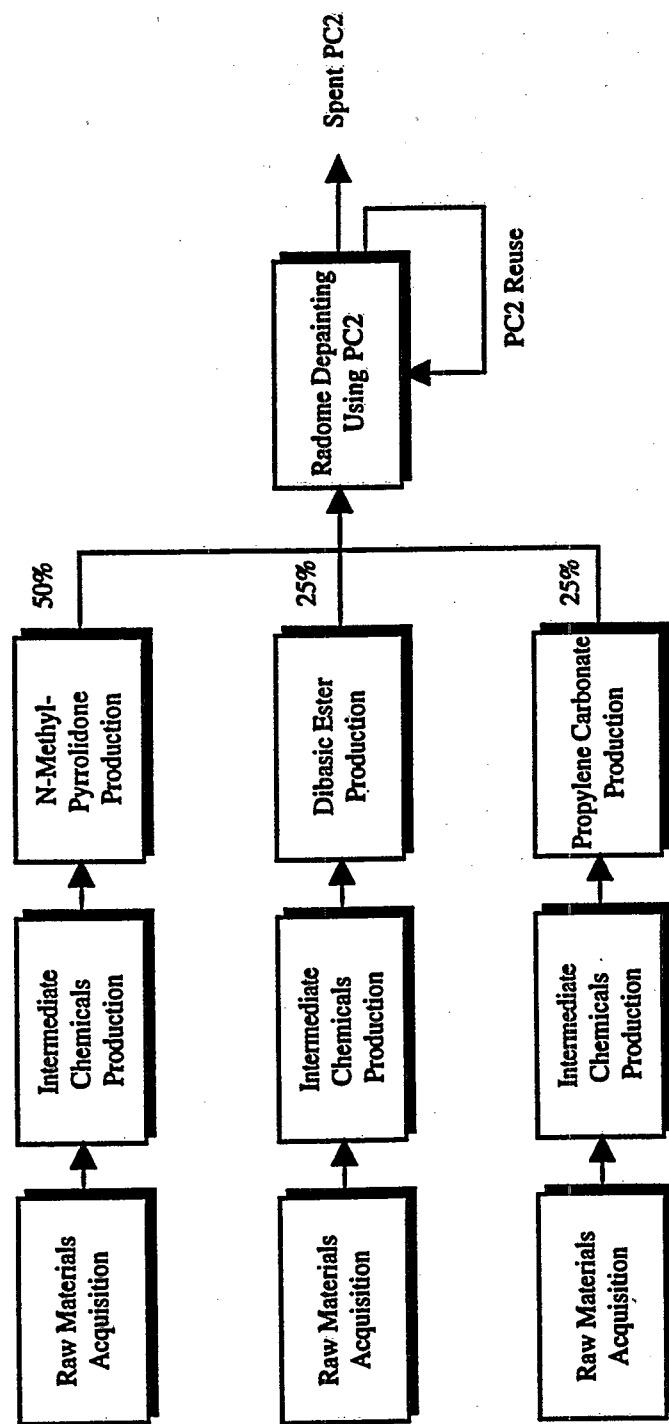
Figure 2-2. LCI study boundary for PC Blend 2 (see Appendix A for detailed material flow diagrams).

Franklin Associates, Ltd. has developed a methodology for performing resource and environmental profile analyses (REPA), commonly called life cycle inventories (LCI). This methodology has been documented for the U.S. Environmental Protection Agency and is incorporated in the EPA report **Product Life-Cycle Assessment Inventory Guidelines and Principles.** The methodology is also consistent with the life cycle inventory methodology described in two workshop reports produced by the Society of Environmental Toxicology and Chemistry (SETAC): **A Technical Framework for Life-cycle Assessment, January 1991** and **Guidelines for Life-Cycle Assessment: 'A Code of Practice', 1993.** The data presented in this report were developed using this methodology, which has been in use for over 20 years.

Figure 2-3 illustrates the basic approach to data development for each major process in an LCI analysis. This approach provides the essential building blocks of data used to construct a complete resource and environmental emissions inventory profile for the entire life cycle of a product. Using this approach, each individual process included in the study is examined as a closed system, or "black box", by fully accounting for all resource inputs and process outputs associated with that particular process. Resource inputs accounted for in the LCI include raw materials and energy use, while process outputs accounted for include products manufactured and environmental emissions.

For each process included in the study, resource requirements and environmental emissions are determined and expressed in terms of a standard unit of output. A standard unit of output, such as 1,000 pounds, is typically used as the basis for determining the total life cycle resource requirements and environmental emissions of a product.

If marketable coproducts or byproducts are produced, adjustments are made in the materials balance, energy requirements, and environmental emissions to reflect the portion of each attributable to the product being considered. Figure 2-4 illustrates an example of coproduct allocation based on mass, the most commonly used basis for allocation.

Material Requirements
Once the LCI study boundaries have been defined and the individual processes identified, a material balance is performed for each individual process. This analysis identifies and quantifies the input raw materials required per standard unit of output, such as 1,000 pounds, for each individual process included in the LCI. The purpose of the material balance is to determine the appropriate weighting factors used in calculating the total energy requirements and environmental emissions associated with the production, use, and disposal of PC2. Energy requirements and environmental emissions are determined for each process and expressed in terms of the standard unit of output.

Once the detailed material balance has been established for a standard unit of output for each process included in the LCI, a comprehensive material balance for the entire life cycle of PC2 is constructed. This analysis determines the quantity of materials required from each process to

2-5
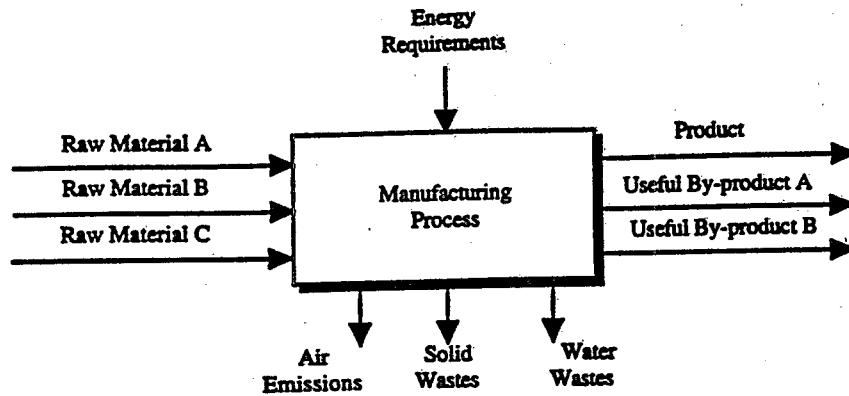
Figure 2-3. "Black box" concept for developing LCI data.

Actual process flow diagram.
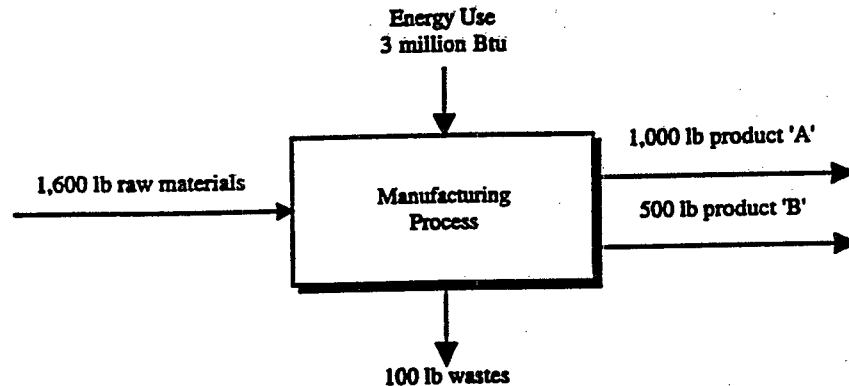
Using co-product allocation, the flow diagram utilized in the life cycle inventory for product 'A', which accounts for two-thirds (2/3) of the total output, would be as shown below.
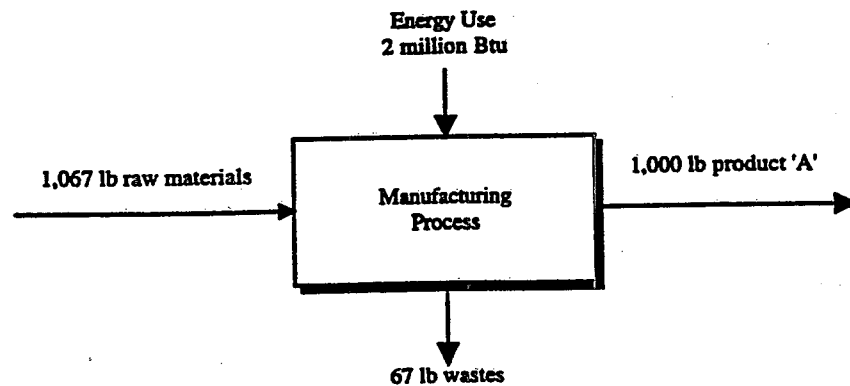
Figure 2-4 **Flow diagrams illustrating coproduct allocation for product 'A'.**

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produce, use, and dispose a standard unit of PC2, and is typically illustrated as a flow chart (see Appendix A for detailed process flow diagrams illustrating the production of 1,000 pounds each of NMP, DBE, and PC).

Energy Requirements

The average energy requirements for each process identified in the LCI are first quantified in terms of fuel or electricity units, such as cubic feet of natural gas, gallons of diesel fuel, or kilowatt-hours (kWh) of electricity. The fuel used to transport raw materials to each process are included as a part of the LCI energy requirements. Transportation energy requirements for each step in the life cycle are developed in the conventional units of ton-miles by each transport mode (e.g. truck, rail, barge, etc.). Government statistical data for the average efficiency of each transportation mode are used to convert from ton-miles to fuel consumption.

Once the fuel consumption for each industrial process and transportation step is quantified, the fuel units are converted from their original units to an equivalent British thermal unit (Btu) based on standard conversion factors. By definition, one Btu is the amount of energy required to raise the temperature of one pound of water one degree Fahrenheit (F) at or near 39.2 degrees F.

The conversion factors have been developed to account for the energy required to extract, transport, and process the fuels and to account for the energy content of the fuels. The energy to extract, transport, and process fuels into a usable form is labeled precombustion energy. For electricity, precombustion energy calculations include adjustments for the average efficiency of conversion of fuel to electricity, and for transmission losses in power lines based on national averages.

The LCI methodology assigns a fuel-energy equivalent to raw materials that are derived from fossil fuels. Therefore, the total energy requirement for coal, natural gas, or petroleum based materials includes the fuel-energy of the raw material (called energy of material resource or inherent energy). In this study, this applies to the crude oil and natural gas used to produce the materials comprising PC2. No fuel-energy equivalent is assigned to combustible materials, such as wood, that are not major fuel sources in this country.

The Btu values for fuels and electricity consumed in each industrial process are summed and categorized into an energy profile according to the five basic energy sources listed below:

- Natural gas
- Petroleum
- Coal
- Nuclear
- Other

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The "other" category includes nonconventional sources, such as hydropower, solar, biomass and geothermal energy. Also included in the LCI energy profile are the Btu values for all transportation steps and all fossil fuel-derived raw materials. Energy requirements for each system examined in this LCI are presented in Chapter 3.

Environmental Emissions

Environmental emissions are categorized as atmospheric emissions, waterborne wastes, and solid wastes, and represent discharges into the environment after the effluents pass through existing emission control devices. Similar to energy, environmental emissions associated with processing fuels into usable forms are also included in the inventory analysis. When efforts to obtain actual industry emissions data fail, published emissions standards are used as the basis for determining environmental emissions.

The different categories of atmospheric and waterborne emissions are not totaled in this LCI because it is widely recognized that various substances emitted to the air and water differ greatly in their effect on the environment. Individual environmental emissions for each process examined in this LCI are presented in Chapter 4.

Atmospheric Emissions

These emissions include substances classified by regulatory agencies as pollutants, as well as selected nonregulated emissions such as carbon dioxide. Atmospheric emissions associated with the combustion of fuel for process or transportation energy, as well as process emissions, are included in this LCI. Emissions are reported as pounds of pollutant per unit of product output. The amounts reported represent actual discharges into the atmosphere after the effluents pass through existing emission control devices. Some of the more commonly reported atmospheric emissions are: carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides, particulates, and sulfur oxides.

Waterborne Wastes

As with atmospheric emissions, waterborne wastes include all substances classified as pollutants. Waterborne wastes are reported as pounds of pollutant per unit of product output. The values reported are the average quantity of pollutants still present in the wastewater stream after wastewater treatment, and represent discharges into receiving waters. This includes both process-related and fuel-related waterborne wastes. Some of the most commonly reported waterborne wastes are: acid, ammonia, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chromium, dissolved solids, iron, and suspended solids.

Solid Wastes

This category includes solid wastes generated from all sources that are landfilled or disposed of in some other way. Also included is the ash from the combustion of materials at combustion facilities, such as an electric utility. It does not include materials that are recovered for reuse or recycling.

When performing an LCI, typically both postconsumer and industrial wastes are considered. Postconsumer solid wastes are primarily packaging materials that are discarded by consumers after they have fulfilled their use. In this analysis, no postconsumer waste is considered and all solid waste generated is categorized as process-related or fuel-related industrial waste. Examples of industrial solid wastes are wastewater treatment sludge, solids collected in air pollution control devices, trim or waste materials from manufacturing operations that are not recycled, fuel combustion residues such as the ash generated by burning coal or wood, and mineral extraction wastes.

In this study, the spent PC2 is assumed to be drummed and disposed off-site by incineration as hazardous waste. Combustion emissions are quantified and categorized as atmospheric emissions in the inventory. An alternative to disposal will be pursued in the improvement assessment phase of this study.

Data Sources

Over the past 20 years, Franklin Associates has performed numerous life cycle inventory studies which have examined the energy requirements and environmental emissions associated with the manufacture and use of a variety of products and processes. Therefore, many of the basic industry descriptions, raw materials requirements, and energy and emissions data for materials and chemicals from previous studies are used as a starting point for LCI studies. Other sources used to update the existing Franklin LCI database are: industry data which is primarily confidential, technical literature, government publications, published industry statistics, and interviews with industry representatives.

For this study, data gathering efforts focused primarily on the production of the three primary materials used in PC2 blend (DBE, NMP, PC), as well as PC2 usage practices for depainting aircraft radomes at TAFB.

Reliability Of Results

An important issue to consider when using LCI study results is the reliability of the data. In a complex study, such as an LCI, with literally thousands of numeric entries, the accuracy of the data and how it affects conclusions is truly a complex subject, and one that does not readily lend itself to standard error analysis techniques. However, the reliability of the LCI study can be assessed in other ways.

A key question is whether the LCI study conclusions are correct. A specific conclusion depends on the accuracy of the numbers that are combined to arrive at that conclusion. Because of the many processes required to produce PC2, many numbers in the LCI are added together for a total numeric result. Each number by itself contributes to a portion of the total, so the accuracy of an individual number by itself can be less important than the overall accuracy of the total. The best available numbers have been used in this study; however, there is no analytical method for assessing the accuracy of each number to any degree of confidence. Often times, plant personnel

report actual plant data. The data reported may represent operations for the previous year or may be estimates representative of the upcoming year. All data received are evaluated to determine whether or not they are representative of the typical industry practices for that operation or process being evaluated. Taking into consideration schedule constraints, the data used in this report are believed to be the best which can be currently obtained.

There are several other important points regarding data accuracy. Some numbers contribute very little to the total value, so a large error in one data point does not necessarily create a problem. It is assumed that with careful scrutiny of the data any errors will be random. That is, some numbers will be a little high due to errors, and some will be slightly low, but in the summing process these errors tend to cancel out. For subprocesses that make a larger than average contribution to the total, special care is taken to insure data quality.

Life cycle inventory data are not amenable to standard statistical analysis. Based on Franklin Associates' knowledge of error and variability of the data, a rule is suggested that if system totals of energy or solid waste (by weight) for two product systems differ by 10 percent or more, there is a 95 percent confidence that the difference is significant. This means that if other LCA practitioners performed this study using the same methodology and sampled the same populations, then 95 out of 100 would arrive at the same conclusion. However, the error and variability of all categories of emissions data is much greater, suggesting that significant differences exist only if the differences exceed 25 percent.

There is another dimension to the reliability of the data. Certain numbers do not stand alone, but rather affect several numbers in the system. An example is the number of times the PC2 can be reused to depaint aircraft radomes. A change in this assumption can have a significant effect on the results of this study.

Another issue is the variability of common practice. This study reports average, or typical, behavior and therefore does not apply to individual actions that deviate from the norm. Also, a particular set of material suppliers were used to provide data for this study. If a different set of suppliers is used to develop the average data, the average data might vary enough to affect the results of the report.

In summary, for the particular data sources used and for the specific methodology described in this report, the results of this report are believed to be accurate and reasonable. However, using this study to make decisions in specific cases which differ significantly from those described in this report may lead to erroneous conclusions.

Basis Of Results
LCI study results are presented on the basis of usage that is appropriate for the particular product or process being examined. For example, results of an LCI for children's diapers may be

presented based on the average number of diapers used daily. For a packaging system, such as beverage containers, the appropriate basis of results may be per gallon of beverage delivered.

In order to assist readers of this report with relative perspective and comprehension, results of this LCI are presented in the following ways:

- per ten KC-135 aircraft radomes depainted (estimated to require 110 gallons of PC2)
- per ten B-52 aircraft radomes depainted (estimated to require 180 gallons of PC2)
- per annual PC2 usage at TAFB for depainting radomes (estimated to require approximately 1,820 gallons, or 33 drums of PC2)

Annual usage estimates are based on historical use of MEK. In 1994, 100 KC-135 radomes and 40 B-52 radomes were depainted at TAFB with 146 drums of MEK. The number and type of radomes processed at TAFB are assumed to remain unchanged.

Key Assumptions

Some general decisions are always necessary to limit a study such as this to a reasonable scope. It is important to understand these decisions. The key assumptions and limitations for this study are discussed in the following sections.

Data Sources

The primary data sources utilized in this study are discussed previously in this chapter. When data are obtained from many sources, it is important to critically review the sources and content of the information prior to using it. In some cases, past experience provides a basis for data evaluation to determine the reasonableness of content. Franklin Associates believes that the data used in this study are both accurate and representative of typical conditions for the production and use of PC2.

Geographic Scope

Data for foreign processes are generally not available. This is usually only a consideration for the production of oil that is obtained from overseas. In cases such as this, the energy requirements and emissions are assumed to be the same as if the materials originated in the United States. Since foreign standards and regulations vary from those of the United States, it is acknowledged that this assumption may introduce some error. Fuel usage for transportation of oil from overseas locations is included in the study.

Precombustion Energy and Emissions

The energy content of fuels has been adjusted to include the energy requirements for extracting, processing, and transporting fuels, in addition to the primary energy of a fuel resulting from its combustion. In this study, this additional energy is called precombustion energy. Precombustion energy refers to all the energy that must be expended to prepare and deliver the

primary fuel. Adjustments for losses during transmission, spills, leaks, exploration, and drilling/mining operations are incorporated into the calculation of precombustion energy.

Precombustion environmental emissions (air, waterborne, and solid waste) are also associated with the acquisition, processing, and transportation of the primary fuel. These precombustion emissions are added to the emissions resulting from the burning of the fuels.

Electricity Fuel Profile

In general, detailed data do not exist on the fuels used to generate the electricity consumed by each industry. Electricity production and distribution systems in the United States are interlinked and are not easily separated. Users of electricity, in general, cannot specify the fuels used to produce their share of the electric power grid. Therefore, the national average fuel consumption by electrical utilities is assumed.

Electricity generated on-site at a manufacturing facility is represented in the process data by the fuels used to produce it. A portion of on-site generated electricity is sold to the electricity grid. This portion is accounted for in the calculations for the fuel mix in the grid.

Waste Management of Spent PC2

Spent PC2 is assumed to be incinerated off-site as a hazardous waste. No energy recovery from combustion is included for the baseline analysis. Additional alternatives for hazardous waste management will be identified and analyzed in the improvement assessment phase of this study.

System Components Not Included

The following components of each system are not included in this LCI study:

Capital Equipment

The energy and wastes associated with the manufacture of capital equipment are not included. This includes equipment to manufacture buildings, motor vehicles, and industrial machinery. The energy and emissions associated with such capital equipment generally, for 1,000 pounds of materials, become negligible when averaged over the millions of pounds of product which the capital equipment manufactures.

Space Conditioning

The fuels and power consumed to heat, cool, and light manufacturing establishments are omitted from the calculations in most cases. For most industries, space conditioning energy is quite low compared to process energy. Energy consumed for space conditioning is usually less than one percent of the total energy consumption for the manufacturing process.

Support Personnel Requirements

The energy and wastes associated with research and development, sales, and administrative personnel or related activities have not been included in this study. Similar to space conditioning,

energy requirements and related emissions are assumed to be quite small for support personnel activities.

Miscellaneous Materials and Additives

Selected materials such as catalysts, pigments, or other additives which total less than one percent of the net process inputs are not included in the assessment. PC2 is assumed to consist of 50 percent NMP, 25 percent DBE, and 25 percent PC. Omitting miscellaneous materials and additives helps keep the scope of the study focused and manageable within budget and time constraints.
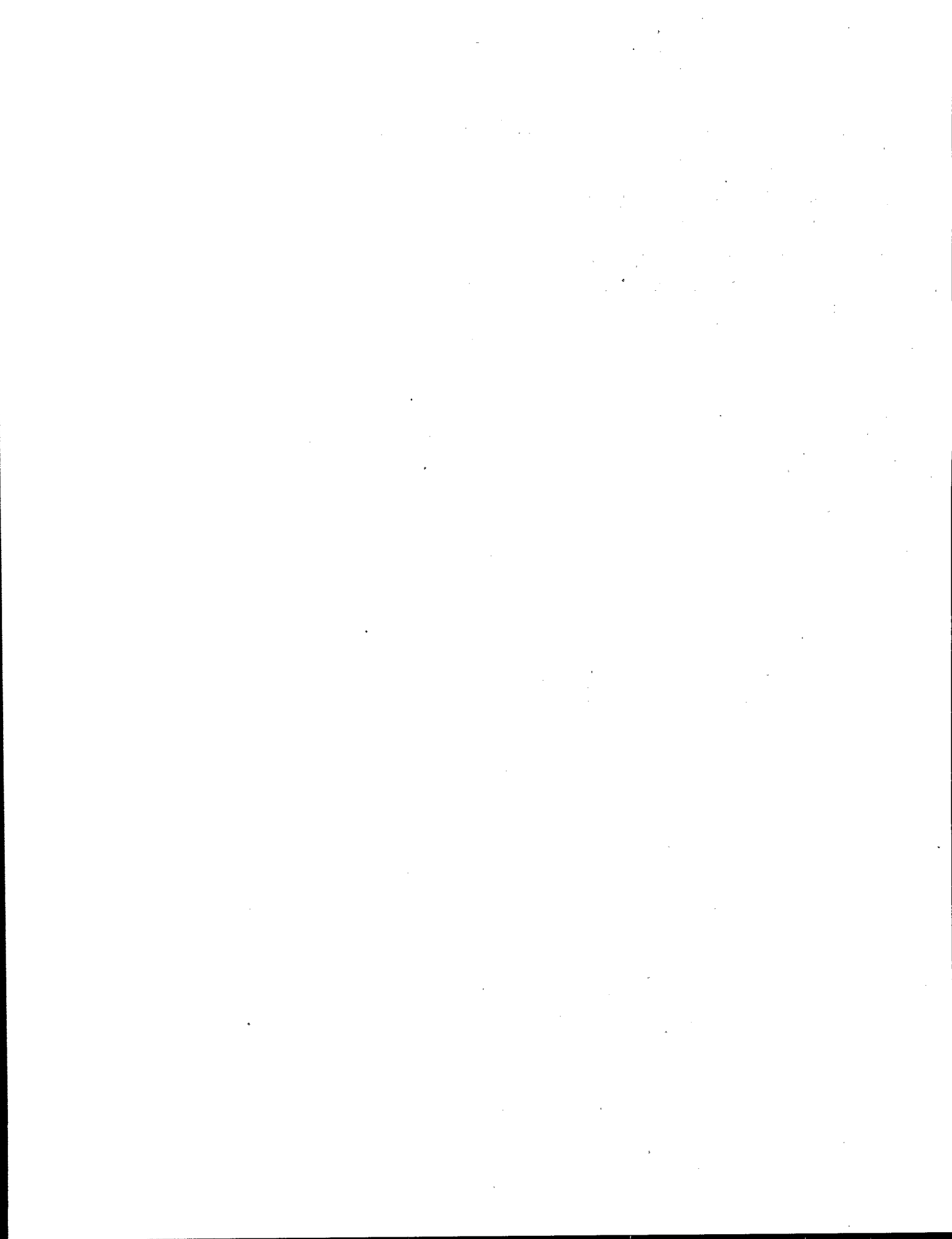
Chapter 3
Energy Requirements For The Production And
Use Of PC2 Aircraft Radome Depainting Solvent

Introduction

This chapter provides a detailed summary of the energy requirements for the production, blending, use, and disposal of PC2, a potential replacement solvent blend for aircraft radome depainting at the Oklahoma City Air Logistics Center (OC-ALC) at Tinker Air Force Base (TAFB). Currently, TAFB uses methyl ethyl ketone (MEK) to depaint B-52 and KC-135 aircraft radomes. The PC2 solvent blend is a mixture of 50 percent n-methyl-pyrrolidone (NMP), 25 percent dibasic ester (DBE), and 25 percent propylene carbonate (PC).

Energy requirements for PC2 are presented in this chapter on the basis of usage scenarios, energy category, and original fuel source. Usage scenarios selected for this study include: ten KC-135 aircraft radomes depainted, ten B-52 aircraft radomes depainted, and annual usage for aircraft radome depainting at TAFB. For a life cycle inventory, the general categories of energy include: process energy, transportation energy, and energy of material resource. Energy of material resource is the inherent energy of a raw material, such as natural gas or petroleum, when used as a material feedstock.

Energy requirements are presented for the system components including the three chemical products comprising PC Blend 2 (i.e., DBE, NMP, PC). These energy requirements include all processing steps up to and including the actual production of DBE, NMP, and PC. Thus, all raw material acquisition and intermediate chemical processing steps are included in these values. Energy requirements associated with transporting and incinerating spent PC2 off-site are also accounted for in the LCI. Additional alternatives for off-site waste management of spent PC2 will be identified and analyzed in the improvement assessment phase of this study.

All energy results are presented in units of million Btu and include both precombustion and combustion energy. Precombustion energy refers to the energy required to extract, transport, and process fuels into a usable form (e.g., refining crude oil into gasoline). Combustion energy refers to the energy content of the process and transport fuels consumed.

Results And Discussion

Energy Requirements by Usage Scenario

Table 3-1 presents total energy requirements for PC2 aircraft radome depainting solvent for

the three usage scenarios considered in this study. These results include all energy use associated with raw materials acquisition, chemical processes for producing the three components comprising PC Blend 2 (i.e., DBE, NMP, PC), PC Blending 2, and PC2 use and disposal for depainting radomes at TAFB.

Table 3-1. Life Cycle Inventory of Energy Requirements by Usage Scenario for PC Blend 2 Radome Depainting Solvent (In million Btu)

	Per Ten (10) KC-135 Aircraft Radomes (1)	Per Ten (10) B-52 Aircraft Radomes (2)	Per Annual Usage at TAFB (3)
Dibasic Ester (DBE)	9.8	16.1	162
N-Methyl-Pyrrolidone (NMP)	23.8	38.9	393
Propylene Carbonate (PC)	6.7	11.0	111
*Subtotal**	40.3	65.9	666
PC2 Blending	0.54	0.88	8.9
PC2 Use at TAFB	1.5	1.5	20.9
PC2 Disposal Off-Site	0.15	0.25	2.5
Total Energy Required	42.5	68.5	699

* Includes all energy use associated with raw materials acquisition and chemical processes required for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC).

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.
(2) Based on 180 gallons of PC2 used per ten B-52 aircraft radomes depainted.
(3) Based on 100 KC-135 and 40 B-52 aircraft radomes depainted annually.

Source: Franklin Associates, Ltd.

For the KC-135, the predominant aircraft radome depainted at TAFB, approximately 43 million Btu of total energy is required per ten radomes depainted. In contrast, approximately 69 million Btu of energy is required per ten B-52 radomes depainted. The difference is due to the assumed amount of PC2 used in radome depainting (110 gallons per ten KC-135 radomes versus 180 gallons per ten B-52 radomes). Based on an estimated average annual operation of 100 KC-135 and 40 B-52 radomes depainted at TAFB, approximately 700 million Btu of total energy is required; this is for a total of 1,820 gallons of PC2.

The energy contributions of each major component included in the LCI are illustrated in Figure 3-1. Raw materials acquisition and chemical processing associated with the three components of PC2 account for 95 percent of the total energy requirements. NMP, which

accounts for 50 percent of PC2, also accounts for the majority of energy – approximately 56 percent of the total energy requirements. Processes related to DBE and PC account for 23 and 16 percent, respectively, of total energy requirements. PC Blending 2 and usage for aircraft radome depainting at TAFB account for a total of only five percent of the total energy requirements. The disposal energy represents transportation to a hazardous waste incinerator and is only 0.4% of the total energy requirements.
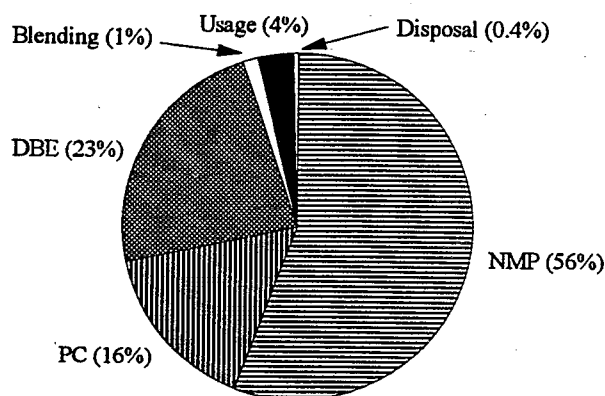
Source: Franklin Associates, Ltd.

Figure 3-1. LCI energy profile by component for PC Blend 2 radome depainting solvent (In percent).

Energy Requirements by Category of Energy

In a life cycle inventory, energy requirements are categorized as process energy, transportation energy, and energy of material resource. Table 3-2 and Figure 3-2 summarize these categories for the production, blending, use, and disposal of PC2 for depainting aircraft radomes. The energy requirements are presented by energy category for each major process and are reported in million Btu per ten KC-135 aircraft radomes depainted.

Process energy accounts for 18.6 million Btu, or 44 percent of the total energy associated with PC2. This includes all energy required for the manufacture of the three components (i.e., DBE, NMP, PC), including all raw material acquisitions and intermediate chemical processing. Electricity for the exhaust ventilation system and air compressor (to drive the sump pump) account for the small amount of process energy used at TAFB.

The energy of material resource is the inherent energy of petroleum, natural gas, and coal when used as a raw material feedstock. Energy of material resource accounts for approximately 22.8 million Btu, or 54 percent of the total energy associated with PC2. The energy of material of resource for NMP accounts for the largest single use of energy, 14.1 million Btu, or approximately 33 percent of the total energy requirements.

3-3

Transportation energy represents the energy used as fuel to transport the chemicals and materials to the next step in the manufacturing process, such as shipping the three components of PC2 to a blending facility. Transportation energy represents a small portion of the total energy, accounting for only three percent of the total energy requirements.

Table 3-2. Life Cycle Inventory of Energy Requirements by Energy Category for PC Blend 2 Radome Depainting Solvent

	Per Ten KC-135 Aircraft Radomes Depainted (1)				
	Process Energy	Transpor-tation Energy	Energy of Material Resource	Total Energy	Percent of Total Energy
Dibasic Ester (DBE)	4.6	0.23	5.0	9.8	23.1%
N-Methyl-Pyrrolidone (NMP)	9.1	0.51	14.1	23.8	55.9%
Propylene Carbonate (PC)	2.9	0.17	3.6	6.7	15.8%
*Subtotal**	16.6	0.90	22.8	40.3	94.9%
PC2 Blending	0.51	0.031	-	0.54	1.3%
PC2 Use at TAFB	1.5	-	-	1.5	3.5%
PC2 Disposal Off-Site	-	0.15	-	0.15	0.4%
Total Energy Required	18.6	1.1	22.8	42.5	100.0%
Percent of Total Energy	43.8%	2.6%	53.6%	100.0%	

* Includes all energy use associated with raw materials acquisition and chemical processes required for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC).

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

Energy Requirements by Fuel Source
The total energy requirements for the production and use of PC2 for depainting radomes are reported by the source of energy in Table 3-3 and Figure 3-3. Energy requirements are categorized into five basic energy sources: natural gas, petroleum, coal, nuclear, and "other." The "other" category is comprised of nonconventional energy sources such as geothermal energy, solar energy for steam generation, and biomass energy.

Natural gas provides the majority of the energy requirements for PC2 followed, to a lesser extent, by petroleum and coal. Natural gas supplies 29.3 million Btu per ten KC-135 radomes depainted, or approximately 69 percent of the total energy requirements. This value includes the energy of material resource attributed to natural gas used as a raw material feedstock. Petroleum fuel generates 9.6 million Btu per ten KC-135 radomes depainted, or approximately 23 percent of the total energy requirements. Coal, which is used primarily for electricity generation, accounts

for approximately six percent of the total energy requirements. Nuclear, hydropower, and other fuel sources account for less than three percent of the total energy requirements. All of these fuels are also used primarily to generate electricity.
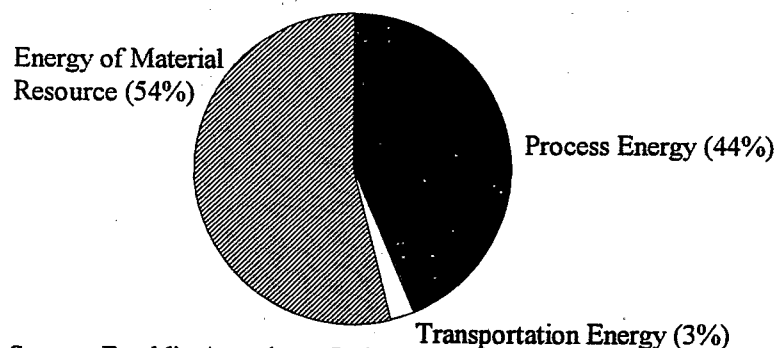
Source: Franklin Associates, Ltd.

Figure 3-2. LCI energy profile by category for PC Blend 2 radome depainting solvent (In percent).

Table 3-3. Life Cycle Inventory of Energy Requirements by Fuel Type for PC Blend 2 Radome Depainting Solvent (In million Btu and percent)

	Per Ten KC-135 Aircraft Radomes Depainted (1)						
	Coal	Natural Gas	Petroleum	Nuclear	Other Sources	Total Energy	Percent of Total Energy
Dibasic Ester (DBE)	0.38	5.3	4.0	0.096	0.019	9.8	23.1%
N-Methyl-Pyrrolidone (NMP)	0.68	18.4	4.4	0.28	0.055	23.8	55.9%
Propylene Carbonate (PC)	0.28	5.3	0.98	0.11	0.022	6.7	15.8%
Subtotal*	1.3	29.0	9.3	0.49	0.095	40.3	94.9%
PC2 Blending	0.28	0.075	0.050	0.11	0.022	0.54	1.3%
PC2 Use at TAFB	0.81	0.22	0.063	0.34	0.065	1.5	3.5%
PC2 Disposal Off-Site	0.0013	0.0094	0.14	5.0E-04	9.7E-05	0.15	0.4%
Total Energy Required	2.4	29.3	9.6	0.94	0.18	42.5	100.0%
Percent of Total Energy	5.7%	69.1%	22.6%	2.2%	0.4%	100.0%	

* Includes all energy use associated with raw materials acquisition and chemical processes required for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC).

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

Figure 2-3

**LCI ENERGY PROFILE BY FUEL TYPE FOR
PC2 BLEND RADOME DEPAINTING SOLVENT
(In percent)**

Other (0.4%)

Nuclear (2%)

Coal (6%)

Petroleum (23%)

Natural Gas (69%)
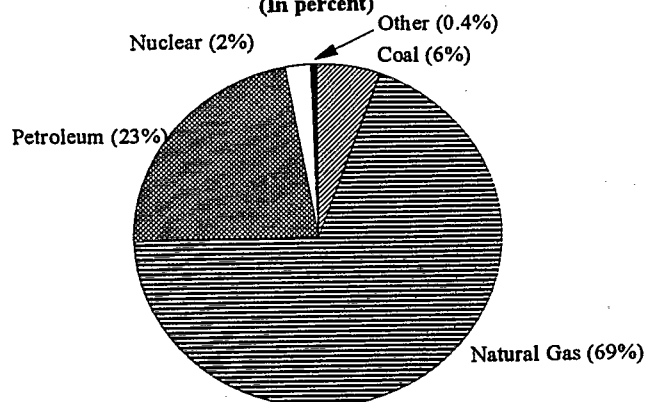
Source: Franklin Associates, Ltd.

Figure 3-3. LCI energy profile by fuel type for PC Blend 2 radome depainting solvent (In percent).

Chapter 4
Life Cycle Inventory Environmental Emissions Results For The Production And Use Of PC2 In Radome Depainting

Introduction

This chapter provides a detailed summary of the environmental emissions for the life cycle of PC2, a potential replacement solvent blend for depainting KC-135 and B-52 aircraft radomes at Tinker Air Force Base (TAFB). The results represent a cradle-to-grave analysis of manufacture of the PC2 components, blending of the mixture, use in depainting, and final disposition of the used fluid.

The environmental emissions examined in this study include solid wastes, atmospheric emissions, and waterborne wastes. Each of these wastes is examined separately. Although this life cycle inventory identifies emissions, it makes no attempt to quantify the effects on the environment or human health due to these wastes. A partial impact assessment will be provided in the next phase of this project.

Summarized emissions results are presented in this chapter on the basis of three PC2 usage scenarios: per 10 KC-135 radomes depainted, per 10 B-52 radomes depainted, and per annual usage at TAFB. More detailed results are presented for the KC-135 radome scenario. This scenario was chosen because the KC-135 radome is the highest volume radome depainted at TAFB. Details are provided for each emission as to what portion originates within the process (process-related emissions) or from the acquisition and use of fuels (fuel-related emissions). The emissions results are presented for each of the system components comprising the PC Blend 2 (i.e. DBE, NMP, and PC), and also PC Blend 2ing, PC2 use at TAFB, and disposal. Waste PC2 is assumed to be incinerated off-site as a hazardous waste. An alternative to disposal of spent PC2 will be addressed in the improvement assessment phase of this analysis.

