Iowa Waste Reduction Center

Analysis of Costs and Benefits Associated With a Department of Defense Transition from Current Chemical Agent Resistance Coatings to a Water Dispersible Alternative

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1.0 EXECUTIVE SUMMARY
1.1 BACKGROUND

In response to newly instated local and federal restrictions on Volatile Organic Compound (VOC) and Hazardous Air Pollutant (HAP) emissions, the Department of Defense (DOD) is in the process of replacing its current solvent-borne Chemical Agent Resistant Coatings (CARC) with CARCs that are in compliance with these restrictions. One alternative is Water Dispersible CARC (WD-CARC). WD-CARC contains 1.5 pounds per gallon of VOCs and no HAPs. In addition to these environmental advantages, there is evidence that WD-CARC is the more cost-effective coating system. Demonstrations have shown that WD-CARC is advantageous over solvent-borne 3.5 VOC CARC in transfer efficiency, painting time, process waste, and durability. The purpose of this study was to report demonstrations that observed these advantages and extrapolate their data to predict potential cost benefits of a DOD transition to WD-CARC. Results showed annual cost savings for DOD depot facilities and substantial long-term cost savings over the duration of coated vehicles' expected service life. These results, taken with the contention that WD-CARC is a "drop-in" replacement (meaning replacement with minimal added expenses such as equipment), suggest that WD-CARC is a viable alternative. MIL-C-53039 Type II, the 1.5 VOC version of this MIL specification, was also compared and evaluated as a possible alternative. Implications of this study, limitations of the coating system as well as an additional method of reducing cost and waste are discussed.

1.2 PROBLEM STATEMENT

Recently, federal and local regulations have detailed more stringent restrictions on VOCs and HAPs emitted during organic coating operations. The Environmental Security Technology Certification Program (ESTCP) and the National Defense Center for Environmental Excellence (NDCEE) report some of these regulations. Many local governments are in the process of regulating VOC content to as low as 1.8 pounds per gallon. At the federal level, the U.S. Environmental Protection Agency (EPA) is in the process of issuing new National Emission Standards for Hazardous Air Pollutants (NESHAPs). Two of these regulations will directly affect DOD coating operations. The EPA has indicated that the NESHAP entitled "Miscellaneous Metal Parts and Products Surface Coating" will apply also to CARC. CARC is the primary coating system utilized by the DOD because of Army Regulation 750-1[2] which indicates that all tactical equipment must be resistant to chemical warfare agents and decontamination processes. Additionally, the NESHAP specific to military operations entitled, the "Defense Land Systems and Miscellaneous Equipment NESHAP," will regulate coating processes for a wide variety of military equipment including, but not limited to, tactical and ground combat vehicles, tactical shelters, and munitions.

In order to comply with the aforementioned NESHAPs and local regulations, the DOD must reduce VOC emissions and eliminate HAPs resulting from its coating operations. To this end, the ESTCP and NDCEE report measures that have been or are in the process of being implemented - some of which are included in this paragraph. The Army Research Laboratory (ARL) has responded with the development of WD-CARC coating systems which have been shown to significantly reduce VOC emissions and eliminate HAP emissions. Traditionally, DOD facilities have utilized Product ID#s MIL-C-46168 and MIL-C-53039 Type I, referred to below as 3.5 VOC CARC, each containing VOCs of approximately 3.5 pounds per gallon. The former has recently been cancelled and replaced with WD-CARC, Product ID# MIL-DTL-64159 Type II, in response to an (ARL) notification. WD-CARC has a VOC content of 1.5 pounds per gallon and contains no HAPs (such as methyl isobutyl ketone, toluene, and xylene). It also eliminates the use of solvent thinners required by 3.5 VOC CARC for thinning and clean-up; one of these thinners (specification MIL-T-81772) has a VOC content of over 7 pounds per gallon. As a result of WD-CARC's lower VOC and HAP content, Goose Creek predicts a reduction of VOC emissions by up to 75% for this facility. Moreover, the ESTCP cost and performance report projects the environmental advantages of WD-CARC at the DOD level, the following projections are from this report. Based on the DOD's estimated annual usage of 3 million gallons of coatings per year, implementation of WD-CARC containing 1.5 pounds per gallon of VOCs would reduce VOC emissions resulting from coating application by at least 5 million pounds of VOCs per year. These projections suggest then that use of WD-CARC would facilitate the DOD's compliance with newly instated local and national regulations regarding VOC and HAP emissions.

Another prospective alternative to 3.5 VOC CARC is MIL-C-53039 Type II referred to below as 1.5 VOC CARC. This coating system, presently used at some facilities, matches the performance of MIL-C-53039 Type I, but contains 1.5 pounds per gallon of VOCs and no HAPs. Thinner is typically not required to reduce this coating system (solvent thinner is used when it does), giving 1.5 VOC CARC the potential to facilitate environmental compliance equally as well as WD-CARC.

In addition to WD-CARC's environmental advantages, evidence suggests that WD-CARC offers advantages over its 3.5 VOC CARC counterpart in the areas of durability and material savings. According to the ESTCP, SERDP laboratory studies comparing WD-CARC and 3.5 VOC CARC showed an 800% life-cycle extension with the former. A 2004 demonstration of WD-CARC conducted at Goose Creek reported a 40% increase in spray transfer efficiency and up to a 20% reduction in material waste. Further details of all the demonstrations reported here will be included later in this report. WD-CARC appears then to offer the DOD a viable and cost-effective alternative for compliance with newly-instated environmental regulations. This alternative, according to the ESTCP, would presumably be more feasible than a transition to a coating system lacking the protective qualities of CARC or the procurement of costly emission control systems.

1.3 PROJECT OBJECTIVES

WD-CARC's advantages of durability and material savings observed from several field demonstrations implicate a substantial cost savings for the DOD. The overall purpose of this project was to report these demonstrations and extrapolate their results to predict potential cost benefits of a DOD transition to WD-CARC. The tool that will be used to calculate cost is an online "Cost Tool" developed and validated by the EPA which allows for a cost comparison of two coating systems. Inputs for the calculator concerning material usage, equipment and energy costs, labor and maintenance costs, and waste will be based on data from reported field demonstrations, two Army National Guard units, and the ESTCP Cost and Performance Report. In addition to the potential savings realized from the use of WD-CARC, the DOD could realize additional savings with the implementation of an advanced training program offered by the Iowa Waste Reduction Center (IWRC) known as the Spray Technique Analysis and Research for Defense (STAR4D) program. This program is briefly discussed and data pertaining to important training outcomes (such as quantity usage, waste, and labor hours) was extrapolated to predict additional cost benefits for the DOD.

2.0 DEMONSTRATION RESULTS

2.1 U.S. ARMY CEG-A GOOSE CREEK

In 2004, paint manufacturer Sherwin Williams, with contributions from the ARL and the NDCEE, conducted a demonstration of WD-CARC at the U.S. Army Combat Equipment Group Afloat (CEG-A) Goose Creek. This facility, located in Charleston, SC, has the mission of maintaining and repairing Army support equipment, tanks, trucks, and High Mobility Multipurpose Wheeled Vehicles (HMMWV). The purposes of the demonstration were to facilitate Goose Creek's transition from 3.5 VOC CARC to WD-CARC and to assess the economic and logistical feasibility of this transition.

Coatings supplied by Sherman Williams were applied to 5kw generators and three M967 Tankers. For all equipment, WD-CARC topcoat was applied over a MIL-C-53039 basecoat. Performance of WD-CARC was observed during the three phases of mixing, application, and curing. Performance measures of WD-CARC on quantity usage, waste, and labor hours were compared to the corresponding performance measures of the 3.5 VOC CARC traditionally used by this facility. A cost comparison of the two coating systems was then extrapolated from the results.

