Assessment of Safer and Effective Alternatives for Coating Removal Products

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I. Introduction

Background

Methylene chloride is a widely used, effective solvent in coating removal products. Methylene chloride is highly volatile and the primary route of exposure is inhalation. Numerous occupational and consumer deaths during coating removal operations have resulted from acute methylene chloride poisoning, with 56 reported accidental exposure deaths linked to methylene chloride since 1980 (Hopkins, 2015). Methylene chloride can cause acute and chronic effects on the central nervous system. The inhalation of methylene chloride can result in short-term effects such as asphyxiation, dizziness, clumsiness, headache, nausea, and numbness of fingers and toes, and long-term effects such as loss of concentration, memory loss, and personality changes (ATSDR, 2000). Further, methylene chloride is classified as "reasonably anticipated to be a human carcinogen" by the U.S. National Toxicology Program (NTP, 2013). There is increasing market, scientific, and regulatory scrutiny of methylene chloride and its use in paint stripping formulations has been restricted by government agencies in Europe and the U.S. and recently by major retailers.

The Massachusetts Toxics Use Reduction Act (TURA) program designated methylene chloride as a higher hazard substance effective in 2014. The goal of designating some toxic chemicals as Higher Hazard Substances is to help Massachusetts companies and communities focus their toxics use reduction efforts on those chemicals that pose the most serious threats to human health and the environment. Solvents used in coating removal products that are listed in the TURA program are provided in Appendix 1.

The three major categories of methylene chloride use in coating removal products are industrial (e.g., in a permanent stationary technical installation), professional (e.g., by a tradesman), and consumer (e.g., by a homeowner for do-it-yourself activities) (RPA, 2007). In 2015, coating removal products with methylene chloride were being sold in Massachusetts to do-it-yourself consumers, industrial users (e.g., Raytheon), and professionals working in businesses such as furniture refinishing, boat restoration, and bathtub refinishing.

The Toxics Use Reduction Institute (TURI) at the University of Massachusetts Lowell (UMass Lowell) initiated a project in 2015 to identify and evaluate safer and effective alternatives to methylene chloride and other chemicals of high concern used in coating removal products. The project team consisted of TURI staff, UMass Lowell faculty, and UMass Lowell graduate and undergraduate students from various academic departments such as chemistry, chemical engineering, and public health.

Approach

The TURI project had the following objectives:

- Determine the requirements for a safe and effective coating removal product
- Conduct an environmental, health, and safety (EHS) evaluation, cost evaluation, and performance evaluation of commercially available coating removal products

- Identify and evaluate new solvent blends with comparable coating removal performance, comparable ingredient costs, and a safer EHS profile than methylene chloride
- Document all the results in order to assist businesses, government agencies and the public with informed decision-making

Determine the Requirements

TURI held meetings in 2015 with The Savogran Company, a Massachusetts-based manufacturer of paint stripping products, to start defining the requirements for safer and effective coating removal products. The discussion was then expanded and to date includes representatives from several paint stripper product manufacturers (e.g. Dumond Chemicals Inc., Fiberlock Technologies, Recochem Inc., Shore Corporation, DS Super Remover, etc.), bathtub refinishers (Outstanding Bath Refinishers, Professional Bathtub Refinishing Association), a furniture refinisher (Belcastro Furniture Restoration), a boat restorer (Burr Brothers Boat), several retailers (The Home Depot, Kingfisher PLC, Lowe's Companies Inc., Sherwin-Williams Company, etc.), and an industrial user (Raytheon Company). In addition, the researchers reviewed publicly available paint stripper-related literature.

Based on feedback from discussions with industry representatives and preliminary performance testing results in 2015, project staff determined that several commercially available coating removal products did not contain methylene chloride; however, their coating removal performance was significantly slower than methylene-chloride-based paint strippers. Therefore, the need for a fast-acting coating removal product with safer chemical ingredients was identified.

Coating removal products are primarily composed of solvents, and also often use additives such as evaporation barriers and thickeners. Evaporation barriers are commonly made from waxes such as paraffin wax that is often used in candles. Thickeners are made of chemicals such as methyl cellulose and hydroxypropyl methyl cellulose that are commonly used as food additives. *Given the low toxicity for evaporation barriers and thickener additives, the scope of this assessment was limited to just the solvents used in coating removal products*.

Based on discussions and review, the primary requirements that would need to be satisfied for a solvent or solvent blend to replace methylene chloride in general purpose coating removal products are listed below.

EHS Requirements

1. Safer Chemicals: Composed of chemicals that are safer from an overall EHS standpoint as compared to methylene chloride and other chemicals of high concern.
2. Fire Hazard: Manufacturers of coating removal products can mitigate fire hazard with one of the following approaches: a) a product flash point greater than 100 °F, or b) an effective evaporation barrier to block solvent evaporation.

3. Volatile Organic Compounds (VOC): Compliance with U.S. state regulations with VOC content less than 50% for paint stripping products and VOC content less than 20% for adhesive removal products.

Cost Requirements

4. Cost: Retail price is a key factor for market acceptance of coating removal products.

Technical Performance Requirements

5. Technical Performance: The product should demonstrate a coating removal performance with comparable removal speed to methylene-chloride-based products across a wide range of coatings: paints (oil, latex), varnishes, lacquers, shellacs, epoxies, adhesives, asphalt/tar, polyurethanes; and across multiple substrate materials: wood, metal, ceramic tile, and masonry.
6. Penetration of Multilayer Coatings: The product should contain solvents that have small molar volumes and low hydrogen bonding values so that they can rapidly penetrate the multiple layers of coatings.
7. Shelf Life: The coating removal product ingredients should not separate over extended periods of time.
8. No Damage to Substrate Material: The product should not stain, discolor, or alter the substrate, or corrode a metal substrate. A substrate damage assessment was not included as part of TURI's evaluation of coating removal products.
9. Odor: The coating removal product should not emit any strong, offensive odors to the user. This requires a qualitative assessment and was not included as part of TURI's evaluation of coating removal products.

Conduct EHS, Cost, and Performance Evaluation

GreenScreen® for Safer Chemicals, developed by the nonprofit organization Clean Production Action, is a comparative chemical hazard assessment method. In this method, a range of human health, environmental toxicity, fate, and physical hazard endpoints are evaluated for each chemical. *Since there was an extensive amount of GreenScreen environmental, health, and safety information already available for the most common solvents used in coating removal products, GreenScreen for Safer Chemicals was selected as the method for comparing environmental, health, and safety for both the evaluation of safer commercially available coating removal product ingredients and for research into new solvent blends*.

Upon completion of a GreenScreen assessment, the chemical receives one of four possible Benchmark scores. The Benchmark scores are shown in Figure 1.

Benchmark 1: Chemical of High Concern – Avoid
Benchmark 2: Use but Search for Safer Substitutes
Benchmark 3: Use but Still Opportunity for Improvement
Benchmark 4: Prefer – Safer Chemical

Figure 1: GreenScreen Benchmark Scores

A GreenScreen List Translator score of "LT-1" means the hazard classifications for a given chemical meet one or more of the GreenScreen Benchmark-1 criteria and this information is based on authoritative lists; if a full GreenScreen assessment were conducted, the chemical would most likely be a Benchmark-1 chemical (CPA, 2019). Further details about the GreenScreen assessment method is provided in Appendix 2.

Manufacturers have been searching for non-methylene-chloride-based paint removers for some time; this accelerated in 2018, when several major retailers (e.g., The Home Depot, Lowe's Companies Inc., Sherwin-Williams Company) implemented voluntary bans for paint stripping products containing methylene chloride or N-methyl-2-pyrrolidone (NMP) (SCHF, 2018). Methylene chloride and NMP are chemicals of high concern that are designated as California Prop 65 chemicals and are under increased regulatory scrutiny globally. In response to this voluntary ban, several major coating removal product manufacturers reformulated their legacy products and introduced new products to the marketplace that did not contain methylene chloride or NMP. Unfortunately, many alternative chemicals used in methylene chloride and NMP-free products are also chemicals of high concern and introduce other significant human and environmental health hazards. These include dimethylformamide (DMF), toluene, methanol, xylene, naphthalene, ethyl benzene, and Stoddard solvent. These chemicals, many of which were included in the Clean Production Action report (or have GreenScreen Assesments), have been designated as GreenScreen Benchmark 1, EPA Hazardous Air Pollutants, and/or California Prop 65 chemicals. U.S. EPA Hazardous Air Pollutants are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects (U.S. EPA, 2019). California Prop 65 listed chemicals are known to the state to cause cancer or reproductive toxicity (OEHHA, 2019). This replacement of one chemical of high concern with another is not considered an effective toxic use reduction technique.

In addition to using GreenScreen information, TURI contracted with Worcester Polytechnic Institute's Department of Fire Protection Engineering to conduct a fire hazard evaluation for coating removal products, and contracted with Oregon State University to evaluate toxicity of the solvent blends used for a new UMass Lowell-developed formulation to be used in a safer coating removal product.

For the cost evaluation, TURI compiled retail online and store pricing for various coating removal products during the 6-month time period from September 2018 through February 2019.

For the technical performance evaluation, testing of various coating removal products was conducted at the TURI Laboratory for the following types of coatings:

- Coatings on wood test panels
- Coatings on masonry blocks
- Automotive coatings
- Boat coatings
- Chemical agent resistant coatings (CARC)
- Adhesive coatings
- Bathtub coatings
- Asphalt/tar coatings
- Latex splatter coatings

The coating removal products used for this performance testing are available for do-it-yourself consumers at retailers such as The Home Depot, Lowe’s Companies Inc., and Sherwin-Williams Company. The coating removal products used for this testing also represent the many types of solvents used, such as methylene chloride, NMP, toluene, methanol, xylene, ethyl benzene, naphthalene, acetone, dibasic esters, benzyl alcohol, dimethyl sulfoxide, d-limonene, methyl acetate, and water.

In addition, limited performance testing for furniture refinishing was conducted at the Belcastro Furniture Refinishers facility.

Research into New Safer Solvent Blends

The TURI project team used the Hansen Solubility Parameters (HSP) approach to help identify solvent blends with the desired solvency parameters (diffusion, polarity, and hydrogen bonding). The HSP-based approach is an efficient method to rapidly identify safer and effective alternatives to methylene chloride and other chemicals of high concern in coating removal products. Further information about HSP theory is provided in Appendix 3.

The universe of solvents was initially screened to generate a smaller, more manageable list of solvents. The solvents were screened for cost, HSP values, molar volume, and environmental, health, and safety issues. This was an iterative process, as the values used for screening were tightened over time. The solvents were screened for significant EHS issues by using information provided in safety data sheets and publicly available chemical hazard sources. Also, the subscription-based Pharos database was used to obtain further environmental, health, and safety information for target solvents. The information from these sources was sufficient to screen out many potential chemicals of high concern. For example, the solvent was screened out from further consideration if it was listed as an EPA Hazardous Air Pollutant; a California Prop 65 chemical; a European Union Annex VI Category 1 carcinogenic, mutagenic, or toxic-to-reproduction substance (ECHA, 2012); or an International Agency for Research on Cancer (IARC) Group 1 agent ("carcinogenic to humans"), Group 2A agent ("probably carcinogenic to humans") or Group 2B agent ("possibly carcinogenic to humans") (IARC, 2019).

The solvents that passed the initial screening process were loaded into the HSPiP software program to determine solvent blends that could potentially work similarly to methylene-chloride-based paint strippers. The solvent blends then underwent technical performance testing for coating removal efficacy for various applications, substrates, and coatings in the TURI Laboratory at UMass Lowell. For the solvents that passed this initial EHS screen as well as the technical performance tests, GreenScreen was then used as the evaluation tool to provide a more detailed and comprehensive EHS assessment of specific ingredients.

TURI developed the "LO3" and "HPM" formulations that met the previously described coating removal requirements, including comparable coating removal performance to methylene-chloride-based paint strippers. The ingredients for these formulations are listed in Table 5. The University of Massachusetts Lowell filed provisional patent applications with the U.S. Patent and Trademark Office in 2016 and 2018 for these formulations under the application title "Composition and Method for Removing a Coating from a Surface."[1]

TURI recently developed a UMass Lowell Formulation NF that is nonflammable with a flash point above 100 °F. A patent application has not yet been filed for this formulation.

[1] A licensing agreement was completed between The University of Massachusetts Lowell and SRD NewGen in 2018 to commercialize this new coating removal technology in the U.S., Canada, and Mexico. The UMass Lowell LO3 formulation has been commercialized under the brand names "DS Super Remover New Generation," "Saman Ultimate Stripper," and "Technoflex Ultimater Remover." The first commercial shipment of the DS Super Remover New Generation product took place in November 2018. DS Super Remover has used this new formulation to completely replace all of their previous coating removal consumer products that contained chemicals of high concern. As of March 31, 2019, DS Super Remover discontinued all retail sales of their previous consumer coating removal products that contained methylene chloride, methanol, toluene, and dimethyl formamide. The UMass Lowell HPM formulation will soon be commercialized under the brand name "DS Super Remover Professional Grade." Subsequent to the signing of the licensing agreement with SRD NewGen, these new methylene-chloride-free paint stripper formulations are available for interested coating removal product manufacturers and retailers through sublicensing by SRD NewGen or private label manufacturing.

II. Evaluation Results

Requirement 1: Environmental, Health, and Safety

GreenScreen Assessments

In 2015, ToxServices, a toxicology and risk assessment consultancy, conducted GreenScreen assessments for the following twelve chemicals commonly used as solvent ingredients in coating removal formulations:

- Methylene chloride
- Benzyl alcohol
- 2-(2-butoxyethoxy) ethanol
- Dimethyl sulfoxide
- 1,3 dioxolane
- Estasol (dibasic esters mixture)
- D-limonene
- Acetone
- Methanol
- Toluene
- Formic acid
- Caustic soda

The results of these GreenScreen assessments were published in a 2015 Clean Production Action report entitled "Alternatives to Methylene Chloride in Paint and Varnish Strippers" (Jacobs, 2015). Although 1-Methyl-2-pyrrolidone (NMP) is a commonly used solvent in coating removal formulations, it was excluded from this report due to regulatory and scientific concerns about its use as an alternative.

To add to the existing body of GreenScreen data for solvents using in coating removal products, TURI contracted with ToxServices to conduct GreenScreen assessments for ingredients in the solvent formulations it was developing, including thiophene, dimethyl carbonate, methyl acetate, dimethyl sulfoxide (DMSO), and 1,3 dioxolane. The complete GreenScreen reports for these chemicals are available on the TURI website. Thiophene provides an example of how the GreenScreen assessment was used to eliminate solvents without a validated safer EHS profile from its formulation. Thiophene was assigned a preliminary Benchmark Level 2 based on currently available data for 18 out of the 20 different hazard endpoints assessed. However, thiophene received a final score of "U-2," which means "Unspecified due to Insufficient Data," since there was insufficient data in the scientific literature to assess thiophene for two hazard endpoints: carcinogenicity and endocrine activity. Therefore, thiophene was excluded from further consideration as a solvent for the UMass Lowell LO3 paint stripper formulation.

The Benchmark scores from GreenScreen evaluations for chemicals used in coating removal products are provided in Table 1. Table 1 also indicates if the chemical is listed as an EPA Hazardous Air Pollutant or a California Prop 65 chemical. Chemicals that have the GreenScreen Benchmark 1 designation are often listed as EPA Hazardous Air Pollutants and/or California Prop 65 chemicals. An exception is Stoddard solvent, for which the Benchmark 1 rating is based on its listing in the EU Annex VI CMR as a Category 1B carcinogen and Category 1B mutagen.

Table 1: *GreenScreen Benchmark Levels for Chemicals Used in Coating Removal Products*

Chemicals Used in Coating Removal Products	CAS Number	GreenScreen Benchmark	EPA HAP	California Prop 65 Listed
Water	7732-18-5	4		
Dimethyl sulfoxide (DMSO)	67-68-5	3		
2-(2-butoxyethoxy) ethanol	112-34-5	2		
2-butoxyethanol	111-76-2	2		
Acetone	67-64-1	2		
Benzyl alcohol	100-51-6	2		
*Dibasic ester mixture	95481-62-2	2		
D-limonene	5989-27-5	2		
Dimethyl carbonate	616-38-6	2		
1,3 Dioxolane	646-06-0	2		
Formic acid	64-18-6	2		
Methyl acetate	79-20-9	2		
Petroleum distillates	64742-47-8	2		
Sodium hydroxide	1310-73-2	2		
Thiophene	110-02-1	U - 2		
Dimethyl formamide	68-12-2	LT-1	✓	✓
Ethyl benzene	100-41-4	LT-1	✓	✓
Methanol	67-56-1	1	✓	✓
Methylene chloride	75-09-2	1	✓	✓
Naphthalene	91-20-3	1	✓	✓
NMP	872-50-4	LT-1		✓
Stoddard solvent	8052-41-3	LT-1		
Toluene	108-88-3	1	✓	✓
Xylene	1330-20-7	1	✓	
Alcohol ethoxylate	68439-46-3	Not evaluated		
Ammonia	7664-41-7	Not evaluated		
Ethanol amine	141-43-5	Not evaluated		
3 Ethoxypropionic acid ethyl ester	763-69-9	Not evaluated		
Calcium hydroxide	1305-62-0	Not evaluated		
Potassium hydroxide	1310-58-3	Not evaluated		
Safenol	111-93-6	Not evaluated		
Tetrahydrofuran	109-99-9	Not evaluated		
Triethyl phosphate	78-40-0	Not evaluated		

* Includes a mixture of dimethyl adipate, dimethyl glutarate, and dimethyl succinate.

The results for each hazard endpoint from the GreenScreen hazard assessments for solvents used in coating removal products are included in Table 2.

Table 2: *GreenScreen Hazard Assessment Results*

Chemical		Group I Human					Group II & II Human									Ecotox		Fate		Physical	
		C	M	R	D	E	AT	ST		N		SnS	SnR	IrS	IrE	AA	CA	P	B	RX	F
								Single	repeated	Single	repeated										
Methylene chloride	75-09-2	**H**	**NE**	**DG**	**DG**	**M**	*M*	*vH*	**H**	*vH*	*vH*	**L**	**DG**	**H**	**H**	**M**	*L*	*vH*	**vL**	**L**	**L**
Benzyl alcohol	100-51-6	**L**	**L**	*L*	*M*	DG	**M**	**L**	**L**	*M*	*H*	**H**	*L*	**L**	**H**	**L**	**L**	**vL**	**vL**	*L*	**L**
2-(2-butoxyethooxy) ethanol	112-34-5	*L*	**L**	**L**	**L**	DG	**L**	**L**	**H**	DG	**L**	**L**	DG	*M*	**H**	**L**	**L**	**vL**	**vL**	*L*	**M**
Dimethyl sulfoxide	67-68-5	*L*	**L**	*L*	**L**	DG	**L**	**L**	**L**	**L**	**L**	**L**	*L*	*M*	*M*	**L**	*L*	*L*	**vL**	*L*	**M**
1,3-dioxolane	646-06-0	*L*	**L**	*M*	*M*	DG	*L*	**M**	**M**	**M**	**L**	**L**	*L*	*M*	*H*	**L**	*L*	*M*	**vL**	*L*	**H**
Estasol (dibasic esters mixture)	95481-62-2	*L*	**L**	*L*	*M*	*M*	**L**	**M**	*M*	**M**	DG	**L**	DG	**L**	*M*	**M**	*L*	**vL**	**vL**	*M*	**L**
D-limonene	5989-27-5	**L**	**L**	DG	**L**	DG	**L**	**L**	**L**	DG	DG	**H**	DG	**H**	*H*	**vH**	**H**	**vL**	**M**	*L*	**M**
Acetone	67-64-1	*L*	**L**	*M*	**M**	DG	**L**	*M*	**M**	**M**	*M*	**L**	DG	**L**	**H**	**L**	**L**	vL	**vL**	**L**	**H**
Methanol	67-56-1	NA	NA	NA	**H**	NA	**H**	**vH**	NA	NA	NA	NA	NA	NA	NA	**L**	*L*	**vL**	*vL*	NA	**H**
Toluene	108-88-3	DG	**L**	**H**	**H**	**M**	**L**	**M**	**H**	**M**	**H**	**L**	DG	**H**	**L**	**H**	*H*	*H*	**vL**	**L**	**H**
Formic acid	64-18-6	**L**	**L**	**L**	*L*	DG	**H**	**vH**	*H*	vH	DG	**L**	DG	vH	vH	**M**	**M**	**vL**	**vL**	**L**	**M**
Caustic soda	1310-73-2	*L*	**L**	*L*	*L*	*L*	**H**	**vH**	*L*	*L*	*L*	**L**	DG	vH	vH	**M**	DG	*L*	*vL*	*M*	**L**
Methyl acetate	79-20-9	**L**	**L**	*L*	*M*	*M*	**L**	**M**	*M*	**M**	*M*	**L**	*L*	**L**	**H**	**L**	**L**	**vL**	**vL**	**L**	**H**
Dimethyl carbonate	616-38-6	*L*	**L**	**L**	*M*	DG	**L**	**L**	**L**	**M**	DG	**L**	*L*	**L**	*M*	**L**	*L*	**vL**	**vL**	*L*	**H**
Thiophene	110-02-1	DG	*L*	*M*	*L*	DG	*H*	*vH*	**M**	*M*	**M**	*L*	*L*	*H*	*H*	**M**	*M*	*M*	**vL**	*L*	**H**

Abbreviations:

C = Carcinogenicity
M = Mutagenicity
R = Reproductive Toxicity
D = Developmental Toxicity
E = Endocrine Activity

AT = Acute Toxicity
ST = Systemic Organ Toxicity
N = Neurotoxicity
SnS = Skin Sensitization
SnR = Respiratory Sensitization
IrS = Skin Irritation
IrE = Eye Irritation

AA = Aquatic Toxicity
CA = Chronic Aquatic Toxicity
P = Persistence
B = Bioaccumulation
RX = Reactivity
F = Flammability

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (VL) in *italics* reflect estimated (modeled values, authoritative B lists, screening lists, weak analogues, and lower confidence. Hazard levels in **BOLD** are used with good quality data, authoritative A lists, or strong analogues. Group II Human Health endpoints differ from Group II Human Health endpoints in that they have four hazard scores (i.e., vH, H, M and L) instead of three (i.e., H, M and L), and are based on single exposures instead of repeated exposures. DG indicates insufficient data for assigning hazard level. NE indicates no determination was made (conflicting data). NA indicates not assessed since Benchmark 1 score already attained.

Methylene chloride has received a GreenScreen Benchmark Level 1 score: "Chemical of High Concern - Avoid." Table 3 provides a non-exhaustive list of methylene chloride based coating removal products. The products included are limited to the products used in the performance testing for this report. The solvents listed for these products are based on manufacturer safety data sheets.

Table 3: *Solvents Used in Coating Removal Products with Methylene Chloride*

Supplier	Product	Data Source	GreenScreen Benchmark 1 Solvent(s)	Other Solvents
Benco	B7	SDS No date listed	Methylene chloride, methanol	2-butoxyethanol, 2-methoxymethyl ethoxproponal
Rust-Oleum	Auto Stripper	SDS 5/18/15	Methylene chloride, methanol	Alcohols ethoxylated, light distillate
Savogran	Strypeeze	SDS 3/10/15	Methylene chloride, methanol, toluene, Stoddard solvent	Acetone
Savogran	Superstrip	SDS 3/10/15	Methylene chloride, methanol, toluene	None
WM Barr	Premium Stripper	SDS 5/1/19	Methylene chloride, methanol	Polyoxy 1,2 ethanediyl
WM Barr	Strip-X	SDS 4/16/15	Methylene chloride, methanol, toluene, xylene, ethylbenzene	Acetone, ethanol, isopropyl alcohol

There are several legacy and newly introduced non-methylene chloride coating removal products that use other Benchmark 1 solvents such as dimethylformamide (DMF), ethyl benzene, methanol, naphthalene, NMP, Stoddard solvent, toluene, and xylene. Table 4 contains a non-exhaustive list of the coating removal products that contain Benchmark 1 chemicals other than methylene chloride. These products are mostly available for do-it-yourself consumers at retail stores such as The Home Depot, Lowe's Companies Inc., and Sherwin-Williams Company. The solvents listed for these products are based on manufacturer safety data sheets or product labels.

