AFTERMARKET CARPET TREATMENTS

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OUR PARTNER

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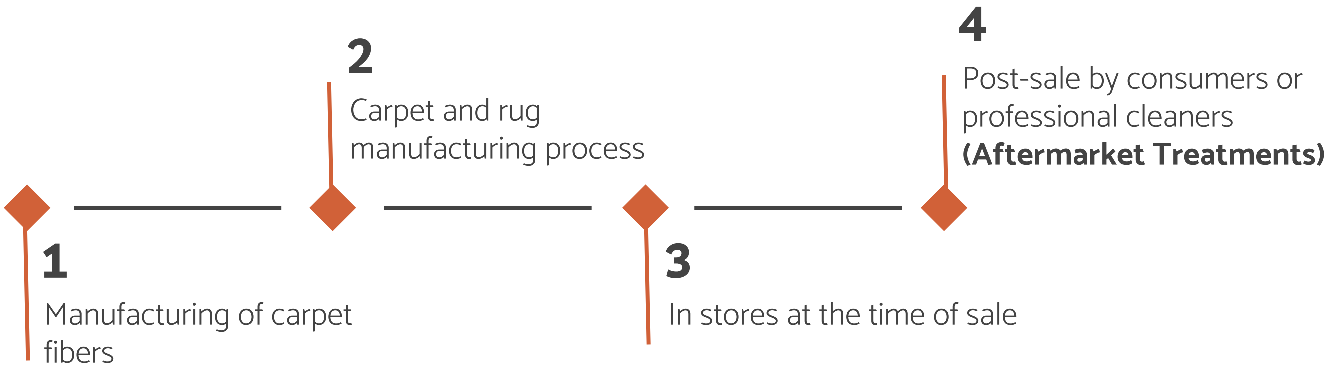
BACKGROUND

01

Background

- PFAS widely used in industrial and consumer products to impart stain/soil/grease resistance
- DTSC has identified carpets and rugs as sources of significant PFAS exposures
- PFAS-containing treatments can be applied to carpets at four different stages
- PFAS in the aftermarket treatment industry predominantly consist of fluorinated polymers such as fluorochemical urethane



BAD ACTOR

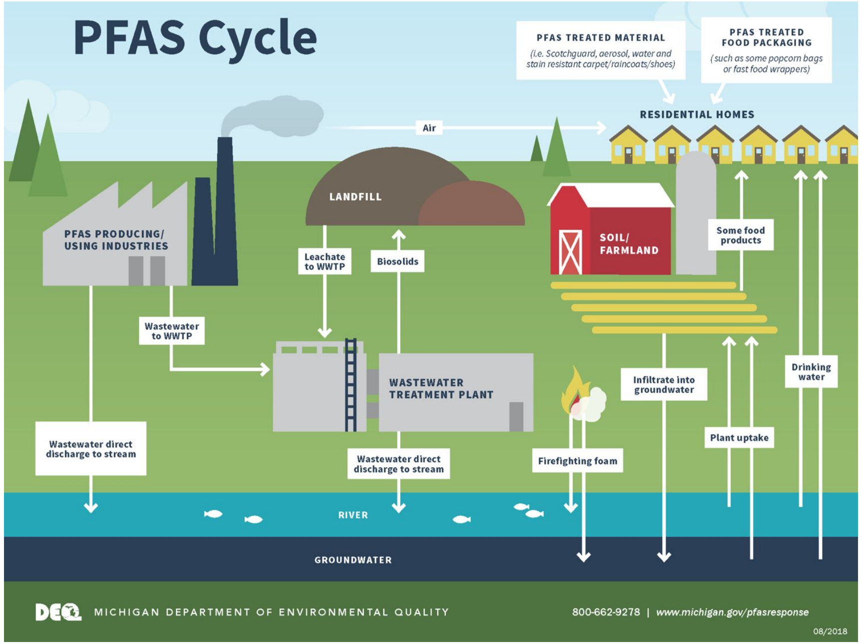
02

Scotchgard

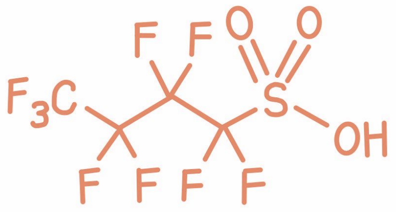
- Scotchgard will be used as our baseline comparison product
- PFAS known as part of its composition
- Developed in the 1950's by 3M
- Widespread consumer name recognition

