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Technical Performance Evaluation of the Potential Biobased Floor Strippers

By Ephraim Massawe, Kenneth Geiser, Michael Ellenbecker and Jason Marshall

Abstract

Biobased products may soon replace most petroleum based chemicals, industrial products and composite materials. Advocates emphasize that these products are environmentally friendlier, safer and healthier for the users. Others argue that promotion of these industrial products would make the United States more secure by depending less on foreign energy sources. This paper presents results of identification and technical performance evaluation of some biobased products. They are potential alternatives to the petroleum based floor strippers.

Within the framework of cleaner production (CP) and toxic use reduction (TUR) this study identified and subjected the potential alternative products to technical performance experiments. Two sets of experiments were performed. The first set of experiments involved laboratory scale experiments using different cleaning products and techniques. The second set of experiments involved pre-field tests conducted on a typical floor in the Toxic Use Reduction Institute (TURI) laboratory. All experiments employed TURI's standard operating procedures (SOP) under different experimental conditions varying the temperature, soaking time, cleaning media (abrasive pads or cotton cloth) and the concentration of products. The cleaning efficiency for each of the biobased or green products used was based on the gravimetric analysis of the coupons or via a standard visual method based on a UV (black) light or both.

A total of 14 floor stripping products were identified from various sources. About 21% of these products were soy-based. Corn and citrus-based products accounted for 7% of each. While about 43% of the products were classified as plant based, 22% of products were labeled only as green products containing biodegradable ingredients without further classifying their specific sources.

Variations in the technical performance of potential biobased floor strippers were observed. Performance of concentrated potential biobased floor strippers was in the range of 50 to 99%, with the Botanic Gold performing best at 94% contaminant removal efficiency. CornSolv was eliminated because of its odor while DBE-6 was abandoned because it peeled off the floor tile surfaces. The technical performance of Botanic Gold at 25% dilution was comparable to the current floor stripping product. It is recommended that larger field trials should be conducted and at the same time determine janitors' perceptions on the use of these products. It is important to investigate the common additives to the biobased industrial chemicals and products and to determine their effects on technical performance of these products.

Finally, we recommend that a review of the current status and future direction of the relevant policies and regulatory frameworks that can promote biobased industrial chemicals and products should be performed. Furthermore, there should be a bold effort to encourage broader public debate about the future of the biobased industry in the context of environmental, health and safety and societal sustainability.

Key words: ***Biobased products, toxic use reduction, technical performance evaluation, EHS, biomass, alternative substitutes, and cleaner production***

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1.0 Introduction

Maintenance of floor surfaces often requires frequent floor stripping in order to remove old waxes or paints in preparation for a new coating. The principal products commonly used for floor stripping are derived from petroleum-based feedstocks. Like many other products derived from petroleum products, current floor strippers are similarly from petroleum feedstocks and they have been linked to significant environmental, health and safety (EHS) impacts [1,2]. Searching for environmentally benign alternatives to the current toxic chemicals and products is driven by the increased attention on the EHS issues together with stringent governmental regulations on emission standards, liability concerns and market drivers sensitive to these issues. Environmentally benign alternative products often come into the market as “green” industrial chemicals and products. Extensive efforts on research and development of alternative products for general cleaning and floor stripping tasks have now presented biobased industrial chemicals and products as the immediate candidates. Some of the biobased products have now reached an advanced stage of commercial utilization with different applications, including floor stripping. However, this is not to say because these products are biobased, they are necessarily free of health and safety hazards.

Biobased industrial products and chemicals can be derived from feedstocks of crops such as corn, soy, palm, and rice. Other sources may include seeds (oilseeds, feedgrains, foodgrains); fruit & melons (apple, orange, pear, etc.); leaves (grasses, flax, rice, wheat, milkweed); (kenaf, sugar cane, trees, hemp); algae (phytoplankton, kelp, etc.); animals (cattle, sheep, bees, fish, sponges, birds, zooplankton, etc.); waste (manure, crop and forest residues, urban biomass waste, food processing waste, etc.) and bacteria (molds, fungi, etc.).

For a number of years the Toxics Use Reduction Institute (TURI) Surface Solution Laboratory (SSL) has being investigating several alternative cleaning solvents from different sources as potential substitutes to toxic cleaning products. Most biobased alternatives investigated by TURI SSL fall into three major classifications of Soy Methyl Ester (SME), Lactate Esters (LE) and D-Limonene (DL) [3]. These classifications, together with some mixtures of the primary sources are presented in Table 1.

