ENVIRONMENTALLY FRIENDLY CLEANERS FOR REMOVING TAR AND ASPHALT FROM TACTICAL AND TRANSPORTATION VEHICLES
Public Works Technical Bulletins are published by the US Army Corps of Engineers, Washington, DC. They are intended to provide information on specific topics in areas of Facilities Engineering and Public Works. They are not intended to establish new Department of the Army (DA) policy.
ENVIRONMENTALLY FRIENDLY CLEANERS FOR REMOVING TAR AND ASPHALT FROM TACTICAL AND TRANSPORTATION VEHICLES

1. Purpose.
   a. This Public Works Technical Bulletin (PWTB) identifies and provides recommendations for the selection of commercially available, environmentally friendly cleaners for removing road tar and asphalt from Army ground vehicles.

   b. All PWTBs are available electronically at the National Institute of Building Sciences’ Whole Building Design Guide (WBDG) webpage, which is accessible through the following link:


2. Applicability.
   a. This PWTB applies to all U.S. Army public works activities and facilities having ground vehicle surface cleaning activities.

   b. Note that the contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. All product names and trademarks cited are the property of their respective owners. The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.
3. References.


4. Discussion.

   a. AR 200-1 requires that Army installations comply with Federal environmental regulations, including air emission restrictions established by the Clean Air Act.

   b. The Resource Conservation and Recovery Act requires the US Environmental Protection Agency (USEPA) to promulgate regulations regarding the storage, processing, and disposal of solid and hazardous wastes. In 1984 the Act was augmented by the Hazardous and Solid Waste Amendments, which included provisions to encourage the recycling and reuse of hazardous wastes.

   c. The Waste Minimization and Pollution Prevention (WMPP) Program was established by Congress to demonstrate promising off-the-shelf environmental technologies at Army installations. Funding for the WMPP program ended in fiscal year 2005 (FY05). During the 12-year tenure of this program, many commercially available, environmentally friendly cleaners were evaluated and demonstrated in the laboratory.

   d. ASTM Standard D6361/D6361M–98(2010)e1 is a general guide that is used in developing cleaning requirements for manufacturing, maintenance, or overhaul specifications. This guide was designed to be application specific for individual cleaning tasks, and to assure the design engineer that cleaning agents and processes selected by the industrial or manufacturing engineer will be compatible with both part materials and with subsequent processes. Industrial or manufacturing engineers use
the guide to customize their selection of cleaning products based on: the materials of the part being cleaned; the cleanliness required for the subsequent processes; and environmental, cost, and health and safety concerns.

e. MIL-PRF-680B is a US Department of Defense (DoD) standard used to describe products that meet specific performance and manufacturing standards for equipment and chemicals.

f. US Army vehicle maintenance facilities make every effort to implement surface cleaners that are environmentally friendly. In other words: (a) cleaners that are free of hazardous air pollutants (HAPs), (b) cleaners that contain the minimum possible amount of volatile organic compounds (VOCs), and (c) cleaners that eliminate greenhouse gas emissions. Also, Army vehicle maintenance facilities have a great interest in reducing the overall energy costs associated with surface cleaning operations.

g. Appendix A contains an evaluation of environmentally friendly cleaners for removing tar and asphalt from tactical and transportation vehicles.

h. Appendix B contains a list of technical references cited in Appendix A and other resources on the subject of this PWTB.

i. Appendix C contains photographs of laboratory experiments performed to evaluate candidate cleaners for recommendation, as described in Appendix A.

j. Appendix D contains a list of abbreviations used.

5. Points of Contact.

a. Headquarters, U.S. Army Corps of Engineers (HQUSACE) is the proponent for this document. The point of contact (POC) at HQUSACE is Mr. Malcolm E. McLeod, CEMP-CEP, 202-761-5696, or e-mail: Malcolm.E.Mcleod@usace.army.mil.

b. Questions and/or comments regarding this subject should be directed to the following technical POC:

US Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
ATTN: CEERD-CN-E (Veera M. Boddu)
2902 Newmark Drive
Champaign, IL 61822-1076
Tel. (217) 398-5511
FOR THE COMMANDER:

JAMES C. DALTON, P.E., SES
Chief, Engineering and
Construction Division
Directorate of Civil Works
Appendix A

EVALUATION OF ENVIRONMENTALLY FRIENDLY CLEANERS FOR REMOVING TAR AND ASPHALT FROM TACTICAL AND TRANSPORTATION VEHICLES

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Introduction

Background

Every Army vehicle receives regular maintenance. Ground vehicles that come into the maintenance facility (especially bitumen spreaders) commonly have asphalt (“road tar”) on their surfaces. Before a vehicle is washed or painted, the tar must be removed. The current method for removing bitumen from the vehicles involves the use of a high-pressure (40,000 psi) water jet, followed by manually scraping any residual asphalt. Any residual asphalt is manually scraped (“spot cleaned”) using such commercial formulations as Biopro and Teskol (from Inland Technologies). The vehicle is visually inspected and sometimes subjected to a water-break test to evaluate the success of the initial tar removal step. Additionally, when bitumen spreaders are cleaned, their nozzle manifolds must also be serviced. Clogged nozzles that cannot be cleaned are replaced. Such mechanical and manual methods of vehicle cleaning and servicing are very expensive and inefficient.

Old Cleaning Process

Before using the water jet to remove residual tar from vehicles, the Army relied on PD-680 type solvents and diesel fuel to clean surfaces coated with tar and asphalt.* These highly refined aliphatic hydrocarbon compounds have been phased out because they contain large amount HAPs and VOCs that have negative environmental impacts. High levels of HAPs and VOCs are toxic, flammable, can contribute to certain health problems, and are considered hazardous waste (Crockett 2007; Trivedi et al. 2007).

* The information regarding current practice to remove tar was obtained from the US Army Tank Automotive Research, Development, and Engineering Center (TARDEC).
It is also difficult to dispose of the waste from these cleaning processes, which may contain chemicals that must be treated before entering wastewater drains.

There are three types of PD-680 solvents, which differ only in their flash points, from Type I (which has the lowest flash point) to Type III (which has the highest). In general, the higher the flash point, the safer the cleaner will be (Crockett 2007). Conversely, the higher the flash point, the lower the overall solvency. In other words, environmentally safer solvents (with relatively high flash points) may not do such a good job. Types I and II do not meet Federal law because of their low flash point and high amount of VOC emissions (Rhee et al. 1999). Nevertheless, many users prefer Types I and II solvents because they are effective degreasers and are non-corrosive. Users are often reluctant to switch to safer substitutes, which leave residue and can corrode metal.

Recent Technological Advances

Most traditional commercial solvents for removing asphalt have been petroleum distillates, or chlorinated solvents, or a combination of the two (Kulkarni et al. 2003). However, recent formulations of tar and asphalt removers use biological extracts and environmentally benign materials (Baird et al. 2009). Several vendors have recently proposed more environmentally friendly (“green”) cleaners to replace PD-680 type cleaners. Many of these cleaners are characterized by a high flash point, no HAPs, and little to no VOCs. Vendors also claim that these environmentally friendly cleaners are equal to or better than PD-680 type solvents.

The use of such environmentally acceptable solvents to remove residual tar from ground vehicles may offer a more efficient and cost-effective alternative. The Army is leading an effort to develop and demonstrate pollution prevention technologies to reduce hazardous air pollutants and other volatile organic emissions at surface cleaning and painting operations at DoD facilities. This effort focuses on evaluation of solvents for removal of tar from ground vehicle surfaces.

Selection of Commercially-Available Cleaners

Literature Search

A literature survey of commercially available solvents was done to identify commercially available solvents suitable for tar removal that were free from hazardous chemicals (i.e., that were
safe for users), and that produced waste that could be disposed of simply. The Material Safety Data Sheets (MSDSs) and properties of each solvent were reviewed. Table A-1 lists the products found, their manufacturers, stated applications, and chemical compositions.
<table>
<thead>
<tr>
<th>No</th>
<th>Company</th>
<th>Cleaner</th>
<th><em>BP</em></th>
<th><em>FP</em></th>
<th>VOC</th>
<th>Major Chemicals</th>
<th>Performance</th>
<th>Cost</th>
<th>Residuals/Byproducts</th>
<th>Disposal</th>
<th>Toxic</th>
<th>First Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Beaver Research</td>
<td>37 A</td>
<td>57</td>
<td>°F</td>
<td>50</td>
<td>Diethanolamine</td>
<td>Spiritually</td>
<td>26.65</td>
<td>CO &amp; CO2</td>
<td>Incinerate according to federal, state, and local regs.</td>
<td>No toxic chemicals according to reporting requirements, Section 313.40 CFR Part 372</td>
<td>Standard (see footnote for details)</td>
</tr>
<tr>
<td>2</td>
<td>Biochem systems</td>
<td>Bio Pro</td>
<td>374</td>
<td>°F</td>
<td>72</td>
<td>D-limonene</td>
<td>Nonionic</td>
<td>Non-toxic; no chlorinated solvents &amp; petroleum distillates</td>
<td>Biodegradable</td>
<td>Eyes: flush with water; skin: wash with soap &amp; water.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BioSystems, Inc.</td>
<td>BioVa</td>
<td>349</td>
<td>°F</td>
<td>1.4</td>
<td>Citrus King</td>
<td>Biodegradable</td>
<td>Eyes: flush with water for 15 min. See physician if irritation persists</td>
<td>Non-toxic; skin: wash with soap &amp; water; Inhalation: remove to fresh air; if symptoms persist, seek medical attention; Ingestion: give milk magnesia, glass water, or milk. Seek physician help.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Chemco Corporation</td>
<td>Citrus</td>
<td>312</td>
<td>°F</td>
<td>1.1</td>
<td>Citra Sol</td>
<td>Biodegradable</td>
<td>Eyes: flush with water for 15 min. See physician if irritation persists</td>
<td>Non-toxic; skin: wash with soap &amp; water; Inhalation: remove to fresh air; if symptoms persist, seek medical attention; Ingestion: give milk magnesia, glass water, or milk. Seek physician help.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*BP = boiling point    *COC = Cleveland open cup tester    *FP = flash point    *PMCC = Pensky-Martens closed cup tester

Standard first aid response would include the following steps, as applicable. INHALATION: Remove affected person to fresh air; provide oxygen if breathing is difficult; if affected person is not breathing, administer CPR and seek emergency medical attention. SKIN: Remove contaminated clothing; wash affected area with soap and water; launder contaminated clothing before reuse; if irritation persists, seek medical attention. EYES: Check for and remove contact lenses. Flush eyes with clear running water for 15 minutes while holding eyelids open; if irritation persists, seek medical attention. INGESTION: DO NOT induce vomiting; if vomiting occurs spontaneously, keep head below hips to prevent aspiration of liquid into lungs; seek immediate medical attention. Vomiting may be induced only under the supervision of a physician.

