BIOMIMICRY INSPIRED SOLUTIONS FOR LEVI STRAUSS & CO.

Greener Solutions
Fall 2013
University of California, Berkeley

Antony Kim, Kathryn Strobel, Katherine Tsen,
Lila Rubenstein, Michel Dedeo, Sara Tischhauser

PRESENTATION OVERVIEW

1. Background
2. Approach
3. Solutions
4. Health
5. Conclusions

LEVI'S CHALLENGE

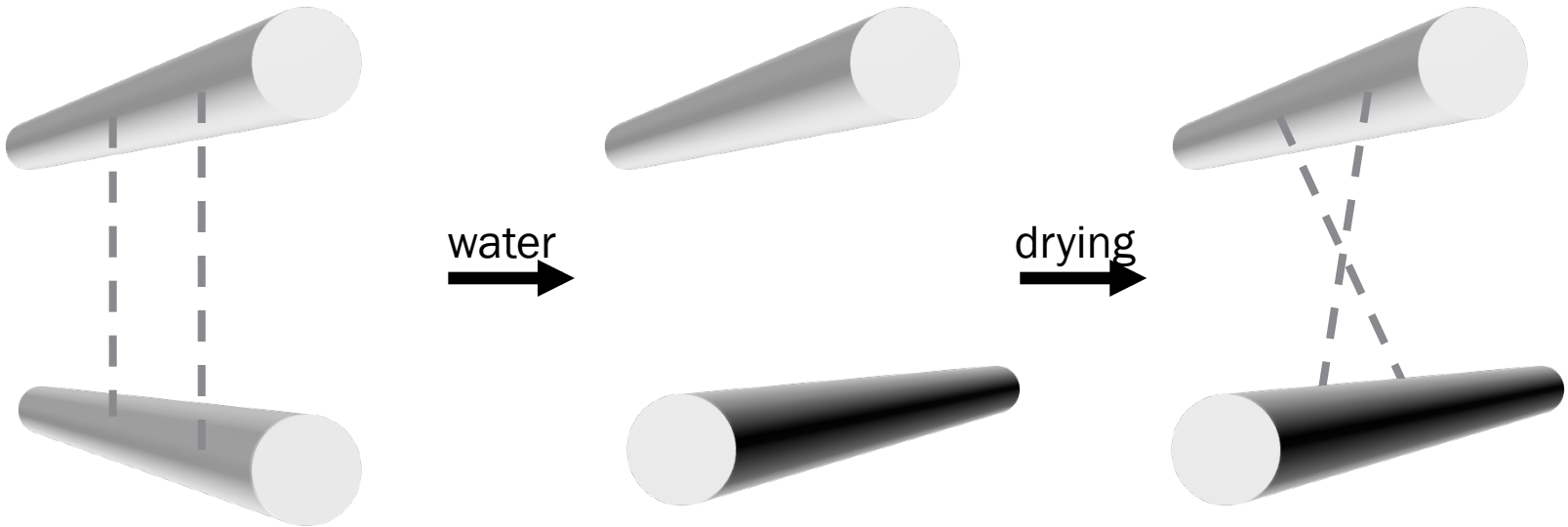
Create a water repellent finish for denim or a permanent press finish for cotton pants without toxic chemical crosslinkers

(Formaldehyde, di-isocyanates, fluorocarbons)