Overall, the results of the Goose Creek demonstration support WD-CARC's many performance advantages. For each type of equipment, an average of 40% less paint was used than the amount previously required with 3.5 VOC CARC. This reduction was attributed primarily to improved build efficiency. For example, less air pressure is required to atomize WD-CARC resulting in less overspray during application. This may be attributable to the lower application viscosities specified on WD-CARC's product data sheet. Consistent with this theory, a substantial reduction in overspray was observed with the use of WD-CARC during the demonstration. Moreover, it was reported that the "wet" appearance of the coating prevented the application of paint over previously coated areas. Each of these phenomena resulted in improved build efficiency and consequently less quantity usage. Another advantage noted was that WD-CARC lacks the requirement of a solvent thinning agent. Use of such an agent results in extra costs attributed to the cost of the agent itself and a 25% increase in waste stream resulting from clean-up. One final noteworthy result of the demonstration was that the number of labor hours needed to paint the M967 tanker was reduced from 5 to 3 hours. The demonstration report attributes this reduction to WD-CARC's ease of application and reduced set-up and clean-up times. Table 1 reports the results of the Goose Creek demonstration and additional savings that can be realized with the IWRC's STAR4D program. Further discussion of the STAR4D program is included in the implications section of this report. The aforementioned findings should result in many economic advantages when using WD-CARC. To confirm this, a high level cost comparison of WD-CARC with 3.5 VOC CARC was performed by extrapolating from the performance results of the demonstration. The results are reported taking into account the following factors: cost per gallon of the coating materials, amount of applied material, cost of thinning agent, and labor cost. The total cost of coating one M967 tanker would be reduced from $1,012 to $670 when using WD-CARC. Excluding labor cost, these results extend to a $1,948 reduction per month. It should be noted that these estimates include the cost of WD-CARC at $56 per gallon which is substantially greater than the cost of 3.5 VOC CARC at $38 per gallon. The ESTCP predicts that the cost of WD-CARC is expected to decrease with an increase in mass production of the material. Moreover, the results of the cost comparison suggest that any additional up-front expenditure of the coating would eventually be offset by its performance advantages.

2.2 ESTCP COST AND PERFORMANCE REPORT

In 2004, the ARL conducted a project for the ESTCP with the purpose of demonstrating and validating the advantages of WD-CARC. The project's primary objectives were to report on WD-CARC demonstrations (performed in 2000) at three depot facilities, compare WD-CARC's performance data obtained from these demonstrations with corresponding laboratory data, and to perform a cost comparison of WD-CARC with various 3.5 VOC CARCs. Demonstration sites included the Marine Corp's Barstow Logistics Base, the Air Force's Ogden Air Logistics Center (ALC), and the Army's Tobyhanna Army Depot. Performance data was collected and compared with corresponding data obtained from laboratory testing under SERDP Project PP-1056 with the intention of validating WD-CARC's superior laboratory performance in a production setting. A cost comparison of WD-CARC with 3.5 VOC CARC, including MIL-C-46168D and MIL-C-29475, ensued.

Demonstration results not only support WD-CARC's performance suitability, but also lend to its superiority compared to its 3.5 VOC CARC counterpart. While comparisons of stripping performance were generally problematic due to the varying composition and conditions of coating systems at the times of baseline and demonstration data collections, WD-CARC's application performance showed many positive results. For all three demonstration sites, surveys indicated that painters perceived WD-CARC overall as a superior coating system. Furthermore, for all performance measures, the obtained data did not statistically differ from the corresponding laboratory data which showed WD-CARC's superior outdoor durability, mar resistance, and flexibility to those of standard coatings systems. Furthermore, the Ogden ALC site demonstration showed a reduction of gallons used by about a third. Therefore, results of these demonstrations in conjunction with those of the Goose Creek demonstration suggest that not only is WD-CARC a suitable replacement to 3.5 VOC CARC, but is also superior in many respects.

A few remarks are appropriate at this point in the discussion concerning the stripping of WD-CARC. As mentioned in the previous paragraph, it was problematic to compare the stripping of WD-CARC and 3.5 VOC CARC due to the differing process variables of the ESTCP demonstrations. A study conducted by the ARL in 2006 compared the performance of various chemical paint strippers on both 3.5 VOC and WD-CARC. Results showed that a greater variety of the HAP-free strippers performed acceptably on WD-CARC, as indicated by the percentage of paint removed from the substrate within a 30-minute time interval. The study concluded that broader use of WD-CARC might eventually serve to maintain shorter strip times and provide a wider selection of HAP-free chemical strippers.

From a cost standpoint, these performance results should translate into economic savings for the DOD with the use of WD-CARC. The ESTCP confirmed this contention through a cost analysis. Calculations first confirmed WD-CARC's greater upfront costs. However, as stated before, the ESTCP reports that these costs are expected to decrease with mass production. Based on the quantity usage results reported at Ogden ALC, this facility would realize savings of CARC costs by nearly one third. Moreover, the ESTCP reports laboratory data that confirms WD-CARC's superiority on weatherability (greater than 6 times exposure duration), abrasion resistance (approximately 3 to 4 times less weight and thickness loss), and flexibility (approximately 3 times impact resistance). Extrapolation from this data produces estimates of up to an 800% life cycle extension. Using the conservative estimate of a 50% life-cycle extension and factoring in the annual labor and material costs of painting 480 HMMWVs, M-1 Tanks, or HEMMTS, the ESTCP estimates a cost savings of $380,000 to $730,000 per year per DOD facility depending on the type of vehicle painted.

3.0 ANALYTICAL PROCEDURES

As mentioned earlier, one purpose of this project was to predict potential cost benefits of a DOD transition from 3.5 VOC CARC to WD-CARC. One tool that was utilized to accomplish this is an online "Cost Tool" developed and validated by the EPA. This tool can be accessed at the following website address:http://cage.rti.org/economics/index.cfm. The "Cost Tool" is designed to acquire various user inputs regarding applied materials, equipment, energy usage, labor/maintenance, and waste. The program then uses these inputs to calculate a cost comparison of two coating systems. It should be noted that the EPA includes the following disclaimer, "This cost comparison tool is designed to provide a cost estimate of a process conversion. It is not intended to give you exact costs of a particular process conversion." Furthermore, input values and coating process variables are expected to vary substantially across DOD facilities. In light of these acknowledgements, the following assumptions were made for this study:

- According to the ESTCP, DOD depot facilities paint approximately 40 vehicles per month.
- The recommended Dry Film Thickness (DFT) for all CARC is 1.8 mils as recommended by MIL-DTL-53072C.
- 25% and 40% reductions in coating usage with the use of WD-CARC were observed at the Ogden ALC and Goose Creek demonstrations respectively, and these reductions were based on the process variables of these demonstrations. 32% (the average of these reductions) was used in this study.
- All calculations were based on the use of HVLP spray equipment for the application of all types of coating systems.

