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Project Summary

Life Cycle Assessment for PC Blend 2 Aircraft Radome Depainter

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This project was sponsored by the Department of Defense Strategic Environmental Research and Development Program (SERDP) and conducted by the U.S. Environmental Protection Agency National Risk Management Research Laboratory (NRMRL). In support of SERDP's objective to develop environmental solutions that improve mission readiness for federal activities, this report was developed to determine the potential environmental and economic impacts of using an alternative chemical depainter for B-52 and KC-135 aircraft radomes at the U.S. Air Force Oklahoma City Air Logistics Center. A life cycle assessment (LCA) was conducted to identify the performance, cost, and environmental impacts of propylene carbonate Blend 2 (PC2), a blend of three low volatile chemicals used to depaint the radomes. The variables analyzed in this study were the volume of PC2 required to depaint a radome, the number of radomes depainted per batch of PC2, the time required to depaint a radome, and the time required to recycle spent PC2. An estimate of volume, number of radomes, and time was provided by the Air Logistics Center as the baseline case. Increases and decreases to the baseline case were analyzed to determine changes in environmental and cost impacts.

This Project Summary was developed by EPA's National Risk Management Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A Life Cycle Assessment (LCA) was performed on a potential replacement solvent blend for aircraft radome depainting at the Oklahoma City Air Logistics Center at Tinker Air Force Base. An LCA is a three-step process, (1) a life cycle inventory, (2) a life cycle impact assessment, and (3) a life cycle improvement analysis.

Tinker Air Force Base currently uses the highly volatile methyl ethyl ketone (MEK) to depaint B-52 and KC-135 aircraft radomes. Significant evaporation occurs during each depainting, and MEK has been targeted for elimination by EPA's 33/50 Voluntary Reduction Program. EPA and Tinker Air Force Base are evaluating several solvent blends containing propylene carbonate (PC) as a nonvolatile, less toxic substitute. This study focuses on one of these blends, known as PC Blend 2 (PC2), which is composed of 50% n-methyl-pyrrolidone (NMP), 25% dibasic ester (DBE), and 25% propylene carbonate.

PC2 is not currently in use at Tinker Air Force Base, therefore, several assumptions were made based on limited knowledge of how PC2 would perform and may not fully characterize actual performance. These assumptions comprise the baseline PC2 use scenario presented in the LCA. To balance the lack of experience in PC2 performance a number of alternative PC2 use and waste management scenarios were also evaluated.

Procedure

The study used a comprehensive approach which encompassed energy requirements, solid wastes, atmospheric emissions, and waterborne wastes associated with and resulting from the production, use, and disposal of the PC2 depainting solvent. Each key processing step, from the extraction of raw material to final disposition of the spent solvent, was included in the assessment. The partial impact assessment used a classification system to categorize the atmospheric and waterborne emissions into relevant potential impact categories of ecosystem and human health. A mass loading characterization model was then used to compare baseline impact results to a variety of improvement alternatives. The improvement assessment used the results of the Life Cycle Inventory (LCI) and impact assessments in tandem with a cost analysis to evaluate the improvement alternatives.

To enhance the utility of the report and its results, the study considered: (1) the amount of PC2 required to depaint 10 KC-135 aircraft radomes (estimated at 110 gallons); (2) the amount of PC2 required to depaint 10 B-52 radomes (estimated at 180 gallons); and (3) annual PC2 usage at Tinker Air Force Base, based on past MEK depaint usage (estimated at 1,820 gallons of PC2).

Baseline Results and Discussion

Energy

The energy contributions of each major component included in the LCI are briefly discussed below. The total energy for depainting 10 KC-135 radomes is approximately 43 million British thermal units (Btu). Raw materials acquisition and chemical processing associated with the production of NMP, DBE, and PC account for 56%, 23%, and 16% of the total energy requirements, respectively. Blending, usage, and disposal of PC2 account for the remaining 5% of the total energy requirements.