PFAS

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

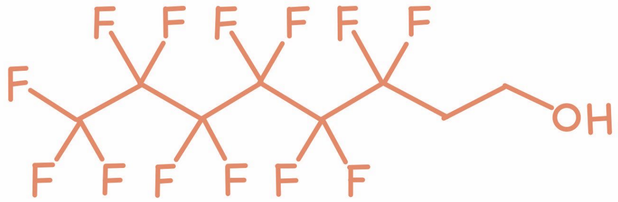


PFAS



PFBS

Perfluorobutanesulfonic acid



6:2 FTOH

6:2 fluorotelomer alcohol

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

Key

Hazard:	Low (L)	Medium (M)	High (H)	Very High (V)	Data Gap (DG)
Confidence:	*Low*	Average	**High**		

APPROACH

03

Goal

Confer stain resistance in carpets through water and oil repellent strategies

Product

Liquid solution directly applied on carpet

Applicator

At-home treatment applied by consumer

Method

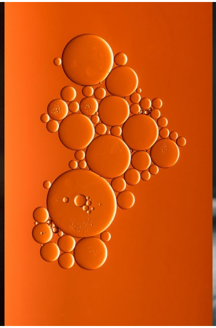
Focus on carpet protection

Properties

Hydrophobicity but also include oleophobicity

Criteria for Success

Performance | Health



Water and oil repellency

Durability/ longevity

Economic viability

Cleanability

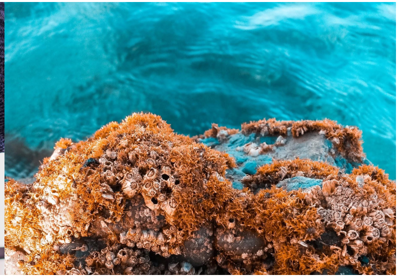
Criteria for Success

Performance | Health

Eye, skin, respiratory irritation

Carcinogenicity,
mutagenicity,
endocrine disruption

Reproductive toxicity



Persistence
Aquatic toxicity

STRATEGIES

04

Strategy 1

Waxes and Oils

} ***Inspiration***

Strategy 2

Biopolymers

Strategy 3

Silicon-Based Materials

1

Waxes and Oils

- Beeswax
- Mink Oil

1

Beeswax

$(C_{15}H_{31}COOC_{30}H_{61})$

What is Beeswax?

- Secreted from bees' special glands
  and used to form the structure of their hive.
- Insoluble in water and completely soluble in fixed or volatile oils, chloroform, ether, benzene and carbon disulfide

Performance

- Hydrophobicity: Beeswax has been used throughout history as waterproofing agent by rubbing beeswax onto a surface like leather or canvas then heating it. The wax seeps into the materials' fibres and blocks water from passing through.
- Washability: Beeswax wraps are a reusable, washable and sustainable alternative to single-use plastic and cling wrap, which could last up to 6 to 12 months.

1 Mink Oil

What is mink oil?

- A mixture of the natural glycerides (mainly triglycerides) of 14 to 20 carbon chain fatty acids obtained from the subdermal fatty tissues of the mink
- Currently used as a water-repellent barrier in cosmetics and leather boot care

Performance

- Hydrophobicity: Mink oil fills and penetrates the pores of leather creating a coat that can repel moisture
- Durability: As a leather shoe polish, mink oil must be reapplied every 2 weeks
- Triglycerides may enhance the penetration of other chemicals

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	6:2 FTOH	DG	H	H	H	L	H
Wax and Oil	BeesWax	L	DG	L	DG	DG	L
	Mink Oil	*L*	DG	L	DG	DG	DG