Water repellant Commuter Jeans

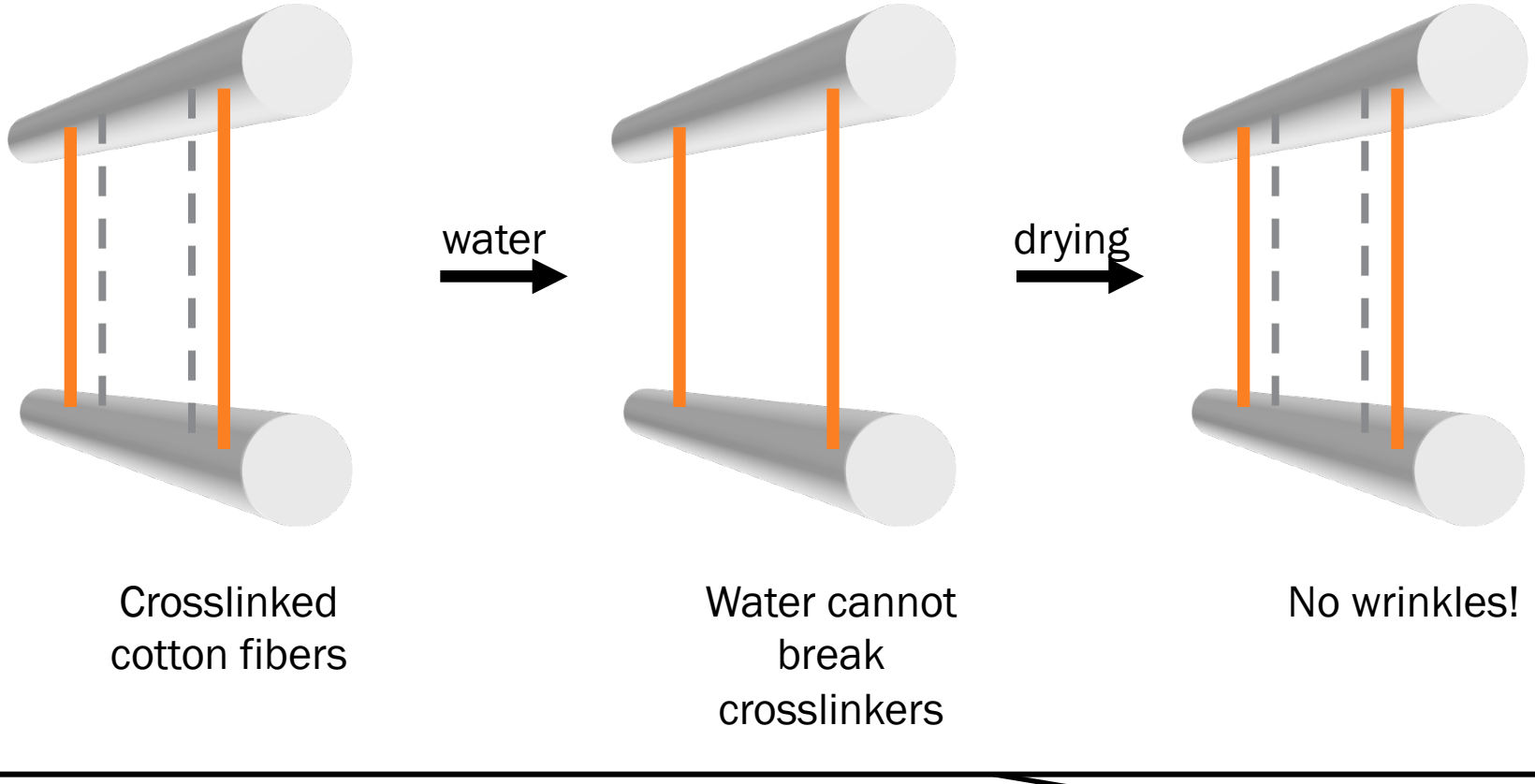
Wrinkle-free Dockers

WHAT IS CROSSLINKING?



Source: Wolf, 2013

WHAT IS CROSSLINKING?