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<table>
<thead>
<tr>
<th>No</th>
<th>Company</th>
<th>Cleaner</th>
<th>*BP</th>
<th>*VP</th>
<th>*TCC</th>
<th>Major Chemicals</th>
<th>Performance</th>
<th>Cost</th>
<th>Residuals/Byproducts</th>
<th>Waste Disposal</th>
<th>Toxic</th>
<th>First Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cleanline Products, Inc.</td>
<td>Citrus Blast</td>
<td>&lt;300 °F</td>
<td>As water</td>
<td>170 °F</td>
<td>Isoparaffins</td>
<td>12 oz, 128 oz, 55 gal drums</td>
<td>From combustion, smoke, CO, unknown organic compounds</td>
<td>Biodegradable</td>
<td>Organics</td>
<td>Eyes: flush with flowing water for 15 min. Ingestion: give 2 glasses of water &amp; summon medical attention.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Coastwide Labs</td>
<td>Orange Waterless</td>
<td>212 °F</td>
<td>NA</td>
<td>160 °F</td>
<td>Nonionic surfactant Citrus distillate</td>
<td>Dissolves, no scrubbing, rinse with soap &amp; water</td>
<td>1-qt bottle; 4-1 gal case; 55 gal drum</td>
<td>Biodegradable</td>
<td>Phosphates or Petroleum products</td>
<td>Non toxic as far as known to Coastwide</td>
<td>Eyes: immediately flush eyes with water for 15 min. Skin: immediately wash skin with soap &amp; water. Inhale: move to fresh air. Get medical attention. Give artificial respiration if not breathing. INGESTION: do not induce vomiting. Get immediate medical attention.</td>
</tr>
<tr>
<td>3</td>
<td>Cogent Environmental Solutions</td>
<td>Eco-gent</td>
<td>NA</td>
<td>None</td>
<td>1-2</td>
<td>Hydroxypropanoi C12-13 alcohol polyglycoside Glucopyranose, oligomer, decyl octyl glycosides</td>
<td>Apply undiluted; allow to penetrate; agitate with cloth or sponge; rinse</td>
<td>1 gal, 5 gal, 55 gal</td>
<td>May include &amp; not limited to oxides of carbon</td>
<td>Review fed, state, local regs before disposal</td>
<td>No pesticides or preservatives</td>
<td>Eyes: flush with flowing water for 15 min. Skin: wash with soap &amp; water. Inhale: move to fresh air. INGESTION: do not induce vomiting.</td>
</tr>
<tr>
<td>4</td>
<td>Continental Research, Corp.</td>
<td>Full Force</td>
<td>352 °F</td>
<td>2</td>
<td>155 °F</td>
<td>1,2-Pentamethylene Propane/n-Butane Carbon Dioxide Nonionic Surfactant</td>
<td>High pressure flushing spray</td>
<td>Aerosol 1 oz. cans = $0.66</td>
<td>Contains no chlorinated solvents or petroleum distillates</td>
<td>Eyes: flush with water for 15 min. Skin: rinse with soap &amp; water. Inhale: remove glass of milk or water. Do not induce vomiting. Inhalation: Remove victim to fresh air.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Continental Research, Corp.</td>
<td>Power Stuff</td>
<td>348 °F</td>
<td>1,0</td>
<td>350 °F</td>
<td>Poly-[oxy-1,2-ethanediyl]-1,8-Menthadiene Propane/n-Butane Carbon Dioxide Nonionic Surfactant</td>
<td>Aerosol 1 oz. cans = $0.91; 8.8 gal = $60/gal; 55 gal = $35/gal</td>
<td>Oral LD50 (rat) = &gt;5000-15000 mg/kg Dermal LD50 (rabbit) = &gt;2000 ug/kg to 20000 mg/kg</td>
<td>Standard</td>
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</tbody>
</table>

*BP = boiling point  
*COC = Cleveland open cup tester  
*FP = flash point  
*PMCC = Pensky-Martens closed cup tester

Standard first aid response would include the following steps, as applicable. INHALATION: Remove affected person to fresh air. Provide oxygen if breathing is difficult; if affected person is not breathing, administer CPR and seek emergency medical attention. SKIN: Remove contaminated clothing and wash affected area with soap and water; launder contaminated clothing before reuse; if irritation persists, seek medical attention. EYES: Check for and remove contact lenses. Flush eyes with clear running water for 15 minutes while holding eyelids open; if irritation persists, seek medical attention. INGESTION: Do not induce vomiting; if vomiting occurs spontaneously, keep head below hips to prevent aspiration of liquid into lungs; seek immediate medical attention. Vomiting may be induced only under the supervision of a physician.

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<table>
<thead>
<tr>
<th>No</th>
<th>Company</th>
<th>Cleaner</th>
<th>*BP °F</th>
<th>*VP mmHg</th>
<th>*VOC g/L</th>
<th>*FP °F</th>
<th>Major Chemicals</th>
<th>Performance</th>
<th>Cost</th>
<th>Residuals/Byproducts</th>
<th>Waste Disposal</th>
<th>Toxic</th>
<th>First Aid</th>
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<tbody>
<tr>
<td>11</td>
<td>Continental Research Corp</td>
<td>Rid-O-Deterese</td>
<td>348</td>
<td>1.0</td>
<td>115 °F</td>
<td>TCC</td>
<td>Citrus solvent</td>
<td>Aerosol or bulk</td>
<td>Biodegradable</td>
<td></td>
<td></td>
<td>Eyes: flush with plenty of water for at least 15 min. Skin; flush with cold water and wash with soap &amp; water; Ingestion: give milk or water; Inhalation: remove to fresh air.</td>
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<td>12</td>
<td>Delco Cleaning Systems</td>
<td>R-107 Delco Red Truck Wash Powder</td>
<td>Spec. Clay 7.84 lb/gal</td>
<td>Sodium Metasilicate, Penta Glycol Ether BB</td>
<td>Cold pressure washers, hot high pressure washers, and steam cleaners</td>
<td>1 lb (114°F); 100 lb (212°F); 500 lb (617°F); 1000 lb (660°F); Min 0.5 lb/gal</td>
<td>See local authorities for restrictions on disposal for chemical waste</td>
<td></td>
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<td>Eyes: flush with plenty of water for at least 15 min. Lifting eyelids, remove contacts if possible. Call physician. Skin: flush with cold water and wash with soap &amp; water. Ingestion: rinse mouth &amp; drink 2 large glasses of water, do not induce vomiting.</td>
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<tr>
<td>14</td>
<td>Delta Foremost Citri-Zip</td>
<td>Citri-Zip</td>
<td>176</td>
<td>No establ</td>
<td>176 °C</td>
<td>TAG, GC</td>
<td>Natural solvent</td>
<td>Emulsifier</td>
<td>Dispose according to local rules</td>
<td></td>
<td></td>
<td></td>
<td>Standard</td>
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</tr>
<tr>
<td>15</td>
<td>Dysol</td>
<td>DS-104</td>
<td>265</td>
<td>125 °C</td>
<td>105 g</td>
<td>40.6 °C</td>
<td>Hand wipes, dip tank, ultrasonic</td>
<td>55 gal drum ($281.16 GSA Schedule 7030-01367-0085)</td>
<td></td>
<td></td>
<td></td>
<td>Low toxicity; no CFCs or HAPs; Propylene glycol monomethyl ether acetate: 8532 mg/kg (oral rat); N-Butyl acetate: 14000 mg/kg (oral rat)</td>
<td>Standard</td>
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</tr>
<tr>
<td>16</td>
<td>Eagle Chem. Inc.</td>
<td>Eagle Melt</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Spec. 0.35</td>
<td>Petroleum Hydrocarbon Ethylene glycol n-Butyl ether</td>
<td>Can remove many materials in 15 min. Heavy layers overnight soak. Pressure washer rinsing with at least 1500 psi for best results.</td>
<td>EC 016-55g $1005.00; EC 016-5g $106.90</td>
<td></td>
<td>Hazardous decomposition on not known</td>
<td>Biodegradable. Prevent materials from entering sewers, storm drains, waterways</td>
<td>Non hazardous liquid</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Eyes: flood with water 15 min. Skin: wash off with soap &amp; water. Ingestion: drink lots of water; seek immediate medical attention. Inhaled: move to fresh air.</td>
</tr>
</tbody>
</table>

*BP = boiling point
*COC = Cleveland open cup tester
*FP = flash point
*PMCC = Pensky-Martens closed cup tester
*TCC = Tag (Tagliabue) closed cup tester
*VOC = volatile organic compound
*VP = vapor pressure

Standard first aid response would include the following steps, as applicable. INHALATION: Remove affected person to fresh air; provide oxygen if breathing is difficult; if affected person is not breathing, administer CPR and seek emergency medical attention. SKIN: Remove contaminated clothing; wash affected area with soap and water; launder contaminated clothing before reuse; if irritation persists, seek medical attention. INGESTION: DO NOT induce vomiting; if vomiting occurs spontaneously, keep head below hips to prevent aspiration of liquid into lungs; seek immediate medical attention. Vomiting may be induced only under the supervision of a physician.