Key

Hazard:	Low (L)	Medium (M)	High (H)	Very High (V)	Data Gap (DG)
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2

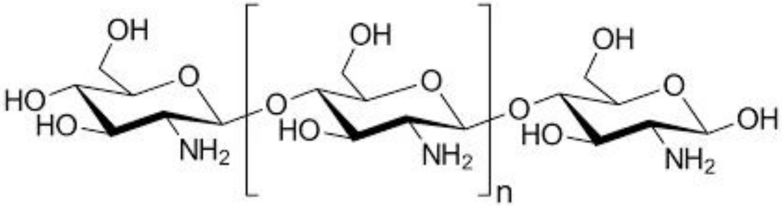
Biopolymers

- Chitosan
- Hydroxyethyl Cellulose

Chitosan

What is chitosan?

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



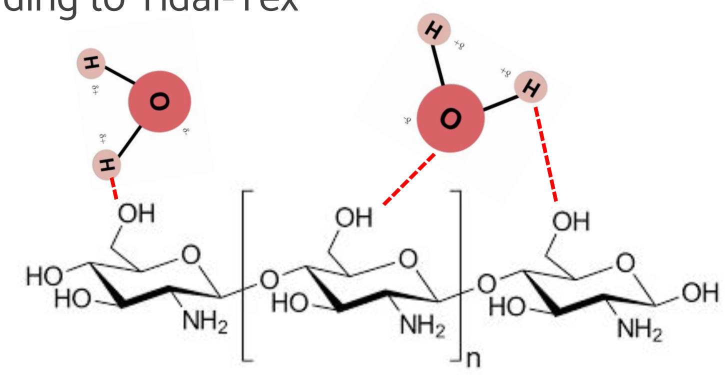
Bio-based derivation

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

2 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 washes according to Tidal-Tex™



--- indicates a hydrogen bond

Photo: (NewbieFitnessAcademy., 2020)

HAZARD TABLE

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	6:2 FTOH	DG	H	H	H	L	H
Waxes and oils	BeesWax	L	DG	L	DG	DG	L
	Mink Oil	*L*	DG	L	DG	DG	DG
Biopolymers	Chitosan	L	*L*	**H**	**H**	L	DG

Key

Hazard:	Low (L)	Medium (M)	High (H)	Very High (V)	Data Gap (DG)
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2

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
- Has acute aquatic toxicity
- Poorer long term hydrophobicity
- Potential for oleophobicity, but data gaps for the best way to do this

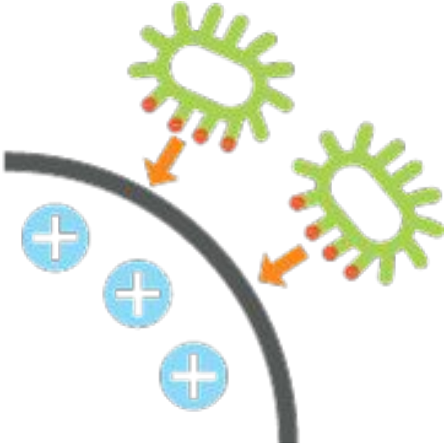


Photo: (Tidal-Tex, 2020)

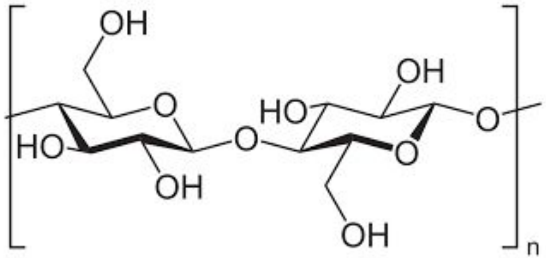
2 Cellulose

What is cellulose?