Table 1 Basic Sources of Biobased Cleaning Products Investigated by TURI SSL [3]

Class	Source	Code
Soy Methyl Ester (SME)	Soy Oil is heated and reacted with methanol in the presence of a catalyst	SME
Lactate Esters (LE)	The process uses sugar starches and oils through high performance microbial fermentation	LE
D-Limonene (DL)	Oils Extracted from Citrus Fruits	DL
SME & LE	Mix SME and LE	SL
LE and DL	Mix of LE and DL	LD

There are many issues associated with the use of these sources of biomass feedstocks for non-food uses. In the future two things might happen: One is the potential competition for use of biomass feedstocks for food and other non-food uses and two is that farmers might be compelled to grow crops mainly for one industry and not for the other [4]. However, with the great availability of biomass in the United States together with the renewable nature of biomass it is highly unlikely that serious problems will arise. Instead, harvesting biomass wastes and other crops for food and feedstocks will help to ensure environmental sustainability in both the food and non-food manufacturing industries. Thus, biomass feedstocks and the products or chemicals derived from them, if processed in an environmentally friendly way, will contribute to reduced environmental footprints compared with those obtained from petroleum based feedstocks. In addition to crops grown for non-food uses, it is estimated that there are about 300 million tons of waste biomass generated from about 35 million acres [5]. This large source of raw materials can ensure that stakeholders could obtain a constant supply of biomass feedstocks required to support this emerging industry.

The environmental, health, and safety (EHS) aspects of some biobased industrial chemicals and products in the cleaning industry were recently evaluated [6]. The results indicate that these products are better than the conventional petroleum based products. However, the technical performance for such biobased cleaning products is not really known. Thus, it may be extremely difficult for top management and consumers in particular to switch to biobased floor strippers if their technical performance is uncertain. Management and consumers' willingness to switch from one product to another is considered to be one of the internal challenges of promoting alternatives substitutes. This is true especially for those products that perform equally as well as the product they are intended to replace under the TUR and CP frameworks [7]. These frameworks are discussed later in another section of this paper. Generally, consumers will switch to alternative products if no major changes to the production units (retrofitting) are required when implementing the most feasible alternative option, such as product substitution. Technical performance characterization of potential product substitutes can be used to identify if such obstacles exist when switching to more sustainable products in specific applications.

This research was designed to evaluate technical performance of biobased cleaning products which can be used as floor strippers. Many types of cleaning products that can be used as floor strippers are usually designed to remove wax or paint from surfaces. Potential biobased floor strippers can become substitutes for petroleum based products which are believed to contain harmful substances. As a result, this study is designed in the context of product substitution - one of the strategies under the Toxics Use Reduction (TUR) or Cleaner Production (CP) paradigms. TUR and CP frameworks are discussed in the following section of this paper. In just over a decade, these new ways of thinking have evolved in the United States and throughout the world in order to help industry move towards sustainability by adopting new alternative processes, products or services that will have minimum ecological, health or safety impacts but work equally well as current systems.

2.0 TUR/CP Technical Performance of Biobased Products

Toxics Use Reduction (TUR) and Cleaner Production (CP) are recent paradigms that promote pollution prevention. TUR planning is a strategy that fundamentally addresses pollution prevention aiming at reducing the production, use and disposal of toxic waste [2]. The genesis of TUR is the Massachusetts Toxic Use Reduction Act (MA-TURA1989), one of the first laws of its kind in the United States, which was developed to promote safer and cleaner products in the state of Massachusetts [3]. TURA does not require Massachusetts facilities to implement toxic use reduction nor does it require them to meet specific reduction goals. Instead, the law has established a framework for business to analyze their operations in order to find TUR opportunities. On the other hand, CP is a term that was coined by the United Nations Environment Program (UNEP) to promote pollution prevention. UNEP defined CP as follows [8].

"….the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment. Cleaner Production can be applied to the processes used in any industry, to products themselves and to various services provided in society…"

In the context of safer, healthier and more ecologically friendlier substitutes, one important thing appears common in these TUR and CP paradigms; the recognition that continuous product and process innovation and improvement play critical roles in the pollution prevention (P2), waste minimization (WM), green productivity, eco-efficiency or the CP paradigms.

Technical performance characterization of safer, healthier and more ecologically friendlier alternatives can often be evaluated under the TUR or CP frameworks. TUR planning and the CP methodology normally follow systematic steps in evaluating the alternative options for current products, processes or services. These systematic steps include, but are not limited to the options identification, followed by detailed assessments which include technical evaluation of products [9]. In 1997, the Office of Technical Assistance (OTA) and TURI issued a report to be used as guidance to the systematic steps in the selection of parts cleaning alternatives products [9]. In that report, nine steps for evaluating alternative cleaning products under the TUR framework were discussed. The technical performance evaluations of the products were given high priority in the testing and implementing of alternative assessment of processes, products and services.

For cleaning or floor stripping products, the emphasis was focused on two stages of assessment. These stages were a benchscale or laboratory testing of cleaning products, and a pilot-scale designed to simulate field conditions [10].

In order to promote biobased products as potential alternatives which could be healthier, safer, and more ecologically friendly products, there was need to identify and subject potential products to systematic technical assessments. Results obtained can ascertain the effectiveness of the products in comparison with currently used products. What this means is that after more than a decade of successful research and development programs in the development of biobased chemicals and products United States, the next step is to ensure that new products enter the market with their technical performance guaranteed. However, with the availability of so many alternative biobased products on the market today, it makes the tasks of identification and technical performance appraisal very daunting. Once the process of identifying potential biobased floor strippers has been accomplished, the cleaning or floor stripping process must be as systematic as possible so as to "screen-out" products that do not perform as well as the current products. Section 3.0 presents the theory and practical aspects of cleaning; and the factors which should be considered during the process of technical appraisal of cleaning products.