Results And Discussion

Solid Waste

The solid waste category includes industrial solid waste generated from the individual processes in the manufacture and use of the PC2 for depainting radomes. There is no postconsumer waste associated with the production of the fluid. Industrial solid waste includes wastewater treatment sludges, solids resulting from air pollution control devices, trim or waste

materials from manufacturing operations that are not recycled, fuel combustion residues, such as ash from burning wood or coal, and extraction wastes. Waste PC2 is assumed to be incinerated off-site as a hazardous waste. An alternative to disposal of waste PC2 will be analyzed in the improvement assessment phase of this analysis. Paint chips generated during the depainting operation are not within the scope of the study. It is assumed that about the same amount will be generated and they will be handled as they were when MEK was used for depainting.

In this study, solid waste is presented in units of weight. All solid waste reported in this study is industrial waste. A constant density factor of 50 pounds per cubic foot can be used to convert the weight of industrial waste generated to landfill volume.

The industrial solid waste by weight for each scenario is displayed by system component in Table 4-1 and Figure 4-1. The production of the three chemicals comprising the PC2 together contribute about 60 percent of the total solid waste generated. Of this amount, the NMP, DBE, and PC each generate about 50, 31, and 20 percent respectively, of the industrial solid waste from production. The blending operation contributes about 11 percent of the total solid waste. The PC2 use component includes fuel-related solid wastes from electricity use at TAFB for the depainting operation and represents about 30 percent of the total solid waste. The PC2 disposal component is comprised of fuel-related solid wastes from transportation of PC2 to the combustion facility and contributes less than one percent to the overall solid waste production. More detailed solid waste results for depainting 10 KC-135 radomes are shown in Table 4-2 and Figure 4-2. Here, total solid wastes are disaggregated by the system categories: industrial process wastes and industrial fuel-related wastes. Process solid wastes are wastes produced as a result of the process steps within the product life cycle. For example, wastewater treatment sludge that is produced at a plant and sent to a landfill is process solid waste. Fuel-related solid

Source: Franklin Associates, Ltd.
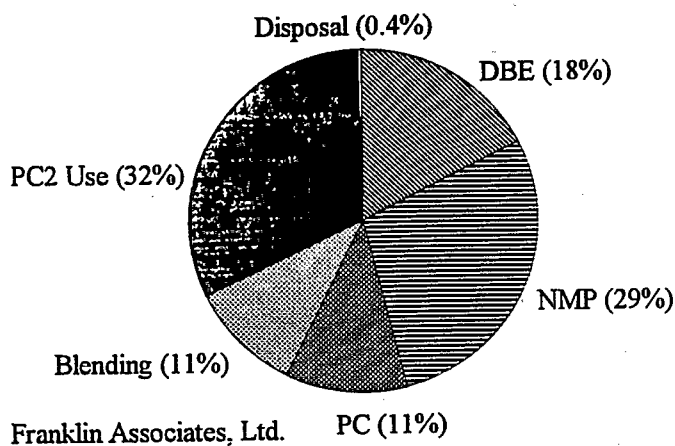
Figure 4-1. LCI solid waste profile by component for PC Blend 2 radome depainting solvent (In percent).

Table 4-1. Life Cycle Inventory of Solid Wastes by Usage Scenario for PC Blend 2 Radome Depainting Solvent (In pounds)

	Per Ten (10) KC-135 Aircraft Radomes (1)	Per Ten (10) B-52 Aircraft Radomes (2)	Per Annual Usage at TAFB (3)
Dibasic Ester (DBE)	14.2	23.3	235
N-Methyl-Pyrrolidone (NMP)	22.9	37.6	380
Propylene Carbonate (PC)	9.2	15.0	152
Subtotal *	46.3	75.8	766
PC2 Blending	8.7	14.2	143
PC2 Use at TAFB ^	25.4	25.4	356
PC2 Disposal Off-Site	0.060	0.099	1.0
Total Solid Wastes	80.5	116	1,267

* Includes all solid wastes associated with raw materials acquisition and chemical processes required for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC).

^ Spent PC2 solvent is assumed to be incinerated as a hazardous waste off-site.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.
(2) Based on 180 gallons of PC2 used per ten B-52 aircraft radomes depainted.
(3) Based on 100 KC-135 and 40 B-52 aircraft radomes depainted annually.

Source: Franklin Associates, Ltd.

Process Waste (6%)

Fuel Related Waste (94%)
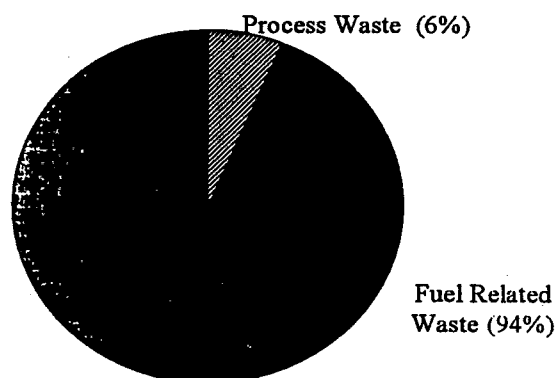
Source: Franklin Associates, Ltd.

Figure 4-2. LCI solid waste profile by category for PC Blend 2 radome depainting solvent (In percent).

Table 4-2. Life Cycle Inventory of Solid Wastes by Component for PC Blend 2 Radome Depainting Solvent (In pounds and percent)

	Per Ten KC-135 Aircraft Radomes Depainted (1)			
	Process-Related	Fuel-Related	Total Solid Wastes	Percent of Solid Wastes
Dibasic Ester (DBE)	3.0	11.2	14.2	18%
N-Methyl-Pyrrolidone (NMP)	1.4	21.5	22.9	29%
Propylene Carbonate (PC)	0.55	8.6	9.2	11%
*Subtotal**	5.0	41.4	46.3	58%
PC2 Blending	-	8.7	8.7	11%
PC2 Use at TAFB	-	25.4	25.4	32%
PC2 Disposal Off-Site^	-	0.060	0.060	0.1%
Total Solid Wastes	5.0	75.5	80.5	100%
Percent of Total Solid Wastes	6.2%	93.8%	100%	

* Includes all solid wastes associated with raw materials acquisition and chemical processes required for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC).

^ Spent PC2 solvent is assumed to be incinerated as a hazardous waste off-site.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

wastes are solid wastes that result from the combustion of fuels. Ash from coal used to generate electricity is an example of a fuel-related solid waste.

All PC2 used is assumed to be incinerated with the exception of an assumed 0.5 percent evaporative loss incurred during PC2 use. The evaporative loss is estimated from the difference in the vapor pressures between PC2 and MEK. The vapor pressure of PC2 is approximately 0.3 percent of the MEK vapor pressure. In this case, MEK is assumed to represent 100 percent evaporation, and a conservative evaporation rate of 0.5 percent is assumed for the PC Blend 2.

For the production of the chemical components of the blend, the fuel-related solid waste contributes about 90 percent of the total industrial solid waste.

Air Emissions
The total air emissions results for all three depainting scenarios are summarized in Table 4-3. More detailed breakdowns of the emissions are shown in Table 3-4 (process-related and fuel-related emissions) and Table 4-5 (emissions for each system component).

Air emissions totals, shown in Table 4-3, include both process and fuel-related atmospheric emissions. Because a large part of each emission is primarily dependent on the chemicals used, the emissions are generally proportionate to the amount of PC2 used for each scenario.

Atmospheric emissions for depainting ten KC-135 radomes are summarized in Table 4-4 with the fuel- and process-related portions shown separately. Fuel acquisition and combustion is a source of atmospheric aldehydes, ammonia, carbon monoxide, fossil carbon dioxide, hydrocarbons, hydrogen chloride, kerosene, lead, methane, nitrogen oxides, other organics, particulate emissions, and sulfur oxides. Kerosene emissions arise during the uranium milling step where kerosene is used in solvent extraction of uranium ore for the production of uranium concentrate (yellow cake). Although not considered a pollutant, the amount of carbon dioxide that is emitted is also shown. Portions of these emissions categories may also come from process emissions. The majority of the carbon dioxide and nitrogen oxide emissions are given off during incineration of the spent PC2.

Process aldehyde emissions come from petroleum refining operations. Ammonia emissions are due to the manufacture of ammonia as an intermediate material, and also to the production of carbon dioxide. The carbon monoxide process emissions come primarily from formaldehyde production and also the operation to produce adipic acid. Hydrocarbon process emissions come primarily from natural gas and crude oil production and processing. The production of propylene oxide results in process isobutane and propylene oxide emissions. Process sulfur oxide emissions are primarily the result of natural gas processing.

Evaporative emissions for the PC2 are assumed to equal 0.5 percent of the total PC2 used, and are shown for each component of the blend. The evaporative loss is estimated from the difference in the vapor pressures between PC2 and MEK. The vapor pressure of PC2 is approximately 0.3 percent of the MEK vapor pressure. In this case, MEK is assumed to represent 100 percent evaporation, and a conservative evaporation rate of 0.5 percent is assumed for the PC Blend 2.

Total emissions for each of the systems components for depainting KC-135 radomes are shown in Table 4-5. The results for the DBE, NMP, and PC components include both process and fuel-related emissions. The emissions for PC Blend 2ing do not include any process emissions; only fuel-related emissions for utility requirements and transportation to TAFB are included. With the exception of DBE, NMP, and PC emissions, the results shown for PC2 use at TAFB include only fuel-related emissions for the electricity used in the depainting operation. The DBE, NMP, and PC emissions are evaporative emissions for the PC Blend 2 (assumed to equal 0.5 percent of the total PC2 used). The results for PC2 disposal include fuel related emissions for transportation and calculated process emissions of nitrogen oxides and carbon dioxide (which are given off during combustion of spent PC2).

Table 4-3. Life Cycle Inventory of atmospheric Emissions by Usage Scenario for PC Blend 2 Radome Depainting Solvent* (In pounds)

Atmospheric Emission	Per Ten (10) KC-135 Aircraft Radomes (1)	Per Ten (10) B-52 Aircraft Radomes (2)	Per Annual Usage at TAFB (3)
Aldehydes	0.058	0.095	0.96
Ammonia	0.43	0.70	7.1
Carbon Dioxide‡	4,415	7,088	72,503
Carbon Monoxide	21.2	34.6	350
Chlorine	9.9E-05	1.6E-04	0.0016
Dibasic Ester (DBE) †	1.2	2.0	20.5
Hydrocarbons	46.6	76.1	771
Hydrogen Chloride	7.2E-05	1.2E-04	0.0012
Isobutane	0.82	1.3	13.5
Kerosene	2.0E-04	2.8E-04	0.0031
Lead	1.9E-04	2.8E-04	0.0030
Mercury	4.4E-05	7.2E-05	7.3E-04
Methane	0.040	0.065	0.67
N-Methyl-Pyrrolidone (NMP) †	2.5	4.1	41.0
Nitrogen Oxides‡	235	384	3,888
Other Organics	0.53	0.86	8.7
Particulates	1.3	2.0	21.1
Propylene	0.080	0.13	1.3
Propylene Carbonate (PC) †	1.2	2.0	20.5
Propylene Oxide	0.039	0.064	0.65
Sulfur Oxides	8.0	11.9	128

* Includes all process and fuel related atmospheric emissions associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, and PC2 use at TAFB.

† Represents estimated atmospheric emissions at TAFB assuming 0.5 percent evaporative loss of PC2 blend during aircraft radome depainting.

‡ Includes emissions from incineration of spent PC2.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.
(2) Based on 180 gallons of PC2 used per ten B-52 aircraft radomes depainted.
(3) Based on 100 KC-135 and 40 B-52 aircraft radomes depainted annually.

Table 4-4. Life Cycle Inventory of Atmospheric Emissions by Component for PC Blend 2 Radome Depainting Solvent* (In pounds)

Atmospheric Emission	Per Ten KC-135 Aircraft Radomes Depainted (1)		
	Process-Related	Fuel-Related	Total Atmospheric Emissions
Aldehydes	0.022	0.036	0.058
Ammonia	0.43	4.1E-04	0.43
Carbon Dioxide‡	1,986	2,429	4,415
Carbon Monoxide	18.4	2.8	21.2
Chlorine	8.3E-05	1.6E-05	9.9E-05
Dibasic Ester (DBE) †	1.2	-	1.2
Hydrocarbons	28.8	17.8	46.6
Hydrogen Chloride	6.0E-05	1.2E-05	7.2E-05
Isobutane	0.82	-	0.82
Kerosene	-	2.0E-04	2.0E-04
Lead	5.6E-07	1.9E-04	1.9E-04
Mercury	4.4E-05	-	4.4E-05
Methane	-	0.040	0.040
N-Methyl-Pyrrolidone (NMP) †	2.5	-	2.5
Nitrogen Oxides‡	229	6.0	235
Other Organics	-	0.53	0.53
Particulates	0.033	1.3	1.3
Propylene	0.080	-	0.080
Propylene Carbonate (PC) †	1.2	-	1.2
Propylene Oxide	0.039	-	0.039
Sulfur Oxides	1.2	6.8	8.0

* Includes all process and fuel related atmospheric emissions associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, and PC2 use at TAFB.

† Represents estimated atmospheric emissions at TAFB assuming 0.5 percent evaporative loss of PC2 blend during aircraft radome depainting.

‡ Includes emissions from incineration of spent PC2.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

Table 4-5. Life Cycle Inventory of Atmospheric Emissions by Process for PC Blend 2 Radome Depainting Solvent (In pounds)

Atmospheric Emission	Per Ten KC-135 Aircraft Radomes Depainted (1)						
	Dibasic Ester * (DBE)	N-Methyl-Pyrrolidone (NMP)	Propylene Carbonate * (PC)	PC2 Blending	PC2 Us at TAFB ^	PC2 Disposal	Total Atmospheric Emissions
Aldehydes	0.021	0.023	0.0070	0.0012	4.0E-04	0.0051	0.058
Ammonia	0.065	0.26	0.11	1.1E-05	1.4E-05	3.4E-05	0.43
Carbon Dioxide‡	589	1,148	381	77.6	215	2,005	4,415
Carbon Monoxide	1.8	18.5	0.42	0.11	0.22	0.19	21.2
Chlorine	4.3E-05	4.4E-05	9.6E-06	4.5E-07	5.3E-07	1.3E-06	9.9E-05
Dibasic Ester (DBE) †	-	-	-	-	1.2	0	1.2
Hydrocarbons	8.5	30.1	7.5	0.12	0.30	0.083	46.6
Hydrogen Chloride	3.0E-05	3.3E-05	7.2E-06	3.4E-07	4.0E-07	9.9E-07	7.2E-05
Isobutane	-	-	0.82	-	-	-	0.82
Kerosene	2.0E-05	6.0E-05	2.3E-05	2.4E-05	7.1E-05	9.5E-08	2.0E-04
Lead	3.5E-05	5.0E-05	3.3E-05	1.8E-05	5.3E-05	1.7E-07	1.9E-04
Mercury	4.4E-05	-	-	-	-	-	4.4E-05
Methane	0.011	0.022	0.0062	4.6E-04	0.0013	2.7E-05	0.040
N-Methyl-Pyrrolidone (NMP) †	-	-	-	-	2.5	0	2.5
Nitrogen Oxides‡	1.5	2.6	0.86	0.36	0.94	229	235
Other Organics	0.095	0.22	0.085	0.021	0.0023	0.10	0.53
Particulates	0.24	0.42	0.16	0.13	0.35	0.027	1.3
Propylene	-	-	0.080	-	-	-	0.080
Propylene Carbonate (PC) †	-	-	-	-	1.2	0	1.2
Propylene Oxide	-	-	0.039	-	-	-	0.039
Sulfur Oxides	1.4	3.0	1.1	0.63	1.8	0.037	8.0

* Includes all process and fuel related atmospheric emissions associated with raw materials acquisition and chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC).

† Represents estimated atmospheric emissions at TAFB assuming 0.5 percent evaporative loss of PC2 blend during aircraft radome depainting.

^ Atmospheric emissions associated with the generation of electricity used at TAFB for depainting aircraft radomes is also included.

‡ Includes emissions from incineration of spent PC2. 229 pounds of the carbon dioxide and 1,983 pounds of the nitrogen oxide emissions are calculated emissions for the incineration of the spent PC2 blend.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

Waterborne Emissions

Total waterborne emissions for all three depainting scenarios are summarized in Table 4-6. More detailed breakdowns of the emissions are shown in Table 4-7 (process-related and fuel-related emissions) and Table 4-8 (emissions for each system component).

Total emissions for the three usage scenarios are shown in Table 4-6. These totals include both process and fuel-related waterborne emissions. As was shown for the atmospheric emissions, the emissions are generally proportionate to the amount of PC2 used for each scenario.

Waterborne emissions for depainting ten KC-135 radomes are summarized in Table 4-7 with the fuel- and process-related portions shown separately. Fuel acquisition and combustion is a source of waterborne acid, ammonia, BOD, chromium, COD, dissolved solids, iron, lead, metal ion, oil, phenol, sulfuric acid, suspended solids, and zinc emissions. Portions of these emissions categories may also come from process emissions.

Process acid emissions come primarily from the process to make benzene, an intermediate for the DBE. Manufacture of ammonia, hydrogen, carbon dioxide, and petroleum refinery operations are all sources of process ammonia emissions. Process BOD emissions occur during the production of ammonia, methanol, and the nitric acid intermediates for DBE. Chromium, phenol, zinc, and COD process emissions come from petroleum refinery operations. The production of ammonia also produces COD emissions. Dissolved solids are produced primarily from the refined petroleum products, but some also come from the production of sodium hydroxide used in the manufacture of DBE. Sodium hydroxide production also results in mercury, zinc, and nickel emissions. Process metal ion emissions come from petroleum products refining. Process oil emissions are a result of crude oil and natural gas production and petroleum products refining. Sulfide process emissions are reported for benzene and sodium hydroxide production. The processes to make ammonia, methanol, and refinery operations are the sources of suspended solids emissions.

Total waterborne emissions for each of the system components for depainting KC-135 radomes are shown in Table 4-8. The results for the DBE, NMP, and PC components include both process and fuel-related emissions. The emissions for PC Blend 2ing do not include any process emissions; only fuel-related emissions for utility requirements and transportation to TAFB are included. The results shown for PC2 use at TAFB include only fuel-related emissions for the electricity used in the depainting operation. The depainting operation does not generate any wastewater. The emissions for PC2 disposal contain only fuel related emissions for the transportation of spent PC2 to the incineration facility.

Table 4-6. Life Cycle Inventory of Waterborne Wastes by Usage Scenario for PC Blend 2 Radome Depainting Solvent* (In pounds)

Waterborne Wastes	Per Ten (10) KC-135 Aircraft Radomes (1)	Per Ten (10) B-52 Aircraft Radomes (2)	Per Annual Usage at TAFB (3)
Acid	0.0026	0.0042	0.042
Ammonia	0.026	0.043	0.44
BOD	0.076	0.12	1.3
Chromium	3.4E-05	5.5E-05	5.6E-04
COD	0.098	0.16	1.6
Dissolved Solids	0.54	0.88	8.9
Iron	0.11	0.16	1.8
Lead	9.6E-07	1.6E-06	1.6E-05
Mercury	2.2E-08	3.7E-08	3.7E-07
Metal Ion	0.011	0.018	0.19
Nickel	1.2E-08	2.0E-08	2.1E-07
Oil	0.071	0.12	1.2
Phenol	5.2E-05	8.6E-05	8.7E-04
Sulfides	0.0011	0.0017	0.017
Sulfuric Acid	0.46	0.65	7.1
Suspended Solids	0.086	0.14	1.4
Zinc	1.4E-05	2.3E-05	2.3E-04

* Includes all process and fuel related waterborne wastes associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, and PC2 use at TAFB.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.
(2) Based on 180 gallons of PC2 used per ten B-52 aircraft radomes depainted.
(3) Based on 100 KC-135 and 40 B-52 aircraft radomes depainted annually.

Source: Franklin Associates, Ltd.

Table 4-7. Life Cycle Inventory of Waterborne Wastes by Component for PC Blend 2 Radome Depainting Solvent* (In pounds)

	Per Ten KC-135 Aircraft Radomes Depainted (1)		
Waterborne Wastes	Process-Related	Fuel-Related	Total Waterborne Wastes
Acid	0.0026	9.0E-08	0.0026
Ammonia	0.026	1.4E-04	0.026
BOD	0.075	0.0011	0.076
Chromium	3.3E-05	3.6E-07	3.4E-05
COD	0.093	0.0052	0.098
Dissolved Solids	0.46	0.074	0.54
Iron	1.6E-04	0.11	0.11
Lead	8.0E-07	1.6E-07	9.6E-07
Mercury	2.2E-08	-	2.2E-08
Metal Ion	0.0094	0.0019	0.011
Nickel	1.2E-08	-	1.2E-08
Oil	0.065	0.0062	0.071
Phenol	4.6E-05	6.2E-06	5.2E-05
Sulfides	0.0011	-	0.0011
Sulfuric Acid	-	0.46	0.46
Suspended Solids	0.085	0.0010	0.086
Zinc	1.2E-05	2.3E-06	1.4E-05

* Includes all process and fuel related waterborne wastes associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, and PC2 use at TAFB.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

Table 4-8. Life Cycle Inventory of Waterborne Wastes by Process for PC Blend 2 Radome Depainting Solvent (In pounds)

Waterborne Wastes	Per Ten KC-135 Aircraft Radomes Depainted (1)						
	Dibasic Ester * (DBE)	N-Methyl-Pyrrolidone * (NMP)	Propylene Carbonate * (PC)	PC2 Blending	PC2 Use at TAFB ^	PC2 Disposal	Total Waterborne Wastes
Acid	0.0026	2.4E-07	5.3E-08	2.5E-09	2.9E-09	7.3E-09	0.0026
Ammonia	0.0042	0.016	0.0065	4.0E-06	4.7E-06	1.2E-05	0.026
BOD	0.0097	0.065	6.5E-04	3.0E-05	3.6E-05	9.0E-05	0.076
Chromium	3.3E-05	9.7E-07	2.1E-07	9.8E-09	1.2E-08	2.9E-08	3.4E-05
COD	0.033	0.061	0.0031	1.4E-04	1.8E-04	4.2E-04	0.098
Dissolved Solids	0.28	0.20	0.044	0.0020	0.0024	0.0060	0.54
Iron	0.017	0.032	0.013	0.013	0.038	5.4E-05	0.11
Lead	4.0E-07	4.3E-07	1.0E-07	4.4E-09	5.2E-09	1.3E-08	9.6E-07
Mercury	1.2E-08	-	1.0E-08	-	-	-	2.2E-08
Metal Ion	0.0047	0.0052	0.0011	5.2E-05	6.2E-05	1.5E-04	0.011
Nickel	6.6E-09	-	5.8E-09	-	-	-	1.2E-08
Oil	0.050	0.018	0.0031	1.1E-04	1.5E-04	2.8E-04	0.071
Phenol	3.1E-05	1.7E-05	3.6E-06	1.7E-07	2.0E-07	5.0E-07	5.2E-05
Sulfides	0.0011	-	-	-	-	-	0.0011
Sulfuric Acid	0.069	0.13	0.051	0.052	0.15	2.0E-04	0.46
Suspended Solids	0.010	0.075	6.0E-04	2.8E-05	3.4E-05	8.2E-05	0.086
Zinc	5.8E-06	6.3E-06	1.4E-06	6.4E-08	7.6E-08	1.9E-07	1.4E-05

* Includes all process and fuel related waterborne wastes associated with raw materials acquisition and chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC).

^ Represents waterborne wastes associated with the generation of electricity used at TAFB for depainting aircraft radomes.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

Chapter 5
Sensitivity Analyses

Introduction

This chapter examines the sensitivity of energy and emissions results to changes in major assumptions concerning the use and disposal of PC Blend 2. As described earlier in the report, the use of PC2 has been very limited thus far. Therefore, the parameters around the use of PC2 may be quite different than assumed in the baseline scenario. The scenarios in this chapter are chosen to illustrate the effects of changes in the major assumptions. The results from the sensitivity analyses will be used for the partial impact assessment and improvement analysis portions of this study.

Systems Examined

A number of alternative PC2 use and waste management scenarios are evaluated in this chapter. The depainting of KC-135 radomes was chosen as the baseline scenario because the KC-135 is the predominant radome processed at TAFB. Detailed results for the baseline are presented in Chapters 3 and 4 of this report. The baseline and alternative scenarios are described below.

- **Baseline PC2 Use Scenario**

  10 KC-135 radomes depainted
  110 gallons PC2 required for 10 radomes
  Each radome is showered continuously for 2 hours
  Disposal of spent PC Blend 2 is by incineration (without energy recovery)

- **Alternative Waste Management Scenario**

  Recycling of spent PC Blend 2

- **Alternative PC2 Use Scenarios**

  Varying volume of PC2 required (plus or minus 20 percent)
  Varying yield of radomes per PC2 volume (five radomes to 20 radomes per 110 gallons)
  Varying time required (one hour to four hours per radome)

Each of the PC2 usage and waste management scenarios evaluated include all of the life cycle steps, from raw materials acquisition through final disposal of the spent PC Blend 2.

Following the format used in Chapter 3, the energy requirements for PC Blend 2 are presented in this chapter on the basis of the various usage scenarios. The energy requirements include: process energy, transportation energy, and energy of material resource. Energy of material resource is the inherent energy of a raw material, such as natural gas or petroleum, when used as a material feedstock.

Energy requirements are presented for each of the system components including the three chemical products comprising PC Blend 2 (i.e., DBE, NMP, PC). These energy requirements include all processing steps up to and including the actual production of DBE, NMP, and PC. Thus, all raw material acquisition and intermediate chemical processing steps are included in these values. In addition, PC Blend 2ing, recycling, use, and disposal are shown as separate components.

All energy results are presented on the basis of million Btu and include both precombustion and combustion energy. Precombustion energy refers to the energy required to extract, transport, and process fuels into a usable form (e.g., refining crude oil into gasoline). Combustion energy refers to energy content of the process and transport fuels consumed.

The environmental emissions examined in this study include solid wastes, atmospheric emissions, and waterborne wastes. Each of these wastes is examined separately. The total emission results for each scenario include both process-related emissions and fuel-related emissions. Although this life cycle inventory identifies emissions, it makes no attempt to quantify the effects on the environment or human health due to these wastes.

Waste Management Alternative: Recycling of Spent PC2

In a recycling system, a material is diverted from disposal by its unlimited recycling or reuse. For example, glass from glass bottles is recycled and fabricated into bottles again. Since recycling of the same material can occur over and over, it theoretically may be permanently diverted from disposal. Figure 5-1 presents a graphical description of how individual processes can be viewed in a recycle loop system. This figure illustrates that, at the ideal 100 percent recycling rate, the energy requirements and environmental emissions from the virgin raw material acquisition/processing (sometimes referred to as "back-end" steps) and disposal become negligible. In contrast, if recycling does not occur, then virgin raw materials must be acquired and processed, and disposal of the waste must occur each time a product is produced.

The recycle of spent PC Blend 2 can be viewed as a recycle loop process. The solvent components that are recovered by distillation from the spent solution can theoretically be re-blended and re-used. It is recognized that the components may begin to chemically break down with continuous recycle and reuse. Therefore, it is uncertain how many times the fluid can

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Recycle loop system at 100 percent recycling
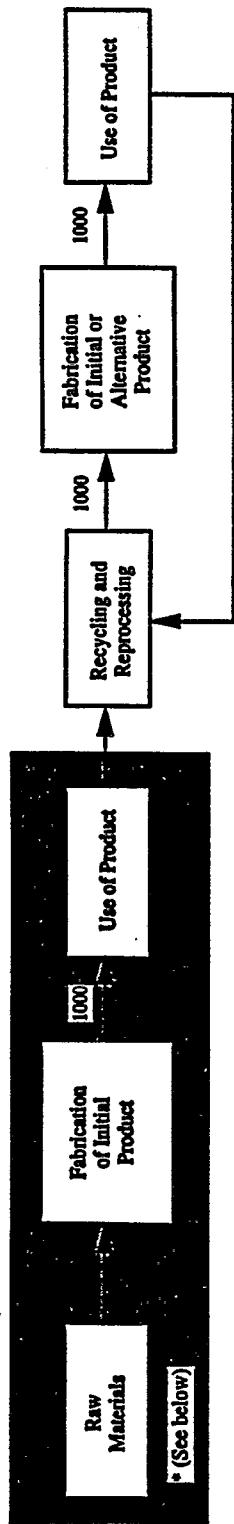
Independent view of the virgin systems at 0 percent recycling
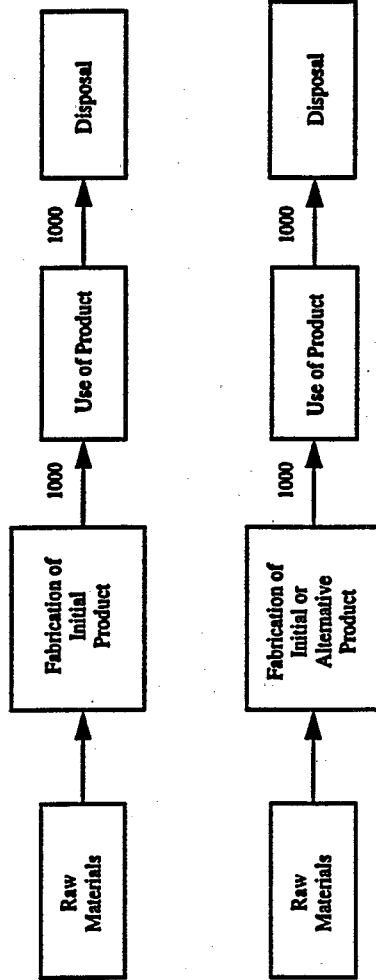
Figure 5-1. Illustration of recycling system in comparison to each virgin system independently.

*Note: In a recycle loop system, since the materials is recycled many time, the energy and emissions of the initial virgin system manufacturing steps are divided between all of the many products made from the that original material. Consequently, these initial effects become negligible, and the only effects associated with recycled material are those which result from the recycling process and any subsequent processes such as fabrication.

be recycled. To simplify the analysis, the recycling of spent PC Blend 2 is assumed to occur again and again in a recycle loop. It is assumed that a recovery of approximately 85 percent can be achieved with the recycling process. The 15 percent lost could either be at TAFB (adhering to waste paint chips or absorbed in the cloth filter) or during distillation. The amount lost is assumed to be ultimately incinerated as hazardous waste. Virgin PC, DBE, and NMP must be us to make up for the 15 percent loss each time the spent PC2 is recycled and also the 0.5 percent evaporative loss assumed to occur during the use of PC2.

Recycling of spent PC2 may or may not be technically feasible. No experience exists to determine the practical feasibility of this option. A pilot batch run would need to successfully demonstrate fractional distillation can be achieved. In addition, the pilot batch run could determine whether any contaminants present in the waste PC2 could be easily handled by the recycler.

Recycling Results And Discussion

Energy Requirements

Table 5-1 presents total energy requirements for PC Blend 2 aircraft radome depainting solvent for the baseline and recycle loop scenarios. These results include all energy use associated with raw materials acquisition, chemical processes for producing the three components (DBE, NMP, PC) comprising PC Blend 2, PC Blend 2ing, and PC2 use and disposal for depainting radomes at TAFB. The energy for producing the three components is to make up for the 15 percent recycling loss plus the 0.5 percent evaporative emissions. The three components of PC2 are shown separately to show their separate contribution to the total. For instance, although DBE comprises 25 percent by weight of the PC2, its energy contribution is over 40 percent of the PC2 subtotal. The recycled system results include the energy for transporting the spent PC2 to a theoretical recycler in Texas, distilling the waste solvent blend, re-blending the components, and transporting the recycled PC2 back to TAFB for another use. The PC2 lost in the recycle loop is assumed to ultimately be transported to a hazardous waste incineration facility for disposal.

By recycling the spent PC2, the total energy requirements are reduced to about 25 percent of the baseline scenario. Most of the reduction comes from decreased process and energy of material resource requirements in the back-end steps for producing the DBE, PC and NMP components of the blend. The energy for disposal of waste is also drastically reduced to about 15 percent of the baseline amount. The energy for distilling the spent PC2 is about 25 percent of the total energy for the recycled system.

Solid Waste

Table 5-2 presents total solid waste generation for the baseline and recycle loop scenarios. These results include all solid waste associated with raw materials acquisition, chemical processes for producing the three components comprising PC Blend 2 (i.e., DBE, NMP, PC), PC Blend 2,

and PC2 use and disposal for depainting radomes at TAFB. The solid waste for producing the three components is to make up for the 15 percent recycling loss plus the 0.5 percent evaporative emissions. The three components of PC2 are shown separately to show their separate

Table 5-1. Life Cycle Inventory of Energy Requirements with and without Recycling of PC Blend 2 Radome Depainting Solvent (In million Btu per 10 KC-135 aircraft radomes depainted)

	Baseline results (1)	Results with 100 percent recycling (1)
Dibasic Ester (DBE)	9.8	1.5
N-Methyl-Pyrrolidone (NMP)	23.8	3.6
Propylene Carbonate (PC)	6.7	1.0
Subtotal *	40.3	6.2
PC2 Distillation	-	2.7
PC2 Blending	0.54	0.54
PC2 Use at TAFB	1.5	1.5
PC2 Disposal Off-Site^	0.15	0.023
Total Energy	42.5	10.9

* Includes all energy use associated with raw materials acquisition and chemical processes required for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC). For the recycling system, includes production of PC2 blend to make up for 15 percent loss assumed in recycling and 0.5 percent evaporative loss assumed in use operation.

^ Spent PC2 Solvent is assumed to be incinerated as hazardous waste off-site.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

contribution to the total. For instance, although DBE comprises 25 percent by weight of the PC2, its contribution to solid waste is over 30 percent of the PC2 subtotal.

Total solid waste generation is decreased by about 50 percent for the recycled system when compared to the baseline system. The reduction of fuel and process-related solid wastes associated with producing the three components of the PC Blend 2 is primarily responsible for this reduction. However, a small increase in fuel-related solid waste results from the distillation process and additional transportation to and from the recovery facility.

Table 5-2. Life Cycle Inventory of Solid Wastes with and without Recycling of PC Blend 2 Radome Depainting Solvent (In pounds per 10 KC-135 aircraft radomes depainted)

	Baseline results (1)	Results with 100 percent recycling (1)
Dibasic Ester (DBE)	14.2	2.2
N-Methyl-Pyrrolidone (NMP)	22.9	3.5
Propylene Carbonate (PC)	9.2	1.4
Subtotal *	46.3	7.1
PC2 Distillation	-	0.60
PC2 Blending	8.7	8.7
PC2 Use at TAFB	25.4	25.4
PC2 Disposal Off-Site^	0.060	0.0091
Total Solid Wastes	80.5	41.9

* Includes all solid wastes associated with raw materials acquisition and chemical processes required for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC). For the recycling system, includes production of PC2 blend to make up for 15 percent loss assumed in recycling and 0.5 percent evaporative loss assumed in use operation.

^ Spent PC2 Solvent is assumed to be incinerated as hazardous waste off-site.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

Atmospheric Emissions

Table 5-3 presents atmospheric emissions results for PC Blend 2 aircraft radome depainting solvent for the baseline and recycle loop scenarios. These results include all emissions associated with raw materials acquisition, chemical processes for producing the three components comprising PC Blend 2 (i.e., DBE, NMP, PC), PC Blending 2 and PC2 use and disposal for depainting radomes at TAFB.

All but four emission categories show a dramatic reduction in emissions for the recycled system. The exceptions are dibasic ester, propylene carbonate, and n-methyl-pyrrolidone (the three components of PC Blend 2), and other organics. The three PC Blend 2 components are the estimated atmospheric emissions during the PC2 use step at TAFB, and are assumed to remain unchanged with the use of recycled PC2. The "other organics" emissions increase for the recycled system because they are primarily related to additional transportation fuel pollutants produced when spent PC2 is transported to and from Texas for recovery.

Table 5-3. Life Cycle Inventory of Atmospheric Emissions with and without Recycling of PC Blend 2 Radome Depainting Solvent* (In pounds per 10 KC-135 aircraft radomes depainted)

Atmospheric Emission	Baseline results (1)	Results with 100 percent recycling (1)
Aldehydes	0.058	0.039
Ammonia	0.43	0.066
Carbon Dioxide‡	4,415	1,251
Carbon Monoxide	21.2	4.7
Chlorine	9.9E-05	2.4E-05
Dibasic Ester (DBE) †	1.2	1.2
Hydrocarbons	46.6	10.1
Hydrogen Chloride	7.2E-05	1.7E-05
Isobutane	0.82	0.13
Kerosene	2.0E-04	1.1E-04
Lead-	1.9E-04	9.1E-05
Mercury	4.4E-05	6.8E-06
Methane	0.040	0.013
N-Methyl-Pyrrolidone (NMP) †	2.5	2.5
Nitrogen Oxides‡	235	37.7
Other Organics	0.53	0.68
Particulates	1.3	0.78
Propylene	0.080	0.012
Propylene Carbonate (PC) †	1.2	1.2
Propylene Oxide	0.039	0.0060
Sulfur Oxides	8.0	3.7

* Includes all process and fuel related atmospheric emissions associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, PC2 use at TAFB, and disposal of spent PC2 by incineration. For the recycling system, includes production of PC2 blend to make up for 15 percent loss assumed in recycling and 0.5 percent evaporative loss assumed in use operation.

† Represents estimated atmospheric emissions at TAFB assuming 0.5 percent evaporative loss of PC2 blend during aircraft radome depainting.

‡ Includes emissions from incineration of spent PC2.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

Waterborne Emissions

Table 5-4 presents waterborne emissions for PC Blend 2 aircraft radome depainting solvent for the baseline and recycle loop scenarios. These results include all emissions associated with raw materials acquisition, chemical processes for producing the three components comprising PC Blend 2 (i.e., DBE, NMP, PC), PC Blending 2 and PC2 use and disposal for depainting radomes at TAFB.

Without exception, all waterborne emissions show a dramatic reduction in emissions for the recycle loop system.

