Identification of Safer Alternatives to Hazardous Solvents for Industrial Cleaning Applications in Kansas

TURI
TOXICS USE REDUCTION INSTITUTE
UMASS LOWELL

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Acknowledgments

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Executive Summary

Several hazardous halogenated and non-halogenated solvents are used in many facilities located throughout the state of Kansas. Many of these businesses use hazardous solvents as cleaning or dissolving solvents for fabricated metal products manufacturing and for machine manufacturing. The Toxics Use Reduction Institute (TURI) was contracted by the Kansas State University Pollution Prevention Institute (PPI), as part of an initiative to help two Kansas companies reduce their use of hazardous solvents, referred to as Company #1 and Company #2.

Company #1 is a manufacturing company that produces metal panels and honeycomb structures. There are different manufacturing processes for: 1) the aluminum parts and 2) the composite fiberglass honeycomb. In the first manufacturing process, the aluminum panels and aluminum honeycomb are soiled with Royco 27A grease. To remove the grease soil before the parts are used in the next production steps, Company #1 utilizes vapor degreasing with TCE as its cleaning solvent. In the second manufacturing process, the composite fiberglass honeycomb is soiled with Glyconol wax. To remove the wax soil before the composite fiberglass honeycomb is used in the next production steps, Company #1 utilizes vapor degreasing with PERC as its cleaning solvent.

Company #2 is an industrial coatings applicator. A fluid-resistant two-component epoxy primer from a major supplier is applied to aluminum-alloy panels. Their method of application is a compressed air siphoning paint gun. Cleaning excess debris off of their paneling after priming, but prior to paint application, is the first cleaning application that was requested by Company #2. This primarily focused on removal of small amounts of primer from the aluminum substrate. This cleaning is done with a quick manual wipe down using methyl ethyl ketone (MEK) on a cloth. The second cleaning application is cleaning wet paint from the paint applicator gun, primarily from the interior and around the nozzle.

TURI identified potential safer alternatives to replace the hazardous halogenated and non-halogenated solvents use by these two Kansas companies for cleaning applications. To help prevent the occurrence of regrettable substitutes, TURI conducted an environmental, health, and safety (EHS) assessment of alternative solvents and cleaners compared to current solvents using TURI's Pollution Prevention Options Analysis System (P2OASys) Hazard Assessment Tool. TURI then conducted performance testing of the alternative solvents and cleaners to validate cleaning performance for various contaminants and the material compatibility for various substrates.

Based on the EHS assessments and performance testing results, TURI provided recommendations for safer solvents and cleaning products for consideration by the two Kansas companies. Kansas State University PPI will use these recommendations for future on-site pilot testing and implementation of alternatives identified at the two Kansas companies.

I. Introduction

Background

Several hazardous halogenated and non-halogenated solvents are used in many facilities located throughout the state of Kansas. Many of these businesses use hazardous solvents as cleaning or dissolving solvents for fabricated metal products manufacturing and for machine manufacturing. The Toxics Use Reduction Institute (TURI) was contracted by the Kansas State University Pollution Prevention Institute (PPI), as part of an initiative to help Kansas companies reduce their use of hazardous solvents, to identify and conduct performance testing for two companies.

TURI and PPI provided the following services to identify and evaluate alternatives for two unnamed clients. Hereafter they shall be referred to as Company #1 and Company #2. Company #1 is seeking a replacement for trichloroethylene (TCE) and perchloroethylene (PERC), and Company #2 is seeking a replacement for methyl ethyl ketone (MEK).

- Test plan development based on criteria and process information provided by the company
- A site visit conducted by a Kansas State University PPI staff member to visually observe the process and facility space
- Use of Hansen Solubility Parameters in Practice (HSPiP) to identify potential alternatives for certain cleaning applications
- Identification of approximately 6-10 solvents, solvent blends, and/or commercially available alternative cleaners for performance testing
- Environmental, health, and safety (EHS) assessments of alternative solvents and cleaners compared to current solvents using TURI's Pollution Prevention Options Analysis System (P2OASys) Hazard Assessment Tool (see Appendix A for further details about this tool)
- Performance testing of the approximately 6-10 identified alternatives on standard test coupons (typically 2" x 4" flat substrates)
- Remote (via phone and email) review of testing results with Kansas PPI and company representatives
- Performance testing on parts for the best performing approximately 2 - 4 effective cleaners (only if parts provided by the company)
- A final report with a summary of testing, results, evaluations, and recommendations to be used by Kansas State PPI with future on-site pilot testing and implementation of alternatives identified.

Assessing the Alternatives

There are numerous criteria to be considered when identifying and evaluating potential alternatives to hazardous solvents. TURI used the following criteria to evaluate the feasibility of alternative solvents, solvent blends, and market available cleaners:

- **Performance and safety criteria.** The performance and safety criteria for hazardous solvent alternatives were provided by each of the Kansas companies involved in this initiative. The criteria were collected at the time of the site visit and through test request form documentation. The criteria were used by TURI to determine testing site-specific protocols for chemical classifications (e.g., aqueous, organic solvent) and

flammability requirements, as well as temperature, time, and method of cleaning (e.g., immersion, equipment agitation).

Environmental and human health criteria. Key environmental and human health criteria for solvents and cleaners as well as their byproducts were considered when identifying and evaluating hazardous solvent alternatives. All hazardous solvents were excluded from consideration due to high human health and environmental hazards. Alternative solvents and cleaner ingredients listed on the SDS were compared to the following criteria, which are consistent with avoiding very high hazard (6 – 10) P2OASys scores.

- The following human health endpoint values were considered not acceptable:
    a) Acute toxicity
        a. Inhalation - GHS Category 1 and 2
            i. LC50 - ≤500 ppm; gas/vapor - ≤10mg/l
        b. Skin - GHS Category 1 and 2; H310 - Fatal in contact with skin; H311 - Toxic in contact with skin; H312 - Harmful in contact with skin
            i. LC50 ≤1000 mg/kg
    b) Carcinogenicity
        a. GHS Category 1, 1A, 1B; H350 - May cause cancer (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)
        b. GHS Category 2; H351 - Suspected of causing cancer (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)
        c. IARC Category 1, 2A/2B
        d. EPA Class A-C
        e. OSHA Category 1 and 2
        f. ACGIH Category A1 and A2
        g. Listed on the Prop 65 List
    c) Mutagenicity/Teratogenicity
        a. GHS Category 1A and 1B; H340 - May cause genetic defects (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)
        b. GHS Category 2; H341 - Suspected of causing genetic defects (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)
    d) Reproductive/ Developmental Toxicity
        a. GHS Category 1A and 1B; H360 - May damage fertility or the unborn child (state specific effect if known) (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)
        b. GHS Category 2; H361 - Suspected of damaging fertility or the unborn child (state specific effect if known) (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard); H362 - May cause harm to breast-fed children (No related GHS category)
        c. Listed on the following
            i. ChemSec SIN List

ii. Prop 65 List

e) Endocrine disruption
   a. Listed on the following:
      i. ChemSec SIN List
      ii. The Endocrine Disruption Exchange (TEDX) List
      iii. European Union List of Endocrine Disruptors List

f) Sensitization
   a. Respiratory
      i. GHS Category 1; H334 - May cause allergy or asthma symptoms or breathing difficulties if inhaled
      ii. Listed on the Association of Occupational and Environmental Clinics (AOEC) List
   b. Skin
      i. GHS Category 1A and 1B; H317 - May cause an allergic skin reaction

g) Neurotoxicity and Target Organ Systemic Toxicity (TOST)
   a. Specific Target Organ Toxicity (STOT)
      i. Single Exposure
         1. GHS Category 1; H370 - Causes damage to organs (or state all organs affected, if known) (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)
         2. GHS Category 2; H371 - May cause damage to organs (or state all organs affected, if known) (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard); GHS Category 2-
   b. Repeated Exposure
      i. GHS Category 1
         1. H372 - Causes damage to organs (state all organs affected, if known) through prolonged or repeated exposure (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)
      ii. GHS Category 2
         1. H373 - May cause damage to organs (state all organs affected, if known) through prolonged or repeated exposure (state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard)

h) Listed on the Grandjean Neurotoxin List

- The following environmental endpoint values were considered not acceptable:
   a) Aquatic toxicity
      a. Acute and Chronic GHS Category 1- 2; H400, H401, H410 and H411
         i. H400 –Very toxic to aquatic life (acute)
         ii. H401 - Toxic to aquatic life (acute)

iii. H410 - Very toxic to aquatic life with long lasting effects (chronic)

b. H411 - Toxic to aquatic life with long lasting effects (chronic)

b) U.S. Environmental Protection Agency for EPI Suite
   a. Acute - ≤ 1mg/l LC50 & EC50
   b. Chronic - ≤ 0.01 mg/l ECx or NOAEC

c) Persistence
   a. U.S. Environmental Protection Agency for EPI Suite
   b. Water half-life, days ≥ 60
   c. Air half-life, days ≥ 5
   d. Soil half-life, days ≥ 180
   e. 28-day Study: % Breakdown Dissolved Organic Carbon - ≥ 55
      i. % Based on O2 or CO2 - ≥ 45
   f. Biochemical Oxygen Command (BOD) - ≥ 500

d) Bioaccumulation
   a. U.S. Environmental Protection Agency for EPI Suite
   b. Log Know/Pow ≥ 6
   c. Bioconcentration Factor (BCF) ≥ 5000 l/kg

e) Atmospheric hazards
   a. Greenhouse gas
      i. Global Warming Potential (GWP) Relative to CO2 ≥ 1000
      ii. Listed on the following:
         1. Center for Climate and Energy Solutions
         2. Green House Gas Protocol List
   b. Ozone depletion
      i. Listed on the EPA Ozone Depleting Substances List
   c. Acid Rain Formation
      i. Product may form SO2 or NOx upon combustion
      ii. Contains SO2 or NOx
   d. Air Pollutant
      i. Listed on the National Emission Standards for Hazardous Air Pollutants (NESHAP)

II. Company #1

Overview

Company #1 is a manufacturing company that produces metal panels and honeycomb structures. There are different manufacturing processes for: 1) the aluminum parts and 2) the composite fiberglass honeycomb. In the first manufacturing process, the aluminum panels and aluminum honeycomb are soiled with Royco 27A grease. To remove the grease soil before the parts are used in the next production steps, Company #1 utilizes vapor degreasing with TCE as its cleaning solvent.

In the second manufacturing process, the composite fiberglass honeycomb is soiled with Glyconol wax. To remove the wax soil before the composite fiberglass honeycomb is used in the next production steps, Company #1 utilizes vapor degreasing with PERC as its cleaning solvent.

Approach

The initial step in the TURI assessment process was to have Kansas PPI members conduct a walk-through of Company #1's facility. Using TURI's internal test request form and company-provided data, Kansas PPI representatives walked through the facility to document part types, contaminants, and the current cleaning method. Two projects arose from this walkthrough; Project #1 being to find an alternative product to TCE that will effectively remove Royco 27A grease from aluminum honeycomb, and Project #2 being to find an alternative product to PERC that will effectively remove Glyconol wax from composite fiberglass honeycomb. TURI used the information gathered from the company and the site visit to research and identify process specific safer alternatives to replace TCE and PERC.

For identifying and evaluating potential alternatives, the research team used EHS criteria previously developed by TURI along with the following process criteria provided by Company #1:

- Remove a variety of contaminants including Royco 27A grease and Glyconol wax
- Compatible with aluminum and composite fiberglass material
- Dries somewhat quickly, similarly to the evaporative properties of TCE and PERC (in order to not need a drying step within their production process)
- Preferably a non-flammable or low flammable alternative option that would be compatible with Company #1's current Vapor Degreaser
- Company #1 was open to process and equipment changes which allowed for some flammable alternative options

Performance Testing

Initial testing began with HSPiP testing to develop a sphere of solubility to be used to identify solvents that are able dissolve the Glyconol wax, if any. This would help to identify other potential alternatives that may have similar characteristics to the solvents used for conducting the HSPiP tests. See Appendix B for more details on the HSPiP testing process and software.

Twenty-four small balls of wax (about 0.5 g), one for each solvent test, were placed in twenty-four unheated vials with 20 ml of the respective solvent in each vial. The solubility ratings listed in Table 2 were assigned to each of the coupons based on how well the solvent dissolved the wax balls. The ratings were based on visual observations. The overall radius of the sphere came out to a value of 18.9, with a core coordinate of [24.8 +/- 1.10, 0.1 +/- 3.10, 15.5 +/- 3.10].