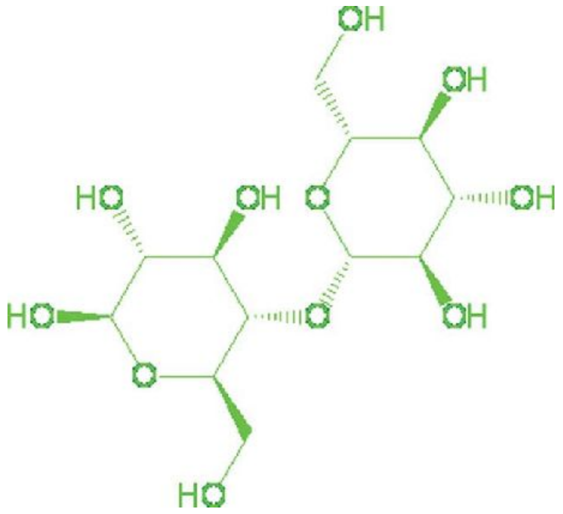
- Main constituent of plant cell walls and a polysaccharide consisting of chains of glucose monomers.

Bio-based derivation

- Cell wall serves as barrier/film
- Hydro- and possibly oleophobicity in nature



2 Cellulose



Advantages

- Extremely sustainable and non-toxic
- Biodegradable

Disadvantages

- Not hydrophobic
- Only used in small concentrations in actual products
- Data gaps

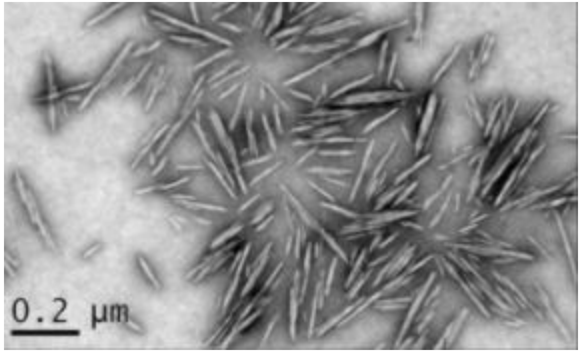
2 Cellulose Nanocrystal (CNC) & Use in Products

What is CNC

- Is obtained through acid hydrolysis of **cellulose**, where the cellulose is exposed to sulfuric acid under controlled temperature and time

Bio-based derivation

- Cell wall serves as barrier/film
- Hydro- and possibly oleophobicity in nature



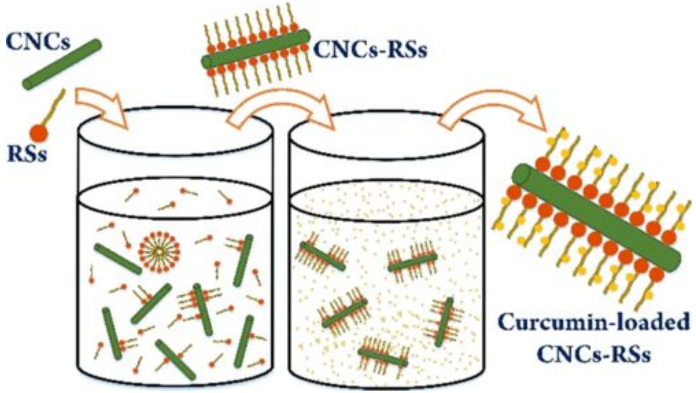
2 Cellulose Nanocrystal & Use in Products

Advantages

- Overall Low Toxicity
- Biodegradable
- Hydrophobic
- Can be easily modified to overcome their limitations

Disadvantages

- Eye/Respiratory irritation/inflammation high
- Cytotoxic
- Unknown Oleophobicity
- Possible Bioaccumulation
- Data Gaps



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	6:2 FTOH	DG	H	H	H	L	H
Waxes and oils	BeesWax	L	DG	L	DG	DG	L
	Mink Oil	*L*	DG	L	DG	DG	DG
Biopolymers	Chitosan	L	*L*	**H**	**H**	L	DG
	CNC	L	DG	H	DG	M	DG

Key

Hazard: Low (L) | Medium (M) | High (H) | Very High (V) | Data Gap (DG)