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<thead>
<tr>
<th>No</th>
<th>Company</th>
<th>Cleaner</th>
<th>*BP</th>
<th>*VOC</th>
<th>*FP</th>
<th>Major Chemicals</th>
<th>Performance</th>
<th>Cost</th>
<th>Residuals/Byproducts</th>
<th>Waste Disposal</th>
<th>Toxic</th>
<th>First Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>Ecolink</td>
<td>Electron</td>
<td>349 °F</td>
<td>Citrus terpene</td>
<td>Fully evaporative, leaves no residue</td>
<td>810</td>
<td>May form CO and CO₂</td>
<td>Not hazardous, dispose according to regs.</td>
<td>Non hazardous EPA &amp; USDA definitions. Acute toxicity: oral toxicity (mice)=LD50 5.6-6.6 g/kg; Skin toxicity: absorption (rabbits)= LD50 500 mg/kg</td>
<td>Ingestion: seek medical attention immediately. If individual is drowsy or unconscious, do not give anything by mouth; place individual on left side with head down. Contact medical facility or poison control center for advice on whether to induce vomiting. Inhalation: remove to fresh air. If breathing is difficult, give oxygen. Keep person warm &amp; quiet. Seek medical attention. Eyes: irrigate immediately with water for at least 15 min. Get medical attention if irritation persists. Skin: wash with soap &amp; water. Thoroughly clean contaminated clothes &amp; shoes before reuse.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Environmental Green Products</td>
<td>Dropovert</td>
<td>&gt; 600 °F</td>
<td>Hydrocarbon heavy</td>
<td>Immiscible in water</td>
<td>200 °F</td>
<td>Tar deposit products; oxides of carbon and hydrocarbon</td>
<td>Biodegradable</td>
<td></td>
<td></td>
<td>Eyes: do not rub, flush with water, get medical attention. Skin: wash thoroughly with soap &amp; water, wash clothing before reuse. Ingestion: get medical attention. Inhalation: remove to fresh air.</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Inland Technology, Inc.</td>
<td>Rekoni ER</td>
<td>370 °F</td>
<td>Naphtha (C12-C13 Hydrocarbons)</td>
<td>Insoluble in water</td>
<td>3 g</td>
<td>$232.84</td>
<td></td>
<td></td>
<td></td>
<td>Eyes: flush with water at least 15 min; call physician if irritation continues. Skin: remove contaminated clothing and wash with soap &amp; water. Inhalation: remove from exposed area and call physician. Ingestion: do not induce vomiting &amp; call physician immediately.</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Inland Technology, Inc.</td>
<td>Breakthrough</td>
<td>370 °F</td>
<td>Naphthalene Spirits (C12-C13 Hydrocarbons)</td>
<td>Insoluble in water</td>
<td>5 g</td>
<td>$149.11</td>
<td></td>
<td></td>
<td></td>
<td>Eyes: flush with water at least 15 min.; call physician if irritation continues. Skin: remove contaminated clothing and wash with soap &amp; water. Inhalation: remove from exposed area and call physician. Ingestion: do not induce vomiting &amp; call physician immediately.</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>TM Rocol North America</td>
<td>Daraclean</td>
<td>212 °F (approx)</td>
<td>Potassium hydroxide 1-5% by wt.</td>
<td>Disposes in water and biodegradable</td>
<td>5 g</td>
<td>$54.06</td>
<td></td>
<td></td>
<td></td>
<td>Eyes: rinse under upper &amp; lower eyelids with water. Skin: wash off with water; use soothing lotion. Inhalation: remove to fresh air. Ingestion: if conscious, give 2 glasses water; call physician or poison center.</td>
<td></td>
</tr>
</tbody>
</table>

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*COC = Cleveland open cup tester  
*FP = flash point  
*PMCC = Pensky-Martens closed cup tester  
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<table>
<thead>
<tr>
<th>No.</th>
<th>Company</th>
<th>Cleaner</th>
<th>*BP</th>
<th>*VPP</th>
<th>*VOC</th>
<th>Major Chemicals</th>
<th>Performance</th>
<th>Cost</th>
<th>Residuals/Byproducts</th>
<th>Waste Disposal</th>
<th>Toxic</th>
<th>First Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Kleen All Plus</td>
<td>#141 Vehicle Wash</td>
<td>212 °F</td>
<td>480</td>
<td>70 g/L</td>
<td>Dipropylene Glycol Methyl Ether Acetate, Acetone</td>
<td>55 gal drum = $399 plus freight. Military $325/drum</td>
<td>No Byproducts</td>
<td>Review fed, state, local regs before disposal</td>
<td>Not to be construed as an official Department of the Army position unless so designated by other authorized documents.</td>
<td>Not to be construed as an official Department of the Army position unless so designated by other authorized documents.</td>
<td>Ears &amp; Skins: flush with water. Eyes: get immediate medical attention.</td>
</tr>
<tr>
<td>23</td>
<td>Ogni-Sol</td>
<td>Ogni-Sol</td>
<td>300-350 °F</td>
<td>1.6</td>
<td>non-volatile</td>
<td>Methyl Ester Soybean oil</td>
<td>55 gal drum = $33.75/gal 35 gal drum = $34.40/gal 20 gal drum = $34.40/gal 5 gal metal pail = $55.00/gal 4-1 gal case = $57.40/gal</td>
<td>CO, CO₂</td>
<td>Biodegradable, biobased, emulsifiable</td>
<td>Not to be construed as an official Department of the Army position unless so designated by other authorized documents.</td>
<td>Not to be construed as an official Department of the Army position unless so designated by other authorized documents.</td>
<td>Ears: flush with water for 15 min.; if irritation persists, call physician. Eyes: flush with water for 15 min.; if irritation persists, call physician. Skin: apply moisturizing lotion; if irritation persists, call physician. Ingestion: do not induce vomiting.</td>
</tr>
<tr>
<td>24</td>
<td>Omega Sol</td>
<td>Omega Sol</td>
<td>340 °F</td>
<td>372 °F</td>
<td>Low % Volatile</td>
<td>Ethyl lactate Methyl Ester Soybean oil</td>
<td>55 gal drum = $50.85/gal 35 gal drum = $51.15/gal 10 gal drum = $51.50/gal 5 gal metal pail = $52.05/gal 4-1 gal case = $54.50/gal</td>
<td>Biodegradable, biobased, emulsifiable</td>
<td>No chlorinated solvents, HAPs, or CFCs</td>
<td>Not to be construed as an official Department of the Army position unless so designated by other authorized documents.</td>
<td>Not to be construed as an official Department of the Army position unless so designated by other authorized documents.</td>
<td>Eyes: flush with water for 15 min.; if irritation persists, call physician. Skin: apply moisturizing lotion; if irritation persists, call physician. Ingestion: do not induce vomiting.</td>
</tr>
</tbody>
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*TCC = Tag (Tagliabue) closed cup tester  *VOC = volatile organic compound  *VOP = vapor pressure