Table 5-4. Life Cycle Inventory of Waterborne Wastes with and without Recycling of PC Blend 2 Radome Depainting Solvent* (In pounds per 10 KC-135 aircraft radomes depainted)

Waterborne Wastes	Baseline results (1)	Results with 100 percent recycling (1)
Acid	0.0026	3.9E-04
Ammonia	0.026	0.0041
BOD	0.076	0.012
Chromium	3.4E-05	5.4E-06
COD	0.098	0.018
Dissolved Solids	0.54	0.12
Iron	0.11	0.062
Lead	9.6E-07	2.3E-07
Mercury	2.2E-08	3.5E-09
Metal Ion	0.011	0.0027
Nickel	1.2E-08	1.9E-09
Oil	0.071	0.013
Phenol	5.2E-05	1.1E-05
Sulfides	0.0011	1.6E-04
Sulfuric Acid	0.46	0.25
Suspended Solids	0.086	0.014
Zinc	1.4E-05	3.3E-06

*   Includes all process and fuel related atmospheric emissions associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, PC2 use at TAFB, and disposal of spent PC2 by incineration. For the recycling system, includes production of PC2 blend to make up for 15 percent loss assumed in recycling and 0.5 percent evaporative loss assumed in use operation.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

PC2 Use Alternatives-Volume, Yield, And Time Sensitivity

The results of this study are heavily dependent on the assumptions regarding material requirements and use parameters for PC2 at TAFB. By far the most critical assumption is the amount of PC2 required to depaint each radome. The personnel at Tinker provided the assumption that approximately 110 gallons of PC Blend 2 would be required to depaint 10 KC-135 radomes.

The depainting process involves continuous showering of the radome with PC Blend 2. It has been estimated that two hours of continuous showering will be required. During the depainting operation, the PC Blend 2 flows over the surface of the radome, passes through a cloth filter, and returns to a reservoir under the depainting area. The PC2 is then recirculated and re-used until Tinker personnel determine that the blend contains excessive contamination, or becomes ineffective in removing the paint. With no full-scale production experience, the amount of PC2 required may be either under-estimated or over-estimated.

The baseline assumption for the KC-135 radomes is that a volume of 110 gallons will depaint 10 radomes. This assumption is varied in two ways for this sensitivity analysis. First, the volume required (110 gallons) is varied by plus or minus 20 percent (88 gallons to 132 gallons per 10 KC-135 radomes). Next, the yield of radomes depainted is first halved and then doubled for a fixed volume of 110 gallons of PC2. In other words, the 110 gallons is assumed to yield only 5 radomes or as many as 20 radomes.

Another sensitivity analysis was performed to determine the sensitivity of the overall results to the amount of time required for each depainting process. The time assumed for the baseline was two hours per radome. In this sensitivity analysis, the time was bracketed with results for a one hour processing time and results for a four hour processing time.

Results And Discussion

Energy Requirements

Table 5-5 presents total energy requirements for PC Blend 2 aircraft radome depainting solvent for the baseline and each of the volume, yield, and time scenarios. These results include all energy use associated with raw materials acquisition, chemical processes for producing the three components comprising PC Blend 2 (i.e., DBE, NMP, PC), PC Blend 2 and PC2 use and disposal for depainting radomes at TAFB.

As shown in Table 5-5, the energy results are very sensitive to any changes in the volume and yield assumptions. An increase or decrease in volume required brings about a proportional increase or decrease in the energy required for the PC Blend 2. Similarly an increase or decrease in yield affects the volume required per radome. Again, the increase or decrease in energy requirements is approximately proportional to the volume change.

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Changes in the time required for depainting do not have as great an effect on the results. This is simply because the energy for the use component is only about three percent of the total energy in the baseline.

Table 5-5. Life Cycle Inventory of Energy Requirements Showing Sensitivity to PC2 use Assumptions* (In million Btu per 10 KC-135 aircraft radomes depainted)

| | Baseline results (1) | Varying volume required | | Varying radome yield | | Varying depainting time | |
		plus 20%	minus 20%	5 per 110 gallons	20 per 110 gallons	1 hour per radome	4 hours per radome
Dibasic Ester (DBE)	9.8	11.8	7.9	19.6	4.9	9.8	9.8
N-Methyl-Pyrrolidone (NMP)	23.8	28.5	19.0	47.5	11.9	23.8	23.8
Propylene Carbonate (PC)	6.7	8.0	5.4	13.4	3.4	6.7	6.7
Subtotal *	40.3	48.3	32.2	80.6	20.1	40.3	40.3
PC2 Blending	0.54	0.65	0.43	1.1	0.27	0.54	0.54
PC2 Use at TAFB	1.5	1.5	1.5	1.5	1.5	0.75	3.0
PC2 Disposal off-site^	0.15	0.18	0.12	0.30	0.076	0.15	0.15
Total Energy	42.5	50.7	34.3	83.4	22.0	41.7	44.0

* Includes all energy use associated with raw materials acquisition and chemical processes required for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC).

^ Spent PC2 solvent is assumed to be incinerated as hazardous waste off-site.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted and 2 hours depainting time.

Source: Franklin Associates, Ltd.

Solid Waste

Table 5-6 presents total solid waste generation for PC Blend 2 aircraft radome depainting solvent for the baseline and each of the volume, yield, and time scenarios. These results include all solid waste associated with raw materials acquisition, chemical processes for producing the three components comprising PC Blend 2 (i.e., DBE, NMP, PC), PC Blend 2, and PC2 use and disposal for depainting radomes at TAFB.

As with the energy results, the total solid waste is quite sensitive to assumptions regarding volume of PC2 required per radome. Because over 60 percent of the solid waste is due to the production of the components (DBE, PC, and NMP) and blending of the PC2, any change in the amount of PC2 required per radome has a substantial effect on the results.

Because the process energy used at TAFB is electricity, changes in the processing time (thus, electricity requirements) result in substantial changes in electricity related fuel pollutants. The dramatic changes in solid waste which result from variations in process time are due primarily to solid waste from electricity generating plants (ash from coal).

Table 5-6. Life Cycle Inventory of Solid Wastes Showing Sensitivity to PC2 use Assumptions* (In pounds per 10 KC-135 aircraft radomes depainted)

| | Baseline results (1) | Varying volume required | | Varying radome yield | | Varying depainting time | |
		plus 20%	minus 20%	5 per 110 gallons	20 per 110 gallons	1 hour per radome	4 hours per radome
Dibasic Ester (DBE)	14.2	17.1	11.4	28.4	7.1	14.2	14.2
N-Methyl-Pyrrolidone (NMP)	22.9	27.5	18.4	45.9	11.5	22.9	22.9
Propylene Carbonate (PC)	9.2	11.0	7.3	18.3	4.6	9.2	9.2
Subtotal *	46.3	55.6	37.1	92.7	23.2	46.3	46.3
PC2 Blending	8.7	10.4	6.9	17.3	4.3	8.7	8.7
PC2 Use at TAFB	25.4	25.4	25.4	25.4	25.4	12.7	50.9
PC2 Disposal Off-Site^	0.060	0.073	0.048	0.12	0.030	0.060	0.060
Total Solid Wastes	80.5	91.5	69.5	136	53.0	67.8	106

* Includes all solid wastes associated with raw materials acquisition and chemical processes required for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC).

^ Spent PC2 solvent is assumed to be incinerated as hazardous waste off-site.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted and 2 hours depainting time.

Source: Franklin Associates, Ltd.

Atmospheric Emissions

Table 5-7 presents atmospheric emissions results for PC Blend 2 aircraft radome depainting solvent for the baseline and each of the volume, yield, and time scenarios. These results include all emissions associated with raw materials acquisition, chemical processes for producing the three components comprising PC Blend 2 (i.e., DBE, NMP, PC), PC Blend 2ing, and PC2 use and disposal for depainting radomes at TAFB.

Increasing the volume of PC2 required results in increased emissions across the board, while decreasing the volume required results in decreased emissions. The decreases/increases in most cases are fairly proportionate to the change in PC2 required. This is because all the "back-end" steps have been changed proportionately. However some emissions categories are less sensitive to the PC2 requirements. For example, sulfur oxides, particulate emissions, kerosene (tied to its

use as a solvent for extraction of uranium concentrate from uranium ore), and lead emissions change to a lesser degree than the other emissions. This is a reflection of their close tie to electricity consumption at TAFB which remains unchanged as the volume is varied.

Table 5-7. Life Cycle Inventory of Atmospheric Emissions Showing Sensitivity of PC2 Use Assumptions* (In pounds per 10 Kc-135 aircraft radomes depainted)

Atmospheric Emission	Baseline results (1)	Varying volume required		Varying radome yield		Varying depainting time	
		plus 20%	minus 20%	5 per 110 gallons	20 per 110 gallons	1 hour per radome	4 hours per radome
Aldehydes	0.058	0.070	0.047	0.116	0.029	0.058	0.059
Ammonia	0.43	0.51	0.34	0.85	0.21	0.43	0.43
Carbon Dioxide ‡	4,415	5,255	3,575	8,615	2,315	4,308	4,630
Carbon Monoxide	21.2	25.4	17.0	42.2	10.7	21.1	21.4
Chlorine	9.9E-05	1.2E-04	7.9E-05	2.0E-04	5.0E-05	9.9E-05	9.9E-05
Dibasic Ester (DBE) †	1.2	1.5	1.0	2.5	0.62	1.24	1.24
Hydrocarbons	46.6	55.9	37.4	92.9	23.5	46.5	46.9
Hydrogen Chloride	7.2E-05	8.7E-05	5.8E-05	1.4E-04	3.6E-05	7.2E-05	7.3E-05
Isobutane	0.82	0.98	0.65	1.6	0.41	0.82	0.82
Kerosene	2.0E-04	2.2E-04	1.7E-04	3.3E-04	1.4E-04	1.6E-04	2.7E-04
Lead	1.9E-04	2.2E-04	1.6E-04	3.3E-04	1.2E-04	1.6E-04	2.4E-04
Mercury	4.4E-05	5.3E-05	3.5E-05	8.8E-05	2.2E-05	4.4E-05	4.4E-05
Methane	0.040	0.048	0.033	0.080	0.021	0.040	0.042
N-Methyl-Pyrrolidone (NMP) †	2.5	3.0	2.0	5.0	1.2	2.5	2.5
Nitrogen Oxides ‡	235.1	282.0	188.3	469.3	118.0	234.7	236.1
Other Organics	0.53	0.63	0.42	1.06	0.27	0.53	0.53
Particulates	1.3	1.5	1.1	2.3	0.84	1.16	1.68
Propylene	0.080	0.097	0.064	0.16	0.040	0.080	0.080
Propylene Carbonate (PC) †	1.2	1.5	1.0	2.5	0.62	1.24	1.24
Propylene Oxide	0.039	0.047	0.031	0.078	0.020	0.039	0.039
Sulfur Oxides	8.0	9.2	6.8	14.2	4.9	7.1	9.8

* Includes all process and fuel related atmospheric emissions associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, PC2 use at TAFB, and disposal of spent PC2 by incineration.

† Represents estimated atmospheric emissions at TAFB assuming 0.5 percent evaporative loss of PC2 blend during aircraft radome depainting.

‡ Includes emissions from incineration of spent PC2.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

Increasing the yield (less PC2 required per radome) results in decreased emissions across the board, while decreasing the yield (more PC2 required) results in increased emissions. Again, the changes in most cases are fairly proportionate to the change in PC2 required, although some emissions categories are less sensitive to the PC2 requirements.

The results for varying the amount of time required per radome are shown in the last two columns. A baseline depainting time of two hours was assumed. For these analyses, the depainting time was halved and doubled. The comparison shows that decreasing the time to one hour results in decreased emissions in almost every category, while increasing the time results in increased emissions. The differences seen are fairly small for most categories of emissions. However, sulfur oxides, particulates, kerosene, and lead emissions change to a greater degree than the other emissions. This is a reflection of their close tie to the electricity consumption at TAFB.

Waterborne Emissions

Table 5-8 presents waterborne emissions for PC Blend 2 aircraft radome depainting solvent for the baseline and each of the volume, yield, and time scenarios. These results include all emissions associated with raw materials acquisition, chemical processes for producing the three components comprising PC Blend 2 (i.e., DBE, NMP, PC), PC Blend 2, and PC2 use and disposal for depainting radomes at TAFB.

Table 5-8. Life Cycle Inventory of Waterborne Wastes Showing Sensitivity to PC2 Use Assumptions* (In pounds per 10 KC-135 aircraft depainted)

		Varying volume required		Varying radome yield		Varying depainting time	
Waterborne Wastes	Baseline results (1)	plus 20%	minus 20%	5 per 110 gallons	20 per 110 gallons	1 hour per radome	4 hours per radome
Acid	0.0026	0.0031	0.0020	0.0051	0.0013	0.0026	0.0026
Ammonia	0.026	0.032	0.021	0.053	0.013	0.026	0.026
BOD	0.076	0.091	0.061	0.15	0.038	0.076	0.076
Chromium	3.4E-05	4.1E-05	2.7E-05	6.8E-05	1.7E-05	3.4E-05	3.4E-05
COD	0.098	0.12	0.079	0.20	0.049	0.098	0.098
Dissolved Solids	0.54	0.64	0.43	1.1	0.27	0.53	0.54
Iron	0.11	0.13	0.099	0.19	0.076	0.095	0.15
Lead	9.6E-07	1.1E-06	7.7E-07	1.9E-06	4.8E-07	9.5E-07	9.6E-07
Mercury	2.2E-08	2.7E-08	1.8E-08	4.5E-08	1.1E-08	2.2E-08	2.2E-08
Metal Ion	0.011	0.014	0.0090	0.022	0.0057	0.011	0.011
Nickel	1.2E-08	1.5E-08	9.9E-09	2.5E-08	6.2E-09	1.2E-08	1.2E-08
Oil	0.071	0.085	0.057	0.14	0.036	0.071	0.071
Phenol	5.2E-05	6.3E-05	4.2E-05	1.0E-04	2.6E-05	5.2E-05	5.3E-05
Sulfides	0.0011	0.0013	8.4E-04	0.0021	5.3E-04	0.0011	0.0011
Sulfuric Acid	0.46	0.52	0.40	0.76	0.30	0.38	0.61
Suspended Solids	0.086	0.10	0.069	0.17	0.043	0.086	0.086
Zinc	1.4E-05	1.7E-05	1.1E-05	2.8E-05	7.0E-06	1.4E-05	1.4E-05

* Includes all process and fuel related waterborne wastes associated with raw materials acquisition, chemical processing for producing the three components comprising PC2 blend (i.e., DBE, NMP, PC), PC2 blending, PC2 use at TAFB, and disposal of spent PC2 by incineration.

(1) Based on 110 gallons of PC2 used per ten KC-135 aircraft radomes depainted.

Source: Franklin Associates, Ltd.

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Increasing the volume of PC2 required results in increased emissions across the board, while decreasing the volume required results in decreased emissions. As with atmospheric emissions, the decreases/increases in most cases are fairly proportionate to the change in PC2 required. However, sulfuric acid and iron emissions change to a lesser degree than the other emissions. This is a reflection of their close tie to electricity consumption at TAFB which remains unchanged as the volume is varied.

Increasing the yield (less PC2 required per radome) results in decreased emissions across the board, while decreasing the yield (more PC2 required) results in increased emissions. Again, the changes in most cases are fairly proportionate to the change in PC2 required, although some emissions categories are less sensitive to the PC2 requirements.

The results for varying the amount of time required per each radome is summarized in the last two columns. For the analyses, the time was halved and doubled. The comparison shows that decreasing the time to one hour results in decreased emissions in almost every category, while increasing the time results in increased emissions. The differences seen are fairly small for most categories of emissions. However, sulfuric acid and iron emissions change to a greater degree than the other emissions. This is a reflection of their close tie to electricity consumption at TAFB.

Conclusions

PC2 Recycling

Energy Results

- Recycling the spent PC2 reduces the total energy requirements by about 70 percent from the baseline system.

Solid Waste Results

- Total solid waste generation is decreased by about 50 percent for the recycled system from the baseline system.

Atmospheric Emissions Results

- All but four atmospheric emission categories (dibasic ester, propylene carbonate, and n-methyl-pyrrolidone, and other organics) show a dramatic reduction in emissions for the recycled system.

- The dibasic ester, propylene carbonate, and n-methyl-pyrrolidone (components of the PC Blend 2) are assumed to remain unchanged with the use of recycled PC2.

- Emissions of "other organics" increase for the recycled system because they are primarily related to additional transportation fuel pollutants produced when spent PC2 is transported to and from Texas for recovery.

Waterborne Emissions Results

- All waterborne emissions show a dramatic reduction in emissions for the recycle loop system.

PC2 Volume, Yield, and Time Sensitivities

Energy Results

- An increase or decrease in volume of PC2 required brings about a nearly proportional increase or decrease in the energy required for the PC Blend 2. Similarly an increase or decrease in yield affects the volume required per radome. Again, the increase or decrease in energy requirements is approximately proportional to the volume change.

- Because the energy for the PC2 use component is only about three percent of the total energy in the baseline, changes in the time required for depainting do not have as great an effect on the energy results.

Solid Waste Results

- Any change in the amount of PC2 required per radome has a substantial effect on the solid waste results. An increase or decrease in volume of PC2 required or change in yield of radomes brings about a nearly proportional increase or decrease in the solid waste results for the PC Blend 2.

- Changes in the processing time (thus, electricity requirements) result in substantial changes in solid waste from electricity generating plants (ash from coal).

Atmospheric Emissions Results

- Either increasing the volume of PC2 required or lowering the yield of radomes results in increased atmospheric emissions across the board; conversely, decreasing the volume required or increasing the yield of radomes results in decreased emissions. The decreases/increases in most cases are fairly proportionate to the change in PC2 required.

- Decreasing the radome processing time results in decreased emissions in almost every category, while increasing the time results in increased emissions. The differences seen are fairly small for most categories of emissions.

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Waterborne Emissions Results

- Either increasing the volume of PC2 required or lowering the yield of radomes results in increased waterborne emissions across the board; conversely, either decreasing the volume required or improving the radome yield results in decreased emissions. As with atmospheric emissions, the decreases/increases in most cases are fairly proportionate to the change in PC2 required.

- Decreasing the radome processing time results in decreased emissions in almost every category, while increasing the time results in increased emissions. The differences seen are fairly small for most categories of emissions.

Chapter 6
A Partial Impact Assessment Of PC2 Use
In Aircraft Radome Depainting

Introduction

A life cycle inventory (LCI) for the use of PC Blend 2 for depainting aircraft radomes is described and summarized in Chapters 2 through 5 of this report. The study provides large quantities of complex information on releases to the environment for the entire "cradle-to-grave" manufacturing process for products. The LCI starts with extraction of raw materials from the ground, and ends with the return of the materials to the environment as solid waste or air and water emissions. For potential impact subcategories that can be expressed in an acceptable common unit of measure (e.g., energy in Btu, solid waste in pounds or cubic feet), conclusions can frequently be made based on LCI results. However, the complexity of data is the greatest for atmospheric and waterborne emissions, and no conclusions can be reached with regards to those emissions without further analysis.

A simple summing of atmospheric and waterborne emission quantities for each product system is generally not meaningful. A pound of one type of airborne or waterborne pollutant can cause vastly different health and environmental effects than a pound of another type of atmospheric or waterborne pollutant. For example, one pound of carbon dioxide emitted to the atmosphere creates an entirely different potential impact on human health and the environment than does one pound of a potent carcinogen. Also, with varying site-specific conditions, a pound of a single pollutant can cause different effects. For example, weather conditions can influence the dispersion, concentration, and human exposure of a pollutant.

The Society of Environmental Toxicology and Chemistry (SETAC) has published a document, **A Conceptual Framework for Life-Cycle Impact Assessment, 1993,** that outlines a general methodology for examining possible applications of impact assessment of atmospheric and waterborne pollutants generated during the life cycle of product systems. This study applies the SETAC methodology to the PC2 inventory results to the degree to which science currently allows. The result is a partial impact assessment which will serve to make the inventory data more relevant by increasing our knowledge about the potential environmental impacts. It will also help summarize the inventory data, in forms that are more managable and meaningful to the decision maker. Readers should not confuse this partial impact assessment with a related tool

called risk assessment. A risk assessment requires a much more detailed and extensive analysis of toxicological data combined with site-specific release and exposure information.

Scenarios Examined

A number of different PC2 use scenarios are evaluated in this study and compared to the baseline PC2 usage scenario. The scenarios are described in detail in Chapter 5 and are listed below.

- Baseline PC2 Use Scenario

    10 KC-135 radomes depainted
    110 gallons PC2 required for 10 radomes
    Each radome is showered continuously for 2 hours
    Disposal of spent PC Blend 2 is by incineration (without energy recovery)

- Alternative Waste Management Scenario

    Recycling of spent PC Blend 2

- Alternative PC2 Use Scenarios

    Varying volume of PC2 required (plus or minus 20 percent)
    Varying yield of radomes per PC2 volume (five radomes to 20 radomes per 110 gallons)
    Varying time required (one hour to four hours per radome)

The PC2 use scenarios evaluated include all of the life cycle steps, from raw materials acquisition, through PC2 production and use, and finally the disposal of the spent PC Blend 2. The reasons for selecting these comparisons and discussion of the basis for comparisons can be found in Chapter 5.

Methodology Summary

SETAC defines a conceptual framework for impact assessment to consist of three steps: classification, characterization, and valuation. As the impact assessment progresses through each of these steps, it becomes more value laden and less objective. This is a report of a partial impact assessment which only considers classification, and, to a small extent, characterization. Complete characterization and valuation are not possible at this time.

Classification

The first step of the impact assessment is classification. This is the process of assigning and aggregating results from the emissions inventory into relatively homogenous potential impact categories. Potential impact categories are chosen to represent the issues of interest for a specific study. For this study, ecosystem quality and human health are the major potential impact

categories examined. Within these two major categories, subcategories are identified based on an extensive analysis of environmental literature.

Examples of specific potential impact subcategories are greenhouse gas/global warming, acid rain, and oxygen depletion of water. Each pollutant emission from the LCI is placed into one or more classification subcategory.

A complete list of subcategories is found in Appendix B, along with the rationale for classification of the emissions. Forty-three different types of emissions were identified in this project, and Appendix B explains how they were classified into two major potential impact categories (ecosystem quality and human health) with 26 specific potential impact subcategories.

Characterization

The second step of the impact assessment is characterization. While classification can be accomplished in all cases, characterization becomes quite complex. Characterization is the assessment of the magnitude of potential impacts on the chosen major categories (human health or ecosystem quality) for each of the subcategories evaluated.

For example, the LCI lists atmospheric emissions of carbon monoxide, carbon dioxide, chlorine, and methane. All are classified under the category greenhouse gas/global warming. Each chemical emission has a potential impact on ecosystem quality through this subcategory. Because it is desirable to combine the different chemicals into a single global warming descriptor, models for the potential impact of each substance are used to equate the quantities of each pollutant to units of global warming potential. In this case, there is a common potential impact metric, usually carbon dioxide equivalents. It is desired to do this in a similar fashion for all subcategories in order to study the potential impact of each system evaluated on the major categories of human health and ecosystem quality as measured by selected subcategory. Unfortunately, conversion models are known for only a few subcategories.

To develop a characterization system to assess the contribution of each emission, various models were reviewed. The goal of each of these models is to assess the magnitude of environmental harm from the product systems being studied. For example, if one system produces 15 pounds of airborne particulates, and the other system produces 30 pounds, some mechanism is desired to assess whether this is a matter for concern or not. Some of the characterization models that have been proposed by SETAC in **A Conceptual Framework for Life-Cycle Impact Assessment, 1993** are:

- Loading: These models assess inventory chemical data on quantity alone, with the assumption that less quantity produces less potential impact.

- Equivalency: These models use derived equivalency factors to aggregate inventory data with the assumption that aggregated equivalency factors measure potential impacts.

- Inherent chemical properties: These models pool inventory data based on chemical properties, toxicity, persistence, and bioaccumulation, with the assumption that these criteria would normalize the inventory data to provide measures of potential impacts.

- Generic exposure/effects: These models estimate potential impact based on generic environmental and human health information.

- Site-specific exposure/effects: These models determine the actual impacts of product systems based on site-specific fate, transport, and impact information for the relevant area or site.

Loading

The loading models are the simplest to execute. The inventory data provide quantities of physical measures, such as kilograms or pounds of the various pollutants. However, physical measures alone are not a measure of potential environmental impact. This means that loading models are best used in a comparative analysis for two or more systems, or for two or more process steps within one system. In that application, the quantities of a specific emission category are compared for each product system, and the system that generates the least is considered to result in the least harm to ecosystem or human health. For example, one system may release 5.3 pounds of atmospheric sulfur oxides for the manufacture of a product, while another system releases 4.3 pounds of the same chemical. In this case, one might be tempted to conclude that the second system produces less potential environmental impact from atmospheric sulfur oxides.

There are several problems with this type of conclusion. One problem is that it is not known if either quantity poses a significant threat and what the severity of that threat is. This would be conditional, in part, upon the concentration of the chemical in the atmosphere. Concentration for these amounts of sulfur oxides is highly variable, depending upon, among other factors, whether the chemical is emitted to the environment in a large amount at one time or is released slowly over a period of time, the climate and weather conditions, and so on. -

Another problem with the loading characterization model is that many emission categories are poorly defined. An example is hydrocarbon emissions. Analytical tests performed to measure this pollutant category do not reveal chemical composition detail. One system may release considerable quantities of hydrocarbons with significant potential environmental impacts, while the other system may release equivalent quantities of more benign hydrocarbons. If hydrocarbon emissions are reported only as a generic total, the product systems will appear equal in potential impact, using the loading model.

Data quality is also a critical issue. Many emission values reported by companies and by other databases do not have high levels of accuracy. In the case cited above, the question arises as to whether the reported value of 5.3 pounds of sulfur oxides is really different from 4.3 pounds.

These two numbers differ by 20 percent. Perhaps the measurement and reporting is error prone to the extent that if the measurements were retaken, the results would be different. After extensive analysis of emission measurements, Franklin Associates has adopted a generic standard for analysis that values representing emissions from two different systems are not significantly different unless their difference exceeds 25 percent. Thus it is concluded that possible errors are so great that the two values given above are not known to be different.

Another disadvantage of loading models is that emission categories cannot be inter compared. For example, one system produces more COD in wastewater but another system produces more phosphates emissions. **The loading model provides no guidance on how to conclude which emission category produces the most potential impact, or if there even is a potential impact.**

With all of these caveats and problems, there is still potential utility in loading models. In some cases, one product system may produce more emissions in virtually every category when compared to other equivalent products. In addition, if the product systems are similar, the hydrocarbon and other combined emission categories may have quite similar composition. Under these conditions, limited conclusions can be drawn with some level of certainty. For the analysis of PC Blend 2, this is clearly the case. The alternative system results which are compared to the baseline are composed of emissions from identical processes as those included in the baseline results. Therefore, conclusions are much more easily drawn than if the comparisons were between two very different systems.

Equivalency

Some of the problems of the loading models could be overcome if equivalency factors could be found. For example, if we could determine the potential impact on human health and ecosystems of one pound of sulfur oxides compared to the potential impacts of one pound of nitrogen oxides, we might be able to construct a system that would allow inter comparison.

The following is a list of possible bases for equivalency factors found in a survey of recent documents. This list is illustrative, and is not meant to be complete, but shows a number of possible options.

- cancer potency index
- molecular weight or other molar basis
- reference dose values (Rfd)
- hydrogen ion or acid equivalents
- carbon equivalents
- oxygen equivalents
- halogen ion equivalents
- acute toxicity values (LD_{50})
- sensory irritation index (RD_{50})
- chemical "potentials" (e.g., ozone depleting potentials, global warming, etc.)

- environmental or ecotoxicity data (e.g., genetic toxicity values, Ames mutagenicity test, chromosomal aberration, aquatic toxicity values)
- other physical or chemical data (e.g., partition coefficients)
- quantitative risk assessment

After assessing all of the techniques listed above, few were considered to be routinely acceptable. Those that have potential utility are discussed at the end of this section.

The main reason for rejection of most equivalency models is the lack of information. In order to use equivalency modeling, an LCI must be available to provide quantitative data in sufficient detail for each emission produced by a product system. One difficulty is to identify what chemicals compose the inventory items designated as particulates, hydrocarbons, other organics, aldehydes, nitrogen oxides, sulfur oxides, organic solids, inorganic solids, and metal ion. The chemical diversity that could exist within each pollutant label makes quantitative risk assessment and other quantitative techniques difficult to use for equivalency modeling. Unfortunately, more detailed information on individual manufacturing processes is usually not available. Data are reported from results of analytical tests completed on waste streams. The data are typically reported in the level of detail obtained during this testing, which follows standards for responding to government reporting agencies. Also, the detail of the data reported does not include information on the exposure rate to the ecosystem or humans.

As an illustration of this problem, particulates in the acid rain potential impact category could be normalized based on molecular weight or acid equivalents. What values would the researcher use? To what fraction of particulates should the potential impact apply (i.e., total suspended particulates or respirable suspended particulates)? The required information is usually not available. However, in some cases data indicate that sulfur oxides dominate the acid-forming potential, so that using SO_x as a surrogate may be acceptable.

Another example occurs with the eutrophication potential impact category for water emissions. Does the researcher assume the nitrogen pollutant is nitrates, nitrites, or possibly even nitrosamines? Most likely, it is a combination of several nitrogen-containing chemical compounds, but testing would only report total nitrogen and this is what is reported in inventories. Another problem with eutrophication demonstrates the need for site-specific data. Specific bodies of water can be phosphate limited or nitrogen limited. In nitrogen-limited water, it is possible that phosphate emissions cause no additional potential impact. Therefore, in this case, phosphate may not create a negative impact on the environment as it would in other bodies of water which are phosphate limited.

Use of the cancer potency index illustrates similar problems with health effects measures. For example, does the researcher use the cancer potency index for benzene as a surrogate measure for the hydrocarbon inventory item? Use of this potency index or other potency estimates (e.g., reference doses, acute toxicity values) is also limited in accuracy by differences in the

experimental design and execution of animal studies, as well as any assumptions (safety factors, animal-to-human extrapolation) used, or errors made during estimate calculations.

Generalized attempts at equivalency modeling are very common in Europe, and to a lesser extent in the U.S. Some of the common names include critical volume approaches, environmental priority strategies, and environmental indicators. A set of dimensionless equivalency impact factors is frequently derived by which inventory data is multiplied or summed, or to which some combination of math operations is applied. The problem is that there is *no* widely accepted single method for doing this that is endorsed by the scientific community. In fact, in the May 1994 issue of **LCA-NEWS** (a SETAC-Europe Publication), it is reported that, at the 1994 Annual SETAC-Europe Congress, it was generally agreed that "...single result systems (e.g. eco-points) are not viable."

One subset of equivalency models, however, has met with some success. These are impact potentials. An example is the global warming set of chemicals. These include carbon dioxide, methane, and CFCs. There are widely accepted equivalency factors for the various chemicals. One factor is that each pound of methane is considered to cause 69 times as much global warming as a pound of carbon dioxide. Factors such as these can be used in the isolated cases where there is general scientific agreement that valid equivalencies exist and specific exposure and fate data are not needed. These could include global warming, ozone depletion, and perhaps acid rain.

Inherent Chemical Properties

These models take into account specific properties of various chemicals emitted. Properties may include toxicity, ignitability, carcinogenicity, bioaccumulation, and so on. Impact ranking systems require appropriate data on the property selected that is relevant to the inventory data. For example, a list of air pollutants emitted during the course of product manufacture and transport can be evaluated for toxicity. In that case, some uniform set of values is needed. An example might be the LD_{50} values for each chemical. These values could be multiplied by the amount of each chemical released, to arrive at a ranking score for the various pollutants emitted, and subsequently products could be ranked.

This approach suffers some of the same serious problems as equivalency models. The use of LD_{50} does not take into account that one chemical may biodegrade at a much faster rate than the other chemical. With a quicker biodegradation, the potential for exposure would be lowered.

Another fundamental problem is that some pollutants are not reported in terms of chemical composition. Primary examples of non-specific air pollutants are particulate emissions and hydrocarbon emissions. These are among the dominant pollutants generated, so this problem is quite serious. Lacking any knowledge of chemical composition makes an appropriate choice of properties to study impossible. This problem is not unique to air pollution, but is a characteristic common to all environmental emission categories.

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The third major problem is data quality. Many types of specific emissions are included in an inventory, and accurate measures of all kinds of pollutants are not always available. Thus, while quite good data may exist for one emission, such as carbon monoxide, the data for highly toxic materials released in very small quantities may be quite poor. In many cases, reported data on toxic emissions are only very rough estimates, and may be in error by factors of 10, 100, or more.

While these chemical property models exist, they need to be used with great care, and with a realization of the potential errors. Typically, use of these models eventually requires an abandonment of purely analytical modeling in favor of subjective weighting factors or other opinion-based measures. The historical record is clear that use of models by governments has sometimes been quite effective at protecting human health and the environment. In these cases, the model is applied to a specific site where exposure is known and the chemicals have similar properties. In other cases, however, the use of models has resulted in unnecessary remediation, and in some cases possibly greater damage to health and the environment than no action at all.

Generic Exposure/Effects

These models seek to use general or generic information to build hypothetical models of the environment in order to assess the complex interaction of emissions and the environment. These are generally very large computer models. These models are only as good as the data available and the ability to accurately model complex environmental and health situations. This requires knowledge of atmospheric dynamics, hydrological dynamics and the complex ways that stressors interact with ecosystems and human health.

Two examples of models that attempt to quantify the fate of chemicals primarily in an aquatic ecosystem are the Mackay unit world approach and the use of "canonical environments." These models are described in the SETAC document, **A Conceptual Framework for Life-Cycle Impact Assessment, 1993.** They use a specific site approach, with the Mackay model defining a site as a unit world of one cubic kilometer and the canonical model defining a generalized stream, lake, or other ecosystem as a site. The Mackay model relies on fugacity coefficients to determine how the chemical will partition between the different environments. The canonical model requires the knowledge of several environmental factors such as stream flow and soil organic matter content.

While some computer models exist, there is no general agreement in the scientific community that the accuracy and reliability of these models is anywhere near what is needed for an LCA impact assessment. The data quality in many cases is a substantial problem, and there is a large degree of subjective content. In addition, application of these models to life cycle inventory data would not be feasible when considering the lack of information on specific chemicals within broad categories and on exposure data.

Site-specific Exposure/Effects

These models are potentially much more successful at this point in time than generic approaches or the approaches that are geographically "global" in scope. The site-specific data are frequently more accurate, and the specific effects on a local environment can be modeled more effectively than in broader based analyses. In fact, many of the identified ecosystem and environmental health problems can be adequately studied only at the local level.

However, LCI is inherently a global approach. The whole point of life cycle assessment is to include indirect effects that go beyond plant boundaries of a single company. A site-specific approach would require site-specific data for each site in the entire production system. This would typically require 40 or more sets of comprehensive site-specific studies, with each set examining the many different emissions identified from the process. This in itself is so expensive and extensive that it is impractical, except in special cases.

There are also other problems. In any production system, there comes a point where specific plants can no longer be tied to the system. For example, if a company is buying fuels on the open market from a pipeline, they are buying a commodity product. The specific sources of the fuel may not be known, and in fact may change from day to day. This makes the site-specific approach impossible for most LCIs. An unpublished EPA document suggests that site-specific models be limited to LCAs of limited scope or used as a supplement to generic methods. In any event, the precise role of site-specific methods for LCAs needs to be carefully analyzed.

Valuation

The third and final step of impact assessment is valuation. Valuation is the assignment of relative values or weights to different impacts. This allows integration across all impact categories. When valuation is completed, the decision makers can directly compare the overall potential impacts of each product. Although it is a highly desirable goal, the valuation step is also highly subjective. **The assignment of relative weights to various potential impacts is inherently value laden, and there is no scientific method for accurately completing the valuation step of impact assessment. This step is not completed for this study.**

The values of one segment of the population can vary greatly from the values of other segments of the population. Who decides which is more important: the ecosystem or human health? It is unlikely that the valuation step of impact assessment will reach a common level of acceptability. It will continue to be an area of discussion for policy makers, environmentalists, and others with a vested interest in environmental decisions.

Results And Discussion

Procedures are still being formulated for conducting the impact portion of a life cycle assessment (**A Conceptual Framework for Life-Cycle Impact Assessment,** SETAC,

March 1993, page 120). However, for this study, a partial impact assessment is constructed. It is partial because no valuation is attempted and mass loading models are primarily used for characterization.

Classification

Once life cycle inventories have been completed for the various product systems, the first step in assessing their comparative potential impacts on the environment is to classify pollutants into potential impact subcategories. The inventory chemicals are classified as having potential impacts on ecosystem quality and human health based on reviews of chemical, environmental, and toxicological data. The classification categories for ecosystem health and human health are shown in Table 6-1 and are those which have a significant potential impact in each global category. The categories in this list are "reasonable" and are not intended to be exhaustive.

Table 6-1. Classification Categories for Ecosystem Quality and Human Health

Categories for Ecosystem Quality	Categories for Human Health
Greenhouse Gas/Global Warming	Human Carcinogen (Class A)
Ozone Depleting Gas/Stratospheric Ozone Depletion	Irritant (Eye, Lung, Skin, GI Tract)/Corrosive
Acid Rain Precursor/Acid Rain	Respiratory System Effects
Smog Precursor/Photochemical Smog/Tropospheric Ozone	Central Nervous System Effects
Air Dispersion/Aging/Transport	Allergenicity/Sensitization
Aquatic Life	Blood Dyscrasias (Methemoglobinemia or Hematopoietic Effects)
Eutrophication/Plant Life	Odors
Visibility Alterations (air or water)	Cardiovascular System Effects
Weather Alterations	Reproductive Effects
Thermal Changes	Behavioral Effects
pH Alterations	Bone Effects
Chemical/Biological Content Alteration	Renal Effects
Oxygen Depletion	
Aquifer Contamination	

Source: Franklin Associates, Ltd.

In order to determine which pollutants create a significant potential impact, the assumption is made that the emissions are present at low concentrations and under hypothetical conditions of low level, general population exposure. *Adverse effects observed from high acute and high chronic exposures are not considered in this assessment.* Appendix B contains a detailed discussion of the classification of individual chemicals and emissions categories into potential impact categories.