Confidence: *Low* Average **High**

3

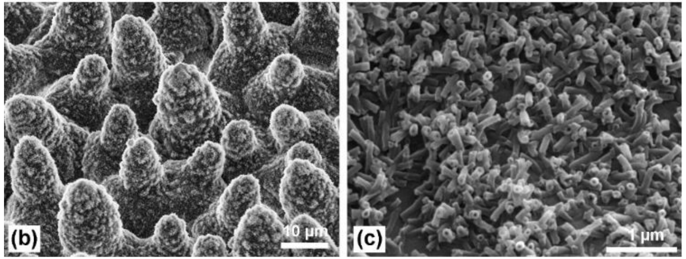
Silicon-based Materials

- Silicon Dioxide Nanoparticles
- Silicones

Silicon Dioxide Nanoparticles (SiNPs)

Inspiration

- Lotus leaf microstructure
- Hierarchical rough patterning prevents water adherence



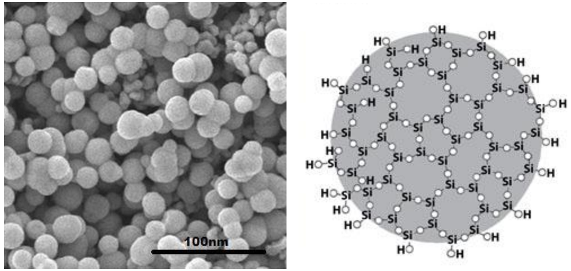
Electron microscopy images of lotus leaf surface

What is a nanoparticle?

- 1-100 nanometer diameter
- Nanoscale: 100-10,000 times smaller than the width of a hair

Structure

- One of many forms of silicon dioxide (SiO_2)
- Tunable; additives during synthesis affect properties



Electron microscopy image and schematic of SiNPs

Ensikat, H. J.; Ditsche-Kuru, P.; Neinhuis, C.; Barthlott, W. *Beilstein J. Nanotechnol.* **2011**, *2*, 152–161.

3 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

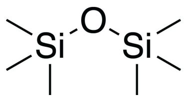
Disadvantages

- 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

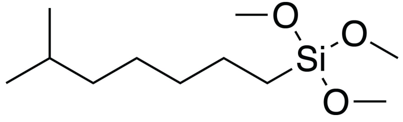
3 Silicon-Containing Small Molecules and Polymers

Synthetic silicon-containing compounds

- Common component of coatings and cosmetics
- Siloxanes: small molecules containing O-Si-O bond
- Silicones: polymers containing O-Si-O bonds



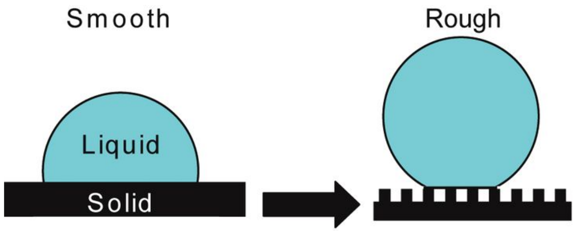
hexamethyldisiloxane



isooctyl trimethoxy silane

Function

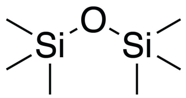
- Chemical water repellency due to hydrophobic groups
- Physical repellency via modification of other structures to impart rough surface patterning



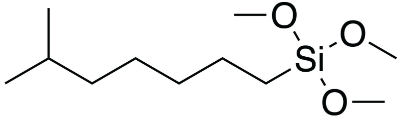
3 Silicon-Containing Small Molecules and Polymers

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



hexamethyldisiloxane



isooctyl trimethoxy silane

Disadvantages

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

HAZARD TABLE

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	6:2 FTOH	DG	H	H	H	L	H
Waxes and oils	BeesWax	L	DG	L	DG	DG	L
	Mink Oil	*L*	DG	L	DG	DG	DG
Biopolymers	Chitosan	L	*L*	**H**	**H**	L	DG
	CNC	L	DG	H	DG	M	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**		