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<table>
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<tr>
<th>No</th>
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<th>Cleaner</th>
<th>*BP</th>
<th>*VP minHg</th>
<th>*VOC g/L</th>
<th>*FP</th>
<th>Major Chemicals</th>
<th>Performance</th>
<th>Cost</th>
<th>Residuals/Byproducts</th>
<th>Waste Disposal</th>
<th>Toxic</th>
<th>First Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>Orange Products, LLC</td>
<td>Orange Oily Slicker Asphalt Remover and Release Agent</td>
<td>N.D.</td>
<td>100</td>
<td>173 °F</td>
<td>151°F</td>
<td>Soy methyl ester water D-limonene Surfactant Soap Amine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Standard</td>
<td>Eyes: flush with water for 15 mins. If irritation persists, call physician. Skin: Apply moisturizing lotion, if irritation persists, call physician. Ingestion: Do not induce vomiting. Drink large volume of water. Inhalation: Mist should be avoided</td>
</tr>
<tr>
<td>26</td>
<td>PCI of America, Inc.</td>
<td>Surflax defender 9030</td>
<td>142°F</td>
<td>142°F</td>
<td>14.2 mmHg</td>
<td>77 °F</td>
<td>Aqueous based</td>
<td>None TCC</td>
<td></td>
<td>None TCC</td>
<td></td>
<td>Non-hazardous, non-flammable, non-toxic, no VOCs, no terpenes.</td>
<td>Eyes: flush with water for 15 mins. If irritation persists, call physician. Skin: apply moisturizing lotion; if irritation persists, call physician. Ingestion: do not induce vomiting. Inhalation: remove to fresh air.</td>
</tr>
</tbody>
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<thead>
<tr>
<th>No.</th>
<th>Company</th>
<th>Cleaner</th>
<th>*BP °F</th>
<th>*VOC g/L</th>
<th>*FP °F</th>
<th>PMCC Tester</th>
<th>Major Chemicals</th>
<th>Performance</th>
<th>Cost</th>
<th>Residuals/Byproducts</th>
<th>Waste</th>
<th>Disposal</th>
<th>Toxic</th>
<th>First Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>Petroferm, Inc.</td>
<td>Anarel 52</td>
<td>430</td>
<td>0.1</td>
<td>205</td>
<td>PMCC</td>
<td>Mixed aliphatic hydrocarbons</td>
<td>$64.52/g</td>
<td>$4.50/</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Standard</td>
</tr>
<tr>
<td>30</td>
<td>Petroferm, Inc.</td>
<td>Bioact 105</td>
<td>&gt;360</td>
<td>&lt;2</td>
<td>105</td>
<td>ASTM 89-55</td>
<td>Isoparaffinic hydrocarbon [C9-12 isooalkanes] 1-Propoxy-2-propional 1-Methyl-4-(1-methyl- ethenyl)-cyclohexene</td>
<td>15g drum</td>
<td>$2.55/lb</td>
<td>None other than normal products of combustion</td>
<td></td>
<td></td>
<td></td>
<td>Standard</td>
</tr>
<tr>
<td>31</td>
<td>Petroferm, Inc.</td>
<td>Bioact 121</td>
<td>340</td>
<td>&lt;32</td>
<td>117</td>
<td>PMCC</td>
<td>1-Methyl-4-(methylene) -cyclohexene</td>
<td>5 gal cans</td>
<td>$4.24/lb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Eyes: flush with water for 15 min; If irritation persists, call physician. Skin: apply moisturizing lotion; if irritation persists, call physician. Ingestion: do not induce vomiting. Inhalation: remove to fresh air.</td>
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<tr>
<th>No</th>
<th>Company</th>
<th>Cleaner</th>
<th>°BP</th>
<th>°VOC</th>
<th>°FP</th>
<th>Major Chemicals</th>
<th>Performance</th>
<th>Cost</th>
<th>Residuals/ Byproducts</th>
<th>Waste Disposal</th>
<th>Toxic</th>
<th>First Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Petrofem, Inc.</td>
<td>Bioact</td>
<td>120</td>
<td>340 °F - 372 °F</td>
<td>&lt; 2</td>
<td>117 °F&lt;br&gt; PMCC 1-methyl-4-(methylene)- cyclohexene Poly(cyclo-1,2-ethanediyl), alpha, (+)-methylphenyl, (+)- cyclohexene</td>
<td>Water rinse</td>
<td>55 gal drum (380 lb) = $9.50/lb; 5 gal cans (25 lb) = $8.44/lb</td>
<td>1-Methylphenyl)-cyclohexene: LD50/oral/rat = &gt; 5000 mg/kg LD50/dermal/rabbit = &gt; 5000 mg/kg Poly(cyclo-1,2-ethanediyl), alpha, (+)-methylphenyl)-cyclohexene: omega-hydroxy: LD50/oral/rat = 1300 mg/kg LD50/dermal/rabbit = 1.8 ml/kg to 4,400 mg/kg</td>
<td>Eyes: flush with water for 15 min; if irritation persists, call physician. Skin: apply moisturizing lotion; if irritation persists, call physician. Ingestion: do not induce vomiting. Inhalation: remove to fresh air.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Cobaeusser NW Co.</td>
<td>Dissolve Away</td>
<td>120</td>
<td>340 °F - 372 °F</td>
<td>&lt; 2</td>
<td>117 °F&lt;br&gt; PMCC 1-methyl-4-(methylene)- cyclohexene</td>
<td>Water rinse</td>
<td>55 gal drum (380 lb) = $9.21/lb; 5 gal cans (25 lb) = $8.91/lb</td>
<td>Eyes: flush with water for 15 min; if irritation persists, call physician. Skin: apply moisturizing lotion; if irritation persists, call physician. Ingestion: do not induce vomiting. Inhalation: remove to fresh air.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Green Research Ltd</td>
<td>Tar N Glue</td>
<td>120</td>
<td>340 °F - 372 °F</td>
<td>&lt; 2</td>
<td>117 °F&lt;br&gt; PMCC 1-methyl-4-(methylene)- cyclohexene</td>
<td>Water rinse</td>
<td>55 gal drum (380 lb) = $9.19/lb</td>
<td>1-Methylphenyl)-cyclohexene: LD50/oral/rat = &gt; 5000 mg/kg LD50/dermal/rabbit = &gt; 5000 mg/kg Poly(cyclo-1,2-ethanediyl), alpha, (+)-methylphenyl)-cyclohexene: omega-hydroxy: LD50/oral/rat = 1300 mg/kg LD50/dermal/rabbit = 1.8 ml/kg to 4,400 mg/kg</td>
<td>Eyes: flush with water for 15 min; if irritation persists, call physician. Skin: apply moisturizing lotion; if irritation persists, call physician. Ingestion: do not induce vomiting. Inhalation: remove to fresh air.</td>
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<tr>
<th>No</th>
<th>Company</th>
<th>Cleaner</th>
<th>*BP</th>
<th>*VP</th>
<th>*VOC g/L</th>
<th>*FP</th>
<th>Major Chemicals</th>
<th>Performance</th>
<th>Cost</th>
<th>Residuals/ Byproducts</th>
<th>Waste Disposal</th>
<th>Toxic</th>
<th>First Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>Sentinel Products, Inc.</td>
<td>Sentinel</td>
<td>370 °F - 518 °F</td>
<td>Negligible</td>
<td>146°F</td>
<td>Refined petroleum solvents Ethylene Glycol Monoethyl Ether</td>
<td>Apply to surface. Agitate or soak for 4-8 min. Rinse with water under pressure.</td>
<td>Thermal decompositi on in presence or air may yield CO and/or CO₂.</td>
<td>All natural, no hazardous chlorinated or flammable solvents. Non caustic &amp; non corrosive.</td>
<td>Standard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Simple Green</td>
<td>Simple Green</td>
<td>210 °F</td>
<td>91.7 mm Hg</td>
<td>1.00%</td>
<td>None</td>
<td></td>
<td>Biodegradable</td>
<td>Non-hazardous, VOC compliant</td>
<td>Eye: flush with plenty of water. After 5 min remove contact lenses. Flush another 10 min moving eyelids out of way. If irritation continues, call physician. Ingestion: drink plenty of water.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Smart Washer ChemFree, Corp.</td>
<td>Steri Juice 2K6-6 (for the Smart Washer System)</td>
<td>210 °F</td>
<td>99 °C</td>
<td>&lt;5 mm Hg</td>
<td>&lt;18g/L</td>
<td>None</td>
<td></td>
<td>Biodegradable</td>
<td>No phosphates, formaldehyde, biocides, or solvents. Non-toxic, non-hazardous, non-caustic</td>
<td>Eyes: rinse if necessary. Skin: wash with soap &amp; water. Ingestion: seek medical attention if necessary. Inhalation: move to fresh air.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>SOYSolv</td>
<td>SOYSolv</td>
<td>420°F</td>
<td>&lt;1</td>
<td>&lt;50g/L</td>
<td>Mixed Fatty &amp; Methyl Esters: Linoleic Oleic Palmitic Linolenic Stearic Palmitoleic Erucic</td>
<td></td>
<td>Biodegradable</td>
<td></td>
<td>Non toxic</td>
<td>Standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>SOYSolv</td>
<td>SOYSolv 2</td>
<td>420°F</td>
<td>&lt;1</td>
<td>&lt;50g/L</td>
<td>Mixed Fatty Acid Methyl Esters</td>
<td></td>
<td>Biodegradable</td>
<td></td>
<td>Non toxic</td>
<td>Oral: call physician. Ventilation procedure: local, mechanical, special</td>
<td></td>
<td></td>
</tr>
</tbody>
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<th>*VP (mmHg)</th>
<th>*VOC (g/L)</th>
<th>*FP</th>
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<tbody>
<tr>
<td>42</td>
<td>SOYSolv</td>
<td>PP Plus</td>
<td>292°F</td>
<td>0.9 @ 68°F</td>
<td>Ethyl lactate</td>
<td>Methyl Soyate</td>
<td>Decomposes to H2O &amp; CO2 completely combusted</td>
<td>Biodegradable</td>
<td>Non toxic</td>
<td>Standard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>SSPENVIRO</td>
<td>Safety Ghost Production Environmental Division 950 Gemini, Suite 1 Houston, TX 77058 1-800-458-2236 Fax: 281-956-1000 <a href="http://www.ssenviro.com">www.ssenviro.com</a></td>
<td>ColdSolV</td>
<td>&gt; 200°F</td>
<td>Organic Ingredients</td>
<td>Case (10 gal) drums @ $125.00; 5 gal pail @ $102.50; 50 gal drum @ $673.95; 155 gal drum @ $977.50</td>
<td>No decomposition products</td>
<td>Biodegradable</td>
<td>Eye contact : Irritant Skin Contact : LD50 (rats/24hr) &gt;2000mg/kg Inhalation: LC50 (rats/hrs) &gt;5400mg/kg Ingestion: LD50 &gt;4000mg/kg (ten) RTECS 1985-86</td>
<td>Standard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>Stoner, Inc.</td>
<td>S570 Robert Fulton Hwy, Quarryville, PA 17566 800-227-5538 <a href="http://www.stonersolutions.com">www.stonersolutions.com</a></td>
<td>Bug &amp; Farni- nator</td>
<td>Not applicable</td>
<td>Petroleum Distillates</td>
<td>Halogenated Hydrocarbon Petroleum Hydrocarbon Glycol ether Aliphatic Hydrocarbon Dimethyl Carbonil Citrus Distillates</td>
<td>12 can case = $40.87 (Free S&amp;H) Burning can produce: CO, CO2, aldehydes, various hydro-carbons, decomposed by very high temp; may produce hydro-fluoric acid and carbonyl fluoride</td>
<td>According to regulations.</td>
<td>Eyes: flush with water for 15 min; contact physician if irritation persists Skin: wash with water for 15 min; contact physician if symptoms persist Wash clothing before reuse. Ingestion: don't induce vomiting; give 8 ounces water to drink; contact physician Inhalation: remove to fresh air; seek medical attention.</td>
<td>Standard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>United Labs</td>
<td>Canadian Headquarters United Laboratories of Canada 214 Dolomite Drive Toronto, ON M3J 2N2 800-323-2594 <a href="mailto:sales@unitedlabsinc.ca">sales@unitedlabsinc.ca</a></td>
<td>United</td>
<td>147°F</td>
<td>1.0 @ 70°F</td>
<td>10 lb. / gal.</td>
<td>115-130°F</td>
<td>P-1,8- (9)- p- menthadiene</td>
<td>Don't allow to dry on surface. Hose off with water. Liquid 5 L Liquid 20 L Liquid 500 L</td>
<td>When ignited produsre CO and CO2.</td>
<td>Ammoniate run-off into oil/water separator.</td>
<td>No petroleimu distillates, acids, or caustics</td>
<td>Standard</td>
</tr>
</tbody>
</table>

*BP = boiling point  
*COC = Cleveland open cup tester  
*FP = flash point  
*PMCC = Pensky-Martens closed cup tester  
*VOC = volatile organic compound  
*VP = vapor pressure

Standard first aid response would include the following steps, as applicable. INHALATION: Remove affected person to fresh air; provide oxygen if breathing is difficult; if affected person is not breathing, administer CPR and seek emergency medical attention. SKIN: Remove contaminated clothing; wash affected area with soap and water; launder contaminated clothing before reuse; if irritation persists, seek medical attention. EYES: Check for and remove contact lenses. Flush eyes with clear running water for 15 minutes while holding eyelids open; if irritation persists, seek medical attention. INGESTION: DO NOT induce vomiting; if vomiting occurs spontaneously, keep head below hips to prevent aspiration of liquid into lungs; seek immediate medical attention. Vomiting may be induced only under the supervision of a physician.