3.0 Surface Cleaning Procedures: Theory and Practice

A cleaning task is defined as the act of making something clean – free from dirt, stain, soil or impurities [11, 12, 13]. Floor surface cleaning requires a concentrated or ready to use (RTU) cleaner and a mop. For concentrated cleaning solution water is used for dilution purposes. Floor stripping task is one of the aspects of floor cleaning. This process removes an old coat or wax in preparation for a new coating. It is a process which takes place periodically; but depending on the nature of the coating, floor materials, geometry and the frequency or how the floor is used, the number of times that a floor requires stripping may vary from room to room. In general, once the floor stripping task is completed, a sealer and floor finish are applied followed by maintenance of the floor surface.

A typical product used for floor stripping is Johnson Wax Professional (*Pro-Strip*). This product contains substances such as sodium xylene sulphonate; benzyl alcohol; and 2-butaxyethanol or ethylene glycol monobutylether ether or EGBE. An eco-toxicological review of these components revealed that they are associated with significantly high negative impacts on the environment, as well as upon the health and safety of users [14]. NIOSH has recommended discontinuation of use of these products for these reasons [15].

Cleaning of surfaces and in particular, the floor stripping process depends upon the following factors: temperature (T), agitation (A) or cleaning/stripping methods, concentration (C) of the cleaning material and the time (T) of cleaning or stripping (TACT) – [16]. The nature and geometry of the surfaces to be cleaned, type of contaminants to be removed, and the degree of cleanliness required are some other factors that need to be considered during the cleaning process.

Temperature

Temperature is an important parameter in surface cleaning or floor stripping. A slight increase in temperature of the surface cleaning or floor stripping product can often result in increased contaminant removal. Some surface cleaning mechanisms that involve first order reactions, such as emulsification or saponification, have been found to double the contaminant removal efficiencies by increasing temperature of cleaning product by only about 10^oC (18^oF) [16].

Agitation/Cleaning or Stripping Methods

Stripping method is as important as the cleaning product itself. Mechanical cleaning that is straight line or rotational cleaning can often be employed. One should be careful that the stripping mechanism used does not contribute to swelling or excessive corrosion of the surfaces because that would not yield results acceptable to the consumers.

Concentration of the Cleaning or Stripping Product

The cleaning product or floor stripper should ideally be matched with the surface to be cleaned or stripped. In this case, a floor stripper should be able to remove an old wax or coating from the floor surface in preparation for a new layer of coating. This information can be obtained from the product data usually available from the technical data sheets. Manufacturers can recommend a concentrated solution, a ready to use diluted solution or may recommend that consumers dilute their product in certain ratios. The important factor in this criterion is that the concentration should be maintained as directed by the manufacturers.

Time requirements in Surface Cleaning or Floor Stripping

Time is considered to be a critical factor in any surface cleaning, including floor stripping. Generally, the longer the time used the better the surfaces become in terms of cleanliness. The cleaning time, the time required for completing the task is dependent upon other factors such as temperature, cleaning mechanism employed and concentration of the cleaning solution used.

The type, size and geometry of the floor surface to be cleaned

The type, size and shape of the floor surfaces to be cleaned are important factors to be considered when selecting a janitorial cleaner or floor stripper. It is necessary to establish the size and geometry of the surface to be cleaned. This helps in determining if a surface, e.g. the floor, is a simple (flat or even surface) or complex (stairs or hard to reach areas) system to be cleaned. The types of the floor surface to be cleaned is also important because some cleaning products may produce swelling or even corrode the surface to be cleaned. These are undesirable, especially at the laboratory stage because they may mislead the researcher in estimating cleanliness, gravimetrically.

The type of contaminants to be removed

The types of contaminants to be removed play a critical role in the identification of the surfactants that will have the affinity to remove such contaminants. The source of contaminants may be oils, such as petroleum or vegetable oils, greases, waxes, fluxes and salts. Surfactants are common ingredients added to cleaning products formulations to help in removing contaminants. Their capability in this function is based on their ability to form dipole-dipole attraction or hydrogen bonding with water.

Degree of cleanliness required

The person performing the floor stripping should ask himself or herself the following basic questions. Do we need the cleaning done? To what degree should cleanliness be achieved? These and other related questions should be answered in order to make the results of technical performance evaluation of the cleaning products more useful. As discussed earlier, floor stripping as a cleaning operation precedes an application of wax or another coating to the floor surface.