RECOMMENDATION

05

HAZARD CRITERIA

	GHS Category	Carcinogenicity / Mutagenicity	Developmental / Reproductive Toxicity	Skin / Eye Irritation	Aquatic Toxicity	Persistence / Bioaccumulation	Endocrine Activity
Safest/low hazard	GHS 3/4	none	none	no/ reversible effects	$LC_{50} > 100$ mg/mL	BCF > 500, rapid degradation	none
Medium Hazard	GHS 2/2B	suspected	suspected	reversible adverse effects	$LC_{50} < 100$ mg/mL	BCF > 500, greater than 70% degradation in 28d	suspected (cell or in vitro studies)
High Hazard	GHS 1B/1C/2A	strong evidence (multiple animal studies)	strong evidence (multiple animal studies)	prolonged adverse effects	$LC_{50} < 10$ mg/mL	BCF < 500, less than 70% degradation in 28d	strong evidence (multiple animal studies)
Very High Hazard	GHS 1/1A	carcinogenic/ mutagenic in humans	toxicity demonstrated in humans	rapid, irreversible damage	$LC_{50} < 1$ mg/mL	BCF > 500, less than 70% degradation in 28d	endocrine activity known in humans
Data Gap		no evidence for either adverse or benign exposure outcome					

HAZARD CRITERIA: Confidence

High Confidence
Multiple authoritative lists and multiple corroborating studies
Medium Confidence
Authoritative list or multiple corroborating studies
Low Confidence
Few or inconclusive studies

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	6:2 FTOH	DG	H	H	H	L	H
Waxes and oils	BeesWax	L	DG	L	DG	DG	L
	Mink Oil	*L*	DG	L	DG	DG	DG
Biopolymers	Chitosan	L	*L*	**H**	**H**	L	DG
	CNC	L	DG	H	DG	M	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**

PERFORMANCE CRITERIA

	Hydrophobicity (Contact Angle)	Oleophobicity (Contact Angle)	Washability	Sustainability and Sourcing
Best performance	>150˚	>150˚	>20 wash cycles	inorganic or plant-derived
Medium performance	90˚-150˚	90˚-150˚	5-20 wash cycles	animal-derived
Low performance	<90˚	<90˚	<5 wash cycles	petroleum-derived or PFAS
Data gap	unspecified	unspecified	unspecified	unspecified

Key

Performance: High (H) | Medium (M) | Low (L) | Data Gap (DG)

Confidence: *Low* Average **High**

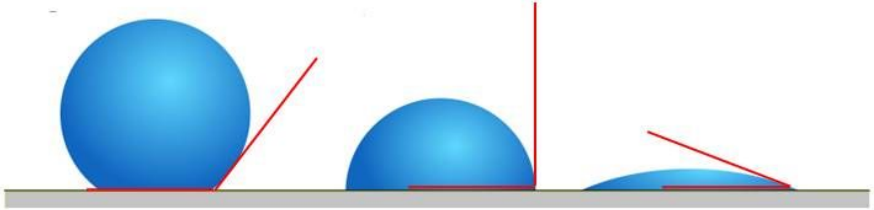


Illustration of contact angle

PERFORMANCE TABLE

		Hydrophobicity (Contact Angle)	Oleophobicity	Washability	Source
Bad Actors (PFAS)	PFAS	170˚	156˚	120+ washes	Artificial
Waxes and oils	BeesWax	153˚	DG	6-12 months	Bees
	Mink Oil	Oil-based	DG	2 weeks	Mink
Biopolymers	Chitosan	102˚	DG	50 washes	Crustacean exoskeletons
	CNC	~>90˚	L	DG	Cellulose isolation + Prep
Silicon-based materials	SiNPs	151˚	140-160˚ on silk	10-30 washes	Silicon

Key

Performance: High (H) | Medium (M) | Low (L) | Data Gap (DG)

Confidence: *Low* Average **High**

Next Steps

Waxes and Oils

- Natural products with low hazard and strong hydrophobicity
- More information about toxicities and additives to increase oleophobicity

Next Steps

Biopolymers

- Chitosan has potential to impart oleophobicity, but more information needed to accomplish this

