Pharos: Powering a virtual learning experience

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4/30/20

HBN HEALTHY BUILDING NETWORK
KNOW BETTER

Slides and recording will be posted to https://pharosproject.net/tutorials

Future Webinars

Chemicals Management
Thursday May 28th @ 1pm CST

Pharos API and Data Downloads
Date TBD

HEALTHY BUILDING NETWORK

MISSION

To advance human and environmental health by improving hazardous chemical transparency and inspiring product innovation

About Pharos

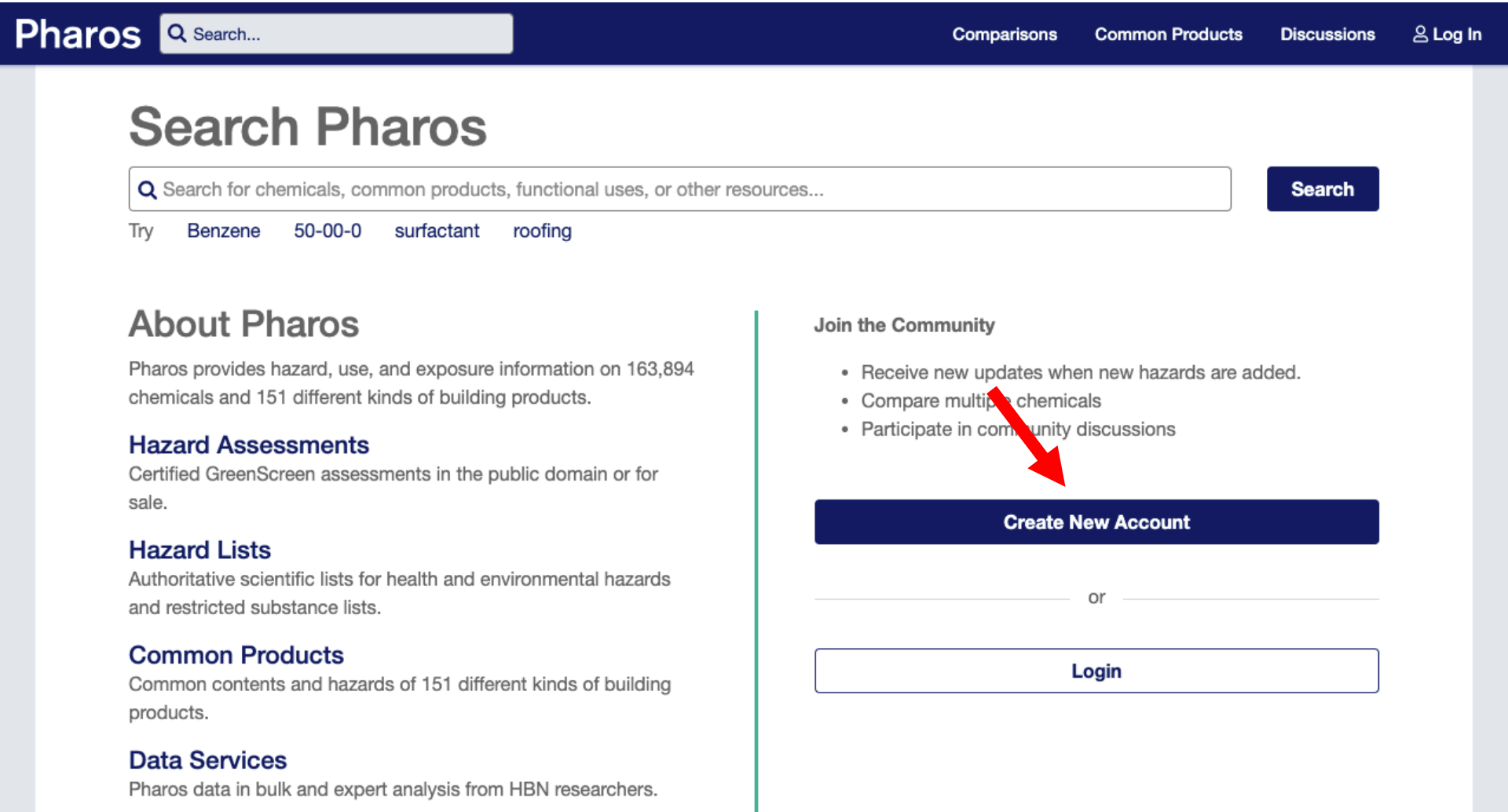
https://pharosproject.net/

Comprehensive independent database of chemicals, polymers, metals and materials

- Hazard data for >160,000 CAS Numbers from 45 hazard lists
- Functional use data show where and why chemicals are used
- Process chemistry data identifies possible contaminants
- >600 compound groups reduce the chances of regrettable substitutions

Sign Up for Free

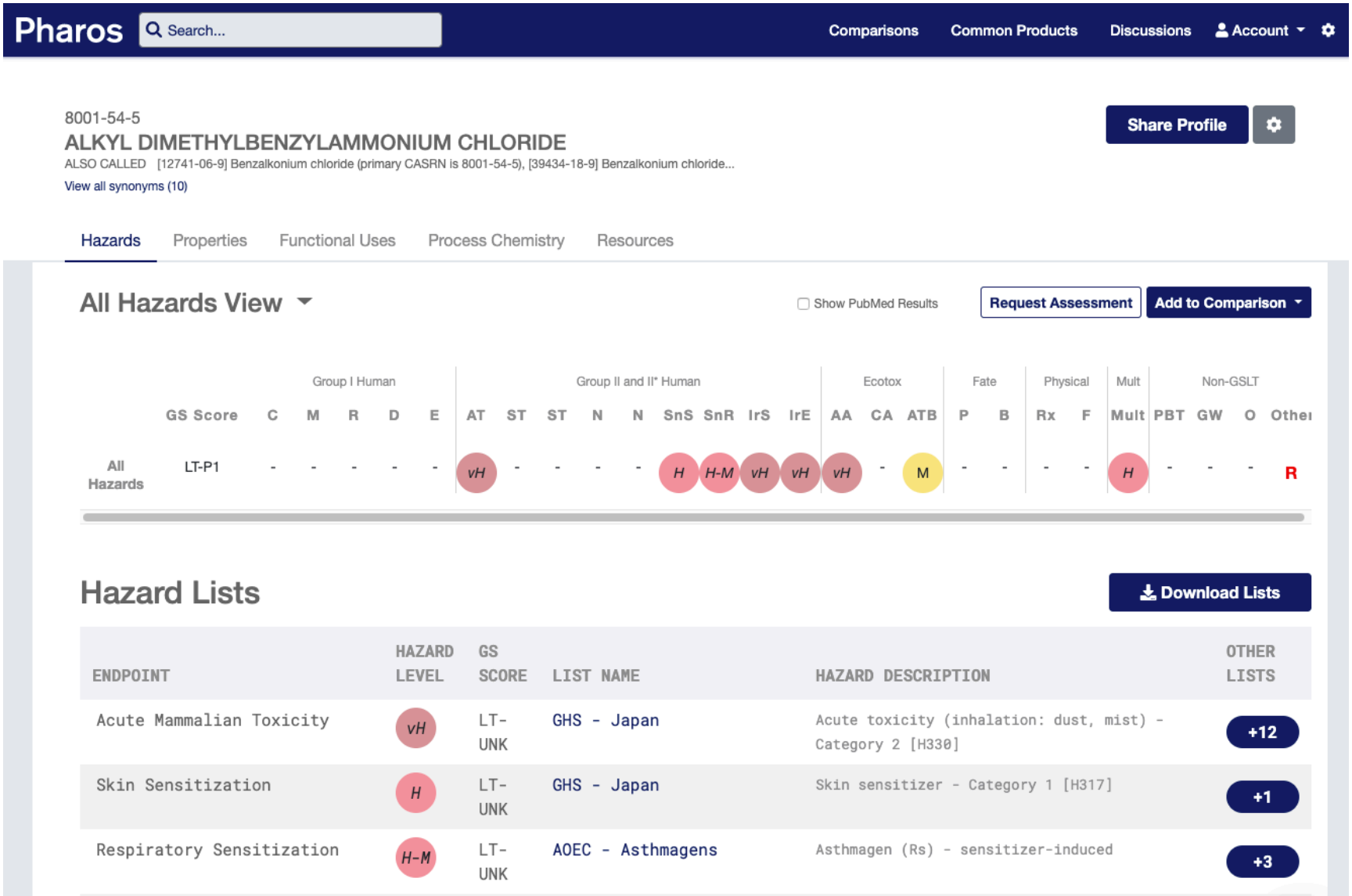
https://pharosproject.net/



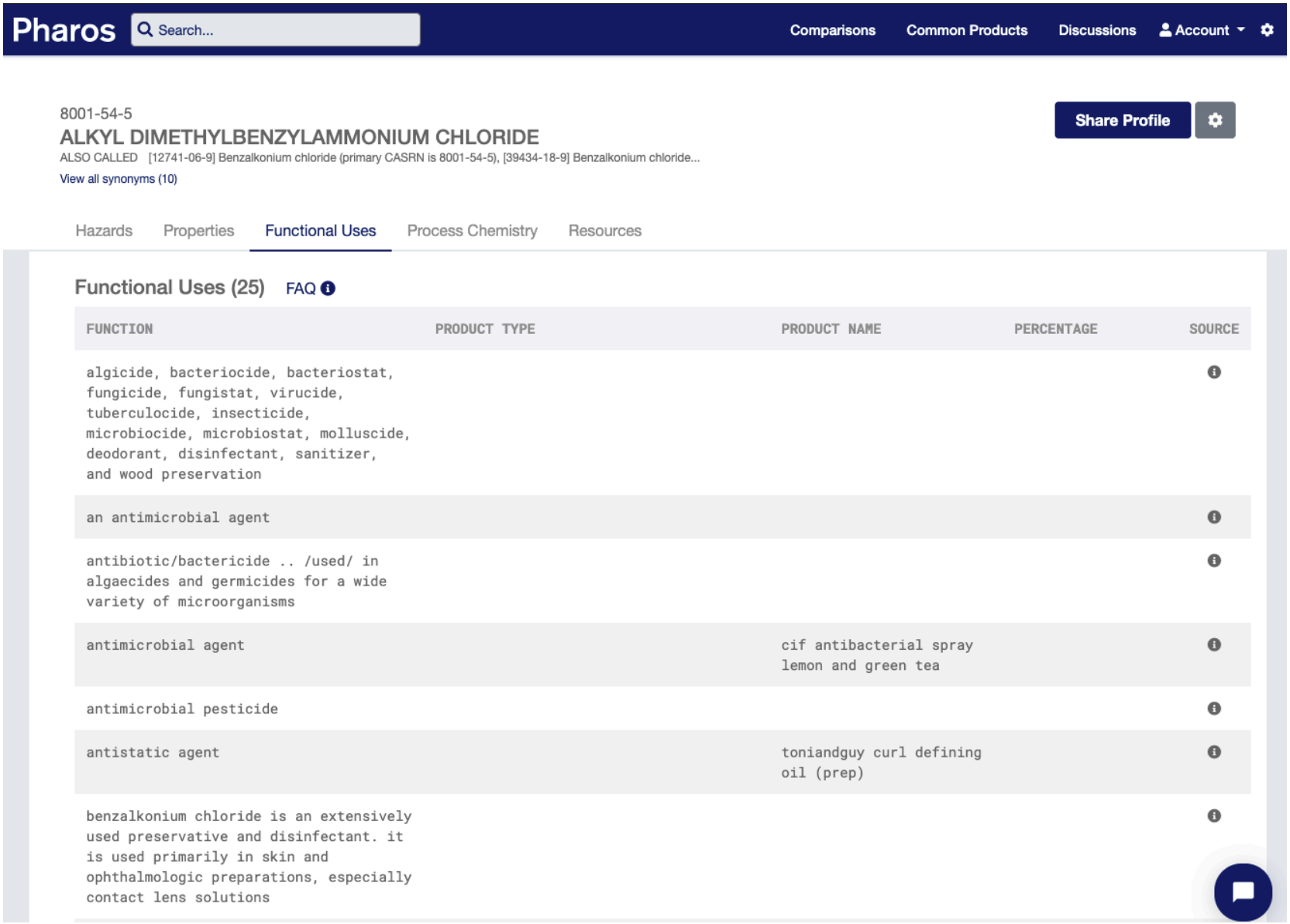
Overview of Pharos Content

1. Chemical Hazard
2. Chemical Function
3. Chemical Comparisons
4. Discussion Forums
5. Common Products (contents of building products)