Table 4: *Solvents Used in Coating Removal Products with Other Benchmark 1 Chemicals*

Supplier	Product	Data Source	GreenScreen Benchmark 1 Solvent(s)	Other Solvents
Dumond	Peel Away 7	SDS 3/3/15	NMP	Benzyl alcohol
Formby's	Furniture Refinisher	SDS 11/15/18	Toluene, methanol	Acetone
Minwax	Antique Furniture Refinisher	SDS 11/13/19	Toluene, methanol	Acetone
Nexeo Solutions	Startex Liquid Paint Stripper MC free	SDS 6/29/18	Toluene	Acetone, 1,3 dioxolane
Packaging Services	Crown STRP Max	SDS 9/14/18	Naphthalene	2-butoxyethanol, unidentified solvent naphtha (H351 "Suspected of Causing Cancer"), acetic acid, benzyl alcohol, proprietary solvent blend
Packaging Services	Tuff Strip MC Free	SDS 4/17/18	Stoddard solvent	Ethyl lactate, petroleum distillates, DGME, benzyl alcohol, acetic acid
Recochem	Heirloom PURE	SDS 8/15/19	Dimethylformamide (DMF)	Diethylene glycol monomethyl ether, ethanolamine, polyethylene glycol monoundecyl ether
Recochem	Heirloom Max Heavy Duty Stripper	SDS 5/8/19	Dimethylformamide (DMF)	Cyclohexanone, methyl acetate
Recochem	Heirloom PLUS Paint Stripper	SDS 5/8/19	Dimethylformamide (DMF)	Cyclohexanone, methyl acetate
Recochem	Zip Strip Paint Remover MC Free	SDS 5/8/19	Dimethylformamide (DMF)	Cyclohexanone, methyl acetate
Rust-Oleum	Watco Furniture Refinisher	SDS 5/21/18	Toluene, methanol	Acetone
Rust-Oleum	Watco Paint and Poly Remover	Product label	Toluene, methanol	Acetone, petroleum distillates, dimethyl decenamide
Savogran	Strypeeze DCM Free	SDS 6/12/18	Toluene, methanol	Acetone
Savogran	Superstrip DCM Free	SDS 6/12/18	Methanol	Dimethyl carbonate, 1,3 dioxolane

Supplier	Product	Data Source	GreenScreen Benchmark 1 Solvent(s)	Other Solvents
Sunnyside	2 Minute Remover (Original)	SDS 5/9/15	Methylene chloride, methanol, xylene	Polyoxy 1,2 ethanediyl, dipropylene glycol monomethyl ether
Sunnyside	2 Minute Remover MC Free	SDS 9/6/18	Methanol	Dimethyl carbonate, 1,3 dioxolane, acetone, hydrotreated distillates
Sunnyside	Aquastrip Safer Marine Paint and Varnish Remover	SDS 6/22/09	NMP	Dibasic esters, formic acid
Sunnyside	Multistrip	SDS 6/24/09	NMP	Formic acid
Sunnyside	Ready Strip Plus	SDS 2/25/15	NMP	Benzyl alcohol, formic acid
Swing Paints	Circa 1850 D Solver Gel no MC	Product Label	Toluene, methanol	Acetone, ethyl 3-ethoxypropionate
West Marine	Marine Paint Remover	Product label	NMP	Dibasic esters, formic acid
WM Barr	Goof Off Pro Strength Remover	SDS 10/9/15	Xylene, ethylbenzene, ,ethanol	Acetone
WM Barr	Citristrip (original)	SDS 12/15/15	NMP	Dimethyl glutruate, dimethyl adipate
WM Barr	Kwik Strip No MC	SDS 9/17/18	Xylene, ethylbenzene	DMSO, dimethyl carbonate
WM Barr	Jasco Paint and Epoxy Remover No MC	SDS 8/6/18	Xylene, ethylbenzene	DMSO, dimethyl carbonate
WM Barr	Klean Strip Premium Stripper No MC	SDS 8/27/18	Xylene, ethylbenzene	DMSO, dimethyl carbonate

Many solvents used for coating removal products have received GreenScreen Benchmark Level 2 (e.g., acetone, benzyl alcohol, dibasic esters, 1,3 dioxolane, formic acid, methyl acetate), Level 3 (e.g., DMSO) and Level 4 (e.g., water) scores. These may be considered safer solvents for use in coating removal products. Table 5 lists coating removal products that do not contain any Benchmark 1 solvents and have GreenScreens completed for all the solvent ingredients. The list of solvents is derived from manufacturer safety data sheets or product labels.

Table 5: *Coating Removal Products with NO Benchmark 1 Chemicals*

Supplier	Product	Data Source	Solvents
3M	Safest Stripper	SDS 2/25/15	Water, dibasic esters
DS Super Remover	New Generation	SDS 10/12/18	Methyl acetate, DMSO, 1,3 dioxolane
DS Super Remover	Professional Grade	Product label	Methyl acetate, 1,3 dioxolane, formic acid
Duck	Adhesive Remover	Product label	Petroleum distillates
Dumond	Smart Strip	SDS 3/3/15	Water, benzyl alcohol
Ecosafety	Ecofast	SDS 5/1/14	Benzyl alcohol, water
Fiberlock	Next Strip 5700	SDS Jan. 2017	Benzyl alcohol
Goo Gone	Pro Power Goo and Adhesive Remover	SDS 10/11/17	Petroleum distillates, d-limonene
Karnak	Karna Klean Asphalt and Tar Remover	Product label	D-limonene, 2-butoxyethanol
Motsenbocker	Lift-off Paint and Varnish Stripper	SDS 4/27/16	Acetone, 2 butoxyethanol
Packaging Services	Crown STRP Sure	SDS 9/4/18	DMSO
Sunnyside	Hi Speed Ready Strip	SDS 8/31/10	Benzyl alcohol, dibasic esters, formic acid, d-limonene
West Marine	Marine Paint Remover Citrus	Product label	Benzyl alcohol, dimethyl glutarate, formic acid, dimethyl succinate, and dimethyl adipate
WM Barr	Goof Off Adhesive Gunk Remover Gel	Product Label	Benzyl alcohol, 2-(2-butoxyethoxy) ethanol
WM Barr	Citristrip (no NMP)	SDS 8/15/18	Benzyl alcohol, 2-(2-butoxyethoxy) ethanol
WM Barr	Klean Strip Adhesive Remover no MC	SDS 12/11/18	2-(2-butoxyethoxy) ethanol, benzyl alcohol

Table 6 lists the commercially available coating removal products that do not contain Benchmark 1 chemicals, but contain one or more solvent ingredients that have not yet had GreenScreen evaluations. The solvents listed are based on manufacturer safety data sheets or product labels. The solvents without GreenScreen evaluations are underlined in the table. The relative safety of the solvents in these products as compared to other coating removal products listed in Tables 4, 5, and 6 can be more effectively determined if GreenScreen evaluations are completed for all the solvent ingredients.

Table 6: *Coating Removal Products with No Benchmark 1 Chemicals But Containing Solvents with No GreenScreen Evaluation*

Supplier	Product	Data Source	Solvents
Dumond	Peel Away 1	SDS 8/28/15	Calcium hydroxide, magnesium hydroxide, sodium hydroxide
EZ Strip	EZ Strip Paint and Varnish Stripper	SDS 9/16/14	Dibasic esters, triethyl phosphate
Franmar	Blue Bear	SDS 8/15/19	Safenol, dibasic esters, ethoxylated alcohols
Sunnyside	MultiStrip Advanced (no NMP)	SDS 9/7/18	Benzyl alcohol, dibasic esters, ethyl 3-ethoxypropionate, formic acid
TEC Skill Set	Concentrated Adhesive Remover	Product label	Water, ethanol amine, 2-butoxyethanol
WM Barr	Klean Strip Floor Adhesive Remover	Product label	Water, benzyl alcohol, alcohol ethoxylate
WM Barr	Green Paint and Varnish Safer Stripper	SDS 7/10/15	Benzyl alcohol, alcohol ethoxylate
WM Barr	Aircraft Paint Remover with no MC	SDS 5/7/19	Tetrahydrofuran, acetone, ammonia, petroleum distillates

Dermal Exposure

Skin absorption is a very important consideration for the safe use of coating removal products. Given the likelihood of dermal uptake of solvents during the coating removal process, it is critical to provide personal protection from both:

1) **Chemicals in the coating removal product.** See Table 2 for a listing of chemicals found in coating removal products.

2) **Chemicals in the coatings being stripped.** Many chemicals of potential concern are used as additives in coating materials. The solvents in the coating evaporate during the drying process, but the chemical additives remain after the coating has dried. These chemical additives may be used in coatings for functions such as biocides, pigments, drying accelerators, and corrosion resistance, and have a variety of hazards. Chemical compounds used for these functions can also contain toxic metals such as mercury, lead, and hexavalent chromium, or nanoparticles such as titanium dioxide, silver, and silicon dioxide (Smulders, 2014).

Residue generated during the coating removal process contains both coating removal product residue and coating residue. There is a possibility of dermal exposure if the user is not wearing any protective gloves, or if the gloves are made of a material that does not adequately prevent the coating removal product chemicals from penetrating through the gloves to the surface of the user's skin.

Human skin is composed of two primary layers, the outer nonvascular epidermis and the underlying dermis, as shown in Figure 2 (Encyclopaedia Britannica, 2020).

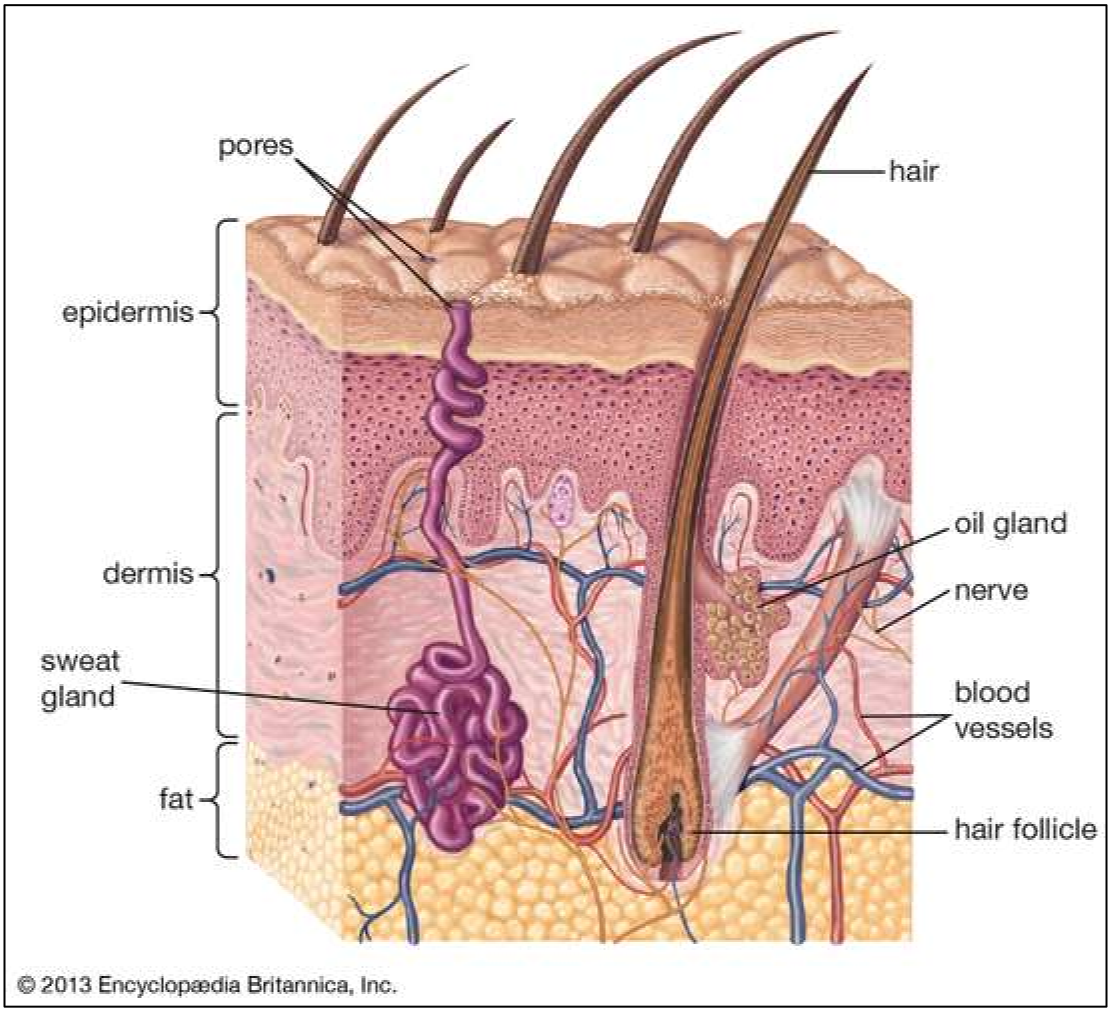

Figure 2: Human Skin Layers

The first and most important barrier to absorption of chemicals is the outermost layer of the epidermis, the stratum corneum (Ngo, 2010). Once the chemical is present on the skin, then skin absorption can occur by two distinct pathways, either via skin appendages or via passive diffusion through the epidermis. There are many categories of chemicals that have rapid skin absorption via passive diffusion through the epidermis, such as alcohols (e.g., benzyl alcohol), glycols, organosulfurs (e.g., DMSO), esters, ketones (e.g., acetone), terpenes, acids (e.g., formic acid), pyrrolidones (e.g., NMP), amines, carbonates (dimethyl carbonate) and amides (e.g., DMF). See Appendix 4 for a detailed explanation of dermal permeability.

The maximum flux (J_{max}) is the rate at which a chemical can passively diffuse across a unit area of skin. The maximum flux has units of micrograms per square centimeter per hour (ug/cm^2/h). Table 7 shows the maximum flux values for chemicals found in coating removal products. The chemicals are sorted by highest maximum flux (2-butoxyethanol with a J_{max} of 1,400) to lowest maximum flux (naphthalene with a J_{max} of 2.3). The higher the maximum flux value, the greater the skin permeation via passive diffusion across the stratum corneum for a given chemical. All chemicals listed in Table 7 have J_{max} values greater than zero, meaning that some level of dermal penetration exists for each chemical. See Appendix 4 for more details on how the maximum flux is calculated.

Table 7: *Skin Permeability Results for Solvents in Coating Removal Products*

Chemical	J_{max} (ug/cm^2/h)
2-butoxyethanol	1,400
Acetic acid	650
Acetone	600
Formic acid	430
1,3 dioxolane	390
Methanol	360
Triethyl phosphate	290
NMP	270
Methyl acetate	230
Benzyl alcohol	110
Dimethyl carbonate	110
DMSO	73
Methylene chloride	62
Dimethyl succinate	56
Diethylene glycol monomethyl ether	54
Toluene	25
Ethyl benzene	13
D-limonene	7.1
Dimethyl adipate	3.7
Naphthalene	2.3

A potential concern is that a single solvent in the coating removal product may pull other ingredients in the solvent blend or coating removal residue through the skin. Toxic lead compounds such as lead chromate, lead oxide, and lead carbonate can be found in lead paint. These lead compounds may be found in coating removal residue upon completion of a coating removal project involving lead paint. A literature review conducted for this project did not identify any scientific studies focused on the ability of solvents used in coating removal products to carry lead compounds across the skin barrier. Molar mass is a significant factor for skin permeation via passive diffusion. In general, the larger the molar mass of a substance, the more difficult it is to diffuse across the skin barrier. The molar mass for octyl acetate is 172 g/mol. The molar masses of the three most common types of lead in paint are 323 g/mol (lead chromate), 685 g/mol (lead oxide), and 775 g/mol (lead carbonate).

Another challenge for characterizing skin absorption rates is that exposures during coating removal operations are often chemical mixtures and not a single chemical. Dermal exposures to chemical mixtures can potentially increase or decrease the ability of the chemical mixture components to penetrate the skin, depending on the physicochemical interactions with the skin. As a result, assumptions based on absorption from single solvents may be inappropriate for risk assessment of chemical mixtures (Ngo, 2010).

The use of appropriate gloves protects against skin permeation and also helps to protect the user from potential skin irritation and skin sensitization. Based on the GreenScreen results, several chemicals used in coating removal products have a high hazard (e.g., d-limonene, toluene) or very high hazard (e.g., formic acid, sodium hydroxide) for skin irritation. Also, several chemicals used in coating removal products have a high hazard (e.g., benzyl alcohol, d-limonene) for skin sensitization. Given the potential for skin uptake and hazards, proper protective gloves should always be worn when applying coating removal products.

Inhalation Exposure

Inhalation exposure is directly related to the amount of solvent evaporation that occurs during the use of coating removal products. See the "Fire Hazard: Evaporation Measurements" section of this report for a detailed discussion of evaporation rates for coating removal products. The coating removal products with effective evaporation barriers generate significantly less solvent vapors during use resulting in much less inhalation exposure to the user of the coating removal products.

Additional Chemical Mixture Evaluation for New UMass Lowell Formulation

Most chemicals in a formulation are evaluated individually, but new hazards may be created when chemicals are combined in a mixture. In developing its new L03 solvent formulation, TURI was interested in evaluating the possibility of new hazards being introduced by combining multiple solvents into a solvent blend in addition to understanding the hazards of individual ingredients. To help address this question, TURI contracted with the Sinnhuber Aquatic Research Laboratory at Oregon State University to assess the vertebrate developmental hazard potential of various individual solvents and solvent mixtures.°

The Sinnhuber Aquatic Research Laboratory describes its zebrafish toxicity screening method as follows:

> These in vivo assays used the zebrafish embryo (D.rerio) as a biological sensor to evaluate a comprehensive battery of developmental endpoints for chemical hazard via multiple mechanisms of action. The developmental zebrafish assays are conducted in physiologically intact organisms, and the embryos develop in a short window in which there is a high probability of detecting adverse outcomes such as developmental delays, morphological abnormalities and behavioral alterations. Zebrafish is a highly prolific, small, complex organism that shares a highly-conserved anatomy and physiology with all vertebrates (ATSDR, 2000). Importantly, the critical processes of zebrafish neurodevelopment are homologous to those in humans.
>
> Early in zebrafish embryogenesis (roughly 19-29 hours post-fertilization, hpf), spontaneous tail flexions occur as the muscles in this region are innervated. This spontaneous behavior at 22 hpf is sensitive to light perturbation via photoreceptors in the developing hindbrain and has been designated the embryo photomotor response (EPR). The EPR

> is an early, fast and sensitive assay to detect chemical perturbation of development. While the EPR readout is behavioral, later stage developmental defects predicted by an abnormal EPR are not restricted to behavioral outcomes but often include morphological deficits as well. Neuronal effects of developmental chemical exposure on larval photomotor response (LPR) activity and behavior following an acoustic startle (LSR) can be easily measured in zebrafish, widening the potential field of bioactivity that we can detect. We have found that developmental mortality and morphology endpoints, combined with the embryo and larval photomotor responses and startle response, serves as a robust biological sensor for chemical hazard potential. (OSU, 2018)

Zebrafish toxicity screening tests were conducted for each of the individual solvents (methyl acetate, DMSO, and 1,3 dioxolane) as well as for the chemical mixture (methyl acetate/DMSO/1,3 dioxolane in the same proportions contained in Formulation LO3). The tests determined that the individual solvents and the LO3 formulation were developmentally benign at the concentrations (0.001 to 80 microM) and test conditions used. Therefore, for the hazard endpoints included in the test, the methyl acetate/DMSO/1,3 dioxolane mixture did not introduce additional toxicity relative to the individual solvents. Methylene chloride was also tested and did not receive a benign rating because it was associated with consistent hyperactivity for EPR and LPR. The full Sinnhuber Aquatic Research Laboratory report is available on the TURI website.

Due to limited funds, the zebrafish toxicity testing was not conducted for any other commercially available coating removal formulations.

Requirement 2: Fire Hazard

Coating removal products are mainly composed of liquid solvents. Under the Federal Hazardous Substances Act label requirements, the Consumer Product Safety Commission classifies a liquid with a flash point less than 20 °F as "Extremely Flammable"; greater than 20 °F and less than 100 °F as "Flammable"; and 100 °F to 150 °F as "Combustible." Flash point is further described in Appendix 5.

TURI contracted with Worcester Polytechnic Institute's Department of Fire Protection Engineering to conduct a fire hazard evaluation for coating removal products. The information provided for the remainder of this section was extracted and summarized from the fire hazard report prepared by Worcester Polytechnic Institute (Ranellone, 2018). The full report is available on the TURI website.

Since it is the vapor of the liquid, not the liquid itself, that burns, vapor generation becomes the primary factor in determining the fire hazard (OSHA, 2016). Three components must be present for a fire to occur: 1) a fuel source (e.g., solvent vapors); 2) oxygen (which may be from the ambient air or another source); and 3) a source of ignition. When the vapor of a flammable liquid solvent is mixed with air in certain concentrations, and in the presence of a source of ignition, a rapid combustion can occur. The specific vapor/air concentration which can support combustion is called the "flammable range." In the flammable range, a flash will occur or a flame will spread if the air/fuel mixture is ignited. The limits of the flammable range are called the Lower Flammability Limit (LFL) and Upper Flammability Limit (UFL). The LFL is the lowest concentration of vapor in air at which the vapor/air mixture will burn, and the UFL is the highest concentration of vapor in air at which the vapor/air mixture will burn. LFL/UFL are usually expressed in terms of percentage by volume of vapor in air. Below the LFL the mixture is "too lean" to burn, and above the UFL the mixture is "too rich" to burn (ACC, 2011).

The use of flammable products can create a significant fire hazard for the users of the product who are unaware that they have exceeded the LFL in the surrounding area where the product has been used. The following is a list of different types of ignition sources that can cause a combustion event if the LFL is exceeded (ACC, 2011):

- Flames: open flames such as welding torches, matches, and gas burners
- Smoldering: materials such as cigarettes
- Hot surfaces: ovens, furnaces, electrical equipment, heating pipes, etc.
- Friction and impact: hot spots and incandescent sparks which arise from friction
- Electric discharges: electrical power and electrostatic discharge

Evaporation barriers are chemical additives that are often included in coating removal formulations to block solvent evaporation and slow down the drying process. This enables the coating removal product to stay wet on the surface of the coatings to be stripped. Coating removal products lose their effectiveness when they dry out. The use of evaporation barriers also mitigates fire hazard by blocking the generation of solvent vapors which are needed to exceed the LFL and start a fire.

Evaporation barriers are usually wax-based additives, such as paraffin. When the coating removal product is brushed onto a surface, it usually takes between one and two minutes for the wax barrier to fully set up. Once the evaporation barrier is set up, it can block almost all of the vapors that would otherwise be generated if there was no evaporation barrier in place.

Evaporation Measurement

Coating removal products work best when they remain in liquid form, so most products have evaporation barrier additives that greatly diminish the evaporation rate of the solvents to keep the product in a liquid form during use. However, some coating removal products do not contain any evaporation barrier. Other types of flammable products typically do not have evaporation retardant additives since they are designed to release the solvents as fast as possible so that they can be "fast-drying." These "fast-drying," flammable products include contact adhesives, primers, brush cleaners, various aerosols, spray paint, lacquer thinner, and many other product categories. In general, these "fast-drying" products can pose a significant fire hazard since the solvent vapors are rapidly entering the surrounding environment.

Evaporation testing of coating removal products was conducted in the TURI laboratory. Each coating removal product was poured into a glass petri dish and spread to cover the entire surface of the petri dish with a paint brush. The petri dish was placed on a scale, and the weight was measured at 1, 2, 3, 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60 minutes.

In order to evaluate the effectiveness of evaporation barriers, three coating removal products that include an evaporation barrier (two with methylene chloride and one without methylene chloride) were compared to similar solvent mixtures without the barrier that were prepared in the lab. The Strypeeze product sold commercially comprises a blend of five solvents as well as chemical additives, including an evaporation barrier. Table 8 provides the concentration ranges for the five solvents listed in the safety data sheet (dated March 10, 2015), as well as the concentration levels used in the lab-prepared solvent mixture without an evaporation barrier.

Table 8: *Strypeeze Solvents*

Solvent	CAS #	Concentration Range in SDS Version 3/10/15 (% Wt)	Concentration Used in Test Sample Without Additives (% Wt)
Methylene chloride	75-09-2	25 – 30%	29%
Methanol	67-56-1	25 – 30%	29%
Toluene	108-88-3	15 - 20%	19%
Acetone	67-64-1	15 - 20%	19%
Stoddard solvent	8052-41-3	0 - 5%	4%

For the Strypeeze commercial product, the initial weight of the coating removal product with an evaporation barrier was 5.91 g and the weight at the end of the 60-minute evaporation test was 5.81 g, resulting in an evaporation loss of 1.7%. The initial weight of the similar solvent blend created in the lab without an evaporation barrier was 5.77 g and the weight at the end of the 60-minute evaporation test was 0.34 g, resulting in an evaporation loss of 94.1%. Therefore, the presence of an evaporation barrier in the commercial product significantly reduces the amount of solvent evaporation by a factor of 55 after a one-hour duration (94.1% / 1.7% = 55).