Energy categories in an LCI consist of process, transportation, and energy of material resource. Process energy is used to manufacture the PC2 and uses 44% of the total energy required for production of the solvent. Transportation energy, requiring only 3% of the total energy, is used to transport the chemicals and materials to the next step in the manufacturing process. The energy of material resource is the inherent energy of petroleum, natural gas, and coal when used as a raw material feedstock. It accounts for 53% of the total energy requirements.

Energy requirements are categorized into five basic sources: natural gas, petroleum, coal, nuclear, and other (i.e., geothermal, solar, hydropower, etc.). The majority of the energy is derived from natural gas and petroleum, which account for 69% and 23% of the total respectively. These values include the energy of material resource attributed to natural gas and petroleum when used as raw material feedstock. The remaining 8% of the energy requirements for the production and use of PC2 are met by nuclear, coal, and other sources.

Solid Waste

Over the entire life cycle about 80 pounds of industrial solid waste is produced for every 10 KC-135 radomes depainted. The production of NMP, DBE, and PC contribute 29%, 18%, and 11%, respectively. The blending operation contributes about 11% of the total solid waste. The PC2 use component includes solid waste from electricity for the depainting operation and represents 32%. The PC2 disposal component contributes less than 1% to the total industrial solid waste produced.

Fuel-related solid waste resulting from the combustion of fuels make the greatest contribution representing 94% of the total industrial solid wastes produced. Process solid wastes comprise the remaining 6% of total process waste.

Atmospheric and Waterborne Emissions

Both process- and fuel-related categories of emissions contribute significantly to the total emissions. Portions of these emission categories may also be attributed to process emissions. Table 1 summarizes the atmospheric and waterborne emissions and their sources.

Results and Discussion of LCI Sensitivity Analysis

The results of the LCI Sensitivity Analyses include all energy use and emissions associated with raw material acquisition, chemical processes for producing the chemical components of PC2 (DBE, NMP, PC), PC2 blending, and PC2 use and disposal for depainting radomes at Tinker Air Force Base. For the baseline, disposal of spent PC2 is accomplished by incineration. For the recycled system, it is assumed that a recovery rate of approximately 85% can be achieved. The 15% lost during the recycling process could be attributed to adherence of the PC2 to waste paint chips, absorption of the PC2 in the cloth filter, or some step in the distillation process. The amount lost is assumed to be ultimately incinerated as hazardous waste. Virgin PC, DBE, and NMP must be used to replenish the 15% lost each time the PC2 is recycled, as well as the 0.5% evaporative loss assumed to occur during PC2 use. The recycling system results also include the energy requirements and emissions produced during transport of the spent PC2 to a theoretical recycling facility in Texas, distillation of the solvent blend, re-blending of the PC2 components, and transportation of the recycled PC2 back to Tinker Air Force Base.

Energy

By recycling the spent PC2, the total energy requirements are reduced by approximately 70%. The majority of this reduction comes from decreased process and energy of material resource requirements in the back-end steps in the production of the DBE, PC and NMP components of PC2. The energy necessary to produce PC2 is spent to make up for the 15% recycling loss, the 0.5% evaporative emissions, and the PC2 blending process. The energy required for disposal of waste is also drastically reduced to about 15% of the baseline amount. The energy required for distillation and transport of the spent PC2 is about 25% of the total energy for the recycling system.

The energy results are also very sensitive to any changes in the volume and yield assumptions. An increase or decrease in the volume required causes 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 because varying the time affects only the PC2 use component, which is estimated to be about 3% of the total energy in the baseline.

Solid Waste

Total solid waste generation is decreased by about 50% for the recycled system compared to the baseline system. The reduction of fuel- and process-related solid waste associated with the production of the PC2 components 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.