Commentary on Industrial Emission Tables

The atmospheric and waterborne emissions inventory results from all the alternative systems in the LCI are classified into a series of tables. The data are so extensive that 12 pages of tables were required. They are presented in Appendix C as Tables C-1 through C-4. Each three-page table summarizes data for a different process scenario. For example, Table C-1 reports emissions for the comparison of the recycling results to the baseline LCI results. The table lists the individual pollutants assigned to each potential environmental impact category, the pounds of chemicals emitted by each system, and the percent difference between the systems.

The quantity (pounds) of each type of airborne or waterborne emission calculated in the inventory is listed in *all applicable* classification categories, taking into account that a category may include air emissions only, water emissions only, or both. In the left column, the "A" or "W" following the emission label designates that entry as being airborne or waterborne. For this assessment, only atmospheric emissions are considered to be significant factors in the potential impact categories of greenhouse gases, photochemical smog, air dispersion/aging/transport, weather alterations, and thermal change. The potential impact category of blood dyscrasias does not include any applicable emissions categories for this study and has been omitted. In the remaining potential impact categories, both atmospheric and waterborne pollutants are included in the assessment.

The emissions are ordered in each classification category so that the pollutants released during the life cycle are listed by largest amount generated to the smallest, according to the baseline scenario. This is not meant to imply that the pollutant emitting the most pounds will have the greatest potential impact.

For this assessment, two characterization models may be used: loading and global warming equivalency models. The global warming equivalency model will only be used if the loading results are inconclusive in the global warming subcategory. The other models either require highly subjective measures with unknown, but probably large, errors associated with them, or there simply are not data available to allow their use.

The tables in Appendix C show the classification results for industrial environmental emissions that may affect ecosystem quality and human health. Industrial emissions are those released during the manufacture and use of the PC Blend 2. This includes emissions from all steps in the life cycle (from raw material extraction to PC Blend 2 formulation, use, and disposal) of the PC Blend 2 for radome depainting. Emissions from the combustion of fuels for process or transportation energy are also included.

A perusal of this very extensive set of data reveals the complexity of interpretation. The data are reported in a series of columns to enhance analysis. For each comparison, the percent change from the baseline is calculated as:

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$$\frac{\text{(alternative scenario emission - baseline emission)}}{\text{baseline emission}} \times 100.$$

Thus, negative values mean that the alternative scenario produces less pounds of emissions in that subcategory, while positive numbers mean that the alternative scenario produces more pounds of emissions.

Another important aspect of the results presented in the third column is the magnitude of the percent difference. Because of errors and uncertainty in the data, differences of less than 25 percent are not normally considered to be significant. However, as stated earlier, the processes included in the alternative scenarios are in most cases identical to the processes in the baseline analysis. Because of the similarities, a difference of less than 25 percent can be considered significant.

The results for recycling PC2 are compared to the baseline scenario in Table C-1. A quick perusal down the percent difference column in Table C-1 shows that all but six emissions categories decrease by over 20 percent, with most categories being more than 75 percent lower for the recycling system. The exceptions are dimethyl succinate, dimethyl glutarate, and dimethyl adipate (the three components of DBE), propylene carbonate, and n-methyl-pyrrolidone (which all remain unchanged), and other organics (which increases). The five which remain unchanged are the components of the PC Blend 2. They are assumed to occur during the PC2 use step at TAFB as evaporative losses, and are thus assumed to remain unchanged with the use of recycled PC2. The "other organics" emissions increase because they are primarily related to transportation fuel pollutants. The recycled system actually requires more transportation of the waste PC2 than the baseline due to the round-trip to Texas required for spent PC2 solvent recovery in the recycled system versus one-way transport to a local combustion facility for the baseline scenario. Other organic emissions fall into the ecosystem category of ozone depletion, and the human health categories of irritant/corrosive and allergenicity. **This means, with the exception of these three potential impact categories, recycling the PC Blend 2 results in less potential impact than the baseline in which the spent PC2 is incinerated.**

The results for varying the volume of PC2 required per 10 KC-135 radomes are compared to the baseline analysis in Table C-2. (This analysis is done to see what effect recirculating a smaller or larger volume of PC2 for depainting 10 radomes has on the results.) A review of the percent difference column in Table C-2 shows that increasing the volume of PC2 required results in increased emissions across the board, while decreasing the volume required results in decreased emissions. The decreases/increases in most cases are fairly proportionate to the change in PC2 required. This is because all the "back-end" steps for PC2 production, blending, and incineration have been changed proportionately. "Back-end" steps refer to the steps for raw material acquisition through final production of the PC2 components (PC, DBE, and NMP). However some emissions categories are less sensitive to the PC2 requirements. For example, sulfur oxides, particulate emissions, sulfuric acid, iron, kerosene, and airborne lead emissions change to a lesser

degree than the other emissions. This is a reflection of their close tie to electricity consumption at TAFB which remains unchanged when the volume is varied. **Therefore, reducing the volume of the PC Blend 2 required per radome results in less potential impact.**

The results for varying the yield of radomes depainted per volume of PC2 required are compared to the baseline analysis in Table C-3. (This analysis is done to see what effect increasing or decreasing the yield of radomes stripped per volume of PC2 used has on the results.) As with the results in Table C-2, the comparison shows that increasing the yield (less PC2 required) results in decreased emissions across the board, while decreasing the yield (more PC2 required) results in increased emissions. Again, most of the changes are fairly proportionate to the change in PC2 required, although some emissions categories are less sensitive to the PC2 requirements. **This means that increasing the yield of radomes depainted with a set volume of PC2 results in less potential impact.**

The results for varying the amount of time required per each radome are compared to the baseline analysis in Table C-3. The baseline time assumed was two hours. For these analyses, the time was halved and doubled. The comparison shows that decreasing the time to one hour results in decreased emissions in almost every category, while increasing the time results in increased emissions. The differences seen are fairly small for most categories of emissions. However, sulfur oxides, particulate emissions, sulfuric acid, iron, kerosene, and airborne lead emissions change to a greater degree than the other emissions. This is entirely a reflection of their close tie to electricity consumption at TAFB. **This means that reducing the time for depainting required per radome results in less potential impact. However, this alternative does not result in differences that are as great as others examined.**

Estimates of Ground Level Emission Concentration from Evaporation of PC2 Solvent Blend

One of the most evident on-site ecological and health risks with the use of volatile solvents is the inhalation by workers or nearby citizens. For the solvents studied here, there are OSHA and/or ACGIH acceptable limits of concentration in air. The following maximum allowable concentration (time-weighted average over 8 hours) information was supplied by the manufacturers.

- DBE - 1.5 ppm, or 10 mg/m^3

- PC - 20 ppm, or 85 mg/m^3

- NMP - 100 ppm or 410 mg/m^3

In order to assess the potential for exceeding these limits during use of the PC2, a model for estimating ground level concentrations of emitted air pollutants was used. The source of the model was: Christian, Joel B., "Estimate the Effects of Air Emissions with this Process Screening Model," Chemical Engineering Progress, June 1995, pp. 59-62. Personal communication with the author verified its use for this application.

The model requires that several assumptions be made. The initial calculations use the following values.

- virtual stack height (height of plume) = 5 m
- wind speed = 3.35 m/s
- ground level coordinate of measurement point = 10 m
- mass flow of contaminant = (assuming 0.5 percent volatilization)
  - NMP - 2.5 lb in 20 hr
  - DBE - 1.2 lb in 20 hr
  - PC - 1.2 lb in 20 hr
- meteorological stability = moderately unstable

Under these conditions, the estimated point concentrations are: 0.066 mg/m^3 for NMP, and 0.032 mg/m^3 for DBE and PC.

The maximum allowable concentrations are about 6,000 times higher for NMP than the estimated values (410/.066 = 6,000), 300 times higher for DBE, and 2,700 times higher for PC.

All of the above calculations are estimates. However, the air emission concentrations are quite conservative. In fact, the wind speeds are generally much higher in central Oklahoma, and using the ground level coordinate of 10 meters from the source is also conservative, especially if the workers are equipped with breathing apparatus. The 0.5 percent evaporation loss of the solvent is also an estimate, but even if it is in error by a factor of 300 (an impossibility), the ground level concentrations still seem to be in a range considered to be safe.

It is our conclusion, based upon these rough estimates, that the direct emission of solvent vapors from the processing location does not result in a significant known problem as defined within the scope of this study to anyone outside the immediate working area.

Summary
The point of this partial impact assessment is to decide whether one system appears to be environmentally more desirable than another. There is no accepted analytical method to reduce the information in Appendix C to a single decision. However, the analysis has proceeded to a point where reasonable judgments can be made.

The four tables in Appendix C are the only level at which scientific interpretation of data is possible. Using a simple loading model ("less is better" for each subcategory approach), these tables show a mix of positive and negative signs in the percent difference comparison columns. This means that in some potential impact subcategories the baseline system produces lower emissions, while in other subcategories it produces higher levels of emissions. This leads to an inconclusive result for some comparisons. However, for most of the comparisons, the results do indicate which improvement alternatives result in less potential environmental impact. In other

words, the results indicate, at least directionally, which operating parameters should be explored for the sake of improvement of the LCA results.

Development of Summary Tables for Communication and Subjective Evaluations

In every decision, there is a scientific level of analysis and interpretation, but in many cases that interpretation must be simplified for communication purposes. It is also common to rely upon subjective evaluations when communicating results of scientific conclusions. This is justifiable only if the summaries and subjective evaluations have credibility when verified at the scientific level.

As an aid to that end, a summary table was developed. The tables in Appendix C are so cumbersome that each three-page set of information has been summarized in Table 6-2. For example, from Table C-1, the first column shows the number of emission entries where pounds of emissions for the alternative system exceeded those for the baseline. Table C-1 is summarized in the first row, with subsequent tables summarized in the following rows. The table reports the number of impact subcategories in which an alternative system results in less potential impact. Thus, high numbers would represent more subcategories of less potential impact and thus that alternative would be more desirable.

In Table 6-2, "less potential impact" means that, in a given subcategory, the system had *no* emissions that were considered higher than the other system's emissions, while *at least 1* emission was higher for the other system. If neither system had any emissions higher than the other, the results for that subcategory were inconclusive. Results for a subcategory were also inconclusive if each system had at least one emission higher than the other. For example, for the first line in Table 6-2, the recycled system has significantly less potential impact in 20 subcategories. However, the results for ozone depletion are considered inconclusive, as are results for the human health categories of irritant and allergenicity/sensitivity because each system is higher than the other for at least one emission in these subcategories.

This table has the advantage of summarizing all of the Appendix C tables in a single page, and continues to convey the conclusions already reached and verified by analysis of the Appendix C tables.

Table 6-2. Summary of Partial Impact Analysis

Alternative System	Number of impact subcategories in which product system named results in significantly less potential impact		
	Baseline	Alternative	Inconclusive
100% closed loop recycling of PC2	0	20	3
20% increase in volume of PC2	23	0	0
20% decrease in volume of PC2	0	23	0
Decrease yield to 5 per 110 gallons	23	0	0
Increase yield to 20 per 110 gallons	0	23	0
Increase depaint time to four hours per radome	23	0	0
Decrease depaint time to one hour per radome	0	23	0

Source: Appendix C, Tables C-1 to C-4.

Conclusions

- With the exception of the ecosystem category of ozone depletion, and the human health categories of irritant/corrosive and allergenicity, recycling the PC Blend 2 results in less potential impact than the baseline in which the spent PC2 is incinerated.

- Reducing the volume of the PC Blend 2 required per radome results in less potential impact.

- Increasing the yield of radomes depainted with a set volume of PC2 results in less potential impact.

- Reducing the time for depainting required per radome results in less potential impact. However, this alternative does not result in differences that are as great as others examined.

- The direct emission of solvent vapors from the processing location does not result in a significant known problem to anyone outside the immediate working area.

Chapter 7
Improvement Analysis

Introduction

This chapter provides an improvement analysis for the use and disposal of PC Blend 2 used for depainting radomes at Tinker Air Force Base (TAFB). The results of the life cycle inventory (LCI) and impact assessment will be used along with a limited cost analysis to evaluate the improvement alternatives set forth. Because the use of PC2 has been very limited thus far, the parameters around the use of PC2 may be quite different than assumed in the baseline scenario. A number of alternative scenarios were explored in the earlier chapters to illustrate the effects of changes in the major assumptions on life cycle inventory and impact results. The results from the sensitivity analyses can now be used to point the way for a number of improvement options.

Purpose

As a maintenance procedure, TAFB removes paint from radomes for KC-135, B-52, and a number of other aircraft. The radomes are currently showered with methyl ethyl ketone (MEK) in a large ventilated paint booth until the paint is loosened and can be removed. All of the MEK volatilizes and is lost into the atmosphere. As a part of the U.S. Environmental Protection Agency's 33/50 Voluntary Reduction Program, the use of MEK is to be reduced by 50 percent by the end of 1995. A number of substitute paint stripping blends were analyzed, with PC2 being identified as the solvent blend with greatest potential to replace the MEK. The PC2 is made up of 25 percent propylene carbonate, 50 percent n-methyl pyrrolidone, and 25 percent dibasic ester. The PC2 has been tested on a very limited basis for this application.

This improvement analysis will combine the results from the life cycle inventory, partial impact assessment, and a cost analysis to recommend areas for process optimization. These alternatives can provide the focus during process optimization for the use of PC2 in radome depainting.

Identification Of Improvement Alternatives

Several improvement alternatives have been identified and analyzed in earlier chapters of this report. For comparison purposes, the process for depainting KC-135 radomes was chosen as the baseline scenario. The KC-135 is the predominant radome processed at TAFB. Detailed LCI results for the baseline are presented in Chapters 3 and 4 of this report, and detailed LCI results for the alternatives can be found in Chapter 5. The improvement scenarios are listed below.

- Baseline PC2 Use Scenario

  10 KC-135 radomes depainted
  110 gallons PC2 required for 10 radomes
  Each radome is showered continuously for 2 hours
  Disposal of spent PC2 by incineration (without energy recovery)

- Alternative Waste Management Scenarios

  Recycling of spent PC2

- Alternative PC2 Use Scenarios

  Varying volume of PC2 required (plus or minus 20 percent)
  Varying yield of radomes per PC2 volume (five radomes to 20 radomes per 110 gallons)
  Varying time required (one hour to four hours per radome)

Each of the PC2 use scenarios evaluated include all of the life cycle steps, from raw materials acquisition, through PC2 production and use, and finally the disposal of the spent PC2 blend. The alternative scenarios were chosen to directionally show the potential improvements that might be derived from various PC2 depainting process and waste management alternatives. Discussion of the basis for comparison and detailed system descriptions can be found in Chapter 5.

Technical Evaluation Of Improvement Alternatives

Energy Requirements
Figure 6-1 summarizes the total energy requirements for PC2 aircraft radome depainting solvent for the baseline and all alternative scenarios. These results include all energy use associated with raw materials acquisition, chemical processes for producing the three components comprising PC2 (i.e., DBE, NMP, PC), PC2 blending, and PC2 use and disposal for depainting radomes at TAFB. The recycled system results also include the energy for transporting the spent PC2 to a theoretical recycling facility in Texas, distilling the waste solvent blend, re-blending the components, and transporting the recycled PC2 back to TAFB for another use.

By recycling the spent PC2, the total energy requirements are reduced to around 25 percent of the baseline requirements. Most of the reduction comes from decreased process and energy of material resource requirements in the "back-end" steps for producing the DBE, PC and NMP components of the blend. "Back-end" steps refer to the steps for raw material acquisition through final production of the PC2 components (PC, DBE, and NMP). The energy for disposal of waste is also drastically reduced to about 15 percent of the baseline amount. The energy for distilling the spent PC2 is about 25 percent of the total energy for the recycled system.

As shown in Figure 7-1, the energy results are also very sensitive to any changes in the volume and yield assumptions. An increase or decrease in volume required brings about a proportional increase or decrease in the energy required to produce the PC2. Similarly, an
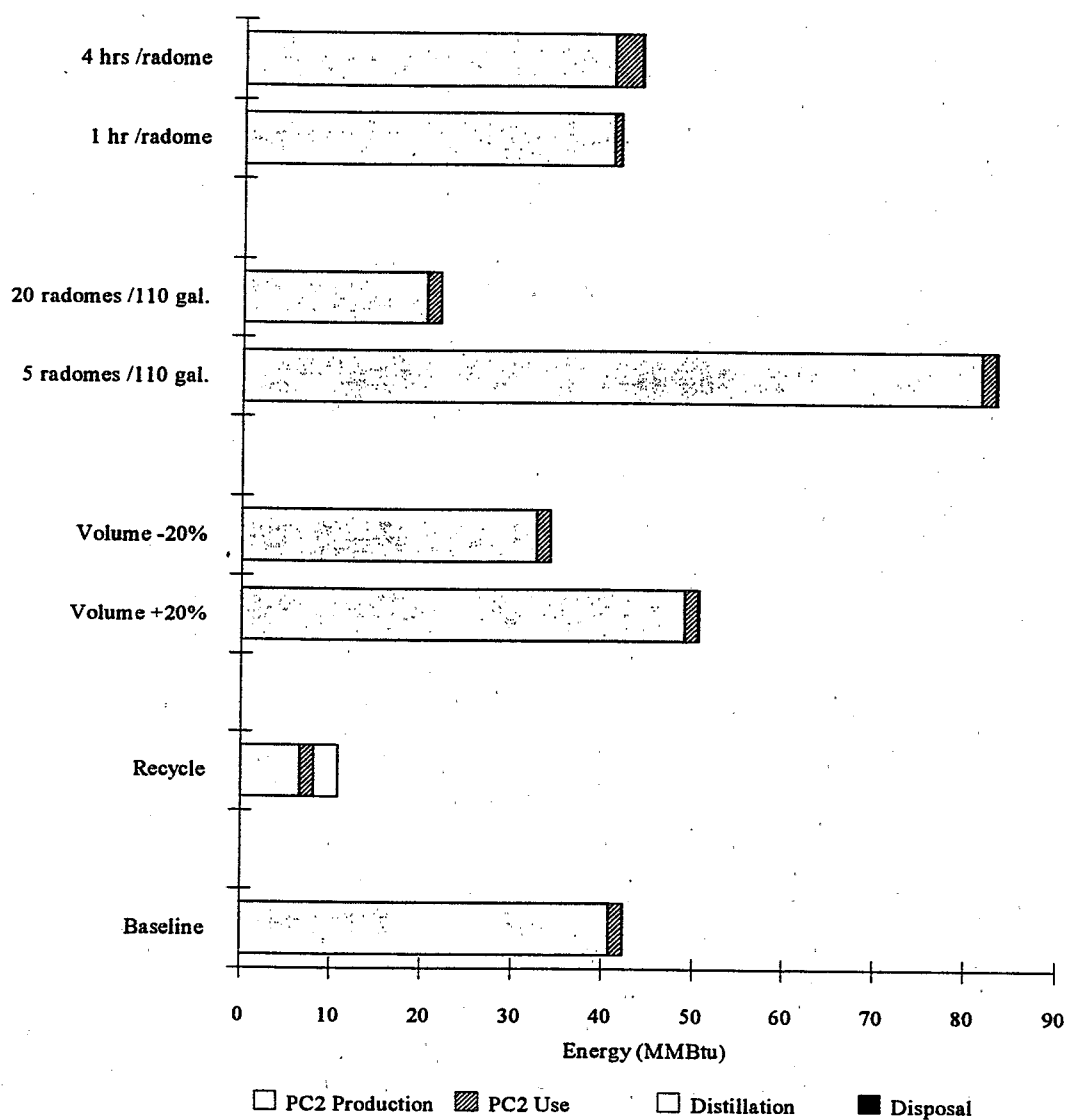
Figure 7-1. LCI energy usage by component showing sensitivity to improvement alternatives.
Source: Tables 5-1 through 5-5.

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increase or decrease in yield affects the volume required per radome. Again the increase/decrease in total energy requirements is approximately proportional to the volume change.

Changes in the time required for depainting do not have as great an effect on the energy results. This is simply because varying the time only affects the PC2 use component, which is only about three percent of the total energy in the baseline.

Solid Waste

Figure 7-2 presents total solid waste generation for the baseline and all alternative scenarios. These results include all solid waste associated with raw materials acquisition, chemical processes for producing the three components comprising PC Blend 2 (i.e., DBE, NMP, PC), PC2 blending, and PC2 use and disposal for depainting radomes at TAFB. The recycled system results also include the solid wastes associated with transportation and recycling of the spent PC2.

Total solid waste generation is decreased by about 50 percent for the recycled system when compared to the baseline system. The reduction of fuel and process-related solid wastes associated with producing the three components of the PC2 is primarily responsible for this reduction. However, a small increase in fuel-related solid waste results from the recycling process and transportation to and from the recycling facility.

As with the energy results, the total solid waste is quite sensitive to assumptions regarding volume of PC2 required per radome. Because over 60 percent of the solid waste is due to the production of the components (DBE, PC, and NMP) and blending of the PC2, any change in the amount of PC2 required per radome has a substantial effect on the solid waste results.

The process energy used at TAFB is electricity; therefore, changes in the processing time (thus, electricity requirements) result in substantial changes in electricity related fuel pollutants. The dramatic changes in solid waste which result from variations in process time are due primarily to solid waste from electricity generating plants (i.e. ash from coal).

Atmospheric and Waterborne Emissions

Table 7-1 summarizes the partial impact assessment results for the atmospheric and waterborne emissions from the use of PC2 aircraft radome depainting solvent in all scenarios. The partial impact assessment is described in detail in Chapter 6.

In Table 7-1, "less potential impact" means that, in a given subcategory, the system had *no* emissions that were considered higher than the other system's emissions, while *at least 1* emission was higher for the other system. If neither system had any emissions higher than the other, the results for that subcategory were inconclusive. Results for a subcategory were also inconclusive if each system had at least one emission higher than the other. For example, for the first line in Table 7-1, the recycled system has significantly less potential impact in 20 subcategories.

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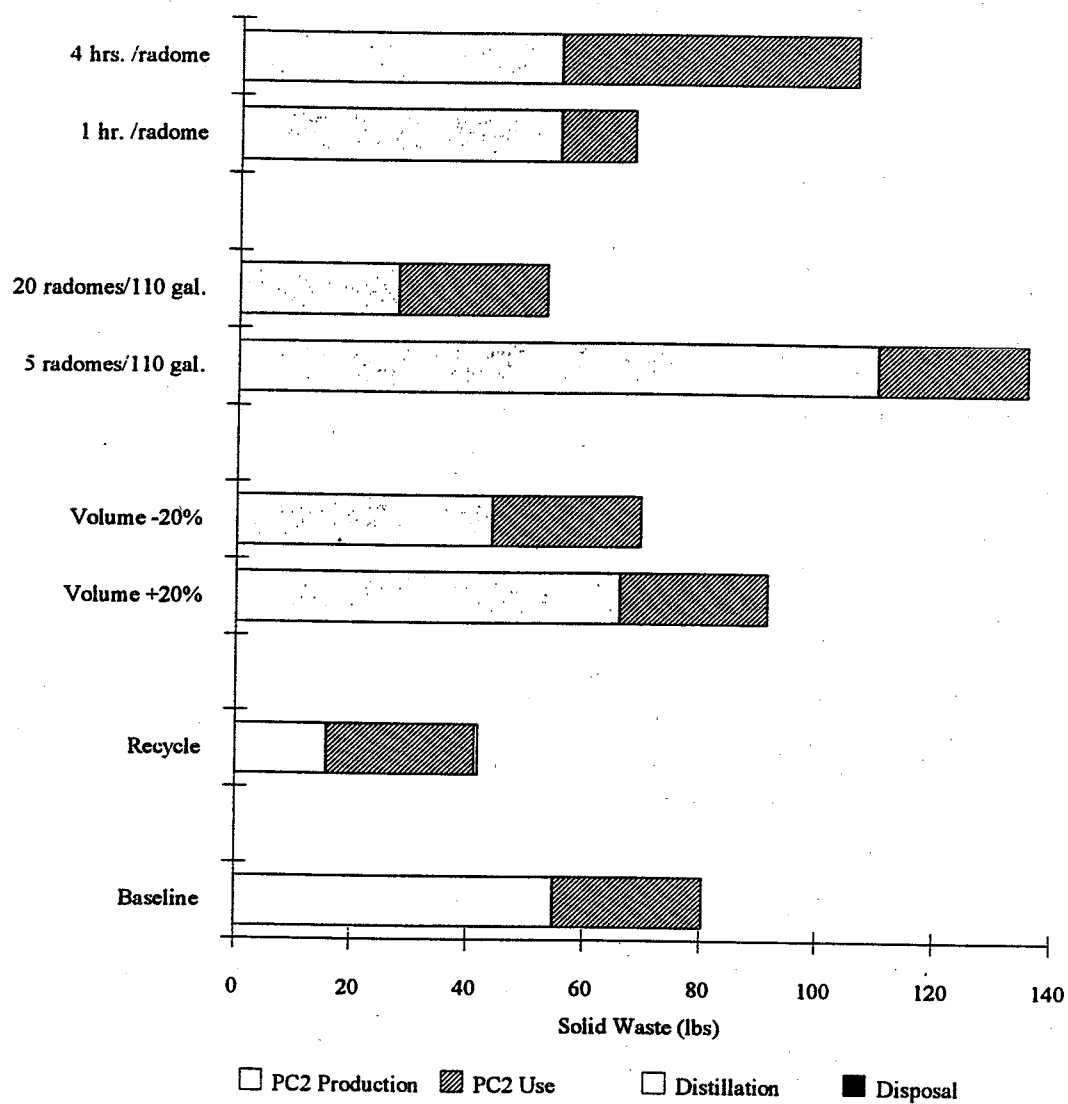
Figure 7-2. LCI solid wastes by component showing sensitivity to improvement alternatives.

Source: Tables 5-2 through 5-6.

Table 7-1. Summary of Impact Assessment Results with Comparison of Improvement Alternatives to Baseline

Alternative System Compared to Baseline	Number of Impact Subcategories with Less Potential Impact	Number of Potential Impact Subcategories with Inconclusive Results
100% closed loop recycling of PC2	20	3
20% increase in volume of PC2	0	0
20% decrease in volume of PC2	23	0
Decrease yield to 5 per 110 gallons	0	0
Increase yield to 20 per 110 gallons	23	0
Increase depaint time to four hours per radome	0	0
Decrease depaint time to one hour per radome	23	0

Source: Appendix C, Tables C-1 to C-4.

However, the results for ozone depletion are considered inconclusive, as are results for the human health categories of irritant and allergenicity/sensitivity because each system is higher than the other for at least one emission in these subcategories.

Figure 7-3 provides some additional insight as to the magnitude of change in total emissions (air and water) for the various alternatives. The figure summarizes the average percent difference (shown by the shaded bars) between the alternative scenario and the baseline. The range of the percent difference is also shown by the dotted lines. It is important to note that while the recycling scenario results in the greatest reduction in emissions as measured by the average percent difference, one emission increases (other organics with a percent difference of about 38 percent) for the recycling scenario. The other organics emissions are found in three different potential impact subcategories and cause the "inconclusive" results shown in Table 7-1.

Economic Evaluation Of Alternatives

Because of the evaporative losses associated with MEK, which is currently being used for depainting radomes, Tinker Air Force Base wants to replace MEK with PC2. An earlier analysis showed that approximately 33 drums per year of PC2 would be required to replace the approximately 145 drums of MEK currently used. The purpose of this economic analysis is to estimate the cost to supply the new solvent (PC2), and the cost of disposal or recovery of the used solvent for each of the improvement alternatives. This analysis is not a life cycle cost analysis, but instead analyzes the cost to TAFB for the various improvement alternatives.

It is important to note that the change-over from MEK to PC2 is not expected to require any
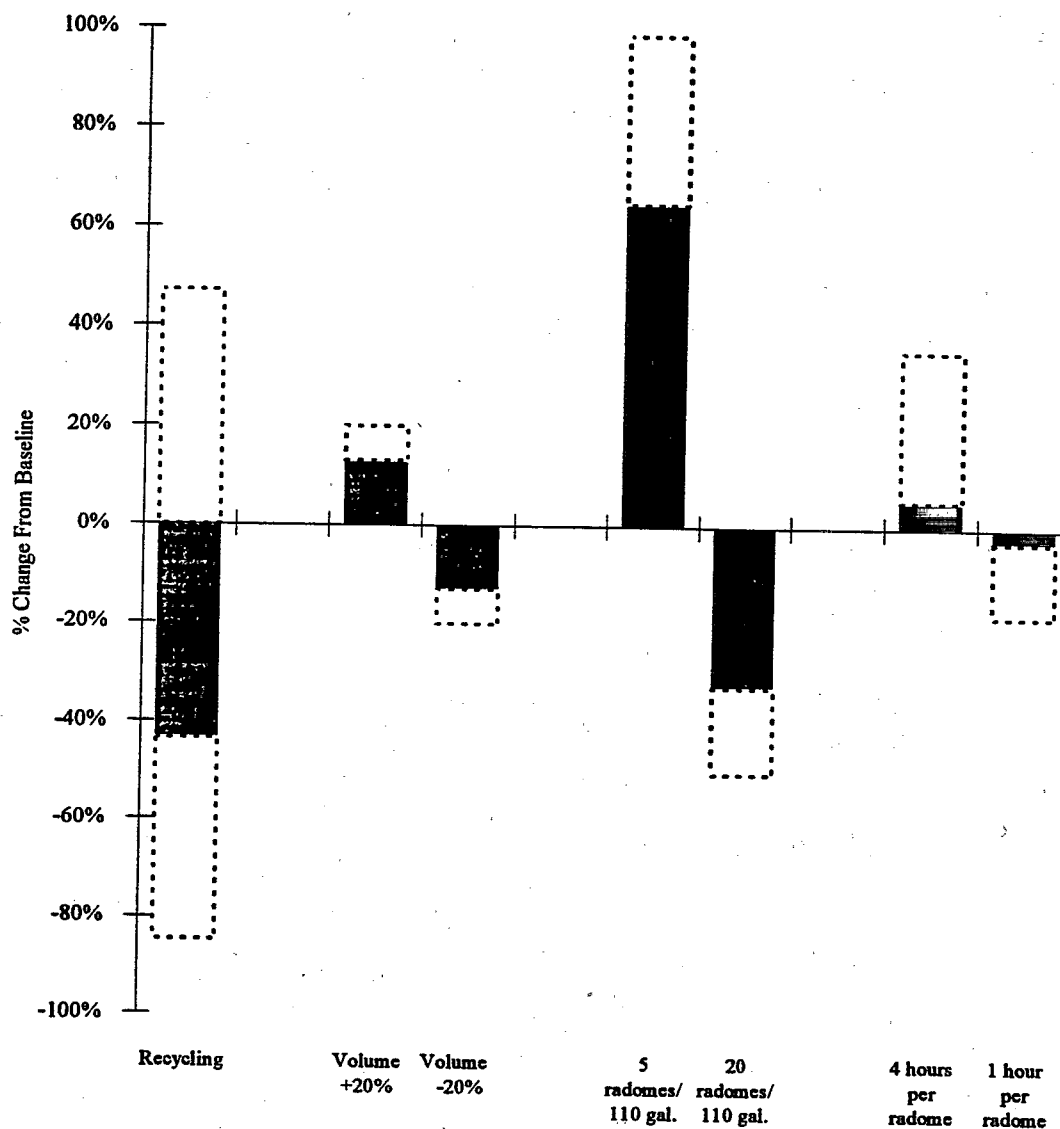
Figure 7-3. Summary of impact analysis average percent difference from baseline over all potential impact categories.

Shaded area shows average percent change from baseline and dotted lines show the range.

Source: Tables C-1 through C-4.

change in capital equipment. Therefore, this cost analysis assumes that no capital expenditures are required.

Cost of Solvent Supply

PC2 consists of 25 percent propylene carbonate (PC), 50 percent n-methyl pyrrolidone (NMP), and 25 percent dibasic ester (DBE). Several chemical suppliers were contacted to obtain estimates of delivered prices. Three estimates, $17.00, $17.03, and $17.20 per gallon, were received. These are costs for the blended solvent, delivered to TAFB, assuming a usage of about 3 drums per month. Based on the previous raw material cost estimate of $9.01 per gallon, about half of the cost is for blending

Cost of Disposal and Recovery

It is assumed that, because of potential heavy metal contamination from the paints, the spent solvent will need to be handled as a hazardous waste. Therefore, combustion in a hazardous waste incinerator is assumed for disposal.

There are no commercial hazardous waste incineration facilities in Oklahoma. Facilities are available in Coffeyville, Kansas (Aptus) and El Dorado, Arkansas (Ensco). The Arkansas facility is over twice as far away from TAFB as the facility in Kansas, which is about 190 miles from TAFB. Facilities in Texas are even farther away.

Disposal costs include the cost of transportation plus the cost of incineration. The transportation cost to Coffeyville, KS depends on the quantity shipped at one time. The cost is $0.13 per pound with a minimum of $250. (The cost for a single drum shipment would be $250 or $4.50 per gallon.)

The estimated cost to incinerate the solvent is between $115 and $165 per drum, depending on the waste profile, which is determined by a one-time acceptability test that costs $550. At $165 per drum, the estimated disposal cost, including transportation, is $7,623 per year, as shown in Table 7-2. This equates to $4.20 per gallon disposed.

Solvent recovery is assumed to be by distillation. The technical and economic feasibility of recovering PC2 are not well known. Because of the high boiling points of the solvent components, and because the contaminant levels from the paint are unknown, laboratory tests will be required to determine the quality of the product that can be expected from the distillation process. The three components of the solvent have boiling points of 115°C to 140°C (DBE), 202°C (NMP), and 240°C (PC).

Because of the technical uncertainties of distilling PC2, a broad range of cost estimates was received. The preliminary estimates received range from $0.45 to $1.50 per pound. At $0.45, a fairly high yield is assumed, and a minimum of 10 drums would be required at one time. As shown in Table 7-2, the cost of distillation may be as high as $29,960 per year ($16.51/gallon),

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Table 7-2 Economic Comparison Disposal and Recovery (1)

	DISPOSAL	
	$/gal	$/year
Transportation	1.20 (2)	2,178
Processing	3.00 (3)	5,445
Totals for incineration	**4.20**	**7,623**

	RECOVERY FOR RECYCLING (4)	
	$/gal	$/year
Transportation	3.00 (5)	5,445
Processing	13.51 (6)	24,515
Totals for recycling	**16.51**	**29,960**

(1) Assumes average usage of 33 drums (1,815 gal) per year and PC2 density of 9.01 lb/gal

(2) Shipment to Coffeyville, KS hazardous waste incinerator.
Shipping cost is $0.13/lb, with a $250 minimum.

(3) Subject to one-time waste acceptability testing (profiling) for $550.

(4) It is assumed that only minimal solid waste is generated from recycling and
the cost for handling this residual is included in the estimate.

(5) Shipment to San Antonio, TX, round trip.

(6) Assumes $1.50 per pound. Cost estimates range from $0.45 to $1.50 per pound. Actual
may be lower or higher. Laboratory sampling will be required to obtain better estimates.

which is almost four times as costly as disposal by incineration. Industry contacts indicated that the transportation cost would be about $0.06 per pound.

Evaluation of PC2 Costs (Without Recycling)

Table 7-3 shows the cost estimates for new solvent (PC2) supply, and disposal by incineration, showing the sensitivity of cost to the actual demand for solvent. In the baseline case, it is assumed 33 drums (1,815 gallons) per year of PC2 are used.   The next two rows of Table 7-2 show how the cost is affected if the demand is increased and decreased by 20 percent. The last two lines of the table show the effect of doubling and halving the demand for solvent (this also corresponds to doubling or halving the yield).

Evaluation of Recycling Alternative

The analysis of costs summarized in Table 7-2 above shows incineration to cost less than recovery by distillation. However, a laboratory analysis of the potential for distillation is recommended.

Assuming 85 percent recovery of spent PC2 from distillation, and a distillation cost of $16.51 per input gallon, the cost of recycled PC2 would be $19.42 (16.51/0.85) per recovered

Table 7-3. Sensitivity of Pc Blend 2 Costs to Demand

	Dollars/year		
	New PC2	**Disposal (1)**	**Total**
Baseline (1,815 gallons/yr)	31,218	7,623	38,841
Baseline w/+20% volume	37,462	9,148	46,609
Baseline w/-20% volume	24,974	6,098	31,073
Baseline w/+100% volume	62,436	15,246	77,682
Baseline w/-50% volume	15,609	3,812	19,421

(1)   Disposal by incineration in a hazardous waste incinerator.

gallon. This is higher than the $17.20 per gallon for new PC2, but since the incinerator disposal cost would not be required, the total cost would be less with recycling. If distillation proves to be technically feasible at $16.51 per gallon or less, then the optimum disposal solution, environmentally and economically, may be distillation for reuse at TAFB.

To further examine the effect of recycling, costs were analyzed for three scenarios of PC2 usage. The scenarios are:

Scenario 1:   Base case, no recycling,
Scenario 2:   Three years of PC2 usage, with recycling, and
Scenario 3:   Five years of PC2 usage, with recycling.

Table 7-4 summarizes the estimated costs for these scenarios.

In the first scenario, it is assumed new PC2 would be purchased each year, and the spent solvent would be disposed of in the Coffeyville hazardous waste incinerator. The total supply and disposal cost would be about $39 thousand per year. The first year is higher by $550 because of the one-time compatibility testing required.

Scenario 2 assumes a three year program of PC2 usage, after which all used solvent would be incinerated. The first year's cost is simply the cost of the new supply of PC2 ($31,218). In the second year, 85 percent of new supply would be comprised of recycled PC2, and 15 percent would be new PC2 makeup. The total second year cost would be $34,643. The third year costs would be like the second, except there would be an additional cost for disposing of the used

Table 7-4. Estimated PC Blend 2 Costs, Various Usage Scenarios (Dollars/Year)*

Scenario 1 (Base Case/No recycling)

	Year 1	Year 2	Year 3	Year 4	Year 5	Total	Average
New PC2 supply	31,218	31,218	31,218	31,218	31,218	156,090	31,218
Recovery/distillation	0	0	0	0	0	0	0
Incineration (1)	8,173	7,623	7,623	7,623	7,623	38,665	7,733
Total	39,391	38,841	38,841	38,841	38,841	194,755	38,951

Scenario 2 (Three years of PC2 usage/with recycling)

	Year 1	Year 2	Year 3	Total	Average
New PC2 supply (2)	31,218	4,683	4,683	40,583	13,528
Recovery/distillation	0	29,960	29,960	59,920	19,973
Incineration (1)(3)	0	0	8,173	8,173	2,724
Total	31,218	34,643	42,816	108,676	36,225

Scenario 3 (Five years of PC2 usage/with recycling)

	Year 1	Year 2	Year 3	Year 4	Year 5	Total	Average
New PC2 supply (2)	31,218	4,683	4,683	4,683	4,683	49,949	9,990
Recovery/distillation	0	29,960	29,960	29,960	29,960	119,840	23,968
Incineration (1)(3)	0	0	0	0	8,173	8,173	1,635
Total	31,218	34,643	34,643	34,643	42,816	177,962	35,592

* Note: Cost escalation is not considered in this table.