Chemical Hazards

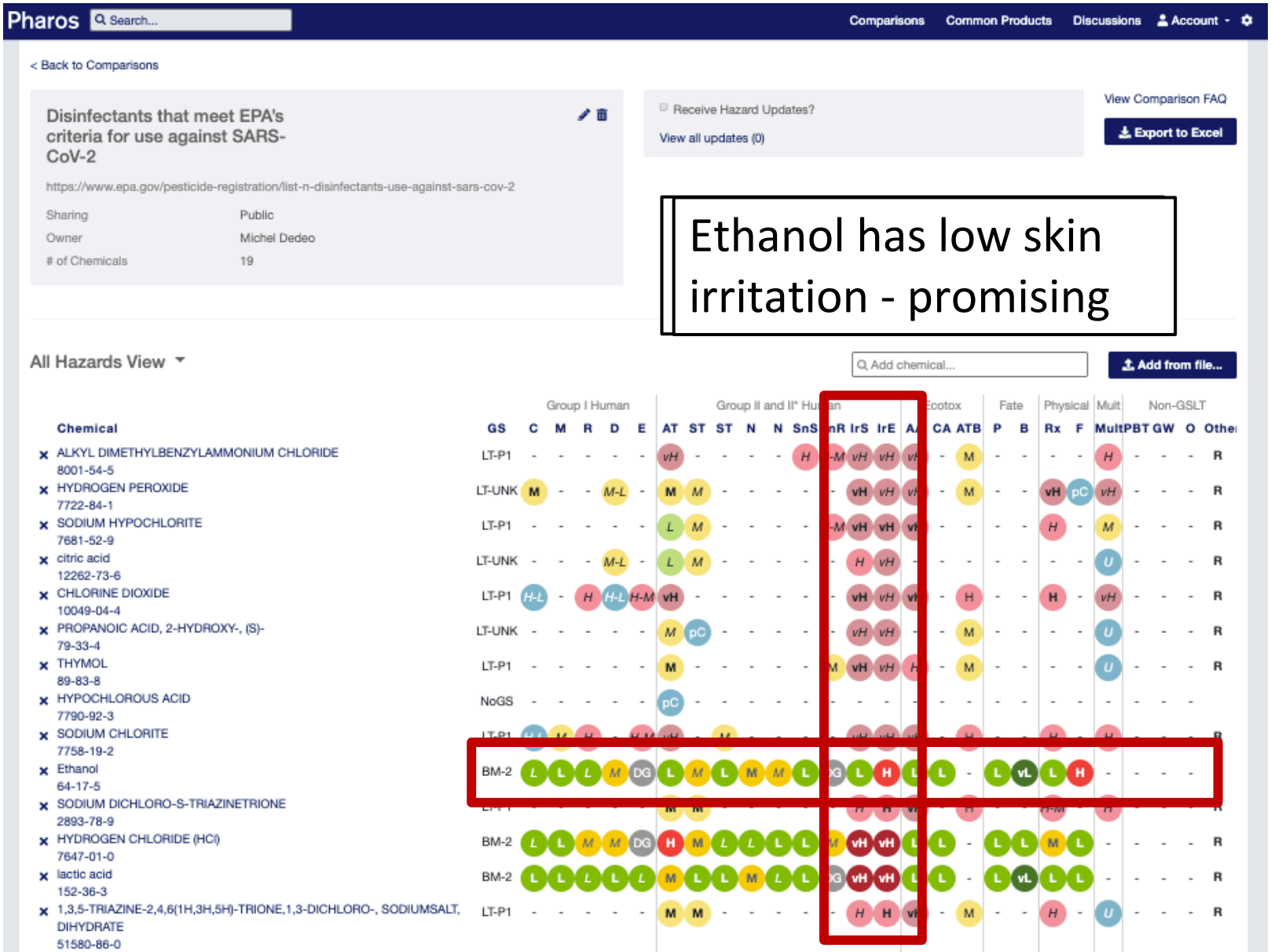


Chemical Functions

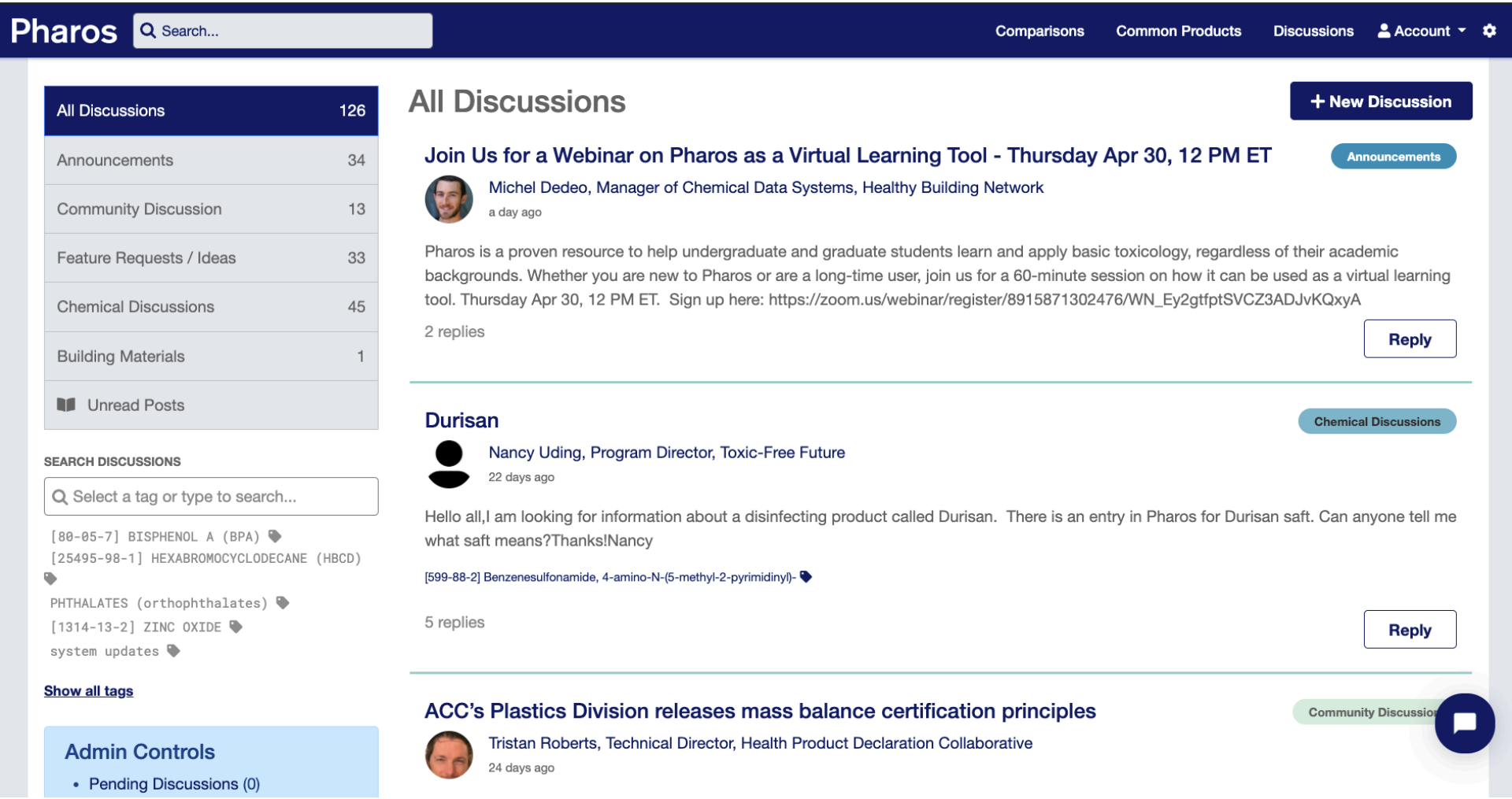


FUNCTION	PRODUCT TYPE	PRODUCT NAME	PERCENTAGE	SOURCE
algicide, bacteriocide, bacteriostat, fungicide, fungistat, virucide, tuberculocide, insecticide, microbiocide, microbiostat, molluscide, deodorant, disinfectant, sanitizer, and wood preservation				
an antimicrobial agent				
antibiotic/bactericide .. /used/ in algaecides and germicides for a wide variety of microorganisms				
antimicrobial agent		cif antibacterial spray lemon and green tea		
antimicrobial pesticide				
antistatic agent		toniandguy curl defining oil (prep)		
benzalkonium chloride is an extensively used preservative and disinfectant. it is used primarily in skin and ophthalmologic preparations, especially contact lens solutions				