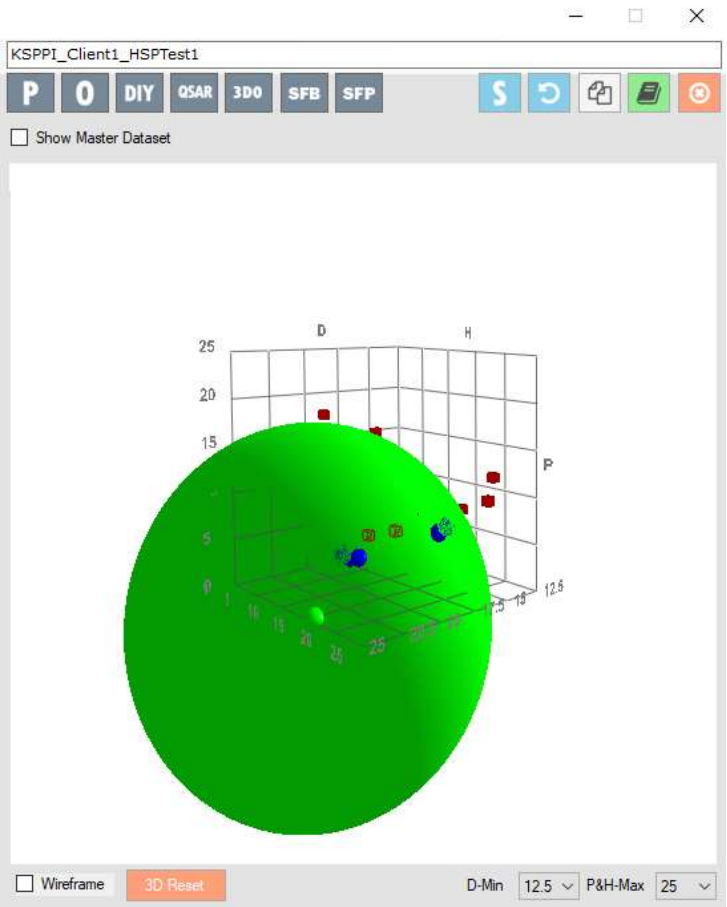

Figure 1: Client #1 HSPiP Solubility Sphere

Rating #	Description
0	Glyconol wax did not dissolve or dissolve completely
1	Glyconol wax completely dissolved

Table 1: Solubility Rating Key Used for Glyconol Wax

The solubility ratings were entered into the Hansen Solubility Parameters in Practice (HSPiP) software, a software tool that utilizes the HSP theory. The HSPiP software can create a solubility sphere in 3D

solubility space based on the HSP parameters and solubility results for numerous solute/solvent interaction tests. For this project, 24 solute/solvent interaction tests were conducted.

The ratings from that HSPiP test listed below were used to establish the solubility sphere for the Glyconol wax to streamline the process of identifying safer solvents that could work within the vapor degreasing application or an ultrasonics cleaning application. The solvents are listed in testing sequence.

During the development of the solubility sphere, three solvents that had a lower hazard assessment final than the original chemical in P2OASys that had a "1" rating were identified as viable alternative solvents to PERC.

Solvent	CAS	δD	δP	δH
1-Propanol 100%	71-23-8	16	6.8	17.4
1-Butanol 100%	71-36-3	16	5.7	15.8
Thiophene 100%	110-02-1	18.9	2.4	7.8

Table 2: Effective Solvents from Hansen Solubility Sphere Testing

A modified alcohol, propylene glycol ether, was identified as having similar HSP parameters to the initial three effective solvents found using the HSPiP software. Since propylene glycol ether is the main active ingredient in a product called Dowanol PnBGE, this product was included in the product testing. Anisole was also identified as a solvent that could potentially remove the wax while offering low flammability.

Other solvent products chosen for performance testing were found on TURI's database CleanerSolutions of past client testing. The products were found to have either been successful past replacements of PERC or were successful in removing a wax contaminant during previous testing. These products include Flexisolv DBE-LVP Esters, SC Aircraft and Metal Cleaner, and Aerokleen Aviation Cleaner. These three products along with the four HSPiP identified solvents were included in the performance testing.

Testing of the safer solvent alternatives started with unheated ultrasonics using gravimetric analysis to determine effectiveness. Bare aluminum coupons were initially weighed without any soil. The aluminum coupons were then soiled with either the Glyconol wax or the Royco 27A grease. A small ball of Glyconol wax (approximately 0.5 grams) was placed on the bottom third of the coupons. The wax was then heated with a heat gun for a few seconds to soften the material. The heated ball of wax was then smeared across the bottom third of the coupon. The Royco 27A grease (about 0.5 grams) was applied to the bottom third of the aluminum coupons using a swab. The weights of the soiled aluminum coupons were recorded to obtain an accurate record of the amount of soil on each coupon. The aluminum coupons were then subjected to unheated immersion (3800 hertz) for 20 mins in each

alternative solvent/cleaner. All solvents were tested at 100% concentration. All commercial products were tested at the vendor recommended dilution for a heavy soil load.

Once cleaned, the coupons were left to air dry overnight. The next morning, the weights of the cleaned coupons were recorded.

Results

All testing trials performed for both Project #1 and Project #2 followed a similar methodology, and the detailed test results are provided in Appendices C and D. To provide a comparison, the results from both Project #1 and Project #2 were compiled and included in Table 3.

Cleaner	Soil	Location of Relevant Testing Trial	Trial Method	Average % Removal	Overall % Removal
1-Propanol 100%	Glyconol wax	Appendix D; Trial #5	Unheated Immersion	99.6	98.1
	Royco 27A Grease	Appendix C; Trial #3	Unheated Ultrasonics	97.5	
Thio-phene 100%	Glyconol wax	Appendix D; Trial #5	Unheated Immersion	99.7	98.5
	Royco 27A Grease	Appendix C; trial #3	Unheated Ultrasonics	98.3	
1-Butanol 100%	Glyconol wax	Appendix D; Trial #3	Unheated Ultrasonics	99.3	99.0
	Royco 27A Grease	Appendix C; Trial #3	Unheated Ultrasonics	98.6	
Dowanol PnBGE 100%	Glyconol wax	Appendix D; Trial #3	Unheated Ultrasonics	97.4	97.8
	Royco 27A grease	Appendix C; Trial #3	Unheated Ultrasonics	98.2	
Flexisolv DBE-LVP Esters 100%	Glyconol wax	Appendix D; Trial #3	Unheated Ultrasonics	80.5	84.9
	Royco 27A grease	Appendix C; Trial #3	Unheated Ultrasonics	89.3	
SC Aircraft and	Glyconol wax	Appendix D; Trial #2	Heated Ultrasonics (130F)	31.2	

Metal Cleaner 100%	Royco 27A grease	Appendix C; Trial #1	Unheated Ultrasonics	94.9	62.3
Aerokleen Aviation Solvent 100%	Glyconol wax	Appendix D; Trial #2	Heated Ultrasonics (130F)	89.9	93.9
	Royco 27A grease	Appendix C; Trial #2	Heated Ultrasonics (130F)	97.8	
Anisole 100%	Glyconol Wax	Appendix D; Trial #6	Unheated Ultrasonics	51.6	74.8
	Royco 27A grease	Appendix C; Trial #4	Unheated Ultrasonics	98.0	

Table 3: Heated/Unheated Ultrasonic/Standard Immersion of Aluminum Coupons for 20 minutes

All products and solvents tested were deemed effective (>80% removal of soil) in removing both soils from the coupons except for the SC Aircraft and Metal Cleaner which was only effective in removing the Royco 27A Grease soil. While the SC Aircraft and Metal Cleaner was unsuccessful in removing the Glyconol wax coupons, it was successful in removing the Royco 27A grease. All products were deemed as reasonable options for alternatives and were used in the next round of testing.

Next, the identified possible alternatives were tested regarding their compatibility with the composite fiberglass honeycomb substrate. Small pieces of the composite fiberglass honeycomb were weighed and had their initial weight recorded. The pieces of the composite fiberglass honeycomb were placed in vials with 10 ml of each of the potential alternative products/solvents and were then placed on an automated roller to provide agitation. The vials were left on the roller overnight. The next morning, the final weights of the small pieces of composite fiberglass honeycomb were recorded to assess whether or not the substrate had been stripped. Visual observations were also used to assess whether any of the products/solvents had caused the substrate to bend, soften, etc. All products/solvents tested were deemed to be compatible with the composite fiberglass honeycomb substrate. The results of this material compatibility investigation can be seen in Appendix D, Trial #4.

Environmental, Health & Safety Evaluation

An environmental, health, and safety assessment was conducted for the original solvents (TCE and PERC) and the list of potential alternative cleaners/solvents for removing Royco 27A grease and Glyconol wax using TURI's P2OASys Hazard Assessment Tool. The P2OASys tool generates scores for each of the eight main hazard categories and related subcategories based on endpoints that correlate with values, key phrases, Global Harmonizing System (GHS) classifications, and other government agencies' designations. Comparisons using the P2OASys tool are made by entering both quantitative

and qualitative data on chemical toxicity, ecological effects, physical properties, process factors, and life cycle factors. The scores for each category and final weighted value are based on a 2 to 10 rating scale. A rating of 2 is the least hazardous and most preferred option, and rating of 10 is the highest hazard and least preferred option. See Appendix A for further P2OASys details.

Table 4 shows the results of the environmental, health, and safety assessment using the P2OASys tool. Each of the colors in the table represent the level of hazard. Red (score of 8-10) represents a very high hazard level, orange (score of 6-7) represents a high hazard level, yellow (score of 4-5) represents a medium hazard level, and green (score of 2-3) is considered a low hazard level. The goal of the Company 1 research was to identify alternative solvents with few or no very high hazard scores.

Category	Original Solvents		Identified Alternatives							
	PERC	TCE	1-Propanol	Thiophene	1-Butanol	Dowanol PnBGE	Flexisolv DBE-LVP Ester	SC Aircraft and Metal Cleaner	Aerokleen Aviation Solvent	Anisole
Acute Human Effects	9	8	8	7	9	8	5	6	6	5
Chronic Human Effects	9	9	5	5	6	3	2	5	5	7
Ecological Hazards	8	8	2	4	2	2	3	4	4	7
Environmental Fate & Transport	10	9	5	5	2	4	6	3	6	5
Atmospheric Hazard	6	6	2	5	2	2	2	2	2	2
Physical Properties	9	10	9	9	9	6	5	7	5	6
Process Factors	8	7	6	6	5	8	4	4	6	6
Life Cycle Factors	10	10	6	6	7	4	3	2	6	7
Weighted Average	8.6	8.4	5.4	5.9	5.3	4.6	3.8	4.1	4.9	5.6

Table 4: Pollution Prevention Options Analysis System Evaluations of Perchloroethylene (PERC), Trichloroethylene (TCE), and identified alternatives

Alternatives with a category score of 8-10 were evaluated to highlight the driving hazard. 1-propanol showed concern in the areas of acute human effects and physical properties. The driving hazard for

acute human effects of 1-propanol is that it has a GHS category level of 1 for eye irritation. The driving hazards for physical properties are its relatively high vapor pressure of 23.2 mm Hg, a relatively low flash point of 15 C, and its categorization as a highly flammable liquid and vapor. Thiophene showed concern in the area of physical properties due to the driving hazards of a strong odor, and its categorization as a highly flammable liquid and vapor. 1-Butanol showed concern in the areas of acute human effects and physical properties. The driving hazard for acute human effects of 1-Butanol is that it has a GHS category level of 1 for eye irritation. The driving hazards for physical properties of 1-Butanol are its relatively low flash point of 36 deg C, and its categorization as a volatile organic compound with a measurement of 810 g/l. Dowanol PnBGE showed concern in the areas of acute human effects and process factors. The driving hazard for acute human effects of Dowanol PnBGE is its GHS category level of 1C for dermal irritation and its GHS category level of 2A for eye irritation. The driving hazard for process factors is its heat generation during use which is measured at 43.33 deg c.

Summary Table

The following table summarizes the proposed cleaning method, flammability, costs, and cleaning effectiveness for the alternative cleaning products/solvents for both Project #1 and Project #2.

