

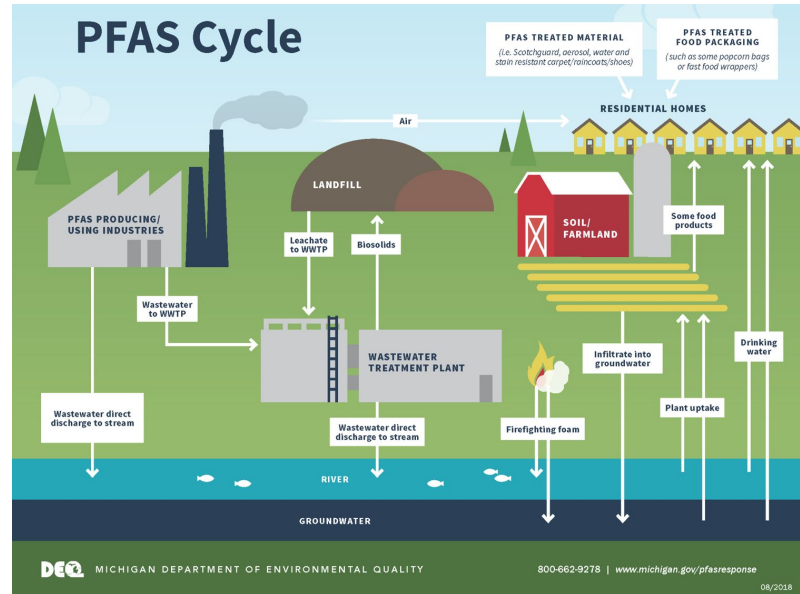


# Alternatives to per- and polyfluoroalkyl substances in Aftermarket Carpet Treatments

Amanda Bischoff, Zhenya Chen, Nancy Gutierrez,  
Emily McGauley, Samantha Vega

# Per- and polyfluorinated alkyl substances (PFAS)

- Environmental Persistence
- Bioaccumulation
- Lactational or transplacental transfer
- Multiple toxicities
- Toxicity to aquatic life and global warming potential





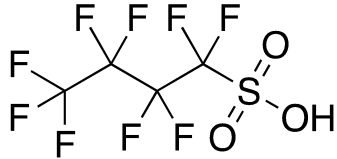
## Our Partner



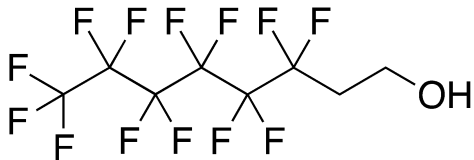
**DTSC**  
**Department of Toxic  
Substances Control**

# Scotchgard

- Scotchgard will be used as our baseline comparison product
- PFAS known as part of its composition
- Developed in the 1950's by 3M
- Widespread consumer name recognition



PFBS: perfluorobutanesulfonic acid



6:2FTOH: 6:2 fluorotelomer alcohol



# Criteria for Success

Performance | Health



Water and oil repellency

Durability/  
longevity

Economic viability

Performance:

High (H)

Medium (M)

Low (L)

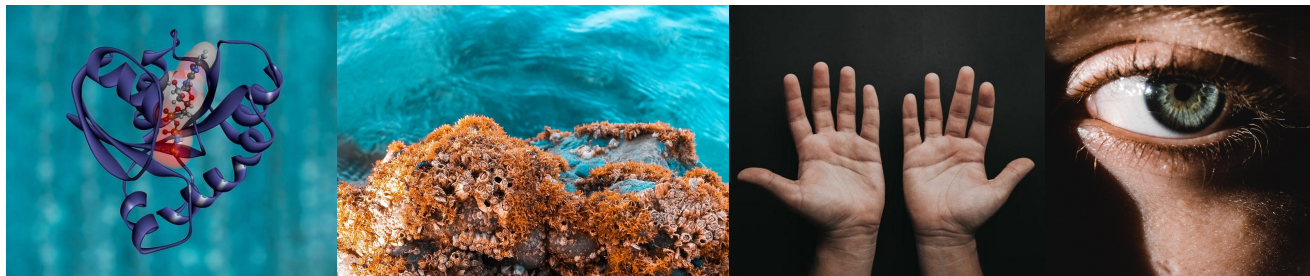
Data Gap (DG)



Illustration of contact angle

# Criteria for Success

Performance | Health



Carcinogenicity,  
mutagenicity,  
endocrine disruption

Persistence  
Aquatic toxicity

Eye, skin, respiratory irritation

## Key

Hazard:

Low (L)

Medium (M)

High (H)

Very High (V)

Data Gap (DG)