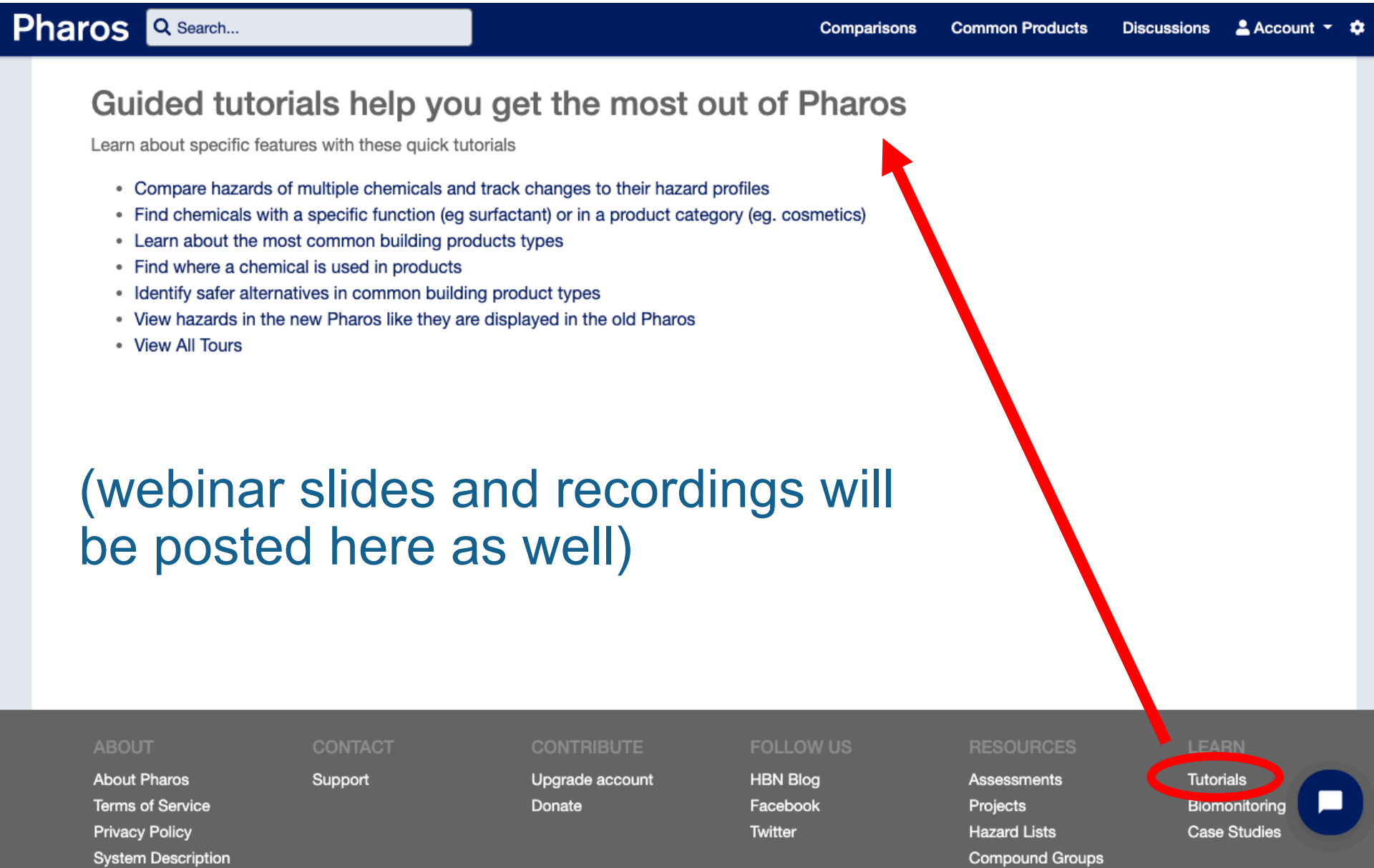
Compare Hazards of Multiple Chems



Discussion Forums

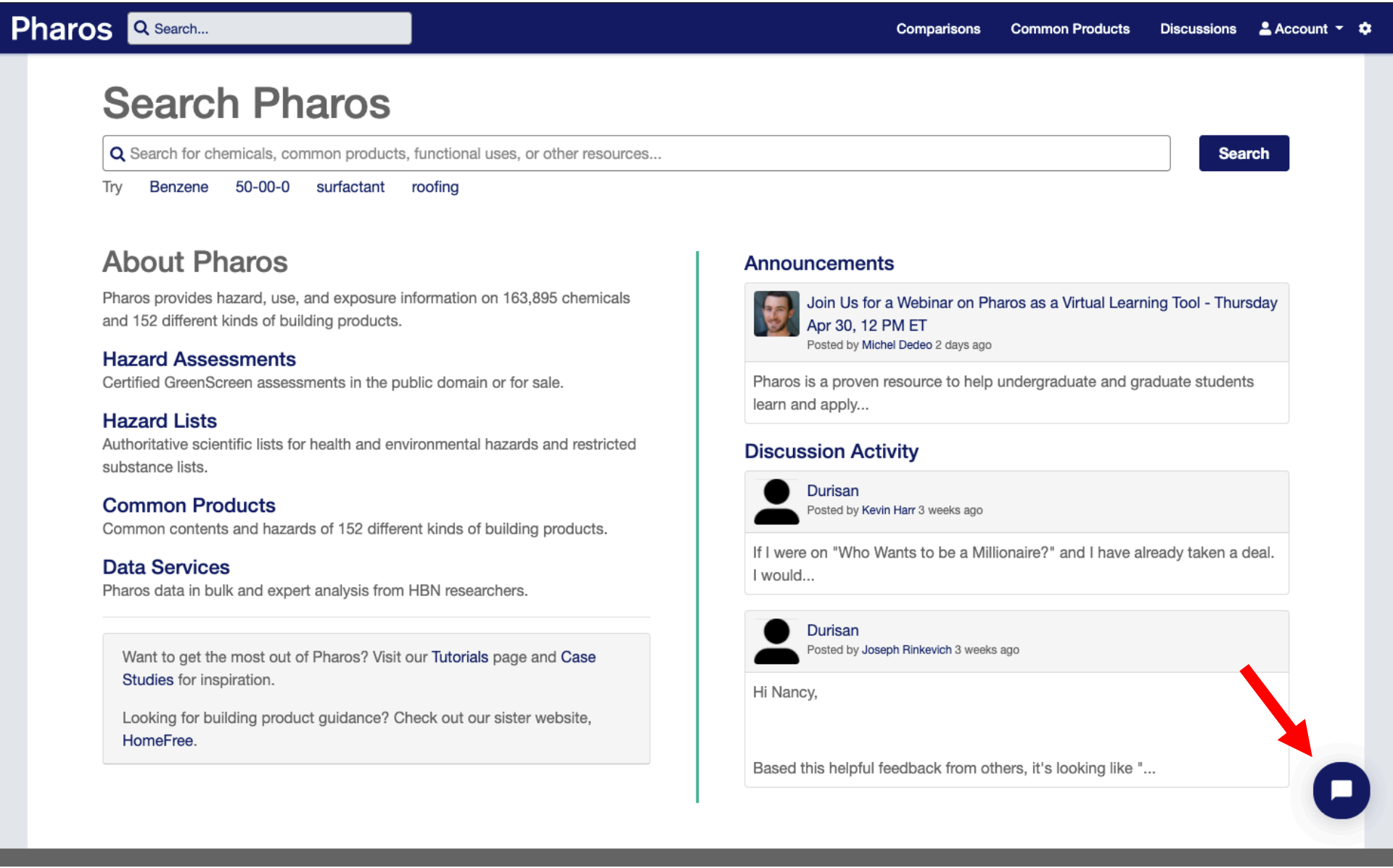


Learn More with Tutorials

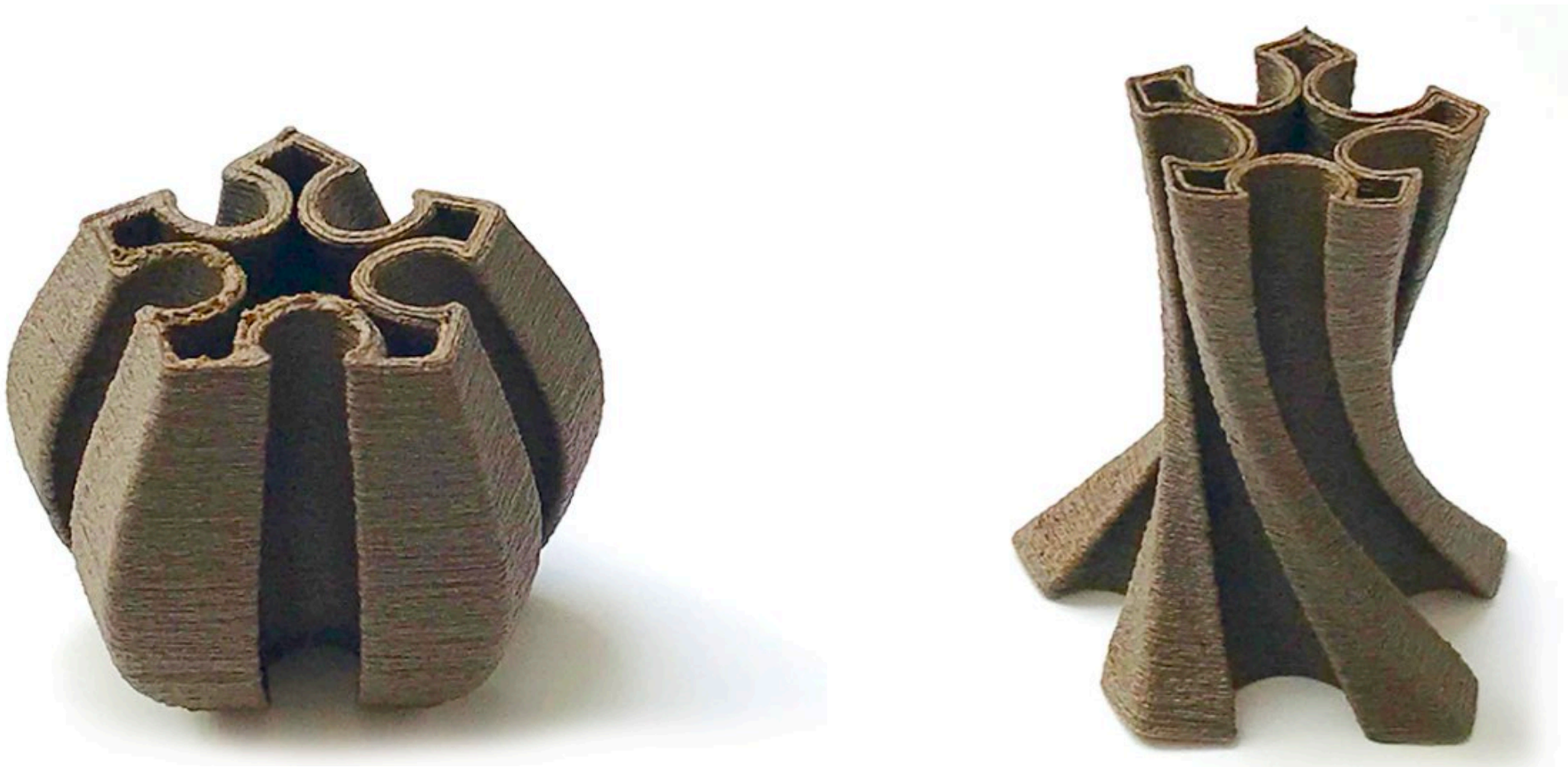


(webinar slides and recordings will be posted here as well)

Quick Answers (sometimes)



Choosing Greener Materials In Product Design With Pharos



Jeremy Faludi, TU Delft

Where I Use Pharos

- Teaching
- **Research**

Teaching

https://VentureWell.org/tools_for_design

Tools for Design and Sustainability

Tools for Design and Sustainability

As engineers and designers, what you create will impact the world we live in. To help solve the global issues we face today, it's more important than ever to invent products and services that help people and the world.

Inventing green can mean inventing a technology whose whole purpose is sustainability (like carbon sequestration or eliminating waste) or it can mean improving the environmental impacts of ordinary products, from material choice to energy use to changing users' lifestyles. For many companies, being environmentally responsible is also good business. By using a mindset of "inventing green," you can: save material costs with more efficient production methods; reduce liability risks associated with the manufacture or disposal of toxic materials; and meet customer demand for products that are safer for their families or less energy-intensive to use.

This site is for you: designers, inventors, and startup founders who are curious about your options and are seeking practical advice for taking action. The following tools allow you to jump into whichever topic you like. Each topic has 'content' for you to read or watch, 'exercises' for you to apply what you have learned, and 'examples' for you to reference.

Different product types will have different priorities for sustainability—some depend more on material choice, others on energy efficiency, and so on. To have the greatest impact with the least amount of work, start with the Whole System Mapping design exercise to clarify the big picture and focus on what's most important for your product.

greener materials

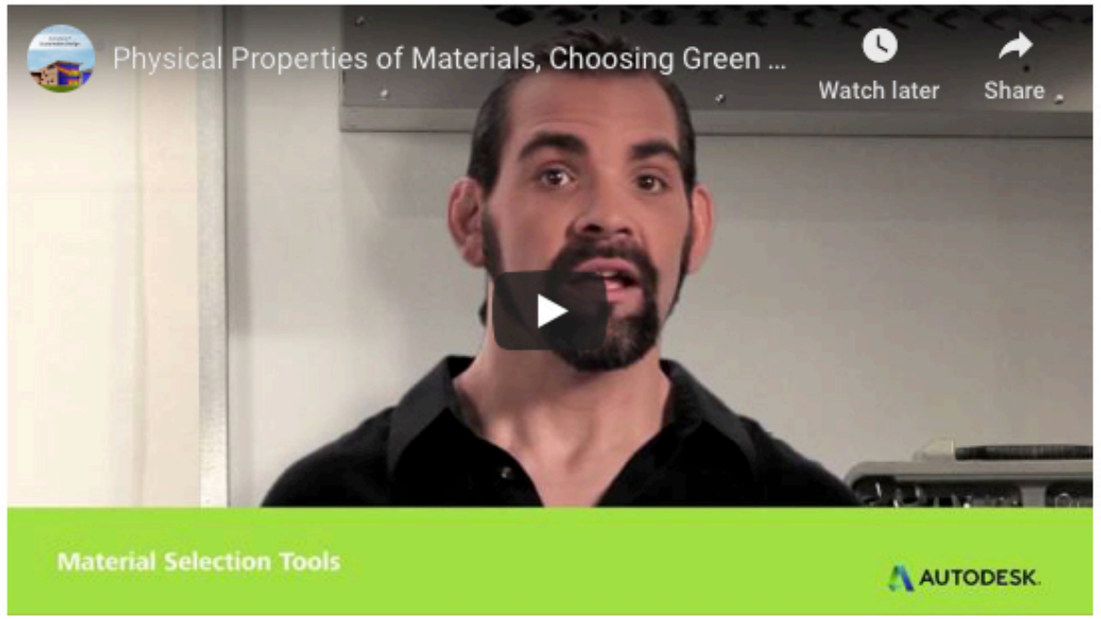
Overview

Goal: Understanding what makes materials more or less sustainable, and comparing common materials.

You have an amazing variety of materials to choose from — more than any inventors or designers of the past ever had. But the sheer multitude of considerations for choosing sustainable materials can be dizzying. There's no such thing as a green material by itself; it's about matching the material to the job. That means considering the environmental impacts of the material, its function, and the whole system it fits into.

An ideal sustainable material:

- is abundant / rapidly renewable
- is resource-cheap (requires minimal energy or other material to produce)



Autodesk Sustainability Workshop Physical Properties of Materials

Choosing Better Materials

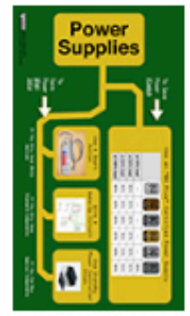
Now that you know about some of the tradeoffs for materials selection, how do you know what options are available?

For quick reference, you can see charts created by Jeremy Faludi, published on Instructables. They can help you compare commonly-available metals, plastics, and woods; for electronics, a chart for choosing power supplies is also included:

Metals

Wood

Plastic



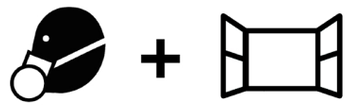
Power Supplies

You can also look up tables of environmental impacts per kg of material calculated by life-cycle assessment (LCA). Two good sources are Okala Practitioner and Ecolizer. Simply look up different materials to compare them—lower scores show lower impacts per kg of material. These scores don't measure everything (like social impacts, some kinds of toxicity, or material functionality), but they're a good start.

For clothing and soft goods, it's often hard to find LCA data. Try the Sustainable Apparel Coalition's Materials Sustainability Index. Note that this system is incompatible with LCA scores, so it won't help you compare

Choosing Greener Plastics

When heating / sanding



Wear a respirator

Have good ventilation

GOOD FOR:

 Eating / Drinking

 Laser-cutting

 Casting

 Strength

 Bearing Surface

PLA = polylactic acid bioplastic
PHA = Polyhydroxyalkanoate bioplastic
HDPE = high-density polyethylene
PET = polyethylene terephthalate
LDPE = low-density polyethylene
PP = polypropylene
PMMA = acrylic
PU = polyurethane
PS = polystyrene
ABS = acrylonitrile butadiene styrene
PC = polycarbonate
PVC = polyvinyl chloride

BETTER

Scrap Plastics

PLA
PHA

Recycled Petroleum Plastics

PP
HDPE
LDPE
PET

Silicone
Acrylic

PU
PS

ABS
PC
Epoxy

PVC

WORSE

greener materials

Exercise

Finding Greener Materials

Time Estimate: 1—4 hours

Goal: Find an alternative material that could replace a high-environmental-impact material in your product, and get a cost estimate for it.

Step 1: Decide on a material in your product to replace

Time Estimate: 5—10 minutes

Identify a high-environmental-impact material in your invention. This doesn't have to be a homogeneous material, it can be an amalgamation of materials, such as a circuit board or a window assembly.

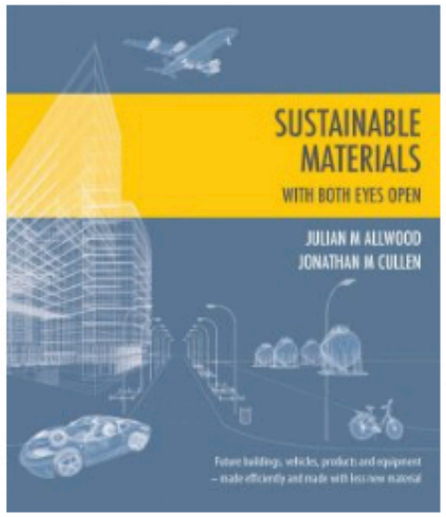
Step 2: Explore material libraries or other resources to find exciting green materials

Time Estimate: 1.5—3 hours

Use the links in the Finding Greener Materials page, search engines, blogs, hard copy catalogs, or whatever means you see fit to go material-hunting. Don't limit yourself to practical things, feel free to find wild, avant garde materials from exotic suppliers, or waste materials from dumpsters. Anything that could be acquired at large production scale.

- Make a list of at least five interesting materials.
- Choose one final material, using whatever criteria you like.
- Get an image of what the winning material looks like.