Location of Relevant Testing Trial	Product	Proposed Cleaning Method	Soil	Flammability NFPA Rating	Flash Point (F)	Cost Estimate ($ per lb. from Thermo Fischer)	Effectiveness
Appendix D; Trial #5, Appendix C; Trial #3	1-Propanol	Unheated Immersion (Glyconol Wax)/ Unheated Ultrasonics (Royco 27A grease)	Both	3	72	$55.48 (Based on 1 L quote)	98.1%
Appendix D; Trial #5, Appendix C; Trial #3	Thiophene	Unheated Immersion (Glyconol Wax)/ Unheated	Both	3	30	$1.93 (Based on 100 ml quote)	98.5%

		Ultrasonics (Royco 27A grease)					
Appendix D; trial #5, Appendix C; trial #3	1-Butanol	Unheated Immersion (Glyconol Wax)/ Unheated Ultrasonics (Royco 27A grease)	Both	3	95	$24.25 (Based on 1000 ml quote)	99.0%
Appendix D; Trial #3, appendix C; Trial #3	Dowanol PNBGE	Unheated Ultrasonics (Glyconol Wax)/ Unheated Ultrasonics (Royco 27A grease)	Both	2	145	Quote not available from vendor	97.8%
Appendix D; Trial #3, Appendix C; Trial #3	Flexisolv DBE LVP Esters	Unheated Ultrasonics (Both Soils)	Both	1	212	$1.40 from Vendor; Invista DBE	84.9%
Appendix C; Trial #1	SC Aircraft and Metal Cleaner	Unheated Ultrasonics (Royco 27A grease)	Royco 27A Grease	0	None	$7.19 from Vendor; Orison Powerful Environmental Products	94.1%
Appendix D; Trial #2, Appendix C; Trial #2	Aerokleen Aviation Solvent	Heated Ultrasonics 130F (Both Soils)	Both	1	216	$5.80 from Vendor; Ecolink (Based on 55-gal quote)	93.9%
Appendix D; Trial #6, Appendix C; Trial #4	Anisole	Unheated Ultrasonics (Royco 27A grease)	Royco 27A Grease	2	113	$45.09 (Based on 500 g quote)	98.0%

Original Solvent	TCE	Vapor Degreasing	Both	1	None	$103.79	N/A
Original Solvent	PERC	Vapor Degreasing	Both	0	None	$15.20 (Based on 500 ml quote)	N/A

Table 5: Summary of Alternatives for Company #1

Recommendations

TURI recommends the alternative solvents 1-propanol, thiophene, 1-butanol, and Dowanol PnBGE, because these solvents displayed the highest efficacy while also working on both contaminants. Although these solvents have a higher flammability than the current solvents in use, TCE and PERC, this higher flammability will be a lesser concern with the process change of unheated ultrasonics implemented as opposed to the current process of vapor degreasing. It is likely that the vapor degreaser Company #1 currently has would have an ultrasonic function built into the equipment which would result in the client being able to continue using their current equipment with a different programming that leaves out the addition of heat used for the vapor degreasing process. If Company #1's current vapor degreaser does not include an ultrasonics option and the purchasing of new equipment is not feasible, TURI recommends the following alternative cleaners/solvents: SC Aircraft and Metal Cleaner, Flexisolv DBE-LVP Esters, Anisole and Aerokleen Aviation Solvent. While these products/solvents are not as effective as the 1-propanol, thiophene, 1-butanol and Dowanol PnBGE, they do not have the same flammability concerns and likely could be used as drop-in replacements for Company #1's current equipment. They could also be used for only one process/soil in which case only one new equipment purchase would be required instead of two. Company #1 would be able to do future in-house testing with these alternatives to see if they meet the minimum cleanliness requirements for their part.

III. Company #2

Overview

Company #2 is an industrial coatings applicator. A fluid-resistant two-component epoxy primer from a major supplier is applied to aluminum-alloy panels. Their method of application is a compressed air siphoning paint gun. Cleaning excess debris off of their paneling after priming but prior to paint application is the first cleaning application that was requested by Company #2. This primarily focused on removal of small amounts of primer from the aluminum substrate. This cleaning is done with a quick manual wipe down using methyl ethyl ketone (MEK) on a cloth. The second cleaning application is cleaning wet paint from the paint applicator gun, primarily from the interior and around the nozzle. Cleaning strategies by workers include siphoning MEK through the paint feed line and through the gun

(the time this took is unknown). Other workers were seen immersing the gun in the solvent solution to clean it, but that was not described as standard procedure (the time this took is unknown).

Approach

The initial step in the TURI assessment process was to have Kansas PPI members conduct a walk-through of Company #2's facility. Using TURI's internal test request form and company-provided data, Kansas PPI representatives walked through the facility to document part types, contaminants, and the current cleaning method. Two projects arose from this walkthrough; Project #1 being to find an alternative product to MEK that will effectively clean aluminum paneling in between the priming and painting steps, and Project #2 being to find an alternative product to MEK that will effectively remove aerospace paint from the interior and exterior of the stainless-steel paint gun. TURI used the information gathered from the company and the site visit to research and identify safer alternatives to replace MEK. For identifying and evaluating potential alternatives, the research team used EHS criteria previously developed by TURI along with the following process criteria provided by Company #2:

- Remove a variety of contaminants including paint, primer, dust, fingerprints
- Compatible with aluminum and stainless-steel substrates
- Somewhat compatible with the rubber gaskets that could potentially come in contact with the solvents within the paint gun
- Company #2 was interested in an enclosed immersion system and were open to this process change if it turned out to be feasible and effective
- Must have a vapor pressure similar or higher to MEK (95.1 mmHg), for the solvent to evaporate quickly after the manual wipe down (In order to not need a drying step within their production process)

Upon receipt of the samples collected from Company #2 by Kansas PPI members, testing began with consulting the TURI P20Asys database for potential MEK replacements. After gathering potential alternatives from this database (outlined in Table 7), testing began with unheated immersion of aluminum substrate panels. A rubber compatibility chart was provided by the staff of KSU PPI, as in addition to the aluminum alloy paneling there were internal components of the aerosol paint gun that may be susceptible to corrosion by cleaning solvents.

Contaminant	Type	Substrate
AkzoNobel Fluid Resistant Epoxy Primer 10P4-2NF	Green Paint	Aluminum/ Tool Steel
AkzoNobel Fluid Resistant Epoxy Primer EC-117S	Clear primer	Aluminum/ Tool Steel

Table 6: Contaminants included in testing and related substrates

The TURI CleanerSolutions database and vendor recommendations were used to identify cleaners/solvents currently on the market that meet the company's needs. Table 13 shows the list of cleaners identified as compatible with the substrates (aluminum and tool steel) and found effective in previous tests. D Super Remover New Generation was included as a reference cleaner, as it was a product in-house used for previous paint stripper testing. Since vapor pressure was an important physical characteristic, it was included in the table below.

Product	Classification	P20Asys Score	Vapor Pressure (mm Hg)	Rubber Compatibility Score (1= Satisfactory, 4 = unsatisfactory)
Methyl Acetate	Carboxylate ester	4.0	173	3.25
Isopropanol	alcohol	5.1	44	1.83
Dimethyl Carbonate	Carbonate ester	5.5	55	Unknown*
Ethylene Glycol	Vicinal diol	5.0	760	1.33
Diethyl Carbonate	Carbonic acid ester	5.5	55	1.92
D Super Remover	Paint stripper	5.2	100	2.97
Benzyl Alcohol	Alcohol	4.8	13.3	Unknown*
Dimethyl Sulfoxide	Polar aprotic solvent	5.9	0.600	Unknown*
1,3-dioxolane	Dioxane	6.1	70	Unknown*
Ethyl Acetate	Ethanol ester	5.1	73	Unknown*
Ethyl Lactate	Ethanol ester	5.3	3.75	Unknown*

Table 7: CleanerSolutions Database list of compatible cleaning alternatives to replace MEK
***Unknown: Solvents not included in compatibility table**

Performance Testing

Initial testing began with HSPiP testing to identify solvents that are able to break the bond between paint and the substrate once dried, if any. Twenty-four stainless steel coupons were soiled with the 1:1 paint and primer mixture (about 0.5 g), one for each solvent, and were placed in an unheated vial with 20 mL of the respective solvent. All solvents were tested at 100% concentration. The solubility ratings listed in Table 2 were assigned to each of the coupons based on how well the solvent removed the paint/primer mixture from the coupon. The ratings were based on visual observations.

Rating #	Description
0	Paint and primer mixture was not removed from coupon
1	Paint and primer mixture was removed from coupon

Table 8: Solubility Rating Key Used for HSPiP Coupons

The solubility ratings were entered into the HSPiP software, a software tool that utilizes the HSP theory. The HSPiP software can create a solubility sphere in 3D solubility space based on the HSP parameters and solubility results for numerous solute/solvent interaction tests. For this project, 24 solute/solvent interaction tests were conducted.

The ratings from that test listed below were used to establish the solubility sphere for the pain to streamline the process of identifying safer solvents that could work within the immersion or manual wipe applications. The solvents are listed in testing sequence.

Solvent	CAS Number	Rating
Toluene	108-88-3	0
Dimethyl Carbonate	616-38-6	1
Xylenes	1330-20-7	0
Benzyl Alcohol	100-51-6	1
Ethylene Glycol	107-21-1	0
Methyl Acetate	79-20-9	1
Undecane	1120-21-4	0
Ethyl Lactate	97-64-3	1
Acetone	67-64-1	1
Ethyl Acetate	141-78-6	1
Methanol	67-56-1	0
Ethanol	64-17-5	0
1,3-Dioxolane	646-06-0	1

Solvent	CAS Number	Rating
Diethyl Carbonate	105-58-8	0
1-Propanol	71-23-8	0
Isopropanol	67-63-0	0
Propylene Carbonate	108-32-7	0
Thiophene	110-02-1	1
1-Methoxy 2-Propanol	107-98-2	1
Dimethyl Sulfoxide	67-68-5	1
1-Butanol	71-36-3	0
Dimethyl Glutarate	1119-40-0	1
Anisole	100-66-3	1
2-Butoxyethyl Acetate	112-07-2	1

Table 9: HSPiP Values of Akzo-Nobel paint-primer mixture

During the development of the solubility sphere, seven solvents that had a lower hazard assessment final than the original chemical (MEK) in P2OASys that had a "1" rating were identified as viable alternative solvents to MEK: dimethyl carbonate, methyl acetate, ethyl lactate, ethyl acetate, dimethyl sulfoxide (DMSO), 1,3 dioxolane, and dimethyl glutarate. These solvents, along with other identified potential alternatives recommended by the TURI Research Program were chosen for future testing. The solubility sphere created for the Paint and Primer soil had a center point of [18.3 +/- 0.40, 9.4 +/- 0.40, 8.9 +/- 1.45] and a radius of 7.2.

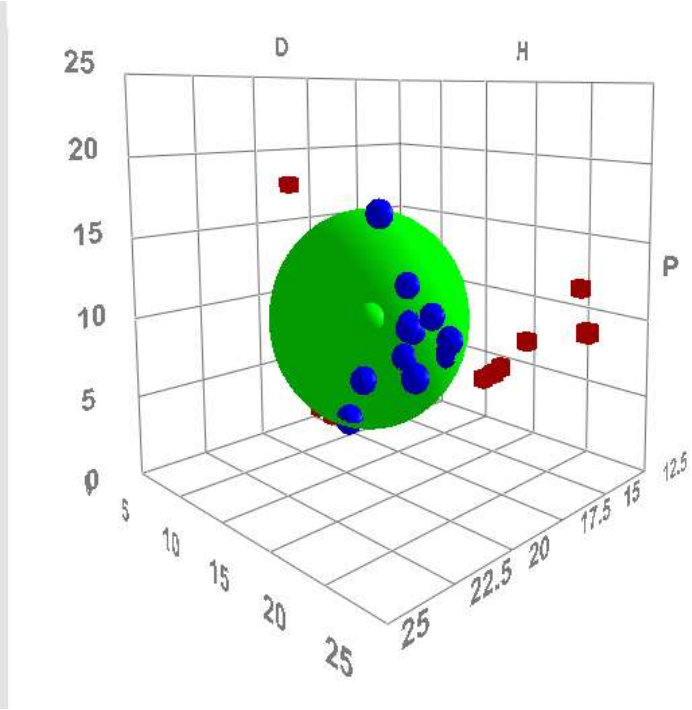

Figure 2: Client #2 HSPiP solubility sphere

After the HSPIP solubility sphere was created and alternative solvents were identified, additional testing took place using unheated immersion of the cleaners for 30 minutes to remove the applied paint-primer mixture from aluminum coupons. The paint-primer mixture was mixed in a 1:1 concentration along the bottom edge of the coupon so that the painted area was completely submersed in the solvent. All solvents/products were tested at 100% concentration. Prior to cleaning, the coupons were rated qualitatively on a scale from 1 to 5 in terms of cleanliness. With 1 being completely clean, and 5 being completely dirty.
The scale used to measure the visual values is as follows:

- 1= 100% of soil removed
- 2=75% of soil removed
- 3= 50% of soil removed
- 4= 25% of soil removed
- 5= 0% of soil removed

Cleaner	Averaged Clean Values
Ethylene Glycol 100%	5.0
D Super Remover 100%	1.8

Cleaner	Averaged Clean Values
Diethyl Carbonate 100%	3.2
Isopropanol 100%	3.7
Dimethyl Carbonate 100%	4.3
Methyl Acetate 100%	3.2
1,3 Dioxolane 100%	3.5
Dimethyl Sulfoxide (DMSO) 100%	2.8

Table 10: Unheated immersion of painted aluminum coupons after 30 minutes

Selected solvents were then retested using a manual wiping method. The paint-primer mixture was mixed in a 1:1 concentration along the bottom edge of the coupon. The coupons were then wiped with a low-lint wipe that had been dipped in the selected solvent, with 3 slow wiping motions along the bottom of each coupon, a separate wipe being used for each coupon. The visual cleanliness of each coupon was then reevaluated. This testing method was also utilized to test the effectiveness of the removal of both oil and sharpie ink from aluminum coupons. Further testing information on both application 1 and 2 for Client #2 and additional data tables are found in Appendix E and F.