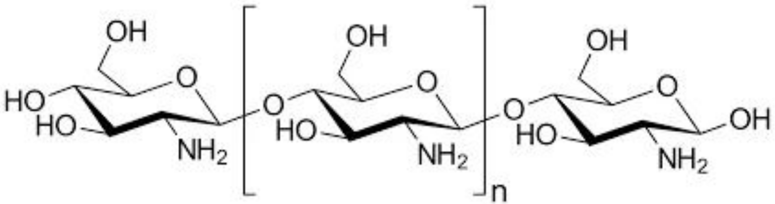
Next Steps

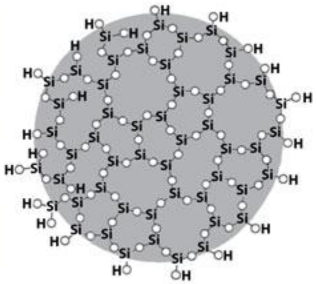
Silicon-based Materials

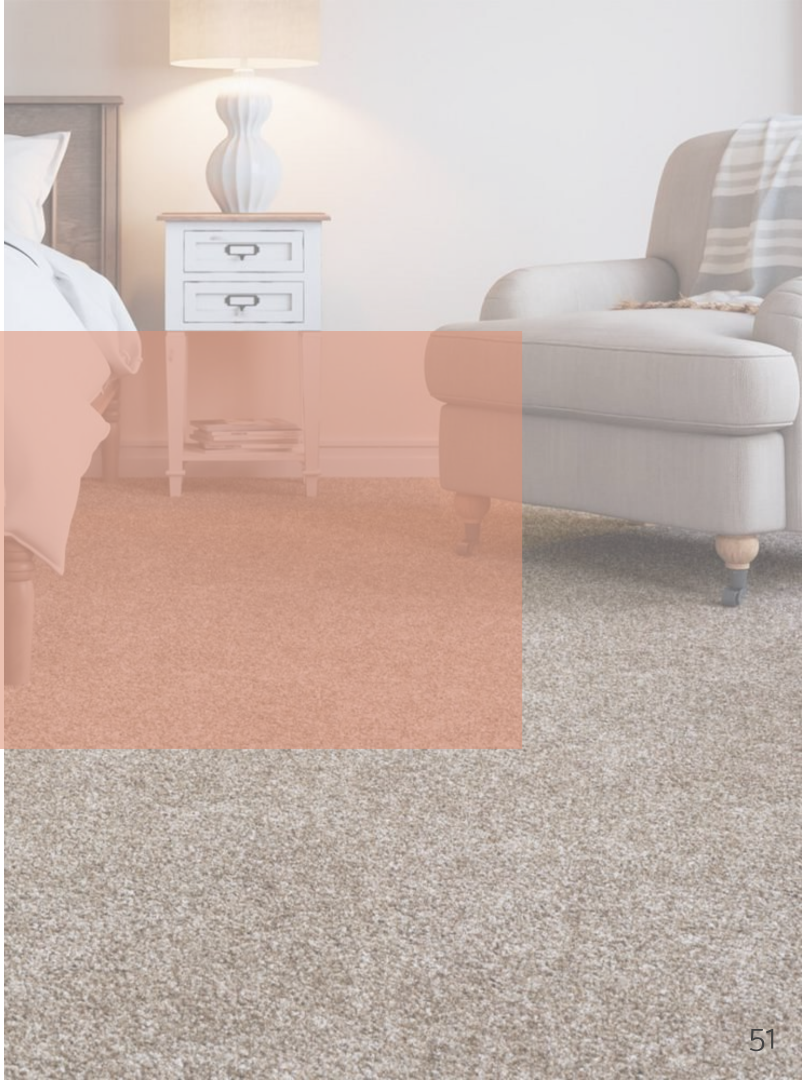
- Cost-effective, high-performing strategy with few known health risks
- Additives are required for oleophobic performance
- More nanoparticle-specific hazard information is needed

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

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- Infographics by Freepik

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