- No additional start-up costs or equipment are required for the application of WD-CARC with the possible exception of Infrared (IR) curing equipment (an explanation of this equipment is included in the implications section of this report).
- Purchased costs for equipment were based on estimates provided by one Midwestern Army National Guard Facility.
- According to the ESTCP, the average labor rate is $70/hour (hr).
- According to the ESTCP, it takes approximately 18 man hours to prepare and 9 man hours to paint one HMMWV unit; 24 man hours to prepare and 12 man hours to paint one M-1 Tank unit; and 48 man hours to prepare and 16 man hours to paint one Heavy Expanded Mobility Tactical Truck (HEMMT) unit.
- According to the ESTCP, the DOD produces a waste stream of approximately 6 million pounds and a typical DOD depot facility produces a waste stream of approximately 600,000 pounds of CARC-related waste annually.
- The ESTCP uses $.35 per pound as waste disposal costs.
- According to the ESTCP, vehicles generally receive depot-level repainting every 6 years.

3.1 INPUTS FOR GENERAL INFORMATION

The general information section of the coatings guide cost tool includes user inputs regarding demographics and paint systems analyzed. Any inputs regarding demographics such as name, company name, email etc. were not deemed relevant to the nature of this project and accordingly were not considered. The coating systems compared included 3.5 VOC CARC, 1.5 VOC CARC and WD-CARC. In this study, 3.5 VOC CARC and WD-CARC were chosen for investigation principally because these systems have been widely researched and include the most expansive data on various performance measures. Although none of the demonstrations reported in this study included1.5 VOC CARC, for the purposes of this study it will be assumed that 1.5 VOC CARC and 3.5 VOC CARC perform similarly in regards to paint usage and labor/maintenance hours as paint costs were the only assumed differences between the two coatings systems. Differences were reported between the durability of 1.5 VOC CARC and the durability of MIL-C-46168, the recently canceled solvent-borne 3.5 VOC CARC (details can be found in the long-term analysis). It should also be noted that the coatings guide cost tool did not include these MIL specifications as among its coatings system options. However, these omissions did not impact the results of this study because sections of the cost tool include inputs that allow for customization of any critical characteristics of the coating systems under investigation.

The cost tool is designed to project the annual total costs of production for one paint facility. For this study, the typical DOD depot facility and one Midwestern Army National Guard facility were the subjects of research. Data for the typical DOD depot facility was obtained from estimates reported by the ESTCP. Equipment costs of the typical DOD depot facility were not available and were therefore substituted with the equipment costs reported by the Army National Guard facility.

3.2 INPUTS FOR APPLIED MATERIALS

The applied materials section of the coatings guide cost tool includes user inputs for coating specifications as well as inputs for facility production rate and spray transfer efficiency. Paint costs were based on those reported in the ESTCP and Goose Creek reports and were about $38.00 per gallon for a 100 gallon order of the 3.5 VOC CARC and about $52.00 per gallon for a 100 gallon order of the WD-CARC. The cost of the 1.5 VOC CARC was estimated to be $45.00 per gallon. Costs of any thinner added to the admixes were added to the paint costs. Based on data reported in the Goose Creek report, .22 gallons of MIL-T-81772 thinner were added to each gallon of 3.5 VOC CARC applied. Since Goose Creek reports the cost of MIL-T-81772 to be $10 per gallon, about $2.00 was added to 3.5 VOC CARC's cost per gallon. WD-CARC included no extra thinner costs because this coating is thinned with deionized water. Percent volume solids and VOC content were based on the specifications reported by each coating's product data sheet. Percent volume solids was 51% for 3.5 VOC CARC and 39.8% for WD-CARC and VOC content was 3.5 pounds per gallon for 3.5 VOC CARC and 1.5 pounds per gallon for WD-CARC. In accordance with MIL-DTL-53072C recommendations, Dry Film Thickness (DFT) for each coating was 1.8 mils.

One qualification concerning percent volume solids is in order. While the ESTCP reports this figure for WD-CARC to be 39.8%, the IWRC has consistently shown this figure to be 50% - 55%. This study will utilize the 39.8% figure; however, it is advised that this figure be reexamined based on these contradictory findings.

Production rates were based on the ESTCP's reported estimates of the number of HMMWVs, M-1 tanks, and HEMMTs coated per year per DOD depot facility. These vehicles served as the equipment under investigation because they are relatively common DOD vehicles. The ESTCP estimates that the production rate of the typical DOD depot facility is approximately 480 units per year translated by this study to be 698,061 ft^2/year (yr), 907,479 ft^2/yr, and 1,186,703 ft^2/yr for HMMWVs, M-1s, and HEMMTs respectively. Note that these production rates are likely to be somewhat conservative estimates; certain depot facilities are purported to produce 40 of these units per day.

Estimates for transfer efficiency were derived from the estimates of paint usage reported by the Ogden ALC and Goose Creek demonstrations. The fact that these facilities reported less quantity usage with WD-CARC suggests that more waste is produced with application of 3.5 VOC CARC, since the theoretical coverage of 3.5 VOC CARC (818.04 ft^2/gallon) is actually greater than that of WD-CARC (638.39 ft^2/gallon). As mentioned before, application of WD-CARC results in little to no overspray and better overlap due to a more visible wet line. Overspray reduction can perhaps be attributed to less air pressure required to atomize the less viscous WD-CARC admix; according to the product data sheet for each coating, the recommended admix viscosities are 4.00-8.85 poises[1] for 3.5 VOC CARC and 1.00-1.65 poises for WD-CARC. However, while the Ogden ALC and Goose Creek demonstrations reported their application viscosities for WD-(CARC),

[1]A poise is defined as the centimeter-gram-second unit of viscosity equal to one dyne-second per square centimeter.

no application viscosities were reported for 3.5 VOC CARC. Moreover, no air pressure data were reported for either demonstration. Nevertheless, estimates of transfer efficiency can be used to calculate the actual coverage of each coating. The equation that can be used for this calculation is: *actual coverage = theoretical coverage/DFT * transfer efficiency*. The production rate (in ft^2/yrs) divided by the product of this equation (in ft^2/gallons) produced the average of the quantity usages reported by the demonstrations. The resulting transfer efficiencies were 60% (the cost tool's default input) for WD-CARC and 32% for 3.5 VOC CARC.

3.3 INPUTS FOR EQUIPMENT

The equipment section of the coatings guide cost tool includes user inputs pertaining to the costs of preparation and application equipment for coating operations. Ultimately this equipment data is used to calculate the annual overhead and maintenance costs associated with equipment operation. However, based on the demonstrations and contentions made within the ESTCP report, no additional start-up costs or equipment are required for the application of WD-CARC with the possible exception of curing equipment (curing issues associated with WD-CARC are discussed within the implications section of this report). Therefore, any differences between the overhead and maintenance costs of 3.5 VOC CARC and WD-CARC are expected to be minimal.

Inputs for equipment costs were based on estimates provided by an Army National Guard facility. As mentioned earlier, these estimates were also utilized for the typical DOD facility because no equipment costs were obtained from these facilities. The Army National Guard facility reported the following purchasing costs and these costs served as the inputs for the cost tool. Purchasing costs for preparation equipment, including blasting equipment etc., were $165,000. Purchasing costs for basic equipment, including tanks, conveyers, and application equipment, were $12,800 and purchasing costs for spray booths were $150,000. The cost calculator's default values were used as the purchasing costs for compressors, piping, and emission controls. It is important to note that these facilities do not represent all DOD facilities, each probably varying substantially in their equipment costs. Therefore, the inputs for equipment might be more or less depending on each respective DOD facility.