Cleaner	Average Dirty Values	Average Clean Values
Diethyl Carbonate 100%	5	1
Dimethyl Sulfoxide (DMSO) 100%	5	1
1,3 Dioxolane 100%	5	1
Methyl Acetate 100%	5	1
Ethyl Acetate 100%	5	1
Ethyl Lactate 100%	5	1
Dimethyl Glutarate 100%	5	1

Table 11: Manual Wiping of Coupons with Selected Solvents

Although dimethyl sulfoxide (DMSO) was effective in removing all soil, it was discontinued from testing and was not recommended to the client because its vapor pressure is far too low to be productive within the production process and it would leave an oily film on the parts. Since DMSO is a major ingredient for the D Super Remover product, this product was also discontinued for further testing.

Results

All testing trials performed for both Project #1 and Project #2 followed a similar methodology, and the detailed test results are provided in Appendices E and F. To provide a comparison, the results from both Project #1 and Project #2 were compiled and included in Table 12.

Location	Product	Classification	P20Asys Score	Vapor Pressure (mm Hg)	Effectiveness(averaged across trials)
Appendix E, Trial #0, #1 Appendix F, Trial #0, #1	Methyl Acetate 100%	Carboxylate ester	4.0	173	37%
Appendix E, Trial #0	Isopropanol 100%	alcohol	5.1	44	23%
Appendix E, Trial #0, #1 Appendix F, Trial #0	Dimethyl Carbonate 100%	Carbonate ester	5.5	55	57%
Appendix E, Trial #0	Ethylene Glycol 100%	Vicinal diol	5.0	760	0%
Appendix E, Trial #0, #1 Appendix F, Trial #0	Diethyl Carbonate 100%	Carbonic acid ester	5.5	55	33%
Appendix E, Trial #0	D Super Remover 100%	Paint stripper	5.2	100	63%
Appendix E, Trial #1	Dimethyl Sulfoxide 100%	Polar aprotic solvent	5.9	0.600	72%
Appendix E, Trial #1	1,3-dioxolane 100%	Dioxane	6.1	70	30%
Appendix F, Trial #1	Ethyl Acetate 100%	Ethanol ester	5.1	73	68%

Table 122: Results of Company #2 Testing

Environmental, Health, & Safety Evaluation

An environmental, health, and safety assessment was conducted for the original solvents MEK and the list of potential alternative solvents for removing the paint, primer, dust, and fingerprints using TURI's P2OASys Hazard Assessment Tool. The P2OASys tool generates scores for each of the eight main hazard

categories and related subcategories based on endpoints that correlate with values, key phrases, Global Harmonizing System (GHS) classifications, and other government agencies' designations. Comparisons using the P2OASys tool are made by entering both quantitative and qualitative data on chemical toxicity, ecological effects, physical properties, process factors, and life cycle factors. The scores for each category and final weighted value are based on a 2 to 10 rating scale. A rating of 2 is the most preferred option, and rating of 10 is the least preferred option. See Appendix A for further P2OASys details.

Table 13 shows the results of the environmental, health, and safety assessment using the P2OASys tool. Each of the colors in the table represent the level of hazard. Red (score of 8-10) represents a very high hazard level, orange (score of 6-7) represents a high hazard level, yellow (score of 4-5) represents a medium hazard level, and green (score of 2-3) is considered a low hazard level. The goal of the Company #2 research was to identify alternative solvents with few or no very high hazard scores.

Category	Original Solvent	Alternatives					
	MEK	Dimethyl Carbonate	Dimethyl Glutarate	Methyl Acetate	Ethyl Acetate	Ethyl Lactate	1,3 Dioxolane
Acute Human Effects	7	3	2	5	7	8	7
Chronic Human Effects	7	2	2	4	5	6	8
Ecological Hazards	6	2	3	2	2	2	4
Environmental Fate & Transport	6	6	8	2	4	4	7
Atmospheric Hazard	2	2	2	2	2	2	2
Physical Properties	9	9	5	8	9	8	9
Process Factors	6	3	4	4	6	6	6

Life Cycle Factors	6	4	3	5	6	6	6
Weighted Average	6.1	3.9	3.6	4.0	5.1	5.3	6.1

Table 13: P2OASys Evaluation of selected alternatives for MEK

Alternatives with a category score of 8-10 were evaluated to highlight the driving hazard. Dimethyl Carbonate showed concern in the area of physical properties. The driving hazard for physical properties is its flash point of 60 degrees F, meaning it is a flammable liquid. It also has an NFPA flammability score of 3. This should pose little problem for Company #2, as the solvent would be used at room temperature within their process. Dimethyl glutarate showed concern in the area of environmental fate and transport. The driving hazard for environmental fate and transport is that it is a persistent chemical, especially in the air. This would pose little problem for Company #2 if they adopted an enclosed immersion system and used spray hoods. Methyl acetate showed concern in the area of physical properties. The driving hazard for physical properties is its high flammability and vapor pressure. It has an NFPA flammability score of 3 meaning that it is a highly flammable liquid. Its vapor pressure is 163 mmHg, meaning that the liquid is volatile. Ethyl Acetate showed concern in the areas of acute human health effects and physical properties. The driving hazard for acute human health effects is its ability to cause severe, potentially permanent, eye damage. It has a GHS category level of 1 for eye irritation. 1,3-dioxolane showed concern in the areas of chronic human health effects and physical properties. The driving hazards for chronic human health effects are its presumed effect on the reproductive system and damage of unborn children, and chronic organ effects through repeated exposure. This chemical may damage fertility or the unborn child and may harm children through breastfeeding. The driving hazards for physical properties are its flash point, and vapor pressure. It has a flash point of 70 degrees F meaning it is a highly flammable liquid. It has an NFPA flammability score of 3. Its vapor pressure is 60 mmHg meaning it is volatile. Because 1,3-Dioxolane showed chronic human health concerns and its overall weighted average is the same as MEK, this solvent was **not** recommended to Company #2.

Summary Table

The following table summarizes the proposed cleaning method, flammability, costs, and cleaning effectiveness for the alternative cleaning products/solvents both Project #1 and Project #2.

Location	Solvent	Proposed Cleaning Method	Flammability	Flash Point (F)	Cost Estimate ($ per lb. from Thermo Fischer)	Effectiveness
Appendix E, Trial #0, Trial #2, Trial #3	Dimethyl Carbonate	Manual Wipe/ Unheated Immersion	3	64.4	$57.18 (Based on 100g quote)	100% (manual wipe) 17.5% (unheated immersion)
Appendix E, Trial #0, Trial #2, Trial #3	Ethyl Acetate	Manual Wipe	2	24.8	$35.66, based on 1L quote	100% (manual wipe)
Appendix E Trial #2, Trial #3, Appendix F, Trial #1	Ethyl Acetate (62%) / Dimethyl Carbonate (38%)	Manual Wipe/ Siphon Fed	3	24.8	$35.66 (Based on 1L Quote), $57.18 (Based on 100g Quote)	100% (Manual Wipe) 50% (1 min Siphon Fed)
Original Solvent	Methyl Ethyl Ketone	Siphon Feeding/ Unheated Immersion	3	19.4	$27.18 (Based on 500 mL quote)	Not Tested In-house

Table 14: Summary of Alternatives for Company #2

Recommendations

TURI recommends Dimethyl Carbonate or Ethyl Acetate as replacements for Methyl Ethyl Ketone in regard to project #1. Project #1 for Client #2 was less stringent in terms of requirements, and given that both chemicals performed adequately, whichever is easier to source for the client is suitable. The mixture of Ethyl acetate and Dimethyl carbonate is specifically for Project #2. This was a mixture that was generated utilizing the HSPiP software's solvent optimizer function. Ethyl Acetate is cheaper than Dimethyl Glutarate, and while they share similar physical characteristics, Ethyl Acetate is slightly less flammable, but has a higher concern regarding eye irritation and inhalation. Dimethyl Carbonate is significantly less hazardous in terms of acute human effects, with a category P20ASys score of only 3, compared to Ethyl Acetate's 7. By utilizing the mixture, the larger percentage of ethyl acetate means that the replacement will not be as expensive as opposed to using entirely dimethyl glutarate but will be diluted to lessen the effects of the health hazards present in the ethyl acetate itself.

TURI recommends dimethyl carbonate, dimethyl glutarate, and methyl acetate to be considered as potential replacements for MEK. Other tested alternatives were either too hazardous on the whole or did not meet the testing criteria of project #2.

Appendix A – About P2OASys

Pollution Prevention Options Analysis System (P20ASys)

The primary goal of alternatives assessment for chemicals of concern is to reduce risks to humans and the environment by identifying safer choices. Beginning in the mid-1990s, TURI developed the Pollution Prevention Options Analysis System (P2OASys) tool to help companies systematically determine whether the toxics use reduction options being considered may have unforeseen negative environmental, worker, or public health impacts. The intended use of the P2OASys tool is to provide a methodical way to assess toxics use reduction process changes. Ideally, the tool will help shed light on environmental, worker, and public health concerns that currently exist or that may arise during a change of manufacturing process(es). The tool is only intended to provide the user with a safety assessment, one of the pieces of the three-legged alternatives assessment process (technical and financial being the other two legs). By providing a systematic, critical-thinking process about the potential hazards posed by current and alternative processes, better informed decisions can be made and regrettable substitutions can be prevented. This document, partnered with an instructional video, will inform the reader how to use the on-line tool (https://p2oasys.turi.org) to help guide them to possible alternatives for their given parameters.

How it works

The score is meant to give the user a way to compare their current process with possible substitutes. The values are not meant to provide the user with a number that would provide a definitive "this is good" or "this is bad" answer. The scores need to be considered in a "How does this compare with that?" mindset. Figure A1 shows the main homepage of the tool.

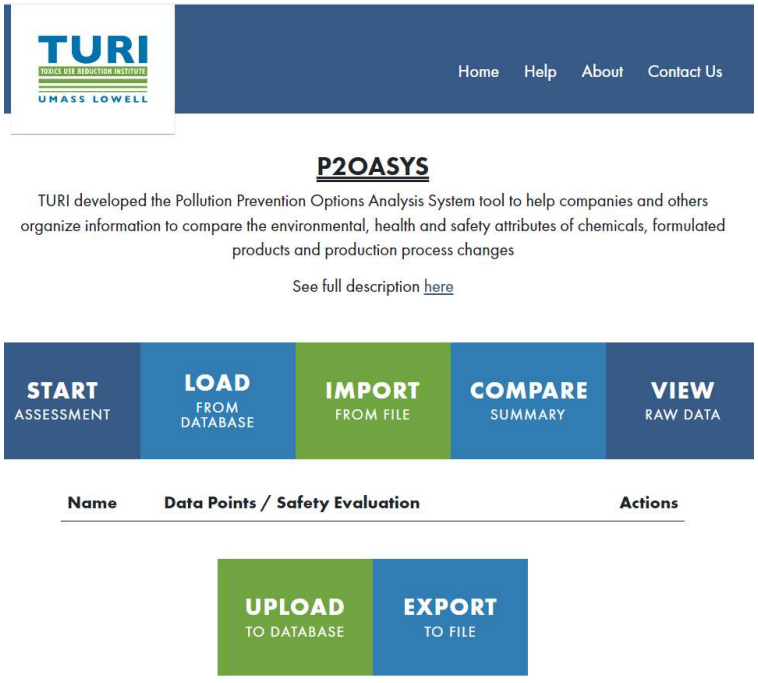

Figure A1: Home page of the P2OASys Tool

The first step in the EHS assessment is to collect as much data on the chemical/product as possible. The more information available, the more robust the assessment can become. Common resources to collect would be safety data sheets (SDSs) and technical data sheets from vendors. During the evaluation process, checking the date of the SDS and determining if a newer version exists is an important step to ensure accurate information is utilized. From the main menu, a user would select “New Assessment” and be directed to the screen pictured below in Figure A2 where you can enter the chemical or product identity information to add it to your active session. The product will now show up on the main page where you can choose to enter your data in the P2OASys format or SDS format.