Books and Articles

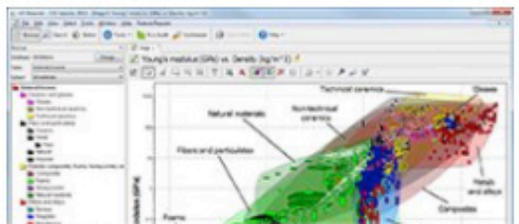


- Sustainable Materials With Both Eyes Open by Allwood and Cullen (2012)
- Materials and the Environment by Ashby (2013)
- Design + Environment, Chapter 4 by Helen Lewis
- Sustainability Metrics: LCA and Green Design in Polymers by Tabone, Cregg JJ, Beckman EI, and Landis AE (2010)
- Creating Safe and Healthy Spaces by Rossi and Lent (2006) (green plastics article)
- Green Chemistry: Theory and Practice by Anastas (2000)

Catalogs of Green Materials

- Cradle to Cradle Certified Products Registry (free access; lists all C2C certified products)
- Fair Trade certified products database by Flocert (free access; lists Fair Trade certified companies)
- FSC Certificate Database of wood & paper products (free access; lists all FSC certified products)
- SA8000 Certified Facilities List by Social Accountability International (free access; lists all companies / factories SA8000 certified)

Databases and Analysis Software



Chemical toxicity libraries

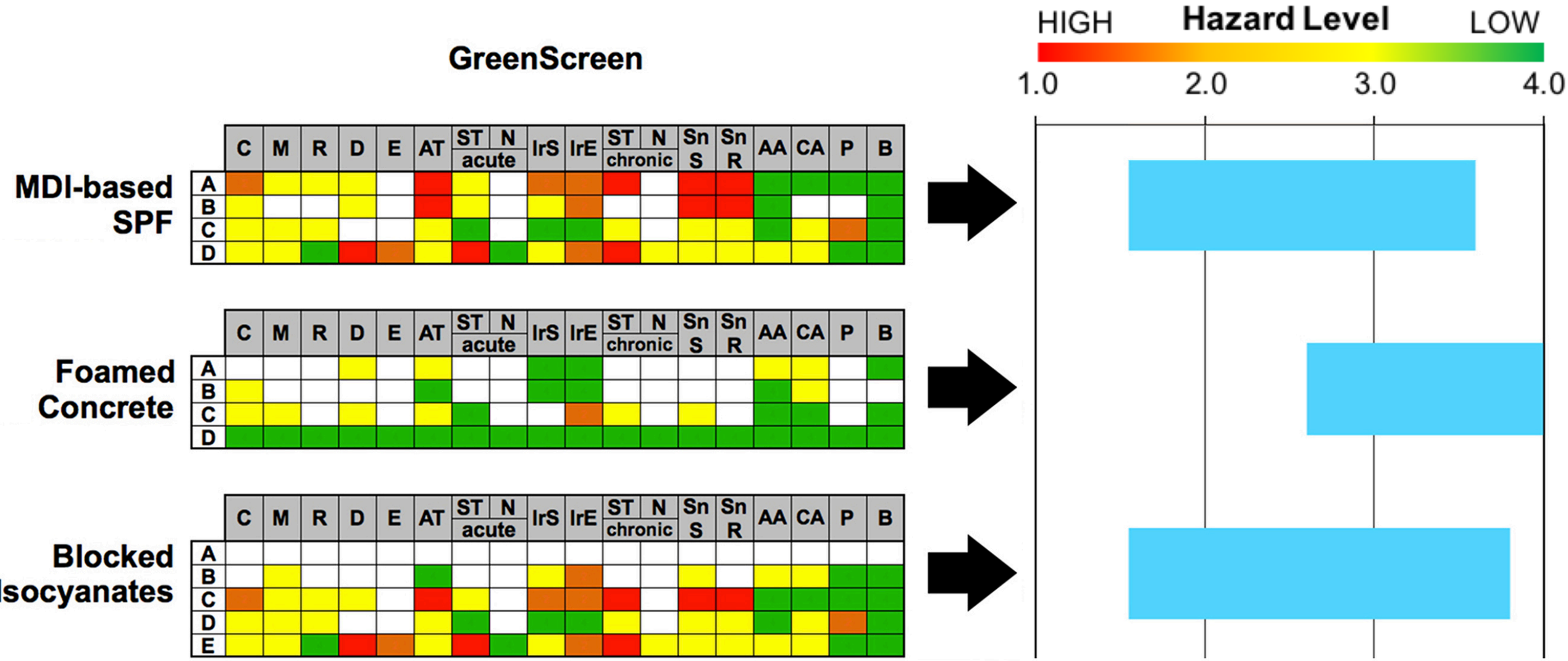
- Pharos Chemical & Material Library (easiest for non-experts to read; toxicity data for both good and bad materials)
- NIOSH pocket guide to chemical hazards (free access; toxicity data for both good and bad materials)
- ChemSec "Sin List" (free access; hazardous chemicals with toxicity data)
- US National Library of Medicine's Hazardous Substances Data Bank, "HSDB" (free access)
- European Chemical Agency (ECHA)'s Registered Substances Database (free access; difficult for non-toxicologists to read)
- International Programme on Chemical Safety (IPCS)'s INCHEM (free access; difficult for non-toxicologists to read)
- Cradle to Cradle Banned List of Chemicals (free access; list of chemicals that will immediately disqualify a product from Cradle to Cradle certification)

Finding Greener Materials Exercise

Finding Greener Materials Examples

Research

Precision Uncertainty GreenScreen



Faludi et al., 2016. "Aiding Alternatives Assessment With an Uncertainty-Tolerant Hazard Scoring Method," *J. Environmental Management.*

Precision Uncertainty GreenScreen

	Carcinogen / Mutagen		Reprod. / Devel. / Endocrine			Acute					Chronic				Aquatic Toxicity		Fate		Physical		Weighted Overall Hazard Score
	Carcinogen	Mutagen	Reproductive	Developmental	Endocrine	Acute toxicity	Acute systemic toxicity	Acute neurotoxicity	Skin irritation	Eye irritation	Chronic systemic toxicity	Chronic neurotoxicity	Skin sensitization	Respiratory sensitization	Acute aquatic tox.	Chronic aquatic tox.	Persistent	Bioaccumulative	Reactivity	Flammability	
Material #1	4	4	1	3	4	1	4	UNK	4	3	1	UNK	4	4	4	UNK	1	4	4	4	worst score / best score
	worst score	best score	worst score		best score	worst score				best score	worst score			best score	worst score	best score	worst score	best score	worst score	best score	**1.9 - 3.6**
	4	4	1		4	1				4	1			4	1	4	1	4	4	4	

Faludi et al., 2016. "Aiding Alternatives Assessment With an Uncertainty-Tolerant Hazard Scoring Method," *J. Environmental Management.*

Precision Uncertainty GreenScreen

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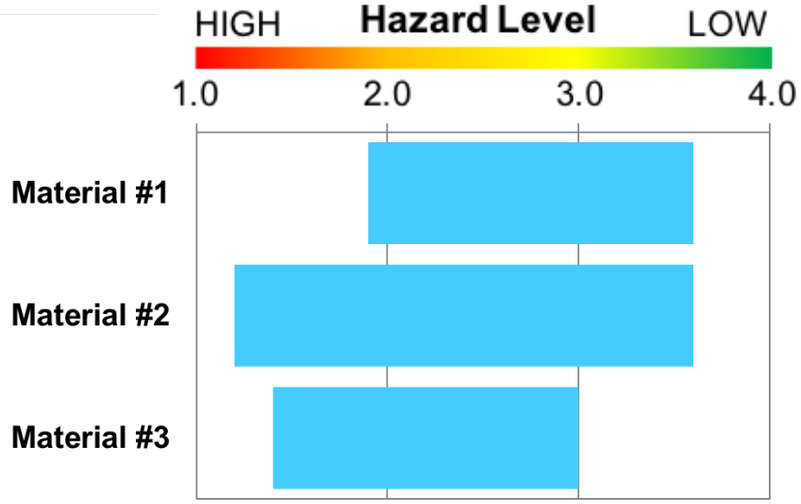
	Carcinogen	Mutagen	Reproductive	Developmental	Endocrine	Acute toxicity	Acute systemic toxicity	Acute neurotoxicity	Skin irritation	Eye irritation	Chronic systemic toxicity	Chronic neurotoxicity	Skin sensitization	Respiratory sensitization	Acute aquatic tox.	Chronic aquatic tox.	Persistent	Bioaccumulative	Reactivity	Flammability	
Material #1	4	4	1	3	4	1	4	UNK	4	3	1	UNK	4	4	4	UNK	1	4	4	4	worst score 1.9 - best score 3.6
	worst score 4	best score 4	worst score 1		best score 4	worst score 1				best score 4	worst score 1			best score 4	worst score 1	best score 4	worst score 1	best score 4	worst score 4	best score 4	
Material #2																					
Ingredient A	3	UNK	UNK	3	UNK	1	3	UNK	3	2	UNK	UNK	1	1	4	4	UNK	4	4	4	
Ingredient B	3	3	3	UNK	UNK	3	4	UNK	4	4	3	UNK	3	3	4	3	2	4	UNK	UNK	
Ingredient C	3	3	4	1	2	3	1	4	3	2	1	3	3	3	3	3	4	4	3	4	
																					worst score 1.2 - best score 3.6
	worst score 2	best score 3	worst score 1		best score 4	worst score 1				best score 4	worst score 1			best score 3	worst score 3	best score 4	worst score 1	best score 4	worst score 1	best score 4	
Material #3																					
Ingredient A	3	3	3	3	2	2	3	3	1	1	3	3	3	1	3	4	2	3	1	2	
Ingredient B	2	3	1	1	1	3	1	UNK	2	2	1	UNK	3	3	4	3	UNK	3	2	2	
																					worst score 1.4 - best score 3.0
	worst score 2	best score 3	worst score 1		best score 3	worst score 1				best score 3	worst score 1			best score 3	worst score 3	best score 4	worst score 1	best score 3	worst score 1	best score 2	
Weight	20%		20%			15%					15%				10%		10%		10%		

Faludi et al., 2016. "Aiding Alternatives Assessment With an Uncertainty-Tolerant Hazard Scoring Method," *J. Environmental Management.*

Precision Uncertainty GreenScreen

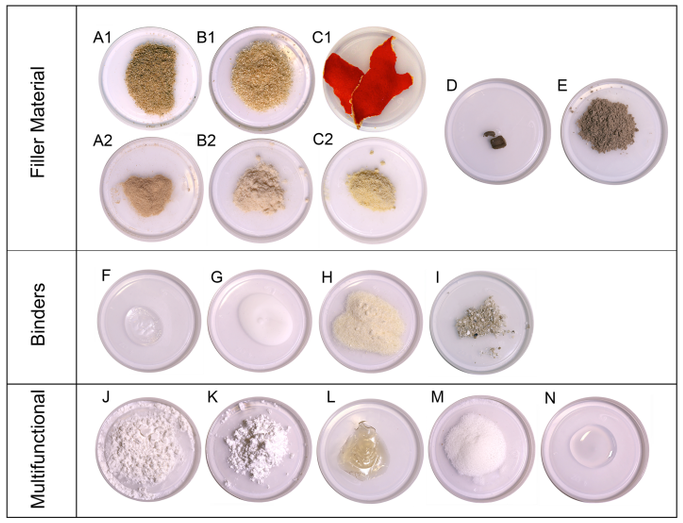
	Carcinogen / Mutagen		Reprod. / Devel. / Endocrine			Acute					Chronic				Aquatic Toxicity		Fate		Physical		Weighted Overall Hazard Score	
	Carcinogen	Mutagen	Reproductive	Developmental	Endocrine	Acute toxicity	Acute systemic toxicity	Acute neurotoxicity	Skin irritation	Eye irritation	Chronic systemic toxicity	Chronic neurotoxicity	Skin sensitization	Respiratory sensitization	Acute aquatic tox.	Chronic aquatic tox.	Persistent	Bioaccumulative	Reactivity	Flammability		
Material #1	4	4	1	3	4	1	4	UNK	4	3	1	UNK	4	4	4	UNK	1	4	4	4	worst score	best score
	worst score	best score	worst score		best score	worst score				best score	worst score			best score	worst score	best score	worst score	best score	worst score	best score		
	4	4	1		4	1				4	1			4	1	4	1	4	4	4	**1.9**	**3.6**
Material #2																						
Ingredient A	3	UNK	UNK	3	UNK	1	3	UNK	3	2	UNK	UNK	1	1	4	4	UNK	4	4	4		
Ingredient B	3	3	3	UNK	UNK	3	4	UNK	4	4	3	UNK	3	3	4	3	2	4	UNK	UNK		
Ingredient C	3	3	4	1	2	3	1	4	3	2	1	3	3	3	3	3	4	4	3	4		
																					worst score	best score
	worst score	best score	worst score		best score	worst score				best score	worst score			best score	worst score	best score	worst score	best score	worst score	best score		
	2	3	1		4	1				4	1			3	3	4	1	4	1	4	**1.2**	**3.6**
Material #3																						
Ingredient A	3	3	3	3	2	2	3	3	1	1	3	3	3	1	3	4	2	3	1	2		
Ingredient B	2	3	1	1	1	3	1	UNK	2	2	1	UNK	3	3	4	3	UNK	3	2	2		
																					worst score	best score
	worst score	best score	worst score		best score	worst score				best score	worst score			best score	worst score	best score	worst score	best score	worst score	best score		
	2	3	1		3	1				3	1			3	3	4	1	3	1	2	**1.4**	**3.0**
Weight	20%		20%			15%					15%				10%		10%		10%			



Faludi et al., 2016. "Aiding Alternatives Assessment With an Uncertainty-Tolerant Hazard Scoring Method," *J. Environmental Management.*

