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Project Summary

Life Cycle Assessment for Chemical Agent Resistant Coating

Robin Thomas and Duane Tolle

This project was sponsored by the Department of Defense's Strategic Environmental Research and Development Program (SERDP) and conducted by the U.S. Environmental Protection Agency's 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 optimum materials and equipment for applying chemical agent resistant coating (CARC) to vehicles at the Army Transportation Center at Fort Eustis, VA. A life cycle assessment (LCA) was conducted to identify the performance, cost, and environmental impacts of various combinations of CARC materials and equipment. The variables for this study were the primer, thinner, CARC topcoat, and spray application equipment. Combinations of the variables were grouped to develop five alternatives. The recommended alternative would change the existing primer and application equipment, but retain the existing thinner and topcoat. This alternative would maintain required performance characteristics, achieve cost objectives, and result in low environmental impacts in relation to the other alternatives.

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 inventory (LCI) of chemical agent resistant coating (CARC) operations was conducted at the U.S. Army's Transportation Center at Fort Eustis, VA. The LCI provided a baseline of environmental and utility data for the production, use, and disposal of spent CARC and blast media. These data included the raw materials used, water and energy requirements, atmospheric emissions, liquid waste, and solid waste streams. The results of this LCI provide the basis for a life cycle environmental evaluation of CARC operations at Fort Eustis. The data were originally presented in units per 1,000 gallons of CARC used, which is slightly less than the CARC produced and purchased due to spills, overspray, and discarded paint. The data were converted to units per 1,000 ft^2 for the life cycle impact assessment (LCIA) and the life cycle improvement assessment (LCImA) to account for the additional CARC required due to overspray, spills, and discards. Therefore, the quantities of materials required for the process, and the emissions released from any process in the CARC cycle, are expressed relative to a functional unit of 1,000 ft^2 of painted surface.

The scope of the LCIA was limited to one topcoat (MIL-C-53039A, Hentzen 08605GUZ), one primer (MIL-P-53022B; Part A, Niles N-1088A and Part B, Niles N-1088BM), one thinner (MIL-T-81772B, Chemical Specialists and Development, Thinner Aircraft Coating), one painting technique (high volume, low pressure [HVLP] spray painting), and one depainting blasting media (aluminum oxide). All of these, except the thinner, were used at Fort Eustis (Fort Eustis adds two quarts of A-A-857B to every five gallons of CARC).

An LCImA was then undertaken, using the results of the LCIA, to define improvement strategies taking into account such factors as cost, performance, and environmental considerations.

Life Cycle Inventory

In developing the LCI, all of the principal ingredients used to produce the final products were identified. The specific chemicals were identified using Material Safety Data Sheets provided by the manufacturers. Literature research was then conducted to identify the processes used to make the principal ingredients and to identify the raw materials. This process was repeated until every raw material was traced back to a fundamental precursor (i.e., one identified as coming from the earth as an ore or a petroleum product). Each process was reviewed to determine the process inputs and the outputs. Process inputs include raw materials, water, and energy (i.e., electrical, natural gas [as fuel], oil, and coal). Outputs include the end product atmospheric emissions, waterborne waste and solid waste.

Data were obtained through telephone surveys to manufacturers, published chemical industry information, and chemical process handbooks. Searches for reports, articles, or other sources of information were undertaken in an attempt to fill remaining gaps in the data. These searches sometimes yielded EPA reports, EPA-contracted reports, or industry trade magazine articles.

As part of the scoping activity for the LCIA, it was determined that several of the chemical components in the CARC life cycle described in the draft LCI could be revised to fill in missing data or to provide more recent data on the manufacturing processes. Chemicals identified as most important for collection of additional LCI data were adiponitrile, cobalt chromite green, hexamethylenediamine, magnesium ferrite, phosgene, sodium cyanide, and sodium dichromate. Second tier chemicals included butyl acetate, butyl alcohol, and methyl isoamyl ketone. Additional chemicals derived closely from the crude oil and natural gas refining processes were not included in this ranked system, because they are part of the crude oil and natural gas extraction and refining models incorporated into the inventory model. This included aromatic 100, carbon monoxide, hydrogen, and propane.

Emissions for the electrical production, crude oil refining, and natural gas production were taken from Battelle LCI databases. The electrical production model calculates pollutant loadings for the national electrical grid based on the fractions of power created from coal, hydrocarbons, nuclear, hydropower, wind, and other energy sources. The crude oil and natural gas models included data on many of the primary refinery chemicals. Emission data from 1993 were cross-referenced with the 1993 Directory of Chemical Producers to determine the manufacturers of the chemicals of interest. The directory also provided production tables, which allowed direct calculation of the emission rates per pound of product produced for several chemicals of interest involved in the process.