3.4 INPUTS FOR LABOR/MAINTENANCE

The labor/maintenance section of the coatings guide cost tool was used to calculate annual labor/maintenance costs associated with painting operations for a typical DOD depot facility. Operating costs per shift/day were assumed to be 8 hours. Operating days per year were the default value provided by the cost tool (260 days). 10 applicators per facility were used for the "number of applicator's" input. These applicators were likely to be divided over several work shifts. These inputs were hypothetical and were derived from the ESTCP's estimate of 480 units painted per year per facility and the number of man hours required to paint the various vehicles. Because certain vehicles like HEMMTs require more man-hours to prepare and paint than a vehicle like a HUMMWV, the number of applicators were adjusted to allow for an annual production rate of 480 units of each vehicle type. Applicator's wages were assumed to be $70/hour[2] (hr) and were based on the average labor rate reported by the ESTCP. The remaining labor/maintenance inputs of the cost tool were zeroed out because this data was not known.

3.5 INPUTS FOR WASTE

The waste section of the coatings guide cost tool includes user inputs pertaining to filter and sludge waste produced from coating operations. For this project, this section of the cost tool was bypassed because a global waste figure for all DOD facilities was obtained from the ESTCP cost and performance report. DOD CARC-related paint and depaint waste production is estimated to be 6 million pounds per year or 600 thousand pounds per year per DOD depot facility. With estimated waste disposal costs at $.35 per pound, the resulting annual waste costs are $2,100,000 for the entire DOD and $210,000 per DOD facility.

3.6 COST-SAVINGS BASED ON LIFE-CYCLE

All of the costs calculated via the coatings guide cost tool were relatively short-term costs spanning one year, whereas long-term costs were calculated by taking into account the life-cycles of the various coating systems. As previously reported, laboratory studies have shown that WD-CARC is superior to its 3.5 VOC CARC counterpart on weatherability, abrasion resistance, and flexibility thereby resulting in a life-cycle extension with the former of approximately 800%. In another study, the ARL performed a weathering test on various coating systems (MIL-C-46168 (3.5 VOC CARC), MIL-DTL-64159 TYPE II, MIL-PRF-85285, and MIL-PRF-85285 Type III) under hot and humid conditions in Florida and under hot conditions in Arizona. Results showed that under both testing conditions, the 3.5 VOC CARC failed after 25 weeks whereas the WD-CARC endured 97 weeks resulting in a life-cycle extension of approximately 300%. Results were reprinted and are presented in Figures 1and 2.

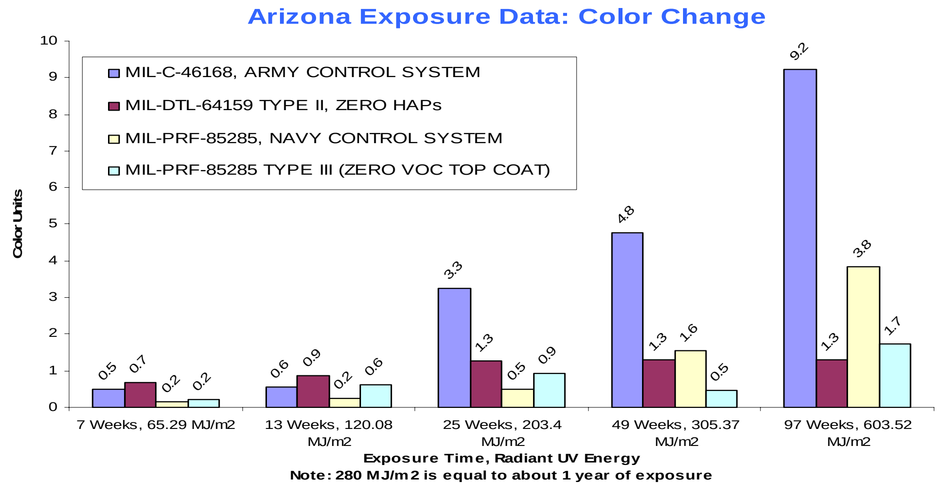

Figure 1. ARL's Arizona Exposure Data**.**

[2] This number can be considered to be fully loaded, meaning that the costs of benefits, vacation times etc. are included. Applicators take-home pay may more likely be about $20/hour.

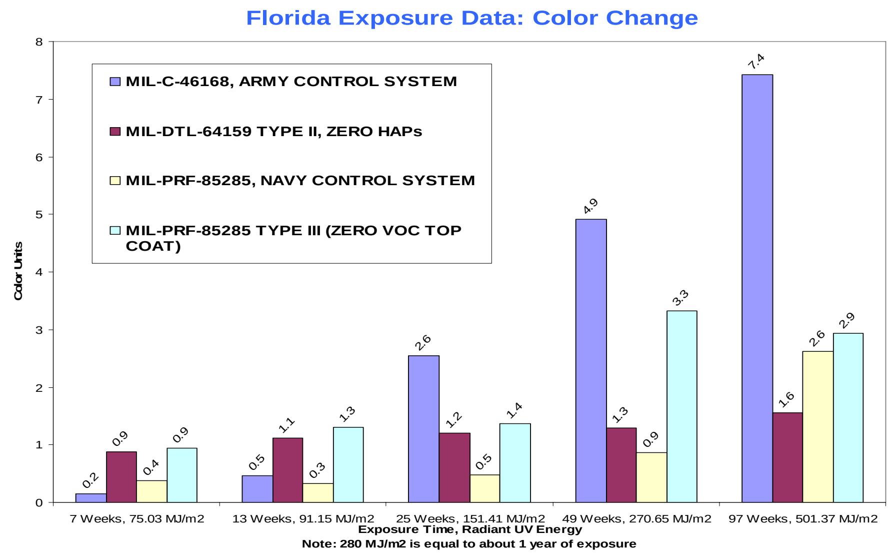

Figure 2. ARL's Florida Exposure Data**.**

The ESTCP estimates that vehicles like HMMWVs generally receive depot level repainting every 6 years. Therefore, a six year life-cycle was assumed for 3.5 VOC CARC and life-cycle extensions of 50% (6 to 9 years) and 300% (6 to 24 years) were assumed for WD-CARC; the 50% life cycle extension was based on the conservative estimate utilized in the cost calculations of the ESTCP report. In this study, the low and high ends of a range of possible life-cycle extensions expected with the use of WD-CARC are represented by extensions of 50% and 300% respectively. It should be noted that results of the laboratory studies reported earlier showed that WD-CARC actually endured beyond the maximum 97 weeks of this study. Moreover, the ESTCP actually reported an 800% life-cycle extension associated with WD-CARC. Thus, it can be inferred that the 300% life-cycle extension is actually a somewhat conservative estimate.

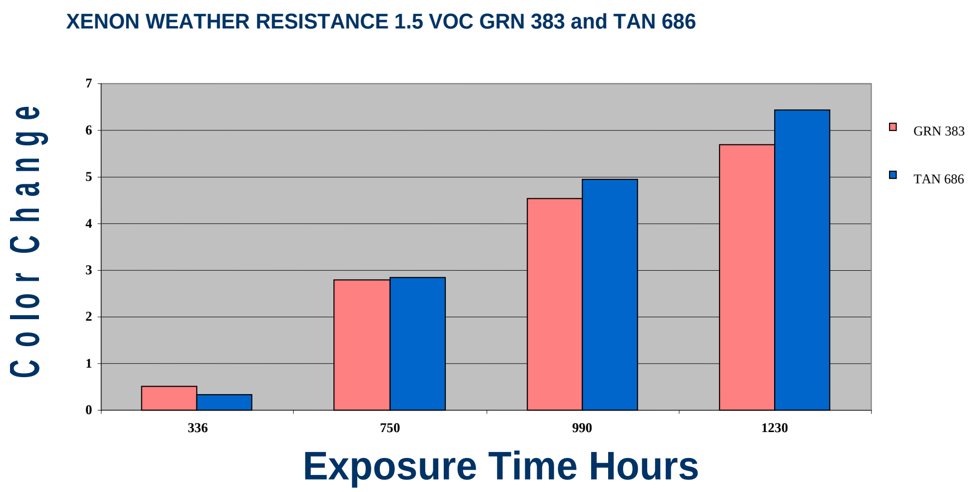

Figure 3. ARL's Xenon Test Data**.**

A Xenon test conducted by the ARL showed that 1.5 VOC CARC endured 32% longer (25 to 33 weeks) than 3.5 VOC CARC when data from this study was compared to data from the Florida and Arizona weathering tests. Results of the Xenon test were reprinted and are presented in Figure 3. Assuming a six year life cycle for 3.5 VOC CARC (based on the data reported in the Xenon study) the 1.5 VOC CARC can be expected to outlast 3.5 VOC CARC by 32% (6-8 years). As was the case with WD-CARC, the results of the laboratory study were used as the high end of a range of possible life-cycle extensions. The low end of the range was 5% thereby making the range for 1.5 VOC CARC proportionate to the range used for WD-CARC.