The degree of cleanliness varies from one person to another. For example, the Operational Services Division (OSD) of the Massachusetts Environmental Preferred Purchasing Program awards contracts to firms who sell environmentally friendly products to state agencies. One of the criteria for awarding these contracts is that the product can remove at least 75% and 80% of contaminants for general purpose cleaner and bathroom cleaners, respectively [17]. On the other hand the TURI SSL evaluation of cleaners under this program, considers all products which have achieved a contaminant removal efficiency of 85% as effective [17].

4.0 Materials and Methods

The methods presented in this section address three key issues: identification and selection of the potential products; benchscale testing; and piloting testing of the products.

4.1 Identification and Selection of Potential Products for Technical Evaluation

The database of the SSL, www.cleanersolutions.org, of over 500 products was used to identify and select the test products. The selection process screened these products for the bio-based cleaners and vendors. Furthermore, telephone communication with the vendors and internet search for unknown vendors was conducted to further expand the list of the alternatives. Technical Data Sheets were used to obtain information on the functions for which the products were intended. Many of the biobased products designed for general purpose cleaning tasks were selected even though they were not specifically made for floor stripping. The selection was based on the product's ability to remove waxes or coatings.

4.2 Bench-Scale Technical Characterization of Potential Biobased Floor Strippers

Products identified as potential floor strippers were subjected to bench-scale tests at the TURI SSL. An industry standard floor stripper called Johnson Wax Professional (*Pro-Strip*) was used for comparison purposes. Products that performed well technically were then tested on a typical floor in the laboratory. This test was designed to simulate field conditions.

The experimental procedure consisted of two steps: The first step was based upon gravimetric assessment of the coupons, before and after cleaning (Table 2). A coupon, also known as a panel was selected from a large number of available options in order to meet the needs of the cleaning process and surface such as type, size and geometry of the cleaning surface which can be a metal, floor or wood. Once a coupon is selected, it is weighed while clean and its weight recorded as (A). The coupon is then contaminated with an appropriate “dirt or a contaminant” and its weight is again, recorded as (B). The weight of the dirty coupon (B) minus the initial weight of the coupon (A) represents the weight of the contaminant (C). When the cleaning operation is completed, the coupon is re-weighed and its weight recorded as (D). This weight is equivalent to the weight of the dirty coupon (B) minus the weight of a clean coupon (A). The amount of contaminant that remains on the coupon is represented as (E). This is the initial weight of the contaminant (C) minus the initial weight of the coupon (A). The percentage removal of the contaminant is calculated as shown in column six (Table 2).

Table 2 Gravimetric Analysis before and After Cleaning of Coupons

Initial Weight of Coupons	Dirt Weight or Contaminated Weight of Coupons	Initial Weight of the Contaminant	Clean Weight of the Coupons	Wt. of the Remaining Contaminant on the Coupons	Percent Removal of the Contaminant
A	B	C	D	E	F
			D = B-A	E = C-A	F = (D-E)/D*100

Source: TURI SSL Report 2005 (www.turi.org)

Coupons of different compositions (ceramic and plastic), generally in the size range of 2” x 4” (Fig 1) were subjected to the following three cleaning procedures: (1) Straight line cleaning by using a straight line washability machine. The TURI SSL’s BYK Gardner Abrasive Testing Machine was used together with cotton clothes/towels (See: Surface Solution Laboratory at www.turi.org); (2) Circular cleaning of the coupons by using a hand held drill with abrasive pads attached; and finally; (3) Straight line cleaning of the coupons by using the BYK Gardner abrasive testing machine and abrasive pads. These tests are described in more detail in the Toxic Use Reduction Institute’s Surface Solution Laboratory Manuals.

Other equipment used to determine technical performance of biobased floor stripping products at this stage were (a) a heating gun, capable of producing hot air at about 300 F; (b) Johnson Floor Finish (Show Case) to coat the coupons; (c) BYK Gardner abrasive machine; (d) drilling machine; (e) weighing balance; (f) a source of the fluorescence light (UV); (g) a stop watch, (h) a hand held swab; (i) thermometer; and (j) a heating mantle.

Fig 1 Coupons used in the laboratory experiments

4.2.1 Straight Line Cleaning Using a BYK Gardner Abrasive Testing Machines

In this experiment, clean rectangular plastic and ceramic coupons (2"x 4") were weighed using a weighing balance (Denver Instrument 250). Three coatings of the Johnson Floor Finish (*Show Case*) were applied on each coupon by using hand held cotton swabs. The first coating was dried using a hand held heat gun at 300^{o}F for two minutes. This process was repeated two more times for the second and third coatings.

Three coupons of the same material were then sprayed with 100% volume by volume (v/v) of biobased cleaning product at room temperature (RT) and allowed to sit on the coating for 10 minutes. The coupons were placed in the BYK Gardner abrasive testing machine and held firmly by "C" clamps. A cotton cloth pad was attached to a rectangular piece of wood by an adhesive tape and both of them were then held by tension on the machine. The abrasive machine was started and left to run for a specified period of time or predetermined number of cycles (e.g. five minutes was equivalent to about 140 machine cycles). This experiment was repeated under different conditions. The purpose of varying the conditions was to obtain comparable performance of products; current vs. alternative products.