NOTE: The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. All product names and trademarks cited are the property of their respective owners. The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.
<table>
<thead>
<tr>
<th>No.</th>
<th>Company</th>
<th>Cleaner</th>
<th>*BP (°F)</th>
<th>*VOC (g/L)</th>
<th>*FP (°F)</th>
<th>Major Chemicals</th>
<th>Performance</th>
<th>Cost</th>
<th>Residues/ Byproducts</th>
<th>Waste Disposal</th>
<th>Toxic</th>
<th>First Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>Walter Surface Technol. J. Walter Inc.</td>
<td>Rio Clean</td>
<td>257°</td>
<td>900</td>
<td>113°</td>
<td>Orange terpenes Ethyl Lactate</td>
<td>$64.75/g</td>
<td>Carbon oxides</td>
<td>Dispose according to local, state, and federal regulations.</td>
<td>Standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>Walter Surface Technol. J. Walter Inc.</td>
<td>O-Force (L-748)</td>
<td>&gt;500°</td>
<td>926</td>
<td>78°</td>
<td>Bottle 5 L</td>
<td>$67.91</td>
<td>CO</td>
<td>Biodegradable, Non-toxic</td>
<td>Standard</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:**

- *BP = boiling point
- *COC = Cleveland open cup tester
- *FP = flash point
- *PMCC = Pensky-Martens closed cup tester
- *TCC = Tag (Tagliabue) closed cup tester
- *VOC = volatile organic compound
- *VP = vapor pressure

Standard first aid response would include the following steps, as applicable. **INHALATION:** Remove affected person to fresh air; provide oxygen if breathing is difficult; if affected person is not breathing, administer CPR and seek emergency medical attention. **SKIN:** Remove contaminated clothing before reuse; if irritation persists, seek medical attention. **EYES:** Check for and remove contact lenses. Flush eyes with clear running water for 15 minutes while holding eyelids open; if irritation persists, seek medical attention. **INGESTION:** DO NOT induce vomiting; if vomiting occurs spontaneously, keep head below hips to prevent aspiration of liquid into lungs; seek immediate medical attention. Vomiting may be induced only under the supervision of a physician.

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Basic Requirements for Green Cleaners

The green solvent that works best must fill three basic criteria:

1. **Cleaning Effectiveness.** This is a quantitative measurement of how much tar or asphalt the solvent can remove. Simply stated, the best solvent removes the most tar or asphalt.

2. **Corrosiveness.** This refers to the solvent’s ability to damage or rust the metal. Very corrosive solvents can cause surface rust immediately after cleaning. Checking the pH of the solvent can give an indication of its corrosiveness. If the pH is either too high or too low, it can easily corrode the metal, rendering it useless.

3. **Cost.** Army maintenance facilities use large quantities of solvents to clean vehicles and other equipment, and have a great interest in minimizing solvent costs. Overall cost can be reduced by the ability to recycle and reuse the solvent after its initial use.

Weapons System-Specific Criteria

Trivedi et al. (2004) presented an excellent review of general cleaner requirements and green cleaning alternatives for weapon systems and machine parts for the DoD. Trivedi et al. have evaluated select cleaners in a laboratory environment, and listed the following requirements for weapon-systems cleaners.

1. **Contaminant Removal.** The primary requirement is that the cleaner must be able to remove contaminants, such as grease, oil, sand/dirt, carbon, copper fouling, etc.

2. **Solvent Residue.** The solvent must be able to dry without leaving a film of nonvolatile residue that may corrode or create toxicity problems. (This is a measure of “solvent purity.”)

3. **Material Compatibility.** The solvent must not degrade or accelerate surface corrosion of different materials used in the weapon system. The degreasing aqueous solution should have a pH between 2.5 and 11.0.

4. **Solvent Stability.** The cleaner should have low VOCs. The cleaner stability affects process cost and operating hazards.
5. **Flammability.** Flammability is an important issue with non-aqueous cleaners. The concentrated product should not be ignitable, i.e., the flash point for the compound should be above 140°F (60°C).

6. **Toxicity.** The concentrated cleaning compound shall have no adverse affects on health of personnel or the environment.

7. **Biodegradability.** The organic ingredient should be readily biodegradable. The manufacturer must provide recycling and disposal instructions, which must comply with applicable local, state, and Federal regulations.

8. **Cost Effectiveness.** The replacement green solvent should be cost effective both in terms of procurement and waste disposal.

9. **Ozone Depletion.** The product should not contain any ozone depleting substances. An ozone depleting substance is any compound with ozone depletion potential greater than 0.01. For example, the ozone depletion potential of CFC 11 is 0.1. Note that this general guidance was adapted with some modifications while developing this PWTB with recommendations for solvents and methods to remove tar and asphalt from metal surfaces prior to painting and as part of general maintenance.

**Vehicle-Specific Criteria**

A survey of DoD facilities (Rhee et al. 1995) listed some desired general properties of cleaning solvents and provided specific guidance to identify cleaners for application to surfaces of tactical and transport vehicles. Those criteria are listed below.

1. The solvent must effectively remove tar and asphalt, and must be fast-drying (~20-30 min).

2. The solvent must have low VOCs.

3. The solvent must have low toxicity.

4. The solvent must have high flash point.

5. The solvent must have low flammability.

6. The solvent must be recyclable.

7. The solvent’s residues must be biodegradable and easily treatable along with regular wastewater streams.
8. The solvent must be compatible with the material(s) being cleaned. The use of the solvent should not lead to corrosion or erosion. If possible, the cleaner should provide a corrosion protection layer.

9. The cost of the solvent and the solvent requirement should be minimal.

**Experimental Protocols for Laboratory Evaluation**

A literature search of laboratory standard testing protocols for tar removal from metal surfaces was conducted on multiple databases. The following section summarizes the most pertinent results. Tar removal experiments were designed and conducted using three selected commercial solvents, which were tested on metal coupons simulating the metal surfaces of military tactical and transport vehicles.

**Literature Review**

Kulkarni et al. (2003) found a variety of environmentally friendly and safe asphalt-removing solvents available in the market. However, they noted there is no quantitative standardized procedure to compare the efficacy of these solvents. Their goal was to develop a standardized procedure that would yield quantitative and repeatable results.

After evaluating various alternatives like metal and glass plates, ceramic tiles, and aluminum foils, the aluminum dish was found most suitable for the study. Test results obtained for solvent comparison were found to be consistent and repeatable, with the coefficient of variation for asphalt removed less than 10% for most solvents. Furthermore, this study provides an outline for cost-effective analysis of solvents used in relation to diesel fuel, and the procedure is able to rank solvents quantitatively.

Sacco (2004) has studied the blending of two plant-derived solvents to clean asphalt from trucks, shovels, and other equipment used to handle paving operations. One of the solvents was ethyl lactate, made from ethanol and lactic acid made by fermenting corn sugars. The other solvent was methyl soyate, a

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2 Databases included Scopus; Academic Search Premier [Ebsco]; Academic Onefile [Gale]; and Web of Science, including Social Sciences, Medicine, Humanities, and Engineering.
mixture of methyl esters of the fatty acids found in triglycerides from soybean oil. The new solvent, “Agri-Solve,” was found to clean without leaving a residue and proved to perform better than diesel fuel and several other solvents currently used.

Bryant and Cannon (1996) found that a substitute, 3% hydrogen peroxide (H$_2$O$_2$), effectively cleans tenacious residues off glass surfaces. They evaluated the solvent both at moderately elevated pH conditions and iron-based catalysts. Results revealed that 100% of an asphalt residue could be removed from glass surfaces within 105 min when it was submerged in a 3% H$_2$O$_2$ solution at pH 9.5 and ambient temperature. Furthermore, the asphalt residue could be completely removed within 45-60 min if the H$_2$O$_2$ solution also included $10^{-3}$ M ferric chloride (FeCl$_3$).

Lahib (2003) also found that 3% H$_2$O$_2$ in water effectively removed residues from glass surfaces. To simulate industrial cleaning conditions, asphalt was employed as a representative surrogate for tough-to-clean residues. Asphalt cleaning was dramatically enhanced by mild heating: whereas 3% H$_2$O$_2$ at pH 9.5 and 23°C removed 100% of a fresh asphalt residue within 60 min., heating to 53°C achieved full removal within 2 min. As asphalt became aged or dried by exposure to air, longer cleaning durations were required. Nevertheless, all of the asphalt could still be removed with 3% H$_2$O$_2$ at pH 9.5 and 70°C within 2-60 min., even after the asphalt had dried onto glass for a week. H$_2$O$_2$ removed asphalt even when visible light was not present. When the H$_2$O$_2$ was excluded, a pH 9.5 bath at 70°C removed only a small fraction of this asphalt, if any.