Figure 3 shows the evaporation loss at 5-minute intervals throughout the duration of the 60-minute evaporation test.

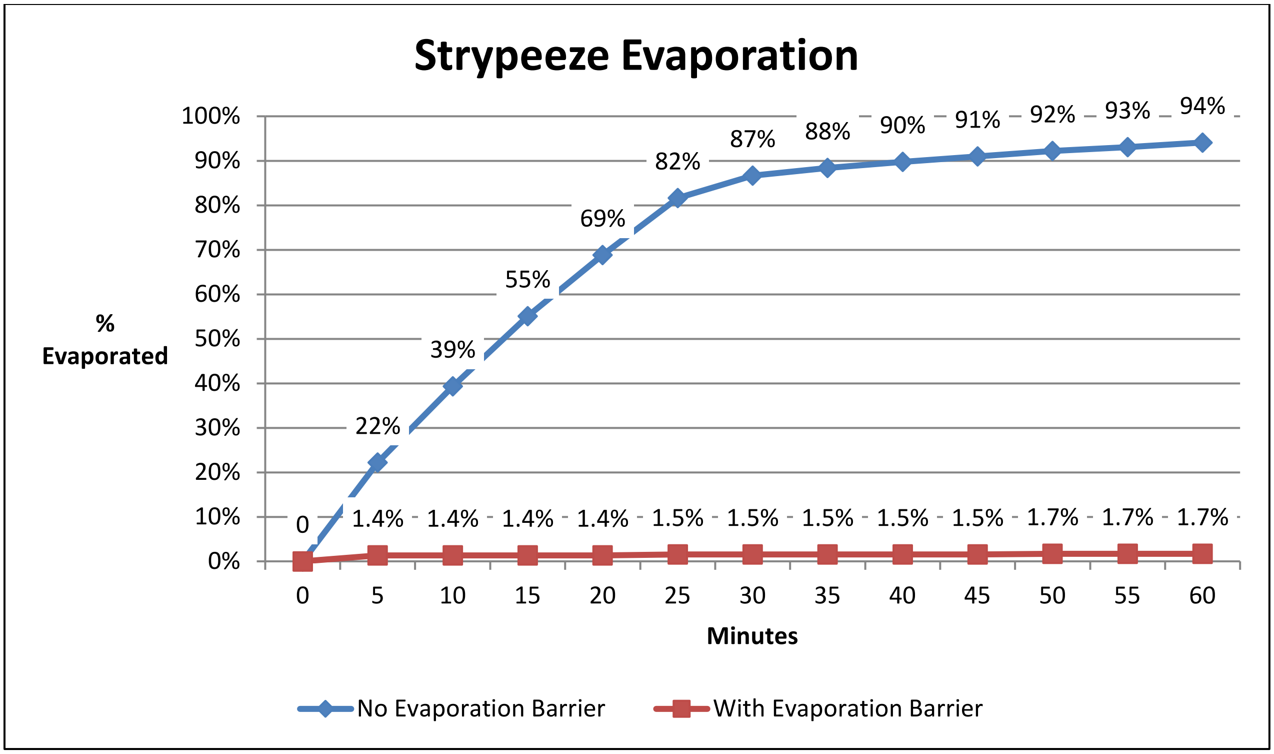

Figure 3: Evaporation Test Results for Strypeeze and Similar Solvent Blend Without Evaporation Barrier

An additional evaporation test was done using a second commercial product, WM Barr Strip X, which comprises a blend of eight solvents (methylene chloride, methanol, acetone, xylene, toluene, ethyl benzene, ethanol, and isopropyl alcohol) as well as chemical additives including an evaporation barrier. To provide another direct comparison for a coating removal product with and without an evaporation barrier additive, the TURI lab created a test sample for a similar coating removal product based on the same eight solvents. The test sample was created using concentration values for each solvent within the concentration ranges listed in the Strip X safety data sheet dated April 16, 2015.

For the Strip X product, the initial weight of the coating removal product with an evaporation barrier was 6.47 g and the weight at the end of the 60-minute evaporation test was 6.44 g, resulting in an evaporation loss of 0.03 g (0.5%).The initial weight of the similar solvent blend made in the lab without an evaporation barrier was 6.55 g and the weight at the end of the 60-minute evaporation test was 0.49 g,resulting in an evaporation loss of 6.06 g (92.5%).Therefore, the presence of an evaporation barrier in this product significantly reduces the amount of solvent generation by a factor of 185 after a one-hour duration (92.5% / 0.5% = 185).

Most of the solvent evaporation occurs during the first minute, while the evaporation barrier is still being established. The evaporation barrier in the Strip X product took one minute to be established after it was brushed on to the petri dish. The weight of the Strip X product at one minute was 6.45 g; at 60 minutes, it was 6.44 g. Only 0.1 g of solvent evaporated after the evaporation barrier was established. Therefore, after the evaporation barrier was established at one minute, then 99.85% of the solvents were blocked from evaporation for the remainder of the test (100% – [0.1 g / 6.45 g] = 99.8%).

Figure 4 shows the evaporation loss at 5-minute intervals throughout the duration of the 60-minute evaporation test.

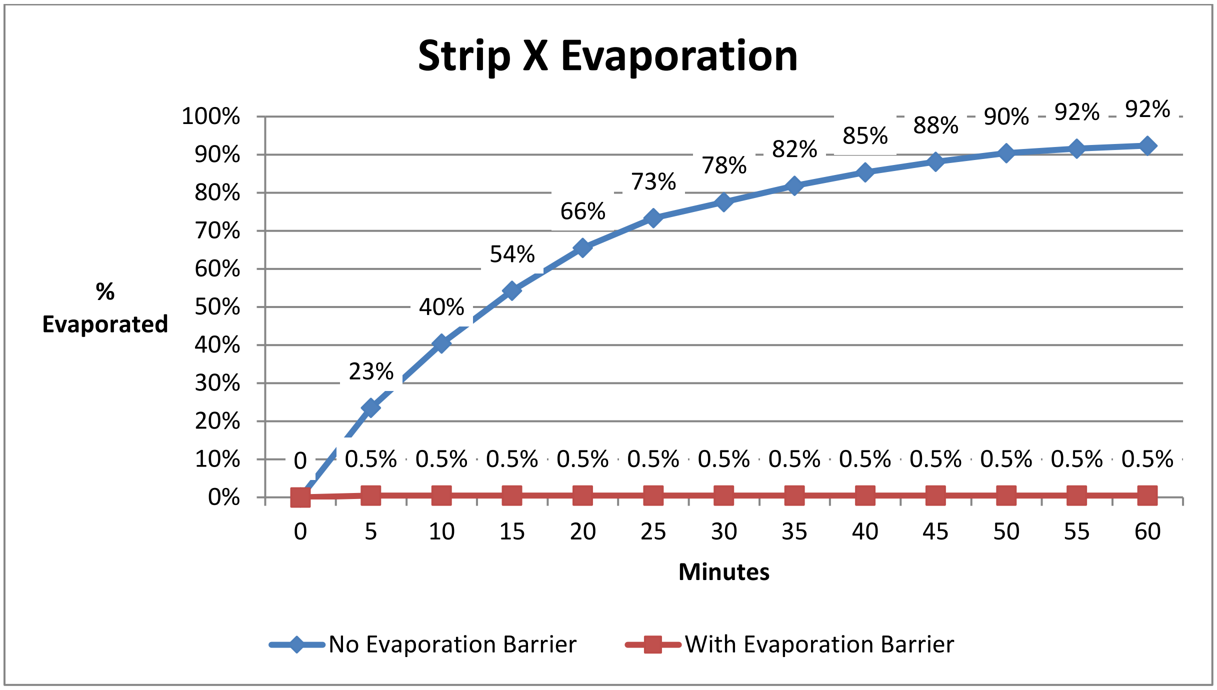

Figure 4: Evaporation Test Results for Strip X and Similar Solvent Blend Without Evaporation Barrier

Evaporation testing was also conducted for the UMass Lowell Formulation LO3 with and without an evaporation barrier. The initial weight of the product with an evaporation barrier was 6.40 g and the weight at the end of the 60-minute evaporation test was 6.34 g, resulting in an evaporation loss of 0.06 g (0.9%). The initial weight of the similar solvent blend made in the lab without an evaporation barrier was 6.44 g and the weight at the end of the 60-minute evaporation test was 1.65 g, resulting in an evaporation loss of 4.79 g (74.4%). Therefore, the presence of an evaporation barrier in this product significantly reduces the amount of solvent generation by a factor of 83 after a one-hour duration (74.4% / 0.9% = 83). The results are shown in Figure 5.

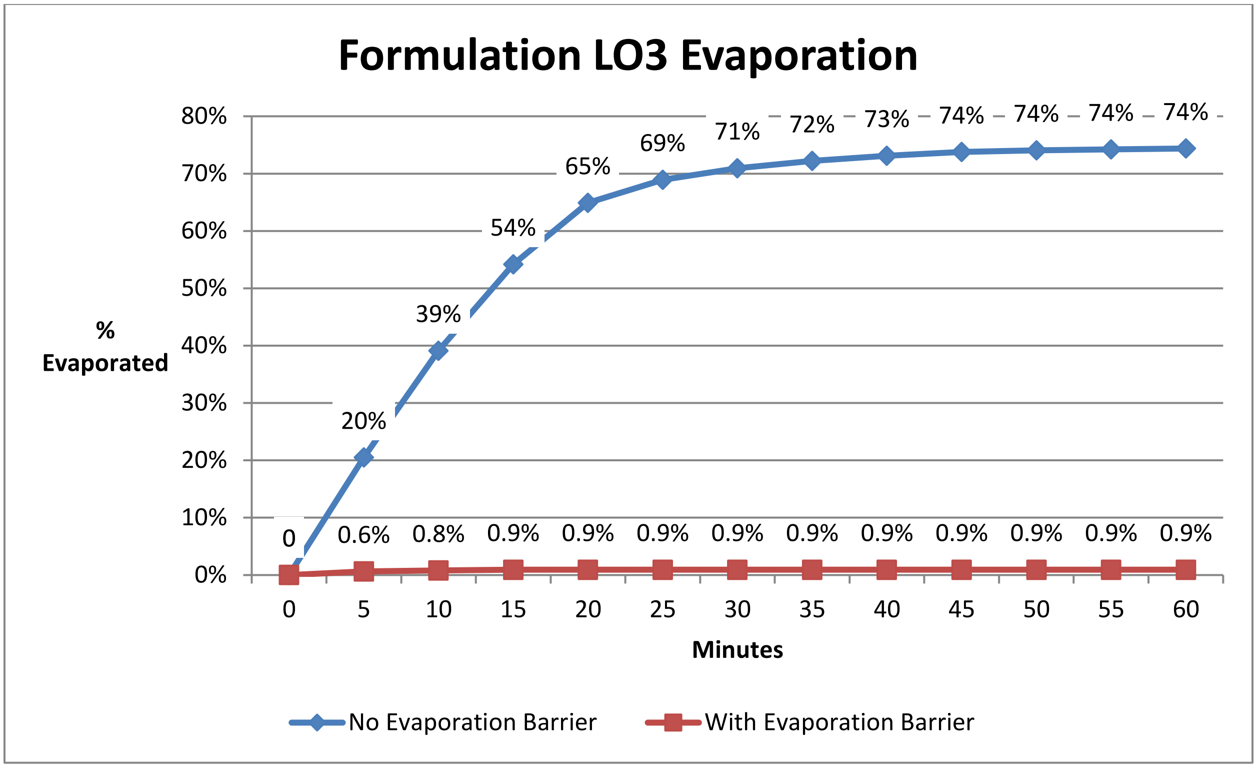

Figure 5: Evaporation Test Results for Formulation LO3 and Similar Solvent Blend Without Evaporation Barrier

For the Strypeeze and Strip X products without evaporation barriers, the amount of solvent evaporated was greater than 90%, since the solvents in the blend all have high evaporation rates. For Formulation LO3, the amount of solvent evaporated was only 74% because the formulation contains DMSO, which has a low evaporation rate, and a one-hour duration is not long enough for most of the DMSO to evaporate.

Evaporation tests for a one-hour duration were conducted for 14 different coating removal products; five products contained evaporation barriers and nine products did not contain evaporation barriers. The evaporation test results for the various coating removal products are shown in Table 9. The products are sorted by percentage solvent evaporated.

Table 9: *Evaporation Test Results*

Supplier	Product	Evaporation Barrier	Percentage Solvent Evaporated
Rust-Oleum	Watco Furniture Refinisher	No	99.8%
Formby's	Furniture Refinisher	No	97.6%
Minwax	Antique Furniture Refinisher	No	97.5%
UMass Lowell	Solvent blend similar to Savogran Strypeeze with MC	No	94.1%
UMass Lowell	Solvent blend similar to WM Barr Strip X	No	92.5%
Sunnyside	2 Minute Remover without MC	No	92.0%
W.M. Barr	Goof Off Pro Strength Remover	No	87.0%
Savogran	SuperStrip without MC	No	74.9%
UMass Lowell	Formulation LO3 with no evaporation barrier	No	74.4%
W.M.Barr	Aircraft Remover without MC	Yes	1.9%
Savogran	Strypeeze with MC	Yes	1.7%
UMass Lowell	Formulation LO3 with an evaporation barrier	Yes	0.9%
W.M. Barr	Strip X	Yes	0.5%
W.M. Barr	Kwik Strip	Yes	0.3%

For the five products containing evaporation barriers, the average percent solvent evaporated after 60 minutes was approximately 1%. For the nine products without evaporation barriers, the average percent solvent evaporated after 60 minutes was approximately 90%.

Fire Hazard Test

The fire hazard test was designed to answer the following question: "Does the use of evaporation barrier additives within a flammable solvent based product reduce the risk of exceeding the Lower Flammable Limit (LFL) in the surrounding area that the product is used?"

The tests were conducted by Worcester Polytechnic Institute to determine if the LFL for the solvent vapors was exceeded within an enclosed space. The intent was to create a challenging test environment to evaluate the fire hazard of various coating removal products. The tests were conducted within a glove box to simulate a small confined working space. The glove box was completely enclosed, and all seams were sealed with silicone to prevent air entering or leaving the glove box during testing. If a combustion event occurs, then it is assumed that the LFL of the solvent vapor has been exceeded. This is assumed since there would need to be sufficient fuel and oxygen present to allow for ignition of the solvent vapor.

The coating removal products were applied to a tray surface inside the glove box and remained on the surface for specified dwell times. A flame was used as the ignition source. The flame was ignited throughout the test cycles at two different heights above the tray surface. The purpose of introducing a flame at these two locations was to determine if there were sufficient solvent vapors within the glove box to exceed the LFL and support a combustion event away from the test surface. The details of the test method are provided in Appendix 5.

The coating removal products tested with an evaporation barrier did not exceed the LFL within the glove box and did not cause a combustion event during the entire test. All coating removal products tested without evaporation barriers caused a combustion event at the 15-minute time frame during the first dwell period. Figure 6 shows a combustion event inside the glove box.

Figure 6: Combustion Event Inside the Glove Box

The Strypeeze coating removal product with an evaporation barrier did not cause a combustion event, and the coating removal product made in the TURI lab with similar solvents to Strypeeze without an evaporation barrier had a combustion event at 15 minutes. The LO3 formulation with an evaporation barrier did not cause a combustion event, and the LO3 formulation without an evaporation barrier had a combustion event at 15 minutes. The Minwax Antique Furniture Refinisher product does not have an evaporation barrier and had a combustion event at 15 minutes. Due to limited funding, additional coating removal products were not included in the fire hazard test.

Based on the results of the evaporation testing and the fire hazard testing, it appears that the presence of the evaporation barrier within the coating removal products tested accomplishes the following:

- Significantly inhibits the generation of solvent vapors from evaporation during the application, dwell, and extraction of the coating removal products

- Prevents the exceeding of the LFL at a distance of 6" or greater from the surface of the coating removal product application within a confined work space with no forced ventilation

- Greatly reduces the risk of a combustion event caused by exceeding the LFL in the area surrounding the use of the tested coating removal products

Therefore, manufacturers of coating removal products can mitigate the fire hazard of their coating removal products with one of the following approaches: a) a flash point greater than 100 F, or b) an effective evaporation barrier to block solvent evaporation.

A summary of commercially available coating removal products and their fire hazard mitigation approach is provided in Table 10. For the coating removal products shown with a flash point greater than 100 °F, this was determined by the flash point value listed on the product safety data sheet. For the coating removal products shown with an evaporation barrier, this was determined either through evaporation testing in the TURI Laboratory or because the product safety data sheet listed wax as a chemical additive. For the coating removal products shown as having a flash point below 20 °F or 100 °F and no evaporation barrier, evaporation testing was conducted at the TURI Laboratory to validate that no evaporation barrier was present. Note that some of these products are marketed for specialty applications, such as use with a soaked steel wool pad that is rubbed on the coating surface until the coating is dissolved.

Table 10: *Fire Hazard Mitigation Method for Coating Removal Products*

Supplier	Product	Product Category	Fire Hazard Mitigation Method
3M	Safest Stripper	No Benchmark 1	Flash point above 100 °F
DS Super Remover	New Generation	No Benchmark 1	Evaporation barrier
DS Super Remover	Professional Grade	No Benchmark 1	Evaporation barrier
Dumond	Smart Strip	No Benchmark 1	Flash point above 100 °F
Ecosafety	Ecofast	No Benchmark 1	Flash point above 100 °F
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	Flash point above 100 °F
Fiberlock	Next Strip Pro	No Benchmark 1	Flash point above 100 °F
Formby's	Furniture Refinisher	Other Benchmark 1	Neither - Flash point below 20 °F without evaporation barrier
Franmar	Blue Bear with Safenol	No Benchmark 1	Flash point above 100 °F
Inseco	NPS Rx	No Benchmark 1	Flash point above 100 °F
Minwax	Antique Furniture Refinisher	Other Benchmark 1	Neither - Flash point below 20 °F without evaporation barrier
Packaging Services	Crown STRP Max Paint Strip. Gel	Other Benchmark 1	Flash point above 100 °F
Packaging Services	Crown Tuff Strip MC Free	Other Benchmark 1	Flash point above 100 °F

Supplier	Product	Product Category	Fire Hazard Mitigation Method
Packaging Services	Crown STRP Sure	No Benchmark 1	Flash point above 100 °F
Recochem	Heirloom Pure	Other Benchmark 1	Flash point above 100 °F
Rust-Oleum	Watco Furniture Refinisher	Other Benchmark 1	Neither - Flash point below 20 °F without Evaporation Barrier
Savogran	Strypeeze with MC	Methylene chloride	Evaporation barrier
Savogran	Strypeeze DCM Free	Other Benchmark 1	Evaporation barrier
Savogran	SuperStrip DCM Free	Other Benchmark 1	Neither - Flash point below 100 °F without Evaporation Barrier
Sunnyside	Hi Speed Ready Strip	No Benchmark 1	Flash point above 100 °F
Sunnyside	2 Minute Remover MC free	Other Benchmark 1	Neither - Flash point below 20 °F without evaporation barrier
Sunnyside	Aquastrip	Other Benchmark 1	Flash point above 100 °F
UMass Lowell	Formulation NF	No Benchmark 1	Flash point above 100 °F
West Marine	Marine Paint Remover – Citrus Paint & Varnish Remover	No Benchmark 1	Flash point above 100 °F
West Marine	Marine Paint Remover (with NMP)	Other Benchmark 1	Flash point above 100 °F
WM Barr	KleanStrip Strip X with MC	Methylene chloride	Evaporation barrier
WM Barr	Aircraft Remover Non MC	No Benchmark 1	Evaporation barrier
WM Barr	Kwik Strip Non MC	Other Benchmark 1	Evaporation barrier
WM Barr	Goof Off Pro Strength Remover	Other Benchmark 1	Neither - Flash point below 20 °F without evaporation barrier
WM Barr	Citristrip (with NMP)	Other Benchmark 1	Flash point above 100 °F
WM Barr	Citristrip (no NMP)	No Benchmark 1	Flash point above 100 °F
WM Barr	Green Paint & Varnish Stripper	No Benchmark 1	Flash point above 100 °F

Requirement 3: Volatile Organic Compounds (VOC) Content

The paint stripper products should have VOC content less than 50% by weight and general purpose adhesive removers should have VOC content less than 20% by weight so that they can meet the VOC requirements for various U.S. states. To achieve this requirement, the paint stripping products should contain 50% or greater of VOC-exempt solvents such as methyl acetate, dimethyl carbonate, acetone, and water, and general purpose adhesive removers should have greater than 80% VOC-exempt solvents. Most paint stripper and adhesive remover safety data sheets provide VOC content for the entire product, and percentage composition ranges for each of the chemicals in the product. The VOC content for some paint strippers and adhesive removal products is provided in Table 11. Some product Safety Data Sheets do not list VOC-exempt solvents or VOC content. These products are either not

VOC-compliant or possibly contain water or other VOC-exempt solvents that are not required to be listed on a Safety Data Sheet.

Table 11: *VOC-Exempt Solvents*

Supplier	Product	Product Type	Safety Data Sheet Date	VOC Content	VOC-Exempt Solvent(s)	Composition
DS Super Remover	New Generation	Paint stripper	10/12/18	42.4% 433 g/L	Methyl acetate	45% - 70%
Dumond	Smart Strip	Paint Stripper	3/3/15	0%	Water	40% – 60%
Goo Gone	Pro Power Goo and Adhesive Remover	Adhesive Remover	10/11/17	Not listed	No VOC-exempt solvents listed	No VOC-exempt solvents listed
Savogran	Strypeeze no MC	Paint stripper	6/12/18	50% 405 g/L	Acetone	20% – 25%
Savogran	Superstrip no MC	Paint stripper	6/12/18	50% 497 g/L	Dimethyl carbonate	45% - 50%
Sunnyside	Aquastrip	Paint stripper	6/22/09	Not listed	No VOC-exempt solvents listed	No VOC-exempt solvents listed
WM Barr	Goof Off Pro Strength Remover	Adhesive Remover	10/9/15	20% 161 g/L	Acetone	60% - 100%
WM Barr	Kwik Strip	Paint stripper	9/17/18	48.87%	Dimethyl carbonate	30% - 60%
WM Barr	Strip-X	Paint stripper	4/16/15	25.14%	Methylene chloride, acetone	30% - 40% < 10%

Requirement 4: Cost

Retail price is a key factor for market acceptance of coating removal products. The final retail price for coating removal products is a function of solvent costs, additive costs, container costs, manufacturing costs, raw material (solvent and additives) transportation costs, final product transportation costs, manufacturer markup costs, distributor markup costs (if applicable), and retailer markup costs.

The alternative solvent blends considered for the new UMass Lowell formulation were selected in part for their low raw material cost. To have commercial potential, the cost of the alternative solvent blends must be cost comparable to commercially available coating removal formulations. The target cost level for alternatives was to have raw material cost less than approximately $0.90 per pound. Therefore, many solvents were screened out from further consideration due to raw material costs significantly above the target cost level.

It is difficult to obtain exact pricing for solvents because of factors such as the quantity of chemicals ordered (e.g., bulk orders of a large tank rather than just a 55-gallon drum), different prices from different chemical suppliers, geographic location of the production facility, domestic or international source of chemicals, and the ongoing price fluctuations of any given solvent.

Product Cost Comparison

Retail pricing information was gathered for quart-size commercially-available coating removal products to provide a rough comparison. Based on this limited review, retail pricing varied from $8.97 to $27.99. Retail pricing also varied for the same product; for example, EZ Strip Paint and Varnish Stripper was sold in-store by Home Depot for $9.97 per quart, but the same product was sold online by Walmart for $15.32 per quart. Table 12 provides retail online and store pricing for various coating removal products during the 6-month time period from September 2018 through February 2019. This time frame was chosen because it covers the transition period for many retailers that voluntarily discontinued sales of products containing methylene chloride and NMP.