Table 1. *Summary of Sources of Atmospheric and Waterborne Emissions*

Source	Emission
Fuel acquisition and combustion	*atmospheric aldehydes, ammonia, carbon monoxide, fossil carbon dioxide, hydrocarbons, hydrogen chloride, kerosene, lead, methane, nitrogen oxides, other organics, particulate emissions, sulfur oxides*
Incineration of spent PC2	*carbon dioxide and nitrogen dioxide*
Petroleum refining operation	*process aldehyde*
Manufacture of ammonia as an intermediate material and the operation to produce carbon dioxide	*ammonia*
Formaldehyde production and the operation to produce adipic acid	*carbon monoxide*
Natural gas and crude oil production and processing	*hydrocarbon*
Production of propylene oxide	*process isobutane and propylene oxide*
Natural gas processing	*sulfur oxide*
Fuel acquisition and combustion	*waterborne acid, ammonia, biochemical oxygen demand, chromium, chemical oxygen demand, dissolved solids, iron, lead, metal ion, phenol, sulfuric acid, suspended solids, zinc*
Process to make benzene (an intermediate for DBE)	*process acid*
Manufacture of ammonia, hydrogen, carbon dioxide, petroleum refinery operations	*process ammonia*
Production of ammonia, methanol, and nitric acid intermediates for DBE	*process biochemical oxygen demand*
Petroleum refinery operations	*chromium, phenol, zinc, chemical oxygen demand*
Production of ammonia	*chemical oxygen demand*
Refined petroleum products and production of sodium hydroxide (used in the manufacture of DBE)	*dissolved solids*
Sodium hydroxide production	*mercury, zinc, nickel*
Refining of petroleum products	*process metal ion*
Crude oil and natural gas production and refining of petroleum products	*process oil*
Benzene and sodium hydroxide production	*sulfide process*
Processes to make ammonia and methanol, and refinery operations	*suspended solids*

As with the energy results, the total solid waste is quite sensitive to assumptions made regarding the volume of PC2 required to depaint each radome. Because over 60% of the solid waste is due to the production and blending of the PC2 components, any change in the amount of PC2 required to depaint each radome has a marked 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 Tinker Air Force Base is electricity; therefore, any changes in the processing time (and corresponding electricity requirements) result in substantial changes in electricity-related fuel pollutants. The dramatic changes in solid waste resulting from variations in process time are due in large part to solid waste from electricity generating plants (e.g., ash from coal).

Atmospheric and Waterborne Emissions

All but four emission categories show a dramatic reduction in emission levels for the recycled system. The exceptions are the atmospheric emissions: DBE, NMP, and PC (the PC Blend 2 chemical components), and other organics. The PC2 components are the assumed atmospheric emission contributors during the PC2 use step, and are estimated to remain unchanged with the use of recycled PC2. The other organic emissions increase for the recycled system because they are so closely related to the additional transportation fuel pollutants produced to transport PC2 to Texas for recovery and back to Tinker Air Force Base.

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

A baseline depainting time of two hours was assumed. For the analyses included in this study, the depainting time was halved and doubled. The comparison demonstrated that decreasing the time to one hour resulted in decreased emissions in almost every category, while increasing the time resulted in increased emissions. The differences seen are fairly small for most emission categories; however, sulfur oxides, particulates, sulfuric acid, iron, kerosene, and airborne lead emissions change to a greater degree. This seems to be a reflection of their close tie to electricity consumption at Tinker Air Force Base.

Partial Impact Results and Discussion

The partial impact assessment results for the atmospheric and waterborne emissions from the use of PC2 aircraft radome depainting solvent are discussed briefly below. In the discussion, it is important to note that “less potential impact” means that, for a particular impact category, the alternative system had no emissions that were considered higher than the baseline system, while at least one emission was higher for the other system.

- When the 100% closed loop recycling of PC2 system results were compared to the baseline system, 20 impact categories had less potential impact, and 3 categories had inconclusive results.
- A 20% increase in the volume of PC2 resulted in no significant potential impact.
- A 20% decrease in the volume of PC2 resulted in 23 impact categories with less potential impact.
- A decrease in the yield to five aircraft radomes depainted per 110 gallons of PC2 resulted in no significant potential impact.
- An increase in the yield to 20 aircraft radomes depainted per 110 gallons of PC2 resulted in 23 impact categories with less potential impact.
- An increase in depaint time to 4 hours per radome resulted in no significant potential impact.
- A decrease in depaint time to 1 hour per radome resulted in 23 impact categories with less potential impact.