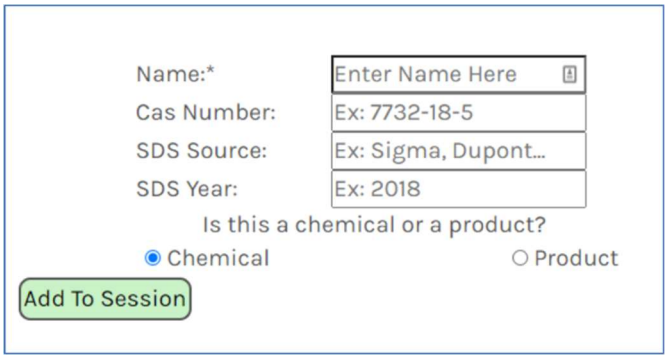

Figure A2: New Assessment page of the P2OASys Tool

Potential hazards posed by current and alternative processes identified during the TUR planning process are compared using data endpoints for eight main categories that encompass chemical, physical, psychological, and environmental hazards, each of which can be expanded to an overall 150 subcategories. Figure A3 is an example of the subcategories in one of the main categories (acute human effects).

Figure A3: P2OASys eight main categories with Acute Human Effects expanded to view the related subcategories

Using both quantitative and qualitative data input, the tool has been set up to rate each category based on endpoints that correlate with values, key phrases, Global Harmonizing System (GHS) classifications, and other government agencies' designations.

Within each category, there are subcategories that can be populated. Each of these subcategories have several options. For subcategories that have multiple options, the most hazardous criterion is used to provide the subcategory score. In each of the eight categories, P2OASys calculates the average of the two most hazardous values for the various subcategories to give a numerical rating for that overall category. To obtain a category score, the user must therefore fill in data or information for all subcategories possible.

The tool does not require every criterion, subcategory, or category to be assessed in order to create an assessment. However, the more data that can be entered into each of the subcategories, the better the overall profile of the process will be.

To complete the EHS review, the user will need to enter some end points for the chemical/process based on their professional judgment. Process and life cycle endpoints are typically case specific and should be part of the judgment assessment. After a level of acceptable data points has been entered and a summary score is generated, the user must then review the values and compare to other products. A further assessment should check for data gaps and go back to fill in if possible, to ensure best comparison of all evaluated options. Then with acceptable data collection complete, the individual category values can be assessed and looked at to identify products that are of low, medium, high, or very high concern.

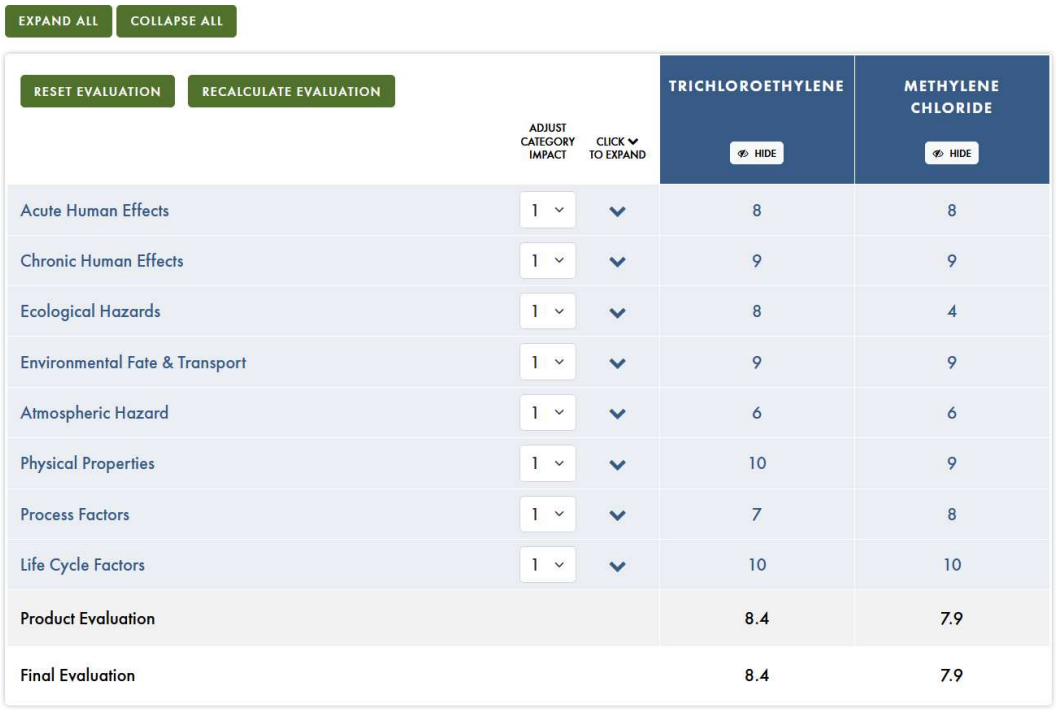

Figure A4: Score Summary of a P2OASys Evaluation of Two Chemicals

P2OASys allows the user to review the information and compare data in many different ways. When you are finished your assessment, from the main screen you can generate a “Score Summary," pictured in Figure A4 above, and you can see final scores and the overall score of each of the main category. Figure A5 is the key used by the main category, subcategory, and final scores.

Color	Level of Hazard	Score Range
	Low (L)	2 < 4
	Medium (M)	4 < 6
	High (H)	6 < 8
	Very High (VH)	8 - 10

Figure A5: Key for P2OASys scores and how the levels are defined in assessments

If your current product or process has a worse score (i.e., a higher overall P2OASys score) than the alternative, this is a good indication that further plans to investigate adoption of the alternative should be considered.

It is important to note that P2OASys does not include economic comparisons or performance criteria. These considerations are necessary for a thorough assessment of alternatives. For projects focused on surface cleaning, TURI can assist with performance testing.

Similar to performing the assessment, you can expand each category to see the score for each endpoint within that category. The side bars next to each category allow for the user to add more weight to a category if that is of particular concern to the user. From this page the user can also choose to export this information into an excel spreadsheet in various ways:

- The 8 category scores and final score (shown above)
- All scores for each endpoint of data gap
- Hazards of concern (endpoints that received an 8 or higher)

It is important to remember that the information the user gets in the excel spreadsheet from the "Score Summary" screen is just the scores. If you want to see what information you put in to drive that score you must go back to the main screen and select "Compare Raw Data." From here the user can expand all categories and view the specific information that was entered. This information can also be saved by selecting "Export Data Comparison" and the user can have all the raw data saved for their own use or to review at a later date.

Assessments made using P2OASys can vary from one person to the next for the same process or chemical, based on the technical expertise of the assessor. But to help make the process easier to start an assessment, the TURI staff are populating the database with common solvents. P2OASys scores for these chemicals can be downloaded to an active P2OASys session.

Load from Database

In addition to the user being able to perform their own personalized assessment, Figure A6 shows the page where the user can load chemicals/products from the database. P2OASys evaluations of various products have been conducted and reviewed by TURI staff for accuracy, to be used as a starting point for a facility-specific assessment. If the user is not finished with an evaluation, they can also export the data collected and save the excel file to their personal device. The user can then reload the unfinished assessment back into the database to continue editing and completing their final assessment.

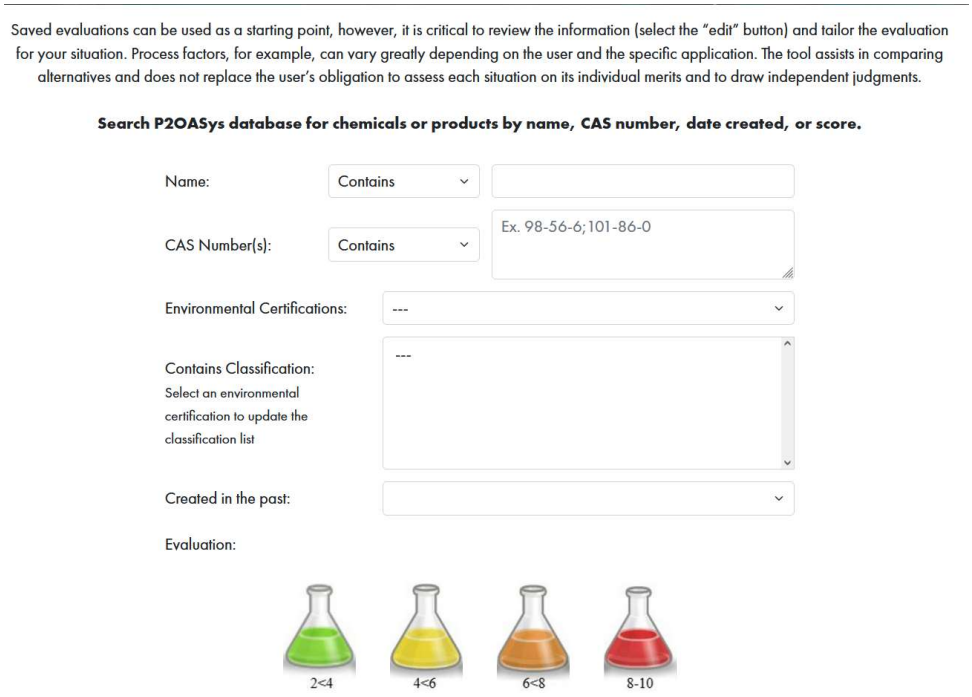

Figure A6: P2OASys database page

Appendix B - HSPiP

Hansen Solubility Parameters Application

Hansen Solubility Parameters in Practice (HSPiP) software was utilized to find safer solvents that could dissolve the Glyconol wax soil as this contaminant proved to be the most difficult to remove for Company #1 and HSPiP was also used for the paint and primer mixture for Company #2. The TURI Lab used preliminary HSPiP testing of these contaminants as a baseline for identifying additional safer solvent and product alternatives to test.

A solute is the substance being dissolved, and a solvent is the substance that dissolves it. Both substances (solute and solvent) must have similar Hansen Solubility Parameters to dissolve the solute. For example, for Company #1 the solvent was PERC or some other alternative solvent, and the solute was the Glyconol wax.

The HSP theory can be used to predict which solvents will be able to dissolve target solutes and is an efficient method to rapidly identify safer and effective alternatives to toxic solvents used in a variety of products. The HSP approach is based on three distinctive forms of inter-molecular force:

1) Dispersion forces (D): 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 (P): Dipole moments are created when atoms of the same molecule have different electronegativities.
3) Hydrogen bond forces (H): This force exists between hydrogen atoms and other atoms present in adjacent molecules.

These three forces or parameters are used to describe solvent and solute interactions. Each parameter can be used as an axis in three-dimensional solubility space. Instead of the common X, Y, and Z axis, the three-dimensional solubility space will have a Dispersion Force (D) axis, a Polar Force (P) axis, and a Hydrogen Bonding Force (H) axis. Each solvent can be represented as a point in three-dimensional solubility space, and each solute can be represented as a sphere in three-dimensional solubility space.

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 the solvent is located inside the sphere of solubility, then it will dissolve the polymer. If the solvent is located outside the sphere of solubility, then it will NOT dissolve the polymer. The distance between HSP points in solubility space is calculated as follows:

$$\text{Distance} = [4\,(D_1-D_2)^2 + (P_1-P_2)^2 + (H_1-H_2)^2\,]^{1/2}$$

In Figure B1, the three axes are shown for the polar force, hydrogen bonding force, and dispersion force. The black dot represents the center point for the sphere of solubility. The green dots represent solvents that are inside the polymer solubility sphere and will dissolve the wax. The red dots represent solvents that are outside the polymer solubility sphere and will NOT dissolve the wax.