Table 12: *Retail Pricing for Coating Removal Products*

Supplier	Product	Product Category	Price for Quart ($ USD) and Retailer	Pricing Source
3M	Safest Stripper	No Benchmark 1	$13.79 Do it Best	Online pricing Jan 2019
3M	Safest Stripper	No Benchmark 1	$14.02 Walmart	Online pricing Jan 2019
DS Super Remover	New Generation	No Benchmark 1	$15.19 Canadian Tire	Online pricing Jan 2019
Dumond	Smart Strip	No Benchmark 1	$21.39 Sherwin Williams	Online pricing Jan 2019
Dumond	Smart Strip	No Benchmark 1	$15.28 Amazon	Online pricing Jan 2019
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	$15.32 Walmart	Online pricing Jan 2019
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	$11.97 Amazon	Online pricing Jan 2019
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	$9.97 Home Depot	Store pricing Dec 2018
Formby's	Furniture Refinisher	Other Benchmark 1	$16.99 Do it Best	Online pricing Jan 2019
Inseco	NPS Rx	No Benchmark 1	$15.97 Home Depot	Online pricing Jan 2019
Minwax	Antique Furniture Refinisher	Other Benchmark 1	$17.81 Walmart	Online pricing Jan 2019
Motsenbocker	Lift-off	No Benchmark 1	$14.99 Ace Hardware	Online pricing Jan 2019
Packaging Services	Crown STRP Sure	No Benchmark 1	$13.98 Lowe's	Online pricing Jan 2019

Supplier	Product	Product Category	Price for Quart ($ USD) and Retailer	Pricing Source
Packaging Services	Crown STRP Max Paint Strip.	Other Benchmark 1	$17.98 Lowe's	Online pricing Jan 2019
Recochem	Zip Strip Premium Paint & Finish Remover with MC	Methylene Chloride	$13.99 Aubuchon	Store pricing Nov 2018
Recochem	Zip Strip Premium Paint & Finish Remover with MC	Methylene Chloride	$12.99 Do it Best	Store pricing Sep 2018
Recochem	Zip Strip Contractors Plus Paint & Finish Remover with MC	Methylene Chloride	$13.79 Do it Best	Store pricing Sep 2018
Rust-Oleum	Auto Stripper with MC	Methylene Chloride	$13.99 Autozone	Store pricing Dec 2018
Rust-Oleum	Watco Furniture Refinisher	Other Benchmark 1	$18.98 Home Depot	Online pricing Jan 2019
Rust-Oleum	Aircraft Remover with MC	Methylene Chloride	$15.79 Walmart	Online pricing Jan 2019
Saman	Ultimate Stripper	No Benchmark 1	$14.40 Lowe's/Rona	Store pricing Jan 2019
Savogran	Strypeeze DCM Free	Other Benchmark 1	$13.47 Home Depot	Online pricing Jan 2019
Savogran	Strypeeze with MC	Methylene Chloride	$18.93 Walmart	Online pricing Feb 2019
Savogran	Strypeeze with MC	Methylene Chloride	$14.15 Amazon	Online pricing Jan 2019
Savogran	Sterling 5F5 with MC	Methylene Chloride	$15.59 Walmart	Online pricing Jan 2019
Savogran	Strypeeze with MC	Methylene Chloride	$12.99 Aubuchon	Store pricing Nov 2018
Savogran	Kutzit with MC	Methylene Chloride	$12.99 Aubuchon	Store pricing Nov 2018
Savogran	Kutzit DCM Free	Other Benchmark 1	$12.62 Home Depot	Online pricing Jan 2019
Savogran	Superstrip DCM Free	Other Benchmark 1	$15.87 Home Depot	Online pricing Jan 2019
Savogran	Superstrip with MC	Methylene Chloride	$12.99 Do it Best	Store pricing Sep 2018
Sunnyside	Aquastrip	Other Benchmark 1	$27.99 West Marine	Store pricing Mar 2019
Sunnyside	Multi Strip	Other Benchmark 1	$14.97 Home Depot	Store pricing Dec 2018
Sunnyside	Multi Strip	Other Benchmark 1	$14.97 Amazon	Online pricing Jan 2019

Supplier	Product	Product Category	Price for Quart ($ USD) and Retailer	Pricing Source
Sunnyside	Hi Speed Ready Strip	No Benchmark 1	$10.99 Do it Best	Online pricing Jan 2019
Sunnyside	Ready Strip Plus	Other Benchmark 1	$13.49 Do it Best	Store pricing Sep 2018
WM Barr	Citristrip (no NMP)	No Benchmark 1	$12.48 Home Depot	Online pricing Jan 2019
WM Barr	Citristrip (no NMP)	No Benchmark 1	$11.98 Lowe's	Store pricing Nov 2018
WM Barr	Citristrip (no NMP)	No Benchmark 1	$10.72 Walmart	Store pricing Dec 2018
WM Barr	Green Paint & Varnish Stripper	No Benchmark 1	$9.99 Walmart	Online pricing Jan 2019
WM Barr	Jasco Premium with MC	Methylene Chloride	$12.28 Walmart	Online pricing Jan 2019
WM Barr	Premium Stripper with MC	Methylene Chloride	$9.98 Home Depot	Store pricing Dec 2018
WM Barr	Premium Stripper with MC	Methylene Chloride	$8.97 Walmart	Store pricing Dec 2018
WM Barr	Jasco Premium with MC	Methylene Chloride	$10.24 Home Depot	Store pricing Dec 2018
WM Barr	Kwik Strip Non MC Formula	Other Benchmark 1	$14.98 Lowe's	Store pricing Dec 2018
WM Barr	Kwik Strip Non MC Formula	Other Benchmark 1	$11.97 Home Depot	Store pricing Dec 2018
WM Barr	Kwik Strip Non MC Formula	Other Benchmark 1	$14.98 Lowe's	Online pricing Jan 2019

The coating removal product retail price ranges are shown in Figure 7 for the following three product categories.

1. Methylene-chloride-based products: The price range was $8.97 (Klean Strip Premium) to $18.93 (Strypeeze)
2. Products with other Benchmark 1 chemicals: The price range was $13.47 (Strypeeze DCM free) to $27.99 (Aquastrip)
3. Products with no Benchmark 1 chemicals: The price range was $9.97 (EZ Strip) to $21.39 (Smart Strip)

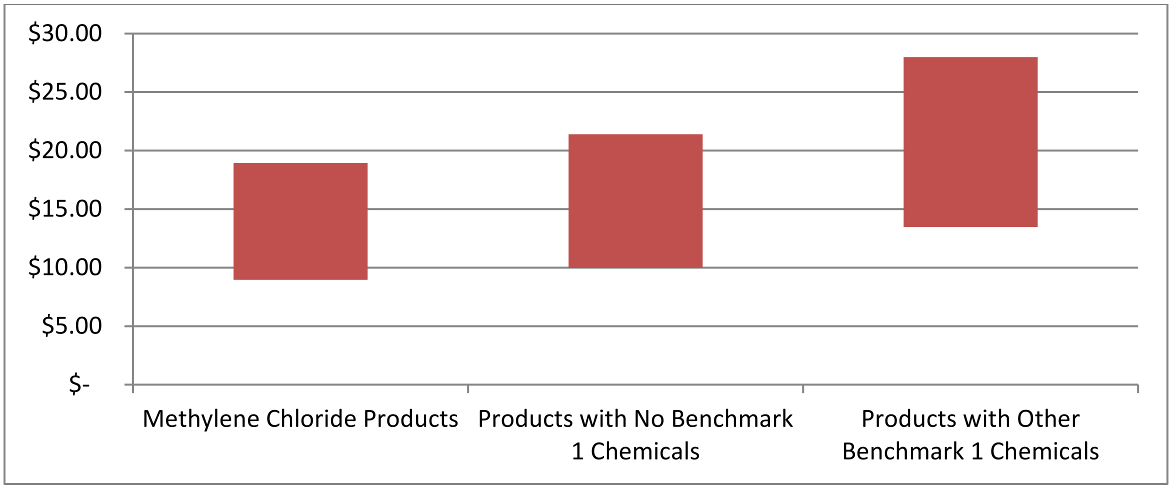

Figure 7: Retail Pricing for Coating Removal Products

There was considerable overlap in pricing for these three product categories. However, it is important to note that this was not a comprehensive price study, and there are possibly coating removal products with retail pricing outside of these ranges, sold during the period from September 2018 through February 2019.

Requirement 5: Technical Performance for a Range of Coatings and Substrates

The performance testing of the coating removal products was conducted at the TURI Laboratory. One of the testing goals for the development of safer alternatives was that the coating removal performance be comparable to methylene chloride-based products for a wide range of coatings, substrate materials, and applications. Performance testing was completed for the following types of coatings:

- Coatings on wood test panels
- Coatings on masonry blocks
- Automotive coatings
- Boat coating
- Chemical agent resistant coatings (CARC)
- Adhesive coatings
- Bathtub coatings
- Asphalt/tar coatings
- Latex splatter coatings
- Furniture refinishing

Methylene-chloride-based coating removal products are considered fast acting since they remove many types of multilayer coatings in 30 minutes or less. There are many commercially available stripping products that are slow acting and require several hours to remove most types of multilayer coatings. There is a consumer market available for both fast-acting and slow-acting coating removal products, since they both ultimately remove the coatings from the substrate material. For some coating removal applications, the time to remove the paint coatings is the primary consideration, and therefore fast-acting coating removal products are preferred. For others, a quick time to remove the paint coatings is not required; it may be acceptable to leave the coating removal product on the substrate for several hours or even overnight until the stripping job is complete. In these situations, the consumer's primary needs may be odor, viscosity, cleanup method, or other factors, and slow-acting coating removal products are acceptable.

When TURI commenced its safer coating removal project in 2015, there were no commercially available fast-acting coating removal products without Benchmark 1 chemical ingredients. Therefore, TURI focused its research effort on developing a fast-acting coating removal product without any Benchmark 1 chemical ingredients. The protocol described below was used for research into new solvent blends and also for performance testing of a variety of commercially available removers, including those containing methylene chloride and NMP, as well as safer formulations.

The ASTM International Standard D6189, "Standard Practice for Evaluating the Efficiency of Chemical Removers for Organic Coatings," was used as a starting point for creating test panels for the project. The scope of the ASTM D6189 standard is the evaluation of the effectiveness of coatings removers used on clear or pigmented coatings as applied to wood and metal. For the creation of test panels, the standard requires that three layers of coating be applied to the substrate.

To create a more challenging and realistic coating removal performance test, the test panels created for most coating applications had the following four additional requirements that were not specified in ASTM International Standard D6189 (ASTM, 2014):

1) the inclusion of a primer layer
2) a minimum of four layers of coatings instead of only three layers
3) extended thermal aging for three weeks in an oven set at 140 °F to simulate approximately 11 months of aging
4) sanding and cleaning between each coating layer to better promote adhesion between the coating layers

Once the various test panels were completed, rubber gaskets were glued onto the aged test panels to designate the testing areas. The rubber gaskets enabled the thickened and un-thickened coating removal solvent blends to remain in one area on the test panel without flowing to other areas of the test panel surface. The rubber gaskets used for the test panels had an inside diameter between 1-1/8 and 1-1/4 inches and height between 1/8 and 3/16 inches.

Test Procedure

For each test, the coating removal product was placed into the test area by pouring, scooping, or applying via pipet, depending upon the product viscosity. The test area was covered with coating removal product at a thickness equivalent to the height of the rubber gasket. After the paint stripper product remained in the test area for a pre-determined dwell time, the coating removal product and coating residue was then removed from the testing area using a plastic spatula and paper towel. Then the coating was scraped with a plastic scraper until no more coating material could be easily removed. Figure 8 shows a wood panel with ring gaskets after testing was completed.

Figure 8: Wood Panel with Ring Gaskets After Testing

After scraping, each testing area was given a visual rating between 0% and 100% to indicate how much substrate surface had been exposed after the given dwell time and scraping process. The ratings were estimates provided by a lab technician after visual inspection of the test area. The ratings were provided in increments of 5% since it was not possible for the lab technician to attain any further resolution with the visual estimation process. The rating "0%" was given if the coating removal product removed some coating layer(s) but the substrate surface was still completely covered by a coating. The rating "**<u>0%</u>**" in bold and underlined was given if the coating removal product did not remove any coating material at all. The rating "50%" would be given if approximately half of the substrate surface was exposed. The rating "100%" would be given if the substrate surface was completely exposed.

All performance test results for the various applications in this report are for a single test conducted for each coating and coating removal product combination. Due to limited resources, replicate tests were not conducted. The tests were not designed to provide statistical significance, but rather to ascertain the relative coating removal effectiveness of the coating removal products.

For all performance testing conducted at the TURI laboratory, four commercially available methylene chloride based coating removal products were used to establish a baseline of performance. The methylene chloride products chosen were from two major U.S. manufacturers of coating removal products that were widely available in retail stores to do-it-yourself consumers. The four products have varying amounts of methylene chloride concentration to capture the potential performance variation in methylene chloride based products. The four products are listed in Table 13. The one exception is testing for automotive coatings also included the Rust-Oleum Auto Stripper product with methylene chloride since it was specifically marketed for automotive coating removal.

Table 13: *Methylene Chloride Products Used for Performance Testing in TURI Laboratory*

Supplier	Product	Methylene Chloride Concentration	Source
Savogran	Strypeeze	25% - 30%	SDS 3/10/15
WM Barr	Strip-X	30% – 40%	SDS 4/16/15
WM Barr	Premium Stripper	70% – 95%	SDS 5/1/19
Savogran	Superstrip	85% - 90%	SDS 3/10/15

The furniture refinisher products (Minwax, Formby's, and Watco) were not tested because these products use a different application method than standard paint and varnish removers. The furniture refinisher products are not left on the substrate surface for a certain dwell time; instead, a steel wool pad is soaked with the product and then the steel wool is rubbed on the coating surface until the coating is dissolved.

Two types of performance testing were conducted: 1) methylene chloride comparison tests and 2) extended dwell time tests. Table 14 shows which type of performance testing was conducted for the different types of applications.

Table 14: *Performance Testing Conducted*

Application	Methylene Chloride Comparison Tests	Extended Dwell Time Tests
Wood panels	✓	✓
Masonry blocks	✓	
Automotive/metal panels		✓
Boat panels		✓
CARC panels		✓
Adhesive panels		✓
Bathtub tiles		✓
Asphalt/tar panels		✓
Latex splatter panels		✓
Furniture refinishing	✓	

Methylene Chloride Comparison Test

This type of test provided a direct comparison for coating removal performance between methylene-chloride- and non-methylene-chloride-based products. To determine the dwell time for each type of coating for wood panels and masonry blocks, the methylene chloride-based strippers were tested at different dwell times until substrate exposure between 65% and 95% was achieved. This target range was selected because it provided a dwell time where the methylene chloride-based stripper was effective at removing the majority of the coating material on the substrate. A target value of 100% would not be helpful for the following reasons: 1) it would not be possible to determine the exact dwell time when 100% coating material removal occurred, and 2) it does not provide the opportunity for non-methylene chloride formulations to potentially exceed methylene chloride's performance.

The resultant dwell times vary between coatings because of the range of difficulty to remove the different types of coatings. For example, the oil, varnish, and epoxy coatings are difficult to remove and require longer dwell times for the methylene chloride-based coating removal products to reach the 65% to 95% target range. In realistic coating removal scenarios, it is sometimes recommended that the coating removal product be reapplied as needed. Reapplication was implemented for the standard wood panels with the epoxy, varnish, and oil coatings as well as the mixed panel. For example, the coating removal product applied on a standard panel with an epoxy coating would have an initial 20 minute dwell time, followed by a scraping, a paint stripper reapplication for a subsequent 10 minute dwell, and then a second scraping, for a total dwell time of 30 minutes.

Extended Dwell Time Test

The objective of the extended dwell time tests was to determine the required duration for coating removal products to remove all coatings from a substrate material. The following test protocol was followed for all of the extended dwell time tests:

- The coating removal product was applied to the test surface for a pre-determined dwell time.
- The coating removal product was removed and the test area was scraped and inspected.
- The test was completed if 90% or higher amount of substrate was exposed.
- If less than 90% of the substrate was exposed, then coating removal product was applied to the test surface for additional pre-determined dwell times.
- The test protocol was repeated until 90% or higher amount of substrate was exposed.
- The test was stopped after a pre-determined cumulative dwell time if 90% or higher substrate exposure was not achieved. For example, the testing for the wood panels was stopped after eight hours of cumulative test duration.

Coatings on Wood Test Panels

For creating the wood test panels, 3.5 inches wide by 15 inches long by 0.75 inch thick planks of white pine wood were used. Two types of wood panels were created: standard and mixed.

Each standard panel contained a different specific coating such as lacquer, oil-based paint, latex-based paint, shellac, epoxy, varnish, or polyurethane. The standard panels were created to ascertain the stripping performance for each type of coating. A general purpose stripper should exhibit good stripping performance across a variety of coating types.

The standard panels were first coated with Kilz Original Interior Oil-Based primer and then left to dry at room temperature overnight. The following day, the panels were then lightly sanded with 100-grit sandpaper to enable better adherence between coating layers. Once sanded, the panels were then wiped clean with isopropanol. The first topcoat layer was then applied on top of the primer layer. Each panel was painted with four layers of its designated top coat, allowing for each layer to dry overnight, be sanded, and cleaned with isopropanol. After the test panels were painted with their final layer of top coat and dried overnight, they were then thermally aged in an oven for three weeks at 140˚F to simulate approximately 11 months of aging. Figure 8 shows the various layers used for a standard panel with an epoxy coating.

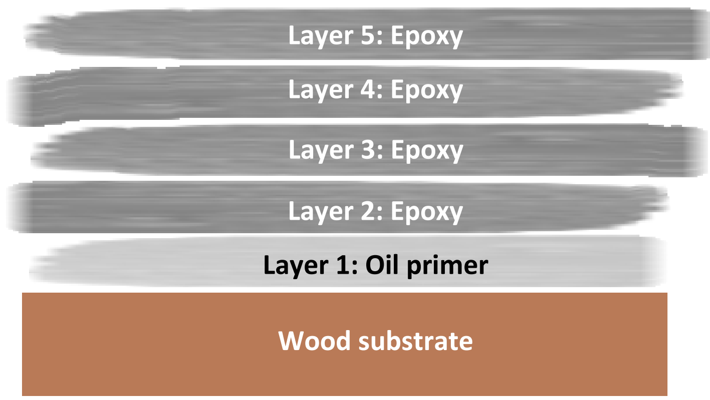

Figure 9: Standard Wood Test Panel – Epoxy

Mixed test panels were created to simulate a scenario where a substrate has different coating types applied over time. The mixed test panels had an oil primer layer, a latex-based paint layer, an oil-based paint layer, another latex-based paint layer, another oil-based paint layer, and two layers of polyurethane (see Figure 9). Similar to the standard wood test panels, between each coating layer, the mixed wood test panels were sanded, wiped clean with isopropanol, and allowed to dry overnight. After the test panels were painted with their final layer of top coat and dried overnight, they were then thermally aged in an oven for three weeks at 140 °F to simulate approximately 11 months of aging. The mixed panels created a challenging scenario for coating removal products.

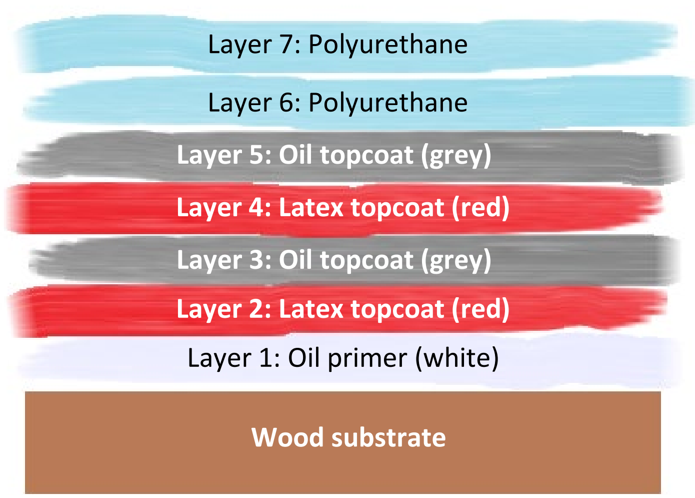

Figure 10: Mixed Coating Wood Test Panel

The following coatings were used for the standard and mixed coupons:

- Primer: Kilz Original Interior Oil Base
- Latex Paint: Behr Premium Plus Paint & Primer in One
- Epoxy: Rust-Oleum Appliance Epoxy
- Lacquer: Minwax Clear Brushing Lacquer
- Varnish: Rust-Oleum Marine Coatings Spar Varnish
- Oil Paint: Glidden Trim, Door, & Furniture
- Shellac: Zinsser Bulls Eye Shellac
- Polyurethane: Varathane Polyurethane Semi Gloss Interior

For the methylene chloride comparison tests on wood panels, the overall range of substrate exposure achieved by the four methylene-chloride-based products (Strypeeze, SuperStrip, KleanStrip Premium, and Klean Strip Strip X) varied across the different types of coatings as shown in Table 15. The data values provided are the percentage substrate exposed after the coating removal tests were completed. For example, the range of substrate exposure varied between 65% and 85% for the panels with shellac coatings.

Table 15: *Wood Panel Test Results for Methylene Chloride Products*

Supplier/ Product	Epoxy 30 minute dwell (20 + 10)	Shellac 8 minute dwell	Lacquer 10 minute dwell	Polyurethane 10 minute dwell	Varnish 32 minute dwell (20 + 12)	Oil 35 minute dwell (25 + 10)	Latex 25 minute dwell	Mixed 35 minute dwell (20 + 15)
Savogran Strypeeze with MC	80	65	75	95	85	95	85	85
Savogran SuperStrip with MC	95	75	95	85	85	90	80	90
WM Barr Klean Strip Premium with MC	95	70	85	85	85	95	85	85
WM Barr Klean Strip Strip X	75	85	85	90	95	95	90	65
Range	75 - 95	65 - 85	75 - 95	85 - 95	85 - 95	90 - 95	80 - 90	65 - 90

Table 16 shows the performance testing results on wood panels for coating removal products that contain no Benchmark 1 chemicals. The products with no Benchmark 1 chemicals had performance overlap with the range of methylene-chloride-based products for all coating types tested. For example, the products with no Benchmark 1 chemicals had a performance range of 0% – 90% substrate exposure for epoxy coatings, and the methylene chloride products had a performance range of 75% – 95% substrate exposure for epoxy coatings. The New Generation and Aircraft Remover no MC had significantly better performance than other products with no Benchmark 1 chemicals since they had solvent blends with more effective Hansen Solubility Parameters and individual solvents with smaller molecular volumes and lower hydrogen bonding parameters as discussed in "Requirement 6: Penetration of Multilayer Coatings."

Table 16: *Wood Panel Test Results for Products with No Benchmark 1 Chemicals*

Supplier/ Product	Epoxy 30 minute dwell (20 + 10)	Shellac 8 minute dwell	Lacquer 10 minute dwell	Polyurethane 10 minute dwell	Varnish 32 minute dwell (20 + 12)	Oil 35 minute dwell (25 + 10)	Latex 25 minute dwell	Mixed 35 minute dwell (20 + 15)
DS Super Remover New Generation	90	85	85	90	95	95	90	90
Dumond Smart Strip	**0**	**0**	0	0	**0**	**0**	0	0
EcoSafety EcoFast	**0**	**0**	0	**0**	**0**	**0**	0	0
EZ Strip Paint and Varnish Stripper	**0**	**0**	0	**0**	**0**	**0**	0	0
Motsenbocker Lift Off	**0**	**0**	0	**0**	**0**	**0**	0	0
WM Barr Aircraft Remover no MC	85	30	85	20	70	70	85	80
Range	0 - 90	0 - 85	0 - 85	0 - 90	0 - 95	0 - 95	0 - 90	0 - 90

Table 17 shows the performance testing results on wood panels for coating removal products that contain other Benchmark 1 chemicals. The products with other Benchmark 1 chemicals had performance overlap with the range of methylene-chloride-based products for some coating types (epoxy, shellac, lacquer, varnish, oil, and mixed) and no performance overlap with the range of methylene-chloride-based products for some coating types (polyurethane, latex). For example, the products with other Benchmark 1 chemicals had a performance range of 0% – 70% substrate exposure for latex coatings, and the methylene chloride products had a performance range of 80% – 90% substrate exposure for latex coatings; therefore there was no overlap.