Life Cycle Impact Assessment

The LCIA is divided into three phases: classification, characterization, and valuation. The classification step involved linking or assigning data from the LCI to individual stressor categories within the three primary stressor categories, which are human health, ecological health, and resource depletion. Stressor/impact chains were developed by considering the energy, water, and raw material input, along with the air, water, and solid waste emission output from each life cycle stage, which were then compared against lists of potential impacts.

The characterization step involved an evaluation of the magnitude of potential impacts caused by individual stressors on a site-independent basis. An estimation of the magnitude of impacts for each stressor category was achieved by multiplying equivalency factors by the quantity of resource or pollutant associated with a functional unit of the CARC process.

The valuation step involved an evaluation of the magnitude of resource depletion impacts associated with the CARC life cycle. The resources included in the analysis were water, minerals, gas, oil, coal, and land. The impacts were evaluated from a time-metric standpoint, which considers the time to exhaustion of the resource.

Economic Assessment

The annual cost to paint and depaint Army vehicles was estimated using a factored estimated approach. Fort Eustis was selected as the baseline site, because it typified depainting and painting operations at a majority of Army bases; therefore, its plant capacity, staffing, and paint-, primer-, and abrasive media-usage rates were used to estimate typical costs.

Capital costs were estimated for depainting, marking and equipment preparation, and CARC application operations for a new facility that would be of similar size and capacity as Fort Eustis. Each major item was identified, sized, and costs were determined (using cost files, standard texts, vendor quotes, and recent procurement information) to estimate the total delivered equipment costs.

Operating costs are composed of the annual costs to operate the depainting and painting operations, including raw materials, utilities, labor, supplies, maintenance, plant overhead, waste disposal, insurance, and regulatory compliance charges. These costs were estimated based on the costs incurred at Fort Eustis. Appropriate factors were applied to convert the usage figures to annual costs (i.e., 3,096 gallons of CARC multiplied by the CARC purchase price). Other charges, such as those incurred to maintain the facility, plant overhead, etc., were also estimated using a factoring approach.

Annualized costs equal the annual operating cost plus amortization of the capital investment. The annualized cost is then divided by the annual quantity of CARC painted surface to compute costs on a $/$ft^2$ basis. The annual surface coated (619,000 ft^2) was estimated from the 1993 Fort Eustis CARC paint consumption level of 3,096 gallons and a calculated CARC usage rate of 5.0 gal/1,000 ft^2 (200 ft^2/gal).

Life Cycle Improvement Assessment

Inventory Analysis

Five alternatives were evaluated against the baseline CARC system (Table 1): (1) alternative primer with the baseline CARC topcoat and thinner; (2) substitution of the turbine HVLP gun against the standard HVLP gun; (3) alternative primer with the alternative gun; (4) alternative thinner along with the baseline topcoat; and (5) alternative thinner and alternative primer with the baseline gun.

The importance of each individual resource or chemical within each impact category was determined by multiplying the equivalency factor times the inventory value in pounds per functional unit. The potential environmental impacts associated with each of the alternatives can be evaluated by comparing the normalized, factored, impact scores for each of the nine major impact categories.

Economic assessment was made by taking the baseline (Fort Eustis) categories of fixed capital investment, the annual operating cost, and the annualized cost and comparing those estimates against the five alternatives.

A performance evaluation was conducted for the impact assessment, which included application equipment, primers, and thinners. Scoring ranks were assigned for each performance evaluation parameter.

A valuation process was conducted in a step-wise fashion, beginning with the construction of a hierarchy tree and continu-

***Table 1**. CARC Systems for Evaluation in LCImA*

CARC Systems Evaluated	*CARC Topcoat[a]*	*Primer[b]*	*Thinner[c]*	*Topcoat Spray Gun[d]*
1 (Baseline)	*BC*	*BP*	*BT*	*BG*
2	*BC*	*AP*	*BT*	*BG*
3	*BC*	*BP*	*BT*	*AG*
4	*BC*	*AP*	*BT*	*AG*
5	*BC*	*BP*	*AT*	*BG*
6	*BC*	*AP*	*AT*	*BG*

[a]BC = Baseline CARC Topcoat, MIL-C-53039A, Hentzen 08605GUZ-GD, 1-part urethane.