(1) Includes one-time acceptability test for $550.
(2) Assumes 85% recovery and 15% makeup PC2 after first year.
(3) Assumes final year's used solvent is incinerated.

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solvent, for a total of $42,816. The average for the three years is estimated at $36,225, which is about $2,800 per year less than the base case scenario.

Scenario 3 estimates the costs for a 5 year program. This is similar to the second scenario, but the average annual cost ($35,952) is $633 lower. The total 5 year savings over the scenario 1 base case is $16,800. The estimated average annual costs for programs of one through five years duration are shown graphically in Figure 7-4. The one-year program assumes no recycling and the other four programs assume recycling of the used solvent, except in the last year of the program.

Note: Cost escalation is not included in this figure.
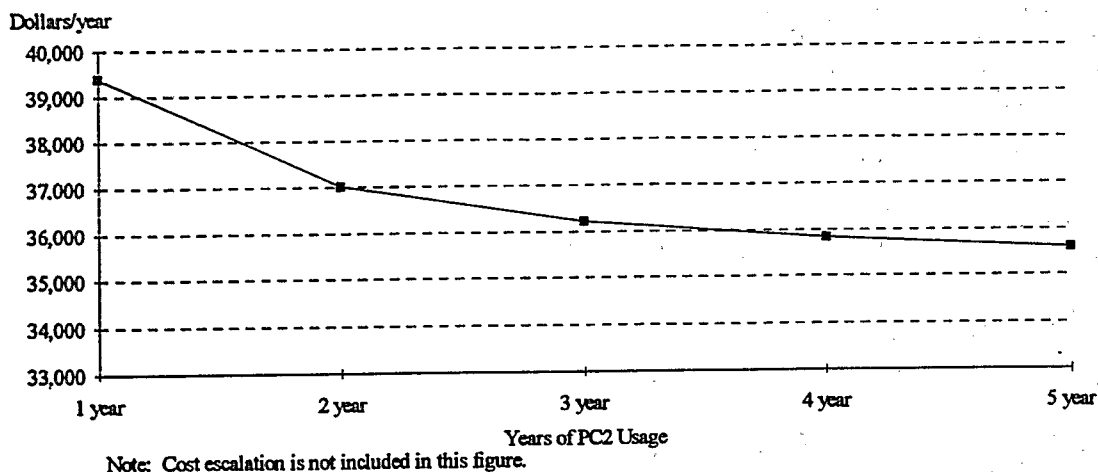
Figure 7-4. Estimated average annual cost of PC2 supply, recycling, and disposal.

Other Considerations
In the course of this study, a number of issues arose which were judged to be beyond the scope of this work. However, this information is provided in order that it can be factored into future decisions.

The evaporative loss of PC2 is estimated from the difference in vapor pressure between PC2 and MEK. The vapor pressure for PC2 is about 0.3 percent that of MEK. Because MEK experiences 100 percent evaporation, a conservative estimate of 0.5 percent of the total PC2 required was used to estimate the evaporative loss for PC2. While most parameters for use of PC2 will be the same as for use of MEK, the fact that the PC2 will be re-used a number of times is quite different than the MEK depainting process. It is possible that the PC2 may be re-used again and again over a period of several weeks or even months. To ensure that evaporative losses are kept to a minimum and to guard against contamination, it is recommended that the PC2 be drummed for storage between uses.

The recycling of spent PC2 is based on surrogate data for distilling a similar, but different waste fluid. The applicability of the data used was judged to be sufficient for the purposes of determining, at least directionally, if recycling might be a practical alternative in terms of energy, solid waste, and air and waterborne emissions. In addition, a recovery of 85 percent of the spent PC2 was used in both the environmental and cost analysis. Industry sources indicated that this was a conservative estimate for most solvent mixtures. However, there were some concerns that two components (NMP and the dimethyl succinate portion of the DBE) of the PC2 may form an azeotropic mixture, thus they could not be fractionally distilled to separate them. If the three components need to be cleanly separated to be used in a product other than PC2, this could be a problem. However, if the mixture could be re-blended into PC2 for use at TAFB, the problem may be quite minor. It should be emphasized that feasibility of recycling PC2 would need to be proven.

One of the suppliers of NMP also suggested that if the NMP could be easily separated from the other components by distillation, that they would might be willing to handle the spent PC2 disposal at no charge. Again, the fractional distillation would need to be run on a pilot scale, and laboratory tests run to prove the technical feasibility of this disposal option.

The hazardous waste firms contacted suggested that the PC2 would be a prime candidate for use as a fuel blend for cement kilns. This is a form of energy recovery. This option for handling hazardous liquid waste carries a substantially lower disposal cost. The cost for a cement kiln disposal of liquid hazardous waste ranges from $85 per drum to $135 per drum, depending on the degree of contamination. It is expected that the spent PC2 would be considered relatively clean. Therefore, this option would probably compare favorably to the estimate of $115 to $165 for incineration of the liquid waste. However, the waste management personnel at TAFB indicated that this is not a preferred alternative for waste management.

Conclusions

- Reducing the volume of the PC Blend 2 required per radome by 20 percent results in a 20 percent reduction of material and disposal costs from the baseline scenario.

- Increasing the yield of radomes depainted with a set volume of PC2 by 100 percent results in a 50 percent reduction of material and disposal costs from the baseline scenario.

- Recycling the PC Blend 2 results in moderately less material and disposal costs than the baseline in which the spent PC2 is incinerated.
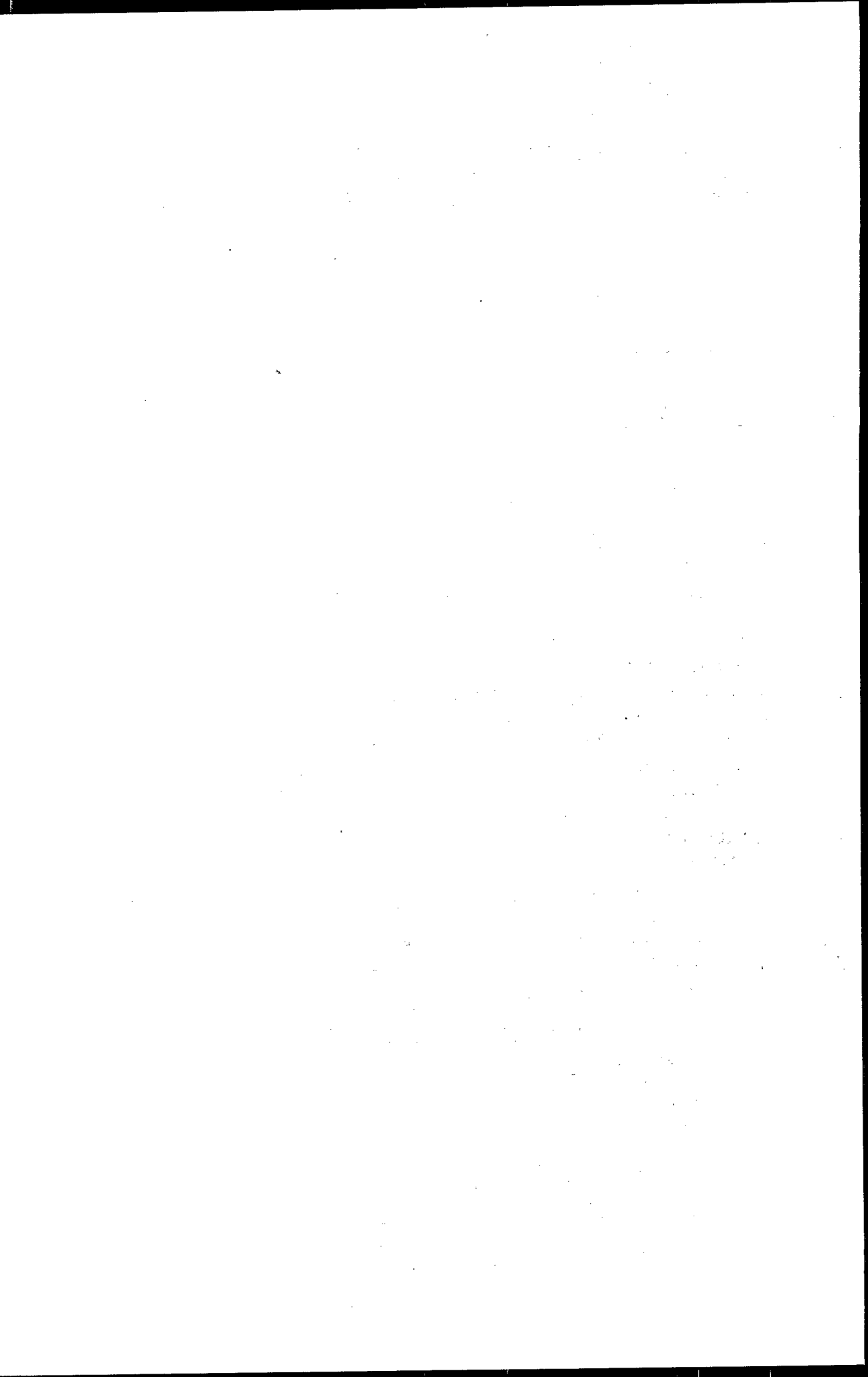
Appendix A
LCI System Components For PC2
Aircraft Radome Depainting Solvent

This appendix provides an overview of each of the steps required for the production, use, and disposal alternatives for PC2, a potential replacement solvent blend for aircraft radome depainting at the Oklahoma City Air Logistics Center (OC-ALC) at Tinker Air Force Base (TAFB). Currently, TAFB uses methyl ethyl ketone (MEK) to depaint B-52 and KC-135 aircraft radomes. The PC2 solvent blend is a mixture of 50 percent n-methyl-pyrrolidone (NMP), 25 percent dibasic ester (DBE), and 25 percent propylene carbonate (PC).

Included in this appendix are process descriptions, materials flow charts, and tables presenting energy requirements and environmental emissions summary results. Summary results tables are presented for the three products comprising PC Blend 2: NMP, DBE, and PC. The data in the tables are presented on the basis of producing 1,000 pounds of each of the three products comprising PC2. These results represent energy use and environmental emissions for all steps in the life cycle of each of the three components, from raw materials extraction through production of the individual PC2 components. The results also reflect precombustion energy and emissions as well as fuel related emissions from the use of fuels as process and transportation energy. The process descriptions are provided to give the reader a basic understanding of the process parameters. As discussed in the methodology chapter of this report, selected materials such as catalysts, pigments, and other very small additives are not included in this life cycle inventory, although they may be mentioned. Generally, such materials total less than one percent of the net process inputs and are not included.

The following steps are required for the production of the three components comprising the PC2 solvent, and are discussed in this appendix:

- N-methyl-pyrrolidone (NMP)
  Natural gas production
  Natural gas processing
  Carbon dioxide production
  Methanol production
  Ammonia production
  Methyl amine production
  Crude oil production
  Distillation, desalting, & hydrotreating

Acetylene production
Formaldehyde production
Butynediol production
Hydrogen production
1,4 Butanediol production
y-Butyrolactone production
N-methyl-pyrrolidone production

- Dibasic Ester (DBE)
  Natural gas production
  Natural gas processing
  Carbon dioxide production
  Methanol production
  Ammonia production
  Nitric acid production
  Crude oil production
  Distillation, desalting, & hydrotreating
  Naphtha reforming
  Benzene production
  Hydrogen production
  Cyclohexane production
  Salt mining
  Sodium hydroxide production
  Adipic acid production
  Dibasic ester production

- Propylene Carbonate (PC)
  Natural gas production
  Natural gas processing
  Crude oil production
  Distillation, desalting, and hydrotreating
  Propylene manufacture
  Oxygen manufacture
  Salt mining
  Sodium hydroxide manufacture
  Propylene oxide manufacture
  Carbon dioxide production
  Propylene carbonate production

A discussion on depainting operations at TAFB and PC2 disposal alternatives is also included in this appendix. Because PC2 is not currently being used in production at TAFB, key assumptions regarding PC2 use and disposal were made and are included in the discussion.

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Process data for each production step were documented and compiled for this study. Because these process data are often proprietary, the data are presented in final aggregated form. That is, process data for each process step from raw material acquisition through chemical intermediates, and finally the end product (NMP, DBE, or PC) are combined into one data set for each end product. More detailed data and references to data sources reside in the internal project files at FAL.

N-Methyl Pyrrolidone (NMP)

Brief descriptions of the processes required for the manufacture of NMP are presented in the following sections. Figure A-1 is a process flow diagram illustrating raw material requirements for the manufacture of 1,000 pounds of NMP.

Natural Gas Production

Natural gas is extracted from deep underground wells, frequently being coproduced with crude oil. Because of its gaseous nature, it flows quite freely from wells that produce primarily natural gas. However, some energy is required to pump natural gas and crude oil mixtures to the surface. Combination wells account for approximately 25 percent of all natural gas production.

Natural Gas Processing

Light straight-chain hydrocarbons are normal products of a gas processing plant. The plants typically use compression, refrigeration, and oil adsorption to extract these products. Heavy hydrocarbons are removed first. The remaining components are extracted and kept under controlled conditions until transported in high-pressure pipelines, insulated railcars, or barges.

Carbon Dioxide, Hydrogen, and Ammonia Manufacture

Carbon dioxide and hydrogen are primarily produced by steam reforming of natural gas and are by-products of ammonia manufacture. Natural gases, or other light hydrocarbons, and steam are fed into a primary reformer, over a nickel catalyst to produce hydrogen and carbon dioxides, generally referred to as synthesis gas. About 70 percent of the hydrocarbon feed is converted to synthesis gas in the primary reformer. The remaining hydrocarbons are converted in the secondary reformer. Air is introduced into the second reformer to supply nitrogen for the ammonia manufacture.

The effluent from the reformers is fed into carbon monoxide shift converters where the carbon monoxide reacts with water to form hydrogen and carbon dioxide. This provides more hydrogen for manufacturing ammonia. The effluent from the shift converters is cooled, and condensed water is removed. The carbon dioxide and some excess hydrogen are then removed from the synthesis gas as coproducts. The remainder of the synthesis gas is purified, dried, and fed to an ammonia converter where nitrogen and hydrogen react to form ammonia (References A-1 through A-4).

Figure A-1. Flow diagram for the production of 1,000 pounds of n-methyl-pyrrolidone (NMP). Numbers represent weight of materials in pounds.

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Methanol Production

Methanol is manufactured from methane-rich natural gas. The early operations synthesizing methanol by this method utilized a high pressure process in the presence of a $ZnO-Cr_2O_3$ catalyst with a Zn:Cr ratio of 70:30. More recently, emphasis has been redirected from the high pressure process to a low or medium pressure process.

The most common low or medium pressure operations for manufacturing methanol occur through reforming operations (steam, combined, or multi-stage). The natural gas or hydrocarbon feedstock is first desulfurized because of potential byproducts formed with the Cu-Zn-aluminum oxide catalyst. A relatively long catalyst life, often up to four years, is typical for this process. From the reforming step the gas mixture is fed through a series of steps which include a circulator, converter, heat exchanger, cooler, and separator. Maximum usage of purge gas and waste heat in this process reduces the overall process energy requirements. The methanol is purified through a distillation unit (References A-1, A-4, A-30).

Methylamine Production

Monomethylamine, the methylamine used to produce n-methyl-pyrrolidone, is primarily produced by the alkylation of ammonia by methanol in the presence of a dehydrating catalyst. A number of variables effect the selectivity of this reaction between mono-, di-, and trimethylamine. These include the catalyst used, the nitrogen to carbon ratio, temperature, and residence time. Optimization of these variables will result in the maximum output of mono-methylamine (Reference A-5). The end product mixture of the various amines, byproducts, and unreacted raw material is separated by distillations and extractions (Reference A-6).

Crude Oil Production

Oil is produced by drilling into porous rock structures generally located several thousand feet underground. Once an oil deposit is located, numerous holes are drilled and lined with steel casing. Some oil is brought to the surface by natural pressure in the rock structure, although most oil requires some energy to drive pumps that lift oil to the surface. Once oil is on the surface, it is separated from water and stored in tanks to await transportation to a refinery. In some cases it is immediately transferred to a pipeline that transports the oil to a larger terminal. It is assumed that 50 percent of the crude oil used comes from domestic sources and 50 percent from foreign sources (Reference A-31).

Distillation, Desalting, and Hydrotreating

A petroleum refinery is a complex combination of processes that serve to separate and physically and chemically transform the mixture of hydrocarbons found in crude oil into a number of products. Modern refineries are able to vary the different processing steps through which a charge of crude oil passes in order to maximize the output of higher value products. This variation of processing steps can change according to the make-up of the crude oil as well as the economic value of the products. Because of this variation, it is necessary to make certain

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assumptions about the refinery steps to which crude oil is subjected in order to produce petrochemical feedstocks.

For this analysis, it is assumed that crude oil used to produce feedstocks for olefins production goes through the following refinery operations: desalting, atmospheric and vacuum distillation, and hydrotreating. Due to a lack of facility-specific data, literature sources were used to estimate the energy requirements for these refining steps. A number of literature references were used, most of which showed similar energy inputs (References A-8 through A-12).

Crude desalting is the water-washing of crude oil to remove water-soluble minerals and entrained solids (Reference A-7). Crude oil atmospheric distillation separates the desalted crude oil into fractions with differing boiling ranges. The residue from the atmospheric distillation unit passes to a vacuum distillation unit where separation of the various fractions can be accomplished at lower temperatures than would be required at atmospheric pressure. Hydrotreating is a catalytic hydrogenation process that reduces the concentration of sulfur, nitrogen, oxygen, metals, and other contaminants in a hydrocarbon feed.

Acetylene Production
Approximately 90 percent of acetylene used in manufacturing is recovered from the hydrocarbon cracking of petroleum at high temperatures. The different hydrocarbon-acetylene processes differ in how the reaction energy is supplied. There are several different methods in operation or under development, including: arc, flame, and pyrolysis technologies.

For maximum acetylene production, the hydrocarbons must reach a reaction temperature of about 1500K and be immediately quenched to about 550K. The desired reaction temperature depends on the length of the hydrocarbon chain. Reaction time is on the order of milliseconds. Because of its unstable nature, acetylene is usually used close to where it is produced (References A-13 through A-16).

Formaldehyde Production
Formaldehyde is most commonly produced by oxidation of methanol in the presence of either a silver or ferric molybdate catalyst. The silver catalyst, methanol, air, and water are preheated and fed into the reactor vessel. The heat from the reaction gas is recovered by generating steam, and gases are sent to an absorption tower. The process for the metal oxide catalyst differs from the silver catalyst process in that the metal oxide reaction occurs at lower temperatures and requires a much greater excess of air in the feed, and the excess steam is exported.

The formaldehyde is stripped from the reaction gases with water and then distilled. A solution containing 60% urea can also be used to extract the formaldehyde. The resulting absorber bottoms can then be condensed into urea/formaldehyde resin (References A-1, A-2, A-4, and A-17).

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y-Butyrolactone Production

Acetylene and formaldehyde are the raw materials required to produce y-butyrolactone. The reaction proceeds through several intermediate steps which include hydrogenation and dehydrogenation of the mixture to produce the y-butyrolactone end product. The reactions are described as follows (Reference A-18):

$$HCCH + 2\ CH_2O \longrightarrow HOCH_2CCH_2OH\quad (1,4\text{-butynediol})$$

$$HOCH_2C\overset{H2}{C}H_2OH \longrightarrow HOCH_2CH_2CH_2CH_2OH\quad (1,4\text{-butanediol})$$

$$HOCH_2CH_2C\underset{Cu}{\overset{-H2}{H_2}}CH_2OH \longrightarrow OCO(CH_2)_3\quad (y\text{-butyrolactone})$$
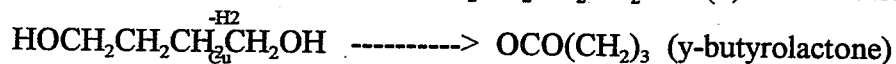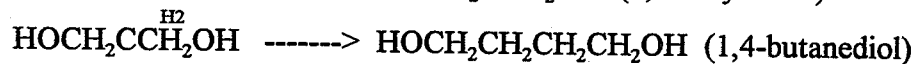
The 1,4-butynediol created in the first step, is produced by a formaldehyde ethynylation process. Acetylene and formaldehyde are reacted at 90°C-100°C and an acetylene partial pressure of about 500 kPa-600 kPa. 1,4-Butynediol yields are over 90 percent with 4-5 percent propargyl alcohol being coproduced. 1,4-Butynediol is then hydrogenated to 1,4-butanediol via the Reppe process. The y-butyrolactone is manufactured by dehydrogenation of 1,4-butanediol. The dehydrogenation occurs with preheated 1,4-butanediol vapor in a hydrogen carrier over a supported copper catalyst at 230°C-250°C. Yields of y-butyrolactone after purification by distillation are about 90 percent (Reference A-18).

n-Methyl-Pyrrolidone Production

Large scale n-methyl-pyrrolidone manufacture is accomplished by condensation of y-butyrolactone with methylamine at 200°-350°C and 10 MPa (References A-21 and A-22). The NMP component of the PC2 solvent blend is assumed to be produced on the Texas gulf coast and transported to Oklahoma City for blending. The total energy requirements and environmental emissions for producing 1,000 pounds of NMP from raw materials acquisition (crude oil and natural gas) through NMP production are aggregated and displayed in Table A-1.

Dibasic Ester (DBE)

A brief description of the processes required for the manufacture of DBE are presented in the following sections. Figure A-2 is a process flow diagram illustrating raw material requirements for the manufacture of 1,000 pounds of DBE.

The following steps in the production of DBE are discussed previously in this appendix:

- Natural gas production
- Natural gas processing
- Crude oil production
- Distillation, desalting, and hydrotreating
- Carbon dioxide production
- Methanol production

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- Ammonia production
- Hydrogen production

Nitric Acid Production

Nitric acid is manufactured from ammonia by air oxidation over a metal catalyst. The reaction occurs at 800 to 950°C to almost 60 percent conversion (Reference A-7).

Naphtha Reforming

The reforming processes are used to convert paraffinic hydrocarbon streams into aromatic compounds such as benzene, toluene, and xylene. Catalysts such as platinum, alumina, or silica-alumina and chromium on alumina are used (Reference A-23).

Benzene Production

Benzene is naturally produced from crude oil as it is distilled in the refinery process. Also, a large portion of benzene is produced by the catalytic reforming of light petroleum distillate (naphtha). In the reforming process, naphtha is fed through a catalyst bed at elevated temperatures and pressures. The most common type of reforming process is platforming, in which a platinum-containing catalyst is used. Products obtained from the platforming process include aromatic compounds (benzene, toluene, xylene), chemical hydrogen, light gas, and liquefied petroleum gas. (References A-24 and A-25).

The reformate from the platforming process undergoes solvent extraction and fractional distillation to produce pure benzene, toluene and other coproducts. Additional benzene is often produced by the dealkylation of toluene.

Cyclohexane Production

Cyclohexane is produced by catalytic hydrogenation of benzene. Benzene is converted to cyclohexane in approximately 95 percent yield. A hydrogen-rich, byproduct fuel gas is recovered for use elsewhere in the plant.

Salt Mining

Most salt-based chlorine and caustic facilities use captive salt from another process or use brine salt. Salt is most commonly removed from brine using solution mining. In solution mining, pressurized fresh water is introduced to the bedded salt through an injection well (Reference A-26). The brine is then pumped to the surface for treatment. Salt mines are widely distributed throughout the United States.

Sodium Hydroxide and Chlorine Production

Caustic soda (sodium hydroxide) and chlorine are produced from salt (sodium chloride) by an electrolytic process. An aqueous sodium chloride solution is electrolyzed to produce caustic soda, chlorine, and hydrogen gas. Chlorine and caustic soda each account for about half of the output of the process, with hydrogen amounting to only one percent by weight.

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Table A-1. Data for the Production of 1,000 Pounds of Nmethyl-Pyrrolidone (NMP)

Energy Usage			Energy* Thousand Btu
Energy of Material Resource			
Natural Gas	931	lb	20,876
Petroleum	395	lb	7,650
Total Resource			28,526
Process Energy			
Electricity	206	kwh	2,183
Natural gas	12,971	cu ft	14,554
LPG	0.065	gal	6.8
Distillate oil	0.27	gal	41.8
Residual oil	0.79	gal	132
Gasoline	0.12	gal	16.7
Total Process			16,934
Transportation Energy			
Combination truck	310	ton-miles	
Diesel	3.7	gal	569
Rail	36.7	ton-miles	
Diesel	0.11	gal	17.7
Barge	46.6	ton-miles	
Diesel	0.093	gal	14.5
Residual oil	0.028	gal	4.7
Ocean freighter	774	ton-miles	
Diesel	0.077	gal	12.0
Residual	0.77	gal	130
Pipeline-natural gas	61.2	ton-miles	
Natural gas	141	cu ft	158
Pipeline-petroleum products	54.2	ton-miles	
Electricity	1.2	kwh	12.6
Total Transportation			918

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Environmental Emissions	Process	Fuel	Total	
Atmospheric Emissions				
Aldehydes	0.015	0.031	0.047	lb
Ammonia	0.52	2.7E-04	0.52	lb
Carbon Dioxide	-	2,318	2,318	lb
Carbon Monoxide	34.8	2.5	37.3	lb
Chlorine	7.8E-05	1.1E-05	8.9E-05	lb
Hydrocarbons	40.9	19.8	60.7	lb
Hydrogen Chloride	5.9E-05	8.0E-06	6.7E-05	lb
Kerosene	-	1.2E-04	1.2E-04	lb
Lead	5.5E-07	1.0E-04	1.0E-04	lb
Methane	-	0.044	0.044	lb
Nitrogen Oxides	0.18	5.0	5.2	lb
Other Organics	-	0.45	0.45	lb
Particulates	0.023	0.83	0.85	lb
Sulfur Oxides	1.5	4.5	6.0	lb
Solid Wastes	2.8	43.5	46.3	lb
Waterborne Wastes				
Acid	4.3E-07	5.9E-08	4.9E-07	lb
Ammonia	0.032	9.5E-05	0.032	lb
BOD	0.13	7.3E-04	0.13	lb
Chromium	1.7E-06	2.4E-07	2.0E-06	lb
COD	0.12	0.0034	0.12	lb
Dissolved Solids	0.36	0.049	0.40	lb
Iron	1.6E-04	0.065	0.065	lb
Lead	7.7E-07	1.0E-07	8.7E-07	lb
Metal Ion	0.0092	0.0013	0.010	lb
Oil	0.030	0.0053	0.036	lb
Phenol	3.0E-05	4.1E-06	3.4E-05	lb
Sulfuric Acid	-	0.26	0.26	lb
Suspended Solids	0.15	6.6E-04	0.15	lb
Zinc	1.1E-05	1.5E-06	1.3E-05	lb

* Values include precombustion and combustion energy and emissions.
Source: Franklin Associates, Ltd.
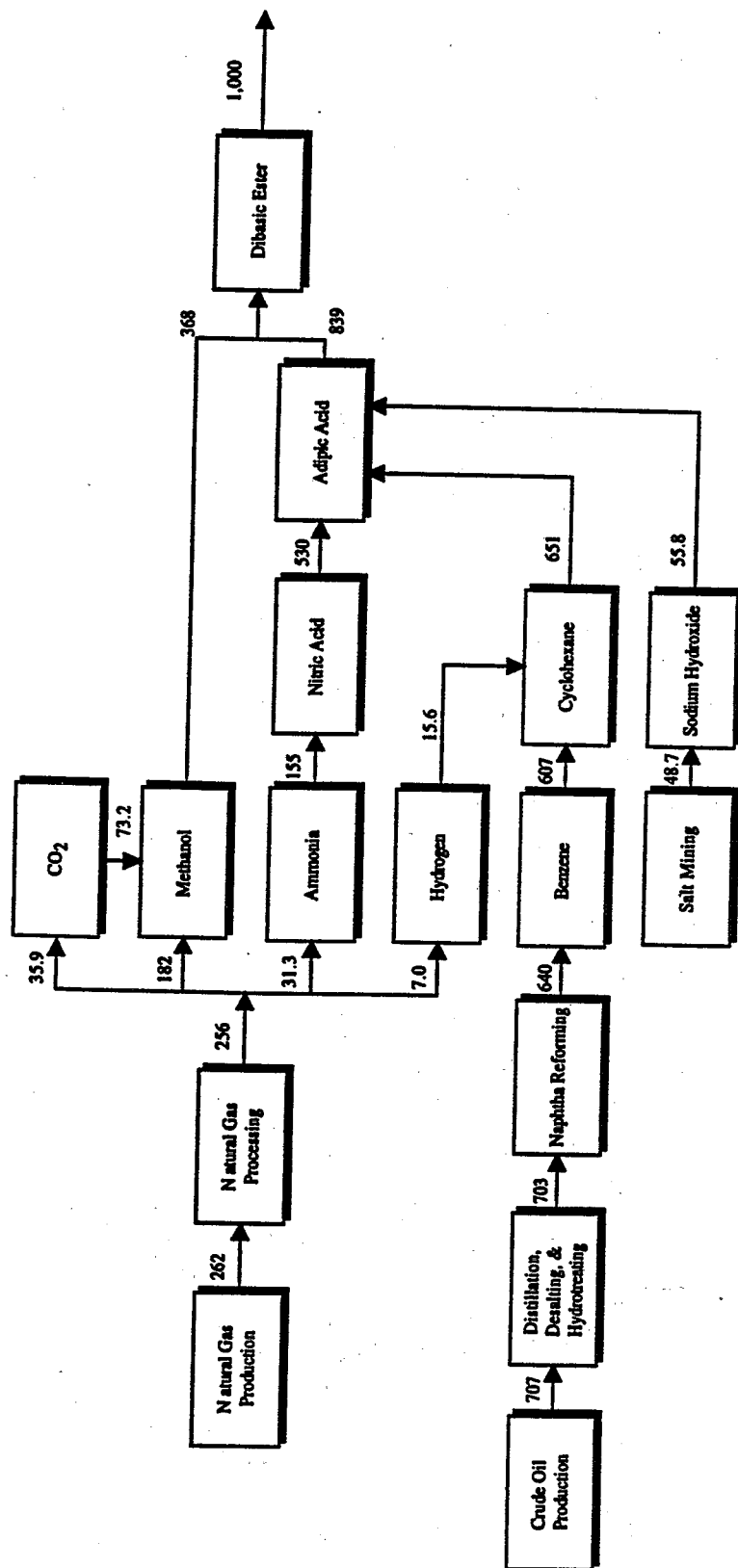
Figure A-2. Flow diagram for the production of 1,000 pounds of dibasic ester (DBE). Numbers represent weight of materials in ounds.

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The electrolysis of sodium chloride is performed by one of two processes: the mercury cathode cell process, and the diaphragm cell process. About 83 percent of electrolyzed chlorine and caustic soda production comes from the diaphragm process, with the remainder coming from the mercury cell process (Reference A-27).

Adipic Acid Production

Nearly all adipic acid made in the U.S. is made from the nitric acid oxidation of a cyclohexanol/cyclohexanone mixture (KA oil). In recent years KA oil has been obtained almost exclusively from the air oxidation of cyclohexane which is obtained from hydrogenation of benzene. The reactions are described as follows (References A-1, A-28 and A-29):

$$C_6H_6 + 3\ H_2 \longrightarrow C_6H_{12} \qquad \text{(cyclohexane)}$$

$$C_6H_{12} + O_2 \longrightarrow C_6H_{10}O + C_6H_{11}OH \qquad \text{(KA oil)}$$

$$C_6H_{10}O + C_6H_{11}OH \longrightarrow C_6H_{10}O_4 \ \text{(adipic acid)}$$

Dibasic Ester Production

Dibasic ester (DBE) is a mixture of the following esters: dimethyl adipate (15 wt%), dimethyl glutarate (60 wt%), and dimethyl succinate (24 wt%). The dimethyl glutarate and dimethyl succinate are by-products of dimethyl adipate production. Dimethyl adipate is produced by refluxing adipic acid and methanol in the presence of an acid catalyst and heat (Reference A-19). The solution is then neutralized, dried, steam filtered, decolorized, and filtered again before being sent to a holding tank (Reference A-20).

The DBE component of the PC2 solvent blend is assumed to be produced on the Texas gulf coast and transported to Oklahoma City for blending. The total energy requirements and environmental emissions for producing 1,000 pounds of DBE from raw materials acquisition (crude oil and natural gas) through DBE production are aggregated and displayed in Table A-2.

Propylene Carbonate (PC)

A brief description of the processes required for the manufacture of PC are presented in the following sections. Figure A-3 is a process flow diagram illustrating raw material requirements for the manufacture of 1,000 pounds of PC.

The following steps in the production of PC are discussed previously in this appendix:

- Natural gas production
- Natural gas processing
- Crude oil production
- Distillation, desalting, and hydrotreating
- Salt mining

- Sodium hydroxide manufacture
- Carbon dioxide production

Table A-2. Data for the Production of 1,000 pounds of Dibasic Ester (DBE)

Energy Usage			Energy* Thousand Btu
Energy of Material Resource			
Natural Gas	272	lb	6,111
Petroleum	732	lb	14,160
Total Resource			20,272
Process Energy			
Electricity	135	kwh	1,428
Natural gas	12,517	cu ft	14,044
LPG	0.12	gal	12.7
Coal	51.4	lb	584
Distillate oil	0.57	gal	88.3
Residual oil	4.9	gal	815
Gasoline	0.091	gal	12.7
Total Process			16,984
Transportation Energy			
Combination truck	255	ton-miles	
Diesel	3.0	gal	468
Rail	38.2	ton-miles	
Diesel	0.12	gal	18.4
Barge	12.8	ton-miles	
Diesel	0.026	gal	4.0
Residual oil	0.0077	gal	1.3
Ocean freighter	1,434	ton-miles	
Diesel	0.14	gal	22.3
Residual	1.4	gal	241
Pipeline-natural gas	17.9	ton-miles	
Natural gas	41.2	cu ft	46.3
Pipeline-petroleum products	102	ton-miles	
Electricity	2.2	kwh	23.7
Total Transportation			825

Environmental Emissions	Process	Fuel	Total	
Atmospheric Emissions				
Aldehydes	0.054	0.033	0.087	lb
Ammonia	0.26	4.5E-04	0.26	lb
Carbon Dioxide	8.4	2,370	2,379	lb
Carbon Monoxide	-	2.4	2.4	lb
Chlorine	1.6E-04	1.8E-05	1.7E-04	lb
Hydrocarbons	15.3	19.0	34.4	lb
Hydrogen Chloride	1.1E-04	1.3E-05	1.2E-04	lb
Kerosene	-	8.2E-05	8.2E-05	lb
Lead	1.0E-06	1.4E-04	1.4E-04	lb
Methane	-	0.043	0.043	lb
Nitrogen Oxides	-	4.8	4.8	lb
Other Organics	-	0.38	0.38	lb
Particulates	0.081	0.91	0.99	lb
Propylene	-	-	-	lb
Propylene Oxide	-	-	-	lb
Sulfur Oxides	0.70	5.0	5.7	lb
Solid Wastes	12.2	45.3	57.4	lb
Waterborne Wastes				
Acid	0.010	9.8E-08	0.010	lb
Ammonia	0.017	1.6E-04	0.017	lb
BOD	0.038	0.0012	0.039	lb
Chromium	1.3E-04	3.9E-07	1.3E-04	lb
COD	0.13	0.0057	0.13	lb
Dissolved Solids	1.1	0.080	1.1	lb
Iron	2.9E-04	0.070	0.070	lb
Lead	1.4E-06	1.7E-07	1.6E-06	lb
Metal Ion	0.017	0.0021	0.019	lb
Oil	0.19	0.0067	0.20	lb
Phenol	1.2E-04	6.7E-06	1.3E-04	lb
Sulfuric Acid		0.28	0.28	lb
Suspended Solids	0.039	0.0011	0.040	lb
Zinc	2.1E-05	2.5E-06	2.3E-05	lb

* Values include precombustion and combustion energy and emissions.
Source: Franklin Associates, Ltd.
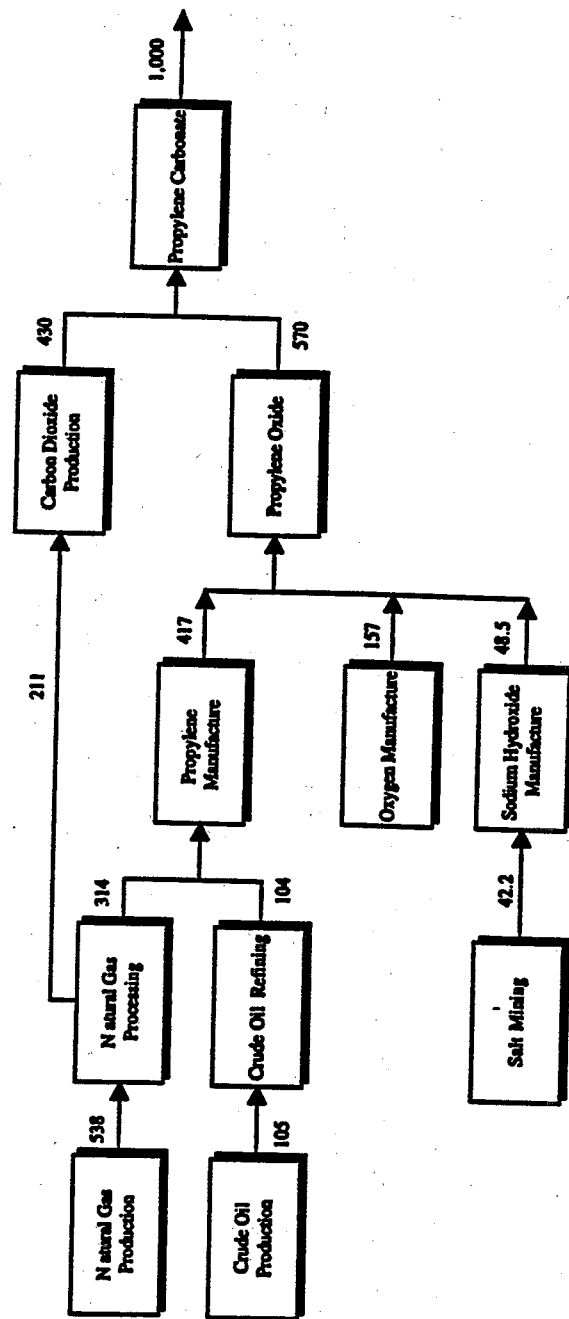
Figure A-3. Flow diagram for the production of 1,000 ounds of propylene carbonate (PC). Numbers represent weight of materials in pounds.