4.0 ANALYSIS AND RESULTS

4.1 SHORT-TERM COST SAVINGS

A short-term cost comparison of 3.5 VOC CARC, 1.5 VOC CARC, and WD-CARC was calculated. Results are reported in Tables 2, 3, and 4. These tables report the annual costs for a typical DOD depot facility to paint HMMWVs, M-1 tanks, or HEMMTs. A description of the methodology is presented below.

The costs of applied materials were calculated with the EPA's cost tool (see Table 2). Annual production rate (measured in ft^2/year) was divided by actual coverage (measured in ft^2/gallon) to derive an estimate of topcoat quantity usage. The resulting quantities were then multiplied by the costs of the two coating systems. Finally, costs of primer (as reported by the ESTCP) were included to derive the total cost of materials for repainting 480 vehicles (the typical production rate of a DOD facility). Results showed that in instances when HEMMTs are coated, material costs per vehicle were $726 with WD-CARC, $805 with 3.5 VOC CARC, and $890 with 1.5 VOC CARC. These patterns of results were similar for each vehicle type. If one considers that the theoretical coverage of WD-CARC (638.39 ft^2 vs 818.04 ft^2 for 1.5 VOC and 3.5 VOC CARC) may be an underestimate as suggested by IWRC findings, the quantity usage with WD-CARC would be even less. Results are reported in Table 2. Table 3 reports the annual cost of materials if an average depot facility were to paint 480 vehicles. Results showed that in instances when HEMMTs are coated, cost savings when 3.5 VOC CARC is replaced with WD-CARC are $37,852 and cost savings when 1.5 VOC CARC is replaced with WD-CARC are $78,652. Once again, this pattern of results applied to all three vehicles types.

Equipment costs were calculated with the EPA's cost tool (see Appendix 1). Purchased equipment costs were supplied by one of the Army National Guard facilities and were used to determine Total Capital Investment (TCI). Administrative charges, property tax, insurance, and capital recovery (as percentages of TCI), were added to overhead (as a percentage of labor/maintenance costs) to derive annual equipment costs. Note that the relative equipment costs for each DOD facility is likely to vary. Also note that man hours dedicated exclusively to maintenance were not figured into the labor/maintenance costs. The result is that estimates of annual equipment costs are likely to be lower than what would be expected if these hours were included. Results showed that annual equipment costs were: $637,444 for HMMWVs, $812,164 for M-1s, and $1,336,324 for HEMMTs. Equipment costs were not figured into the long-term cost analysis because the supposed similar equipment costs for all three coating systems (excluding IR curing equipment) would result in equal cost savings.

Short-term cost savings for waste were calculated by taking the annual cost of DOD waste disposal and applying the 20% waste stream reduction observed at the Goose Creek demonstration. Table 1 reports the results and additional savings that can be realized with the IWRC's STAR4D program. Results showed that annual costs for waste disposal were $2,100,000 with 3.5 VOC CARC and $1,680,000 with WD-CARC. The 1.5 VOC CARC was not included in these results because the Goose Creek demonstration did not include this coating system.

Labor/maintenance costs were calculated with the EPA's cost tool and are reported in Table 4. The number of man hours per year was calculated by multiplying the number of labor hours per day/shift with the number of operating days per year and the resulting product was multiplied by the number of applicators. Man hours per year were multiplied by the average applicator wage to determine annual labor/maintenance costs. The remaining section of Table 4 reports the maximum number of each vehicle type that could be painted given the annual man hours available to the facility. This maximum potential is realized only when the facility is running at 100% efficiency with no down time. Results showed that at maximum potential (when the only production equipment were HMMWVs) 1,284 HMMWVs could be painted with WD-CARC, while only 770 HMMWVs could be painted with 3.5 VOC CARC or 1.5 VOC CARC. This pattern of results was also found for M-1s and HEMMTs. This increase in maximum potential was attributed to the 40% reduction in labor/maintenance hours observed at the Goose Creek demonstration.

4.2 LONG-TERM COST SAVINGS

The reported long-term cost savings represent the cost savings resulting from a life-cycle extension with the use of WD-CARC or 1.5 VOC CARC. As previously mentioned, a 50% to 300% increase in life-cycle can be realized with the use of WD-CARC and 5% to 32% increase with the use of 1.5 VOC CARC. These percentages were used to derive the number of repaints required for one of three vehicle types (coated with either 3.5 VOC CARC, 1.5 VOC CARC, or WD-CARC) over the expected service life of the vehicle. For example, assuming a six year life-cycle with 3.5 VOC CARC, if the expected life of a vehicle is 15 years, then the expected number of repaints for the vehicle coated is two. The number of repaints for the vehicle coated with WD-CARC would be adjusted from this estimate based on the percentage increase in life-cycle (see Tables 5 and 6). The resultant frequencies were then multiplied by the total annual cost for repaint, based on the costs of applied materials and labor/maintenance costs reported in this study, to arrive at the total costs to repaint the vehicle during its expected service life. Total costs of repaint for both coating systems were multiplied by 480 (the estimated annual production rate per facility) to determine the total costs of repainting 480 vehicles over their expected service lives. This procedure was repeated for each vehicle type and separately for the 5%, 50%, 32% and 300% life-cycle extensions.

Results are reported in Tables 5 and 6 that show that use of WD-CARC resulted in fewer repaints than 3.5 VOC CARC or 1.5 VOC CARC and the outcome was long-term cost savings. Assuming the conservative 50% life-cycle extension, one less repaint over the entire service life of each vehicle type was shown with use of WD-CARC. For HMMWVs, the long-term savings resulting from this reduced frequency was $676,900 with the switch from 3.5 VOC CARC and $726,900 with the switch from 1.5 VOC CARC. Assuming the laboratory-based 300% life cycle extension, two less vehicle repaints resulted in savings of $1,363,825 with the switch from 3.5 VOC CARC and one less vehicle repaint resulted in savings of $363,450 with the switch from 1.5 VOC CARC. In instances when M-1s and HEMMTs are painted, switches from 3.5 VOC CARC and 1.5 VOC CARC resulted in three less and two less vehicle repaints respectively. Long-term savings associated with a switch from 3.5 VOC CARC to 1.5 VOC CARC are shown in Tables 5 and 6. The laboratory-based 32% life-cycle extension resulted in one less vehicle repaint for all three vehicles. However, use of 1.5 VOC CARC rather than 3.5 VOC CARC did not result in reduced repaint frequencies when the conservative 5% life-cycle extension was assumed.