The IceMaster process (Kipp 2007) has penetrated many areas of industry where coatings must be gently removed from surfaces. In the IceMaster process a mixed stream of dry ice particles and compressed air is emitted from a nozzle on to the surface being cleaned. The strong refrigeration effect of the dry ice embrittles materials such as oils, waxes, greases, paints, and bitumens. The coating cracks and the dry ice particles convert to carbon dioxide gas and evaporate. The surfaces themselves being cleaned are not attacked or embrittled by the cold. Therefore, it is not necessary to remove seals and rubber parts when using IceMaster process. After cleaning, only coating residues must be removed. To supply the handheld IceMaster device, a carbon dioxide flask with feed pipe or tank and a high performance compressor are needed. The compressed air need is small at a rate of 0.75-8.00 m$^3$/min. (depending on facility
IceMaster can run at 4.5 bar, is almost maintenance-free, and is simple to use.

Kopparal et al. (2005) developed a countercurrent continuous washing apparatus for tar removal under ultrasonic irradiation. Tar was dissolved in dimethylformamide (DMF) and sand was soaked into the resulting tar solution to prepare samples of tar-contaminated sand. Tar contents in DMF were determined by a UV-spectrophotometer from absorbance at 336.5 nm. The removal rate of tar content from this tar-contaminated sand was measured in two different conditions, one under the condition of mechanical stirring and the other with ultrasonically induced agitation. The removal rate was described in terms of a first order reaction equation, which makes it possible to calculate the residue fraction in continuous washing at a steady state. Comparison of tar removal with mechanical stirring and ultrasonically induced agitation has demonstrated that the ultrasound is more effective than the simple mechanical stirring. The basic mechanism of tar removal is, for both removal procedures, peeling of a tar-covered layer on the sand surface and the particles produced under the ultrasonic field are much finer than for the case of mechanical agitation.

Sheldon (2005) found that a non-toxic, non-hazardous, environmentally safe composition provides an effective, fast-acting cleaning solution for removal of tar, oils, asphalt and other bituminous materials from industrial equipment surfaces. The composition is a mixture of a carrier monocyclic monoterpene and a nonionic surfactant such as an alkylphenol ethoxylate. The mixture is applied directly to surfaces to be cleaned, and rinsed with water in the absence of mechanical intervention.

Zaki and Troxler (2005) found that water-soluble solvent compositions removed petroleum residue from a substrate. Compositions included:

- from about 10% to about 60% by weight of an aromatic ester
- from about 30% to about 60% by weight of an aliphatic ester
- from 0% to about 15% by weight of a co-solvent
- from 0% to about 20% of one of a cyclic terpene and a terpenoid
- from 0% to about 1% by weight of an odor-masking agent
- from 0% to about 20% by weight of a nonionic surfactant.

The composition can also include higher concentrations of water. Furthermore, the method for removing petroleum residue from a substrate can allow the solvent to be recycled using a
countercurrent separation column charged with compressed ammonia and/or carbon dioxide and a spinning band distillation column to separate the solvent from the petroleum residue.

Discussion of Literature and Experimental Protocol

From the review of the literature it appears that the best performing solvents all have appreciable ability to dissolve asphalt and asphalt compounds. Both terpene based compounds and vegetable oil esters appear to be especially favored due to their perceived environmental friendliness. Commercial biobased formulations such as Citrus King, BioAct MSO, Citri-Kote, and Citrus Zip claim excellent performances for removing tar and asphalt on surfaces. The inclusion of surfactants appears to aid the process. This may explain the differences in effectiveness along with other compounding differences for the widely different cleaning efficacies of a number of terpene based cleaners (Kulkarni et al. 2003). It appears that dioctylsulfosuccinate could be particularly useful (based on Phieffer et al. 2003).

The use of H₂O₂ is intriguing (Brant and Cannon 1996), but the results were obtained on glass surfaces. More study is needed to see whether such an approach will work on metal surfaces.

The physical approach of cryogenic blasting may also be particularly useful as no chemicals are involved and such processes have a history of use within the DoD.

Only two of the above cited papers (Kulkarni et al. 2003; Brant and Canon 1996) are of direct relevance to adoption of an experimental protocol to evaluate solvent effectiveness for removal of asphalt. The protocols discussed by Kulkarni et al. (2003) can be summarized as follows.

Protocol 1

Protocol 1 includes the following steps:

1. Number each aluminum dish and determine its weight. The dishes used are FISHERBRAND™ Aluminum Weighing Dishes (Fisher Scientific, Pittsburgh, PA). The catalog number is 08-732 and the capacity of each dish is 42 mL.

2. Apply 1.5 g of emulsified asphalt (CRS-2) into the standard aluminum dish, ensuring that asphalt emulsion fully covers the bottom surface area of the dish.
3. Heat the aluminum dish, with asphalt emulsion, for 24 hours at the temperature of 140°F. (60°C).

4. Remove the dish after 24 hr and cool to room temperature. Determine the weight of the dish and calculate the weight of residual asphalt.

5. Apply 0.5 g of solvent into the dish by dropper. Make sure that the asphalt remains completely submerged in the solvent for 5 min.

6. Let the dish drain for 5 min by putting it upside down.

7. Rinse the dish thoroughly for 5 min under running water.

8. Heat the dish at 140°F (60°C) for 15 hr to remove the traces of water completely.

9. Weigh the dish to calculate asphalt removed.

Strengths and Weakness of Protocol 1

Protocol 1 is clearly defined, easily carried out, and allows quantitative comparisons of the different solvents. However, it suffers from the restriction of using fixed substrate (aluminum). This raises the possibility that the results obtained with this test may not be applicable to other surfaces, especially painted surfaces. Another drawback in this method is that it measures the relative effectiveness of the dissolution powers of the solvent alone. In normal practice, additional forms of energy input may be present from activities such as wiping or spraying. Finally, a water rinsing step is also employed in this protocol. As explained in Greenway (2000), this step simulates the practice among asphalt paving workers of applying a cleaning solvent to the truck beds followed by water rinsing to minimize residual solvent. Apparently, the accumulation of excess residue results in poor-quality asphalt by leaching binders from the mix. However, this consideration may not be relevant for the present application—cleaning vehicles prior to rebuilding.

Protocol 2

Protocol 2 includes the following steps:

1. Preparation of Test Strips.
   a. The assay uses test strips of stainless steel with dimensions 1.5 x 2.0 x 1/32 in. Immersions in solvents were
carried out by placing the strips in clamps and immersing two thirds of the total area of the strip. This provides a total uniform area of exposure of 2.0 sq in. (The 1/32-in. thickness of the strip was disregarded.) The strips were desiccated and weighed with the clamp assembly so that the strip itself would not be handled.

b. The asphalt used in these experiments was a standard commercially available material containing latex polymers called CRS28, manufactured by Patterson Oil Company, Sullivan, MO. Upon procurement, each batch was cured by heating in a conventional laboratory oven for 7 days at 200 °F (93 °C).

c. A bath of the cured latex polymer-containing SuperPave asphalt was heated to 175 °F - 180 °F (79.5 °C – 82 °C). The strips were immersed in the molten asphalt to provide 2.0 sq in. of exposure. Exposure time was 2-3 sec. The strips were cooled to room temperature, desiccated for 24 hr, and weighed. Each data point is the arithmetic average of 10 strips treated identically.

2. Assay

The strips were immersed in the test solvents so that the entire asphalt coated areas were exposed to the solvent. The strips were withdrawn from the solution after 60 sec and drained for 2 min. They were again immersed for 60 sec and withdrawn. The strips were allowed to dry at room temperature for 2 hr and desiccated overnight. Desiccations were performed in an ordinary bell jar in the presence of a standard commercial desiccant. The test strips were then reweighed. The data expressed in percentage by weight of removal was calculated by subtracting the weight of the treated strip from the weight of the untreated strip and dividing by the weight of the untreated strip.

Strengths and Weakness of Protocol 2

Protocol 2 is also a clearly defined protocol that allows replications and quantitative evaluations. The coating of the strips by immersion may lead to variations in the individual weight, but this variation can be minimized by simultaneous dip coating, temperature control, and withdrawal. The effect of such variations can also be accounted for by normalizing the residual amount with respect to the initial coat weight. This protocol also follows a more rigorous and realistic aging of the asphalt contaminants that are likely to adhere to military vehicles. Finally, the protocol allows flexibility in the choice of
coupons. One drawback in this method is that it measures the relative effectiveness of the dissolution powers of the solvent alone. In normal practice, additional forms of energy input may be present from activities such as wiping or spraying. While this protocol does not explicitly include a water rinsing step, the source literature clearly indicates that such a step is usually carried out.

Experimental Procedure

Based on the literature review of the protocols presented in the previous section, this experimental study followed the modified protocol described below. These experiments were designed to facilitate ranking the performance of the cleaners. The cleaner evaluation involves estimating the solubility/dissolution power of the solvents, and cleaning ability using coupon studies. The coupon studies at different temperatures and times will provide information if any residues that remain on the surface and practical details useful for developing cleaning process. Experimental evaluation also includes cleaning complex parts such as chains obtained from the bitumen spreaders.