GHS 3/4

GHS 2/2B

GHS 1B/1C/2A

GHS 1/1A

Little hazard

Suspected

Strong evidence

Known and severe

# Hazard Table

		Table 1. Hazard of PFAS					
		Carcinogenicity / Mutagenicity	Developmental / Reproductive Toxicity	Skin / Eye Irritation	Aquatic Toxicity	Bioaccumulation/ Persistence	Endocrine Activity
Bad Actors (PFAS)	PFBS	DG	M	H	H	H	H
	6:2 FTOH	DG	H	H	H	L	H

## Key

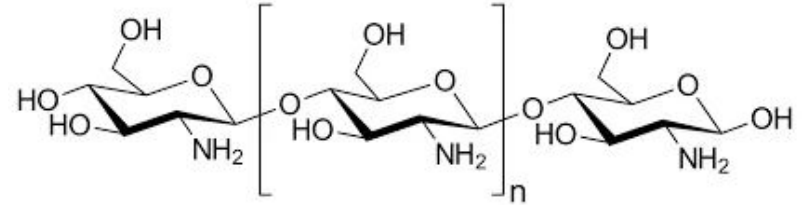
Hazard:

Low (L)	Medium (M)	High (H)	Very High (V)	Data Gap (DG)
---------	------------	----------	---------------	---------------

# Biopolymers: Chitosan

## Chitosan

- A linear polysaccharide composed of randomly repeating acetylated and deacetylated units
- Created when chitin is partially deacetylated under basic conditions



## Bio-based derivation

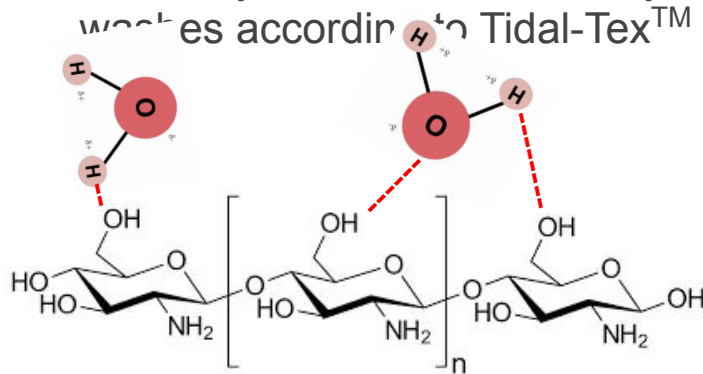
- Found in crustacean exoskeletons (crab and shrimp shell waste) and cell walls of fungi
- Has applications in the biomedical and food industry due to antimicrobial activity



# Biopolymers: Chitosan

## Performance

- Hydrophobicity: Chitosan can hydrogen bond with Nylon-6 fibers and alter its mechanical properties
- Chitosan can coat the carpet fibers and hydrogen bond with water-based stains to prevent the stains from permeating the carpet
- Antimicrobial activity
- Durability: Antimicrobial activity remains on clothing for up to 50 weeks according to Tidal-Text™



--- indicates a hydrogen bond

# Biopolymers: Chitosan

## Advantages

- Easily sourced due to natural abundance
- Antimicrobial and self-healing properties
- Soluble in acetic acid, a safer solvent, when pH of solution is less than 6

## Disadvantages

- Chitosan becomes overly viscous above 2% (w/w), losing its ability to flow
- Acidified chitin displays acute aquatic toxicity
- Additives required for oleophobicity

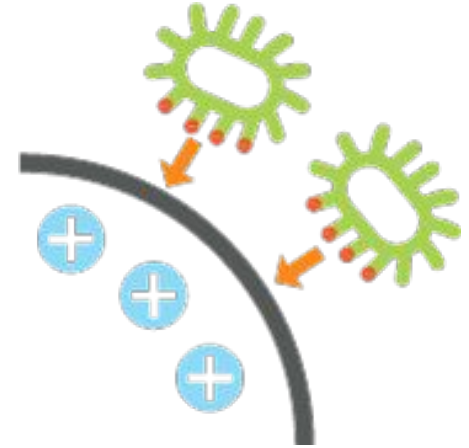
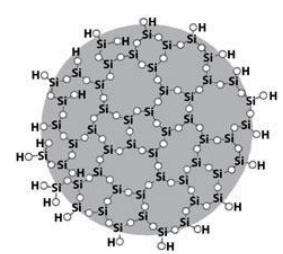
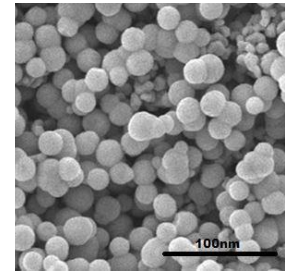


Photo: (Tidal-Tex, 2020)

# Silicon Dioxide Nanoparticles (SiNPs)

## Advantages

- Performance: high stain repellency against water- and oil-based stains; durable
- Health: environmentally friendly; little irritation and toxicity
- Practical: economically feasible and deliverable in a spray form; already used in many products; earth-abundant