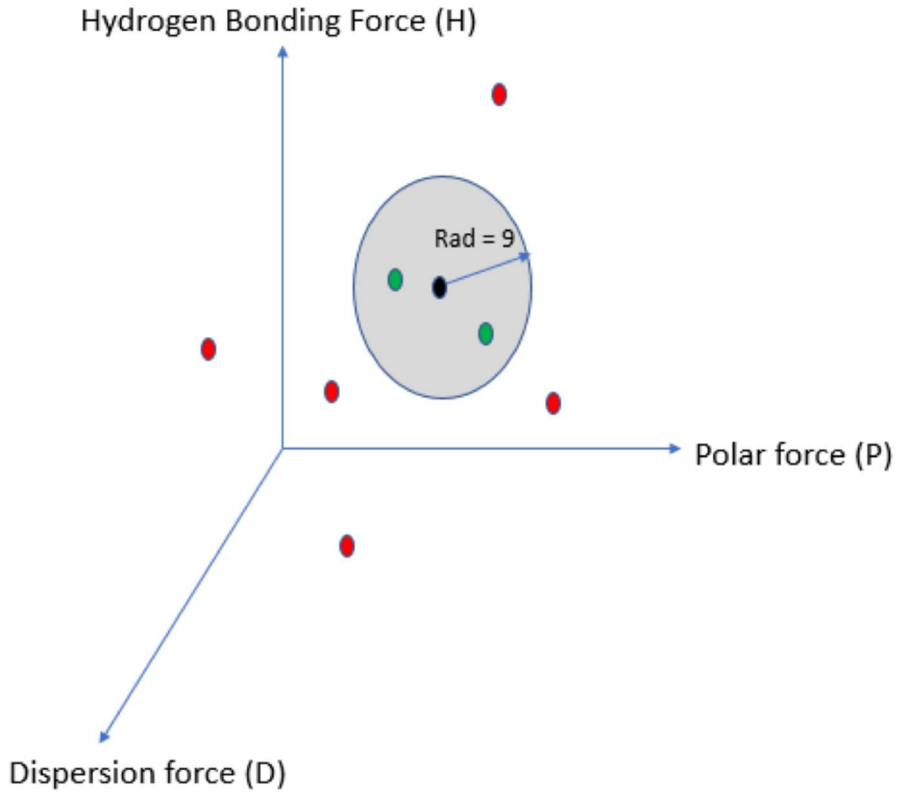

Figure B1: Solvents and Sphere of Solubility in Hansen Solubility Parameter 3D Space

In general, the lower the HSP distance between the solvent and the solute, the better the solubility performance. The lower the HSP distance between solvent and the center of the solute (coating) solubility sphere, the faster the contaminant

Appendix C – Individual Testing Trials: Company #1, Project 1

Performance Testing

Testing of the safer solvent alternatives started with unheated ultrasonics using gravimetric analysis to determine effectiveness. Pre-weighed aluminum coupons were soiled with the Royco 27A grease. The Royco 27A grease (about 0.5 grams) was applied to the bottom third of the aluminum coupons using a swab. The weights of the soiled aluminum coupons were recorded to have an accurate record of the amount of soil on the coupons. The aluminum coupons were then subjected to unheated immersion (3800 hertz) for 20 mins in each alternative solvent/cleaner. Once cleaned, the coupons were left to air dry overnight. The next morning, the clean weights of the coupons were recorded. This strategy was utilized for several trials.

Trial #0

Purpose: To evaluate the effectiveness of multiple cleaners in removing the Royco 27A grease contaminant from aluminum coupons

Equipment: Ultrasonics

Substrates: Aluminum

Contaminants: Greases

Rinsing Conditions: None

Drying Methods: Nones

Analysis Methods: Gravimetric

Experimental Procedure: Three cleaning products were chosen using previous testing data on their performance for removing other greases. Three pre weighed aluminum coupons were assigned to each cleaner for a total of 9 aluminum coupons. The coupons were soiled with the Royco 27A grease (about 0.5 grams) by applying the soil to the bottom third of the coupons with a swab. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of unheated ultrasonics in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt. of cont.	Final wt. of cont.	% Cont. Removed	% AVG
Metalnox M6324R 12%	0.0768	-0.1380	279.7	226.5
	0.1856	-0.1519	181.8	
	0.2207	-0.2602	217.9	
Shopmaster LPH 10%	0.1767	0.0291	83.5	79.9
	0.0825	0.0216	73.8	

	0.2105	0.0370	82.4	
Soyclear 1500 100%	0.1583	0.0006	99.6	86.8
	0.1382	0.0143	89.7	
	0.1202	0.0346	71.2	

Table C1: Trial #0 Test Results

Metalnox M6324R attacked and stripped the substrate of aluminum. This is why the clean weights for these coupons are significantly lower than the initial weights.

Conclusion: Metalnox M6324R is not an effective cleaner for aluminum substrates because it attacks aluminum. Shopmaster LPH is a somewhat effective cleaner in removing the Royco grease. Soyclear 1500 is an effective cleaner in removing the soil, however it would require a drying step which may not be the most efficient process for the client.

Trial #1

Purpose: To evaluate the effectiveness of multiple cleaners in removing the Royco 27A grease contaminant from aluminum coupons

Equipment: Ultrasonics

Substrates: Aluminum

Contaminants: Greases

Rinsing Conditions: None

Drying Methods: None

Analysis Methods: Gravimetric

Experimental Procedure: Three cleaning products were chosen using previous testing data on their performance for removing other greases. Three pre weighed aluminum coupons were assigned to each cleaner for a total of 9 aluminum coupons. The coupons were soiled with the Royco 27A grease (about 0.5 grams) by applying the soil to the bottom third of the coupons with a swab. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of unheated ultrasonics in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt of cont.	Final wt of cont.	% Cont Removed	% AVG
SC Aircraft and Metal Cleaner 100%	0.1195	0.0068	94.3	94.9
	0.1045	0.0039	96.3	
	0.0533	0.0032	94.0	
Aerokleen Aviation Solvent 100%	0.0470	0.0045	90.4	50.9
	0.0534	0.0521	2.4	
	0.0870	0.0350	59.8	
Aquavantage 815GD 25%	0.1098	0.0628	42.8	45.4
	0.0768	0.0410	46.6	
	0.0713	0.0380	46.7	

Table 152: Results of Trial #1

Conclusion:

SC Aircraft and Metal Cleaner is an effective cleaner in removing the Royco 27A grease. Aerokleen Aviation Solvent and Aquavantage 815GD are not effective cleaners in removing the Royco grease soil.

Trial #2

Purpose: To evaluate the effectiveness of multiple cleaners in removing the Royco 27A grease contaminant from aluminum coupons

Equipment: Ultrasonics

Substrates: Aluminum

Contaminants: Greases

Rinsing Conditions: None

Drying Methods: Nones

Analysis Methods: Gravimetric

Experimental Procedure: Two cleaning products were chosen using previous testing data on their performance for removing other greases. Three pre weighed aluminum coupons were assigned to each cleaner for a total of 6 aluminum coupons. The coupons were soiled with the Royco 27A grease (about 0.5 grams) by applying the soil to the bottom third of the coupons with a swab. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of heated ultrasonics at 130 degrees F in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt. of cont.	Final wt. of cont.	% Cont. Removed	% AVG
SC Aircraft and Metal Cleaner 100%	0.0819	0.0066	91.9	93.5
	0.0890	0.0061	93.2	
	0.1284	0.0060	95.3	
Aerokleen Aviation Solvent 100%	0.1282	0.0032	97.5	97.8
	0.0891	0.0026	97.1	
	0.1090	0.0013	98.8	

Table 163: Results of Trial #2

Conclusions: Both cleaners are effective in removing the Royco 27A grease from aluminum coupons utilizing a heated ultrasonics method.

Trial #3

Purpose: To evaluate the effectiveness of multiple cleaners in removing the Royco 27A grease contaminant from aluminum coupons

Equipment: Ultrasonics

Substrates: Aluminum

Contaminants: Greases

Rinsing Conditions: None

Drying Methods: Nones

Analysis Methods: Gravimetric

Experimental Procedure: Five solvents were chosen using previous testing data on their performance for removing other waxes and greases. Three pre weighed aluminum coupons were assigned to each solvent for each substrate for a total of 15 aluminum coupons. The coupons were soiled with the Royco 27A grease soil (about 0.5 grams) on the bottom third of the coupons using a swab. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of unheated ultrasonics in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt. of cont.	Final wt. of cont.	%Cont. Removed	% AVG
1-Propanol 100%	0.0864	0.0040	95.4	97.5
	0.0767	0.0005	99.4	
	0.0650	0.0014	97.9	

Thiophene 100%	0.0627	0.0010	98.4	98.3
	0.0869	0.0004	99.5	
	0.0428	0.0013	97.0	
1-Butanol 100%	0.0383	0.0008	97.9	98.6
	0.0295	0.0003	99.0	
	0.0776	0.0009	98.8	
Dowanol PnBGE 100%	0.0499	0.0010	98.0	98.2
	0.0452	0.0006	98.7	
	0.0631	0.0013	97.9	
Flexisolv DBE-LVP Esters 100%	0.0973	0.0084	91.4	89.3
	0.0669	0.0019	97.2	
	0.0765	0.0157	79.5	

Table 174: Results of Trial #3

Conclusion: 1-Propanol, Thiophene, 1-Butanol, and Dowanol PnBGE are all very effective cleaners in removing the Royco 27A grease soil. The Flexisolv DBE-LVP is a reasonably effective cleaner in removing the Royco 27A grease soil.

Trial #4

Purpose: To evaluate the effectiveness of identified low flammability solvents in removing Royco 27A grease

Equipment: Ultrasonics

Substrates: Aluminum

Contaminants: Greases

Rinsing Conditions: None

Drying Methods: None

Analysis Methods: Gravimetric+

Experimental Procedure: Three solvents were chosen using previous testing data on their low flammability. Three pre weighed aluminum coupons were assigned to each solvent for each substrate for a total of 9 aluminum coupons. The coupons were soiled with the Royco 27A grease (about 0.5 grams) by spreading on the bottom third of the coupons with a swab. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of unheated ultrasonics in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt. of cont.	Final wt. of cont.	%Cont. Removed	% AVG
Anisole 100%	0.0664	0.0020	97.0	98.0
	0.1013	0.0024	97.6	
	0.0584	0.0003	99.5	
Dimethyl Glutarate 100%	0.0843	0.0763	9.5	32.0
	0.0857	0.0583	32.0	
	0.0776	0.0308	60.3	
Triethyl Phosphate 100%	0.1240	0.0503	59.4	71.7
	0.1189	0.0152	87.2	
	0.1203	0.0378	68.6	

Table 185: Results of Trial #4

Conclusion: Anisole is highly effective in removing Royco 27A grease. Neither Dimethyl Glutarate nor Triethyl Phosphate were effective in removing Royco 27A grease.

Appendix D – Individual Testing Trials: Company#1, Project 2

Performance Testing

Hansen Solubility Parameters Application

Hansen Solubility Parameters software was utilized to find solvents that could break down the glyconol wax soil as this contaminant proved to be the most difficult to remove. Other recommendations within this report are based on other client testing and need to be tested on-site by the company for feedback. TURI used preliminary HSPiP testing of the glyconol wax as a baseline for identifying safer solvent and product alternatives to test on their parts.

Twenty-four small balls of wax (about 0.5 g), one for each solvent, were placed in an unheated vial with 20 ml of the respective solvent. The solubility ratings listed in Table 3 were assigned to each of the coupons based on how well the solvent dissolved the wax from the aluminum coupons. The ratings were based on visual observations.

Rating #	Description
0	Glyconol wax did not dissolve or dissolve completely
1	Glyconol wax completely dissolved

Table 191: Solubility Rating Key used for Glyconol Wax

The solubility ratings were entered into the HSPiP software, a software tool that utilizes the HSP theory. The HSPiP software can create a solubility sphere in 3D solubility space based on the HSP parameters and solubility results for numerous solute/solvent interaction tests. For this project, 24 solute/solvent interaction tests were conducted. A junction value between the two solubility spheres was then calculated by the HSPiP software to identify the most effective Hansen Solubility Parameters for dissolving both coatings. All solvents were tested at 100% concentration.

The ratings from that test listed below were used to establish the solubility sphere for the glyconol wax to streamline the process of identifying safer solvents that could work within the vapor degreasing application or an ultrasonics cleaning application. The solvents are listed in order of testing sequence to create the solubility sphere.

Solvent	CAS Number	Rating
Toluene	108-88-3	1
Dimethyl Carbonate	616-38-6	0
Xylenes	1330-20-7	1
Benzyl Alcohol	100-51-6	0
Ethylene Glycol	107-21-1	0

Solvent	CAS Number	Rating
Methyl Acetate	79-20-9	0
Undecane	1120-21-4	0
Ethyl Lactate	97-64-3	0
Acetone	67-64-1	0
Ethyl Acetate	141-78-6	0
Methanol	67-56-1	0
Ethanol	64-17-5	0
1,3-Dioxolane	646-06-0	0
Diethyl Carbonate	105-58-8	0
1-Propanol	71-23-8	1
Isopropanol	67-63-0	0
Propylene Carbonate	108-32-7	0
Thiophene	110-02-1	1
1-Methoxy 2-Propanol	107-98-2	0
Dimethyl Sulfoxide	67-68-5	0
1-Butanol	71-36-3	1
Dimethyl Glutarate	1119-40-0	0
Anisole	100-66-3	0
2-Butoxyethyl Acetate	112-07-2	0

Table 202: HSP Solvents tested on Glyconol Wax

During the development of the solubility sphere, three solvents that had a lower hazard assessment final than the original chemical in P2OASys that had a "1" rating were identified as viable alternative solvents to PERC.

Solvent	CAS	δD	δP	δH
1-Propanol 100%	71-23-8	16	6.8	17.4
1-Butanol 100%	71-36-3	16	5.7	15.8
Thiophene 100%	110-02-1	18.9	2.4	7.8

Table 213: Effective Solvents from HSP Solubility Sphere Testing

An additional solvent potential alternative modified alcohol was identified as having similar HSP parameters to the initial three solvents found using the HSPIP software. The modified alcohol, Propylene Glycol Ether, was found to be the main active ingredient in a product called Dowanol PnBGE. This product along with the three identified solvents were chosen for performance testing. Other solvent products chosen for performance testing were found on TURI's database CleanerSolutions of

past client testing. The products were found to have either been successful past replacements of PERC or were successful in removing a wax contaminant during previous testing. These products include Flexisolv DBE-LVP Esters, SC Aircraft and Metal Cleaner, and Aerokleen Aviation Cleaner.