Materials

CRS-2 asphalt and stainless steel 2 x 3.5 x 0.02-in. test panels (#Q-D-46) were obtained from Emulsicoat, Inc. (Urbana, IL) and Q-Lab Corporation (Cleveland, OH), respectively. Bio T Max was acquired from Biochem Systems (Woodland, TX). BioAct 105, BioAct 120, BioAct 121, and BioAct MSO were all obtained from Petroferm Inc. (Gurnee, IL). Delta Foremost Chemical Corporation (Memphis, TN) supplied both Citri-Zip Asphalt Remover and Citri-Kote. DS-104 was acquired from Dysol (Fort Worth, TX). Full Force, Rid-O-Grease, and Tuff Stuff were obtained from Continental Research Corporation (St. Louis, MO). Orange Products LLC (McLeanville, NC) supplied Orange Oily Slicker Asphalt Remover and Release Agent as well as Citrus Soy Gold. Citrus King Asphalt Remover was acquired from Citrus Depot (St. Petersburg, FL). The isopropanol was purchased from Acros Organics (Thermo Fisher Scientific of Fairlawn, NJ).

Asphalt Solubility in Vials

Glass vials of about 10 mL volume were cleaned using isopropanol and then dried in an oven at 60 °C for 1 hr. The vials were then cooled to room temperature before being labeled and recording the weight. A pipette was used to transfer approximately 5 mL of asphalt into the vial. The asphalt was cured in a 60 °C oven.
overnight and then cooled to room temperature before weighing. There were 5 mL of each solvent added to marked vials, and the solvents were mixed using an oscillator for 15 min (See Appendix C: Figure C-1). The solvents were drained from the vials, after which they were allowed to drip dry (Figure C-2) for 30 min, and then put into the oven at 60 °C for 2 hr to evaporate the remaining solvent and re-solidify the remaining asphalt. The samples were cooled to room temperature and weighed.

Asphalt Removal on Metal Coupons

The 2 x 3.5 x 0.02-in. test coupons were cleaned with isopropanol and then dried in an oven at 60 °C for 1 hr. The coupons were cooled to room temperature before recording the weight. This procedure was also used for the control coupon. The ASTM G122-98: Method B (nonvolatile residue (NVR) sample, double side) was used to apply the contaminant, CRS-2 asphalt. The coated coupon was baked in the oven at 60 °C for 1 hr. After allowing the coupon to cool to room temperature, the test strip was weighed and then placed in a desiccator.

The cleaners were diluted according to the manufactures recommendations. The test coupons were immersed in solvent such that the entire asphalt coated area was exposed to the solvent. The coupons were removed from the cleaner after 60 sec and allowed to drip for 2 min. This was repeated 2 more times for a total of 3 solvent rinses. Afterward the coupons were rinsed with water and allowed to dry at room temperature over night. The spray solvents were held 6-8 in. away while applying. After applying over the entire contaminated area, the coupons were allowed to drip for 2 min. This was also repeated 2 more times for a total of 3 solvent applications, and then rinsed with water and allowed to dry overnight at room temperature. Weight of the dried coupons was acquired, and the cleaning effectiveness factor (CEF) was calculated using the following equation:

\[
CEF = \frac{MX_2 - MX_3}{MX_2 - MX_1}
\]

where:
- \(MX_2\) is the weight of the coupon with the asphalt
- \(MX_1\) is the weight of the coupon
- \(MX_3\) is the weight of the coupon plus any residual asphalt after the solvent has been applied (See Appendix C: Figure C-3 through Figure C-14).
Asphalt Removal on Chains at Room Temperature

Chains covered in asphalt were acquired from bitumen spreaders that were waiting to be cleaned at Red River Army Depot, Texarkana, TX. These chains were originally at a length of approximately 1 ft. These were cut down to 3-in. pieces, which were more suitable for the test procedure. About 400 mL containers were used to hold 300 mL of one of the five solvents chosen for this experiment. The solvents Citri-Zip, Citrus Soy Gold, BioAct MSO, Bio T Max, and Citrus King were chosen based on how much asphalt was removed during the vial tests. The chains were weighed with a paperclip that was used to suspend the chain in the solvent. The chains were then immersed in the solvent with constant agitation using a magnetic stir bar. After 30 min, the chains were taken out and washed with water to obtain the amount of asphalt remaining on the chain. This was repeated every 30 min for a total of 2 hr. The chains were allowed to air dry overnight and were then re-weighed.

Asphalt Removal on Chains at 90 °F

Five additional 3-in. asphalt-covered chain pieces were weighed with paper clips. The solvents Citri-Zip, Citrus Soy Gold, BioAct MSO, Bio T Max, and Citrus King were again chosen for this experiment. Exactly 300 mL of solvent was placed in a 400 mL container, which was then placed in beaker filled with water acting as a water bath to keep a consistent temperature. A Corning Stirrer/Hot Plate and a Cole Parmer Stirrer/Hot Plate were used both as heating elements and as sources of agitation for the solvent. The solvent and water bath were heated to 90±5 °F for 30 min before introducing the chain to the solvent so that the solvent would reach equilibrium with the water at the desired temperature. After 30 min of having the chain in the solvent, the chain was taken out and washed. This was repeated every 30 min over a course of 2 hr. The chains were allowed to air dry overnight and then were weighed again with their respective paperclips (See Appendix C, Figure C-15 and Figure C-16).

Evaluation of Solvents

From the vial test, it was possible to narrow down solvents that would perform best based on how much asphalt was removed. Based on the percentage of asphalt dissolved, the data in Table A-2 indicated that the top 10 solvents are: Citri-Zip, BioAct 121, Citrus Soy Gold, Bio T Max, BioAct 105, Citrus King, BioAct MSO, BioAct 120, Full Force, and Tuff Stuff.
Table A-2. Removal of Asphalt from Vials.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Bottle Wt. (g)</th>
<th>Bottle Wt. with Tar (g)</th>
<th>Tar Wt. (g)</th>
<th>Bottle Wt. after 5 mL Solvent (g)</th>
<th>Amount Tar Removed (g)</th>
<th>% Tar Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuff Stuff</td>
<td>12.79</td>
<td>17.66</td>
<td>4.87</td>
<td>17.55</td>
<td>0.11</td>
<td>2.26%</td>
</tr>
<tr>
<td>Rid-O-Grease</td>
<td>12.69</td>
<td>17.29</td>
<td>4.60</td>
<td>17.20</td>
<td>0.09</td>
<td>1.96%</td>
</tr>
<tr>
<td>Full Force</td>
<td>12.70</td>
<td>17.33</td>
<td>4.63</td>
<td>17.19</td>
<td>0.14</td>
<td>3.02%</td>
</tr>
<tr>
<td>Citri-Zip</td>
<td>12.64</td>
<td>17.13</td>
<td>4.49</td>
<td>16.95</td>
<td>0.18</td>
<td>4.01%</td>
</tr>
<tr>
<td>DS-104</td>
<td>12.60</td>
<td>17.72</td>
<td>5.12</td>
<td>17.61</td>
<td>0.11</td>
<td>2.15%</td>
</tr>
<tr>
<td>BioAct 105</td>
<td>12.75</td>
<td>17.56</td>
<td>4.81</td>
<td>17.40</td>
<td>0.16</td>
<td>3.33%</td>
</tr>
<tr>
<td>BioAct 120</td>
<td>12.61</td>
<td>16.88</td>
<td>4.27</td>
<td>16.75</td>
<td>0.13</td>
<td>3.04%</td>
</tr>
<tr>
<td>BioAct 121</td>
<td>12.16</td>
<td>16.94</td>
<td>4.78</td>
<td>16.75</td>
<td>0.19</td>
<td>3.97%</td>
</tr>
<tr>
<td>BioAct MSO</td>
<td>12.20</td>
<td>17.30</td>
<td>5.10</td>
<td>17.14</td>
<td>0.16</td>
<td>3.14%</td>
</tr>
<tr>
<td>Bio T Max</td>
<td>12.61</td>
<td>17.52</td>
<td>4.91</td>
<td>17.35</td>
<td>0.17</td>
<td>3.46%</td>
</tr>
<tr>
<td>Orange Oil Slicker</td>
<td>12.68</td>
<td>17.56</td>
<td>4.88</td>
<td>17.45</td>
<td>0.11</td>
<td>2.25%</td>
</tr>
<tr>
<td>Citrus King</td>
<td>12.16</td>
<td>17.23</td>
<td>5.07</td>
<td>17.07</td>
<td>0.16</td>
<td>3.16%</td>
</tr>
<tr>
<td>Citrus Soy Gold</td>
<td>12.64</td>
<td>16.60</td>
<td>3.96</td>
<td>16.45</td>
<td>0.15</td>
<td>3.79%</td>
</tr>
<tr>
<td>Citri-Kote</td>
<td>12.69</td>
<td>17.01</td>
<td>4.32</td>
<td>16.93</td>
<td>0.08</td>
<td>1.85%</td>
</tr>
</tbody>
</table>

After reviewing the MSDS and product sheets of each of the top solvents along with the cost per gallon shown in Table A-3, five solvents were selected to undertake the next experiment, asphalt removal from chains.

Table A-3. Cost of Solvents.

<table>
<thead>
<tr>
<th>Solvent Name</th>
<th>Cost per gallon*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuff Stuff</td>
<td>$166.00**</td>
</tr>
<tr>
<td>Rid-O-Grease</td>
<td>$56.00</td>
</tr>
<tr>
<td>Full Force</td>
<td>$39.00</td>
</tr>
<tr>
<td>Citri-Zip</td>
<td>$58.85</td>
</tr>
<tr>
<td>DS-104</td>
<td>$30.82</td>
</tr>
<tr>
<td>BioAct 105</td>
<td>$16.92</td>
</tr>
<tr>
<td>BioAct 120</td>
<td>$24.82</td>
</tr>
<tr>
<td>BioAct 121</td>
<td>$22.40</td>
</tr>
<tr>
<td>BioAct MSO</td>
<td>$22.18</td>
</tr>
<tr>
<td>Bio T Max</td>
<td>$25.65</td>
</tr>
<tr>
<td>Orange Oil Slicker</td>
<td>$26.91</td>
</tr>
<tr>
<td>Citrus King</td>
<td>$39.00</td>
</tr>
<tr>
<td>Citrus Soy Gold</td>
<td>$28.73</td>
</tr>
<tr>
<td>Citri-Kote</td>
<td>$36.50</td>
</tr>
</tbody>
</table>

*Price per gallon based on a 55-gal drum. ** Only sold in packs of a dozen aerosol cans. Net weight 15 oz per can. Costs were obtained during June-July 2010.
Cleaners Chosen for Detailed Study

Based on the tar removal and cost information shown in Tables A-2 and A-3, five solvents were selected for further evaluation.