Green 3D Printing

Alternative Materials

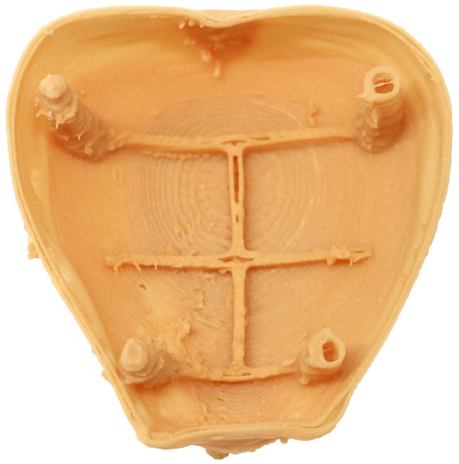


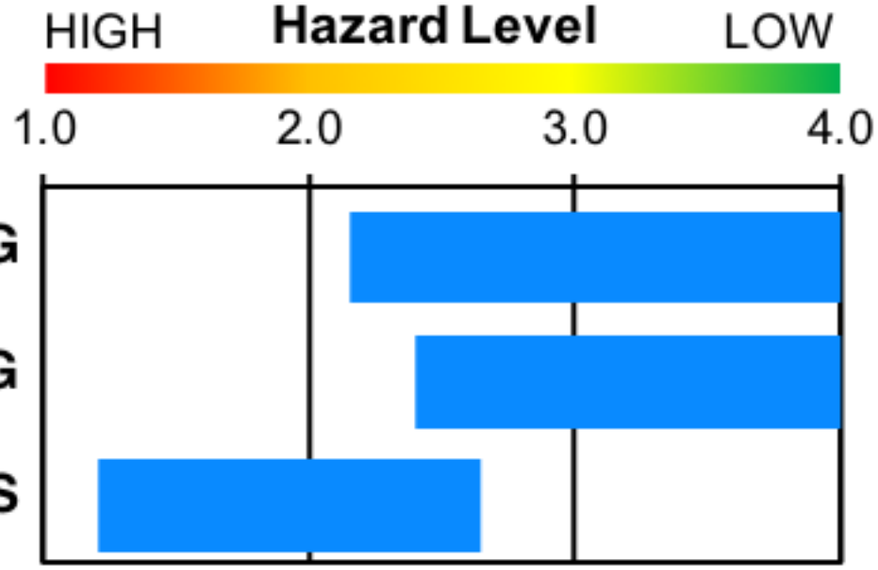
Assessment Protocol

- LCA
- Toxicity
- Resource circularity

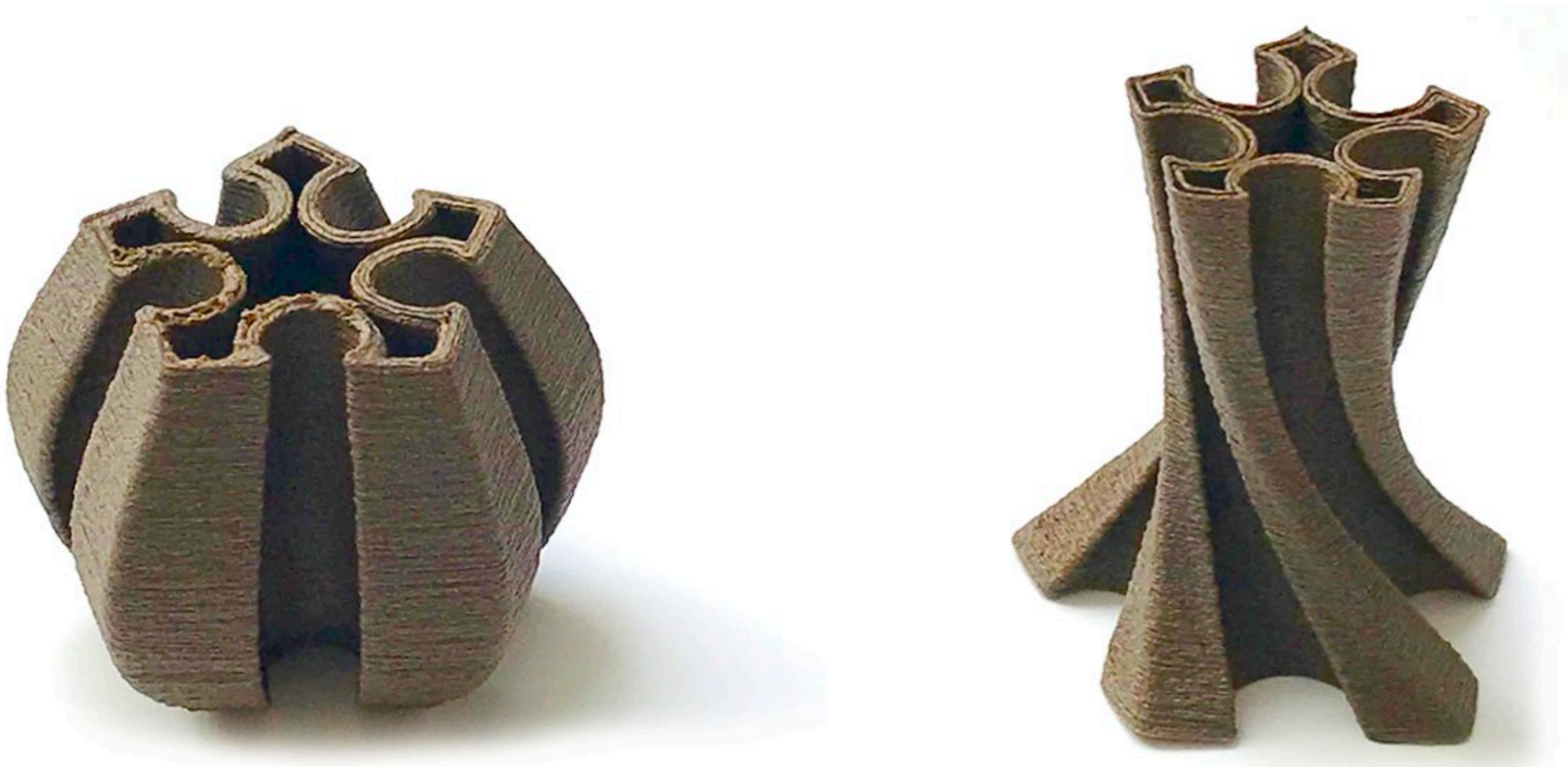
- Mechanical strength
- Cost
- Print quality

Green 3D Printing

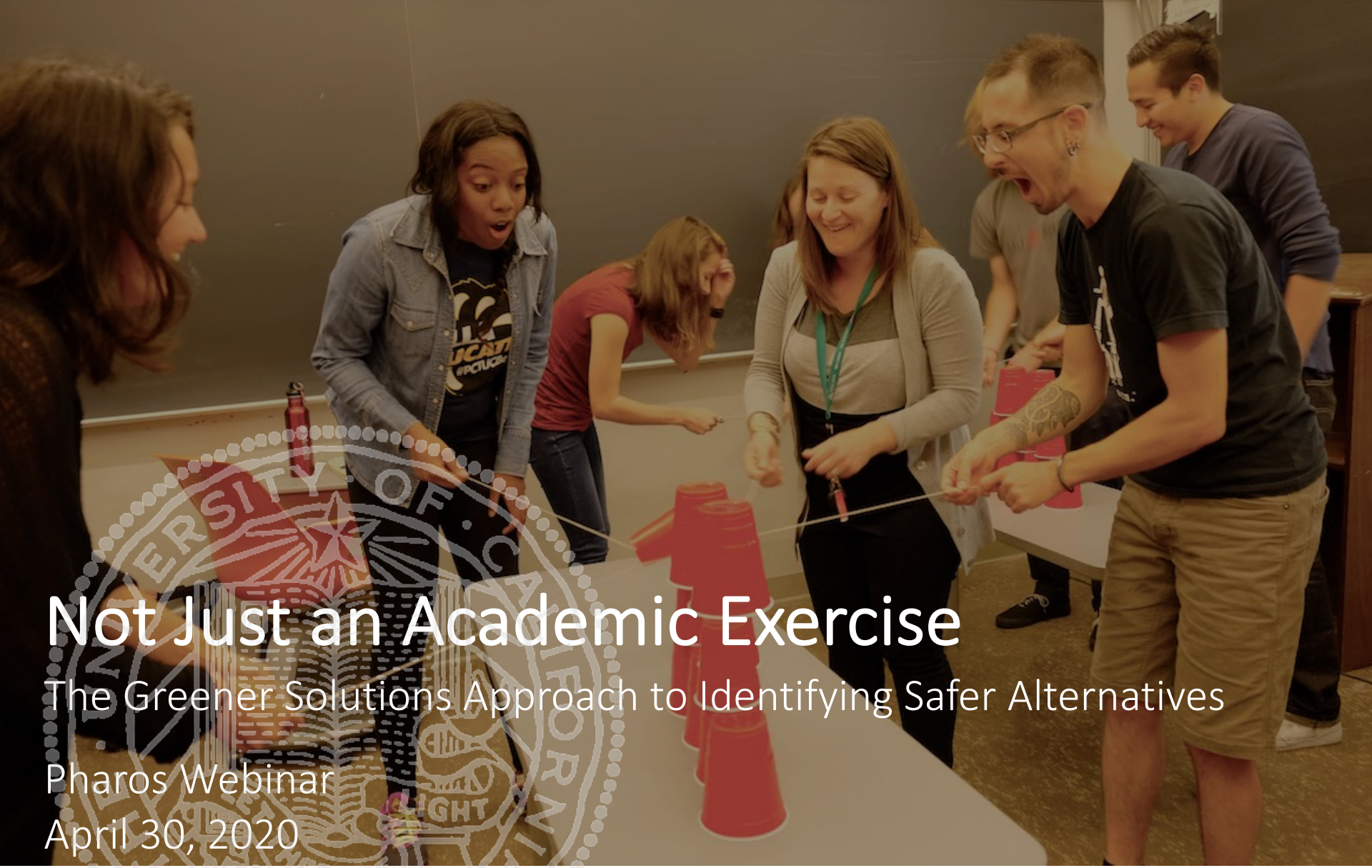




Choosing Greener Materials In Product Design With Pharos



Jeremy Faludi, TU Delft



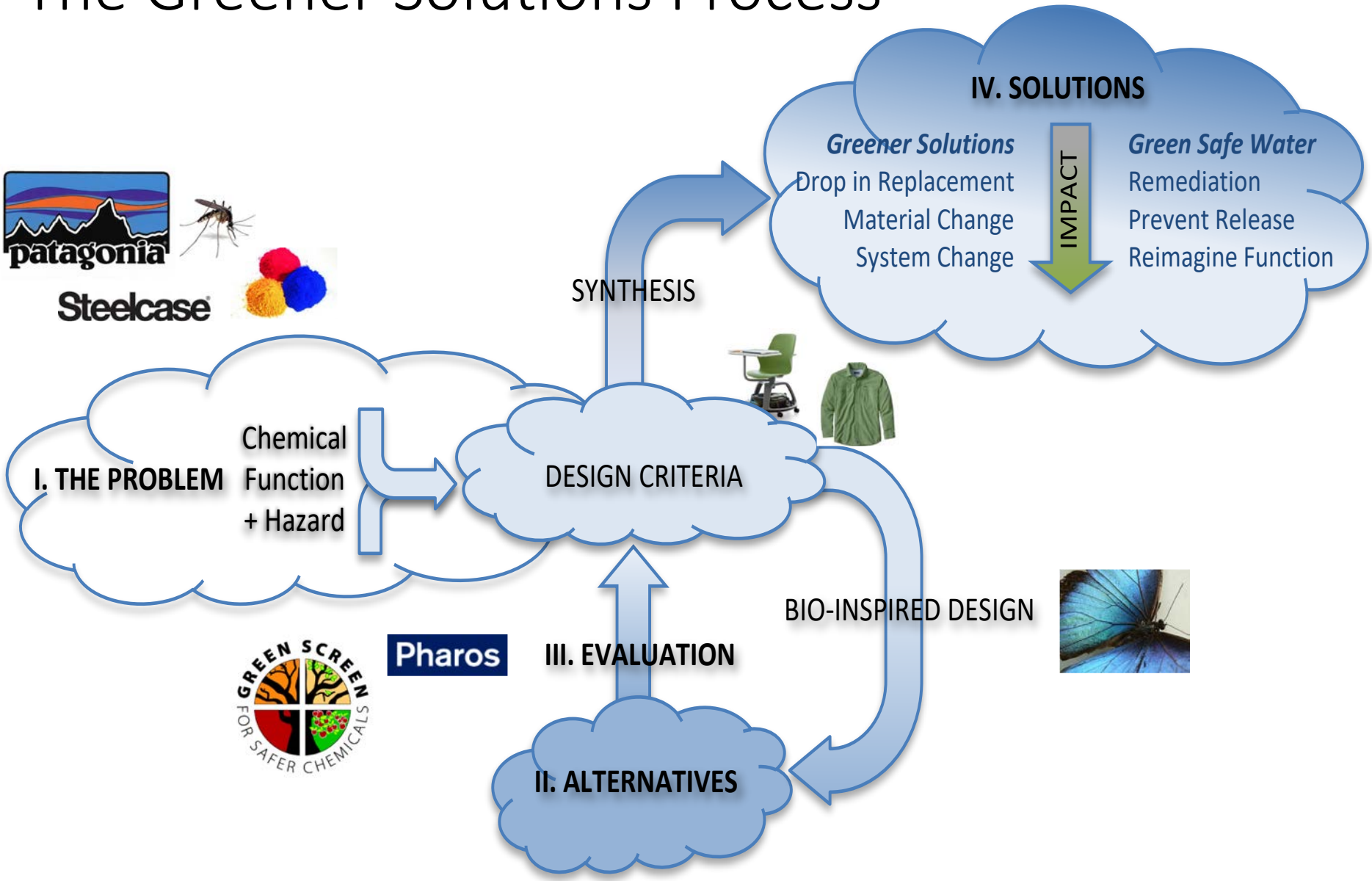
Not Just an Academic Exercise

The Greener Solutions Approach to Identifying Safer Alternatives

Pharos Webinar
April 30, 2020

Meg Schwarzman, MD, MPH
Berkeley Center for Green Chemistry - University of California, Berkeley