At the end of each cleaning process, the coupons were wiped once to remove any cleaning product and contaminant residues. The final weights of the "clean" coupons were recorded and cleaning efficiencies were calculated.

In other tests that followed, a UV (black) light, UVP Inc. Black light, Model UVL-56 longwave UV-366nm (Spectronics Corporation's AR-GLO® 1 fluorescent marker) was used to estimate the cleanliness. This was a visual technique that estimated the cleanliness values qualitatively. The entire experiment was repeated for different cleaning products under different conditions (e.g. temperatures, machine cycles and soaking times). The purpose of varying the conditions was again to obtain information about the performance of alternative products in comparison with the currently used products.

4.2.2 Circular Cleaning Using a Hand Held Drill with Abrasive Pads

In this experiment, coupons were prepared as in the previous experiment. Abrasive pads were used for cleaning in order to simulate the field conditions. Type QEP Grout Clean UP Kit Coarse abrasive pads were selected because they are similar to those used in the field.

When the coupons were ready for cleaning, they were held firmly onto the laboratory bench by a "C" clamp. The type QEP Grout Clean UP Kit Coarse abrasive pads were held firmly onto the drilling machine with a screw. The cleaning lasted for five minutes at 175 RPM as recommended by the manufacturers when using floor rotating stripping machines. At the end of the cleaning process, the coupons were left to dry for about 1 hour and their final weights were recorded. The final weights of the coupons were recorded and cleaning efficiencies calculated. This process was repeated under different conditions (e.g. drying times).

4.2.3 Straight line cleaning using BYK Gardner abrasive testing machines and abrasive pads

In this experiment, coupons were coated using the same procedure as above. Cleaning was done by using the BYK Gardner abrasive testing machine. Abrasive pads (*QEP Grout Clean UP Kit Coarse*) were used instead of cotton cloths used in 5.1.1. At the end of the cleaning process, the coupons were wiped once to remove residual cleaning products and contaminants and were left to dry for 1 hour after which their final weights were recorded. This experiment was repeated varying the drying times (24 hours). The final weights were recorded and the contaminant removal efficiencies calculated. Instead of using quantitative estimates of efficiency removal as before, a UV (black) light was used to qualitatively estimate the contaminant removal efficiencies.

4.3 Pilot -Scale Technical Characterization of Potential Biobased Floor Strippers

The materials used in this experiment were two sets of six floor tiles (2 ft x 3 ft). Other materials used were the general floor maintenance equipment, *Model KC18* and a circular abrasive pad (*Green Pad*). Both the equipment and abrasive pad were provided by the University of Massachusetts Lowell, physical facility department. Other materials used in the experiments were a fan, a stop watch and the Johnson Floor Finish Product (*Show Place*).

In this experiment, six floor tiles were coated by the *Show Case*. Three coats were applied at an interval of 40 minutes as recommended by the manufacturer. In between each coating, a fan was used to speed up the drying of the previous coating. At the end of the three coatings, the floor tiles were left to dry overnight (about 24 hours). The next day, one type of biobased or green floor stripping product was used to clean the three tiles. The floor stripper was permitted to remain on the tiles for about 10 minutes after which the stripping process was performed. At the end of the cleaning process, warm water and a clean mop were used to clear the floor of any residual floor stripping product or contaminants. The cleaning efficiency was determined qualitatively by visual observation.

5.0 Results and Discussions

5.1 Identification and Selection of Biobased Products

Fourteen products were identified in the SSL database as potentially useful for this research. Table 3 shows the products selected for the assessment as well as their biobased sources. The products' corresponding costs are also indicated.

Table 3 Potential green/biobased floor strippers identified/selected for assessment

	Category	**Biological Sources**	**Remarks**	**Cost USD/U.S gallon**	**Cost USD/liter**
1	Soysolv	Soy Based		16.70	4.42
2	Soysolv11	Soy Based	These products	19.90	5.26

3	Soysolv 11 plus	Soy Based	remove a variety of contaminants, including waxes and paint from surfaces. From TURI data sheet, manufacturers have claimed products can remove adhesive; coatings; buffing and polishing compounds.	22.00	5.82
4	CornSolv	Corn Based		25.80	6.83
5	Solsafe 245	Plant based		26.80	7.09
6	Bio T Max	citrus		33.80	8.94
7	EZ Solv	Plant Based[a]		31.40	8.31
8	SC Supersolve	Plant Based		39.5	10.45
9	SC Actisolv	Plant Based		44.30	11.72
10	Eco Natural Floor Stripper (WPR)	Plant based[b]		15.50	4.10
11	Botanic Gold	Plant based		59.00	15.61
12	DBE-5	[c]		35	9.26
13	DBE-6				
14	EnviroStar Green Floor Stripper	n/a		15.80	4.18
	Pro-Strip	Solvent based	Current product	9.9	2.62

[a]Different plants depending on season (e.g. canola, palm oil and cotton seeds). [a]Ocean kelp based plants. [c] Dibasic esters: although the product was mentioned green, these products are typically composed of about 17% dimethy adipate, 66% dimethyl glutarate and 17% dimethyl succinate [Re: Guidebook of parts cleaning – page 33]. I Different plants depending on season (e.g. canola, palm oil and cotton seeds). nvista – Dupont Sold the DBE manufacturing plant to the Invista - http://www.invista.com

About 21% of the biobased or green products identified were soy based. While corn and citrus accounted for 7% each. Approximately 43% of the products identified were classified as plant based without any further clarification of the plant sources of the substances contained in them. Personal communication with some vendors revealed that most of these products do not usually reveal the plant sources because that is proprietary information, and because the specific biological sources for about 22% of such products are dependent on the season of the year.