Table 17: *Wood Panel Test Results for Products with Other Benchmark 1 Chemicals*

Supplier/ Product	Epoxy 30 minute dwell (20 + 10)	Shellac 8 minute dwell	Lacquer 10 minute dwell	Polyurethane 10 minute dwell	Varnish 32 minute dwell (20 + 12)	Oil 35 minute dwell (25 + 10)	Latex 25 minute dwell	Mixed 35 minute dwell (20 + 15)
Recochem Heirloom Max	10	Not tested	Not tested	Not tested	90	Not tested	Not tested	60
Recochem Heirloom Plus	20	Not tested	Not tested	Not tested	80	Not tested	Not tested	35
Savogran Strypeeze No MC	80	80	Not tested	60	90	Not tested	50	80
Savogran SuperStrip No MC	60	0	Not tested	60	70	Not tested	Not tested	50
Sunnyside 2 Minute Remover No MC	90	0	85	30	95	90	0	50
Sunnyside Ready-Strip Plus	**0**	**0**	0	0	**0**	**0**	0	0
Swing Paint Circa 1850 D-Solver	90	Not tested	Not tested	Not tested	95	Not tested	50	85
Watco Paint and Poly	60	Not tested	Not tested	Not tested	90	Not tested	Not tested	40
WM Barr CitriStrip with NMP	**0**	**0**	0	**0**	**0**	**0**	0	0
WM Barr Kwik Strip	0	0	85	30	90	0	70	85
Range	0 - 90	0 - 80	0 - 85	0 - 60	0 - 95	0 - 90	0 - 70	0 - 85

Extended dwell time testing for wood panels was conducted only for 1) the coating removal products that did not achieve any substrate exposure for the dwell times used for the methylene chloride comparison tests, and 2) other slow-acting coating removal products. Table 18 shows the dwell times and cumulative test duration used for the wood panels.

Table 18: *Dwell Times for Wood Panels*

Number of Dwell Periods	Dwell Time	Cumulative Test Duration
1	60 minutes	1 hour
2	60 minutes	2 hours
3	60 minutes	3 hours
4	60 minutes	4 hours
5	60 minutes	5 hours
6	60 minutes	6 hours
7	60 minutes	7 hours
8	60 minutes	8 hours

The results for the extended dwell time tests for wood panels are provided in Table 19. The results are sorted from fastest to slowest based on performance for the mixed panel, since this type of panel includes several types of coatings (oil primer, oil topcoat, latex topcoat, and polyurethane).

Table 19: *Extended Dwell Time Test Results for Wood Panels*

Supplier	Product	Product Category	Mixed Panel	Epoxy Panel	Varnish Panel
UMass Lowell	Formulation NF	No Benchmark 1	1 – 2 hours	1 – 2 hours	1 – 2 hours
Ecosafety	Ecofast	No Benchmark 1	3 – 4 hours	5 – 6 hours	2 – 3 hours
Packaging Services	Crown STRP Max Paint Strip Gel	Other Benchmark 1	3 – 4 hours	4 – 5 hours	1 – 2 hours
Packaging Services	Crown STRP Sure	No Benchmark 1	3 – 4 hours	4 – 5 hours	3 – 4 hours
Sunnyside	Hi Speed Ready Strip	No Benchmark 1	3 – 4 hours	4 – 5 hours	3 – 4 hours
Sunnyside	Multistrip Advanced (no NMP)	No Benchmark 1	3 – 4 hours	2 – 3 hours	2 – 3 hours
WM Barr	Citristrip (no NMP)	No Benchmark 1	3 – 4 hours	4 – 5 hours	4 – 5 hours
WM Barr	Citristrip with NMP	Other Benchmark 1	3 – 4 hours	4 – 5 hours	2 – 3 hours
Franmar	Blue Bear with Safenol	No Benchmark 1	4 – 5 hours	3 – 4 hours	3 – 4 hours
WM Barr	Green Paint & Varnish Stripper	No Benchmark 1	4 – 5 hours	6 – 7 hours	5 – 6 hours
Dumond	Smart Strip	No Benchmark 1	5 – 6 hours	5 – 6 hours	5 – 6 hours
Motsenbocker	Lift-off	No Benchmark 1	5 – 6 hours	6 - 7 hours	5 – 6 hours
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	6 - 7 hours	7 – 8 hours	5 – 6 hours
Sunnyside	MultiStrip with NMP	Other Benchmark 1	6 – 7 hours	3 – 4 hours	2 – 3 hours
3M	Safest Stripper	No Benchmark 1	7 – 8 hours	6 – 7 hours	4 – 5 hours
Dumond	Peel Away 1	No Benchmark 1	Greater than 8 hours	Greater than 8 hours	Greater than 8 hours
Dumond	Peel Away 7	Other Benchmark 1	Greater than 8 hours	Greater than 8 hours	Greater than 8 hours
Sunnyside	Aquastrip	Other Benchmark 1	Not tested	Not tested	3 – 4 hours

Coatings on Masonry Blocks

For testing the masonry substrate, masonry (concrete) blocks were used. Each masonry block was 3.5 inches wide, 7.5 inches long, and 2.25 inches high. Each masonry block was first coated with white Behr Premium Concrete Stain. Next, the masonry blocks were coated with either four layers of white Behr Masonry, Stucco, and Brick paint, or they were coated with four layers of grey Behr Premium Basement and Masonry Waterproofer. Similar to the wood test panels, the masonry test blocks were sanded and wiped clean with isopropanol between each coating layer and allowed to dry overnight for each layer. The finished masonry blocks were then thermally aged in an oven for three weeks at 140˚F. Figure 10 shows the coating layers used for the masonry blocks with grey paint.

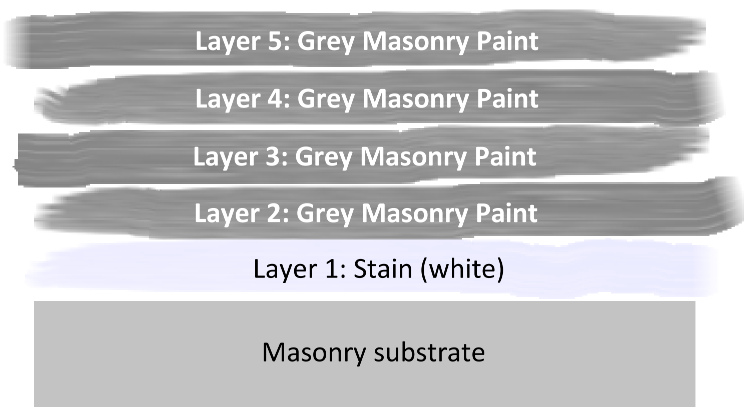

Figure 11: Masonry Test Block with Grey Paint

For the methylene chloride comparison tests on masonry blocks, the overall range of substrate exposure achieved by the four methylene-chloride-based products (Strypeeze with MC, SuperStrip with MC, Premium with MC, and Strip X) varied across the two different types of coatings, as shown in Table 20. The data provided are the percentage substrate exposed after the coating removal tests were completed. For example, the range of substrate exposure varied between 85% and 95% for the masonry blocks with white paint.

Table 20: *Masonry Block Test Results for Methylene Chloride Products*

Coating Removal Product	White (7-minute dwell)	Grey (8-minute dwell)
Savogran Strypeeze with MC	85	95
Savogran SuperStrip with MC	95	100
WM Barr Klean Strip Premium with MC	95	95
WM Barr Strip X	85	80
Range	85 - 95	80 - 100

Table 21 shows the performance testing results on masonry blocks for coating removal products that contain no Benchmark 1 chemicals. The products with no Benchmark 1 chemicals had performance overlap with the range of methylene-chloride-based products for both coating types tested. For example, the products with no Benchmark 1 chemicals had a performance range of 0% – 95% substrate exposure for white paint, and the methylene chloride products had a performance range of 85% – 95% substrate exposure for white paint.

Table 21: *Masonry Block Test Results for Products with No Benchmark 1 Chemicals*

Coating Removal Product	White (7-minute dwell)	Grey (8-minute dwell)
DS Super Remover New Generation	95	90
Dumond Smart Strip	0	0
EcoFast	0	0
EZ Strip	0	0
Motsenbocker Lift Off	0	0
WM Barr Aircraft Remover no MC	90	90
Range	0 - 95	0 - 90

Table 22 shows the performance testing results on masonry blocks for coating removal products that contain other Benchmark 1 chemicals. The products with other Benchmark 1 chemicals had performance overlap with the range of methylene-chloride-based products for both coating types tested. For example, the products with no Benchmark 1 chemicals had a performance range of 0% – 90% substrate exposure for grey paint, and the methylene chloride products had a performance range of 80% – 100% substrate exposure for grey paint.

Table 22: *Masonry Block Test Results for Products with Other Benchmark 1 Chemicals*

Coating Removal Product	White (7-minute dwell)	Grey (8-minute dwell)
WM Barr Kwik Strip	95	85
Sunnyside 2 Minute Remover No MC	90	90
Sunnyside Ready-Strip Plus	0	0
Peel Away 7	0	0
WM Barr CitriStrip with NMP	20	20
Range	0 - 95	0 - 90

Automotive Coatings

For the automotive metal test panels, steel sheets with a galvanized finish were used. Each steel sheet was 12 inches wide, 12 inches long, and 28 gauge thick. The coatings used on the metal panels were selected to simulate the coating layers used for automobiles. The automotive metal test panels were first coated with two layers of grey Rust-Oleum Auto Body Acrylic Primer. Next, four layers of orange

Rust-Oleum Auto Body Acrylic Basecoat Paint were applied. Finally, two layers of Rust-Oleum Auto Body Acrylic Clearcoat were applied. Similar to the wood test panels, the metal test panels were sanded, wiped clean with isopropanol, and allowed to dry overnight between each coating layer. Figure 12 shows the coating layers used for the automotive metal test panels.

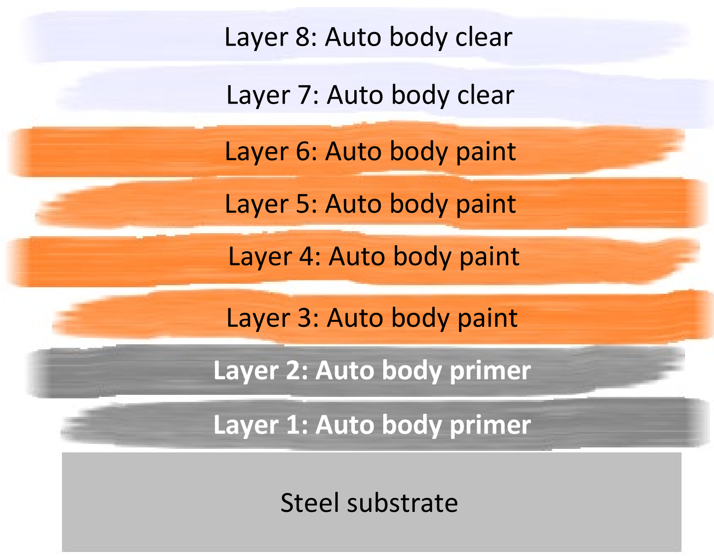

Figure 12: Automotive Metal Test Panel

Coating operations for the automobile industry typically include four layers: electrodeposition (for rust and corrosion protection), primer, base coat, and clear coat. During automobile manufacturing, typically the primer layer is cured for 30 minutes at 284–356 °F, the base coat layer 30-40 minutes at 257–260 °F, and the clear coat layer 30–40 minutes at 257–356 °F (Offley, 2016; Akafuah, 2016). The TURI lab attempted to cure the automotive metal test panels using the dwell times and temperatures provided in Table 23.

Table 23: *Oven Dwell Times for Automotive Coatings*

Coating Layer	Oven Dwell Time	Temperature
Primer	30 minutes	356 °F
Base coat	40 minutes	260 °F
Clear coat	30 minutes	356 °F

However, these times and temperatures caused excessive blistering of the paint surface. Therefore, the finished panels were instead thermally aged in an oven for three weeks at 140 °F, similar to the wood test panels. While this coating does not mimic a high-quality coating from an automobile manufacturer, it provides an indication of performance on metal surfaces with automotive coatings available to do-it-yourself consumers. Table 24 shows the dwell times and the cumulative test duration used for the automotive metal panels.

Table 24: *Dwell Times for the Metal Automotive Panels*

Number of Dwell Periods	Dwell Time	Cumulative Test Duration
1	2 minutes	2 minutes
2	3 minutes	5 minutes
3	5 minutes	10 minutes
4	5 minutes	15 minutes
5	5 minutes	20 minutes
6	5 minutes	25 minutes
7	5 minutes	30 minutes

Table 25 shows the extended dwell time test results for the metal automotive panels created by the TURI lab. The results are sorted from fastest to slowest performance. The Rust-Oleum Auto Stripper product with methylene chloride was also included since it was specifically marketed for automotive coating removal.

Table 25: *Extended Dwell Time Test Results for Automotive Panels*

Supplier	Product	Product Category	Dwell Time (to achieve 90% or greater substrate exposure)
Rust-Oleum	Auto Stripper (with MC)	Methylene chloride	Less than 2 minutes
DS Super Remover	New Generation	No Benchmark 1	Less than 2 minutes
Savogran	Superstrip with MC	Methylene chloride	Less than 2 minutes
WM Barr	Klean Strip Premium with MC	Methylene chloride	Less than 2 minutes
WM Barr	Strip X	Methylene chloride	Less than 2 minutes
Savogran	Strypeeze with MC	Methylene chloride	2 – 5 minutes
WM Barr	Aircraft Remover with no MC	No Benchmark 1	2 – 5 minutes
WM Barr	Kwik Strip	Other Benchmark 1	2 – 5 minutes
Packaging Services	Crown STRP Max	Other Benchmark 1	5 – 10 minutes
Packaging Services	Crown STRP Sure	No Benchmark 1	10 – 15 minutes
Franmar	Blue Bear with Safenol	No Benchmark 1	15 – 20 minutes
Sunnyside	Multi Strip Advanced (no NMP)	No Benchmark 1	15 –20 minutes
Dumond	Smart Strip	No Benchmark 1	25 – 30 minutes
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	25 – 30 minutes
Sunnyside	Ready Strip Plus	Other Benchmark 1	25 – 30 minutes
WM Barr	Citristrip (no NMP)	No Benchmark 1	25 – 30 minutes

The methylene-chloride-based products had a range of performance of less than two minutes (several products) to 2–5 minutes (Strypeeze with MC). The products with no Benchmark 1 chemicals had a range of performance from less than 2 minutes (New Generation) to 25–30 minutes (several products), which overlaps with the methylene-chloride-based products. The products with other Benchmark 1 chemicals had a range of performance from 2–5 minutes (Kwik Strip) to 25–30 minutes (Ready Strip Plus), which also overlaps with the methylene-chloride-based products. The range of performance for the different product categories is shown in Figure 13.

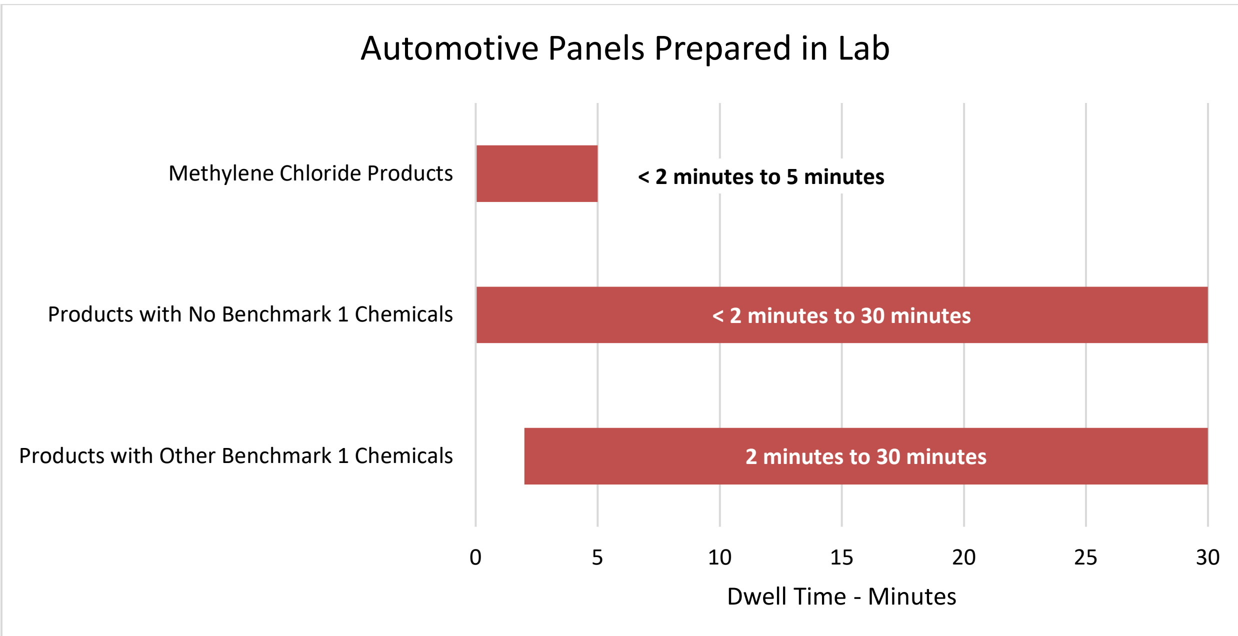

Figure 13: Performance Ranges for Automotive Panels Prepared in the TURI Laboratory

In addition to the automobile test panels created in the TURI lab, testing was also conducted on an actual automobile surface. The right front quarter panel of a 2012 Toyota Prius was used for coating removal product performance testing. This quarter panel was donated by Greenwood Auto Body of Groveland, Massachusetts. Table 26 shows the dwell times and cumulative test duration used for the Toyota Prius quarter panel tests.

Table 26: *Dwell Times for the Toyota Prius Quarter Panel Tests*

Number of Dwell Periods	Dwell Time	Cumulative Test Duration
1	30 minutes	30 minutes
2	30 minutes	60 minutes
3	30 minutes	90 minutes
4	30 minutes	2 hours
5	60 minutes	3 hours
6	60 minutes	4 hours
7	60 minutes	5 hours
8	60 minutes	6 hours
9	60 minutes	7 hours
10	60 minutes	8 hours
11	16 hours	24 hours

The long 16-hour dwell time was used to enable the tests to continue overnight while there were no lab staff available to check the results. A watch glass was used to cover the test area for the 16-hour dwell time so that the coating removal product would not dry out.

Table 27 shows the extended dwell time test results for the Toyota Prius quarter panel. Since the electrodeposition layer is highly chemical resistant (even for methylene chloride), the tests were run until 90% or greater area of the electrodeposition (not metal substrate) was exposed. The results are sorted from fastest to slowest performance.

Table 27: *Toyota Prius Extended Dwell Time Test Results*

Supplier	Product	Product Category	Dwell Time (to achieve 90% or greater electrodeposition exposure)
Rust-Oleum	Auto Stripper with MC	Methylene chloride	30 – 60 minutes
WM Barr	Klean Strip Premium with MC	Methylene chloride	30 – 60 minutes
Savogran	Superstrip with MC	Methylene chloride	60 – 90 minutes
DS Super Remover	Professional Grade	No Benchmark 1	60 – 90 minutes
WM Barr	Aircraft Remover with no MC	No Benchmark 1	5 – 6 hours
WM Barr	Strip X	Methylene chloride	5 – 6 hours
DS Super Remover	New Generation	No Benchmark 1	7 – 8 hours
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	Greater than 24 hours
Packaging Services	Crown STRP Max	Other Benchmark 1	Greater than 24 hours
Savogran	Strypeeze no MC	Other Benchmark 1	Greater than 24 hours
Savogran	Strypeeze with MC	Methylene chloride	Greater than 24 hours
Savogran	Superstrip no MC	Other Benchmark 1	Greater than 24 hours
Sunnyside	Multistrip Advanced no NMP	No Benchmark 1	Greater than 24 hours
Sunnyside	2 Minute Remover with no MC	Other Benchmark 1	Greater than 24 hours
WM Barr	Kwik Strip	Other Benchmark 1	Greater than 24 hours

The methylene chloride-based products had a wide range of performance, from 30–60 minutes (Rust-Oleum Auto Stripper and Premium with MC) to greater than 24 hours (Strypeeze with MC). The products with no Benchmark 1 chemicals had a range of performance from 60–90 minutes (DS Super Remover Professional Grade) to greater than 24 hours (EZ Strip and MultiStrip Advanced no NMP) which overlaps with the methylene-chloride-based products. The products with other Benchmark 1 chemicals all required greater than 24 hours, which also overlaps with the methylene-chloride-based products. The range of performance for the different product categories is shown in Figure 13. The testing was only conducted on a single automobile make/model/year. The performance results could vary depending upon the automobile make/model/year tested.

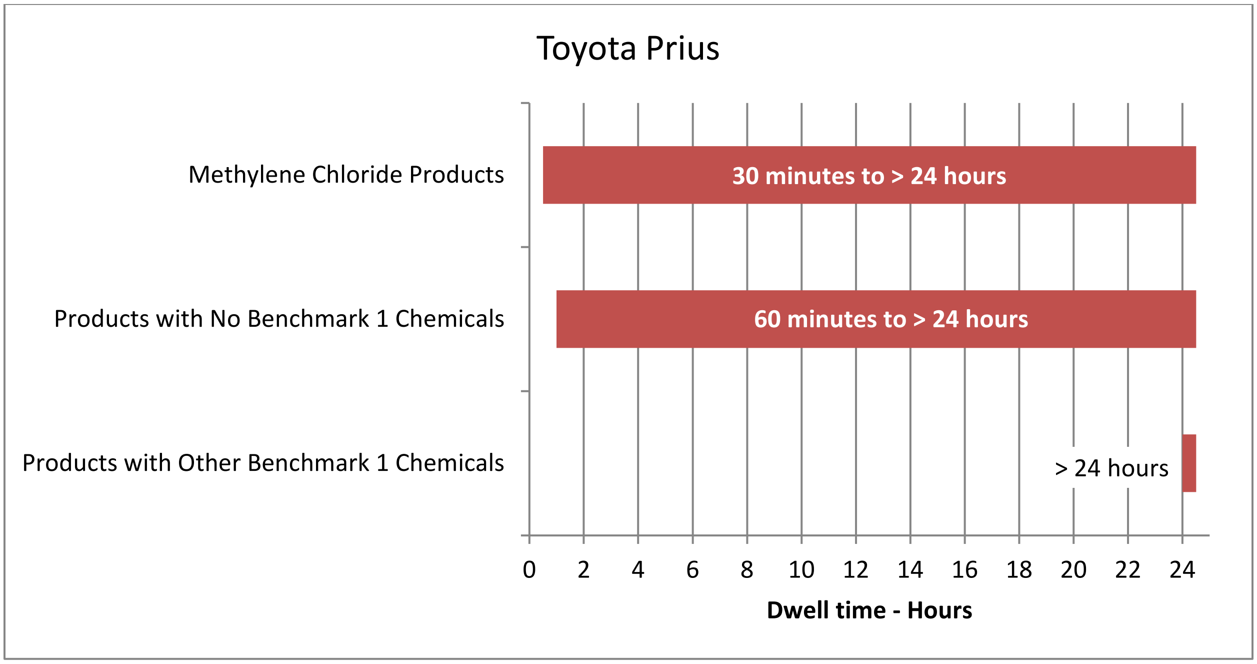

Figure 14: Performance Ranges for Toyota Prius Automotive Panels

Boat Coatings

For the boat test panels, the substrate and coating materials were selected to simulate a boat application. An aluminum tray, 9 inches long by 13 inches wide by 1 inch deep, was used to contain all of the layers required to create the boat panel. The underlying substrate consisted of three stacked substrate materials. The first substrate material was a Totalboat Polyester Laminating Resin with a methyl ethyl ketone peroxide hardener catalyst, that was impregnated with 3M Bondo fiberglass cloth. The second substrate material was a Totalboat Polyester Finishing Resin with a methyl ethyl ketone peroxide hardener catalyst. The third substrate material was a Sea Hawk gel coat with a methyl ethyl ketone peroxide hardener catalyst. The first coating layer was an Interlux Primocon grey underwater primer. Next, four layers of red Totalboat JD Select Ablative Antifouling BottomPaint were applied. Similar to the wood test panels, between each coating layer, the boat test panels were sanded, wiped clean with isopropanol, and allowed to dry overnight. The finished boat panels were thermally aged in an oven for three weeks at 140 °F. Figure 15 shows the coating layers used for the boat test panels.

Figure 15: Boat Test Panel

Table 28 shows the dwell times and cumulative test duration used for the boat test panels.