Trial #0

Purpose: To evaluate the effectiveness of multiple cleaners in removing glyconol wax from aluminum coupons

Equipment: Ultrasonics

Substrates: Aluminum (although during the manufacturing process the glyconol wax is only used on the composite fiberglass honeycomb, aluminum coupons were used to initially observe the wax's reaction the chemistries being tested. Upon successful cleaning, the chemistries will then be tested on the composite fiberglass to ensure substrate compatibility.)

Contaminants: Glyconol Wax

Rinsing Conditions: None

Drying Methods: None

Analysis Methods: Gravimetric

Experimental Procedure: Three cleaning products were chosen using previous testing data on their performance for removing other waxes. Three pre-weighted aluminum coupons were assigned to each cleaner for 9 coupons. The coupons were soiled with the glyconol wax (about 0.5g) by placing a small ball of wax on the bottom third of the coupons, heating the wax with a heat gun for a few seconds, then smearing the wax across the bottom third of the coupons. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of unheated ultrasonics in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt of cont.	Final wt of cont.	%Cont Removed	% AVG
Metalnox M6342R 12%	0.3536	0.1054	70.2	77.6
	0.3104	0.0821	73.6	
	0.2656	0.0288	89.2	
Shopmaster LPH 10%	0.4065	0.3470	14.4	50.4
	0.2870	0.0206	92.8	
	0.6323	0.3550	43.9	
Soyclear 1500 100%	0.2270	0.0169	92.6	92.8
	0.4814	0.0410	91.5	
	0.2945	0.0165	94.4	

Table 224: Trial #0 Results

Metalnox M6324R attacked and stripped the substrate of aluminum. The removal performance of the Metalnox may be inaccurate due to removal percentage that also includes the removal of the substrate.

Conclusion: Neither the Metalnox M6324R nor the Shopmaster LPH were effective in removing the glyconol wax from the aluminum coupons. The Soyclear 1500 is an effective cleaner in removing the glyconol wax from the aluminum coupons, however it would require a manual wiping step post cleaning to remove all the solid wax not broken-down during ultrasonics which may not be the most efficient process for the client.

Trial #1

Purpose: To evaluate the effectiveness of multiple cleaners in removing glyconol wax from aluminum coupons

Equipment: Ultrasonics

Substrates: Aluminum (although during the manufacturing process the glyconol wax is only used on the composite fiberglass honeycomb, aluminum coupons were used to initially observe the wax's reaction the chemistries being tested. Upon successful cleaning, the chemistries will then be tested on the composite fiberglass to ensure substrate compatibility.)

Contaminants: Glyconol Wax

Rinsing Conditions: None

Drying Methods: None

Analysis Methods: Gravimetric

Experimental Procedure: Three cleaning products were chosen using previous testing data on their performance for removing other waxes. Three pre-weighted aluminum coupons were assigned to each cleaner for 9 coupons. The coupons were soiled with the glyconol wax (about 0.5g) by placing a small ball of wax on the bottom third of the coupons, heating the wax with a heat gun for a few seconds, then smearing the wax across the bottom third of the coupons. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of unheated ultrasonics in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt. of cont.	Final wt. of cont.	%Cont. Removed	% AVG
SC Aircraft and Metal Cleaner 100%	0.1806	0.1091	39.6	58.4
	0.0693	0.0117	83.1	
	0.0942	0.0447	52.6	
	0.0940	0.0340	63.8	46.4
	0.1543	0.1463	5.2	

Aerokleen Aviation Solvent 100%	0.0835	0.0248	70.3	
Aquavantage 815GD 25%	0.2192	0.1712	21.9	14.6
	0.2052	0.1838	10.4	
	0.1135	0.1006	11.4	

Table 235: Trial #1 Results

Conclusions: None of the tested products were effective in removing the glyconol wax from the aluminum coupons.

Trial #2

Purpose: To evaluate the effectiveness of multiple cleaners in removing glyconol wax from aluminum coupons

Equipment: Ultrasonics

Substrates: Aluminum (although during the manufacturing process the glyconol wax is only used on the composite fiberglass honeycomb, aluminum coupons were used to initially observe the wax's reaction the chemistries being tested. Upon successful cleaning, the chemistries will then be tested on the composite fiberglass to ensure substrate compatibility.)

Contaminants: Glyconol Wax

Rinsing Conditions: None

Drying Methods: None

Analysis Methods: Gravimetric

Experimental Procedure: Three cleaning products were chosen using previous testing data on their performance for removing other waxes and greases. Three pre weighed aluminum coupons and three pre weighed fiberglass composite coupons were assigned to each cleaner for each substrate for a total of 9 coupons. The aluminum coupons were soiled with Glyconol Wax (about 0.5 grams) by applying to soil to the bottom third of the coupons with a swab. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of heated ultrasonics at 130 degrees F in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt. of cont.	Final wt. of cont.	%Cont. Removed	% AVG
SC Aircraft and Metal Cleaner 100%	0.0491	0.0549	-11.8	31.2
	0.1498	0.1114	25.6	
	0.1637	0.0333	79.7	

Aerokleen Aviation Solvent 100%	0.1192	0.0201	83.1	89.9
	0.0773	0.0050	93.5	
	0.1166	0.0081	93.1	
Soyclear 1500 100%	0.0929	0.0031	96.7	95.0
	0.0486	0.0049	89.9	
	0.0672	0.0011	98.4	

Table 246: Trial #2 Results

Although both the Aerokleen Aviation Solvent and the Soyclear 1500 removed a high percentage of the wax from the fiberglass coupons, some of the wax visibly remained on the coupons.

Conclusion: SC Aircraft and Metal Cleaner is not effective in removing the wax. Aerokleen Aviation Solvent and Soyclear 1500 are effective cleaners in removing the wax soil from the aluminum coupons.

Trial #3

Purpose: To evaluate the effectiveness of multiple cleaners in removing glyconol wax from aluminum coupons

Equipment: Ultrasonics

Substrates: Aluminum (although during the manufacturing process the glyconol wax is only used on the composite fiberglass honeycomb, aluminum coupons were used to initially observe the wax's reaction the chemistries being tested. Upon successful cleaning, the chemistries will then be tested on the composite fiberglass to ensure substrate compatibility.)

Contaminants: Glyconol Wax

Rinsing Conditions: None

Drying Methods: None

Analysis Methods: Gravimetric

Experimental Procedure: Six solvents were chosen using previous testing data on their performance for removing other waxes and greases. Three pre weighed aluminum coupons were assigned to each solvent for each substrate for a total of 18 aluminum coupons. The coupons were soiled with the glyconol wax soil (about 0.5 grams) by placing a small ball of wax onto the bottom third of the coupon, heating it with a heat gun to melt the wax, and then spreading the wax into a strip across the bottom third of the coupons. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of unheated ultrasonics in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt. of cont.	Final wt. of cont.	%Cont. Removed	% AVG

1-Propanol 100%	0.0888	0.0015	98.3	98.6
	0.0818	0.0004	99.5	
	0.0731	0.0014	98.1	
Thiophene 100%	0.0590	0.0007	98.8	98.6
	0.0446	0.0012	97.3	
	0.0487	0.0001	99.8	
1-Butanol 100%	0.0761	0.0015	98.0	99.3
	0.0530	0.0000	100.0	
	0.0429	0.0000	100.0	
Dowanol PnBGE 100%	0.0531	0.0021	96.1	97.4
	0.0786	0.0020	97.5	
	0.0757	0.0010	98.7	
PC 118 EPS Stripper 100%	0.0755	0.0616	18.4	25.4
	0.0824	0.0633	23.2	
	0.0628	0.0411	34.6	
Flexisolv DBE-LVP Esters 100%	0.0703	0.0171	75.7	80.5
	0.0925	0.0069	92.5	
	0.0689	0.0185	73.2	

Table 257: Results of Trial #3

Although the Flexisolv DBE-LVP Esters removed a high percentage of the soil from the coupons, some of the wax visibly remained on the coupons after cleaner.

Conclusion: 1-Propanol, Thiophene, 1-Butanol, and Dowanol PnBGE are all effective cleaners in removing the wax soil from aluminum coupons. PC 118 EPS Stripper is not an effective cleaner in removing the wax soil from aluminum coupons. Flexisolv DBE-LVP Esters is a somewhat effective cleaner in removing the wax soil from aluminum coupons.

Trial #4

Purpose: Compatibility testing for previously identified effective solvents on the fiberglass composite material supplied by the client.

Equipment: Immersion/Soak

Substrates: Composite Fiberglass

Contaminants: None

Rinsing Conditions: None

Drying Methods: None

Analysis Methods: Gravimetric, Visual

Experimental Procedure: Four small pieces of the fiberglass composite material were used for compatibility testing. Each piece had its initial weight recorded. Each piece was placed in a vial of 10ml

of one of the previously identified solvents (1-propanol, Thiophene, 1-Butanol, Dowanol PnBGE). The vials were placed on an automated roller to subject the vials to slight agitation. The pieces were left to soak overnight. The next day, the pieces were removed from the vials in order to record their final weights. They were also visually analyzed to see if any of the solvents cause shape, hardness, or other property changes.

Results:

Solvent	Initial Weight of Substrate (g)	Final Weight of Substrate (g)	Visual Observations
1-Propanol 100%	0.0995	0.0995	No Change
Thiophene 100%	0.1438	0.1438	No Change
1-Butanol 100%	0.1400	0.1402	No Change
Dowanol PnBGE 100%	0.1770	0.1771	No Change
Flexisolv DBE-LVP Esters 100%	0.1409	0.1414	No Change
SC Aircraft and Metal Cleaner 100%	0.1597	0.1614	No Change
Aerokleen Aviation Solvent 100%	0.1421	0.1436	No Change
Anisole 100%	0.1441	0.1448	No Change

Table 268: Compatibility test for composite honeycomb

Conclusion: All of the tested solvents are compatible with the fiberglass composite material.

Trial #5

Purpose: To evaluate the effectiveness of the previously identified successful solvents utilizing methods other than ultrasonics.

Equipment: Immersion/Soak

Substrates: Aluminum

Contaminants: Glyconol Wax

Rinsing Conditions: None

Drying Methods: None

Analysis Methods: Gravimetric, Visual

Experimental Procedure: Four solvents were chosen using previous testing data on their performance for removing other waxes and greases. Three pre weighed aluminum coupons were assigned to each solvent for each substrate for a total of 12 aluminum coupons. The coupons were soiled with the glyconol wax soil (about 0.5 grams) by placing a small ball of wax onto the bottom third of the coupon, heating it with a heat gun to melt the wax, and then spreading the wax into a strip across the bottom

third of the coupons. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of unheated immersion with a stir bar set at 300 rpm in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt. of cont.	Final wt. of cont.	%Cont. Removed	% AVG
1-Propanol 100%	0.0610	0.0002	99.7	99.6
	0.0561	0.0003	99.5	
	0.0448	0.0002	99.6	
Thiophene 100%	0.0774	0.0001	99.9	99.7
	0.0663	0.0003	99.6	
	0.0576	0.0002	99.7	
1-Butanol 100%	0.0457	0.0016	96.5	91.5
	0.0518	0.0014	97.3	
	0.0890	0.0171	80.8	
Dowanol PnBGE 100%	0.0245	0.0023	90.6	71.7
	0.0549	0.0142	74.1	
	0.0819	0.0407	50.3	

Table 279: Trial #5 Results

Although 1-Propanol, and 1-Butanol removed a high percentage of the wax soil, some wax visibly remained on the coupons after cleaning. Coupons cleaned with Thiophene were completely void of any remaining wax.

Conclusion: 1-Butanol is a somewhat effective cleaner in removing the wax soil using unheated immersion methods. Thiophene and 1-Propanol are very effective cleaners in removing the wax soil using unheated immersion methods. Dowanol PnBGE is not an effective cleaner in removing the wax soil using unheated immersion methods.

Trial #6

Purpose: To evaluate the effectiveness of identified low flammability solvents in removing Glyconol Wax.