All 14 selected products were used in the experiments on the basis of the manufacturers' recommendations that the products can remove oils, waxes or strip floors or paint from different surfaces. For example, the three SoySolv products were classified by the manufacturers as industrial strength cleaning products capable of cleaning oils, greases, tar and adhesive products. These contaminants are similar in characteristics to what the Johnson Wax Professional (*Pro-Strip*) is designed to remove – the Johnson Wax Professional floor coating (*Show Place*). Two DBE (DBE-5 and DBE-6) products were described as capable of stripping off paints and cleaning adhesives [18].

All of the selected products, with the exception of the EnviroStar Green Floor Stripper, DBE-5 and DBE-6; met the criteria of biobased products. Apart from their capabilities in removing waxes, oils and paints, the manufacturers of these products also claimed that they are environmentally friendly. The MSDS for the EnviroStar Green Floor Strippers, DBE-5 and DBE-6 [18] products state that these products are greener and that they contain ingredients which are biodegradable. The extent of biodegradability (days and at what temperature) were, however, not presented. The MSDS further stated that the products do not contain VOCs, such as ethylene glycol based solvents; 2-butoxyethanol (butyl); alkyl phenol ethoxylate surfactants or environmentally toxic preservatives which could exceed established regulatory limits.

According to the MSDS, the products selected could be used at full strength or in diluted form.

5.2 Results of Benchscale Experiments

5.1.1 Effects of the temperature, agitation, concentration and soaking time (TACT) variables

This section presents the results of laboratory tests performed on different floor strippers identified in Table 3. Tables 4 through Table 9 present technical performance tests of these potential floor stripping products under different experimental conditions [e.g. temperatures, agitation, concentration and time (TACT)].

Table 4 Performance of 4 Products at Room Temperature (RT) - 20^{o}C

5 minute soaking time; 50 second cleaning time - *BYK Gardner*				
Product Name	**C oncentration (v/v) %**	**Efficiency**	**Effective**	**Remarks**
Solsafe 245	100	50	Yes	
EZ Solv	100	10	No	
SC Supersolve	10	19	No	
Eco Natural Floor Stripper (WPR)	10	2	No	+ 1%[a]
Pro-Strip	25	69	Yes	

[a] *the second additional cleaning cycle for this product increased the contaminant removal efficiency by 1 % (i.e. 2 + 1 =3%)*

Johnson wax (*Pro-Strip*) is currently used by many governmental facilities, including hospitals and health care centers as a floor stripper. In this experiment, the *Pro-Strip* had a contaminant removal efficiency of 69% followed by the SolSafe 245, which had a contaminant removal efficiency of 50%.

When the eco-natural floor stripper (WPR) was subjected to another second cleaning cycle, the cleaning efficiency was increased by 1%, to about 3%. At room temperature (20^{o}C), the soaking time of 10 minute (600 seconds) and 1 minute (60 seconds) of cleaning had the following effects: the cleaning efficiency of the SolSafe 245 increased to about 69% from about 50%. Also, the cleaning efficiency of the EZ-Solv product increased to about 42%, compared to 10% that was obtained with a 50 seconds of cleaning time (Table 4, 5). There was also a slight increase of the contaminant removal efficiency for the eco-natural floor stripper (WPR) and SC-Supersolve products. These efficiencies were about 9 and 8%, respectively when the two were subjected to the longer cleaning time (Table 5).

In all the other experiments that followed, a cleaning efficiency of about 50-70 by the alternative products was considered comparable to that of the Pro-Strip (69%) which was obtained at the room temperature. Thus, the performance of the pro-strip was used for benchmarking other products. The variations of the cleaning parameters were made for the subsequent experiments in order o achieve this value or more.

Table 5 Performance of 4 Products at RT – 20^{o}C

10 minute soaking time - *BYK Gardner*					
Product Name	**Concentration (v/v) %**	**60 sec**		**90 sec**	
		Efficiency	**Effective**	**Efficiency**	**Effective**
Eco Natural Floor Stripper (WPR)	20	9	No	24	No
SC Supersolve	10	8	No	20	No
EZ Solv	100	42	No	82	Yes
Solsafe 245	100	69	Yes	72	Yes

When the cleaning time was extended to 90 seconds from 60 seconds, the contaminant removal efficiency increased for all the four floor stripping products. These values had more than doubled for the Eco Natural Floor Stripper, SC-Supersolve and EZ-Solv, (9 -24%; 8-20%; and 42-82%; respectively). At this cleaning time, there was a slight increase of the efficiency for the Solsafe 245 from 69% to 72%. These results prompted another test to determine the effects of temperature on the performance of these products (Table 6).