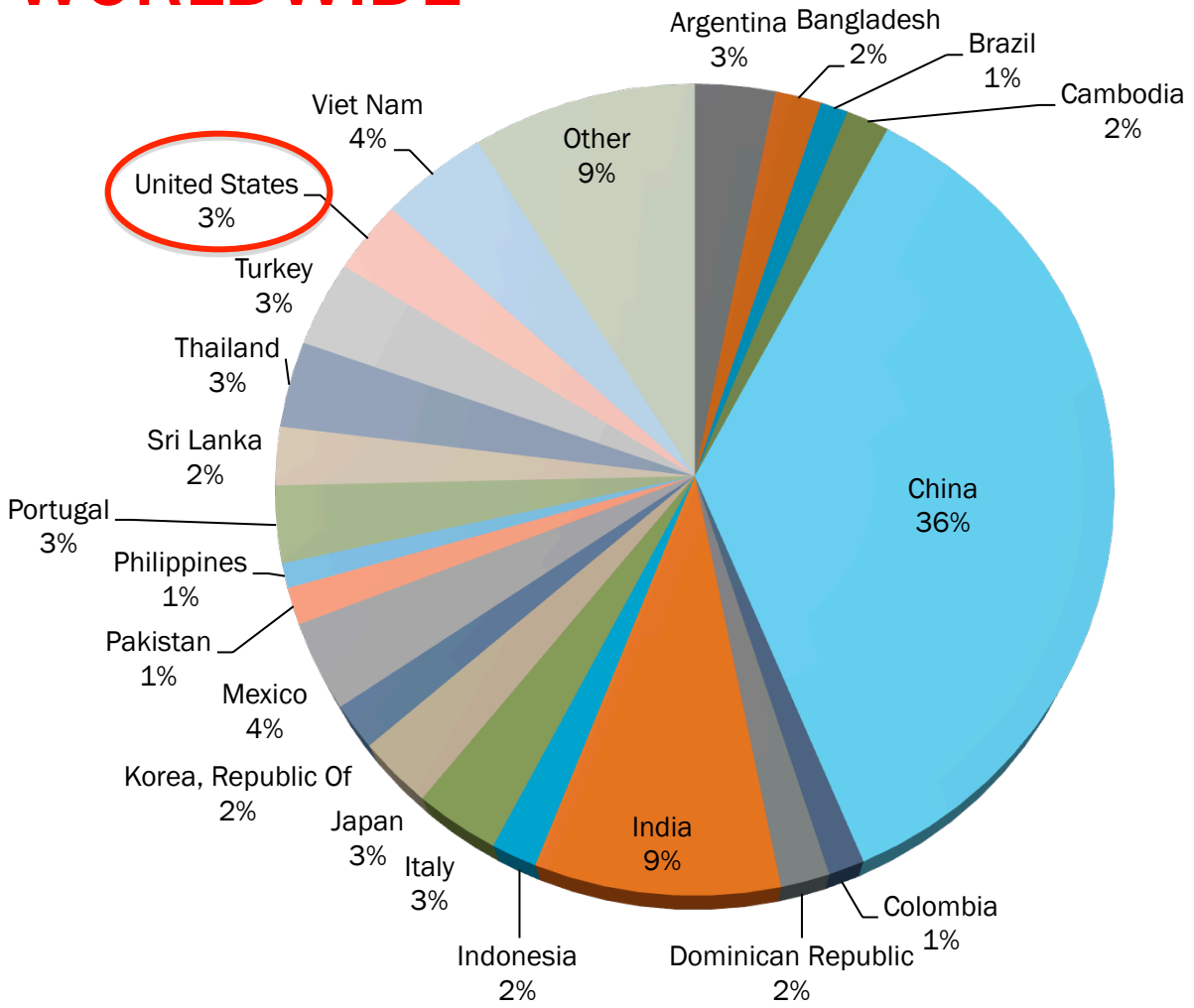
Source: Wolf, 2013

HEALTH HAZARDS: CURRENTLY USED CHEMISTRY

Chemical	Use	Exposure	Summary of Health Effects
Formaldehyde-based resins	Used to impart wrinkle resistance	Readily absorbed via respiratory tract	• Causes cancer in humans (nasopharyngeal and leukemia). • Strong weight of evidence from numerous human and animal studies • Nasopharyngeal irritation, causes contact skin irritation, asthma.

Source: Schwarzman, 2013

LEVI'S GARMENT FACTORIES WORLDWIDE



Source: Levi Strauss & Co. Factory List, 2011


Sri Lanka


Xintang, China


Los Angeles, CA


Dhaka, Bangladesh

HAZARD VS. RISK MANAGEMENT

Hazard-based Approach

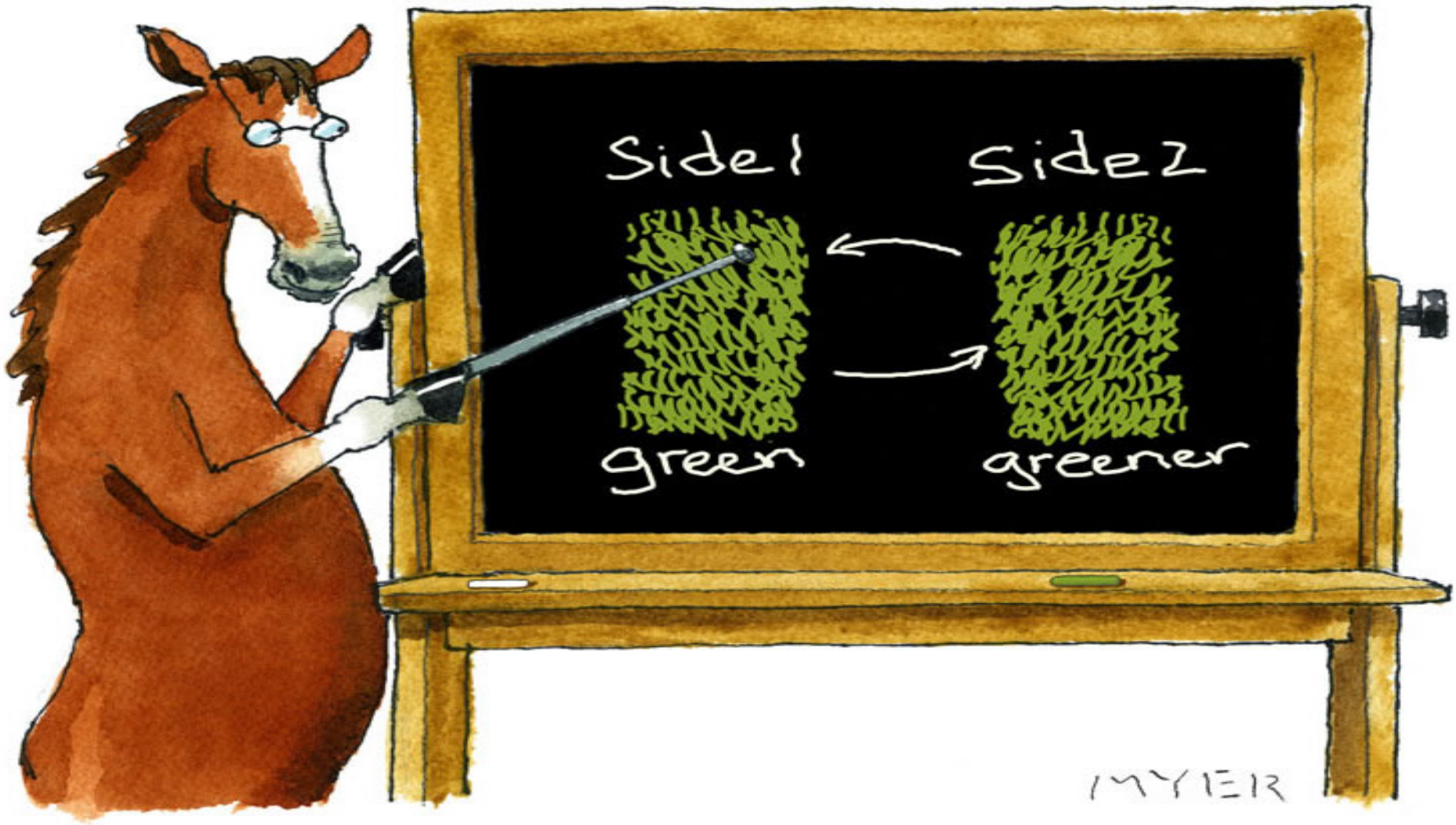
Reduce inherent hazard of chemicals used in the manufacturing process