Propylene Manufacture

The primary process used for manufacturing propylene and other olefins is the thermal cracking of saturated hydrocarbons such as ethane, propane, naphtha, and other gas oils. Currently, the feedstocks in the United States are approximately 75 percent ethane/propane and 25 percent naphtha.

Typical production of propylene and other coproducts begins when hydrocarbons and steam are fed to the cracking furnace. After being heated to temperatures around 1,000 degrees Celsius, the cracked products are quenched in heat exchangers which produce high pressure steam. Fuel oil is separated from the main gas stream in a multistage centrifugal compressor. The main gas stream then undergoes hydrogen sulfide removal and drying. The final step involves fractional distillation of the various reaction products.

Oxygen Manufacture

Oxygen is manufactured by cryogenic separation of air, a technique by which air is liquefied, and the oxygen is collected by fractionation. The oxygen is produced in the form of a liquid which boils at 300°F below zero at normal atmospheric pressure.

Propylene Oxide Manufacture

The propylene oxide for the production of propylene carbonate in PC2 is manufactured by the isobutane hydroperoxide process. In this process, propylene oxide and tert-butyl alcohol are formed from isobutane, oxygen, and propylene. Isobutane is first oxidized to the intermediate, tert-butyl hydroperoxide. Some tert-butyl alcohol is formed in this step. A low conversion of isobutane is used to minimize the tert-butyl alcohol that is produced in this reaction. The unreacted isobutane is recycled.

The tert-butyl hydroperoxide and alcohol mixture is combined with propylene at a rate of two to six moles of propylene per mole of hydroperoxide. This is reacted to nearly 100 percent conversion of the hydroperoxide over a catalyst usually made of molybdenum. The products stream contains propylene oxide and tert-butyl alcohol. Propylene and propylene oxide are separated from the product in distillation columns. Recoverable catalyst is also obtained in the heavy end bottoms from the purification columns.

Propylene Carbonate Production

Propylene carbonate is produced by the reaction of propylene oxide with carbon dioxide over a tetraethyl/ammonium bromide catalyst. In this case, the equipment used to produce propylene carbonate is also used to produce ethylene carbonate. Wastewater is generated when equipment is rinsed between product changes. Solid waste generated is assumed to be small and is not considered in this study.

The PC component of the PC2 solvent blend is assumed to be produced on the Texas gulf coast and transported to Oklahoma City for blending. The total energy requirements and

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environmental emissions for producing 1,000 pounds of PC from raw materials acquisition (natural gas and crude oil) through production of PC are aggregated and displayed in Table A-3.

Table A-3. Data for the Production of 1,000 Pounds of Propylene Carbonate (PC)

Energy Usage			Energy* Thousand Btu
Energy of Material Resource			
Natural Gas	559	lb	12,539
Petroleum	109	lb	2,100
Total Resource			14,639
Process Energy			
Electricity	165	kwh	1,748
Natural gas	7,014	cu ft	7,869
LPG	0.018	gal	1.9
Coal	2.0	lb	22.7
Distillate oil	0.14	gal	21.0
Residual oil	6.7	gal	1117
Gasoline	0.060	gal	8.4
Total Process			10,788
Transportation Energy			
Combination truck	240	ton-miles	
Diesel	2.8	gal	440
Rail	64.8	ton-miles	
Diesel	0.20	gal	31.2
Barge	7.7	ton-miles	
Diesel	0.015	gal	2.4
Residual oil	0.0046	gal	0.77
Ocean freighter	213	ton-miles	
Diesel	0.021	gal	3.3
Residual	0.21	gal	35.7
Pipeline-natural gas	36.8	ton-miles	
Natural gas	84.6	cu ft	94.9
Pipeline-petroleum produc	14.9	ton-miles	
Electricity	0.33	kwh	3.5
Total Transportation			612

Environmental Emissions

	Process	Fuel	Total	
Atmospheric Emissions				
Aldehydes	0.0042	0.024	0.028	lb
Ammonia	0.43	4.4E-04	0.43	lb
Carbon Dioxide	3.1	1,534	1,537	lb
Carbon Monoxide	-	1.7	1.7	lb
Chlorine	2.1E-05	1.7E-05	3.9E-05	lb
Hydrocarbons	19.1	11.3	30.4	lb
Hydrogen Chloride	1.6E-05	1.3E-05	2.9E-05	lb
Isobutane	3.3	-	3.3	lb
Kerosene	-	9.4E-05	9.4E-05	lb
Lead	1.5E-07	1.3E-04	1.3E-04	lb
Methane	-	0.025	0.025	lb
Nitrogen Oxides	-	3.5	3.5	lb
Other Organics	-	0.34	0.34	lb
Particulates	0.0063	0.65	0.66	lb
Propylene	0.32	-	0.32	lb
Propylene Oxide	0.16	-	0.16	lb
Sulfur Oxides	0.90	3.6	4.5	lb
Solid Wastes	2.2	34.8	37.0	lb
Waterborne Wastes				
Acid	1.2E-07	9.6E-08	2.1E-07	lb
Ammonia	0.026	1.5E-04	0.026	lb
BOD	0.0015	0.0012	0.0026	lb
Chromium	4.7E-07	3.8E-07	8.5E-07	lb
COD	0.0069	0.0055	0.012	lb
Dissolved Solids	0.098	0.079	0.18	lb
Iron	4.4E-05	0.052	0.052	lb
Lead	2.3E-07	1.7E-07	4.0E-07	lb
Metal Ion	0.0025	0.0020	0.0045	lb
Oil	0.0070	0.0054	0.012	lb
Phenol	8.2E-06	6.6E-06	1.5E-05	lb
Sulfuric Acid	-	0.21	0.21	lb
Suspended Solids	0.0013	0.0011	0.0024	lb
Zinc	3.1E-06	2.5E-06	5.6E-06	lb

* Values include precombustion and combustion energy and emissions.
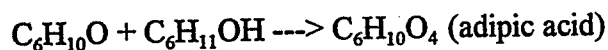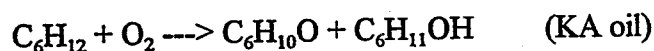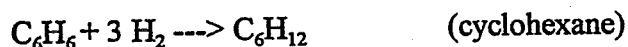Source: Franklin Associates, Ltd.

PC Blend 2

PC2 is produced by combining the NMP (50 wt%), DBE (25 wt%), and PC (25 wt%). The blending of the PC2 is assumed to take place in the Oklahoma City, OK area via a batch blending process. Energy for blending electricity and transportation to Oklahoma City are included.

Spent PC2 Disposal by Incineration

After the PC2 has been used to depaint the radomes, the sump is emptied by pumping the spent PC2 into steel drums for disposal. For the baseline scenario, spent PC2 is assumed to be transported approximately 190 miles to hazardous waste incineration facility in southeastern Kansas. Process emissions from incineration were calculated assuming complete combustion of the spent PC2 to carbon dioxide and nitrogen dioxide. The contribution of air combustion to total emissions was neglected. Fuel related energy and emissions arise from the transportation to the combustion facility. Combustion is assumed to occur without energy recovery.

The quantity generated and management of the paint chips that are captured in the stripping booth are not expected to change with the introduction and use of PC2. Paint chips will continue to be sent off-site for disposal as a hazardous waste. Waste management of paint chips was not within the scope of this study.

Recycling of Spent PC2

A possible alternative to disposal of the spent PC2 is recycling. DBE, NMP, and PC, the three components of PC2, have respective boiling temperatures of 115°-140°C, 202°C, and 242°C. Therefore, spent PC2 may be easily separated by fractional distillation. Distillation is assumed to take place at a theoretical recycling facility in Texas. It is assumed that a recovery of approximately 85 percent can be achieved with the recycling process. The 15 percent may either be lost at TAFB (adhering to paint chips or absorbed in the filter cloth) or in distillation. Either way, it is assumed to be collected and incinerated as a hazardous waste. Virgin PC, DBE, and NMP must be used to make up for the 15 percent loss and also the 0.5 percent evaporative loss. After recovery, it is assumed that the reblended PC2 mixture is transported back to TAFB for reuse. Energy and emissions for distillation, transportation to and from the recycling facility, and transport to the incinerator are included.

There is some concern that two components of the PC2 (NMP and the dimethyl succinate portion of the DBE) may form an azeotropic mixture, thus they could not be separated by fractional distillation (Reference A-3). If the three components need to be cleanly separated to be used in a product other than PC2, this could be a problem. However, if the mixture could be re-blended into PC2 for use at TAFB, the problem may be quite minor. It should be emphasized that the feasibility of recycling PC2 would need to be proven.

A-19

Radome Depainting at Tafb Using PC2

Introduction

An important element of any life cycle analysis (LCA) is the usage profile of the product or process under consideration. Usage practices can have a significant effect on the results of an LCA. From the standpoint of an LCA for PC2, usage practices at Tinker Air Force Base (TAFB) have a multiplier effect on energy use and environmental emissions from all the processes associated with the production of n-methyl-pyrrolidone (NMP), propylene carbonate (PC), and dibasic ester (DBE).

Because of the importance of usage practices on the results of an LCA, the following description of the depainting operation at TAFB is provided. The description assumes that PC2 is used in place of methyl ethyl ketone (MEK). Key assumptions and a detailed description of the depainting booth operation are presented. It is assumed that the change over to PC2 will not require any change to the existing capitol equipment. This provides a base case usage scenario which will be used in the impact and improvement analysis of this study. Disposition and usage alternatives of PC2 will be considered in the life cycle improvement analysis of this study.

Key Assumptions

Because PC2 is not currently being used in aircraft radome depainting operations at TAFB, key assumptions were made based on limited knowledge of how PC2 would likely perform in use. These assumptions form the baseline scenario and are listed below. A more detailed description of assumed radome depainting operations using PC2 follows the key assumptions.

- Basic radome depainting operations (i.e., receiving, stripping, and sanding) will remain the same when using PC2 in place of MEK.

- PC2 is received pre-blended in 55 gallon drums.

- 110 gallons of PC2 will be used for depainting ten KC-135 radomes.

- 180 gallons of PC2 will be used for depainting ten B-52 radomes.

- PC2 needed per single radome depainting is estimated to be 11 gallons per KC-135 radome and 18 gallons per B-52 radome. These figures take into account the use assumption described above.

- No significant spillage losses are expected when using PC2. A total evaporative loss of 1/2% of the PC2 is assumed during use at TAFB.

- Two hours of continuous showering per radome is required when using PC2.

- Sump pump and exhaust ventilation system are the only significant energy uses associated with the depainting booth.

- No significant water usage is associated with the depainting booth.

- Paint chips will continue to be managed off-site as a hazardous waste.

- Used PC2 will be pumped back into drums for off-site disposal by incineration as a hazardous waste

Depainting Booth Operations

For this analysis the PC2 is assumed to be delivered from a local blender to TAFB in 55 gallon steel drums pre-mixed and ready for use in the depainting booth. Following removal of used PC2 from the stripping booth sump, the new PC2 is poured from the drums into the sump. The sump is located below the grated floor of the booth, with a maximum volume of approximately 110 gallons. If the three chemicals were to be delivered individually, the PC2 would be formulated by mixing the chemicals in the sump of the stripping booth. The normal operation is assumed to fully charge the sump with approximately 110 gallons of PC2. No significant PC2 losses (e.g., spillage) are assumed for this step of the depainting process.

Radomes are moved under a shower head in the stripping booth for depainting. The PC2 is pumped from the sump to a shower head placed directly over the radome. The radome is continuously showered with the blend, causing removal of the topcoat paint and primer. The residue primer and topcoat is captured by passing the used PC2 through a filter sheet that is placed on the sump grate below the radome. The solvent flows through the filter to the sump where it is pumped to the shower head for reuse. When using MEK solvent, radome depainting in the stripping booth typically takes 1.5 to 3 hours. Based on previous test results, similar shower times are expected with the PC2. (For this analysis, 2 hours of continuous showering per radome is assumed for the baseline when using PC2.)

For the life cycle inventory analysis, the only significant energy use associated with depainting aircraft radomes is the electricity used to drive the exhaust ventilation system and the air compressor (for driving the pneumatic sump pump). Both the pump and exhaust fan are assumed to run only during depainting operations. Electricity requirements for the air compressor and exhaust system per radome depainted (i.e., 2 hours in the stripping booth) are estimated to be 1.5 and 11.6 kilowatt-hours (kwh), respectively.

Current radome depainting practices require approximately 50 gallons of MEK per KC-135 radome, and approximately 1.5 drums (83 gallons) for B-52 radomes. In contrast to depainting with MEK, using PC2 allows the solvent to be reused a number of times. For this analysis new PC2 is assumed to be reused for ten radome depaintings. Based on estimates provided by TAFB personnel, PC2 usage requirements are assumed to be 110 gallons per 10 KC-135 radomes, and

180 gallons per 10 B-52 radomes. The surface areas of the radomes (49 ft²/KC-135 radome and 116 ft²/B-52 radome) have no direct correlation to the amount of PC2 used for depainting (2.2 gal/ ft² for KC-135 and 1.6 gal/ft² for B-52 radomes). Assuming 100 KC-135 radomes and 40 B-52 radomes are depainted annually (estimated based on 1994 statistics), 1,820 gallons, or approximately 33 drums, of PC2 per year would be required for depainting radomes at TAFB.

During depainting, a large percentage of the MEK is lost to the atmosphere through evaporation. Because PC2 has a very low vapor pressure, evaporative losses to the atmosphere during depainting are assumed to be insignificant. PC2 evaporative losses do, however, occur after depainting when the radome is allowed to sit and dry. This evaporative loss is estimated from the differences in the vapor pressures between PC2 and MEK. The vapor pressure of PC2 is approximately 0.3 percent of the MEK vapor pressure. In this case, MEK was assumed to represent 100 percent evaporation and a conservative evaporation rate of 0.5 percent was assumed for the PC2.

After the PC2 has been used to depaint the radomes, the sump is emptied by pumping the spent PC2 into steel drums for disposal. For the baseline analysis, spent PC2 is assumed to be shipped off-site for disposal by incineration as a hazardous waste. The quantity generated and management of the paint chips that are captured in the stripping booth are not expected to change with the introduction and use of PC2. Paint chips will continue to be sent off-site for disposal as a hazardous waste. Waste management of paint chips is outside the scope of this study.

Appendix A References

A-1   Series of energy and environmental impact studies performed by Franklin Associates, Ltd. for various government and private clients, 1974-1994.

A-2   Welch, R.O., et al. **Study of Environmental Impacts of Disposables versus Reusables.** Prepared for the U.S. Environmental Protection Agency by Midwest Research Institute and Franklin Associates, Ltd. April 1, 1977.

A-3   Personal communication between Franklin Associates, Ltd. and industry representatives (i.e. Jeff Folks).

A-4   **Hydrocarbon Processing**, November issues, 1972-1989.

A-5   **Riegel's Handbook of Industrial Chemistry**. Ninth Edition. Edited by James A. Kent. Van Nostrand Reinhold. New York. 1992. p. 1109-1115.

A-6   **Kirk-Othmer Encyclopedia of Chemical Technology.** Third Edition. Volume 2. John Wiley and Sons. New York. 1982. p. 276-282.

A-7   **Riegel's Handbook of Industrial Chemistry.** Ninth Edition. Edited by James A. Kent. Van Nostrand Reinhold. New York. 1992.

A-8   **Energy and Materials Flows in Petroleum Refining.** ANL/CNSV-10. Argonne National Laboratory. February 1981.

A-9   **Hydrocarbon Processing - Refining Handbook '92.** November 1992. Volume 71. Number 11.

A-10   **1989 Industrial Process Heating Energy Analysis.** Gas Research Institute. May, 1991.

A-11   Gary, James H. and Glenn E. Handwerk. **Petroleum Refining - Technology and Economics.** Marcel Dekker, Inc. 1984.

A-12   Meyers, Robert A., ed. **Handbook of Petroleum Refining Processes.** McGraw-Hill Book Company. 1986.

A-13   **Riegel's Handbook of Industrial Chemistry**. Ninth Edition. Edited by James A. Kent. Van Nostrand Reinhold. New York. 1992. p. 1109-1115.

A-14   **Kirk-Othmer Encyclopedia of Chemical Technology.** Third Edition. Volume 1. John Wiley and Sons. New York. 1982. p. 211-235.

A-15 **Encyclopedia of Chemical Processing and Design.** Executive editor John M. McKetta. Marcel Dekker, Inc. New York and Basel. Volume 1. p. 372-382.

A-16 **Kirk-Othmer Encyclopedia of Chemical Technology.** Fourth Edition. Volume 1. John Wiley and Sons. New York. 1991. p. 195-215.

A-17 Monsanto Research Corp. **Potential Pollutants from Petrochemical Processes. 1975.**

A-18 **Kirk-Othmer Encyclopedia of Chemical Technology.** Fourth Edition. Volume 1. John Wiley and Sons. New York. 1991. p. 195-215.

A-19 **Ullman's Encyclopedia of Industrial Chemistry.** Fifth Edition. Volume A1. p. 274.

A-20 **Encyclopedia of Chemical Processing and Design.** Volume 19. New York and Basel. John J. McKetta, editor. p. 397-398.

A-21 **Ullman's Encyclopedia of Industrial Chemistry.** Volume A22. p. 458-459.

A-22 **Kirk-Othmer Encyclopedia of Chemical Technology.** Third Edition. Volume 19. John Wiley and Sons. New York. 1982. p. 510-517.

A-23 **Hydrocarbon Processing.** Petrochemical Handbook for the years 1973-1989.

A-24 **Kirk-Othmer Encyclopedia of Chemical Technology.** Third Edition. Volume 13. John Wiley and Sons. New York. 1982.

A-25 Meyers, Robert A. **Handbook of Chemicals Production Processes.** McGraw Hill, Inc. 1986.

A-26 U.S. Bureau of Mines. **Minerals Yearbook.** 1989 and earlier years.

A-27 The Chlorine Institute, Inc. **North American Chlor-Alkali Plants and Production Data Book.** Chlorine Institute Pamphlet. January 1994.

A-28 U.S. Department of the Interior, Bureau of Mines. **Mineral Facts and Problems.** 1984.

A-29 U.S. Department of Interior, Bureau of Mines. **Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4 - Energy Data and Flowsheets, etc.).** Prepared by Battelle Columbus Laboratories. Washington, D.C. June, 1975.

A-30 K. Weissermel and H.-J. Arpe. **Industrial Organic Chemistry.** Verlag Chemie Weinheim. New York. 1978.

A-31 Energy Information Administration. **Petroleum Supply Annual 1993.** Volume 1. June, 1994.

Appendix B
Classification Methodology and Results
For Partial Impact Assessment for the
Use of PC Blend 2 in Aircraft Radome Depainting

Introduction

This appendix contains the methodology and results for impact classification of the air and waterborne releases occurring in the production and use of PC Blend 2 in aircraft radome depainting. These results have been prepared with the assistance of Dr. James Cholakis as a subcontractor to Franklin Associates, Ltd.

Inventory chemicals reported as atmospheric emissions or waterborne emissions were classified into **potential** impact categories by surveying chemical, environmental, and toxicological data for incorporation under two major global groups: ecosystem and human health. Results from this classification scheme may help to establish common or equivalent impacts for a large number of diverse environmental chemicals. No pollutant quantities have been applied to the categories in this appendix. The solid wastes reported on the emissions inventories were not classified into potential impacts categories. Once the solid waste is disposed of, any atmospheric and waterborne emissions that result are related to the combination of wastes from different sources and not to one single source.

Methodology

The scientific literature was surveyed in order to classify inventory chemicals or emissions (atmospheric and water releases) into potential impact categories. The following inventory emissions or chemicals were researched for this classification:

Acid	Aldehyde	Ammonia
BOD (Biochemical Oxygen Demand)	Carbon Dioxide	Carbon Monoxide
Chlorine	Chromium	COD (Chemical Oxygen Demand)
Dimethyl Adipate	Dimethyl Glutarate	Dimethyl Succinate
Dissolved Solids	Hydrocarbons	Hydrogen Chloride
Iron	Isobutane	Kerosene
Lead	Mercury	Metal Ion

Methane	N-Methyl Pyrrolidone	Nickel
Nitrogen	Nitrogen Oxides	Odorous Sulfur
Oil	Other Organics	Particulates
Phenol	Propylene	Propylene Carbonate
Propylene Oxide	Sulfides	Sulfur Oxides
Sulfuric Acid	Suspended Solids	Zinc

For the major global groups under the ecosystem, potential impact categories may include:

- Greenhouse Gas - Global Warming
- Ozone Depleting Gas - Stratospheric Ozone Depletion
- Acid Rain Precursor - Acid Rain
- Smog Precursor - Photochemical Smog - Tropospheric Ozone
- Air Dispersion/Aging/Transport
- Aquatic Life
- Eutrophication/Plant Life
- Visibility Alterations (air or water)
- Weather Alterations
- Thermal Changes
- pH Alterations
- Chemical/Biological Content Alteration
- Oxygen Depletion
- Aquifer Contamination

Many of the impact categories are directly related to chemical emissions and are described in detail in the potential impacts section which follows. Examples include greenhouse gases, stratospheric ozone depleting gases, acid rain precursors, and smog precursors. Air dispersion/aging/transport, visibility alterations, weather alterations, and thermal changes are impact categories used to describe the dynamics of air-chemical interactions, and may be more appropriately combined under other potential impact categories (i.e., smog precursor or acid rain for particulates).

Still others are results of standardized environmental quality measurements that are difficult to relate to specific chemical emissions. These include suspended solids, chemical oxygen demand, biochemical oxygen demand, dissolved solids, metal ion, and waterborne acid. These tests are indicators of water quality and are categorized as potentially affecting aquatic life.[1]

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[1] Physical, chemical, and microbiological tests of water quality may include acidity, alkalinity, color, odor, turbidity, chemical oxygen demand (COD), dissolved oxygen (D), total oxygen demand (TOD), hardness, biochemical oxygen demand (BOD), salinity, pH, acid neutralizing capacity, dissolved organic carbon, suspended solids, total

For the major global human health group, potential impact categories may include:

- Human Carcinogen (Class A)
- Irritant (Eye, Lung, Skin, GI Tract)/Corrosive
- Respiratory System Effects
- Central Nervous System Effects
- Allergenicity/Sensitization
- Blood Dyscrasias (methemoglobinemia or hematopoietic)
- Odors
- Cardiovascular System Effects
- Reproductive System Effects
- Behavioral Effects
- Bone Effects
- Renal Effects.

Under human health, inventory chemicals were researched for potential impacts that best represented *potential low level general population exposures*. Without concrete exposure data, the estimation or classification of chemicals to impact categories may be an oversimplification of risk and potentially in error by many orders of magnitude. Furthermore, adverse health effects observed in humans from high acute or high chronic exposures were **not** used in this analysis (i.e., industrial or occupational accidents or intentional overdoses) because it is unlikely to be relevant to the processes studied. These events are unusual occurrences in the processes studied.

To emphasize, there is no representation or implication in this report as to exposure quantification (i.e., dose). Since actual exposure data is lacking, the classification of a chemical to a potential ecological impact category or human health target site does not indicate that actual impacts will be observed. It implies only that there is a potential linkage between the environmental emissions and the impacts.

Workplace or occupational exposures may have been considered for background information and, where applicable, included in this report if the inventory chemical was classified by regulatory agencies as a class A human carcinogen. However, occupational evaluation was not considered directly relevant to this classification analysis since no exposure or concentration data were available. Moreover, there are over six million workplaces (industrial and non-industrial) in the U.S., and an overall impact analysis is not practicable because of variable or unknown concentration levels.

Similarly, animal toxicology data were not directly incorporated into this analysis since experimental design criteria (i.e., high dose studies, inbred animal strains) in toxicity studies,

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dissolved solids (TDS), electrical conductivity, and bacterial/fungal growth.

particularly carcinogenesis studies, may not be relevant to very low level general population exposure. Toxicology data were used as background information.

To repeat, the purpose of this part of the impact analysis was to classify each chemical or inventory emission into a potential impact site (ecosystem) or potential target organ (human health), *assuming* that the chemical or inventory emission was present at very low concentrations and under hypothetical conditions of low level general population consumer exposure, not workplace environments. The goal was to produce a relative impact analysis, not an absolute analysis. It is not certain that all of the inventory releases actually cause the impact under which they are classified.

Potential Impacts

Table B-1 (at the end of this appendix) summarizes the classification of inventory chemicals by potential impact. After a general survey of the scientific literature, the basis for these classifications is presented below by chemical.

Many of the chemicals can affect multiple impact categories, but, where practicable, the predominant or the most predictable impact categories were chosen for each inventory chemical. By reading across the tables, it can be noted that a specific impact category can be affected by a number of chemicals. For example, inventory chemicals identified as potentially contributing to the green house gas pool are carbon dioxide, carbon monoxide, chlorine compounds, and methane. Chemicals identified as potentially impacting or contributing to the eutrophication/plant life category are acid, ammonia, hydrogen chloride, nitrogen oxides, sulfur oxides, metal ion, and nitrogen.

Similarly, inventory chemicals potentially having an effect on the respiratory system under the major category of human health were carbon monoxide, chlorine compounds, nitrogen oxides, particulates, sulfur oxides, and sulfuric acid.

The following background information provides a partial basis for classification of inventory emissions into potential impact categories. Emissions are discussed in the order in which they are presented in Table B-1. The letters "A" and/or "W" in parentheses following the name indicates whether the emission is atmospheric, waterborne, or both.

The following emission categories are not discussed:

    Acid (A, W)
    BOD (W)
    COD (W)
    Dissolved Solids (W)

Metal Ion (W)
Sulfides (W)
Suspended Solids (W)

Some of the categories are results of standardized environmental quality measurements and are difficult to relate to specific chemical emissions. The specific chemical compositions of inorganic and organic solids are not identified in the available data and therefore are not discussed in the following summary information.

1. ALDEHYDES (A)

Ecosystem: Smog Precursor/Tropospheric Ozone
                Aquatic Life
                Visibility Alterations

Formaldehyde is a common aldehyde released to the environment. It is used in the production of ethylene glycol, a chemical used in the manufacture of PET resin. The chemical has a short half-life in the atmosphere because it is degraded by photochemical processes. Aldehydes also occur as a chemical byproduct of manmade hydrocarbons released to the air that photo-oxidize to form formaldehyde and acrolein and many other byproducts. About 50% of the total aldehyde concentration in ambient air is formaldehyde, about 15% is acetaldehyde, and about 5% is acrolein.

Human Health: Eye Irritant
                Respiratory Irritant

Aldehydes probably contribute to photochemical smog and to the eye irritation caused by smog. Acrolein is more irritating than formaldehyde even at a much lower

concentration. Another aldehyde with similar but lesser effects than formaldehyde is propionaldehyde.

2. AMMONIA (A, W)

Ecosystem: Eutrophication/Plant Life
                Aquatic Life
                pH Alterations

Ammonia is a naturally occurring compound which is a key intermediate in the nitrogen cycle. In the environment it is an aquatic plant nutrient which can stimulate excessive plant growth (eutrophication). The chemistry and toxicity in the environment can be different with the same concentration of ammonia, depending on other characteristics of the receiving water. Rain can be

a prominent source of the ammonia gas deposited to surface waters. Ammonia may kill fish at 1 mg/liter of water by decreasing the oxygen combining capability of fish hemoglobin. In water, the toxic action depends on the pH; toxicity increases with increased pH and with low concentrations of dissolved oxygen.

Human Health: Odors
Eye Irritant
Nasal Irritant
Respiratory Irritant

The main route of exposure to the general population is through inhalation and dermal contact with household cleaning products.

3. CARBON DIOXIDE (A)

Ecosystem: Greenhouse Gas

The major anthropogenic greenhouse gas in the atmosphere is carbon dioxide, resulting primarily from the combustion of fossil fuels. It is estimated that the relative contribution of carbon dioxide to total greenhouse gases may be as high as 70%.

Human Health: Central Nervous System Effects

It has been suggested that high concentrations of carbon dioxide in office and school environments (non-industrial workplace environments) may be associated with indoor air quality complaints (headache and dizziness).

4. CARBON MONOXIDE (A)

Ecosystem: Greenhouse Gas
Ozone Depleting Gas

About two-thirds of all carbon monoxide (CO) emissions come from transportation activities, with the combustion of solid waste and fuel providing most of the remainder. Carbon monoxide as an inventory emission is classified as a greenhouse gas on the basis of its infrared absorbing properties. Although it is a relatively weak greenhouse gas, it is extremely important because of its reactions with the hydroxyl radical, OH. If the concentration of CO continues to increase, the resulting decrease in the OH concentration could increase the lifetime (and produce larger concentrations) of important greenhouse gases such as methane, CH_4.

Human Health: Respiratory System Effects
Cardiovascular System Effects

Effects from exposure to carbon monoxide at ambient levels are generally limited to respiratory symptoms in elderly individuals whose symptoms are closely related to the carboxyhemoglobin concentration in blood. Although not scientifically established, any chemicals that decrease the available oxygen to the heart are primary suspects for adverse cardiovascular effects.

5. ODOROUS SULFUR (CARBONYL SULFIDE) (A)

Ecosystem: Ozone Depleting Gas

The most abundant sulfide in the atmosphere is carbonyl sulfide.

Human Health: Odors

6. CHLORINE COMPOUNDS (A)

Ecosystem: Greenhouse Gas
Ozone Depleting Gas

The inventory chemical "Chlorine Compounds" may also include chlorofluorohydrocarbons (CFCs), brominated compounds, methyl chloroform (1,1,1-trichloroethane), HCFCs (transitional fluorocarbons), methyl bromide (fumigant), and carbon tetrachloride. Chlorine and bromine released into the atmosphere have been implicated as major factors in stratospheric ozone depletion.

Human Health: Eye Irritant
Respiratory System Effects
Corrosive

Also see Hydrocarbons (10) and Other Organics (18).

7. DIMETHYL ADIPATE (A)

Ecosystem: Water quality/aquatic Life

Dimethyl adipate (hexanedecanoic acid) is produced in significant quantities but how much is released to affect the environment is not known. It is used as a plasticizer in cellulose type resins, thus being a potentially significant source of exposure to consumers. Information on environmental fate is scanty since few studies are available for review. The low vapor pressure and capacity to hydrogen bond, along with its high water solubility suggest that the ester will not readily volatilize from water or soils. Therefore, its potential effects will concern water quality

and aquatic life. Studies show dimethyl adipate to be moderately toxic to fathead minnows (LC50 at 96 hours is 18-24 mg/L).

Human Health: Irritant (eye and skin)
                 Respiratory system (lung)

Exposure to dimethyl adipate most likely occurs in workers during its manufacture as a plasticizer. The general population might be exposed to it from using products containing cellulose-type resins in which dimethyl adipate was used as a plasticizer. Dimethyl adipate may irritate the skin, causing discomfort or rash. Contact with the eyes may cause irritation with discomfort, tearing, or blurry vision. Blurry vision has also been observed when some individuals have been overexposed to dimethyl adipate by inhalation or skin contact. Inhalation may cause irritation of the upper respiratory passages, coughing and discomfort. Animal data from experiments with rabbits and rats showed it to be mildly irritating to eyes and skin, and very low toxicity if ingested orally. Animal experiments with rat fetuses show some teratogenic abnormalities at high concentrations of dimethyl adipate.

8. DIMETHYL SUCCINATE (A)

Ecosystem: Water quality/aquatic Life

Dimethyl succinate (butanedioic acid, dimethyl butanedioate) has been shown to be moderately toxic to fathead minnows (see dimethyl adipate).

Human Health: Irritant (eye)
                 Respiratory system (lung)

Dimethyl succinate may irritate the eyes, nose and throat, and cause blurry vision and tearing. The mechanism of blurred vision in humans is unknown. However, since the formulation contains a small amount of methanol, this could be a contributing cause. Inhalation of vapors may cause irritation of the upper respiratory passages, coughing and discomfort. Animal data for dimethyl succinate showed it to be a mild eye, but not a skin irritant. The compound did not produce genetic damage in bacterial cell cultures.

9. DIMETHYL GLUTARATE (A)

Ecosystem: Water quality/aquatic Life

Dimethyl glutarate (pentanedioic acid, dimethyl pentanedioate) has shown moderate toxicity in bluegill sunfish (96 hour LC50 is 30.9 mg/L) and moderate toxicity in fathead minnows (96 hour LC50 is 18-24 mg/L). Its major use is as a chemical intermediate in different resins for paper, coating, and plasticizers.

Human Health: Irritant (skin and eye)
                 Respiratory system (lung)

Dimethyl glutarate may cause irritation, discomfort, and rash on contact with the skin. Contact with eyes may cause irritation with discomfort, tearing, or blurring of vision. Exposure by inhalation of dimethyl glutarate may irritate the upper respiratory passages causing discomfort and coughing. Dermal contact or overexposure by inhalation has caused blurry vision in some individuals.

10. HYDROCARBONS (A)

Ecosystem: Smog Precursor

The hydrocarbons found in the atmosphere comprise an extremely numerous and chemically diverse group of compounds. Methane is the most abundant of the hydrocarbons. Methane and kerosene are treated separately. Other hydrocarbon emissions include (but are not limited to) methyl chloroform (1,1,1-trichloroethane), benzene, toluene, naphthalene, ethyl benzene, isobutane, propylene, and triphenylmethane.

Methyl chloroform is a colorless solvent which can be found in both groundwater and the atmosphere. When discharged or leached into the groundwater, it can eventually evaporate into the air. In the atmosphere, methyl chloroform photochemically decomposes to produce carbon monoxide, hydrogen chloride, phosgene, and other halogenated products. Therefore, it contributes to ozone depletion and greenhouse effects.

Human Health: Eye Irritant
                 Odor
                 Human Carcinogen

Various hydrocarbons contribute to different human health effects.

Inhalation is the main route of exposure to methyl chloroform. At high concentrations it produces mild eye irritation and throat irritation; however, humans may also be exposed dermally and orally.

Benzene is a class A human carcinogen.

Propylene, an aliphatic hydrocarbon, is a colorless, flammable gas of low toxicity.

Ethyl benzene is a flammable liquid with a very pungent odor. High concentrations of ethyl benzene may primarily present an eye irritation hazard, and secondarily may produce central nervous system effects.

B-9

Isobutane is a flammable gas, and direct contact may produce chemical burns. High concentrations of isobutane at or near animal acute LD_{50} levels may produce central nervous system and respiratory depression.

Note: The toxicology of hydrocarbons in the context of air pollution is not of major concern in this classification since their concentrations in ambient air do not usually reach levels high enough to produce adverse effects. They are important, however, because most enter into chemical reactions that may potentially lead to the formation of photochemical smog.

11. HYDROGEN CHLORIDE (A)

Ecosystem: Smog Precursor/Photochemical Smog
Aquatic Life
Eutrophication/Plant Life
pH Alteration (acidity)

Hydrogen chloride (in aqueous solution hydrochloric acid) can be emitted to the atmosphere during the manufacturing of hydrogen chloride.

Human Health: Irritant (eye, lung, skin)

Hydrochloric acid is a potential cause of chronic bronchitis and asthma because it is carried on ultra-fine metal particles, which are breathed deeply into the lungs.

12. KEROSENE (A)

Ecosystem: Oxygen Depletion
Chemical/Biological Content Alteration

Kerosene is a mixture of petroleum hydrocarbons, chiefly C10 - C16 alkanes. A typical chemical analysis may include n-dodecanes, alkyl benzene derivatives, naphthalene, and tetrahydronaphthalenes. Therefore it is difficult to predict the ecological effects of kerosene as a whole. Several components of kerosene may bioconcentrate in fish and aquatic organisms, and may bind to soil depending on its water content, whereas other components of kerosene may not bind to soil and migrate or evaporate.

Human Health: No apparent impact categories

Large concentrations if inhaled or aspirated may cause chemical pneumonitis. Potential human health effects would be predicted to be consistent with the hydrocarbon category.

13. LEAD (A, W)

Ecosystem: No apparent impact categories

Lead in the environment is mainly caused by anthropogenic sources such as automobile gasoline combustion, mining, and smelters; higher concentrations occur in urban areas and along roadsides. It is very persistent in both water and soil. Emissions from farm machinery can lead to contamination of food crops. Lead in the form of solid wastes is also a large source of lead contribution to the environment.

Human Health: Reproductive System Effects
                  Behavioral Effects
                  Cardiovascular System Effects

Susceptible general populations are preschool children, unborn fetuses, and white males 40-59 years old. Humans are exposed to excess lead in foods and air (dust). It is not a proven carcinogen. The same toxic effects occur whether it is ingested or breathed. Exposure of pregnant women transfers to the fetus and may cause preterm birth, lower birth weight or low IQ in the infant. Preschool children who are exposed through household and lead paint dust by hand-to- mouth activity may have decreased IQ and reduced growth. Middle-aged white men may suffer increased blood pressure. At high levels, severe brain and kidney damage have been reported, along with spontaneous abortion and male sterilization.

14. MERCURY (A, W)

Ecosystem: Aquatic Life

Mercury exists in inorganic and organic forms in nature. The inorganic form exists in drinking water. The organic form can become highly (10,000-100,000 times) concentrated in the flesh of certain fish; low levels of organic methylmercury contamination of the oceans and lakes can lead to high levels in pike, tuna, and swordfish. Eight hundred metric tons per year are released to global surface water by weathering of rocks containing mercury. Industrial effluents, mining processes, application of fertilizer and fungicides to soil which leaches into water, and solid disposal of mercury-containing products (i.e., batteries and thermometers) in landfills which leach into the soil also contribute to excess levels in water.