5.0 IMPLICATIONS

The primary purpose of this study was to extrapolate from the results of various WD-CARC demonstrations in order to predict the potential cost savings of a DOD transition to WD-CARC. Results of this study lent near unequivocal support for the cost effectiveness of this implementation. Table 7 provides a results summary. While short-term savings resulting from reduced process time and materials were predicted (note that short-term cost savings can be expected to increase if and when the price per gallon of WD-CARC decreases with mass production), it was the long-term savings resulting from WD-CARC's extensive life-cycle that were perhaps the more appreciable. The results of this study suggest that over the course of its expected service life, a vehicle coated with WD-CARC will need to be repainted fewer times than one coated with 3.5 VOC CARC. If one considers the estimated cost of repaint and the production rate at the typical DOD depot facility, the cost savings resulting from this reduced frequency would be appreciable, even when a conservative 50% life-cycle extension is assumed. When a 300% life-cycle extension is assumed, it is conceivable that a vehicle will require only one coating (the initial coating after manufacture) over the entire service life of the vehicle. Of course this prediction accounts only for repaint due to coating failure and not for repaint due to camouflage adjustment. However, at minimum, any realized life-cycle increase would have the potential to substantially reduce the frequency of repaints and therein allow a transition to WD-CARC to be cost effective.

Low-solvent 1.5 VOC CARC has few, if any, short-term advantages, and some long term advantages over 3.5 VOC CARC, although further research on this issue may be warranted. According to the assumptions of this study, use of the 1.5 VOC CARC is expected to be more expensive from year to year in terms of materials cost. Our results showed that a HEMMT coated with 1.5 VOC CARC would cost $890, one coated with 3.5 VOC CARC would cost $805 and one coated with WD-CARC would cost $726. Long-term savings may be more promising. Results from one laboratory study (the Xenon study) did show that the 1.5 VOC CARC was more durable than 3.5 VOC CARC, enduring 32% longer. Within the present cost analysis, these results translated into one less repaint over the life-cycle of the vehicles. However, with the more conservative estimate of 5%, any benefits involving fewer vehicle repaints were almost entirely absent. Conversely, the conservative 50% life-cycle extension with the use of WD-CARC still resulted in appreciable benefits.

After considering these savings, one might scrutinize the conditions under which a 300% extension might be approached. One answer might concern the procedure which the vehicle is prepared. One possible disadvantage associated with WD-CARC is longer substrate preparation. The Goose Creek report notes that more concerns (ie. blisters or other coating defects) are introduced when applying WD-CARC over hydrocarbons or oil contaminants than 3.5 VOC CARC. Further, paint manufacturers such as Sherwin Williams list necessary conditions for the maximum durability potential of WD-CARC to be realized. One of these conditions concerns the manner in which a surface is stripped and prepared. Therefore, surface preparations (ie. cleaning and pretreatments) for the use of WD-CARC may need to be more extensive. It is at this point in this discussion that one result of the Goose Creek demonstration may be particularly relevant. Results from the demonstration showed that annual labor/maintenance hours could be reduced with a WD-CARC replacement by as much as 40%. However, as noted in the Goose Creek report, it is likely that any reduced man hours required for production would actually translate into increased production rather than abbreviated work shifts (increased production that might be needed in war time, see Table 4). Yet another utilization of these extra labor hours might be time spent during preparation. For example, taking the labor estimates provided by the ESTCP and applying the results of the Goose Creek demonstration, a typical depot facility producing one HMMWV vehicle might realize a reduction in labor hours required for application from 9 to 5.4 hours (assuming similar process variables to those of the Goose Creek demonstration). This added time might be spent on more extensive surface preparation, enough to nearly eliminate surface contaminants and conform to the paint manufacturer's recommendations thereby maximizing the durability potential of WD-CARC. In this manner, the life-cycle of the coating system might approach the upper limit of 24 years. If a vehicle's service life is 15-20 years, this sort of durability could mean the elimination of repaints due to coating failure. For example, the elimination of vehicle repaints resulted in long-term cost savings of $3,176,815 over the service lives of M-1s and $5,324,495 over the service lives of HEMMTs when WD-CARC was used rather than 3.5 VOC CARC. These results are shown in Table 6.

A few disadvantages associated with WD-CARC have been noted by researchers and practitioners which could increase the time and equipment requirements of this coating system. First, it has been documented that WD-CARC requires longer cure times than 3.5 VOC CARC. To exacerbate this problem, additional coats of WD-CARC should be added only when the previous coat has dried lest blistering and other coating defects occur. To address this issue, the STAR4D program at the Iowa Waste Reduction Center conducted studies on the effects of IR heating as a forced dry technique on WD-CARC topcoat. Results showed that a dry moderate condition (no major finish impressions when subjected to moderate finger pressure and a 90° twist) can be achieved within 20-40 minutes under medium wavelength IR heating at part surface temperatures of 130°F.-

160°F. Results also showed that a rain resistant condition can be achieved after approximately 45 minutes under medium wavelength IR heating at part surface temperatures of 130°F. These results suggest that the cure time disadvantage of WD-CARC can be ameliorated with infrared heating, although additional studies on the effects of IR heating on production and costs are topics for future research by the STAR4D program. Nevertheless, this sort of implementation implicates a need for additional procurements of curing equipment. In particular, IR Catalytic curing equipment large enough to accommodate a HMMWV includes a purchase with installation fee of approximately $85,000. As evidenced by the results of this study, these added up-front costs are likely to be offset by WD-CARC's performance advantages.

It is appropriate at this point to make a few concluding remarks about 1.5 VOC CARC, a coating system currently in use at certain DOD facilities. As mentioned in the problem statement of this report, 1.5 VOC CARC produces low VOC emissions and is HAPS free. Therefore, while 1.5 VOC CARC may be inferior to WD-CARC in terms of performance, it has the potential to match WD-CARC environmentally. As far as how the coating system compares to 3.5 VOC CARC, it can be inferred that it results in slightly higher expenses annually and is slightly more durable. In terms of environmental and safety factors, results are mixed. Environmentally, 1.5 VOC CARC is obviously superior to 3.5 VOC CARC, potentially matching the advantages observed with use of WD-CARC, though these advantages are diminished if solvent thinner is used when 1.5 requires thinning. In terms of safety, it should be noted that the addition of acetone to 1.5 VOC CARC results in a lower flash point. On the other hand, WD-CARC has a solvent-free and acetone-free composition and thus has the highest flash point of the coating systems of this report.

As mentioned earlier, additional cost savings for the DOD could be realized from an advanced training program provided by the IWRC known as the STAR4D program (see Tables 1, 2, 3, and 4). The STAR4D program, with the inclusion of the LaserPaint™ targeting tool, has resulted in 20% - 30% improvements in transfer efficiency, quantity usage, labor hours, productivity, and waste. If a goal of the DOD is to maximize the cost savings from its coating operations, then the STAR4D program is yet another implementation it could utilize.

5.1 CONCLUSION

The purpose of this project was to report and extrapolate the results of select WD-CARC demonstrations in order to predict potential cost benefits of a DOD 3.5 VOC CARC to WD-CARC transition. WD-CARC's potential advantages of durability and material savings over 3.5 VOC CARC implicate substantial cost savings to the DOD. In terms of material savings, use of WD-CARC did result in improved transfer efficiency at two demonstration sites which translated into annual cost savings in applied materials within the results of this study. There was also evidence that process waste can be reduced with the use of WD-CARC. The most appreciable savings however might be attributed to the increased durability of WD-CARC. Laboratory studies suggest that the longevity of a coating system's life-cycle can be increased by as little as 50% and as much as 300% with use of WD-CARC. Extrapolation from these results suggested a reduction of vehicle repaints over the service life of the vehicle to as little as none. It can therefore be concluded from the results of this study and various demonstrations that WD-CARC would be a cost effective replacement to 3.5 VOC CARC and facilitate the DOD's compliance with newly instated local and national environmental regulations regarding VOC and HAP emissions. While further research on the preparation and curing issues of WD-CARC (as well as field studies of its durability) is warranted, the results of this study and demonstrations of the coating system suggest that a DOD transition to WD-CARC is warranted.