Table 6 Performance of 4 Products at 40^{O}C

10 min. soaking time; 90 second washing - *BYK Gardner*				
Product Name	**Concentration (v/v) %**	**Efficiency**	**Effective**	**Remarks**
Eco Natural Floor Stripper (WPR)	20	318	n/a	Excess moisture
SC Supersolve	10	27	No	
EZ Solv	100	41	No	
Solsafe 245	100	20	No	

Contrary to the expectations the higher the temperature, the higher the cleaning efficiency, Table 6 shows the opposite. All four products used in this particular experiment, with the exception of the eco natural floor stripper (WPR) showed a relatively poor technical performance at the higher temperature. The coupons cleaned by this WPR product retained excess moisture, even after the normal drying time. As a result, unreasonable contaminant efficiency greater than 100 %, were obtained.

At this point, the products to be used at the pilot experiments were selected as SolSafe 245 and EZ Solv. Pilot experiments are the tests performed in order to simulate the field conditions. Since raising the temperature to 40^{o}C did not seem to have had any positive effects on the efficiency (Table 5 and 6), all the subsequent experiments that followed were performed at the room temperature (20^{o}C).

Comparison of the Cleaning and Assessment Methods

Up to this time, only the *BYK Gardner* had been used. Table 7 and 8 show the results of three other potential floor stripping products that were tested by using a rotating abrasive method in addition to the *BYK Gardner*. The rotating abrasive method was considered as it simulated the field conditions. These experiments were conducted at two different cleaning times. The results presented in these three tables are based on the quantitative (gravimetric analyses of the coupons) and qualitative assessments (visual observations of the coupons).

Table7 Performance of 3 Products at RT (20^{o}C)

Product Name	***(100% v/v) - BYK Gardner***				
	5 min soaking; 60 sec cleaning		**10 min. soaking; 300 sec cleaning**		
	Efficiency	**Effective**	**Efficiency[a]**	**Effective**	**Remarks**
Bio T Max	68	Yes	27	No	
Botanical Gold	42	Yes	87	Yes	
SC Actisolv	77	Yes	26	No	

[a]with spraying of cleaning product on the floor surface every other minute

Table 8 Performance of 3 Products at RT (20^{o}C).

Product Name	***(100% v/v) - Rotating Abrasive Pads at 175 rpm***					
	10 min soaking; 60 sec cleaning		**10 min. soaking time; 300 seconds**			
	Efficiency	**Effective**	**Efficiency[a]**		**Effective**	**Remarks**
			qualitative	**quantitative**		
Bio T Max	130[b]	Yes	50	18	No	
Botanical Gold	27	No	86	42	Yes	
SC Actisolv	85	Yes	49	-21	No	

[a]with spray of cleaners every other minute; [b]swelling of the coupons

Overall, Table 7 and 8 demonstrate that gravimetric analysis was inconclusive due to the abrasive pad causing damage to the coupons, altering the final quantitative measurements. However, visually, all three products worked as well as the current floor stripper. These products were therefore selected for further investigation in the pre-field or pilot stage experiments.

5.2 *Evaluation of the potential products based on qualitative assessment (UV-Analysis)*

At this point, several problems were observed. However, one of these problems was more critical: use of the gravimetric analysis method was giving inconsistent results. In order to solve this problem, a UV light was recommended in place of the gravimetric analysis. The working principles of the UV light assessment of cleanness are discussed in more detail at (www.turi.org). The experiments that followed used this analysis method continued to use the two cleaning processes; BYK Gardner and Rotating Abrasive Pads at 175 rpm. It was, nonetheless felt important to the evaluate the *pro-strip* first in order to use the results, once again, as a benchmark for the other products (Table 9).

Table 9 Performance of the *Pro-Strip* at RT (20°C) – Qualitative Assessment

Efficiency[a] at 10 min. soaking; 300 sec. cleaning						
Type of Cleaning	**Efficiency Removal on Ceramic Tiles**			**Efficiency Removal on Plastic Tiles**		
	Observer-1	**Observer-2**	**Average**	**Observer-1**	**Observer-2**	**Average**
Mechanical Agitation ***(185 cycles)***	91	99	95	95	99	97
Rotary Pads ***(175 rpm)***[a]	92	82	87	99	94	96

[a] (With spray of cleaners on the surface every other minute)

The current floor stripper (*Pro Strip*) worked very well and the evaluation of the cleanliness of the two different coupons, based on these qualitative assessments (Table 9) were in close agreement.

On the basis of these results, tests for other floor strippers were carried out and analyzed by using the qualitative assessment method on the coupons. The results presented in Table 10 summarize many experiments performed under different conditions (e.g. temperatures, agitation or cleaning type, concentration and time (TACT)).