The cleaners chosen for detailed study were Citri-Zip, BioAct MSO, Citrus Soy Gold, Citrus King, and Bio T Max. Time of immersion and temperature of the solvent were chosen during this experiment using the experimental setup shown in Figure C-7 and Figure C-11 (Appendix C). A comparison of Table A-4 and Table A-5 reveals that the optimum temperature is at 90°F, which generally cuts the immersion time by at least 60 min. It also shows that the maximum time that every solvent (except citrus soy gold) needs to work is 60 min. Therefore, the recommended time of immersion is between 30 and 60 min. Note that Figure C-15 and Figure C-16 show significant corrosion of the chain. Unfortunately, it could not be determined whether this corrosion occurred before the asphalt was accumulated, if it was caused by the solvents, or if the metal rusted during the period of time the asphalt was on the chain. Nevertheless, the metal coupon tests helped narrow down the cleaner selection process for further testing. Based on these results, and on cost, the three solvents chosen for field-testing were: Bio T Max, BioAct MSO and Citrus King.

Table A-4. Removal of asphalt from chains at 78 °F.

<table>
<thead>
<tr>
<th>Solvent Name</th>
<th>Weight</th>
<th>Time submerged (min)</th>
<th>Amount of Solvent (mL)</th>
<th>Weight After Tar Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citri-Zip</td>
<td>54.31</td>
<td>120</td>
<td>300</td>
<td>47.49</td>
</tr>
<tr>
<td>Bio T Max</td>
<td>50.84</td>
<td>120</td>
<td>300</td>
<td>46.62</td>
</tr>
<tr>
<td>Citrus King</td>
<td>54.04</td>
<td>120</td>
<td>300</td>
<td>47.79</td>
</tr>
<tr>
<td>BioAct MSO</td>
<td>54.25</td>
<td>120</td>
<td>300</td>
<td>47.5</td>
</tr>
<tr>
<td>Citrus Soy Gold</td>
<td>54.35</td>
<td>120</td>
<td>300</td>
<td>47.97</td>
</tr>
</tbody>
</table>

Table A-5. Removal of asphalt from chains at 90°F.

<table>
<thead>
<tr>
<th>Solvent Name</th>
<th>Weight</th>
<th>Time submerged (min)</th>
<th>Amount of Solvent (mL)</th>
<th>Weight After Tar Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citri-Zip</td>
<td>54.95</td>
<td>60</td>
<td>300</td>
<td>48.86</td>
</tr>
<tr>
<td>Bio T Max</td>
<td>60.27</td>
<td>60</td>
<td>300</td>
<td>55.66</td>
</tr>
<tr>
<td>Citrus King</td>
<td>55.02</td>
<td>60</td>
<td>300</td>
<td>48.48</td>
</tr>
<tr>
<td>BioAct MSO</td>
<td>50.6</td>
<td>60</td>
<td>300</td>
<td>47.25</td>
</tr>
<tr>
<td>Citrus Soy Gold</td>
<td>51.31</td>
<td>120</td>
<td>300</td>
<td>47.75</td>
</tr>
</tbody>
</table>
Conclusions and Recommendations

This PWTB presented a simple approach to evaluate commercial tar/asphalt cleaners. Several ASTM test methods are also available for evaluation of grease and oil cleaner performance. The simple laboratory experiments described in this PWTB can be used to evaluate tar and asphalt cleaners.

This work also identified two broad categories of solvent blends that can remove asphalt from metal: (1) terpene-based solvents/esters, and (2) blends of aliphatic hydrocarbons and esters assisted by surfactants. Of the solvents reviewed, the five solvents listed in Table A-5 performed well in the laboratory. It is recommended that any of these five cleaners may be used for removing the tar/asphalt from surfaces:

1. Citri – Zip
2. Bio T Max
3. Citrus King
4. BioAct MSO
5. Citrus Soy Gold

Of these five tested solvents, Citrus King appears to combine both functionality and desirable environmental characteristics. The actual selection, however, would be based on the specific application (such as removing tar from a smooth surface or a part with complex geometry such as a chain) and mode of application (flexibility to heat the part, immersion cleaning or spray cleaning, and the time that could be allocated for cleaning).

Note that the feasibility of using these solvents for routine large scale cleaning must be demonstrated in the overall framework of economics, environment, and health. New cleaners are continuously being developed by commercial vendors. Follow-on studies shall be conducted within a constraining set of environmental and health criteria and a price point specific to field conditions. Nevertheless, the information in this PWTB should be sufficient to give operators enough information to select a cleaner for surface spot cleaning or immersion cleaning for tar and asphalt removal based on operational requirements, negotiated cost of solvents, and waste disposal requirements.
Appendix B

REFERENCES and RESOURCES

References cited in text


Additional Resources


http://www.sciencedirect.com/science/journal/0926860X


Rule 234, Automotive refinishing operations. Adopted 11-03-94 (Amended 8-24-95, 8-8-96, 4-9-98), http://www.placer.ca.gov/Departments/Air/~media/apc/documents/rules/rule_234_automotive_refinishing_operations%20pdf.ashx


Appendix C

PHOTOGRAPHS OF LABORATORY EXPERIMENTS

Vial Experiments

Figure C-1. Vials with tar and solvent on rotating shaker.

Figure C-2. Vials drained after shaking.
Coupon Experiments

Figure C-3. Asphalt-coated coupon.

Figure C-4. Asphalt-coated coupon submerged in 400 mL Citrus King (15 min at 30-35°C).
Figure C-5. Asphalt-coated coupon submerged in 400 mL Citrus King (30 min at 30-35 °C).

Figure C-6. Asphalt-coated coupon submerged in 400 mL Citrus King (45 min at 30-35 °C).
Figure C-7. Solvent Simple Green set-up at room temperature.

Figure C-8. Asphalt-coated coupon submerged in Simple Green for 30 min at room temperature.
Figure C-9. Asphalt-coated coupon submerged in Simple Green for 60 min at room temperature.

Figure C-10. Asphalt-coated coupon submerged in Simple Green for 90 min at room temperature.
Figure C-11. Solvent Simple Green set-up at 80 °C.

Figure C-12. Asphalt-coated coupon submerged in Simple Green at 80 °C for 30 min.
Figure C-13. Asphalt-coated coupon submerged in Simple Green at 80 °C for 60 min.

Figure C-14. Asphalt-coated coupon submerged in Simple Green at 80 °C for 90 min.
Chain Experiments

Figure C-15. Dirty chains before immersion in Citri-Zip solvent.

Figure C-16. Chain after immersion in Citri-Zip for 90 min and after rinse.
# Appendix D

## ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Spelled Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>Army Regulation</td>
</tr>
<tr>
<td>CECW</td>
<td>Directorate of Civil Works, U. S. Army Corps of Engineers</td>
</tr>
<tr>
<td>CEF</td>
<td>cleaning effectiveness factor</td>
</tr>
<tr>
<td>CEMP</td>
<td>Directorate of Military Programs, U. S. Army Corps of Engineers</td>
</tr>
<tr>
<td>CERL</td>
<td>Construction Engineering Research Laboratory</td>
</tr>
<tr>
<td>CFC</td>
<td>Chlorofluorocarbon</td>
</tr>
<tr>
<td>CFR</td>
<td>Code of the Federal Regulations</td>
</tr>
<tr>
<td>DA</td>
<td>Department of the Army</td>
</tr>
<tr>
<td>DMF</td>
<td>dimethylformamide</td>
</tr>
<tr>
<td>DPW</td>
<td>Directorate of Public Works</td>
</tr>
<tr>
<td>DoD</td>
<td>Department of Defense</td>
</tr>
<tr>
<td>ERDC</td>
<td>Engineer Research and Development Center</td>
</tr>
<tr>
<td>H₂O₂</td>
<td>hydrogen peroxide</td>
</tr>
<tr>
<td>HAP</td>
<td>hazardous air pollutant</td>
</tr>
<tr>
<td>HQUSACE</td>
<td>Headquarters, U. S. Army Corps of Engineers</td>
</tr>
<tr>
<td>HSWA</td>
<td>Hazardous and Solid Waste Amendments</td>
</tr>
<tr>
<td>MSDS</td>
<td>Material Safety Data Sheet</td>
</tr>
<tr>
<td>NVR</td>
<td>non-volatile residue</td>
</tr>
<tr>
<td>PL</td>
<td>public law</td>
</tr>
<tr>
<td>POC</td>
<td>point of contact</td>
</tr>
<tr>
<td>PWTB</td>
<td>Public Works Technical Bulletin</td>
</tr>
<tr>
<td>RCRA</td>
<td>Resource Conservation and Recovery Act</td>
</tr>
<tr>
<td>TARDEC</td>
<td>Tank Automotive Research, Development, and Engineering Center</td>
</tr>
<tr>
<td>USACE</td>
<td>US Army Corps of Engineers</td>
</tr>
<tr>
<td>USEPA</td>
<td>US Environmental Protection Agency</td>
</tr>
<tr>
<td>VOC</td>
<td>volatile organic compound</td>
</tr>
<tr>
<td>WBDG</td>
<td>Whole Building Design Guide</td>
</tr>
<tr>
<td>WMPP</td>
<td>Waste Minimization and Pollution Prevention</td>
</tr>
</tbody>
</table>
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