The Greener Solutions Process



Schwarzman M. and Buckley H. *Not Just an Academic Exercise.* J Chem Educ. 2020

BERKELEY CENTER FOR GREEN CHEMISTRY

Greener Solutions Projects

2012	Identifying emerging contaminants from e-waste	Hewlett Packard
2013	Alternatives to formaldehyde in permanent press fabric	Levi Strauss & Co.
2014	Safer preservatives for personal care products Alternatives to spray polyurethane foam insulation	Seventh Generation, Method General Coatings, DTSC
2015	Inherently safer 3D printing resins Safer surfactants for cleaning products	Autodesk Method, Amrys
2016	Safer colorants for polymer furniture Inherently mosquito-repellant clothing Biodegradable pigments for marine coatings	Steelcase Patagonia Mango Materials
2017	Durable water repellent coating for outerwear Biobased treatments for mycelium “leather”	Gore MycoWorks
2018	Safer UV blockers for sunscreen Packaging to prevent ocean contamination Safer UV blockers for roofing materials	Method Method Oakland Ecoblock
2019	Safer solvents in synthetic leather production Replacing hazardous crosslinkers in SLA resins	Nike NWGC, Millipore sigma

The Hazard Table

A means of organizing chemical hazard data

Useful for comparing multiple compounds

Common/ Trade Name	CAS Number	Group I Human Endpoints			Group II and Group II* Endpoints			Aquatic Toxicity	Persistence and Bio-accumulation	Physical Hazard or other P/C Traits
		Carcinogenicity Mutagenicity	Developmental and Reproductive Toxicity	Endocrine Activity	Systemic Toxicity	Neuro-toxicity	Skin, Eye, Respiratory Irritation			
Compound	### - ## - #	?	?	?	?	?	?	?	?	?
Compound	### - ## - #	?	?	?	?	?	?	?	?	?

4 step process

1. Identify compounds of interest
2. List screening: Search for hazard information based on ‘authoritative’ lists found in Pharos
   - Obtain detailed info from the source lists
3. Literature review: Search for information on chemicals not listed by authoritative bodies
   - Go to the primary literature
4. Fill gaps: For chemicals with little or no hazard data, consider functional group analysis, chemical class information, and analogies to similar chemicals/materials

Example assignment submission: Initial hazard assessment for solvent alternatives for DMF

	Common name or trade name	Abbrev.	CAS Number	Group I Human Endpoints			Group II and Group II* Endpoints				Ecotoxicity	Fate	Physical Hazard
				Carcinogenicity / Mutagenicity	Developmental and Reproductive Toxicity	Endocrine Activity	Systemic Toxicity	Acute Mammalian Toxicity	Neurotoxicity	Skin, Eye, Respiratory Irritation/ Sensitization	Aquatic Toxicity Acute/chronic	Persistence Bioaccumulation	Reactivity, flammability / Other Pchem traits
Bio-based feedstock	Dihydrolevoglucosenone (Cyrene)	Cyrene	53716-82-8	DG	DG	DG	DG	Acute Tox. 4 -	DG	Causes serious	DG	DG	DG
	Gamma-valerolactone	GVL	108-29-2	Muta. 2; H341 - Suspected of	DG	DG	DG	DG	DG	Irritant of the	LT-P1, possible	DG	Combustible
	Ethyl levulinate	ELV	539-88-8	micronuclei induction @ >1000n	LC50: 83mg/L + ele	DG	DG	6.1E (oral)/Caterge	DG	DG	EC50: 0.982 mg L(:	DG	DG
	Dimethyl isosorbide	DMI	5306-85-4	no cardiovascular effect in sheep	DG	DG	DG		DG	No skin permeatio	DG	DG	DG
	DMTHF (dimethyl-tetrahydrofuran)	DMTHF	1003-38-9	DG	DG	DG	DG	Acute Tox. 4 - Harr	DG	DG	Aquatic Chronic 3 - Harmful to aquati		3.1C - Flammable l
	Ethyl levulinate propyleneglycol ketal	ELPK	5413-49-0	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG
	Dimethyl glutarate	DMG	1119-40-0	Inherently Toxic to Humans (iTH	Toxic as DBE mixtu	DG	DBE cytotoxicity is	H302-Harmful if swallowed (unverifie		H315 - Causes skin	9.1D (algal) - Slig	No/No	DG
SPPS	2-methylfuran	2MF	534-22-5	micronuclei induction @ 20.0 m	LC50: 405mg/L	DG	DG	LT-UNK - List Trans	DG	LT-UNK - List Trans	Class 1 - Low Haza	(Chemspider) Bioa	Flammable liquids
	cyclopentylmethylether	cPME	5614-37-9	Mutagenicity: Negative In Vivo M	DG	DG	DG	LD50(rats) = 1000-	DG	Rabbit: moderate	DG	DG	Highly flammable
	2-Methyltetrahydrofuran	2MTHF	96-47-9	micronuclei induction @ >1000n	LC50: 2980mg/L	DG	LC50: (rat inhale) (	6.1E (dermal) - Acu	DG	Eye: High Hazard L	LT-P1 - List Transla	(chemspider) Bioa	3.1B - Flammable
	propylene carbonate	PC	108-32-7	DG	DG	DG	DG	DG	DG	Eye Irrit. Cat. 2A (f	DG	DG	DG
	ethylene carbonate	EC	96-49-1	DG	DG	DG	LC50 - Ceriodaphr	Cat. 4 (from SDS)	DG	Eye Irrit. Cat. 2A (f	DG	DG	DG
Other	Dimethylpropylene urea	DMPU	7226-23-5	DG	EU - GHS- Suspect	DG	DG	EU-GHS- Harmful if swallowed		GHS hazard staten	German FEA- Class	DG	DG
	Ethyl cynide	EtCN	107-12-0	DG	High (Toxic to	DG	High - (Very High,	Very High-High	High (Neurotoxicit	High (skin -	DG	Persistence -	High -
	Acetonitrile	ACN	75-05-8	Carcinogenicity - High-Low	Moderate-Low	DG	Potential concern	Moderate (H302	Potential concern	High (H319 -	DG	Very High - High	High (H225 -
	N-methylformamide	NMF	123-39-7	DG	High (Toxic to	DG	Very High	Moderate (H312	DG	Moderate	DG	DG	DG
	Polypropylene glycol	PPG	25322-69-4	GRAS**	GRAS**	DG	GRAS**	**Category 4** "Mode	CNS: "These mate	Potential Skin H31	LC50 (3 species): C	EC - CEPA DSL - Pe	1 - Materials that
	THFP Glycofurol 75	THFP	5831-59-4	no cardiovascular effect in	DG	DG	LD50 7800 mg/kg (	Acute Tox. 4 DK-EI	Glycofurol (GF) no	(unspecified) IRRIT	DG	Bioaccumulation	DG
	1H-imidazolium,3-butyl-1-methyl tetrafluo	IL1	174501-65-6	DG	DG	DG	Log10(EC50) (um)	Oral Cat. 3	DG	Skin Cat. 2, Eye Ca	Acuate & Chronic	Forms HF in water	DG
		other	bio-based feedsto	SPPS	**On Restricted Substance List**								
Process Change Chemicals	Polycat	-	7560-83-0	DG	DG	DG	DG	6.1D (oral) - Acute	LD50 ? (rat oral) 4	8.2C - Corrosive to	LT-P1 - List Transla	Bioaccumulation	Estimates from Log K
	Dabco	-	280-57-9	DG	Toxic to reproduct	DG	Specific target org	Acute Toxicity (ora	LD50? rat (1100 m	LT-UNK - List Trans	Aquatic Chronic 3	Bioaccumulation E	H228 - Flammable

Category	Chemical/ Strategy	Chronic Human Health	Acute Human Health	Ecotoxicity	Fate	Physical
Cross-linker	Genipin	M	M	O	L	L
Enzymatically derived o-quinone cross-linker	Tyrosinase	L	M	O	O	L
	p-Cresol	M	H	M	O	M
Nanocomposite cross-linker	Chitin Nanowhiskers	L	H	L	L	L
	2-iodophenylboronic acid	M	H	L	O	L
	Suberic acid	L	M	L	L	L
Moisture barrier	Corn Zein	L	L	O	L	L
	PEG	L	L	L	M	L
Solvent	Acetic acid w/ leather, genipin	L	H	M	L	M
	Ethanol w/ corn zein, genipin	M	H	L	L	H
	Hydrochloric acid w/ nanowhiskers, tyrosinase	M	H	L	L	M
	Sodium hydroxide w/ nanowhiskers	M	H	H	M	M

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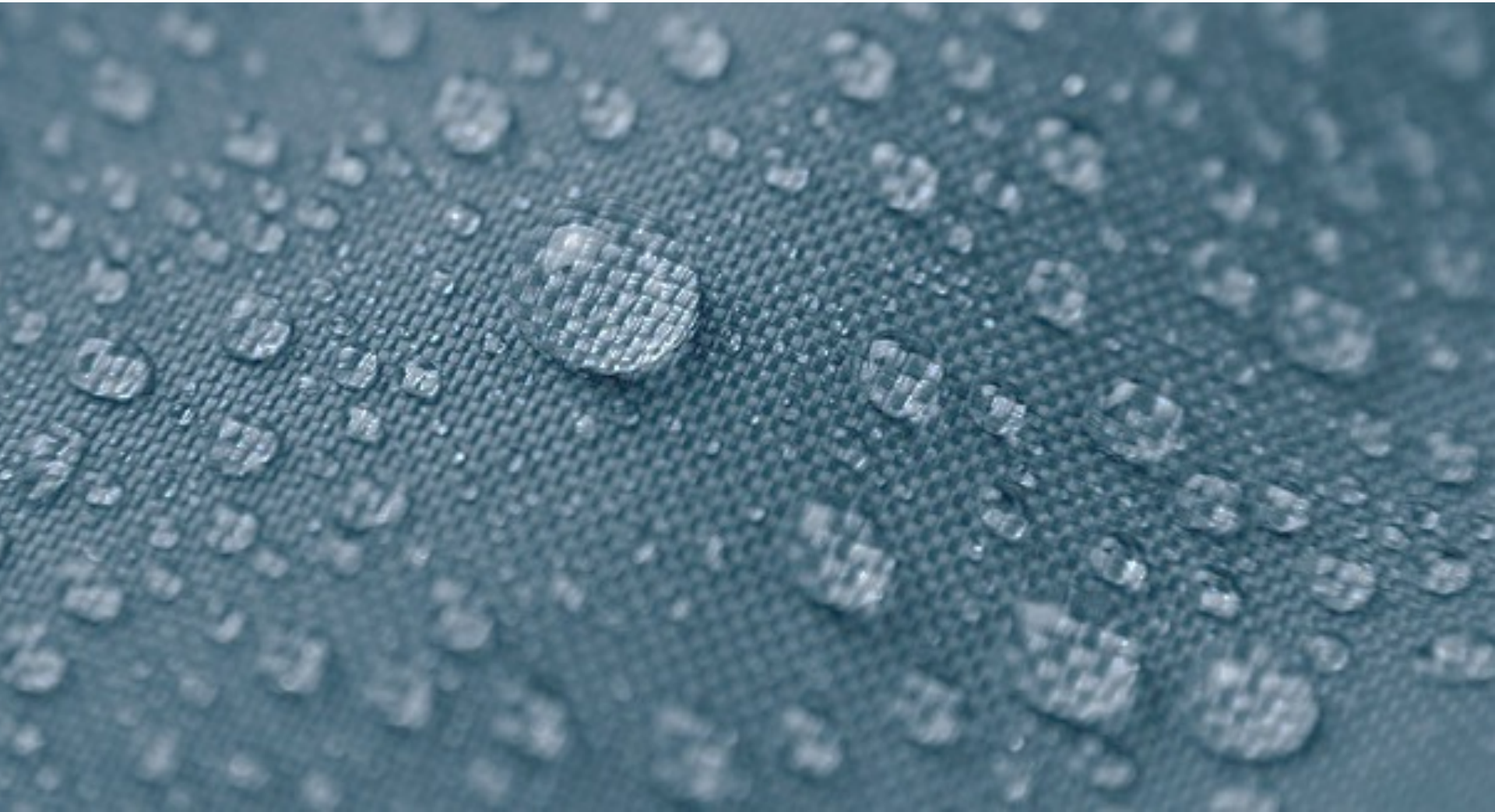
Example 1: PFAS-free DWR coatings

Addressing a priority chemical hazard with non-chemical alternatives



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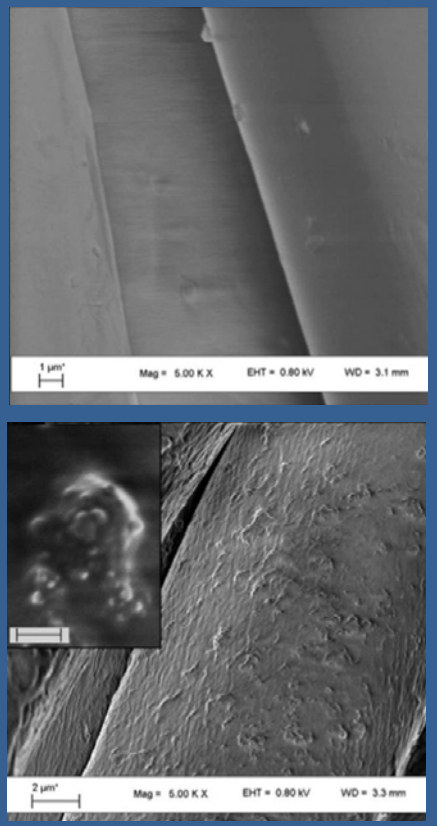
Greener Solutions students identify non-chemical alternatives to PFAS coatings that can produce water repellent synthetic fabrics.