Table 10 Summary Performance of 7 potential floor strippers - Qualitative Assessment

Product Name	**Abrasive Machine**			
	Concentration (v/v) %	**Overall Efficiency**		**Effective**
		Ceramic Coupons	**Plastic Coupons**	
EnviroStar Green Floor Stripper	25	97	98	Yes
Soy Solv 11 Plus	100	42	98	Yes
SolSafe 245	100	41	93	Yes
Corn Solv	100	69	99	Yes
Soy Solv Industrial	100	65	83	Yes
DBE 6	100	54	99	Yes
Pro-Strip	25	99	95	Yes
DBE 5	100	23	99	No

Table 10 shows that DBE-5 worked very well on the plastic coupons but not on the ceramic coupons. All the other products worked well on both types of the coupons. These other products were selected as the potential floor strippers to be further evaluated on the pilot stage or pre-field experiments/trials. Selection of these products for the pre-field work was also based on the combined results of the previous experiments. The results of the pre-field experiments are presented in section 5.3.

5.3 Products Selected for the (pilot-scale) pre-field experiments on a floor in the SSL

This section presents results of pre-field testing of products that performed well at the laboratory stage. Table 11 shows the list of products selected for the *pre-field experiments.* Some products, such as SC-Actisolv and EZ-Solv were not available in the laboratory in sufficient quantities therefore; these two products were eliminated for further testing. Although the CornSolv performed well in the benchscale tests the odor it emitted during the experiments was objectionable. Nonetheless, for comparison purposes, it was included in products used in the *pre-field experiments.*

Table 11 Products Selected for Pilot Stage Testing

Product Name	**Remark**
EnviroStar Green Floor Stripper	Worked well
SoySolv11 Plus	Worked well
Solsafe 245	Worked well
CornSolv	Worked well; odor problems eliminated the product
DBE-6	Worked well
SC Actisolv	Not available for testing during the time of experiments
Products from the earlier experiments	
EZ-Solv	Not available for testing during the time of experiments
Bio T Max	Worked well
Botanic Gold	Worked well

Although the DBE-6 product can be used as a floor stripper, according to its technical sheet and personal communication with one of the officials of the Invista Company which manufactures this product, it was found that this is not a product in itself but an ingredient to be incorporated into cleaning products. For this reason alone it was not evaluated any further. CornSolv performed poorly in these experiments (30%). Furthermore, as stated previously, its strong odor was objectionable and necessitated the cessation of further investigations.

5.4 Technical Performance Assessment at the Pilot Stage Experiments

As expected, the *Pro-Strip* performed exceptionally well (Table 12) followed by the Botanic Gold (94%), SoySolv 11 Plus (84%), Bio T Max (65%) and Solsafe245 (50%). When the Botanic Gold was diluted to 25% v/v, its contaminant removal was reduced from 94 to 55%.

Table 12 Qualitative Assessment of Product Performance at the Pilot Stage Experiments

	Qualitative Assessment (Removal Efficiency Qualitatively)

Product Name	Observer 1	Observer 2	Average	Remarks
Botanic Gold	90	96	94	
Solsafe 245	60	40	50	Slippery floor
Bio-T-Max	70	60	65	
EnviroStar Green Floor Stripper	50	45	48	
CornSolv	35	25	30	Odor unbearable
DBE-6	25	20	23	Sticky and edges peeled off
DBE-6 (2^ND Soaking)	50	49	50	Average of four people
SoySolv11 Plus	92	76	84	Average of 4 people
Pro Strip	99	99	99	

6 Conclusion and Recommendations

The technical performance of the products tested - Solsafe 245, EZ Solv, Botanic Gold, Eco Natural Floor Stripper (WPR), DBE-6, EnviroStar Green, CornSolv and SoySolv and SoySolv 11 Plus - were in the range of 50 to 99%. CornSolv was eliminated because of its odor while DBE-6 was abandoned because it removed the floor tile surfaces. The top alternative, Botanic Gold, had 94% contaminant removal efficiency at full strength. At the concentration of 25% v/v, the technical performance of Botanic Gold was about 55%. In accordance with the benchmark to the current product at a similar concentration, this performance was found to be satisfactory.

It is recommended that large field trials should be conducted and also to determine the janitors' perceptions on the use of these products. It is equally important to investigate the common additives in the biobased industrial chemicals and products as well as their implication to the technical and EHS performance of these products. Finally, we recommend that a review of the current status and future direction of the relevant policies, programs, regulations and standards be carried out. This work should become part of the planning frameworks for promoting biobased materials as alternative or substitutes to toxic chemicals in the United States. Based on the results obtained for the performance of some biobased materials, the cleaner production or toxics use reduction advocates should start up campaigns to encourage broader public debate about the future of the biobased industry in the context of EHS and other sustainability criteria.

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DISCLAIRMER:

Any mention of product by name or manufacturers of products in this article does not constitute endorsement by the authors.

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