[b]BP = Baseline Primer, MIL-P-53022, Niles 2-part epoxy, solvent thinned; AP = Alternative Primer, MIL-P-53030, Deft 2-part epoxy, water thinned.

[c]BT = Baseline Thinner, MIL-T-81772B, CSD; AT = Alternative Thinner, Fed. Std. A-A-857B (used by Fort Eustis, but not evaluated by LCI.

[d]BG = Baseline Gun, high volume, low pressure (HVLP) spray gun (thinning of topcoat required); AG = Alternative Gun, turbine HVLP spray gun with increased transfer efficiency relative to conventional HVLP gun.

ing with the environmental, cost, and performance weighting, respectively.

Results and Discussion

Results of the impact characterization and valuation process showed that the impacts of greatest concern are ozone depletion (weight = 0.362), acid deposition (weight = 0.219), and global warming (weight = 0.126). Of secondary concern (with a combined normalized, weighted, factored score) were all forms of toxicity, including human, terrestrial, and aquatic.

Results for the five alternatives evaluated against the baseline CARC system are summarized in Table 2.

Environmental Impact/Hazard Characterization

The CARC system with the most (7 out of 9) low scores (i.e., fewest potential impacts) in each impact category was alternative 3, the alternative primer and alternative spray gun option. Use of the alternative gun decreased the use rates of topcoat, primer, and thinner, which results in a reduction of potential environmental impact in all nine of the impact categories compared to the baseline. Alternative 3 was also the most attractive option in the areas of global scale impact categories (ozone depletion, global warming, and natural resource use), and regional scale impact categories (acid deposition and smog creation). Although alternative 3 was the most viable option for two (human health and terrestrial wildlife) of the three toxicity impact categories (the third being aquatic toxicity), use of this option was worse on aquatic toxicity than the baseline system. Alternatives 2 and 3 rated the most favorably with regard to local scale impact of land use.

Economic Assessment

Estimated fixed capital investments, annual operating costs, and annualized costs for each of the five alternative systems as compared to the baseline are provided in Table 3.

Performance Evaluation

The alternative spray gun (the Can-am system) had a transfer efficiency of 90%, which represents an increase in transfer efficiency of approximately 38% over the baseline system.

The performance of the two primers (Baseline: MIL-P-53022, Niles; Alternative: MIL-P-53030, Deft) were similar, except that some users have reported poor adhesion using the alternative primer. Since the alternative primer is water thinnable, poor adhesion in isolated cases may be due to environmental factors, such as humidity.

Performance of the two thinners (Baseline: MIL-T-81772B; Alternative: Federal Standard A-A-857B) varied from user to user. Environmental effects are suspected to be the reason for the differences between the two. However, the effect of the alternative thinner on the appearance and performance of the topcoat was noticeable. If the alternative thinner is found to be unacceptable for use with the topcoat, it should be considered for use in the cleaning of process guns and hoses.

Valuation Process

The results of the weighting exercise in the three major dimensions assigned 65% of the value to the environmental dimension, 24% to the performance aspects, and 11% to cost. Since the scoping process assumed that the threshold criteria would result in alternatives that perform adequately and do not differ markedly in cost, the results should be reviewed considering those assumptions. Further tracing the weighting process into the three major branches indicates that global environmental issues were assigned 32% of weight, or about half of the overall environmental contribution. Regional and local issues received 20% and 13%, respectively. In the cost branch, O&M costs were considered approximately three times as important as capital costs. In the performance branch, the primer was considered the most important factor, with the thinner and the spray gun receiving about equal consideration.

Overall Improvement Assessment Results

The score summaries (lower being preferable) for the assessment results are shown below in decreasing order:

Baseline	1.191
Alternative Thinner	1.134 (Alternative 4)
Alternative Primer	1.019 (Alternative 1)
Alternative Thinner and Primer	1.016 (Alternative 5)
Alternative Gun	1.006 (Alternative 2)
Alternative Primer and Gun	0.898 (Alternative 3)

The results indicate that use of the alternative gun makes the largest potential improvement for an alternative that changes only a single factor, and in combination with the alternative primer, results in the best CARC option.

Conclusions

Of the five alternatives considered, two (Alternative 2, the alternative gun; and Alternative 3, alternative primer used with the alternative gun) demonstrate the greatest potential for environmental improvement; the remaining three alternatives exhibit slight improvements that are not significant, considering the scope of the study.