Equipment: Ultrasonics

Substrates: Aluminum

Contaminants: Glyconol Wax

Rinsing Conditions: None

Drying Methods: None

Analysis Methods: Gravimetric

Experimental Procedure: Three solvents were chosen using previous testing data on their low flammability. Three pre weighed aluminum coupons were assigned to each solvent for each substrate for a total of 9 aluminum coupons. The coupons were soiled with the glyconol wax soil (about 0.5 grams) by placing a small ball of wax onto the bottom third of the coupon, heating it with a heat gun to melt the wax, and then spreading the wax into a strip across the bottom third of the coupons. After soiling, the dirty weights of the coupons were recorded. The coupons were then subjected to 20 mins of unheated ultrasonics in their respective cleaners. The coupons were left to air dry overnight before the clean weights were recorded.

Results:

Cleaner	Initial wt. of cont.	Final wt. of cont.	%Cont. Removed	% AVG
Anisole 100%	0.1369	0.1063	22.4	51.6
	0.1580	0.0565	64.2	
	0.1748	0.0556	68.2	
Dimethyl Glutarate 100%	0.1521	0.1179	22.5	30.0
	0.1355	0.0862	36.4	
	0.1646	0.1133	31.2	
Triethyl Phosphate 100%	0.1194	0.0137	88.5	60.8
	0.1294	0.0256	80.2	
	0.2369	0.2044	13.7	

Table 2810: Trial #6 Results

Conclusion: None of the solvents tested were effective in removing the glyconol wax soil.

Appendix E– Individual Testing Trials: Company #2, Project 1

Performance Testing

Hansen Solubility Parameters Application

Initial testing began with HSPIP testing to identify solvents that are able to break the bond between paint and the substrate once dried, if any. Twenty-four stainless steel coupons were soiled with the 1:1 paint and primer mixture (about 0.5 g), one for each solvent, and were placed in an unheated vial with 20 ml of the respective solvent. The solubility ratings listed in Table 2 were assigned to each of the coupons based on how well the solvent dissolved paint mixture. The ratings were based on visual observations.

Rating #	Description
0	Paint and primer mixture was not removed from coupon
1	Paint and primer mixture was removed from coupon

Table 291: Solubility Rating Key Used for HSP coupons

Trial #0

Purpose: Determining an effective replacement to Methyl Ethyl Ketone (MEK) in cleaning
Equipment: Immersion/Soaking
Substrates: Aluminum
Contaminants: Paints
Rinsing Conditions: None
Drying Methods: None
Analysis Methods: Visual

Experimental Procedure: Six alternatives were identified and selected for testing. These were, Ethylene Glycol, D-Super Remover, Diethyl Carbonate, Isopropanol (70%), Dimethyl Carbonate, and Methyl Acetate. Aluminum C1020 alloy coupons were rated on a visual cleanliness scale, with 5 being completely dirty, and 1 being completely clean, with 3 coupons for each cleaner for experimental redundancy. Paint and Primer mixture provided by client were mixed in a 1:1 ratio and applied to the bottom section of the aluminum coupons as per industrial testing standard procedure. The coupons were then rated with wet paint present to get dirty rating values. The coupons were then immersed in the unheated cleaner/solvent such that the painted portions were completely submersed, and a magnetic stir bar was used to stir the solution for 30 minutes. After 30 minutes had passed, the coupons were removed and allowed to dry overnight. The following day, the coupons were once again rated for visual cleanliness, and the least effective options were eliminated for subsequent testing.

Results

Cleaner	Coupon	Average Dirty Values	Average Clean Values
Ethylene Glycol 100%	16	5	5
	17		
	18		
D Super Remover 100%	19	5	1.83
	20		
	22		
Diethyl Carbonate 100%	24	5	3.33
	28		
	30		
Isopropanol 100%	31	5	3.83
	35		
	36		
Dimethyl Carbonate 100%	16	5	4.33
	17		
	18		
Methyl Acetate 100%	19	5	3.16
	20		
	22		

Table 302:Trial #0 Results

Conclusion: In conclusion, ethylene glycol, Isopropanol, and Dimethyl Carbonate were removed from further testing as they were the least effective options in this test. Diethyl Carbonate, and Methyl Acetate were selected as cleaners for the next round of testing. D-super remover was eliminated from testing, as the contents of the product were deemed too hazardous to recommend as an alternative.

Trial #1

Purpose: Determining an effective replacement to Methyl Ethyl Ketone (MEK) in cleaning wet paint form inside of a siphoned-air paint gun
Equipment: Immersion/Soaking with Manual Wipe
Substrates: Aluminum
Contaminants: Paints
Rinsing Conditions: None
Drying Methods: None
Analysis Methods: Visual

Experimental Procedure: 4 alternative solvents were selected for testing. These were Diethyl Carbonate, Dimethyl Sulfoxide, 1,3- Dioxolane, and Methyl Acetate. Aluminum C1020 alloy coupons were rated on a visual cleanliness scale, with 5 being completely dirty, and 1 being completely clean, with 3 coupons for each cleaner for experimental redundancy. Paint and Primer mixture provided by client were mixed in a 1:1 ratio and applied to the bottom section of the aluminum coupons as per industrial testing standard procedure. The coupons were then rated with wet paint present to get dirty rating values. The coupons were then wiped with a low-lint wipe that had been dipped in the selected solvent, with 3 slow wiping motions along the bottom of each coupon, with a separate wipe being used for each coupon. The coupons were then allowed to dry overnight. The following day, the coupons were once again rated for visual cleanliness.

Results:

Cleaner	Coupon	Average Dirty Values	Average Clean Values
Diethyl Carbonate 100%	1	5	1
	2		
	3		
Dimethyl Sulfoxide 100%	4	5	1
	5		
	6		
1,3-Dioxolane 100%	7	5	1
	8		
	9		
Methyl Acetate 100%	10	5	1
	11		
	12		

Table 313: Trial #1 Results

Conclusion: Due to the change in cleaning method, the above cleaners were far more effective than they would have been for standard immersion. This means that every cleaner was able to remove the entirety of the wet paint contaminant. Given that standard immersion is not exactly a 1-to-1 replication of the currently employed cleaning methodology, the laboratory felt it pertinent to test a variety of cleaning techniques.

Trial #2

Purpose: To evaluate the efficacy of previously identified solvents and mixture in removing oil from aluminum panels via manual wipe
Equipment: Manual Wipe
Substrates: Aluminum
Contaminants: Oil
Rinsing Conditions: None
Drying Methods: None

Analysis Methods: Gravimetric

Experimental Procedure: Three pre-weighed aluminum coupons were used per cleaner for a total of 9 coupons. The coupons were then soiled with a mixture of 1 teaspoon of AATCC synthetic soil and 50 mL of mineral oil by swabbing the mixture onto the bottom third of the coupons. The dirty weights of the coupons were then recorded. The coupons were then cleaned with their respective cleaners by a singular wipe of a paper towel wet with the correct cleaner. The coupons were then left to dry for 20 mins before the clean weights were recorded.

Results:

Cleaner	Initial wt. of cont.	Final wt. of cont.	%Cont. Removed	% AVG
Dimethyl Carbonate 100%	0.0944	0.0033	96.5	98.5
	0.0967	0.0000	100.0	
	0.0365	0.0004	98.9	
Ethyl Acetate 100%	0.0535	0.0011	97.9	98.1
	0.0776	0.0004	99.5	
	0.0321	0.0010	96.9	
62% Ethyl Acetate + 38% Dimethyl Carbonate	0.0762	0.0007	99.1	97.9
	0.0500	0.0022	95.6	
	0.0750	0.0007	99.1	

Conclusion: Dimethyl Carbonate, Ethyl Acetate, and the mixture of 62% Ethyl Acetate + 38% Dimethyl Carbonate all effectively removed the oil from the aluminum coupons with a singular manual wipe.

Trial #3

Purpose: To evaluate the efficacy of previously identified solvents and mixture in removing sharpie ink from aluminum panels via manual wipe
Equipment: Manual Wipe
Substrates: Aluminum
Contaminants: Sharpie Ink
Rinsing Conditions: None
Drying Methods: None
Analysis Methods: Visual

Experimental Procedure: Three aluminum coupons were used per cleaner for a total of 9 coupons. The coupons soiled with sharpie ink by drawing a squiggle along the bottom third of the coupon. The dirty visual rankings were then recorded. The coupons were then cleaned with their respective cleaners by

manually wiping a paper towel wet with the cleaner on the coupons for a total of 5 seconds. The cleaned visual rankings were then recorded.
Visual Rankings Key:
1: 100% soil removed
2: 75% soil removed
3: 50% soil removed
4: 25% soil removed
5: 0% soil removed

Results:

Cleaner	Coupon	Average Dirty Values	Average Clean Values
Diethyl Carbonate 100%	1	5	1.2
	2		
	3		
Ethyl Acetate 100%	4	5	1.0
	5		
	6		
62% Ethyl Acetate + 38% Dimethyl Carbonate	7	5	1.0
	8		
	9		

Conclusion: Dimethyl Carbonate, Ethyl Acetate, and the mixture of 62% Ethyl Acetate + 38% Dimethyl Carbonate were all able to effectively remove sharpie ink from aluminum coupons within 5 seconds via manual wiping.

Appendix F– Individual Testing Trials: Company #2, Project 2

Trial #0

Purpose: Determining the effectiveness of selected cleaners for removing aerospace paint from a stainless-steel substrate.
Equipment: Immersion/Soaking
Substrates: Stainless Steel
Contaminants: Paints
Rinsing Conditions: None
Drying Methods: None
Analysis Methods: Visual

Experimental Procedure: 4 alternative solvents were identified and selected for testing. These were Diethyl Carbonate, Dimethyl Sulfoxide, 1,3-Dioxolane, and Methyl Acetate. Stainless Steel 316 alloy coupons were rated on a visual cleanliness scale, with 5 being completely dirty, and 1 being completely clean, with 3 coupons for each cleaner for experimental redundancy. The Paint and Primer mixture provided by client were mixed in a 1:1 ratio and applied to the bottom section of the stainless-steel coupons as per industrial testing standard procedure. The coupons were then rated with the wet paint present to get dirty rating values. The coupons were then immersed in the unheated cleaner such that the painted portions were completely submersed, and a magnetic stir bar was used to stir the solution for 30 minutes. After 30 minutes had passed, the coupons were removed and allowed to dry overnight. The following day, the coupons were once again rated for visual cleanliness, and the least effective options were eliminated for subsequent testing.

Results:

Cleaner	Coupon	Average Dirty Visual Ratings	Average Clean Visual Ratings
Diethyl Carbonate 100%	5	5	4.5
	13		
	17		
Dimethyl Sulfoxide 100%	21	5	2.8
	22		
	26		
1,3-Dioxolane 100%	27	5	3.5
	28		
	31		
Methyl Acetate 100%	33	5	4.6
	34		
	36		

Table 32: Trial #0 Results

Conclusion: Both the 1,3-Dioxolane and Dimethyl Sulfoxide started removing paint immediately after the coupons were immersed, but ultimately were unable to remove the entirety of the paint. Diethyl Carbonate and Methyl Acetate ultimately struggled to remove any of the paint, while Dimethyl Sulfoxide was marginally more effective than 1,3-dioxolane, with both not performing to the degree that is satisfactory. Further testing will examine Hansen Solubility Parameters and their application to removal of the paint and substrate compatibility testing.

Trial #1

Purpose: Evaluating efficacy of HSPIP solvent mixtures on cleaning wet paint from gun interior parts via siphoning

Equipment: High Pressure Spray

Substrates: Stainless Steel
Contaminants: Paints
Rinsing Conditions: None
Drying Methods: None
Analysis Methods: Visual

Experimental Procedure: This experiment focused on trying to replicate process conditions as closely as possible. As such, the supplied compressed air paint gun from the client was used as a coupon. Prior to testing, the feed tube for the paint gun was cleaned using in-house paint removers to ensure that there was as little dried paint present as possible. Pictures were taken of the interior prior to soiling. The interior of the feed tube was then soiled with the 1:1 mixture of primer and paint, and pictures were taken after soiling. The HSPiP calculated mixtures; (1) 16% Dimethyl Glutarate + 84% Methyl Acetate, (2) 38% Dimethyl Carbonate + 62% Ethyl Acetate, were prepared and then siphoned through the gun for 1 minute each. The interior of the feed tube was photographed after each solvent mixture was siphoned through to establish effectiveness. Cleanliness was then rated on the standard scale of 1 to 5, with 1 being completely clean and 5 being completely dirty.

Results:

Solvent Mixture	Coupon 1 Final Visual	Averaged Final Values
(1) 16% Dimethyl Glutarate, 84% Methyl Acetate	5	4.83
	5	
	4.5	
(2) 38% Dimethyl Carbonate, 62% Ethyl Acetate	3	3.16
	3.5	
	3.0	

Table 33: Trial #1 Results

Conclusion: In conclusion, the results of this test indicated that mixture 2 was more effective at removing the wet paint from the paint feed tube interior. However, given the difficulties of testing using the method of actually spraying solvent through the gun, it is the opinion of the experimenters that testing should be done with these mixtures on-site by the client in addition to in-house testing.