Table 28: *Dwell Times for Boat Panels*

Number of Dwell Periods	Dwell Time	Cumulative Test Duration
1	10 minutes	10 minutes
2	3 minutes	13 minutes
3	17 minutes	30 minutes
4	30 minutes	1 hour
5	60 minutes	2 hours
6	60 minutes	3 hours
7	60 minutes	4 hours
8	60 minutes	5 hours
9	60 minutes	6 hours
10	60 minutes	7 hours
11	60 minutes	8 hours

Table 29 shows the extended dwell time test results for the boat panels. The coating removal products tested include general purpose products as well as products specifically marketed for marine applications (e.g. Aqua Strip). The results are sorted from fastest to slowest performance to achieve 90% or greater substrate (gel coat) exposure.

Table 29: *Extended Dwell Time Test Results on Boat Panels*

Supplier	Product	Product Category	Dwell Time (to achieve 90% or greater gel coat substrate exposure)
WM Barr	Klean Strip Premium with MC	Methylene chloride	Less than 10 minutes
Savogran	Superstrip with MC	Methylene chloride	Less than 10 minutes
DS Super Remover	New Generation	No Benchmark 1	10 - 13 minutes
Savogran	Strypeeze with MC	Methylene chloride	10 - 13 minutes
WM Barr	Aircraft Remover with no MC	No Benchmark 1	10 – 13 minutes
WM Barr	Strip X	Methylene chloride	10 – 13 minutes
Sunnyside	Aqua Strip (with NMP)	Other Benchmark 1	1 – 2 hours
West Marine	Marine Paint Remover – Citrus Paint & Varnish Remover	No Benchmark 1	7 – 8 hours
West Marine	Marine Paint Remover (with NMP)	Other Benchmark 1	> 8 hours

The methylene chloride-based products had a range of performance of less than 10 minutes (Premium with MC and Superstrip with MC) to 10–13 minutes (Strypeeze with MC and Strip-X). The products with no Benchmark 1 chemicals had a performance range from 10–13 minutes (New Generation) to 7–8 hours (Marine Paint Remover – Citrus), which overlaps with the methylene chloride-based products. The products with other Benchmark 1 chemicals had a range of performance from 1 to 2 hours (Aqua Strip) to greater than 8 hours (Marine Paint Remover with NMP), which does not overlap with the methylene chloride-based products. The range of performance for the different product categories is shown in Figure 15. The testing was only conducted for a single boat panel application. The performance results could vary if different boat coatings are tested.

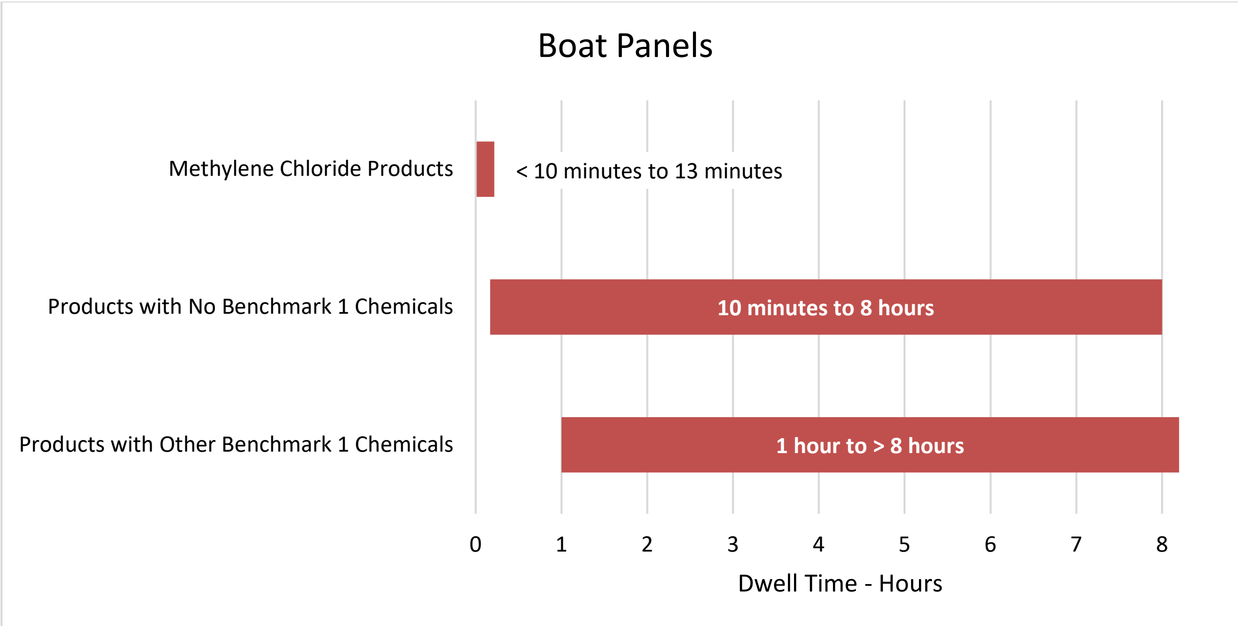

Figure 16: Performance Ranges for Boat Panels

For performance result tests for varnish used on boat topsides, see the Rust-Oleum Marine Coatings Spar Varnish test results in the wood panel section of this report.

Chemical Agent Resistant Coatings (CARC)

For the CARC test panels, the substrate and coating materials were selected to simulate a military application requiring CARC. TURI investigated a CARC coating to help companies in the defense industry to evaluate safer coating removal products. The CARC panels were made of 6061 aluminum alloy and were 12 inches wide and 12 inches long, and had a yellow chromate conversion coating applied per MIL-DTL-5541F Type I Class 1A. This conversion coating was applied by TT Anodizing of Lowell, Massachusetts. The test panels were then coated with a single layer of NCP Coatings Dynaspec N-8959A/BDR, a two-part lead- and chromate-free buff epoxy primer that meets the requirements of MIL-DTL-53022E Type IV. Next, three layers of black DynaSpec Camouflage Topcoat were applied onto the CARC test panels. This chemical-agent-resistant coating meets the requirements of MIL-DTL-53039D Type IV. Similar to the wood test panels, between each layer the CARC test panels were sanded, wiped clean with isopropanol, and allowed to dry overnight. However, the finished CARC test panels were not thermally aged. Figure 17 shows the coating layers used for the CARC test panels.

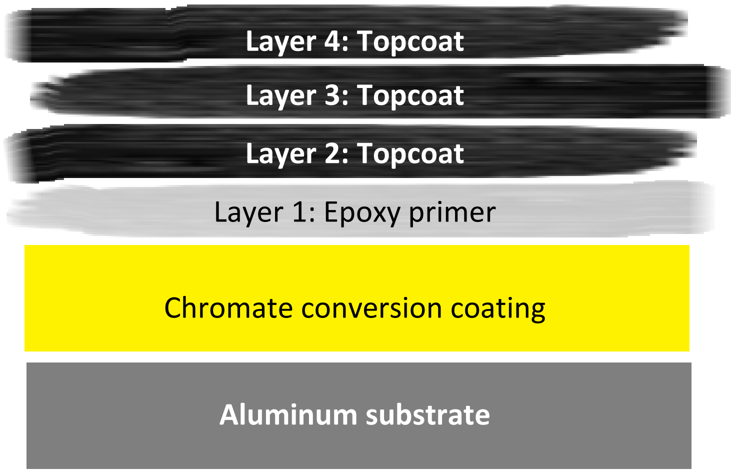

Figure 17: CARC Test Panel

Table 30 shows the dwell times and cumulative test duration used for the CARC test panels.

Table 30: Dwell Times for the CARC Test Panels

Number of Dwell Periods	Dwell Time	Cumulative Test Duration
1	60 minutes	1 hour
2	60 minutes	2 hours
3	60 minutes	3 hours
4	60 minutes	4 hours
5	60 minutes	5 hours
6	60 minutes	6 hours
7	60 minutes	7 hours
8	60 minutes	8 hours
9	16 hours	24 hours
10	8 hours	32 hours
11	16 hours	48 hours

The long 16-hour dwell times were used to enable the tests to continue overnight while there were no lab staff available to check the results. A watch glass was used to cover the test area for the longer dwell times (8 hours and 16 hours) so that the coating removal product would not dry out.

Table 31 shows the extended dwell time test results for the CARC panels. The results are sorted from fastest to slowest performance. The CARC panels were extremely resistant to coating removal; tests required much longer dwell times than for other types of coatings.

Table 31: *CARC Panel Extended Dwell Time Test Results*

Supplier	Product	Product Category	Dwell Time (to achieve greater than 90% substrate exposure)
WM Barr	Klean Strip Premium with MC	Methylene chloride	1 – 2 hours
DS Super Remover	Professional Grade	No Benchmark 1	3 – 4 hours
Savogran	Strypeeze with MC	Methylene chloride	4 – 5 hours
Savogran	Superstrip with MC	Methylene chloride	4 – 5 hours
WM Barr	Strip X	Methylene chloride	4 – 5 hours
DS Super Remover	New Generation	No Benchmark 1	6 – 7 hours
WM Barr	Aircraft Remover No MC	No Benchmark 1	7 – 8 hours
3M	Safest Stripper	No Benchmark 1	Greater than 48 hours
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	Greater than 48 hours
Franmar	Blue Bear with Safenol	No Benchmark 1	Greater than 48 hours
Motsenbocker	Lift-off	No Benchmark 1	Greater than 48 hours
Packaging Services	Crown STRP Sure	No Benchmark 1	Greater than 48 hours
Packaging Services	Crown STRP Max	Other Benchmark 1	Greater than 48 hours
Savogran	Strypeeze no MC	Other Benchmark 1	Greater than 48 hours
Savogran	Super Strip no MC	Other Benchmark 1	Greater than 48 hours
Sunnyside	Hi Speed Ready Strip	No Benchmark 1	Greater than 48 hours
Sunnyside	MultiStrip Advanced (no NMP)	No Benchmark 1	Greater than 48 hours
Sunnyside	2 Minute Remover with no MC	Other Benchmark 1	Greater than 48 hours
WM Barr	Kwik Strip	Other Benchmark 1	Greater than 48 hours
WM Barr	Citristrip (no NMP)	No Benchmark 1	Greater than 48 hours
WM Barr	Green PV Stripper	No Benchmark 1	Greater than 48 hours

The methylene chloride-based products had a range of performance from 1–2 hours (Premium with MC) to 4–5 hours (SuperStrip with MC, Strypeeze with MC, and Strip-X). The products with no Benchmark 1 chemicals had a range of performance from 3–4 hours (DS Super Remover Professional Grade) to more than 48 hours for several products, which overlaps with methylene chloride-based products. All products with other Benchmark 1 chemicals took more than 48 hours, which does not overlap with methylene chloride-based products. The range of performance for the different product categories is shown in Figure 18.

Overall, most products tested had a dwell time of over 48 hours, and many of these products did not even penetrate the first layer of the CARC panels after 48 hours. The testing was only conducted for a single CARC application. The performance results could vary if different CARC coatings are tested.

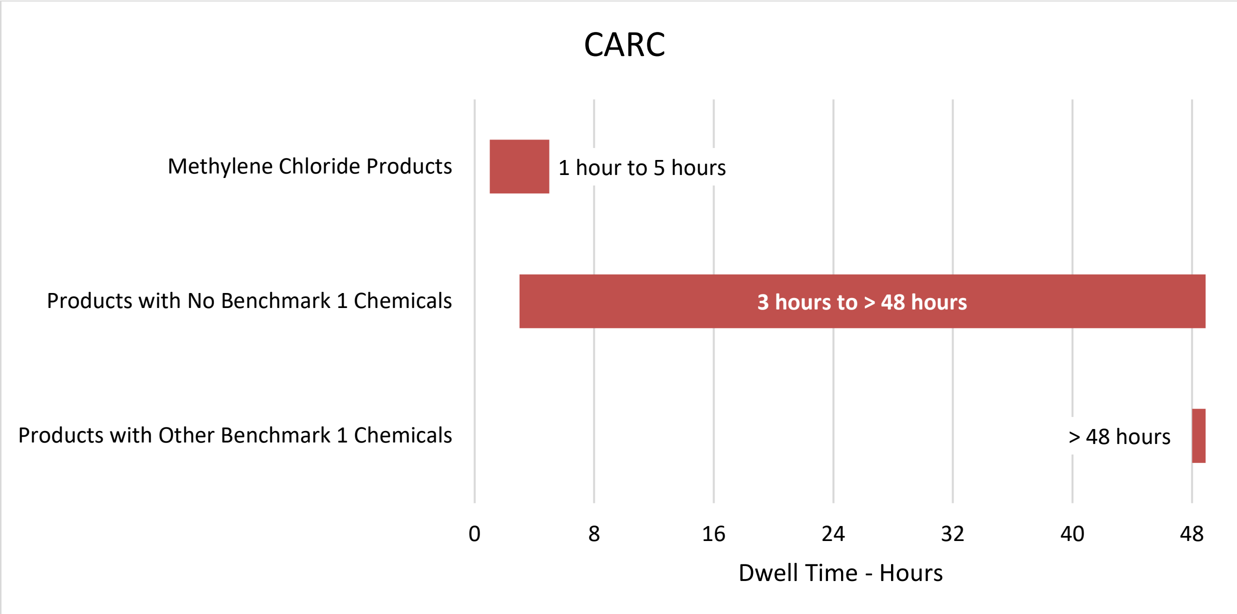

Figure 18: Performance Ranges for CARC Panels

Adhesive Coatings

White pine wood planks measuring 3.5 inches wide by 15 inches long by 0.75 inch thick were used as the substrate material for creating the adhesive test panels. The adhesive used was Roberts 6700 Superior Indoor/Outdoor Carpet Adhesive. The single coating of the adhesive was evenly spread over the surface of the wood substrate using a metal trowel. The panels were then thermally aged in an oven for three weeks at 140 °F.

Table 32 shows the dwell times and cumulative test duration used for the adhesive test panels.

Table 32: *Dwell Times for Adhesive Panels*

Number of Dwell Periods	Dwell Time	Cumulative Test Duration
1	30 minutes	30 minutes
2	30 minutes	1 hour
3	30 minutes	1 hour 30 minutes
4	30 minutes	2 hours
5	60 minutes	3 hours
6	60 minutes	4 hours
7	60 minutes	5 hours
8	60 minutes	6 hours
9	60 minutes	7 hours
10	60 minutes	8 hours

Table 33 shows the extended dwell time results for the adhesive test panels. The results are sorted from fastest to slowest performance. The coating removal products tested include general purpose products as well as products specifically marketed for adhesive applications (e.g., Duck Adhesive Remover).

Table 33: *Adhesive Panel Extended Dwell Time Test Results*

Supplier	Product	Product Category	Dwell Time (to achieve 90% or greater substrate exposure)
WM Barr	Klean Strip Premium with MC	Methylene chloride	30 – 60 minutes
Savogran	Strypeeze with MC	Methylene chloride	60 – 90 minutes
Savogran	Superstrip with MC	Methylene chloride	60 – 90 minutes
DS Super Remover	New Generation	No Benchmark 1	60 – 90 minutes
WM Barr	Strip X	Methylene chloride	60 – 90 minutes
Savogran	Strypeeze no MC	Other Benchmark 1	90 – 120 minutes
Sunnyside	2 Minute Remover with no MC	Other Benchmark 1	90 – 120 minutes
WM Barr	Kwik Strip	Other Benchmark 1	90 – 120 minutes
WM Barr	Goof Off Pro Strength Remover	Other Benchmark 1	90 – 120 minutes
WM Barr	Aircraft Remover with no MC	No Benchmark 1	1 – 2 hours
Goo Gone	Pro Power Goo and Adhesive Remover	No Benchmark 1	3 – 4 hours
Packaging Services	Crown STRP Max	Other Benchmark 1	3 – 4 hours
WM Barr	Klean Strip Adhesive Remover no MC	No Benchmark 1	3 – 4 hours
Duck	Adhesive Remover	No Benchmark 1	4 – 5 hours
WM Barr	Klean Strip Floor Adhesive Remover	No Benchmark 1	4 – 5 hours
WM Barr	Goof Off Adhesive Gunk Remover Gel	No Benchmark 1	5 – 6 hours
TEC	Concentrated Adhesive Remover	No Benchmark 1	6 – 7 hours
Sunnyside	Ready Strip Plus	Other Benchmark 1	Greater than 8 hours

The methylene-chloride-based products had a range of performance from 30–60 minutes (Premium with MC) to 60–90 minutes (Strip X, Superstrip with MC, and Strypeeze with MC). The products with no Benchmark 1 chemicals had a range of performance from 60–90 minutes (New Generation) to 6–7 hours (TEC), which overlaps with methylene chloride-based products. The products with other Benchmark 1 chemicals had a range of performance from 90–120 minutes (several products) to greater than 8 hours (Ready Strip Plus), which does not overlap with methylene chloride-based products. The range of performance for the different product categories is shown in Figure 19.

The testing was only conducted for a single adhesive application. The performance results could vary if different types of adhesive coatings are tested.

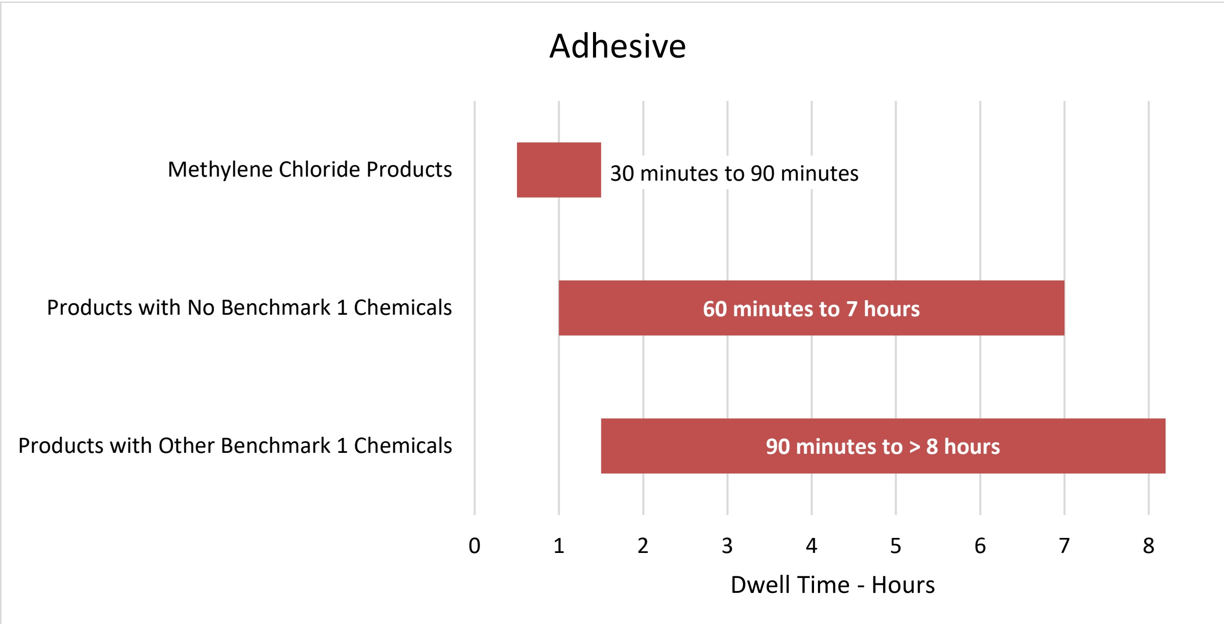

Figure 19: Performance Ranges for Adhesive Panels

Bathtub Coatings

The bathtub ceramic tiles were provided by Outstanding Bath based in Milford, Massachusetts. Ceramic tiles 4.25 inches wide by 4.25 inches long were used as the substrate material. Outstanding Bath prepared the tiles by sanding them lightly and then spraying them with the following three coatings from Standard Paints Inc.:

1) Epoxy SG Part A White and Epoxy Activator Part B clear
2) EP – Acrylic Gloss White
3) EP – Acrylic Clear

The bathtub ceramic tiles were not thermally aged.

Figure 20 shows the coating layers used for the bathtub ceramic tile test panels.

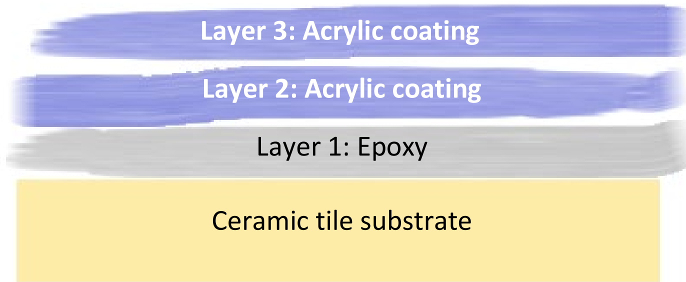

Figure 20: Bathtub Ceramic Tile Test Panel

Table 34 shows the dwell times and cumulative test duration used for the bathtub ceramic tiles.

Table 34: *Dwell Times for Bathtub Ceramic Tiles*

Number of Dwell Periods	Dwell Time	Cumulative Test Duration
1	10 minutes	10 minutes
2	10 minutes	20 minutes
3	10 minutes	30 minutes
4	10 minutes	40 minutes
5	10 minutes	50 minutes
6	10 minutes	1 hour
7	60 minutes	2 hours
8	60 minutes	3 hours
9	60 minutes	4 hours
10	60 minutes	5 hours
11	60 minutes	6 hours
12	60 minutes	7 hours
13	60 minutes	8 hours

Table 35 shows the extended dwell time results for the bathtub ceramic tiles. The results are sorted from fastest to slowest performance.

Table 35: *Bathtub Ceramic Tile Extended Dwell Time Test Results*

Supplier	Product	Product Category	Dwell Time (to achieve greater than 90% substrate exposure)
WM Barr	Klean Strip Premium with MC	Methylene chloride	10 – 20 minutes
Savogran	Superstrip with MC	Methylene chloride	10 – 20 minutes
DS Super Remover	Professional Grade	No Benchmark 1	20 – 30 minutes
Savogran	Strypeeze with MC	Methylene chloride	20 – 30 minutes
WM Barr	Strip X	Methylene chloride	20 – 30 minutes
DS Super Remover	New Generation	No Benchmark 1	30 – 40 minutes
Savogran	Super Strip no MC	Other Benchmark 1	30 – 40 minutes
Sunnyside	2 Minute Remover with no MC	Other Benchmark 1	30 – 40 minutes
WM Barr	Aircraft Remover with no MC	No Benchmark 1	30 – 40 minutes
WM Barr	Kwik Strip	Other Benchmark 1	50 – 60 minutes
Dumond	Smart Strip	No Benchmark 1	5 – 6 hours
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	Greater than 8 hours
Packaging Services	Crown STRP Max	Other Benchmark 1	Greater than 8 hours
WM Barr	Citristrip no NMP	No Benchmark 1	Greater than 8 hours

The methylene-chloride-based products had a range of performance between 10–20 minutes (Premium with MC and Superstrip with MC) and 20–30 minutes (Strypeeze with MC and Strip X). The products with no Benchmark 1 chemicals had a range of performance from 20 to 30 minutes (DS Super Remover Professional Grade) to greater than 8 hours (EZ Strip and Citristrip no NMP), which overlaps with methylene-chloride-based products. The products with other Benchmark 1 chemicals had a range of performance from 30–40 minutes (SuperStrip no MC and 2 Minute Remover with no MC) to greater than 8 hours (Crown STRP Max), which does not overlap with methylene-chloride-based products. The range of performance for the different product categories is shown in Figure 20.

The testing was only conducted for a single bathtub application. The performance results could vary if different bathtub coatings are tested.