Table 1. A Comparison of 3.5 VOC CARC to WD-CARC and WD-CARC with STAR4D Training (Not including surface preparation costs).

	Man Hours Needed to Paint 1 M967-Tanker	Cost for Painting 1 M967-Tanker	Annual Cost of DOD Waste Disposal *(based on 6 million pounds @ $.35 per pound)*	Service Life Re-Paint Cost for 1 M967-Tanker
3.5 VOC CARC *(MIL-C-53039)*	10	$1,012	$2,100,000	$3,036
WD-CARC *(MIL-DTL-64159)*	6	$670	$1,680,000	$670 *(300% Coating Life Improvement)*
WD-CARC With STAR4D Training[3]	4.8	$536	$1,260,000	N/A (Training Affect on Coating Durability Cannot be Calculated)
Total Savings With WD-CARC and STAR4D Training	5.2	$476	$840,000	$2,366

[3] The STAR4D program, with the inclusion of the LaserPaint™ targeting tool, has resulted in 20% - 30% improvements in transfer efficiency, productivity, and waste. These figures were calculated by applying a conservative 20% reduction in man hours, materials cost, and waste.

Table 2. The Applied Materials Cost to Paint the Average Number of Vehicles a DOD Depot Facility Paints per Year (480 vehicles) and Materials Cost to Paint 1 of these Vehicles.

	HMMWV			**M-1**			**HEMMT**		
	3.5 VOC CARC	1.5 VOC CARC	WD-CARC	3.5 VOC CARC	1.5 VOC CARC	WD-CARC	3.5 VOC CARC	1.5 VOC CARC	WD-CARC
% Volume Solids	51%		39.8%	51%		39.8%	51%		39.8%
Theoretical Coverage (TC) *%Volume Solids/1063*	818.04 ft^2/gal.		638.39 ft^2/gal.	818.04 ft^2/gal.		638.39 ft^2/gal.	818.04 ft^2/gal.		638.39 ft^2/gal.
Dry Film Thickness (DFT)	1.8 mils								
Transfer Efficiency (TE)	32%		60%	32%		60%	32%		60%
Actual Coverage (AC) *TC/DFT * TE*	145.43 ft^2/gal.		212.80 ft^2/gal.	145.43 ft^2/gal.		212.80 ft^2/gal.	145.43 ft^2/gal.		212.80 ft^2/gal.
Production Rate (PR)	698,061 ft^2/yr.			907,479 ft^2/yr.			1,186,703 ft^2/yr.		
Quantity Usage of Topcoat (QUT) *PR/AC*	4,800 gal.		3,264 gal.	6,240 gal.		4,243 gal.	8,160 gal.		5,549 gal.
Quantity Usage of Primer (QUP)	1,440 gal.			1,920 gal.			2,400 gal.		
Cost per Gallon of Topcoat (CT)	$40	$45	$52	$40	$45	$52	$40	$45	$52
Cost per Gallon of Primer (CP)	$25								
Total Cost of Topcoat (TCT) *CT * QUT*	$192,000	$216,000	$169,728	$249,600	$280,800	$220,636	$326,400	$367,200	$288,548
Total Cost of Primer (TCP) *CP * QUP*	$36,000			$48,000			$60,000		
Total Cost of Materials for Repainting **480** Vehicles *TCT + TCP*	$228,000	$252,000	$205,728	$297,600	$328,800	$268,636	$386,400	$427,200	$348,548
Cost of Materials With STAR4D Training[4]	$182,400	$201,600	$164,582	$238,080	$263,040	$214,909	$309,120	$341,760	$278,838
Total Cost of Materials for Painting **1** Vehicle	**$475**	**$525**	**$429**	**$620**	**$685**	**$560**	**$805**	**$890**	**$726**

[4] The STAR4D program, with the inclusion of the LaserPaint™ targeting tool, has resulted in 20% - 30% improvements in transfer efficiency and material usage. These figures were calculated by applying a conservative 20% reduction in materials cost.

Table 3. The Savings Associated with Using WD CARC Materials Instead of 3.5 VOC CARC or 1.5 VOC CARC Materials for an Average DOD Depot Facility Painting 480 vehicles.

	HMMWV			**M-1**			**HEMMT**		
	3.5 VOC CARC	1.5 VOC CARC	WD-CARC	3.5 VOC CARC	1.5 VOC CARC	WD-CARC	3.5 VOC CARC	1.5 VOC CARC	WD-CARC
Total Cost of Materials for Repainting **480** Vehicles	$228,000	$252,000	$205,728	$297,600	$328,800	$268,636	$386,400	$427,200	$348,548
Annual Cost Savings (3.5 VOC CARC to WD-CARC)	$22,272			$28,964			$37,852		
Annual Cost Savings (1.5 VOC CARC to WD-CARC)	$46,272			$60,164			$78,652		

Table 4. The Labor/Maintenance Costs for an Average DOD Depot Facility with 10 Painters and the Increased Potential Productivity Due to Using WD-CARC.

	HMMWV *(9 Man Hours to Paint, 18 man hours to prepare)*		**M-1** *(12 man hours to paint, 24 man hours to prepare)*		**HEMMT** *(16 man hours to paint, 48 man hours to prepare)*	
	3.5 VOC and 1.5 VOC CARC	WD-CARC *(40% reduction in painting time)*	3.5 VOC and 1.5 VOC CARC	WD-CARC *(40% reduction in painting time)*	3.5 VOC and 1.5 VOC CARC	WD-CARC *(40% reduction in painting time)*
Man Hours Per Year (Total Hours)	20,800					
Number of Applicators	10					
Applicators' Wages	$70/hr					
Labor/Maintenance Cost per year *Wage ($/hr) * Total Hours*	$1,456,000					
Potential Number of Units Painted Per Year W/O Overtime *(Total Hours / hours needed to paint a vehicle)*	770	1284	577	963	325	542
Potential Number of Units Painted Per Year With STAR4D Training	924	1541	692	1,156	390	650
Labor/Maintenance Cost per Vehicle When Achieving Maximum Potential	**$1,575.75**	**$944.85**	**$2,104.05**	**$1,259.52**	**$3,733.33**	**$2,240.00**

Table 5. The Savings Associated With Using WD CARC Instead of 3.5 VOC or 1.5 VOC CARC to Paint 500 vehicles over the Service-Life of Those Vehicles Based on a 50% Life Cycle Increase.