Silica nano-sols create a hydrophobic nano-texture

Texturized fabric



Silver ragwort leaf inspiration for electro-spun fiber mat

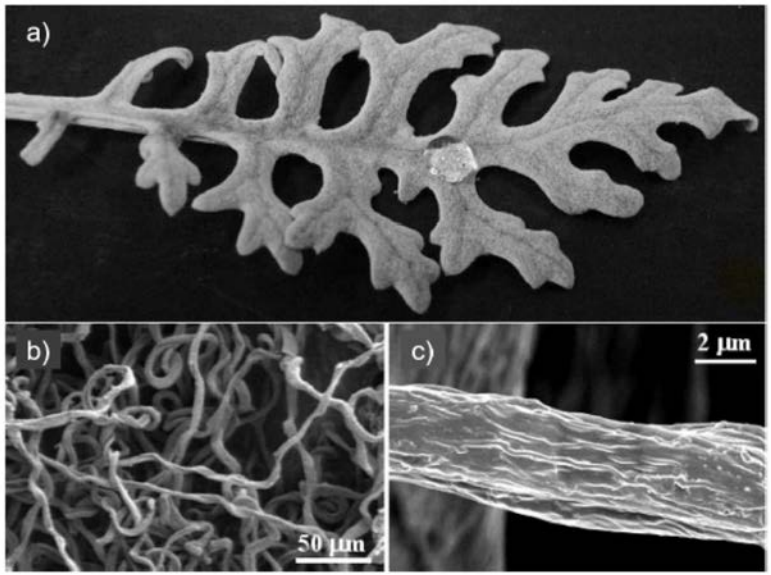
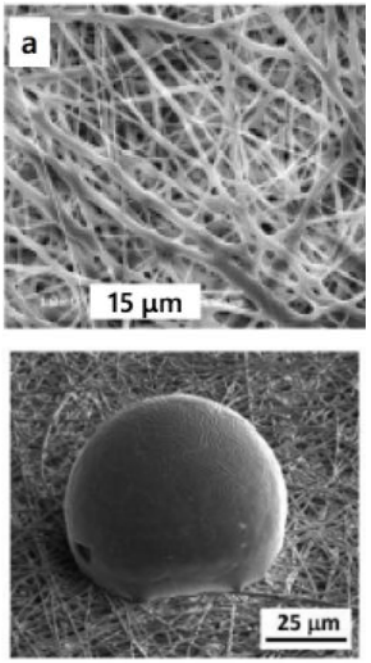


Fig. 4.13. Silver ragwort leaf. a) Digital photograph of a leaf with a beaded water droplet. b) and c) SEM images showing the tangle of fibers and the structuring on the fibers.



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The alternative DWR solutions identified in Greener Solutions are safer than PFASs

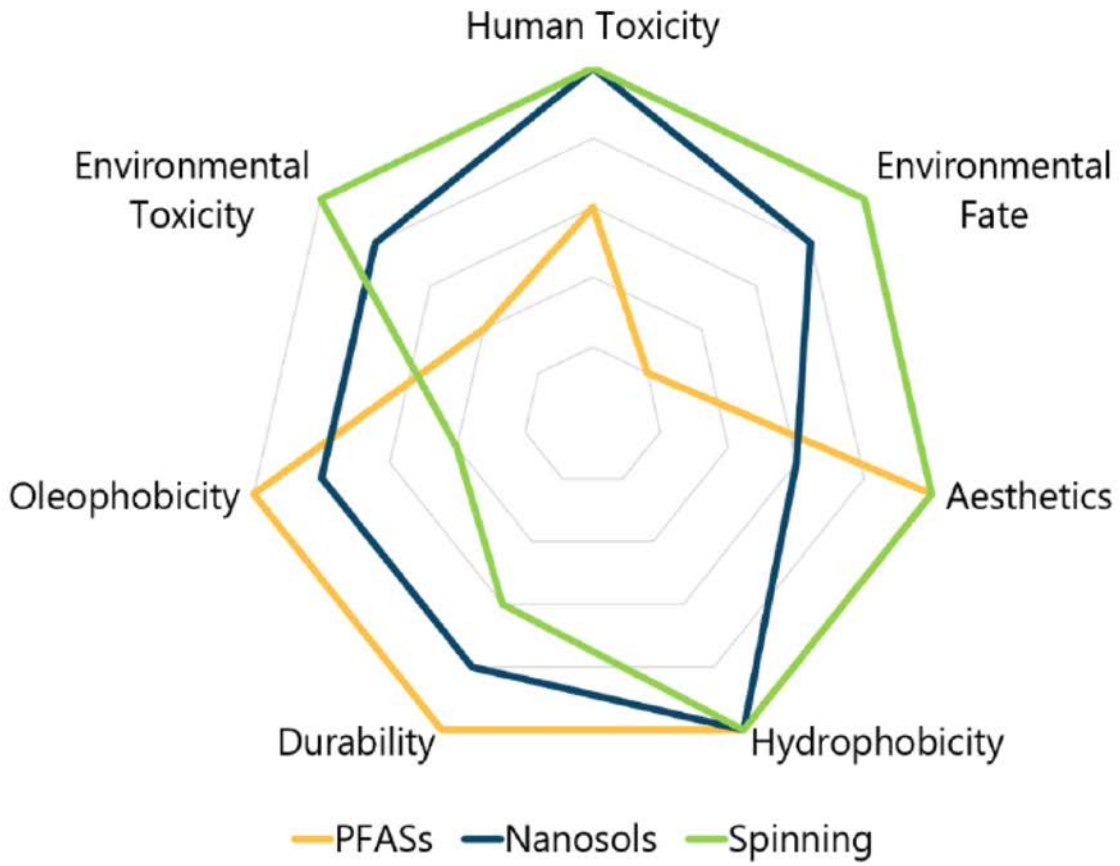

Fig. 5.1. Relative hazard and performance comparison between PFAS and the two alternatives presented in this report. A strategy is better performing if its endpoints lie closer to the outer ring of the chart. More hazardous and poorer performing alternatives will score closer to the center.

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Example 2: Safer Resins for 3D printing

Designing and testing alternative resins in collaboration with industry and NGOs

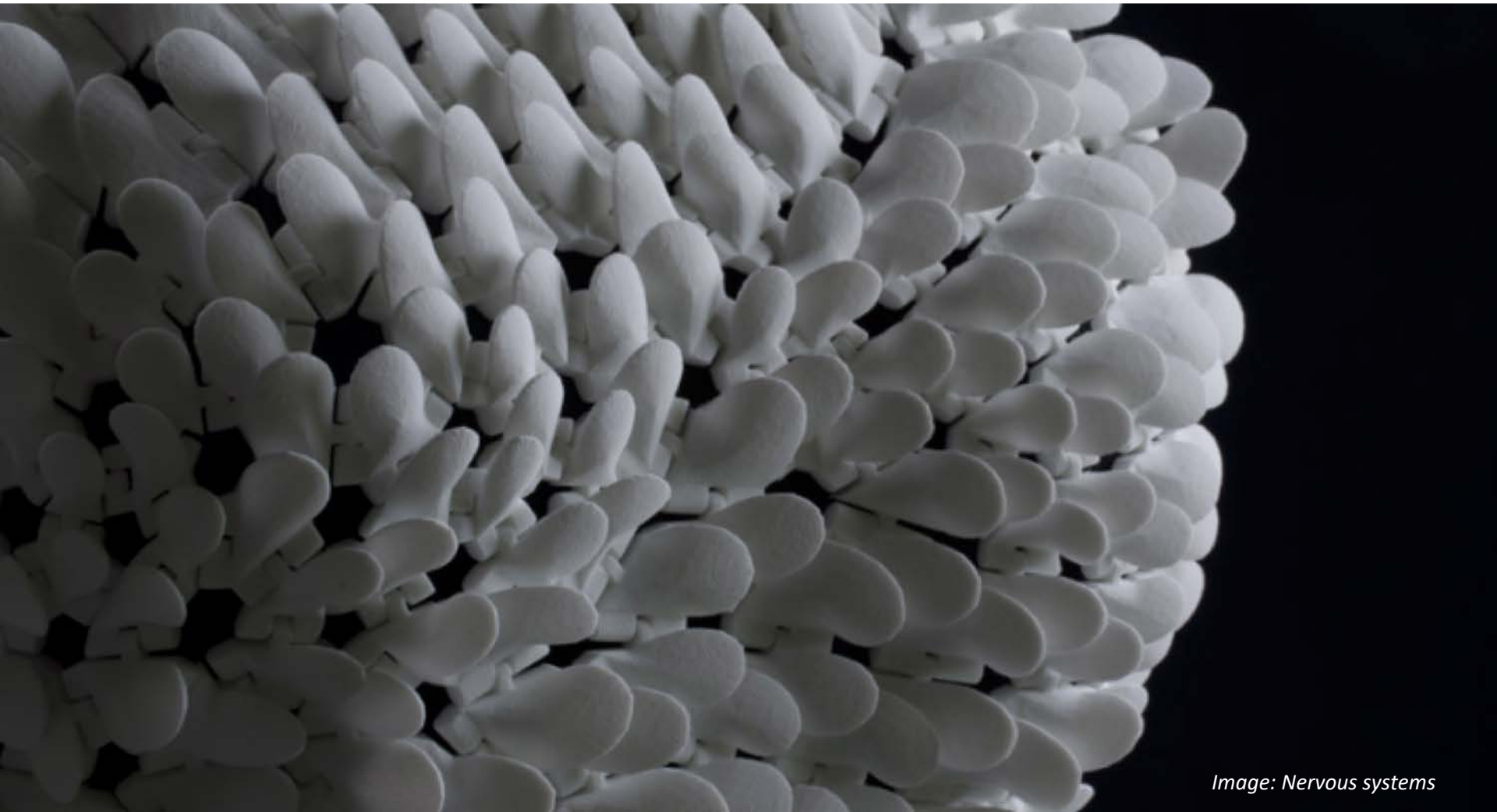

Image: Nervous systems

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Greener Solutions students identify bio-inspired alternatives to hazardous components of 3D printing resins.

Approach 1: Replace the Photoinitiator

- **Strategy A:** Curcumin & Riboflavin

Approach 2: Modify Acrylate-based Resins

- **Strategy B:** Triglycerides
- **Strategy C:** Chitosan

Approach 3: pH Photoinitiated Resins

- **Strategy D:** Calcite
- **Strategy E:** Metal Catechol Complex

Greener Solutions assessment of health and environmental performance of SLA resin alternatives

Health/Environmental Performance Rating					
Strategy	Carcinogenicity, Mutagenicity, Reproductive/ Developmental, Endocrine Disrupting	Systemic Toxicity	Skin, Eye, Respiratory Irritation/ Sensitization	Ecotoxicity	Sustainably Sourced Chemical
PR48	2	2	3	2	3
Biobased Polymers	U	1	3	2	1
Click Chemistry	2	2	3	2	1
pH Induced	U	1	2	1	1
Spider Silk	U	2	3	2	2
Micelles	U	U	U	U	U

Legend			
(1) Low Hazard	(2) Medium Hazard	(3) High Hazard	(U) Unknown

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Example 3: Safer Preservatives

Protecting water quality by designing safer antimicrobials for consumer products

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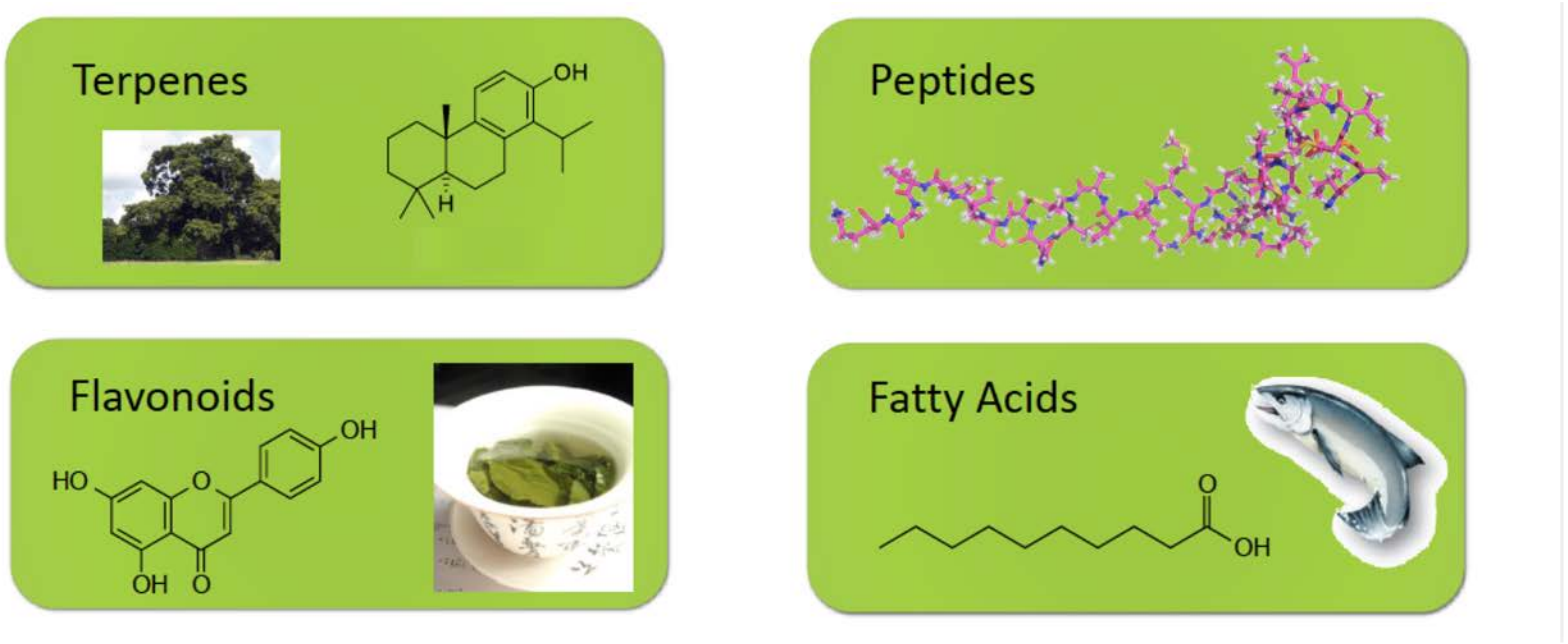
Greener Solutions students identify alternative antimicrobials for use in personal care and household products to replace hazardous parabens and methylisothiazone (MIT)