Human Health: Central Nervous System (developing nervous system)

Irreversible damage to the human brain, kidneys, and developing fetuses occurs with excess mercury exposure, but it has not been proven to be carcinogenic. Humans may be exposed if they have high dietary fish intake since methylmercury bioaccumulates in the top of aquatic food chains. The general population is also exposed through drinking water that contains mercury.

Recent investigations suggest that humans may be exposed from dental amalgams. Occupational exposures usually result from inhalation of the organic mercury vapor.

15. METHANE (A)

Ecosystem: Greenhouse Gas
Ozone Depleting Gas

Methane is produced by anaerobic digestion of animal waste, the natural breakdown of sewage, and through industrial production. Combustion of methane gas leads to the production of carbon monoxide, water, and carbon dioxide (greenhouse gases). Methane is a good absorber of infrared radiation. In fact, recent analysis suggests that methane contributes about 10% to the greenhouse gas pool.

Human Health: No apparent impact categories

Methane has no physiological effects, but at high concentrations can be an asphyxiant by displacing oxygen.

16. N-METHYL-2-PYRROLIDONE (NMP) (A)

Ecosystem: No apparent impact categories

NMP has many commercial applications. It is used as an intermediate in the pharmaceutical and agricultural chemical industries and as a replacement solvent for more toxic materials in a variety of industrial uses such as paint and coating removal. It is approved by the FDA for indirect contact with food. If released to the environment, it readily undergoes biodegradation under aerobic conditions in soil and water, and reacts with photochemically induced hydroxyl radicals in the atmosphere along with removal by wet deposition processes. NMP is considered a natural substance and has been identified in roasted nuts.

Human Health: Irritant (eye, skin)
Hematopoietic system (?)

Occupational exposure to NMP may occur by inhalation or dermal contact during its production or use. It is estimated that the permissible daily inhalation dose to humans is 1.2 mg/kg/day. In humans NMP has been found to be mildly irritating to the eye, but is not expected to cause permanent eye damage. In the general human population, ingestion of food or contaminated drinking water is the principal pathway for exposure. In animal studies at high test concentrations, the vapors and mists can produce burning and irritation to the nose, throat and mucous membranes of the respiratory tract, cough, laryngitis, lung damage, emphysema, and

death. In animals, based on the available evidence, the hematopoietic system appears to be the principal target organ for NMP toxicity. No evidence exists for carcinogenicity.

17. NITROGEN OXIDES (A)

Ecosystem: Acid Rain Precursor
            Smog Precursor
            Aquatic Life
            Eutrophication/Plant Life
            Visibility Alterations (air)

The key nitrogen oxide in ecological and human health is nitrogen dioxide (NO_2). Nitrogen dioxide is a major by-product of fossil fuel combustion and a major contributor to photochemical oxidation. As a smog precursor gas, nitrogen dioxide reacts with other atmospheric gases to form ozone. As an acid rain precursor, nitrogen dioxide is converted to nitric acid, and through wet and dry deposition (clouds, rain) enters surface and groundwater to lower pH.

The absorption of short wavelength sunlight by gaseous NO_2 results in a brownish discoloration of the atmosphere, thus reducing visibility.

Nitrogen oxides are also a source of nitrogen, which may promote plant growth. Because nitrogen is the most commonly limiting nutrient to growth in both managed and unmanaged terrestrial ecosystems, deposition of nitrogen in any form has the potential to increase plant growth. Given the currently low ambient concentrations of nitrogen oxides, the effect on terrestrial ecosystems is probably small. In aquatic systems, however, the addition of nitrogen can trigger a rapid growth of organisms, turning the water turbid and green.

Human Health: Respiratory System Effects
               Odors
               Irritant/Corrosive

Some of the health effects of nitrogen dioxide include impairment of dark adaptation, changes in lung morphology and biochemistry, increased airway resistance, and eye and nasal irritation.

18. OTHER ORGANICS (i.e., carbon tetrachloride) (A, W)

Ecosystem: Ozone Depleting Gases

The emission category "Other Organics" includes a variety of organic chemicals, including carbon tetrachloride, which can contribute to ozone depletion. Carbon tetrachloride is not normally occurring in the environment and, since it evaporates rapidly, is found mostly as a gas in the atmosphere. It is produced in large quantities by man for use in manufacturing refrigerants, its

major current use. It is no longer used as widely as in the past due to its human health hazards. Carbon tetrachloride is very stable in air; elimination of 50% takes 30-100 years. In the troposphere it does not photodissociate since the vapor state has no chromophores to absorb light in the visible or near UV region of the spectrum. Ultimately, the carbon tetrachloride which is not removed by rainfall, diffuses up into the stratosphere where it may be photodegraded by shorter wavelength UV light to form chloroform and chlorine atoms. The chlorine formed by this reaction in the stratosphere can catalyze reactions that destroy ozone.

Human Health: Eye Irritation
                    Skin Irritation
                    Sensitization (propylene oxide)

Some organic chemicals included in the "Other Organics" category that can affect human health are carbon tetrachloride, propylene oxide, and acetophenone.

The general population is not exposed to excess levels of carbon tetrachloride. Susceptible people are usually workers involved in manufacturing chlorofluorocarbons, paint, and glue, or those who reside near these industries or waste sites. People who drink alcohol are usually much more susceptible to adverse effects from exposure than those who do not drink. Accidental excess occupational exposure on the job causes harmful health effects involving three organs: brain, liver, and kidneys. The effects can be very serious and permanent. There are no studies which establish that inhalation exposure to carbon tetrachloride poses a risk of human cancer. Concentrations and intake data are highly variable; more studies are needed to define the range of health risks to humans.

Propylene oxide, an epoxy compound, may produce tissue sensitization after repeated exposure, and may be classified as severely irritating to the eyes and skin in either the liquid or vapor form. According to the National Toxicology Program, propylene oxide is classified as an animal carcinogen via the inhalation route. However, the general population (consumer) exposure to propylene oxide may occur through the ingestion of residues in foods from its use as an indirect food additive and as an adjuvant for pesticides.

Acetophenone, a ketone, has an orange blossom odor and a low odor threshold (0.3 ppm). The principal hazards of high concentration of acetophenone are eye and skin irritation.

19. PARTICULATES (A)

Ecosystem: Acid Rain Precursor
              Smog Precursor
              Air Dispersion
              Chemical Alteration
              Weather Changes

Thermal Changes
Visibility Alterations (air)

Particulates refer to dispersed solid or liquid matter emitted into the atmosphere, of a size ranging between 0.01 and 100 microns. Particulates come from both natural and anthropogenic sources. Natural sources (sea spray, crustal erosion) typically result in larger particles, ranging between 1 and 100 microns, whereas anthropogenic sources (combustion, smelting) typically result in fine particles, ranging between 0.01 and 1 micron. Fine particles behave almost like a gas or vapor: they follow the airflow and are capable of traveling hundreds of miles (so are often called aerosols). They are also capable of coagulation and condensation. Larger particles have more of the characteristics of solid matter; they are strongly influenced by gravity and usually settle out close to their source.

The ecological effects of particulates include increasing atmospheric turbidity, leading to decreased visibility, and an effect on the energy balance of the earth, due to a change in the atmosphere's ability to absorb and reflect radiation. Particulates also promote the oxidation of sulfur dioxide to sulfate aerosols contributing to acid rain. Volatile metallic oxides of zinc, lead, and arsenic condense on the surfaces of fly ash particles and interact with hydrocarbons to form smog.

Human Health: Respiratory System Effects

The chemical behavior of particulates is determined either by the composition of the particles themselves or by the gases adsorbed by the surfaces of the particles. In some cases, the combination of particle and adsorbed gas produces a synergistic chemical effect more powerful than that of the individual components.

Particluates between 10 and 100 microns in size are inhaled, but are trapped by the upper respiratory tract and expelled. Particulates smaller than around 3 microns in size can escape the defense mechanisms of the upper respiratory tract and penetrate the deep lung. It is these fine particulates that are the cause for concern, for they can alter oxygen transfer in the lungs, and cause acute irritation of the sensitive lung tissue. Toxic oxides of lead, cadmium, vanadium, arsenic, and zinc often occur as fine particulates. In addition, because of their long lifetime in the atmosphere, fine particulates adsorb significant quantities of toxic gases such as SO_2 and HCl which can lead to synergistic health effects.

20. PROPYLENE (A)

Ecosystem: Smog precursor

Propylene occurs naturally in some fruits and plants, being biological in origin. Its release to the environment is wide spread since it is a ubiquitous product of incomplete combustion. If

released to the atmosphere, propylene will exist in the vapor-phase which may be degraded. Volatilization is expected to be the primary environmental fate in soil and water. It is expected to be released to the environment in the combustion gasses of hydrocarbon fuels, wood, and synthetic polymers such as polyethylene. It is unknown if propylene will biodegrade in the environment, but it is not expected to bioaccumulate or bioconcentrate in organisms and food chains. Propylene has been shown to affect plant growth.

Human Health: Respiratory system (lung)
                      Central nervous system

Under environmental conditions, propylene is a gas, therefore the most probable route of exposure for the general population is by inhalation of contaminated air. Propylene is usually handled commercially in liquid form, and will cause freezing burns when in contact with skin or eyes. Gross inhalation may cause reduced blood pressure and heart rhythm. Propylene has shown anesthetic effects in humans. In animal studies, it was found to be a cardiac sensitizer in dogs. There is inadequate evidence in humans or animals for the carcinogenicity of propylene.

21. PROPYLENE CARBONATE (A)

Ecosystem: No apparent impact categories

Human Health: Irritant (skin and eye)
                      Respiratory system (lung)

Propylene carbonate (carbonic acid, cyclic propylene ester) is used as a laboratory reagent, and has many potential uses in which it could react with other chemicals or materials. Human toxic effects due to overexposure to propylene carbonate include tightness and pain in the chest, coughing and difficulty in breathing if inhaled; skin irritation if in prolonged contact with the chemical; and eye irritation. Rabbit skin and eye irritation studies show moderate irritation effects.

22. PROPYLENE OXIDE (A)

Ecosystem: Smog precursor

Human Health: Irritant (skin and eye)
                      Respiratory system (lung)
                      Allergenicity/sensitization
                      Central nervous system

Propylene oxide, an epoxy compound, may produce tissue sensitization after repeated exposure, and may be classified as severely irritating to the eyes and skin in either the liquid or

vapor form. CNS effects have been reported in humans. According to the National Toxicology Program, propylene oxide is classified as an animal carcinogen via the inhalation route. However, the general population (consumer) exposure to propylene oxide may occur through the ingestion of residues in foods from its use as an indirect food additive and as an adjuvant for pesticides.

23. SULFUR OXIDES (A)

Ecosystem: Acid Rain Precursor
                  Air Dispersion/Aging/Transport (acid fogs)
                  Aquatic Life
                  Eutrophication/Plant Life

Sulfur oxides are emitted into the atmosphere by the combustion of fossil fuels, forming sulfate aerosols with particulate matter. Through nucleation processes with water (clouds, rain), they grow and form by peroxidation into sulfuric acid aerosols. Sulfur oxides, particularly sulfur dioxide, are important precursors to acid rain precipitation.

Human Health: Eye Irritant
                  Respiratory System Effects

In urban areas, respiratory effects have been associated with elevated sulfur dioxide concentrations, although its effects have not been separated from those of gaseous and particulate sulfur oxides. Concerns about sulfur dioxide emissions are mainly related to their role as sulfate precursors and dispersion to distant regions.

24. CHROMIUM (W)

Ecosystem: Aquatic Life

Solutions of hexavalent chromium occur in many types of industrial waste and are precipitated by sewage. The more common trivalent form may settle onto the bottoms of lakes where it affects bottom dwelling aquatic life; in fact, it bioaccumulates in aquatic organisms and mollusks, but not fish. It is not known if the precipitated chromium can reenter the food web. Chromium is about 1000 times less toxic than mercury to aquatic animals. There is little information regarding toxicity to plants, mammals, birds, and terrestrial invertebrates.

Human Health: Class A Human Carcinogen (mainly industrial workplace)
                  Respiratory Irritant/Skin Sensitizer (if air emissions are present)

Hexavalent chromium is mainly an occupational hazard (class A human carcinogen) to workers in metallurgical, refractory, and chemical industries. Hexavalent chromium is harmful to humans as a respiratory irritant and a potent sensitizer of the skin. There is extensive evidence of

lung cancer in people who work in the chromium production industry, usually due to inhaling insoluble chromium. At high dose levels (2-5g chromate compounds) in drinking water, humans can exhibit gastrointestinal bleeding, liver and kidney damage, and death. Trivalent chromium compounds are considerably less toxic than hexavalent forms and are neither irritating nor corrosive.

25. IRON (W)

Ecosystem: Visibility Alterations (water)

Human Health: Gastrointestinal Tract Irritant

Under normal conditions, excess ingested iron is excreted; however, there are cases of accidental chronic iron overload in adults. Iron accumulates by abnormal absorption from the gastrointestinal tract (genetic), by excess dietary iron ingestion, and by regular blood transfusions. The varied effects can be liver function effects, diabetes mellitus, endocrine disturbances, and cardiovascular effects. Accidental inhalation of iron oxide fumes may cause a silicosis-like lung problem among mine and steel workers.

26. NICKEL (W)

Ecosystem: Aquatic Life
              Aquifer Contamination

The primary source of nickel in water is from industrial pollution and waste disposal. The form of nickel in water depends on the chemical and physical properties of the water; it can be dissolved, adsorbed, coated, solid, and crystalline. Nickel is very persistent in both water and soil, but not air. It may significantly bioaccumulate in some aquatic organisms. Nickel present in dump sites will have higher mobility under acid rain conditions and is more likely to contaminate the aquifer.

Human Health: Class A Human Carcinogen
                 Allergenicity (dermal sensitization)
                 Eye Irritant
                 Lung Irritant

The general population exposure to nickel is from breathing air, drinking water, ingesting food, and skin contact with a wide range of products containing nickel. Ingestion of certain foods such as fruits, vegetables, milk, and seafoods containing excess nickel can cause toxic effects, but since it is poorly absorbed from the gastrointestinal tract, it acts as an emetic.

27. NITROGEN (W)

Ecosystem: Eutrophication/Plant Life
                Oxygen Depletion

Nitrogen occurs in groundwater mainly in three forms: nitrates, nitrites, and as the ammonium ion. Nitrates can be converted by bacteria to ammonia plus free nitrogen (denitrophication). Fertilizers and detergents add nitrogen to surface and ground waters as nitrates or nitrites.

Human Health: Methemoglobinemia

There appears to be a potential relationship between high nitrate concentrations in groundwater consumed for drinking and alimentary methemoglobinemia in infants.

28. OIL (W)

Ecosystem: Oxygen Depletion
                Chemical/Biological Content Alteration

The effects of crude oil pollution on wildlife is adverse, destroying marine and inland fisheries and killing waterfowl. The petroleum industry produces waste effluents of varied compositions consisting of oil and assorted acids, alkalis, phenols, and sulfides. The oils that cause the worst pollution effects are usually the most stable in the environment, although most oils are eventually broken down by microbial action. The main adverse effect of oil pollution is on aquatic life, and crude oil is known to injure fish and shellfish. The oxygen demand of oils is quite high, tending to decrease dissolved oxygen in polluted waters.

Human Health: No apparent impact categories (see Hydrocarbons)

There is not much literature to substantiate the danger to human health of crude oils in the water environment. Most information on its toxicity focuses on effects on animal or aquatic life. Many petrochemicals do have animal carcinogenic properties, but there is little evidence that it causes cancer in man. Cutting oil in particular has some possible carcinogenic potential if ingested, and crude oil may be irritating to the human skin under certain conditions.

29. PHENOL (W)

Ecosystem: No apparent impact categories

Phenol is chiefly a manmade chemical whose largest single use is as an intermediate in phenolic resin production. It is found in a large number of consumer products typically used by

the general population. It is released to the environment as an industrial effluent at hazardous waste sites and leaches through the soil to groundwater.

Human Health: Corrosive

The largest consumer exposure is through dermal contact or ingestion of phenol contaminated drinking water. Phenol produces irritation, blisters, and burns when applied to the skin in concentrated forms; even in dilute forms, it can cause death if large areas of skin are exposed. Phenol can enter the body through ingestion of drinking water, food, and other products contaminated with phenol, although the health effects from exposure to phenol in food and air are not known. Repeated exposure to low levels in drinking water has been associated with diarrhea and mouth sores in humans. Ingestion of very high concentrations of phenol in water has caused death in humans.

30. SULFURIC ACID (W)

Ecosystem: Aquatic Life
                Acid Rain Precursor
                pH Alteration (acidity)

The largest source of waterborne sulfuric acid is acid mine drainage from coal mines. Acid mine drainage results primarily from the subsidence of layers of material above deep coal mines as abandoned tunnels collapse. Invariably this subsidence ruptures water bearing structures above the mine level and water eventually fills the mine. This water leaches minerals from the structure through which it moves. The resulting acidified water usually ends up in local lakes and streams, lowering pH levels and adversely affecting aquatic organisms.

Human Health: Respiratory System Effects
                Pulmonary Irritant

Sulfuric acid is a potential cause of chronic bronchitis and asthma because it is carried on ultra-fine metal particles, which are breathed deeply into the lungs.

31. ZINC (W)

Ecosystem: No apparent impact categories

Waste sites and industrial areas such as lead smelters are the greatest source of ambient zinc released to surface and groundwater with the highest concentrations. Since zinc is so common in the earth's crust, the largest input of zinc to water results from erosion of soil particles containing natural zinc traces. Concentrating in the sediments of streams and rivers, zinc finds its way into drinking water.

Human Health: No apparent impact categories (mainly industrial workplace)

A deficiency of zinc in humans is equally as important as the effects caused by excess zinc for the general population. Except for high workplace exposure to zinc, it is relatively uncommon to have health effects from ingesting excess zinc. However, some cases have been reported involving ingestion of large doses of zinc in which stomach and digestion problems resulted, possibly due to zinc interference with the body's ability to absorb and use other essential minerals. Zinc may possibly cause a decrease in HDL cholesterol blood levels, increasing the risk of heart disease, or it may cause problems with the immune system. It is not known to cause cancer or birth defects. Occupational exposure occurs from inhaling zinc dust or fumes from galvanizing, smelting, welding, or brass foundry operations; the effect is called "metal fume fever" and can be fatal at very high exposure levels.

Table B-1. Classification of Inventory Chemicals by Potential Impact Category

INVENTORY EMISSION	Aldehydes	Ammonia	Carbon Monoxide	Chlorine	Dimethyl Adipate	Dimethyl Glutarate	Dimethyl Succinate	Fossil Carbon Dioxide	Hydrocarbons	Hydrogen Chloride
Atmospheric/Waterborne	A	A	A	A	A	A	A	A	A	A
POTENTIAL IMPACT CATEGORY										
ECOSYSTEM										
Greenhouse Gas/Global Warming			•	•				•		
Ozone Depleting Gas/Ozone Depletion			•	•						
Acid Rain Precursor/Acid Rain										
Smog Precursor/Photochemical Smog	•								•	•
Air Dispersion/Aging/Transport										
Aquatic Life*	•	•			•	•	•			•
Eutrophication/Plant Life		•								•
Visibility Alterations	•									
Weather Alterations										
Thermal Changes		•								•
pH Alterations										
Chemical/Biological Content Alteration										
Oxygen Depletion										
Aquifer Contamination									•	
HUMAN HEALTH										
Human Carcinogen	•								•	•
Irritant (Eye, Lung, Skin, GI Tract, etc,)/Corrosive		•		•	•	•	•		•	•
Respiratory System Effects		•		•	•	•	•			
Central Nervous System Effects (CNS)								•		
Allergenicity/Sensitization										
Methemoglobinemia/Blood Diseases										
Odors									•	
Cardiovascular System Effects (CVS)			•							
Reproductive Effects										
Behavioral Effects										
Bone Effects										
Renal Effects										

* Physical, chemical, or microbiological tests of water quality may include acidity, alkalinity, color, odor, turbidity, chemical oxygen demand (COD), dissolved oxygen (DO), hardness, biochemical oxygen demand (BOD), salinity, pH, acid neutralizing capacity, dissolved organic carbon, total oxygen demand (TOD), suspended solids, total dissolved solids (TDS), electrical conductivity, and bacterial/fungal growth.

Table B-1. Classification of Inventory Chemicals by Potential Impact Category

INVENTORY EMISSION / POTENTIAL IMPACT CATEGORY	Isobutane	Kerosene	Lead	Mercury	Methane	N-Methyl-Pyrrolidone	Nitrogen Oxides	Non-fossil Carbon Dioxide	Odorous Sulfur	Other Organics
Atmospheric/Waterborne	A	A	A	A	A	A	A	A	A	A
ECOSYSTEM										
Greenhouse Gas/Global Warming					•			•		
Ozone Depleting Gas/Ozone Depletion					•					
Acid Rain Precursor/Acid Rain					•				•?	•
Smog Precursor/Photochemical Smog	•						•			
Air Dispersion/Aging/Transport							•			
Aquatic Life*										
Eutrophication/Plant Life				•			•			
Visibility Alterations							•			
Weather Alterations							•			
Thermal Changes										
pH Alterations										
Chemical/Biological Content Alteration		•								
Oxygen Depletion		•								
Aquifer Contamination	•									
HUMAN HEALTH										
Human Carcinogen	•									
Irritant (Eye, Lung, Skin, GI Tract, etc.)/Corrosive						•				•
Respiratory System Effects							•			•
Central Nervous System Effects (CNS)				•				•		
Allergenicity/Sensitization										
Methemoglobinemia/Blood Diseases										•
Odors	•					•?			•	
Cardiovascular System Effects (CVS)							•			
Reproductive Effects			•							
Behavioral Effects			•							
Bone Effects			•							
Renal Effects			•	•						•

* Physical, chemical, or microbiological tests of water quality may include acidity, alkalinity, color, odor, turbidity, chemical oxygen demand (COD), dissolved oxygen (DO), hardness, biochemical oxygen demand (BOD), salinity, pH, acid neutralizing capacity, dissolved organic carbon, total oxygen demand (TOD), suspended solids, total dissolved solids (TDS), electrical conductivity, and bacterial/fungal growth.

Table B-1. Classification of Inventory Chemicals by Potential Impact Category

INVENTORY EMISSION	Particulates	Propylene	Propylene Carbonate	Propylene Oxide	Sulfur Oxides	Acid	Ammonia	BOD	Chromium	COD	Dissolved Solids
Atmospheric/Waterborne	A	A	A	A	A	A	W	W	W	W	W
POTENTIAL IMPACT CATEGORY											
ECOSYSTEM											
Greenhouse Gas/Global Warming											
Ozone Depleting Gas/Ozone Depletion											
Acid Rain Precursor/Acid Rain	•				•						
Smog Precursor/Photochemical Smog	•	•		•							
Air Dispersion/Aging/Transport	•			•	•						
Aquatic Life*					•	•	•	•	•	•	•
Eutrophication/Plant Life					•		•				
Visibility Alterations	•										
Weather Alterations	•										
Thermal Changes	•						•				
pH Alterations	•					•	•				
Chemical/Biological Content Alteration								•		•	
Oxygen Depletion								•		•	
Aquifer Contamination											
HUMAN HEALTH											
Human Carcinogen				•					•		
Irritant (Eye, Lung, Skin, GI Tract, etc.)/Corrosive			•	•	•						
Respiratory System Effects	•	•	•		•						
Central Nervous System Effects (CNS)				•							
Allergenicity/Sensitization											
Methemoglobinemia/Blood Diseases											
Odors							•				
Cardiovascular System Effects (CVS)											
Reproductive Effects				•							
Behavioral Effects											
Bone Effects									•		
Renal Effects											

* Physical, chemical, or microbiological tests of water quality may include acidity, alkalinity, color, odor, turbidity, chemical oxygen demand (COD), dissolved oxygen (DO), hardness, biochemical oxygen demand (BOD), salinity, pH, acid neutralizing capacity, dissolved organic carbon, total oxygen demand (TOD), suspended solids, total dissolved solids (TDS), electrical conductivity, and bacterial/fungal growth.

Table B-1. Classification of Inventory Chemicals by Potential Impact Category

INVENTORY EMISSION	Iron	Lead	Mercury	Metal Ion	Nickel	Nitrogen	Oil	Phenol	Sulfides	Sulfuric Acid	Suspended Solids	Zinc
Atmospheric/Waterborne	W	W	W	W	W	W	W	W	W	W	W	W
POTENTIAL IMPACT CATEGORY												
ECOSYSTEM												
Greenhouse Gas/Global Warming												
Ozone Depleting Gas/Ozone Depletion												
Acid Rain Precursor/Acid Rain												
Smog Precursor/Photochemical Smog												
Air Dispersion/Aging/Transport												
Aquatic Life*			•	•	•				•	•	•	
Eutrophication/Plant Life				•		•						
Visibility Alterations	•											
Weather Alterations												
Thermal Changes												
pH Alterations										•		
Chemical/Biological Content Alteration							•		•			
Oxygen Depletion						•	•					
Aquifer Contamination					•							
HUMAN HEALTH												
Human Carcinogen	•				•							
Irritant (Eye, Lung, Skin, GI Tract, etc.)/Corrosive					•			•		•		
Respiratory System Effects												
Central Nervous System Effects (CNS)			•									
Allergenicity/Sensitization				•	•							
Methemoglobinemia/Blood Diseases						•						
Odors												
Cardiovascular System Effects (CVS)		•										
Reproductive Effects		•										
Behavioral Effects		•										
Bone Effects		•										
Renal Effects		•	•									

* Physical, chemical, or microbiological tests of water quality may include acidity, alkalinity, color, odor, turbidity, chemical oxygen demand (COD), dissolved oxygen (DO), hardness, biochemical oxygen demand (BOD), salinity, pH, acid neutralizing capacity, dissolved organic carbon, total oxygen demand (TOD), suspended solids, total dissolved solids (TDS), electrical conductivity, and bacterial/fungal growth.

Appendix B
Bibliography of
Data Bases and Documents

Medline, National Library of Medicine, Bethesda, MD.

Toxline, The National Library of Medicine, Bethesda, MD.

Toxnet, The National Library of Medicine, Bethesda, MD.
    Hazardous Substances Data Base (HSDB),
    Chemical Carcinogenesis Research Information System (CCRIS),
    Registry of Toxic Effects of Chemical Substances (RTECS).

Material Safety Data Sheets (MSDS) for propylene carbonate, dibasic ester (dimethyl glutarate, dimethyl adipate, dimethyl succinate, methanol, hydrogen cyanide, 1-methyl-2-pyrrolidinone [M-Pyrol]), dimethyl glutarate, dimethyl succinate, and dimethyl adipate.

Bundavari, S. (ed.) 1989. **The Merck Index**, Eleventh edition. Rahway: Merck & Co.

Amdur, M.O., Doull, J., and Klaassen, C.D. (eds.) 1991. **Casarett and Doull's Toxicology: The Basic Science of Poisons**. Fourth edition. New York: Pergamon Press.

Sullivan, J.B. and Krieger, G.R. (eds.) 1992. **Hazardous Materials Toxicology: Clinical Principles of Environmental Health**. Baltimore: Williams & Wilkins.

International Specialty Products, 1994. **Toxicity Overview of N-Methyl Pyrrolidone (M-Pyrol).**

Appendix C
Tables of Industrial Environmental Emissions
By Potential Impact Classification Subcategory

This appendix contains four tables which are each three pages in length. They contain atmospheric and waterborne emission values from the life cycle inventory (LCI) results summarized in Chapters 3 through 5 of this report.

The values report pounds of emissions, organized into classification categories (ecosystem quality and human health). Pounds of emissions are reported for each applicable impact category. Therefore, the same emissions may be shown in more than one impact subcategory, depending on the potential impacts that could be caused by each emission. For example, atmospheric carbon monoxide appears in four subcategories: greenhouse gas/global warming, ozone depletion, respiratory system effects, and cardiovascular system effects. The letter "A" or "W" in parentheses following the name of the emission indicates whether it is an atmospheric or waterborne emission.

On each table, the values for the baseline analysis are displayed, followed in the next columns by the values for alternative analyses. The next column is the percent change from the baseline, calculated as:

$$\frac{(\text{alternative scenario emission - baseline emission})}{\text{baseline emission}} \times 100.$$

Thus, a negative value means that the alternative scenario produces less pounds of emissions in that subcategory, while a positive number means that the baseline scenario produces less pounds of emissions.

Table C-1. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Results with 100 percent closed loop recycling (1)	% Change from baseline
Ecosystem Quality			
Greenhouse Gas/Global Warming			
Fossil Carbon Dioxide (A)	4,415	1,311	-70.3%
Carbon Monoxide (A)	21.2	4.9	-76.9%
Methane (A)	0.040	0.014	-66.4%
Chlorine (A)	9.9E-05	2.5E-05	-74.8%
Ozone Depleting Gas/Ozone Depletion			
Carbon Monoxide (A)	21.2	4.9	-76.9%
Other Organics (A)	0.53	0.78	47.0%
Methane (A)	0.040	0.014	-66.4%
Chlorine (A)	9.9E-05	2.5E-05	-74.8%
Acid Rain Precursor/Acid Rain			
Nitrogen Oxides (A)	235	38.1	-83.8%
Sulfur Oxides (A)	8.0	3.7	-53.3%
Particulates (A)	1.3	0.80	-39.6%
Smog Precursor/Photochemical Smog			
Nitrogen Oxides (A)	235	38.1	-83.8%
Hydrocarbons (A)	46.6	10.6	-77.3%
Particulates (A)	1.3	0.80	-39.6%
Isobutane (A)	0.82	0.13	-84.6%
Propylene (A)	0.080	0.012	-84.6%
Aldehydes (A)	0.058	0.045	-23.3%
Propylene Oxide (A)	0.039	0.0060	-84.6%
Hydrogen Chloride (A)	7.2E-05	1.8E-05	-74.5%
Air Dispersion/Aging/Transport			
Sulfur Oxides (A)	8.0	3.7	-53.3%
Particulates (A)	1.3	0.80	-39.6%
Aquatic Life			
Nitrogen Oxides (A)	235	38.1	-83.8%
Sulfur Oxides (A)	8.0	3.7	-53.3%
Dimethyl Glutarate (A)	0.74	0.74	0.0%
Dissolved Solids (W)	0.54	0.13	-76.4%
Sulfuric Acid (W)	0.46	0.25	-45.7%
Ammonia (A)	0.43	0.066	-84.5%
Dimethyl Succinate (A)	0.30	0.30	0.0%
Dimethyl Adipate (A)	0.19	0.19	0.0%
COD (W)	0.098	0.018	-81.4%
Suspended Solids (W)	0.086	0.014	-83.9%
BOD (W)	0.076	0.012	-83.7%
Aldehydes (A)	0.058	0.045	-23.3%
Propylene Oxide (A)	0.039	0.0060	-84.6%
Ammonia (W)	0.026	0.0041	-84.2%
Metal Ion (W)	0.011	0.0029	-74.5%
Acid (W)	0.0026	3.9E-04	-84.6%
Sulfides (W)	0.0011	1.6E-04	-84.6%
Hydrogen Chloride (A)	7.2E-05	1.8E-05	-74.5%
Mercury (A)	5.5E-05	1.1E-05	-79.9%
Chromium (W)	3.4E-05	5.4E-06	-83.9%
Mercury (W)	2.2E-08	3.5E-09	-84.6%
Nickel (W)	1.2E-08	1.9E-09	-84.6%
Eutrophication/Plant Life			
Nitrogen Oxides (A)	235	38.1	-83.8%
Sulfur Oxides (A)	8.0	3.7	-53.3%
Ammonia (A)	0.43	0.066	-84.5%
Ammonia (W)	0.026	0.0041	-84.2%

Source: Tables 5-3 and 5-4

Table C-1. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Results with 100 percent closed loop recycling (1)	% Change from baseline
Metal Ion (W)	0.011	0.0029	-74.5%
Hydrogen Chloride (A)	7.2E-05	1.8E-05	-74.5%
Visibility Alterations			
Nitrogen Oxides (A)	235	38.1	-83.8%
Particulates (A)	1.3	0.80	-39.6%
Iron (W)	0.11	0.062	-45.8%
Aldehydes (A)	0.058	0.045	-23.3%
Weather Alterations			
Particulates (A)	1.3	0.80	-39.6%
Thermal Changes			
Particulates (A)	1.3	0.80	-39.6%
pH Alterations			
Sulfuric Acid (W)	0.46	0.25	-45.7%
Ammonia (A)	0.43	0.066	-84.5%
Ammonia (W)	0.026	0.0041	-84.2%
Acid (W)	0.0026	3.9E-04	-84.6%
Hydrogen Chloride (A)	7.2E-05	1.8E-05	-74.5%
Chemical/Biological Content Alteration			
Particulates (A)	1.3	0.80	-39.6%
COD (W)	0.098	0.018	-81.4%
BOD (W)	0.076	0.012	-83.7%
Oil (W)	0.071	0.013	-81.0%
Sulfides (W)	0.0011	1.6E-04	-84.6%
Kerosene (A)	2.0E-04	1.1E-04	-43.3%
Oxygen Depletion			
COD (W)	0.098	0.018	-81.4%
BOD (W)	0.076	0.012	-83.7%
Oil (W)	0.071	0.013	-81.0%
Kerosene (A)	2.0E-04	1.1E-04	-43.3%
Aquifer Contamination			
Hydrocarbons (A)	46.6	10.6	-77.3%
Isobutane (A)	0.82	0.13	-84.6%
Nickel (W)	1.2E-08	1.9E-09	-84.6%
Human Health			
Human Carcinogen			
Hydrocarbons (A)	46.6	10.6	-77.3%
Chromium (W)	3.4E-05	5.4E-06	-83.9%
Nickel (W)	1.2E-08	1.9E-09	-84.6%
Irritant (Eye, Lung, Skin, GI Tract, etc.)/Corrosive			
Nitrogen Oxides (A)	235	38.1	-83.8%
Hydrocarbons (A)	46.6	10.6	-77.3%
Sulfur Oxides (A)	8.0	3.7	-53.3%
n-Methyl-Pyrrolidone (A)	2.5	2.5	0.0%
Propylene Carbonate (A)	1.2	1.2	0.0%
Isobutane (A)	0.82	0.13	-84.6%
Dimethyl Glutarate (A)	0.74	0.74	0.0%
Other Organics (A)	0.53	0.78	47.0%
Sulfuric Acid (W)	0.46	0.25	-45.7%
Ammonia (A)	0.43	0.066	-84.5%
Dimethyl Succinate (A)	0.30	0.30	0.0%
Dimethyl Adipate (A)	0.19	0.19	0.0%
Iron (W)	0.11	0.062	-45.8%
Aldehydes (A)	0.058	0.045	-23.3%
Propylene Oxide (A)	0.039	0.0060	-84.6%

Source: Tables 5-3 and 5-4

Table C-1. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Results with 100 percent closed loop recycling (1)	% Change from baseline
Ammonia (W)	0.026	0.0041	-84.2%
Chlorine (A)	9.9E-05	2.5E-05	-74.8%
Hydrogen Chloride (A)	7.2E-05	1.8E-05	-74.5%
Phenol (W)	5.2E-05	1.2E-05	-77.6%
Nickel (W)	1.2E-08	1.9E-09	-84.6%
Respiratory System Effects			
Nitrogen Oxides (A)	235	38.1	-83.8%
Carbon Monoxide (A)	21.2	4.9	-76.9%
Sulfur Oxides (A)	8.0	3.7	-53.3%
Particulates (A)	1.3	0.80	-39.6%
Propylene Carbonate (A)	1.2	1.2	0.0%
Dimethyl Glutarate (A)	0.74	0.74	0.0%
Ammonia (A)	0.43	0.066	-84.5%
Dimethyl Succinate (A)	0.30	0.30	0.0%
Dimethyl Adipate (A)	0.19	0.19	0.0%
Propylene (A)	0.080	0.012	-84.6%
Propylene Oxide (A)	0.039	0.0060	-84.6%
Chlorine (A)	9.9E-05	2.5E-05	-74.8%
Central Nervous System Effects (CNS)			
Fossil Carbon Dioxide (A)	4,415	1,311	-70.3%
Propylene (A)	0.080	0.012	-84.6%
Propylene Oxide (A)	0.039	0.0060	-84.6%
Mercury (A)	5.5E-05	1.1E-05	-79.9%
Mercury (W)	2.2E-08	3.5E-09	-84.6%
Allergenicity/Sensitization			
Other Organics (A)	0.53	0.78	47.0%
Propylene Oxide (A)	0.039	0.0060	-84.6%
Metal Ion (W)	0.011	0.0029	-74.5%
Nickel (W)	1.2E-08	1.9E-09	-84.6%
Odors			
Nitrogen Oxides (A)	235	38.1	-83.8%
Hydrocarbons (A)	46.6	10.6	-77.3%
Isobutane (A)	0.82	0.13	-84.6%
Ammonia (A)	0.43	0.066	-84.5%
Ammonia (W)	0.026	0.0041	-84.2%
Cardiovascular System Effects (CVS)			
Carbon Monoxide (A)	21.2	4.9	-76.9%
Lead (A)	1.9E-04	9.2E-05	-51.6%
Lead (W)	9.6E-07	2.4E-07	-74.7%
Reproductive Effects			
Propylene Oxide (A)	0.039	0.0060	-84.6%
Lead (A)	1.9E-04	9.2E-05	-51.6%
Lead (W)	9.6E-07	2.4E-07	-74.7%
Behavioral Effects			
Lead (A)	1.9E-04	9.2E-05	-51.6%
Lead (W)	9.6E-07	2.4E-07	-74.7%
Renal Effects			
Other Organics (A)	0.53	0.78	47.0%
Lead (A)	1.9E-04	9.2E-05	-51.6%
Mercury (A)	5.5E-05	1.1E-05	-79.9%
Chromium (W)	3.4E-05	5.4E-06	-83.9%
Lead (W)	9.6E-07	2.4E-07	-74.7%
Mercury (W)	2.2E-08	3.5E-09	-84.6%