			Labor Cost per Vehicle for an average DOD Depot Facility with 10 Painters	Material Cost per Vehicle	Number of Re-Paints Per Vehicle *(based on service life)*	Total Vehicle Service Life Cost of Repaint	Total Cost of Re-Painting 500 Vehicles Over the Entire Service Life of the Vehicles	Savings for Re-Painting 500 Vehicles Over the Entire Service Life of the Vehicles
Total Costs Based on Life-Cycle Increases of **50%** with WD-CARC and **5%** With 1.5 VOC CARC	**HMMWV** **Estimated 15 year service life*	3.5 VOC CARC	$1,575.75	$475	2	$4,101.50	$2,050,750.00	3.5 VOC CARC to WD CARC **$676,900**
		1.5 VOC CARC		$525		$4,201.50	$2,100,750.00	1.5 VOC CARC to WD CARC **$726,900**
		WD-CARC	$944.85	$429	1	$2,747.70	$1,373,850.00	
	M-1 **Estimated 20 year service life*	3.5 VOC CARC	$2,104.05	$620	3	$8,172.15	$4,086,075.00	3.5 VOC CARC to WD CARC **$2,266,555**
		1.5 VOC CARC		$685		$8,367.15	$4,183,575.00	1.5 VOC CARC to WD CARC **$2,364,055**
		WD-CARC	$1,259.52	$560	2	$3,639.04	$1,819,520.00	
	HEMMT **Estimated 20 year service life*	3.5 VOC CARC	$3,733.33	$805	3	$13,614.99	$6,807,495.00	3.5 VOC CARC to WD CARC **$3,841,495**
		1.5 VOC CARC		$890		$13,869.99	$6,934,995.00	1.5 VOC CARC to WD CARC **$3,968,995**
		WD-CARC	$2,240.00	$726	2	$5,932.00	$2,966,000.00	

Table 6. The Savings Associated With Using WD CARC Instead of 3.5 VOC or 1.5 VOC CARC to Paint 500 vehicles over the Service Life of Those Vehicles based on a 300% Life Cycle Increase.

			Labor Cost per Vehicle for an average DOD Depot Facility with 10 Painters	Material Cost per Vehicle	Number of Re-Paints Per Vehicle *(based on service life)*	Total Vehicle Service Life Cost of Repaint	Total Cost of Re-Painting 500 Vehicles Over the Entire Service Life of the Vehicles	Savings for Re-Painting 500 Vehicles Over the Entire Service Life of the Vehicles
Total Costs Based on Life-Cycle Increases of **300%** with WD-CARC and **32%** With 1.5 VOC CARC[5]	**HMMWV** **Estimated 15 year service life*	3.5 VOC CARC	$1,575.75	$475	2	$4,101.50	$2,050,750.00	3.5 VOC CARC to WD CARC **$1,363,825**
		1.5 VOC CARC		$525	1	$2,100.75	$1,050,375.00	1.5 VOC CARC to WD CARC **$363,450**
		WD-CARC	$944.85	$429	0	$1,373.85	$686,925.00	
	M-1 **Estimated 20 year service life*	3.5 VOC CARC	$2,104.05	$620	3	$8,172.15	$4,086,075.00	3.5 VOC CARC to WD CARC **$3,176,815**
		1.5 VOC CARC		$685	2	$5,578.10	$2,789,050.00	1.5 VOC CARC to WD CARC **$1,879,790**
		WD-CARC	$1,259.52	$560	0	$1,819.52	$909,260.00	
	HEMMT **Estimated 20 year service life*	3.5 VOC CARC	$3,733.33	$805	3	$13,614.99	$6,807,495.00	3.5 VOC CARC to WD CARC **$5,324,495**
		1.5 VOC CARC		$890	2	$9,246.66	$4,623,330.00	1.5 VOC CARC to WD CARC **$3,140,330**
		WD-CARC	$2,240.00	$726	0	$2,966.00	$1,483,000.00	

[5] The 300% and 32% life-cycle extensions are based on the results of the National Guard study that compared WD-CARC, 1.5 VOC CARC, and MIL-C-46168.

Table 7. A Summary Chart of the Short-term and Long-term Costs and Cost Savings Reported in this Study (Includes surface preparation labor/maintenance costs).

	Man Hours Needed to Paint 1 Vehicle			Cost for Painting 1 Vehicle[6]			Annual Cost of DOD Waste Disposal[7]	Service Life Re-Paint Cost for 1 Vehicle[8]		
	HMMWV	M-1	HEMMT	HMMWV	M-1	HEMMT	All Vehicles	HMMWV	M-1	HEMMT
3.5 VOC CARC	9	12	16	$2,050.75	$2,724.05	$4,538.33	$2,100,000	$4,101.50	$8,172.15	$13,614.99
1.5 VOC CARC				$2,100.75	$2,789.05	$4,623.33	$1,680,000	$2,100.75	$5,578.10	$9,246.66
WD-CARC	5.4	7.2	9.6	$1,373.85	$1,819.52	$2,966.00	$1,680,000	$1,373.85	$1,819.52	$2,966.00
WD-CARC With STAR4D Training[9]	4.3	5.8	7.7	$1099.08	$1,455.62	$2372.80	$1,260,000	N/A (Training Affect on Coating Durability Cannot be Calculated)		
Total Savings With Switch from 3.5 VOC CARC to WD-CARC and STAR4D Training	4.7	6.2	8.3	$951.67	$1,268.43	$2,165.53	$840,000	$2,727.65	$6,352.63	$10,648.99
Total Savings With Switch from 1.5 VOC CARC to WD-CARC and STAR4D Training				$1001.67	$1333.43	$2,250.53	420,000	$726.90	$3,758.58	$6,280.66

[6] Includes material cost per vehicle and labor/maintenance (preparation and painting) cost per vehicle when facility is producing maximum potential; maximum potential will increase with use of WD-CARC because of the associated 40% reduction in labor/maintenance hours.

[7] Based on 6 million pounds @ $.35 per pound

[8] 300% and 32% Coating Life Improvement with use of WD-CARC and 1.5 VOC CARC respectively

[9] The STAR4D program, with the inclusion of the LaserPaint™ targeting tool, has resulted in 20% - 30% improvements in transfer efficiency, productivity, and waste. These figures were calculated by applying a conservative 20% reduction in man hours, materials cost, and waste.

Appendix 1. The Equipment Costs to Paint the Average Number of Vehicles A DOD Depot Facility Paints Per Year.

	3.5 VOC CARC or WD-CARC
Purchased Cost of Preparation Equipment	$165,000
Purchased Cost of Basic Equipment	$12,800
Purchased Cost of Compressor	$4,000
Purchased Cost of Spray Booth	$150,000
Purchased Cost of Piping Etc.	$2,000
Expected Life of System	15 yrs.
Interest Rate	7%
Total Purchased Equipment Costs (PEC)	$393,884
Cost of Foundations and Supports (*12% of PEC)*	$47,266
Cost of Handling and Erection (*40% of PEC)*	$157,554
Electrical Cost (*1% of PEC)*	$3,939
Cost of Piping (*2% of PEC)*	$7,878
Cost of Insulation (*1% of PEC)*	$3,939
Cost of Painting (*2% of PEC)*	$7,878
Cost of Engineering (*10% of PEC)*	$39,388
Cost of Construction *(10% of PEC)*	$39,388
Contractor Fees (*10% of PEC)*	$39,388
Cost of Startup (*1% of PEC)*	$3,939
Unexpected Costs (*3% of PEC)*	$11,817
Total Capital Investment (TCI)	$756,250
Administrative Charges (AC) (*2% of TCI)*	$15,125
Property Tax (PT) (*1% of TCI)*	$7,563
Cost of Insurance (CI) *(1% of TCI)*	$7,563
Capital Recovery (CR)	$83,033
Overhead Costs (OC) *Overhead as % of Labor and Maintenance (60%) * Annual Labor/Maintenance Cost*	$524,160 (HMMWV) $698,880 (M-1) $1,223,040 (HEMMT)
Annual Equipment Costs *OC + AC + PT + CI + CR*	$637,444 (HMMWV) $812,164 (M-1) $1,336,324 (HEMMT)

6.0 REFERENCES

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