Next Generation Chemical Preservatives:

Protecting People, Products, and our Planet

HEATHER L. BUCKLEY, ADAM P. BYRNE, WILLIAM M. HART-COOPER & JIAWEN LIAO
UNIVERSITY OF CALIFORNIA BERKELEY – GREENER SOLUTIONS
DECEMBER 10, 2014



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Greener Solutions students' multi-criteria assessment of alternative antimicrobials

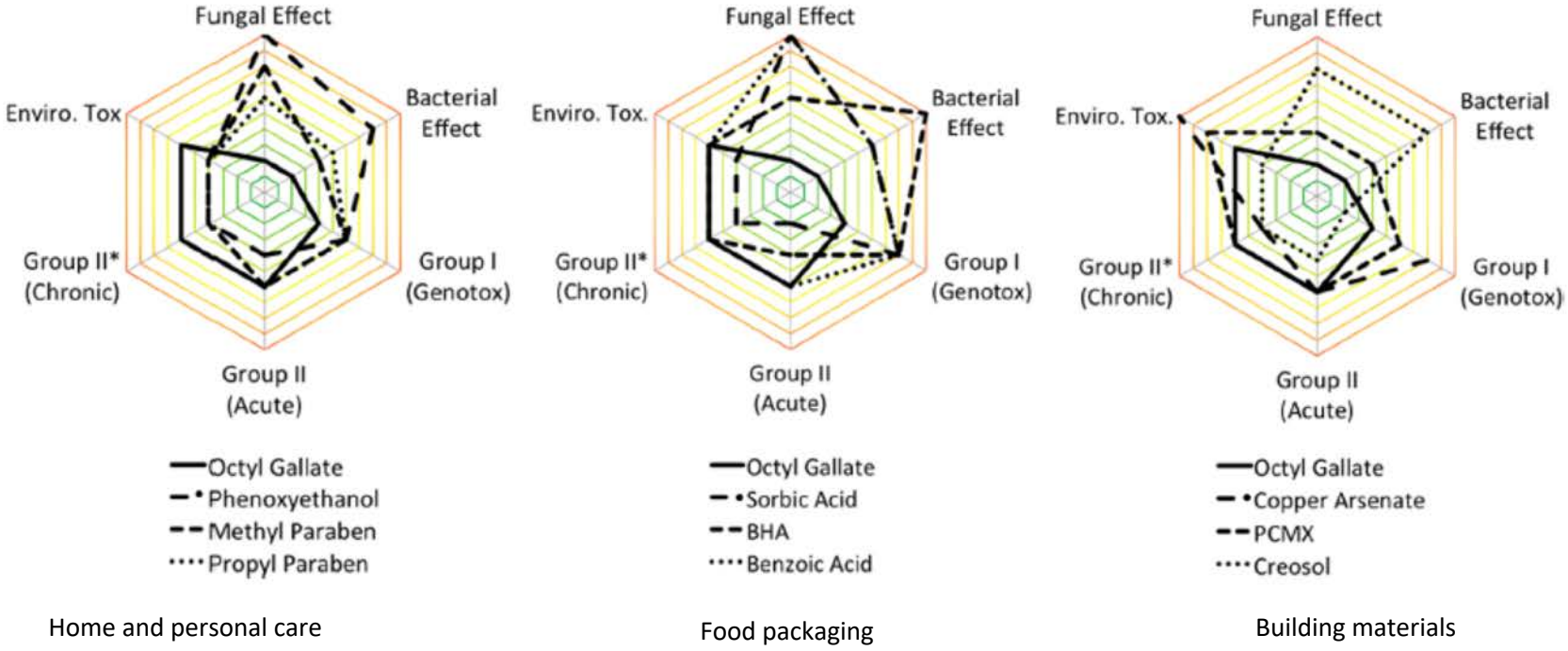
		Hazard	Antimicrobial Efficacy	Level of Uncertainty	Biodegradability	Origin of Raw Materials	Product Compatibility	Regulatory Concerns		Cost
Bioinspired alternative chemistries	Terpenes	1	2	2	2	3	2	3	1	2
	Peptides	3	2	1	3	3	3	3		1
	Flavonoids	2	2	2	2	3	2	3		1
	Lipids	2	2	2	3	3	3	3		3
Incumbent	Phenoxyethanol	2	1	2	3	2	3	3	1	3

Figure 2. Example of a student-generated opportunity map summary figure, a multicriteria decision-making framework comparing an existing preservative in personal care product formulations and their proposed bioinspired alternatives. Higher scores/darker colors are better (i.e., a score of 3 indicates low hazard, high biodegradability).[20]

Inspired by candidates identified in the course, students identified gallates as a class of safer and more effective preservatives

ACS Sustainable Chemistry & Engineering

Research Article

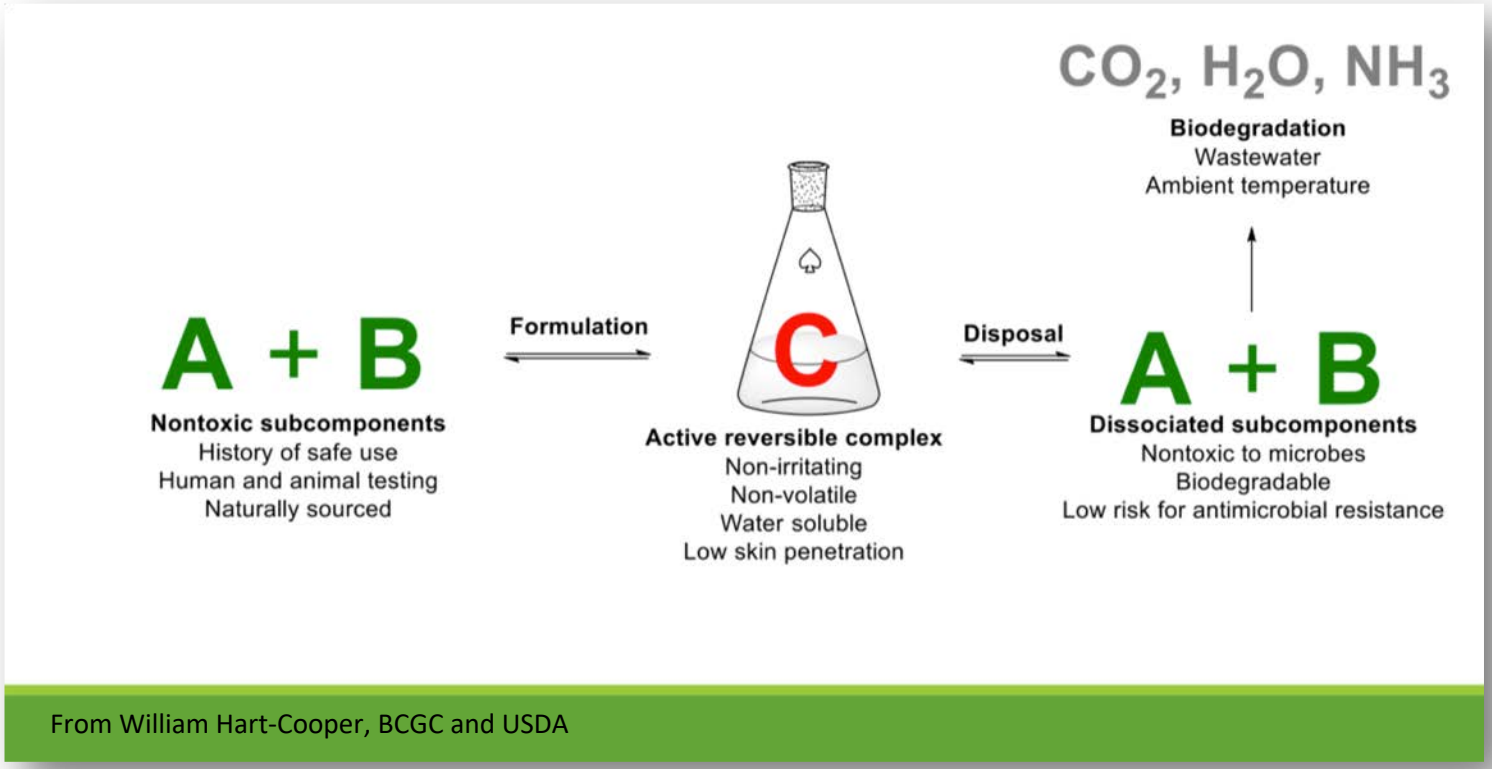


Smaller values (closer to the center) indicate better performance for that metric

Octyl gallate was more effective than existing preservatives and safer for some, but not all, endpoints

Buckley H. et al., ACS Sustainable Chem. Eng. 2017, 5, 4320−4331

Continued work brings a non toxic reversible antimicrobial to market



The team shifted focus to a structurally similar class of two-subunit compounds that decomposed rapidly when diluted.

These “reversible” preservatives have antimicrobial effects when bound together but de-dimerize once diluted (as they would be in wastewater), reducing the potential environmental impact of the compounds.

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Reversible Preservative Wins 2018 GC3 Challenge

GREEN CHEMISTRY & COMMERCE COUNCIL
Business Mainstreaming Green Chemistry

- The project was one of four **first place** recipients from among 48 entries in the 2018 GC3 Preservatives Challenge sponsored by two dozen companies, including giants Johnson & Johnson, Unilever, Walmart, and Target.
- The group is now investigating potential commercial partnerships to bring the reversible preservative to market.
- A research paper on the design and function of the reversible preservatives will be published early next year.

UVic green scientist develops new enviro-friendly preservative for cosmetics & cleaners

"Reversible" anti-microbial fights bacteria while in the container, but breaks down into two harmless ingredients once outside of it

September 14, 2018 · Less than a minute

Heather Buckley, PhD, 2014 Greener Solutions research team, BCGC Post-Doc, now Assistant Professor of Chemistry and Civil Engineering, University of Victoria

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Greener Solutions

Trains environmental health scientists, chemists, and engineers to:

- Perform chemical hazard assessment
- Grapple with data gaps, complex hazard information, and tradeoffs
- Addresses complexities of mixtures (e.g., formulations)
- Permits exploration despite uncertainties (cost, formulation compatibility)

Students say:

"I learned a LOT about hazard assessment, which as an IH is an extremely(!!!) valuable tool."

"I learned way more(and had a lot more fun learning it) than in a typical lecture-based course… It was really valuable to have instructors from different fields and perspectives."

"I found this course far more interesting and motivating than others I've taken at Berkeley. It was refreshing to feel like my work had impact."

Teaching Resources

Meg Schwarzman's Greener Solutions Course (UC Berkeley)

Course Materials:

- *Greener Solutions* student accomplishments (PDF)
- Presentation slides from *Greener Solutions* team-building exercise (PDF)
- *Greener Solutions* assessment materials: final assignments, student feedback form for draft presentation, and peer evaluation template (PDF)
- *Green Safe Water* assessment materials: final assignments and grading rubrics (PDF)

(from the free Supporting Information of the peer reviewed paper below)

Peer reviewed paper:
Not Just an Academic Exercise: Systems Thinking Applied to Designing Safer Alternatives https://pubs.acs.org/doi/full/10.1021/acs.jchemed.9b00345 (paywall)

Article:
https://chemistry.berkeley.edu/news/public-health-and-chemistry-join-forces-reimagine-chemistry-education-sustainability

Teaching Resources

Jeremy Faludi's Teaching Resources (TU Delft)

VentureWell online course pages on green material choice
https://venturewell.org/tools_for_design/greener-materials/finding-greener-materials/

Peer reviewed paper:
Aiding alternatives assessment with an uncertainty-tolerant hazard scoring method
http://faludidesign.com/work/publications/Faludi_2016__Aiding_Alternatives_Assessment.pdf

Teaching Resources

Heather Buckley's Green Safe Water Course (U.Victoria)

- Example Assignment: Chemical Hazard Query Log
- Example Assignment: Design Project & Final Report
- Example Final Report: Chromium in Leather Tanning
- Example Final Report: Tin Stabilizers in Drinking Water
- Curriculum: Backwards Design Course Description
- Curriculum: Backwards Design Tox Unit

Assignments, reports, and curricula at
https://pharosproject.net/case-studies/university-of-victoria

Thank You!

Sign up:
https://pharosproject.net/

For more information contact:
Michel Dedeo
mdedeo@healthybuilding.net

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