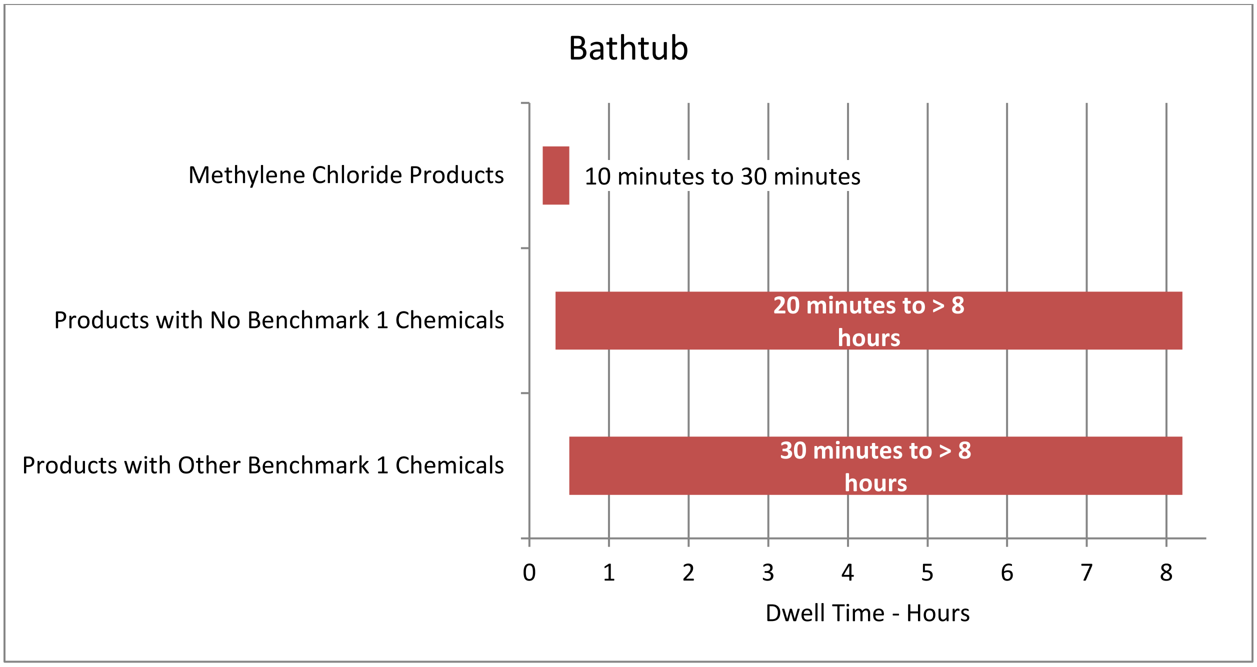

Figure 21: Performance Ranges for Bathtub Tiles

Asphalt/Tar Coatings

White pine wood planks measuring 3.5 inches wide by 15 inches long by 0.75 inch thick were used as the substrate material for creating the asphalt/tar test panels. The asphalt/tar material used was Karnac Professional Grade 19 Flashing Cement. The single coating of the asphalt/tar material was spread over the surface of the wood substrate using a metal trowel. The panels were then thermally aged in an oven for three weeks at 140 °F.

Table 36 shows the dwell times and cumulative test duration used for the asphalt/tar panels.

Table 36: *Dwell Times for Asphalt/Tar Panels*

Number of Dwell Periods	Dwell Time	Cumulative Test Duration
1	60 minutes	1 hour
2	60 minutes	2 hours
3	60 minutes	3 hours
4	60 minutes	4 hours
5	60 minutes	5 hours
6	60 minutes	6 hours
7	60 minutes	7 hours
8	60 minutes	8 hours
9	16 hours	24 hours

The long 16-hour dwell times were used to enable the tests to continue overnight while there were no lab staff available to check the results. A watch glass was used to cover the test area for the 16-hour dwell times so that the coating removal product would not dry out.

Table 37 shows the extended dwell time results for the asphalt/tar test panels. The results are sorted from fastest to slowest performance. The coating removal products tested include general purpose products as well as products specifically marketed for asphalt/tar applications (e.g., Karnak).

Table 37: *Asphalt/Tar Test Panel Extended Dwell Time Test Results*

Supplier	Product	Product Category	Dwell Time (to achieve greater than 90% substrate exposure)
WM Barr	Klean Strip Premium with MC	Methylene chloride	3 – 4 hours
DS Super Remover	New Generation	No Benchmark 1	3 – 4 hours
Savogran	Strypeeze with MC	Methylene chloride	3 – 4 hours
Savogran	Superstrip with MC	Methylene chloride	3 – 4 hours
WM Barr	Strip X	Methylene chloride	3 – 4 hours
WM Barr	Kwik Strip	Other Benchmark 1	3 – 4 hours
Karnak	Karna Klean Asphalt & Tar Remover	No Benchmark 1	4 – 5 hours
WM Barr	Goof Off Pro Strength Remover	Other Benchmark 1	4 – 5 hours
Goo Gone	Pro Power Goo & Adhesive Remover	No Benchmark 1	5 – 6 hours
Packaging Services	STRP Max	Other Benchmark 1	5 – 6 hours
WM Barr	Aircraft Remover with No MC	No Benchmark 1	5 – 6 hours
Sunnyside	2 Minute Remover no MC	Other Benchmark 1	7 – 8 hours
Dumond Chemicals	Smart Strip	No Benchmark 1	Greater than 24 hours
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	Greater than 24 hours
Sunnyside	Multistrip Advanced no NMP	No Benchmark 1	Greater than 24 hours
Sunnyside	Ready Strip Plus with NMP	Other Benchmark 1	Greater than 24 hours

The four methylene-chloride-based products all had a range of performance from 3 to 4 hours. The products with no Benchmark 1 chemicals had a range of performance from 3–4 hours (New Generation) to greater than 24 hours for several products, which overlaps with methylene-chloride-based products. The products with other Benchmark 1 chemicals had a range of performance from 3–4 hours (Kwik Strip) to greater than 24 hours (Ready Strip Plus), which also overlaps with methylene-chloride-based products. The range of performance for the different product categories is shown in Figure 21.

The testing was only conducted for a single asphalt/tar application. The performance results could vary if different asphalt/tar coatings are tested.

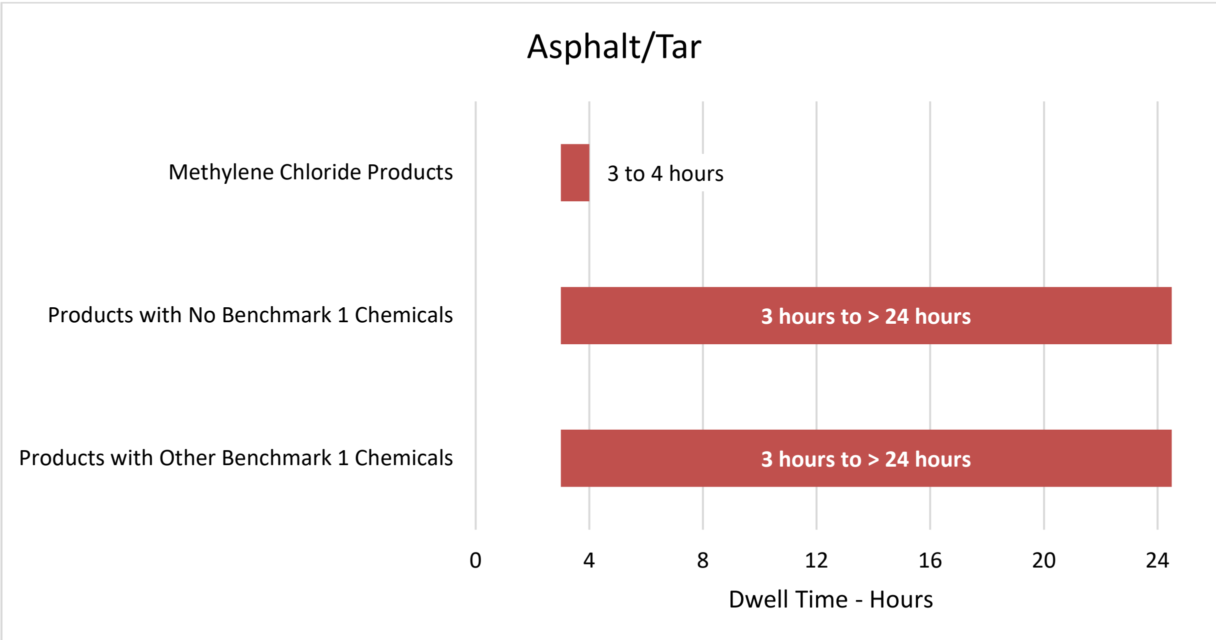

Figure 22: Performance Ranges for Asphalt/Tar Panels

Latex Splatter Coatings

White pine wood planks measuring 3.5 inches wide by 15 inches long by 0.75 inch thick were used as the substrate material for creating the latex splatter test panels. Two coats of beige Behr Premium Plus Paint & Primer in One Latex Paint were applied to the substrate surface. The latex splatter test panels were not thermally aged.

Figure 23 shows the coating layers used for the latex splatter test panels.

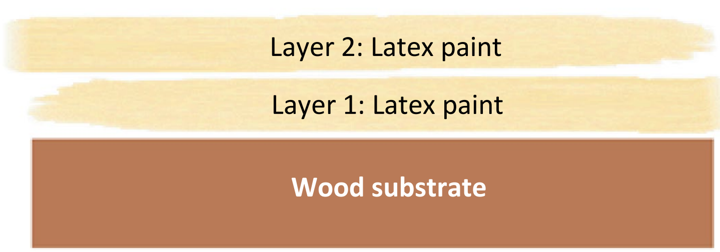

Figure 23: Latex Splatter Test Panel

Table 38 shows the dwell times and cumulative test duration used for the latex splatter test panels.

Table 38: *Dwell Times for Latex Splatter Test Panels*

Number of Dwell Periods	Dwell Time	Cumulative Test Duration
1	5 minutes	5 minutes
2	5 minutes	10 minutes
3	5 minutes	15 minutes
4	15 minutes	30 minutes
5	15 minutes	45 minutes
6	15 minutes	1 hour

Table 39 shows the extended dwell time results for the latex splatter test panels. The results are sorted from fastest to slowest performance.

Table 39: *Latex Splatter Test Panel Extended Dwell Time Test Results*

Supplier	Product	Product Category	Dwell Time (to achieve greater than 90% substrate exposure)
DS Super Remover	New Generation	No Benchmark 1	Less than 5 minutes
Sunnyside	2 Minute Remover no MC	Other Benchmark 1	Less than 5 minutes
WM Barr	Aircraft Remover no MC	No Benchmark 1	Less than 5 minutes
WM Barr	Goof Off Pro Strength Remover	Other Benchmark 1	Less than 5 minutes
WM Barr	Klean Strip Premium with MC	Methylene chloride	Less than 5 minutes
WM Barr	Kwik Strip	Other Benchmark 1	Less than 5 minutes
WM Barr	Strip X	Methylene chloride	Less than 5 minutes
Savogran	Strypeeze with MC	Methylene chloride	5 – 10 minutes
Savogran	Superstrip with MC	Methylene chloride	5 – 10 minutes
Packaging Services	Crown STRP Max	Other Benchmark 1	10 – 15 minutes
Dumond	Smart Strip	No Benchmark 1	15 – 30 minutes
Sunnyside	Multistrip Advanced no NMP	No Benchmark 1	15 – 30 minutes
WM Barr	Citristrip no NMP	No Benchmark 1	15 – 30 minutes
EZ Strip	EZ Strip Paint and Varnish Stripper	No Benchmark 1	30 – 45 minutes
Sunnyside	Ready Strip Plus with NMP	Other Benchmark 1	30 – 45 minutes

The methylene-chloride-based products had a range of performance of less than 5 minutes (Premium with MC and Strip-X) to 5–10 minutes (Strypeeze with no MC and SuperStrip with no MC). The products with no Benchmark 1 chemicals had a range of performance from less than 5 minutes (New Generation) to 30–45 minutes (EZ Strip Paint and Varnish Stripper), which overlaps with methylene-chloride-based products. The products with other Benchmark 1 chemicals had a range of performance from less than 5 minutes (several products) to 30–45 minutes (Ready Strip Plus), which overlaps with methylene-chloride-based products. The range of performance for the different product categories is shown in Figure 24.

The testing was only conducted for a single latex splatter application. The performance results could vary if different latex splatter coatings are tested.

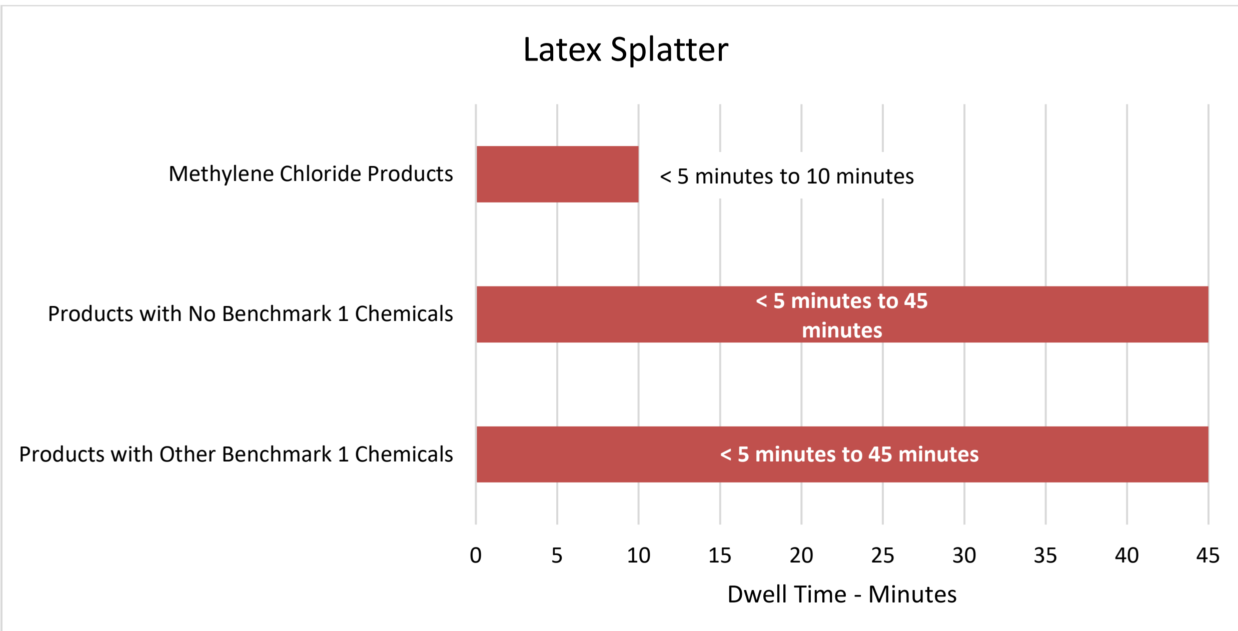

Figure 24: Performance Ranges for Latex Splatter Panels

Furniture Refinishing

A methylene chloride comparison test was conducted at the Belcastro Furniture Refinishers facility located in Tyngsboro, Massachusetts. A wood table with a varnish coating was selected by Belcastro for a hand stripping test. The type of varnish and the number of layers of varnish on the table was not known. The dwell time and products to be tested were determined by Belcastro. The application and the removal of the coating removal products during the test was conducted by an employee of Belcastro.

Three different coating removal products were used for this test: Benco B7 with Methylene chloride, Super Remover New Generation, and Super Remover Professional Grade. This testing was conducted as part of the research into safer solvent blends. Due to time constraints, additional coating removal products were not included in the evaluation. The coating removal samples used for the test were fresh and not previously used for other coating removal projects.

The coating removal products were applied using a paint brush to the top surface of the table. The coating removal products were applied to separate areas on the table surface. The coating removal products remained on the table surface for a five-minute dwell time, and were then scraped and removed with a plastic spatula. A substrate visibility rating from 0% to 100% was then provided for each test area on the table surface. The table surface after the scraping process is shown in Figure 24.

Figure 25: Table with Varnish Coating

The results of the test are shown in Table 40. For this particular test, the two coating removal products without methylene chloride (the Super Remover products) performed better than the coating removal product with methylene chloride (Benco B7). However, this was a limited test for a single furniture-refinishing application. Furniture refinishing encompasses a wide variety of applications, and the coating removal results could vary depending upon factors such as substrate material, coating type, number of coating layers, age of the furniture piece, and stripping method (hand, flow-over, or dip tank).

Table 40: *Methylene Chloride Comparison Test Results for Furniture Refinishing*

Supplier	Product	% Substrate Exposure After 5 Minute Dwell
Benco	B7 with Methylene Chloride	30%
Super Remover	New Generation	80%
Super Remover	Professional Grade	95%

Requirement 6: Penetration of Multilayer Coatings

Coating penetration is an important consideration for removing multiple coating layers in a single application of a coating removal product. Penetrating multiple coating layers and breaking the bond between the first coating layer and substrate make it easy to remove all layers with a scraper. Coating penetration is a function of the molar volume and the Hansen hydrogen bonding parameter. In general, the smaller the molar volume, the better the coating penetration, and the lower the Hansen hydrogen bonding parameter, the better the coating penetration (Young, 2011).

The solvents selected for the research into safer formulations were composed of chemicals that have small molar volumes so that they could penetrate the various polymer coatings. Based on the results of numerous tests, it was found that the ability of the solvent blends to effectively strip multi-layer coatings was significantly decreased after the molar volume size of the solvent blend exceeded 80 ml/mol. Methylene chloride has a molar volume of 64 ml/mol. The solvents chosen for the LO3 formulation—DMSO (71 ml/mol), methyl acetate (80 ml/mol), and 1,3 dioxolane (70 ml/mol)—have molar volume sizes less than or equal to 80 ml/mol. Many of the chemicals typically found in commercially available alternative coating removal formulations have a molar volume size much greater than 80 ml/mol, such as NMP (96 ml/mol), benzyl alcohol (104 ml/mol), dimethyl glutarate (152 ml/mol), and d-limonene (163 ml/mol).

The range of hydrogen bonding parameter values in the HSPiP database is 0 to 42.7 $MPa^{1/2}$ (HSPiP, 2019). Although water has a low molar volume (18 ml/mol), it has a very high hydrogen bonding parameter (42.3 $MPa^{1/2}$), and therefore is not an effective penetrant of polymer matrices found in coating materials. Conversely, d-limonene has a low hydrogen bonding parameter (4.3 $MPa^{1/2}$) but has a high molar volume (163 ml/mol), which reduces its ability to penetrate coatings. Methylene chloride has a low hydrogen bonding parameter (7.1 $MPa^{1/2}$) and a low molar volume (64 ml/mol), which makes it an effective penetrator of coating materials. Table 41 shows the molar volume and hydrogen bonding parameters for chemicals commonly used in coating removal products (Abbott, 2019).

Table 41: *Molar Volumes and Hydrogen Bonding Parameters*

Chemical Used in Coating Removal Products	CAS Number	Molar Volume (ml/mol)	Hydrogen Bonding Hansen Solubility Parameter ($MPa^{1/2}$)
Acetone	67-64-1	74	7
Ammonia	7664-41-7	25	18.8
Benzyl alcohol	100-51-6	104	13.7
2-(2-butoxyethoxy) ethanol (DEGME)	112-34-5	170	10.6
Dimethyl adipate	627-93-0	168	8.5
Dimethyl carbonate	616-38-6	85	9.7
Dimethyl glutarate	1119-40-0	152	8.3
Dimethyl succinate	106-65-0	135	8.8
Dimethylformamide (DMF)	68-12-2	77	11.3
D-limonene	5989-27-5	163	4.3
1,3 Dioxolane	646-06-0	70	9.3
Dimethyl sulfoxide (DMSO)	67-68-5	71	10.2
Ethanol amine	141-43-5	60	21
Ethyl benzene	100-41-4	123	1.4
Formic acid	64-18-6	38	14
Methanol	67-56-1	41	22.3
Methyl acetate	79-20-9	80	7.6
Methylene chloride	75-09-2	64	7.1
Naphthalene	91-20-3	131	5.9
NMP	872-50-4	97	7.2
Tetrahydrofuran	109-99-9	81	8
Thiophene	110-02-1	79	7.8
Toluene	108-88-3	107	2.0
Triethyl phosphate	78-40-0	171	9.2
Water	7732-18-5	18	42.3

Requirement 7: Shelf Life

Coating removal products are typically composed of several solvents and several chemical additives such as evaporation barriers and thickeners. The integrity of the product is maintained if the solvents and additives are uniformly dispersed within the product. When ingredients are separated and not uniformly dispersed, the performance can be compromised. The coating removal product should exhibit long-term stability, and should not experience separation of the product ingredients over extended periods of time. From a customer perspective it is more desirable for coating removal products to not require shaking prior to each use, and to not have a short-term product expiration date. Many coating removal product containers are not translucent and it is difficult to determine if the product is adequately mixed after shaking. A short expiration date may require the consumer to purchase additional product if the expiration date is exceeded prior to using up all of the product content.

To evaluate the shelf life, coating removal products were shaken for 60 seconds and then approximately 50 ml of product was poured into clear glass bottles. The bottles were examined once per week over a 8-month duration to determine if the product ingredients had separated into distinct layers within the clear glass bottle. Table 42 shows the results of this ingredient separation test. Most coating removal products did not exhibit ingredient separation; however, Sunnyside Hi Speed Ready Strip, Sunnyside 2 Minute Remover without MC, Sunnyside Advanced Multi Strip without NMP, WM Barr Kwik Strip, and WM Barr KleanStrip Strip X did exhibit ingredient separation. To help mitigate this issue, four of the five products had language on labels to shake (Kwik Strip, Hi Speed Ready Strip, Strip X) or stir (Advanced Multi Strip without NMP) the product before using. Further, the Kwik Strip product label states: "Dispose of product within 3 months of opening."

Table 42: *Ingredient Separation*

Supplier	Product	Ingredient Separation Observed	Time Period Before Separation Occurred
3M	Safest Stripper	No	No separation
DS Super Remover	New Generation	No	No separation
Dumond	Smart Strip	No	No separation
Ecosafety	Ecofast	No	No separation
EZ Strip	EZ Strip Paint and Varnish Stripper	No	No separation
Franmar	Blue Bear with Safenol	No	No separation
Minwax	Antique Furniture Refinisher	No	No separation
Motsenbocker	Lift-off Paint & Varnish Stripper	No	No separation
Packaging Services	Crown STRP Max Paint Strip. Gel	No	No separation
Packaging Services	Crown STRP Sure	No	No separation
Savogran	SuperStrip with MC	No	No separation
Rust-Oleum	Watco Furniture Refinisher	No	No separation
Sunnyside	Hi Speed Ready Strip	Yes	1 week
Sunnyside	Advanced Multi Strip without NMP	Yes	10 weeks
Sunnyside	2 Minute Remover without MC	Yes	1 week
WM Barr	Kwik Strip	Yes	1 week
WM Barr	Citristrip (no NMP)	Yes	34 weeks
WM Barr	Green Paint & Varnish Safer Stripper	No	No separation
WM Barr	KleanStrip Strip X	Yes	3 weeks

III. Conclusions

Based on the results from the GreenScreen chemical hazard assessment method, the solvents used in numerous commercially available coating removal products with no Benchmark 1 chemicals have overall EHS profiles that are safer than Benchmark 1 solvents such as methylene chloride, DMF, NMP, toluene, methanol, xylene, naphthalene, ethyl benzene, and Stoddard solvent. Numerous coating removal products with no Benchmark 1 chemicals also meet requirements for fire hazard and VOC compliance.

Technical performance testing was conducted for a variety of coating applications for wood, masonry, boat, CARC, adhesive, bathtub tiles, asphalt/tar, automotive, and latex splatter applications. The testing results showed that coating removal products with methylene chloride delivered a wide range of coating removal performance speeds. The testing results also showed that coating removal products with no Benchmark 1 chemicals delivered a wide range of coating removal performance speeds, including stripping performance overlapping with methylene chloride-based coating removal products for all coating applications tested. Numerous coating removal products with no Benchmark 1 chemicals also met the shelf life performance requirement.

Based on retail prices identified from a limited product review, there was considerable overlap in price ranges for the following three coating removal product categories: 1) products with methylene chloride, 2) products with other Benchmark 1 chemicals, and 3) products without any Benchmark 1 chemicals.

Based on this evaluation, there are safer, cost-effective, and performance-effective coating removal products commercially available that are viable replacements for coating removal products containing Benchmark 1 chemicals.

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Appendix 1: Coating Removal Product Solvents and TURA

Table A1-1 lists the solvents used in coating removal products that are listed under the Massachusetts Toxics Use Reduction Act (TURA). The table indicates whether a chemical is designated as a higher hazard substance and also includes the threshold amount required for each chemical.