When cost and performance are considered along with environmental factors, Alternative 2 and Alternative 3 emerge as the preferred alternatives for implementation, but the degree of differentiation relative to the baseline is minor. Alternative 3 is the recommended implementation choice followed by Alternative 2.

The full report was submitted in fulfillment of Contract No. 68-C4-0020, work assignment 2-11, to Lockheed Environmental Systems & Technologies Company through Purchase Order Number 07PPG7 from Lockheed to Battelle, under the sponsorship of the U.S. Environmental Protection Agency

***Table 2**. Results of Alternatives Against Baseline System from the LCImA Inventory Analysis*

Alternative	*Results*	
	Increase	*Decrease*
1 Alternative primer used with the baseline CARC topcoat and thinner.	*Small increases for fuel, sodium chloride, chlorine, and the ilmenite and rumenite from production of TiO_2. Slight increases in chlorine and methane. Water discharges for titanium dioxide, chlorine, and heavy metals (cadmium, lead, and chromium). Addition of new chemicals from the production of nitroethane (acetaldehyde, methanol, 2-nitropropane, acetone, acetonitrile, nitric acid, ammonia).*	*Small decrease in resource consumption (electricity, natural gas, steam, water, crude oil, refinery gases, oxygen, and minor components). Elimination of phosphate and zinc ores. Decreases in air emissions of CO_2, volatile organic compounds, PM, NO_x, hydrocarbons, and CO. Decreases in ODP, water usage and discharges, including reductions in mobile ions, sodium, chloride, oil and grease, and boron. Slight reduction in hazardous solid waste.*
2[a] Substitution of the turbine HVLP gun against the standard (baseline) HVLP gun.	*None.*	*Decreases noted in resource consumption, energy usage, and emissions.*
3[a] Alternative primer with alternative gun.	*Mixed (both increases and decreases) in emissions from baseline.*	*Even larger decreases in energy and resource consumption than alternatives 1 and 2. Mixed emissions, but for those emissions common to the baseline, overall amounts decreased.*
4 Alternative thinner with baseline topcoat.	*Slight increase in SO_x in air emissions.*	*Decreases in resource and energy demands for electricity, steam, water, crude oil, bauxite, air, residual and distillate fuel oils. Reduced CO_2 and hydrocarbons in air emissions. Decreases in water usage and discharge rates. Decreases in mobile ions, chloride, oil, grease, and minor constituents. Slight decrease in solid waste.*
5 Alternative thinner and alternative primer with baseline gun.	*Increases in fuel, sodium chloride, chlorine, rumenite, ilmenite (from TiO_2 production). Slight increases in minor organic chemical releases. Increases in heavy metal content for water usage and emissions. Increases in solid wastes from nitroethane production processes.*	*Decreases in resource and energy consumption in the areas of electricity, natural gas, steam, water, crude oil, air, and refinery gases. Decreases in major air emissions in CO_2, VOCs, PM, NO_x, hydrocarbons, and CO. Decreases in water usage and overall emissions. Decreases in ODP, solid wastes (except those from the nitroethane production processes).*

[a]Preferred alternatives.

***Table 3.** Summary of Economic Assessment for Each of the Five Alternatives Compared to the Baseline CARC System*

Cost Category	*Baseline*	*Alternative 1*	*Alternative 2*	*Alternative 3*	*Alternative 4*	*Alternative 5*
Fixed Capital Investment [a]	*516*	*516*	*548*	*548*	*516*	*516*
Annual Operating Cost	*1,797 [a]* *2,903 [b]*	*1,788 [a]* *2,888 [b]*	*1,574 [a]* *2,542 [b]*	*1,565 [a]* *2,928 [b]*	*1,797 [a]* *2,901 [b]*	*1,787 [a]* *2,885 [b]*
Annualized Cost	*1,845 [a]* *2,981 [b]*	*1,837 [a]* *2,966 [b]*	*1,625 [a]* *2,625 [b]*	*1,616 [a]* *2,611[b]*	*1,845 [a]* *2,979 [b]*	*1,835 [a]* *2,963 [b]*

[a]Numbers are in thousands of dollars.

[b]Reported as \$/l000 ft^2.

Robin Thomas is with Lockheed-Martin Environmental, Las Vegas, NV 89119 and Duane Tolle is with Battelle Columbus, Columbus, OH 43201.
Kenneth R. Stone and Johnny Springer, Jr., *are the EPA Project Officers (see below).*
The complete report, entitled "Life Cycle Assessment for Chemical Agent Resistant Coating," (Order No. PB96-207378; Cost: $47.00, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officers can be contacted at:

National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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