Source: Tables 5-3 and 5-4

Table C-2. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

Ecosystem Quality	Baseline results (1)	plus 20%	% Change from baseline	minus 20%	% Change from baseline
Greenhouse Gas/Global Warming					
Fossil Carbon Dioxide (A)	4,415	5,255	19.0%	3,575	-19.0%
Carbon Monoxide (A)	21.2	25.4	19.8%	17.0	-19.8%
Methane (A)	0.040	0.048	19.3%	0.033	-19.3%
Chlorine (A)	9.9E-05	1.2E-04	19.9%	7.9E-05	-19.9%
Ozone Depleting Gas/Ozone Depletion					
Carbon Monoxide (A)	21.2	25.4	19.8%	17.0	-19.8%
Other Organics (A)	0.53	0.63	19.9%	0.42	-19.9%
Methane (A)	0.040	0.048	19.3%	0.033	-19.3%
Chlorine (A)	9.9E-05	1.2E-04	19.9%	7.9E-05	-19.9%
Acid Rain Precursor/Acid Rain					
Nitrogen Oxides (A)	235	282	19.9%	188	-19.9%
Sulfur Oxides (A)	8.0	9.2	15.4%	6.8	-15.4%
Particulates (A)	1.3	1.5	14.7%	1.1	-14.7%
Smog Precursor/Photochemical Smog					
Nitrogen Oxides (A)	235	282	19.9%	188	-19.9%
Hydrocarbons (A)	46.6	55.9	19.9%	37.4	-19.9%
Particulates (A)	1.3	1.5	14.7%	1.1	-14.7%
Isobutane (A)	0.82	0.98	20.0%	0.65	-20.0%
Propylene (A)	0.080	0.097	20.0%	0.064	-20.0%
Aldehydes (A)	0.058	0.070	19.9%	0.047	-19.9%
Propylene Oxide (A)	0.039	0.047	20.0%	0.031	-20.0%
Hydrogen Chloride (A)	7.2E-05	8.7E-05	19.9%	5.8E-05	-19.9%
Air Dispersion/Aging/Transport					
Sulfur Oxides (A)	8.0	9.2	15.4%	6.8	-15.4%
Particulates (A)	1.3	1.5	14.7%	1.1	-14.7%
Aquatic Life					
Nitrogen Oxides (A)	235	282	19.9%	188	-19.9%
Sulfur Oxides (A)	8.0	9.2	15.4%	6.8	-15.4%
Dimethyl Glutarate (A)	0.74	0.89	20.0%	0.59	-20.0%
Dissolved Solids (W)	0.54	0.64	19.9%	0.43	-19.9%
Sulfuric Acid (W)	0.46	0.52	13.3%	0.40	-13.3%
Ammonia (A)	0.43	0.51	20.0%	0.34	-20.0%
Dimethyl Succinate (A)	0.30	0.36	20.0%	0.24	-20.0%
Dimethyl Adipate (A)	0.19	0.22	20.0%	0.15	-20.0%
COD (W)	0.098	0.12	20.0%	0.079	-20.0%
Suspended Solids (W)	0.086	0.10	20.0%	0.069	-20.0%
BOD (W)	0.076	0.091	20.0%	0.061	-20.0%
Aldehydes (A)	0.058	0.070	19.9%	0.047	-19.9%
Propylene Oxide (A)	0.039	0.047	20.0%	0.031	-20.0%
Ammonia (W)	0.026	0.032	20.0%	0.021	-20.0%
Metal Ion (W)	0.011	0.014	19.9%	0.0090	-19.9%
Acid (W)	0.0026	0.0031	20.0%	0.0020	-20.0%
Sulfides (W)	0.0011	0.0013	20.0%	8.4E-04	-20.0%
Hydrogen Chloride (A)	7.2E-05	8.7E-05	19.9%	5.8E-05	-19.9%
Mercury (A)	5.5E-05	6.6E-05	19.2%	4.5E-05	-19.2%
Chromium (W)	3.4E-05	4.1E-05	20.0%	2.7E-05	-20.0%
Mercury (W)	2.2E-08	2.7E-08	20.0%	1.8E-08	-20.0%
Nickel (W)	1.2E-08	1.5E-08	20.0%	9.9E-09	-20.0%
Eutrophication/Plant Life					
Nitrogen Oxides (A)	235	282	19.9%	188	-19.9%
Sulfur Oxides (A)	8.0	9.2	15.4%	6.8	-15.4%
Ammonia (A)	0.43	0.51	20.0%	0.34	-20.0%
Ammonia (W)	0.026	0.032	20.0%	0.021	-20.0%

Source: Tables 5-7 and 5-8

Table C-2. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Varying volume required			
		plus 20%	% Change from baseline	minus 20%	% Change from baseline
Metal Ion (W)	0.011	0.014	19.9%	0.0090	-19.9%
Hydrogen Chloride (A)	7.2E-05	8.7E-05	19.9%	5.8E-05	-19.9%
Visibility Alterations					
Nitrogen Oxides (A)	235	282	19.9%	188	-19.9%
Particulates (A)	1.3	1.5	14.7%	1.1	-14.7%
Iron (W)	0.11	0.13	13.3%	0.099	-13.3%
Aldehydes (A)	0.058	0.070	19.9%	0.047	-19.9%
Weather Alterations					
Particulates (A)	1.3	1.5	14.7%	1.1	-14.7%
Thermal Changes					
Particulates (A)	1.3	1.5	14.7%	1.1	-14.7%
pH Alterations					
Sulfuric Acid (W)	0.46	0.52	13.3%	0.40	-13.3%
Ammonia (A)	0.43	0.51	20.0%	0.34	-20.0%
Ammonia (W)	0.026	0.032	20.0%	0.021	-20.0%
Acid (W)	0.0026	0.0031	20.0%	0.0020	-20.0%
Hydrogen Chloride (A)	7.2E-05	8.7E-05	19.9%	5.8E-05	-19.9%
Chemical/Biological Content Alteration					
Particulates (A)	1.3	1.5	14.7%	1.1	-14.7%
COD (W)	0.098	0.12	20.0%	0.079	-20.0%
BOD (W)	0.076	0.091	20.0%	0.061	-20.0%
Oil (W)	0.071	0.085	20.0%	0.057	-20.0%
Sulfides (W)	0.0011	0.0013	20.0%	8.4E-04	-20.0%
Kerosene (A)	2.0E-04	2.2E-04	12.9%	1.7E-04	-12.9%
Oxygen Depletion					
COD (W)	0.098	0.12	20.0%	0.079	-20.0%
BOD (W)	0.076	0.091	20.0%	0.061	-20.0%
Oil (W)	0.071	0.085	20.0%	0.057	-20.0%
Kerosene (A)	2.0E-04	2.2E-04	12.9%	1.7E-04	-12.9%
Aquifer Contamination					
Hydrocarbons (A)	46.6	55.9	19.9%	37.4	-19.9%
Isobutane (A)	0.82	0.98	20.0%	0.65	-20.0%
Nickel (W)	1.2E-08	1.5E-08	20.0%	9.9E-09	-20.0%
Human Health					
Human Carcinogen					
Hydrocarbons (A)	46.6	55.9	19.9%	37.4	-19.9%
Chromium (W)	3.4E-05	4.1E-05	20.0%	2.7E-05	-20.0%
Nickel (W)	1.2E-08	1.5E-08	20.0%	9.9E-09	-20.0%
Irritant (Eye, Lung, Skin, GI Tract, etc.)/Corrosive					
Nitrogen Oxides (A)	235	282	19.9%	188	-19.9%
Hydrocarbons (A)	46.6	55.9	19.9%	37.4	-19.9%
Sulfur Oxides (A)	8.0	9.2	15.4%	6.8	-15.4%
n-Methyl-Pyrrolidone (A)	2.5	3.0	20.0%	2.0	-20.0%
Propylene Carbonate (A)	1.2	1.5	20.0%	1.0	-20.0%
Isobutane (A)	0.82	0.98	20.0%	0.65	-20.0%
Dimethyl Glutarate (A)	0.74	0.89	20.0%	0.59	-20.0%
Other Organics (A)	0.53	0.63	19.9%	0.42	-19.9%
Sulfuric Acid (W)	0.46	0.52	13.3%	0.40	-13.3%
Ammonia (A)	0.43	0.51	20.0%	0.34	-20.0%
Dimethyl Succinate (A)	0.30	0.36	20.0%	0.24	-20.0%
Dimethyl Adipate (A)	0.19	0.22	20.0%	0.15	-20.0%
Iron (W)	0.11	0.13	13.3%	0.099	-13.3%
Aldehydes (A)	0.058	0.070	19.9%	0.047	-19.9%
Propylene Oxide (A)	0.039	0.047	20.0%	0.031	-20.0%

Source: Tables 5-7 and 5-8

Table C-2. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Varying volume required			
		plus 20%	% Change from baseline	minus 20%	% Change from baseline
Ammonia (W)	0.026	0.032	20.0%	0.021	-20.0%
Chlorine (A)	9.9E-05	1.2E-04	19.9%	7.9E-05	-19.9%
Hydrogen Chloride (A)	7.2E-05	8.7E-05	19.9%	5.8E-05	-19.9%
Phenol (W)	5.2E-05	6.3E-05	19.9%	4.2E-05	-19.9%
Nickel (W)	1.2E-08	1.5E-08	20.0%	9.9E-09	-20.0%
Respiratory System Effects					
Nitrogen Oxides (A)	235	282	19.9%	188	-19.9%
Carbon Monoxide (A)	21.2	25.4	19.8%	17.0	-19.8%
Sulfur Oxides (A)	8.0	9.2	15.4%	6.8	-15.4%
Particulates (A)	1.3	1.5	14.7%	1.1	-14.7%
Propylene Carbonate (A)	1.2	1.5	20.0%	1.0	-20.0%
Dimethyl Glutarate (A)	0.74	0.89	20.0%	0.59	-20.0%
Ammonia (A)	0.43	0.51	20.0%	0.34	-20.0%
Dimethyl Succinate (A)	0.30	0.36	20.0%	0.24	-20.0%
Dimethyl Adipate (A)	0.19	0.22	20.0%	0.15	-20.0%
Propylene (A)	0.080	0.097	20.0%	0.064	-20.0%
Propylene Oxide (A)	0.039	0.047	20.0%	0.031	-20.0%
Chlorine (A)	9.9E-05	1.2E-04	19.9%	7.9E-05	-19.9%
Central Nervous System Effects (CNS)					
Fossil Carbon Dioxide (A)	4,415	5,255	19.0%	3,575	-19.0%
Propylene (A)	0.080	0.097	20.0%	0.064	-20.0%
Propylene Oxide (A)	0.039	0.047	20.0%	0.031	-20.0%
Mercury (A)	5.5E-05	6.6E-05	19.2%	4.5E-05	-19.2%
Mercury (W)	2.2E-08	2.7E-08	20.0%	1.8E-08	-20.0%
Allergenicity/Sensitization					
Other Organics (A)	0.53	0.63	19.9%	0.42	-19.9%
Propylene Oxide (A)	0.039	0.047	20.0%	0.031	-20.0%
Metal Ion (W)	0.011	0.014	19.9%	0.0090	-19.9%
Nickel (W)	1.2E-08	1.5E-08	20.0%	9.9E-09	-20.0%
Odors					
Nitrogen Oxides (A)	235	282	19.9%	188	-19.9%
Hydrocarbons (A)	46.6	55.9	19.9%	37.4	-19.9%
Isobutane (A)	0.82	0.98	20.0%	0.65	-20.0%
Ammonia (A)	0.43	0.51	20.0%	0.34	-20.0%
Ammonia (W)	0.026	0.032	20.0%	0.021	-20.0%
Cardiovascular System Effects (CVS)					
Carbon Monoxide (A)	21.2	25.4	19.8%	17.0	-19.8%
Lead (A)	1.9E-04	2.2E-04	14.4%	1.6E-04	-14.4%
Lead (W)	9.6E-07	1.1E-06	19.9%	7.7E-07	-19.9%
Reproductive Effects					
Propylene Oxide (A)	0.039	0.047	20.0%	0.031	-20.0%
Lead (A)	1.9E-04	2.2E-04	14.4%	1.6E-04	-14.4%
Lead (W)	9.6E-07	1.1E-06	19.9%	7.7E-07	-19.9%
Behavioral Effects					
Lead (A)	1.9E-04	2.2E-04	14.4%	1.6E-04	-14.4%
Lead (W)	9.6E-07	1.1E-06	19.9%	7.7E-07	-19.9%
Renal Effects					
Other Organics (A)	0.53	0.63	19.9%	0.42	-19.9%
Lead (A)	1.9E-04	2.2E-04	14.4%	1.6E-04	-14.4%
Mercury (A)	5.5E-05	6.6E-05	19.2%	4.5E-05	-19.2%
Chromium (W)	3.4E-05	4.1E-05	20.0%	2.7E-05	-20.0%
Lead (W)	9.6E-07	1.1E-06	19.9%	7.7E-07	-19.9%
Mercury (W)	2.2E-08	2.7E-08	20.0%	1.8E-08	-20.0%

Source: Tables 5-7 and 5-8

Table C-3. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Varying radome yield			
		5 per 110 gallons	% Change from baseline	20 per 100 gallons	% Change from baseline
Ecosystem Quality					
Greenhouse Gas/Global Warming					
Fossil Carbon Dioxide (A)	4,415	8,615	95.1%	2,315	-47.6%
Carbon Monoxide (A)	21.2	42.2	99.0%	10.7	-49.5%
Methane (A)	0.040	0.080	96.7%	0.021	-48.3%
Chlorine (A)	9.9E-05	2.0E-04	99.5%	5.0E-05	-49.7%
Ozone Depleting Gas/Ozone Depletion					
Carbon Monoxide (A)	21.2	42.2	99.0%	10.7	-49.5%
Other Organics (A)	0.53	1.1	99.6%	0.27	-49.8%
Methane (A)	0.040	0.080	96.7%	0.021	-48.3%
Chlorine (A)	9.9E-05	2.0E-04	99.5%	5.0E-05	-49.7%
Acid Rain Precursor/Acid Rain					
Nitrogen Oxides (A)	235	469	99.6%	118	-49.8%
Sulfur Oxides (A)	8.0	14.2	77.1%	4.9	-38.6%
Particulates (A)	1.3	2.3	73.6%	0.84	-36.8%
Smog Precursor/Photochemical Smog					
Nitrogen Oxides (A)	235	469	99.6%	118	-49.8%
Hydrocarbons (A)	46.6	92.9	99.3%	23.5	-49.7%
Particulates (A)	1.3	2.3	73.6%	0.84	-36.8%
Isobutane (A)	0.82	1.6	100.0%	0.41	-50.0%
Propylene (A)	0.080	0.16	100.0%	0.040	-50.0%
Aldehydes (A)	0.058	0.12	99.3%	0.029	-49.7%
Propylene Oxide (A)	0.039	0.078	100.0%	0.020	-50.0%
Hydrogen Chloride (A)	7.2E-05	1.4E-04	99.4%	3.6E-05	-49.7%
Air Dispersion/Aging/Transport					
Sulfur Oxides (A)	8.0	14.2	77.1%	4.9	-38.6%
Particulates (A)	1.3	2.3	73.6%	0.84	-36.8%
Aquatic Life					
Nitrogen Oxides (A)	235	469	99.6%	118	-49.8%
Sulfur Oxides (A)	8.0	14.2	77.1%	4.9	-38.6%
Dimethyl Glutarate (A)	0.74	1.5	100.0%	0.37	-50.0%
Dissolved Solids (W)	0.54	1.1	99.5%	0.27	-49.8%
Sulfuric Acid (W)	0.46	0.76	66.4%	0.30	-33.2%
Ammonia (A)	0.43	0.85	100.0%	0.21	-50.0%
Dimethyl Succinate (A)	0.30	0.59	100.0%	0.15	-50.0%
Dimethyl Adipate (A)	0.19	0.37	100.0%	0.093	-50.0%
COD (W)	0.098	0.20	99.8%	0.049	-49.9%
Suspended Solids (W)	0.086	0.17	100.0%	0.043	-50.0%
BOD (W)	0.076	0.15	100.0%	0.038	-50.0%
Aldehydes (A)	0.058	0.12	99.3%	0.029	-49.7%
Propylene Oxide (A)	0.039	0.078	100.0%	0.020	-50.0%
Ammonia (W)	0.026	0.053	100.0%	0.013	-50.0%
Metal Ion (W)	0.011	0.022	99.4%	0.0057	-49.7%
Acid (W)	0.0026	0.0051	100.0%	0.0013	-50.0%
Sulfides (W)	0.0011	0.0021	100.0%	5.3E-04	-50.0%
Hydrogen Chloride (A)	7.2E-05	1.4E-04	99.4%	3.6E-05	-49.7%
Mercury (A)	5.5E-05	1.1E-04	96.1%	2.9E-05	-48.1%
Chromium (W)	3.4E-05	6.8E-05	100.0%	1.7E-05	-50.0%
Mercury (W)	2.2E-08	4.5E-08	100.0%	1.1E-08	-50.0%
Nickel (W)	1.2E-08	2.5E-08	100.0%	6.2E-09	-50.0%
Eutrophication/Plant Life					
Nitrogen Oxides (A)	235	469	99.6%	118	-49.8%
Sulfur Oxides (A)	8.0	14.2	77.1%	4.9	-38.6%
Ammonia (A)	0.43	0.85	100.0%	0.21	-50.0%
Ammonia (W)	0.026	0.053	100.0%	0.013	-50.0%

Source: Tables 5-7 and 5-8

Table C-3. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Varying radome yield			
		5 per 110 gallons	% Change from baseline	20 per 100 gallons	% Change from baseline
Metal Ion (W)	0.011	0.022	99.4%	0.0057	-49.7%
Hydrogen Chloride (A)	7.2E-05	1.4E-04	99.4%	3.6E-05	-49.7%
Visibility Alterations					
Nitrogen Oxides (A)	235	469	99.6%	118	-49.8%
Particulates (A)	1.3	2.3	73.6%	0.84	-36.8%
Iron (W)	0.11	0.19	66.4%	0.076	-33.2%
Aldehydes (A)	0.058	0.12	99.3%	0.029	-49.7%
Weather Alterations					
Particulates (A)	1.3	2.3	73.6%	0.84	-36.8%
Thermal Changes					
Particulates (A)	1.3	2.3	73.6%	0.84	-36.8%
pH Alterations					
Sulfuric Acid (W)	0.46	0.76	66.4%	0.30	-33.2%
Ammonia (A)	0.43	0.85	100.0%	0.21	-50.0%
Ammonia (W)	0.026	0.053	100.0%	0.013	-50.0%
Acid (W)	0.0026	0.0051	100.0%	0.0013	-50.0%
Hydrogen Chloride (A)	7.2E-05	1.4E-04	99.4%	3.6E-05	-49.7%
Chemical/Biological Content Alteration					
Particulates (A)	1.3	2.3	73.6%	0.84	-36.8%
COD (W)	0.098	0.20	99.8%	0.049	-49.9%
BOD (W)	0.076	0.15	100.0%	0.038	-50.0%
Oil (W)	0.071	0.14	99.8%	0.036	-49.9%
Sulfides (W)	0.0011	0.0021	100.0%	5.3E-04	-50.0%
Kerosene (A)	2.0E-04	3.3E-04	64.3%	1.4E-04	-32.1%
Oxygen Depletion					
COD (W)	0.098	0.20	99.8%	0.049	-49.9%
BOD (W)	0.076	0.15	100.0%	0.038	-50.0%
Oil (W)	0.071	0.14	99.8%	0.036	-49.9%
Kerosene (A)	2.0E-04	3.3E-04	64.3%	1.4E-04	-32.1%
Aquifer Contamination					
Hydrocarbons (A)	46.6	92.9	99.3%	23.5	-49.7%
Isobutane (A)	0.82	1.6	100.0%	0.41	-50.0%
Nickel (W)	1.2E-08	2.5E-08	100.0%	6.2E-09	-50.0%
Human Health					
Human Carcinogen					
Hydrocarbons (A)	46.6	92.9	99.3%	23.5	-49.7%
Chromium (W)	3.4E-05	6.8E-05	100.0%	1.7E-05	-50.0%
Nickel (W)	1.2E-08	2.5E-08	100.0%	6.2E-09	-50.0%
Irritant (Eye, Lung, Skin, GI Tract, etc.)/Corrosive					
Nitrogen Oxides (A)	235	469	99.6%	118	-49.8%
Hydrocarbons (A)	46.6	92.9	99.3%	23.5	-49.7%
Sulfur Oxides (A)	8.0	14.2	77.1%	4.9	-38.6%
n-Methyl-Pyrrolidone (A)	2.5	5.0	100.0%	1.2	-50.0%
Propylene Carbonate (A)	1.2	2.5	100.0%	0.62	-50.0%
Isobutane (A)	0.82	1.6	100.0%	0.41	-50.0%
Dimethyl Glutarate (A)	0.74	1.5	100.0%	0.37	-50.0%
Other Organics (A)	0.53	1.1	99.6%	0.27	-49.8%
Sulfuric Acid (W)	0.46	0.76	66.4%	0.30	-33.2%
Ammonia (A)	0.43	0.85	100.0%	0.21	-50.0%
Dimethyl Succinate (A)	0.30	0.59	100.0%	0.15	-50.0%
Dimethyl Adipate (A)	0.19	0.37	100.0%	0.093	-50.0%
Iron (W)	0.11	0.19	66.4%	0.076	-33.2%
Aldehydes (A)	0.058	0.12	99.3%	0.029	-49.7%
Propylene Oxide (A)	0.039	0.078	100.0%	0.020	-50.0%

Source: Tables 5-7 and 5-8

Table C-3. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Varying radome yield			
		5 per 110 gallons	% Change from baseline	20 per 100 gallons	% Change from baseline
Ammonia (W)	0.026	0.053	100.0%	0.013	-50.0%
Chlorine (A)	9.9E-05	2.0E-04	99.5%	5.0E-05	-49.7%
Hydrogen Chloride (A)	7.2E-05	1.4E-04	99.4%	3.6E-05	-49.7%
Phenol (W)	5.2E-05	1.0E-04	99.6%	2.6E-05	-49.8%
Nickel (W)	1.2E-08	2.5E-08	100.0%	6.2E-09	-50.0%
Respiratory System Effects					
Nitrogen Oxides (A)	235	469	99.6%	118	-49.8%
Carbon Monoxide (A)	21.2	42.2	99.0%	10.7	-49.5%
Sulfur Oxides (A)	8.0	14.2	77.1%	4.9	-38.6%
Particulates (A)	1.3	2.3	73.6%	0.84	-36.8%
Propylene Carbonate (A)	1.2	2.5	100.0%	0.62	-50.0%
Dimethyl Glutarate (A)	0.74	1.5	100.0%	0.37	-50.0%
Ammonia (A)	0.43	0.85	100.0%	0.21	-50.0%
Dimethyl Succinate (A)	0.30	0.59	100.0%	0.15	-50.0%
Dimethyl Adipate (A)	0.19	0.37	100.0%	0.093	-50.0%
Propylene (A)	0.080	0.16	100.0%	0.040	-50.0%
Propylene Oxide (A)	0.039	0.078	100.0%	0.020	-50.0%
Chlorine (A)	9.9E-05	2.0E-04	99.5%	5.0E-05	-49.7%
Central Nervous System Effects (CNS)					
Fossil Carbon Dioxide (A)	4,415	8,615	95.1%	2,315	-47.6%
Propylene (A)	0.080	0.16	100.0%	0.040	-50.0%
Propylene Oxide (A)	0.039	0.078	100.0%	0.020	-50.0%
Mercury (A)	5.5E-05	1.1E-04	96.1%	2.9E-05	-48.1%
Mercury (W)	2.2E-08	4.5E-08	100.0%	1.1E-08	-50.0%
Allergenicity Sensitization					
Other Organics (A)	0.53	1.1	99.6%	0.27	-49.8%
Propylene Oxide (A)	0.039	0.078	100.0%	0.020	-50.0%
Metal Ion (W)	0.011	0.022	99.4%	0.0057	-49.7%
Nickel (W)	1.2E-08	2.5E-08	100.0%	6.2E-09	-50.0%
Odors					
Nitrogen Oxides (A)	235	469	99.6%	118	-49.8%
Hydrocarbons (A)	46.6	92.9	99.3%	23.5	-49.7%
Isobutane (A)	0.82	1.6	100.0%	0.41	-50.0%
Ammonia (A)	0.43	0.85	100.0%	0.21	-50.0%
Ammonia (W)	0.026	0.053	100.0%	0.013	-50.0%
Cardiovascular System Effects (CVS)					
Carbon Monoxide (A)	21.2	42.2	99.0%	10.7	-49.5%
Lead (A)	1.9E-04	3.3E-04	71.8%	1.2E-04	-35.9%
Lead (W)	9.6E-07	1.9E-06	99.5%	4.8E-07	-49.7%
Reproductive Effects					
Propylene Oxide (A)	0.039	0.078	100.0%	0.020	-50.0%
Lead (A)	1.9E-04	3.3E-04	71.8%	1.2E-04	-35.9%
Lead (W)	9.6E-07	1.9E-06	99.5%	4.8E-07	-49.7%
Behavioral Effects					
Lead (A)	1.9E-04	3.3E-04	71.8%	1.2E-04	-35.9%
Lead (W)	9.6E-07	1.9E-06	99.5%	4.8E-07	-49.7%
Renal Effects					
Other Organics (A)	0.53	1.1	99.6%	0.27	-49.8%
Lead (A)	1.9E-04	3.3E-04	71.8%	1.2E-04	-35.9%
Mercury (A)	5.5E-05	1.1E-04	96.1%	2.9E-05	-48.1%
Chromium (W)	3.4E-05	6.8E-05	100.0%	1.7E-05	-50.0%
Lead (W)	9.6E-07	1.9E-06	99.5%	4.8E-07	-49.7%
Mercury (W)	2.2E-08	4.5E-08	100.0%	1.1E-08	-50.0%

Source: Tables 5-7 and 5-8

Table C-4. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Varying Depainting Time			
		1 Hour per KC135	% Change from baseline	4 Hours per KC135	% Change from baseline
Ecosystem Quality					
Greenhouse Gas/Global Warming					
Fossil Carbon Dioxide (A)	4,415	4,308	-2.4%	4,630	4.9%
Carbon Monoxide (A)	21.2	21.1	-0.5%	21.4	1.0%
Methane (A)	0.040	0.040	-1.7%	0.042	3.3%
Chlorine (A)	9.9E-05	9.9E-05	-0.3%	9.9E-05	0.5%
Ozone Depleting Gas/Ozone Depletion					
Carbon Monoxide (A)	21.2	21.1	-0.5%	21.4	1.0%
Other Organics (A)	0.53	0.53	-0.2%	0.53	0.4%
Methane (A)	0.040	0.040	-1.7%	0.042	3.3%
Chlorine (A)	9.9E-05	9.9E-05	-0.3%	9.9E-05	0.5%
Acid Rain Precursor/Acid Rain					
Nitrogen Oxides (A)	235	235	-0.2%	236	0.4%
Sulfur Oxides (A)	8.0	7.1	-11.4%	9.8	22.9%
Particulates (A)	1.3	1.2	-13.2%	1.7	26.4%
Smog Precursor/Photochemical Smog					
Nitrogen Oxides (A)	235	235	-0.2%	236	0.4%
Hydrocarbons (A)	46.6	46.5	-0.3%	46.9	0.7%
Particulates (A)	1.3	1.2	-13.2%	1.7	26.4%
Isobutane (A)	0.82	0.82	0.0%	0.82	0.0%
Propylene (A)	0.080	0.080	0.0%	0.080	0.0%
Aldehydes (A)	0.058	0.058	-0.3%	0.059	0.7%
Propylene Oxide (A)	0.039	0.039	0.0%	0.039	0.0%
Hydrogen Chloride (A)	7.2E-05	7.2E-05	-0.3%	7.3E-05	0.6%
Air Dispersion/Aging/Transport					
Sulfur Oxides (A)	8.0	7.1	-11.4%	9.8	22.9%
Particulates (A)	1.3	1.2	-13.2%	1.7	26.4%
Aquatic Life					
Nitrogen Oxides (A)	235	235	-0.2%	236	0.4%
Sulfur Oxides (A)	8.0	7.1	-11.4%	9.8	22.9%
Dimethyl Glutarate (A)	0.74	0.74	0.0%	0.74	0.0%
Dissolved Solids (W)	0.54	0.53	-0.2%	0.54	0.5%
Sulfuric Acid (W)	0.46	0.38	-16.8%	0.61	33.6%
Ammonia (A)	0.43	0.43	0.0%	0.43	0.0%
Dimethyl Succinate (A)	0.30	0.30	0.0%	0.30	0.0%
Dimethyl Adipate (A)	0.19	0.19	0.0%	0.19	0.0%
COD (W)	0.098	0.098	-0.1%	0.098	0.2%
Suspended Solids (W)	0.086	0.086	0.0%	0.086	0.0%
BOD (W)	0.076	0.076	0.0%	0.076	0.0%
Aldehydes (A)	0.058	0.058	-0.3%	0.059	0.7%
Propylene Oxide (A)	0.039	0.039	0.0%	0.039	0.0%
Ammonia (W)	0.026	0.026	0.0%	0.026	0.0%
Metal Ion (W)	0.011	0.011	-0.3%	0.011	0.6%
Acid (W)	0.0026	0.0026	0.0%	0.0026	0.0%
Sulfides (W)	0.0011	0.0011	0.0%	0.0011	0.0%
Hydrogen Chloride (A)	7.2E-05	7.2E-05	-0.3%	7.3E-05	0.6%
Mercury (A)	5.5E-05	5.4E-05	-1.9%	5.7E-05	3.9%
Chromium (W)	3.4E-05	3.4E-05	0.0%	3.4E-05	0.0%
Mercury (W)	2.2E-08	2.2E-08	0.0%	2.2E-08	0.0%
Nickel (W)	1.2E-08	1.2E-08	0.0%	1.2E-08	0.0%
Eutrophication/Plant Life					
Nitrogen Oxides (A)	235	235	-0.2%	236	0.4%
Sulfur Oxides (A)	8.0	7.1	-11.4%	9.8	22.9%
Ammonia (A)	0.43	0.43	0.0%	0.43	0.0%
Ammonia (W)	0.026	0.026	0.0%	0.026	0.0%

Source: Tables 5-7 and 5-8

Table C–4. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Varying Depainting Time			
		1 Hour per KC135	% Change from baseline	4 Hours per KC135	% Change from baseline
Metal Ion (W)	0.011	0.011	-0.3%	0.011	0.6%
Hydrogen Chloride (A)	7.2E-05	7.2E-05	-0.3%	7.3E-05	0.6%
Visibility Alterations					
Nitrogen Oxides (A)	235	235	-0.2%	236	0.4%
Particulates (A)	1.3	1.2	-13.2%	1.7	26.4%
Iron (W)	0.11	0.095	-16.8%	0.15	33.6%
Aldehydes (A)	0.058	0.058	-0.3%	0.059	0.7%
Weather Alterations					
Particulates (A)	1.3	1.2	-13.2%	1.7	26.4%
Thermal Changes					
Particulates (A)	1.3	1.2	-13.2%	1.7	26.4%
pH Alterations					
Sulfuric Acid (W)	0.46	0.38	-16.8%	0.61	33.6%
Ammonia (A)	0.43	0.43	0.0%	0.43	0.0%
Ammonia (W)	0.026	0.026	0.0%	0.026	0.0%
Acid (W)	0.0026	0.0026	0.0%	0.0026	0.0%
Hydrogen Chloride (A)	7.2E-05	7.2E-05	-0.3%	7.3E-05	0.6%
Chemical/Biological Content Alteration					
Particulates (A)	1.3	1.2	-13.2%	1.7	26.4%
COD (W)	0.098	0.098	-0.1%	0.098	0.2%
BOD (W)	0.076	0.076	0.0%	0.076	0.0%
Oil (W)	0.071	0.071	-0.1%	0.071	0.2%
Sulfides (W)	0.0011	0.0011	0.0%	0.0011	0.0%
Kerosene (A)	2.0E-04	1.6E-04	-17.9%	2.7E-04	35.7%
Oxygen Depletion					
COD (W)	0.098	0.098	-0.1%	0.098	0.2%
BOD (W)	0.076	0.076	0.0%	0.076	0.0%
Oil (W)	0.071	0.071	-0.1%	0.071	0.2%
Kerosene (A)	2.0E-04	1.6E-04	-17.9%	2.7E-04	35.7%
Aquifer Contamination					
Hydrocarbons (A)	46.6	46.5	-0.3%	46.9	0.7%
Isobutane (A)	0.82	0.82	0.0%	0.82	0.0%
Nickel (W)	1.2E-08	1.2E-08	0.0%	1.2E-08	0.0%
Human Health					
Human Carcinogen					
Hydrocarbons (A)	46.6	46.5	-0.3%	46.9	0.7%
Chromium (W)	3.4E-05	3.4E-05	0.0%	3.4E-05	0.0%
Nickel (W)	1.2E-08	1.2E-08	0.0%	1.2E-08	0.0%
Irritant (Eye, Lung, Skin, GI Tract, etc.)/Corrosive					
Nitrogen Oxides (A)	235	235	-0.2%	236	0.4%
Hydrocarbons (A)	46.6	46.5	-0.3%	46.9	0.7%
Sulfur Oxides (A)	8.0	7.1	-11.4%	9.8	22.9%
n-Methyl-Pyrrolidone (A)	2.5	2.5	0.0%	2.5	0.0%
Propylene Carbonate (A)	1.2	1.2	0.0%	1.2	0.0%
Isobutane (A)	0.82	0.82	0.0%	0.82	0.0%
Dimethyl Glutarate (A)	0.74	0.74	0.0%	0.74	0.0%
Other Organics (A)	0.53	0.53	-0.2%	0.53	0.4%
Sulfuric Acid (W)	0.46	0.38	-16.8%	0.61	33.6%
Ammonia (A)	0.43	0.43	0.0%	0.43	0.0%
Dimethyl Succinate (A)	0.30	0.30	0.0%	0.30	0.0%
Dimethyl Adipate (A)	0.19	0.19	0.0%	0.19	0.0%
Iron (W)	0.11	0.095	-16.8%	0.15	33.6%
Aldehydes (A)	0.058	0.058	-0.3%	0.059	0.7%
Propylene Oxide (A)	0.039	0.039	0.0%	0.039	0.0%

Source: Tables 5-7 and 5-8

Table C-4. Industrial Environmental Emissions by Potential Impact Subcategory for PC Blend 2 Radome Depainter Improvement Alternatives

	Baseline results (1)	Varying Depainting Time			
		1 Hour per KC135	% Change from baseline	4 Hours per KC135	% Change from baseline
Ammonia (W)	0.026	0.026	0.0%	0.026	0.0%
Chlorine (A)	9.9E-05	9.9E-05	-0.3%	9.9E-05	0.5%
Hydrogen Chloride (A)	7.2E-05	7.2E-05	-0.3%	7.3E-05	0.6%
Phenol (W)	5.2E-05	5.2E-05	-0.2%	5.3E-05	0.4%
Nickel (W)	1.2E-08	1.2E-08	0.0%	1.2E-08	0.0%
Respiratory System Effects					
Nitrogen Oxides (A)	235	235	-0.2%	236	0.4%
Carbon Monoxide (A)	21.2	21.1	-0.5%	21.4	1.0%
Sulfur Oxides (A)	8.0	7.1	-11.4%	9.8	22.9%
Particulates (A)	1.3	1.2	-13.2%	1.7	26.4%
Propylene Carbonate (A)	1.2	1.2	0.0%	1.2	0.0%
Dimethyl Glutarate (A)	0.74	0.74	0.0%	0.74	0.0%
Ammonia (A)	0.43	0.43	0.0%	0.43	0.0%
Dimethyl Succinate (A)	0.30	0.30	0.0%	0.30	0.0%
Dimethyl Adipate (A)	0.19	0.19	0.0%	0.19	0.0%
Propylene (A)	0.080	0.080	0.0%	0.080	0.0%
Propylene Oxide (A)	0.039	0.039	0.0%	0.039	0.0%
Chlorine (A)	9.9E-05	9.9E-05	-0.3%	9.9E-05	0.5%
Central Nervous System Effects (CNS)					
Fossil Carbon Dioxide (A)	4,415	4,308	-2.4%	4,630	4.9%
Propylene (A)	0.080	0.080	0.0%	0.080	0.0%
Propylene Oxide (A)	0.039	0.039	0.0%	0.039	0.0%
Mercury (A)	5.5E-05	5.4E-05	-1.9%	5.7E-05	3.9%
Mercury (W)	2.2E-08	2.2E-08	0.0%	2.2E-08	0.0%
Allergenicity/Sensitization					
Other Organics (A)	0.53	0.53	-0.2%	0.53	0.4%
Propylene Oxide (A)	0.039	0.039	0.0%	0.039	0.0%
Metal Ion (W)	0.011	0.011	-0.3%	0.011	0.6%
Nickel (W)	1.2E-08	1.2E-08	0.0%	1.2E-08	0.0%
Odors					
Nitrogen Oxides (A)	235	235	-0.2%	236	0.4%
Hydrocarbons (A)	46.6	46.5	-0.3%	46.9	0.7%
Isobutane (A)	0.82	0.82	0.0%	0.82	0.0%
Ammonia (A)	0.43	0.43	0.0%	0.43	0.0%
Ammonia (W)	0.026	0.026	0.0%	0.026	0.0%
Cardiovascular System Effects (CVS)					
Carbon Monoxide (A)	21.2	21.1	-0.5%	21.4	1.0%
Lead (A)	1.9E-04	1.6E-04	-14.1%	2.4E-04	28.2%
Lead (W)	9.6E-07	9.5E-07	-0.3%	9.6E-07	0.5%
Reproductive Effects					
Propylene Oxide (A)	0.039	0.039	0.0%	0.039	0.0%
Lead (A)	1.9E-04	1.6E-04	-14.1%	2.4E-04	28.2%
Lead (W)	9.6E-07	9.5E-07	-0.3%	9.6E-07	0.5%
Behavioral Effects					
Lead (A)	1.9E-04	1.6E-04	-14.1%	2.4E-04	28.2%
Lead (W)	9.6E-07	9.5E-07	-0.3%	9.6E-07	0.5%
Renal Effects					
Other Organics (A)	0.53	0.53	-0.2%	0.53	0.4%
Lead (A)	1.9E-04	1.6E-04	-14.1%	2.4E-04	28.2%
Mercury (A)	5.5E-05	5.4E-05	-1.9%	5.7E-05	3.9%
Chromium (W)	3.4E-05	3.4E-05	0.0%	3.4E-05	0.0%
Lead (W)	9.6E-07	9.5E-07	-0.3%	9.6E-07	0.5%
Mercury (W)	2.2E-08	2.2E-08	0.0%	2.2E-08	0.0%

Source: Tables 5-7 and 5-8