Table A1-1: *Solvents Used in Coating Removal Products*

Solvent	CAS Number	MA TURA Higher Hazard	Otherwise Used Threshold (pounds)	Manufactured and Processed Threshold (pounds)
2-(2-butoxyethoxy) ethanol	112-34-5		10,000	25,000
2-butoxyethanol	111-76-2		10,000	25,000
Acetone	67-64-1		10,000	25,000
Ammonia	7664-41-7		10,000	25,000
Formic acid	64-18-6		10,000	25,000
Sodium hydroxide	1310-73-2		10,000	25,000
Dimethyl formamide	68-12-2	✓	1,000	1,000
Ethyl benzene	100-41-4		10,000	25,000
Methanol	67-56-1		10,000	25,000
Methylene chloride	75-09-2	✓	1,000	1,000
Naphthalene	91-20-3		10,000	25,000
NMP	872-50-4		10,000	25,000
Potassium hydroxide	1310-58-3		10,000	25,000
Tetrahydrofuran	109-99-9		10,000	25,000
Toluene	108-88-3		10,000	25,000
Xylene	1330-20-7		10,000	25,000

Appendix 2: GreenScreen for Safer Chemicals

GreenScreen for Safer Chemicals, developed by Clean Production Action, is a comparative chemical hazard assessment method. In this method, several human health, environmental toxicity, fate, and physical hazard endpoints are evaluated for each chemical.

Group I Human Health endpoints reflect priorities that are consistent with national and international governmental regulations, and cover hazards that can lead to chronic or life-threatening effects or adverse impacts that are potentially induced at low doses and transferred between generations. Group II and II★ Human Health endpoints reflect hazards that are also important for understanding and classifying chemicals. Typically, Group II hazards may be mitigated. Group II and II★ are differentiated from one another in the Benchmarking system because Group II endpoints have 4 hazard levels (i.e., vH, H, M and L) while Group II★ endpoints have 3 hazard levels (i.e., H, M and L) and are evaluated based on repeated exposure. Environmental Toxicity and Fate endpoints include Acute and Chronic Aquatic Toxicity, Persistence and Bioaccumulation potential. Physical hazard endpoints include Flammability and Reactivity and are based on Globally Harmonized System (GHS) criteria. Table A2-1 shows the hazard endpoints used in the GreenScreen for Safer Chemicals methodology (CPA, 2018).

Table A2-1: *GreenScreen Hazard Endpoints*

Hazard Grouping	Hazard Endpoint (Abbreviation)
Human Health Group I	Carcinogenicity (C) Mutagenicity and Genotoxicity (M) Reproductive Toxicity (R) Developmental Toxicity, including Neurodevelopmental Toxicity (D) Endocrine Activity (E)
Human Health Group II	Acute MammalianToxicity (AT) Systemic Toxicity & Organ Effects (ST-single) Neurotoxicity (N-single) Skin Irritation (IrS) Eye Irritation (IrE)
Human Health Group II★	Systemic Toxicity & Organ Effects, Repeated Exposure sub-endpoint (ST-repeated) Neurotoxicity – Repeated Exposure sub-endpoint (N-repeated) Skin Sensitization (SnS) Respiratory Sensitization (SnR)
Environmental Toxicity & Fate	Acute Aquatic Toxicity (AA) Chronic Aquatic Toxicity (CA) Persistence (P) Bioaccumulation (B)
Physical Hazards	Reactivity (Rx) Flammability (F)

The GreenScreen assessments are conducted in the following 6 steps (CPA, 2018):

Step 1 – Identify Chemical to Assess
Chemicals used in coating removal product formulations were assessed.

Step 2 – Research
Assessing chemicals is accomplished by examining comprehensive toxicological data, checking GreenScreen Specified Lists, and using estimated data from suitable analogs or modeled data where measured data are lacking for the parent chemical.

Step 3 – Classify Hazards
Step 3a – Classify hazard level for each hazard endpoint.
The GreenScreen Chemical Hazard Criteria are used to classify the hazard level for the parent chemical as High (H), Moderate (M), Low (L) or in some cases very High (vH) or very Low (vL) for each hazard endpoint. The color scheme shown in Figure A2-1 was used to indicate the hazard score assigned for each hazard endpoint.

Hazard Score	
Very High	vH
High	H
Moderate	M
Low	L
Very Low	vL
Data gap	DG

Figure A2-2: Hazard Scores

Step 3b – Determine level of confidence (high or low) for each hazard level assigned.
The level of confidence is determined by data source(s), data quality, and expert judgment considering the strength of evidence.

Step 3c – Assign a data gap (DG) to each hazard endpoint with insufficient information.
When assessing chemicals, it is ideal to use a complete set of publicly available data covering all hazard endpoints. In reality, most chemicals have insufficient data to assess and classify all of the hazard endpoints.

Step 3d – Document hazard levels.
It is essential to provide detailed documentation of the supporting data and rationale for all hazard levels in an assessment report.

Step 3e – Fill in the Hazard Summary Table.
Fill in the designated hazard level for each hazard endpoint in the respective box of the Hazard Summary Table.

Step 4 – Identify Environmental Transformation Product(s)
The GreenScreen Benchmark score for a chemical includes the evaluation of the chemical itself (i.e. parent chemical) and any feasible and relevant environmental transformation product(s) of the parent chemical.

Step 5 – Assess Environmental Transformation Product(s)
Assess each feasible and relevant environmental transformation product identified in Step 4 above using the GreenScreen List Translator at a minimum. The GreenScreen List Translator™ is an automated tool that provides an abbreviated version of GreenScreen for Safer Chemicals. A GreenScreen List Translator score of "LT-1" means the hazard classifications for a given chemical meet one or more of the GreenScreen Benchmark-1 criteria and this information is based on authoritative lists; if a full GreenScreen assessment were conducted, the chemical would most likely be a Benchmark-1 chemical (CPA, 2019).

Step 6 – Assign a GreenScreen Benchmark™ Score
First, assign a preliminary Benchmark score by comparing the completed Hazard Summary Table for the chemical to the Benchmark Criteria. Next, perform a data gap analysis. Consider feasible and relevant environmental transformation products to assign a final Benchmark score. The Benchmark scores are shown in Figure A2-3.

Benchmark 1: Chemical of High Concern - Avoid

Benchmark 2: Use but Search for Safer Substitutes

Benchmark 3: Use but Still Opportunity for Improvement

Benchmark 4: Prefer – Safer Chemical

Figure A2-3: GreenScreen Benchmark Scores

Appendix 3: Hansen Solubility Parameters

The TURI project team used the Hansen Solubility Parameters (HSP) theory to help identify solvent blends with the desired solvency parameters (diffusion, polarity, and hydrogen bonding). The HSP-based approach is an efficient method to rapidly identify safer and effective alternatives to methylene chloride and NMP in coating removal products.

The HSP approach was used to characterize the solvency of methylene chloride and potential alternatives, and is based on three distinctive forms of inter-molecular force:

1) Dispersion forces (δD): All atoms are surrounded by electron "clouds." The electron cloud is, on average, evenly distributed around the atom. At a given instant, however, the electron distribution may be uneven. This temporary polarization results in attractive interactions with nearby atoms.
2) Polar forces (δP): Dipole moments are created when atoms of the same molecule have different electronegativities.
3) Hydrogen bond forces (δH): This force exists between hydrogen atoms and other atoms present in adjacent molecules.

These three parameters are used to describe solvent and solute interactions. Each parameter can be used as an axis in three-dimensional solubility space so that each solvent and solute can be represented as points and spheres in three-dimensional solubility space. The distance between HSP points in solubility space is calculated as follows:

$$\text{Distance}^2 = 4(\delta D_1-\delta D_2)^2 + (\delta P_1-\delta P_2)^2 + (\delta H_1-\delta H_2)^2$$

HSP values are based on the principle that "like dissolves like," meaning that the closer the solute and solvent are in three-dimensional solubility space, the greater the likelihood that the solvent will be effective. If a single solvent with the desired HSP values does not exist, then mixing together multiple solvents with different HSP values can generate a solvent blend with the desired HSP values (Abbott, 2013).

Hansen Solubility Parameters in Practice (HSPiP) software is a commercially available software program that enables the user to more rapidly and effectively apply the Hansen Solubility Parameters theory (Abbott, 2019). The HSPiP software can be used to quickly scan through thousands of chemicals to find the optimal solvent and solvent blends for the target HSP values. The larger the molecule (molar volume), the more it will affect kinetics and slow down the dissolution reaction. With other things being equal, small solvents dissolve better than large solvents. Smaller molecules penetrate more easily into the polymer network typically present in coating materials. This is one reason that methylene chloride performs so well in coating removal applications. For the coating removal process, the size of the molecule is important to enhance the transport through multiple paint layers, so that the solvent can penetrate the paint and attack the adhesive bond to the substrate (Luey, 2000).

Appendix 4: Dermal Exposure

Human skin is composed of two primary layers: 1) the outer nonvascular epidermis, and 2) the underlying dermis. The first and most important barrier to absorption of chemicals is the outermost layer of the epidermis is the stratum corneum (Ngo, 2010). Once the chemical is present on the skin, then skin absorption can occur by two distinct pathways:

1) **Directly via skin appendages (sweat glands, sebaceous glands, and hair follicles)**. This pathway is referred to as "shunt diffusion" where dermal penetration can occur directly through the skin appendages. The total cross-sectional area of skin appendages has been estimated to be 0.1 – 1.2% of the area of the skin, however, studies have shown significant differences in overall skin absorption due to this pathway. Skin appendages also appear to be an important mechanism by which larger molecules may penetrate the skin. Further, the contribution of skin appendages to dermal absorption is greatest in the initial period following application, but at later stages, diffusion through the stratum corneum predominates and determines the steady state tissue concentrations. For example, the hair follicles are the only pathway for fast dermal absorption of caffeine during the first 20 minutes after topical application (Ngo, 2010; Shen, 2014).

2) **Passive diffusion through the epidermis**. Chemicals applied to the skin surface pass through the stratum corneum via passive diffusion. There are many categories of chemicals that have rapid skin absorption via passive diffusion through the epidermis such as alcohols (i.e. benzyl alcohol), glycols, organosulfurs (i.e. DMSO), esters, ketones (i.e. acetone), terpenes, acids (i.e. formic acid), pyrrolidones (i.e. NMP), amines, carbonates (dimethyl carbonate) and amides (i.e. DMF).

The significance of skin absorption for a target compound via passive diffusion is evaluated by determining the skin permeability (K_p) of the compound in the stratum corneum. Quantitatively, the K_p describes the rate of chemical permeation through the outermost layer of the epidermal skin (Chen, 2018).

The skin permeability coefficient can be determined by one of the following three methods:

1) **In vivo experimental testing, with humans or animals.** This involves the indirect measurements of radioactivity within different body tissues and fluids following the topical application of a radiolabeled chemical (Ngo, 2010). This is the method with the highest reliability; however, the availability of results for these types of tests are limited since they have significant practical, ethical, and cost restrictions (Schenk, 2018). In vivo data are not available for all the commonly used solvents in coating removal products. Therefore, this method was not used to compare skin absorption rates for chemicals in coating removal products.

2) **In vitro experimental testing**. In vitro testing techniques typically involve placing a piece of excised skin into a diffusion chamber, applying a radiolabeled compound to one side of the skin, and then quantifying the amount of labeled material found in the collection fluid on the other side of the skin. The utility of experimental data on dermal chemical uptake from in vitro studies

in the scientific literature is also limited. In several instances, different researchers report different skin absorption data for the same chemical. These discrepancies occur since there are significant skin absorption differences due to variables in the donor skin, such as animal species (pig, rat, monkey, mouse, etc.), anatomical location on the body (forearm, forehead, etc.), pre-existing skin damage (aging, disease, etc.), and skin thickness (full thickness, epidermal layer only, etc.). The measured absorption rates also depend on various test procedures such as the form in which the chemical is applied, the concentration and solubility of the chemical, ambient test conditions (temperature, humidity, airflow, etc.), the effects of the chemical on the physiological status of the skin, the exposure duration, the use of occlusion, the type of receptor fluid, and the sampling time (Shen, 2014; Ngo, 2010). In vitro data with consistent test methods are not available for all the commonly used solvents in coating removal products. Therefore, this method was not used to compare skin absorption rates for chemicals in coating removal products.

3) **Quantitative structure activity relationship (QSAR) modelling**. This modelling is also referred to as Quantitative Structure Permeability Relationships (QSPRs) for skin permeation applications. When relevant experimental data are not available, mathematical modeling can be used to predict the amount of a substance permeating through the skin. Several studies have found that the dermal permeability coefficient can be related to physicochemical properties of chemicals (Kupczewska-Dobecka, 2010). Although further improvement of predictive equations is necessary, QSPRs provide a useful tool for determining skin permeability coefficients for dermal absorption estimations (Ngo, 2010). QSAR skin permeation modelling was used to compare dermal penetration across coating removal chemicals.

The Potts and Guy equation is a commonly used modelling approach to estimate the skin permeability coefficient, K_p with units centimeters per hour (cm/h). For example, this equation is used for the National Institute for Occupational Safety and Health (NIOSH) Skin Permeation Calculator. The skin permeability coefficient is a function of molecular weight (MW) and lipophilicity, and is calculated using the equation below (Guy, 2010).

$$\text{Log } K_p \text{ (cm/hr)} = -2.7 + 0.71 * \log K_{ow} - 0.0061 * MW$$

Molecular weight has units g per mole (g/mol)

The octanol/water partition coefficient (K_{ow}) is used to measure lipophilicity and is defined as the ratio of a chemical's concentration in the octanol phase to its concentration in the aqueous phase of a two-phase octanol/water system. K_{ow} is unitless.

$$K_{ow} = \text{Concentration in octanol phase / Concentration in aqueous phase}$$

The maximum flux (J_{max}) is the rate at which a chemical can passively diffuse across a unit area of skin. The maximum flux has units milligrams per square centimeter per hour (ug/cm^2/h) and is a function of K_p and water solubility (C_{sat}). The maximum flux is calculated as follows (Guy, 2010):

$J_{max} = K_p * C_{sat} * 1{,}000$

Where C_{sat} is the water solubility with units of milligrams per cubic centimeter (mg/cm^3). This value represents the concentration of the chemical in a saturated aqueous solution.

Table A4-1 shows the Log K_{ow} and water solubility values for the chemicals found in coating removal products (PubChem, 2019).

Table A4-1: *Log K_{ow} and Water Solubility Values*

Chemical	Log K_{ow}	Source	Water Solubility (mg/cm3)	Source
2-butoxyethanol	0.83	PubChem	1,000	PubChem
Acetic acid	-0.17	PubChem	1,000	PubChem
Acetone	-0.24	PubChem	1,000	PubChem
Formic acid	-0.54	PubChem	1,000	PubChem
1,3 Dioxolane	-0.37	PubChem	1,000	PubChem
Methanol	-0.77	PubChem	1,000	PubChem
Triethyl phosphate	0.8	PubChem	500	PubChem
NMP	-0.38	PubChem	1,000	PubChem
Methyl acetate	0.18	PubChem	243	PubChem
Benzyl alcohol	1.1	PubChem	43	PubChem
Dimethyl carbonate	0.23	PubChem	138	PubChem
DMSO	-1.35	PubChem	1,000	PubChem
Methylene chloride	1.25	PubChem	13	PubChem
Dimethyl succinate	0.35	PubChem	123	ECHA REACH Dossier
Diethylene glycol monomethyl ether	-1.18	PubChem	1,000	PubChem
Toluene	2.73	PubChem	0.53	PubChem
Ethyl benzene	3.15	PubChem	0.17	PubChem
D-limonene	4.57	PubChem	0.01	PubChem
Dimethyl adipate	1.03	PubChem	4.00	ECHA REACH Dossier
Naphthalene	3.3	PubChem	0.03	PubChem

Table A4-2 shows the calculated skin permeability coefficient (K_p) and maximum flux (J_{max}) values for chemicals found in coating removal products. The chemicals are sorted by highest maximum flux (2-butoxyethanol with a J_{max} of 1,473.7) to lowest maximum flux (naphthalene with a J_{max} of 2.3). The higher the maximum flux (J_{max}) value, the greater the skin permeation across the stratum corneum for a given chemical. All chemicals listed in Table 7 have J_{max} greater than zero, meaning that some level of dermal penetration exists for each chemical.

Table A4-2: *Skin Permeability Results for Solvents in Coating Removal Products*

Chemical	Molecular Weight (g/mol)	Log K_{ow}	Log K_p	k_p (cm/h)	Water Solubility (mg/cm^3)	J_{max} ($ug/cm^2/h$)
2-butoxyethanol	118.18	0.83	-2.83	1.47E-03	1,000	1,400
Acetic acid	60.05	-0.17	-3.19	6.50E-04	1,000	650
Acetone	58.08	-0.24	-3.22	5.96E-04	1,000	600
Formic acid	46.02	-0.54	-3.36	4.32E-04	1,000	430
1,3 Dioxolane	74.08	-0.37	-3.41	3.85E-04	1,000	390
Methanol	32.04	-0.77	-3.44	3.61E-04	1,000	360
Triethyl phosphate	182.16	0.8	-3.24	5.71E-04	500	290
NMP	99.13	-0.38	-3.57	2.66E-04	1,000	270
Methyl acetate	74.08	0.18	-3.02	9.46E-04	243	230
Benzyl alcohol	108.14	1.1	-2.58	2.64E-03	43	110
Dimethyl carbonate	90.08	0.23	-3.09	8.20E-04	138	110
DMSO	78.13	-1.35	-4.14	7.33E-05	1,000	73
Methylene chloride	84.93	1.25	-2.33	4.67E-03	13	62
Dimethyl succinate	146.14	0.35	-3.34	4.54E-04	123	56
Diethylene glycol monomethyl ether	120.15	-1.18	-4.27	5.36E-05	1,000	54
Toluene	92.14	2.73	-1.32	4.75E-02	0.53	25
Ethyl benzene	106.17	3.15	-1.11	7.74E-02	0.17	13
D-limonene	136.24	4.57	-0.29	5.17E-01	0.01	7.1
Dimethyl adipate	174.20	1.03	-3.03	9.30E-04	4.00	3.7
Naphthalene	128.17	3.3	-1.14	7.26E-02	0.03	2.3

Appendix 5: Fire Hazard

Flash Point

"Flash point" is defined by U.S. Occupational, Safety and Health Administration and the U.S. Department of Transportation in the U.S. Code of Federal Regulations as: "The minimum temperature at which a liquid gives off vapor within a test vessel in sufficient concentration to form an ignitable mixture with air near the surface of the liquid" (OSHA, 2009; USDOT, 2009). There are several flash point testing methods. Two common flash point testing methods used for coating removal products are:

1) ASTM Standard D93 Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester (ASTM, 2016)

2) ASTM Standard D3278 Standard Test Methods for Flash Point of Liquids by Small Scale Closed-Cup Apparatus (ASTM, 2011)

The Pensky-Martens Closed Cup method is conducted in a closed vessel while the coating removal product is continually stirred. The stirring is accomplished by operating two bladed metal propellers within the test vessel (ASTM, 2016). Coating removal products are not stirred during their use for coating removal. Instead, they are applied to a painted surface in a manner that precludes stirring. Coating removal product manufacturers typically recommend that coating removal products be applied in one direction with a single brush stroke. The continual stirring of the sample during flash point testing disrupts the evaporation barrier from forming and consequently enables the evaporation of significant amounts of solvent vapor from the coating removal product sample, resulting in a low flash point measurement for coating removal products with evaporation barriers.

The Small Scale Closed-Cup method is also conducted within a closed vessel, and the coating removal product is not stirred. The sample is injected into the closed vessel via a syringe and then tested after one minute has elapsed (ASTM, 2011). However, the evaporation barrier is disrupted as the sample passes through the syringe into the closed vessel. The evaporation barrier typically takes about one to two minutes to be fully re-established. Since this flash point test is conducted one minute after a sample is inserted, it is executed before the evaporation barrier is fully in place. Consequently, this enables the evaporation of solvent vapor at the surface of the coating removal product sample, resulting in a low flash point measurement for coating removal products with evaporation barriers.

Fire Hazard Test Method

The intent was to create a challenging test environment to evaluate the fire hazard of various coating removal products. The tests were conducted within a glove box to simulate a small confined working space (see Figure A5-1). The glove box walls were made of clear polycarbonate so that all events within the glove box were clearly visible from outside the glove box. Also, the glove box provided an impact- and shatter-resistant safety barrier between the combustion event and the operator and observers. The internal dimensions of the glove box were 3 feet wide by 3 feet long by 3 feet high (0.91m x 0.91m x 0.91m) resulting in a volume of 27 cubic feet (765 liters). The glove box was completely enclosed and all seams were sealed with silicone to prevent air entering or leaving the glove box during testing. In addition, there was no fan or any other type of forced ventilation present within the glove box during the testing. A sealable door opening that was 28" high and 28" wide (0.71m x 0.71m) was used to introduce and remove the test materials from the glove box. Drybox gloves were installed onto a hinged panel cover and used by the operator during testing. The glove box had a movable ignitor arm to accommodate varying the location of the ignition source.

Figure A5-1: Glove box with test materials

The testing surface was an aluminum tray with a one inch high raised edge so that the coating removal product did not spill over the edge. The inside dimensions of the aluminum tray that was the actual test surface area was 17 inches wide by 25 inches long (0.43m x 0.64m), resulting in a test area of 2.95 square feet (0.27 sq. meters). For the tests, a coating removal product thickness of 1 gallon per 50 square feet was used (3.79L per 4.65 sq. meters). This resulted in a volume of 223 ml for the first application, and 223 ml for the second application of each test. For the two application cycles, a total of 446 ml of coating removal product was used. The test surface was placed in the center of the floor of the glove box for the testing.

The fire hazard testing of the coating removal products included the following nine steps:

1) Materials Insertion: The operator opened the glove box door and inserted the clean test surface, a paint brush, a closed glass container with 446 ml of coating removal product, cloth rags, a plastic scraper, and a one gallon plastic disposal bucket without a lid. The glove box door was then closed and remained closed for steps 2 through 8.

2) First Application: The operator placed his arms into the glove box arms, grasped the glass container with the coating removal product, unscrewed the container lid, tipped the container, poured half of the removal product (approximately 223 ml) from the container onto the test surface, and screwed the lid back onto the container. The operator then spread the removal product evenly onto the test area surface with a paint brush, while brushing in one direction only. The operator then removed his arms from the glove box arms. The average time for the operator to conduct this step was approximately 3 minutes.

3) First Dwell: A thirty minute dwell time was conducted with the coating removal product residing undisturbed on the surface of the test area. An ignition source was applied inside the glove box at 5 minute intervals.

4) First Extraction: The operator placed his arms into the glove box arms, grasped the 6" plastic scraper, and extracted the coating removal product from the test area surface with the 6" plastic scraper onto cloth rags, and then deposited the cloth rags into the disposal bucket. The disposal bucket did not have a lid and remained open for the duration of the test. The average time for the operator to conduct this step was approximately 3 minutes.

5) Second Application: The operator then grasped the glass container with the coating removal product, unscrewed the container lid, tipped the container, poured the remaining half of the removal product (approximately 223 ml) from the container onto the test surface, and screwed the lid back onto the container. The operator then spread the removal product evenly onto the test area surface with a 2" paint brush, while brushing in one direction only. The operator then removed his arms from the glove box arms. The average time for the operator to conduct this step was approximately 3 minutes.

6) Second Dwell: A thirty minute dwell time was conducted with the coating removal product residing undisturbed on the surface of the test area. An ignition source was applied inside the glove box at 5 minute intervals.

7) Second Extraction: The operator placed his arms into the glove box arms, grasped the 6" plastic scraper, and extracted the coating removal product from the test area surface with the 6" plastic scraper onto cloth rags, and then deposited the cloth rags into the disposal bucket. The disposal bucket did not have a lid and remained open for the duration of the test. The operator then removed his arms from the glove box arms. The average time for the operator to conduct this step was approximately 3 minutes.

8) Final Ignition: Conducted one final ignition sequence.

9) Materials Removal: The operator opened the glove box door and took out the test surface, 2" paint brush, empty container of removal product, remaining cloth rags, 6" plastic scraper, and disposal bucket. The glove box inside air environment was thoroughly flushed at the conclusion of each test until the air environment was returned to ambient conditions. The glove box door and top vent

were opened and the glove box was purged by turning on the air nozzle attached to the glove box. The glove box was located under a 53,000 cfm hood and exhaust unit.

The total duration to conduct steps 2 through 8 was approximately 72 minutes.

The ignition source was provided at two locations within the glove box: 1) approximately 2 feet above the surface of the coating removal product near the center of the test area; and 2) approximately 6 inches above the surface of the coating removal product near the center of the test area.

The purpose of introducing a flame at these two locations was to determine if there were sufficient solvent vapors within the glove box to exceed the lower flammability limit and support a combustion event away from the test surface.

The following is the ignition sequence that was repeated every five minutes during the dwell time portion of the test:

- Flame ignited at 24 inches above test surface for 3 second duration
- Flame moved to next location while the flame remained ignited
- Flame located at 6 inches above test surface for 3 second duration

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