Improvement Analysis

The improvement alternatives have been compared by their energy requirements, produced emissions, and relative potential impact. An economic evaluation is also 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; instead, it analyzes the cost to Tinker Air Force Base for various improvement alternatives. The analysis assumes no new capital equipment requirements for the change-over from MEK to PC2 (no capital expenditures will be required). Also, for the 3 year and 5 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 2.

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 is estimated at $38,841 per year.

The first recycling scenario assumes a 3 year PC2 usage and recycling program, which would be followed by incineration of used solvent. For this scenario, new PC2 must be purchased the first year of operation. In subsequent years, 85% of the new supply would be composed of recycled PC2, and 15% would be new PC2 makeup. The average 3 year cost is estimated at $36,225, which is approximately $2,800 per year less than the baseline scenario.

The second recycling scenario is similar to the first, except it is based on a 5 year PC2 usage and recycling program. For this scenario, the average annual cost is estimated at $35,952 or $3,359 per year less than the baseline scenario.

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

Conclusions

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

For the Recycling Scenario:

- Total energy requirements decrease by about 70%.
- Total solid waste is reduced by approximately 50%.
- Total atmospheric and waterborne emissions show an average reduction of about 65%. However, the other organic atmospheric emissions increase by 28%.
- 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.

***Table 2.** Sensitivity of PC Blend 2 Costs to Demand*

	Dollars/year[a]			
	New PC2	Disposal[b]	Recovery/ Distillation	Total
Baseline (1,815 gallons/year)	31,218	7,623	-	38,841
Baseline w/recycling (3-year usage)	13,528	2,724[c]	19,973	36,225
Baseline w/recycling (5-year usage)	9,990	1,635[d]	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

All costs are in constant dollars. Escalation of costs is not included in these estimates.
[b] Disposal by incineration.
[c] Represents a one-time disposal of PC Blend 2 averaged over three years.
[d] Represents a one-time disposal of PC Blend 2 averaged over five years.

- Total costs for the 3 year recycling program show an average of a 7% reduction in costs.
- Total costs for the 5 year recycling program show an average of a 9% reduction in costs.

By *increasing* the PC2 volume required per radome by 20%:

- Total energy requirements increase about 19%.
- Total solid waste increases about 14%.
- Total atmospheric and waterborne emissions show an average increase of about 19%.
- The overall potential impact on ecosystem quality and human health is increased.
- Total costs show an increase of 20%.

By *decreasing the PC2 volume* required per radome by 20%:

- Total energy requirements are reduced by about 19%.
- Total solid waste decreases about 14%.
- Total atmospheric and waterborne emissions show an average decrease of about 19%.
- The overall potential impact on ecosystem quality and human health is decreased.
- Total costs show a decrease of 20%

By *halving the yield* from 10 to 5 radomes per 110 gallons:

- Total energy requirements are reduced by only 2%.
- Total solid waste is reduced by 16%.
- Atmospheric and waterborne emissions are reduced an average of 3%.
- 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 yield* from 10 to 20 radomes per 110 gallons:

- Total energy requirements are reduced by 48%.
- Total solid waste is reduced by 34%.
- Total atmospheric and waterborne emissions are reduced by an average of 47%.
- The overall potential impact on ecosystem quality and human health is decreased.
- Total costs are reduced by 50%.

By *halving the time* required for depainting from two to one hour per radome:

- Total energy requirements are reduced by only 2%.
- Total solid waste is reduced by 16%.
- Atmospheric and waterborne emissions are reduced an average of 3%.
- 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 4%.
- Total solid waste shows an increase of 32%.
- Total atmospheric and waterborne emissions increase by an average of 5%.
- 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 Tinker Air Force Base does not result in significant known health problems to individuals outside the immediate working area as defined within the scope of this study.

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The complete report, entitled "Life Cycle Assessment for PC Blend 2 Aircraft Radome Depainter," (Order No. PB96-207386 Cost: $38.00, subject to change) will be available only from:

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