Electron microscopy image and schematic of SiNPs

## Disadvantages

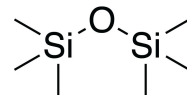
- Performance: additives (such as silicones) are needed to achieve oil resistance
- Health: more research needed to understand nanoparticle-specific effects, as well as hazard during production



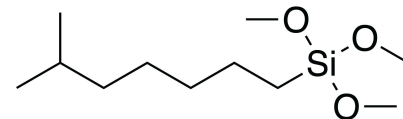
# Silicon-Containing Small Molecules and Polymers

## Function

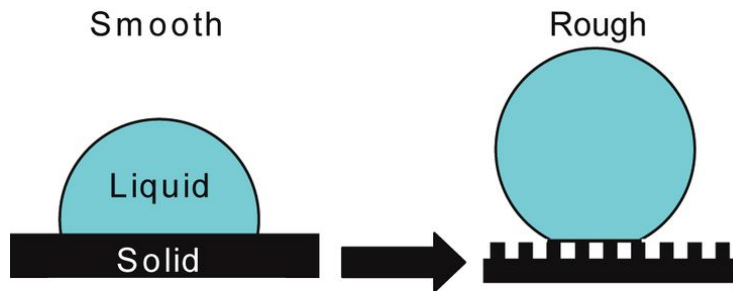
- Chemical water repellency due to hydrophobic groups
- Physical repellency via modification of other structures to impart rough surface patterning



hexamethyldisiloxane



isooctyl trimethoxy silane



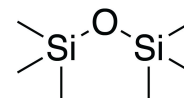
# Silicon-Containing Small Molecules and Polymers

## Advantages

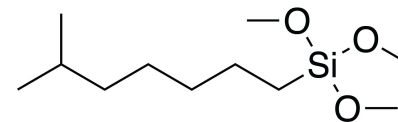
- Performance: incorporation into other solutions can impart high hydro- and oleophobicity
- Health: many compounds used have benign human health and environmental effects
- Practical: economically feasible, currently components of many coatings and cosmetics

## Disadvantages

- Health: highly dependent on the specific compound used; some have serious health and environmental effects



hexamethyldisiloxane



isooctyl trimethoxy silane

# Performance Table

		Hydrophobicity (Contact Angle)	Oleophobicity	Washability	Source
Bad Actors (PFAS)	PFAS	170°	156°	120+ washes	artificial
Biopolymers	Chitosan	102°	DG	50 washes	Crustacean exoskeletons
Silicon-based materials	SiNPs	151°	133°	10-30 washes	Silicon

## Key

Performance:

High (H)

Medium (M)

Low (L)

Data Gap (DG)

# Hazard Table

		Carcinogenicity / Mutagenicity	Developmental / Reproductive Toxicity	Skin / Eye Irritation	Aquatic Toxicity	Bioaccumulation / Persistence	Endocrine Activity
Bad Actors (PFAS)	PFBS	DG	M	H	H	H	H
	6:2 FTOH	DG	H	H	H	L	H
Biopolymers	Chitosan	L	L	H	H	L	DG
Silicon-based	SiNPs	M	H	M	L	L	L

## Key

Hazard:

Low (L)

Medium (M)

High (H)

Very High (V)

Data Gap (DG)

Confidence:

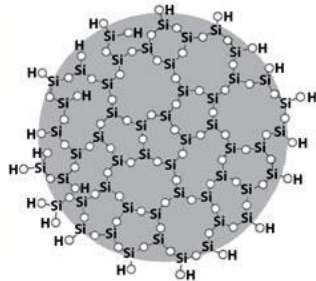
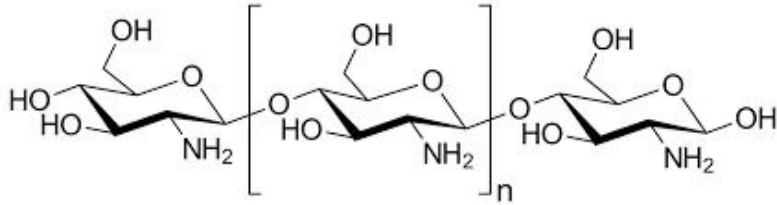
Low

Average

High

# Next Steps

More of our performance requirements can be met by combining multiple strategies, such as SiNPs plus silicone additives. We recommend exploring new ways to combine our strategies to achieve the greatest performance.





# CREDITS

We would like to give special thanks to:

- The teaching team: Megan Schwarzman, Billy Hart-Cooper, Tom McKeag, and Kimberly Hazard for their guidance, feedback and support
- Simona Balan for productive discussions and her enthusiasm exploring new ideas
- Pexels and Unsplash for stock photos
- Infographics by Freepik