Risk-based Approach

Control and limit exposure to hazardous based substances (personal protective equipment, ventilation, mechanization)

STAKEHOLDERS

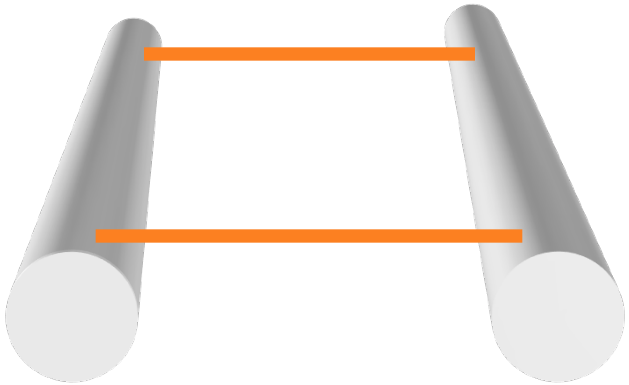
DEFINING GREENER SOLUTIONS



IN THE CONTEXT OF LEVI'S CHALLENGE, OUR GREENER SOLUTION MUST:

Priority 1	be **less hazardous** than the existing solution
Priority 2	have **performance and durability** metrics *comparable* to existing treatments
Priority 3	minimize changes to the application process, cost, and consumer experience

CURRENTLY AVAILABLE "GREENER" SOLUTIONS



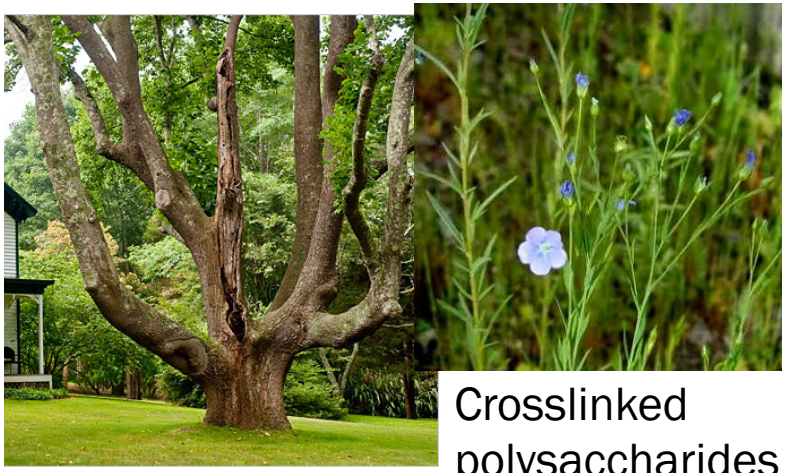
	Performance	Durability	Cost	Formaldehyde (PPM)
DMDHEU	+++	+++	$	50
DMeDHEU	++	++	$$$$	0
BTCA	++	++	$$$$	0
Citric Acid	+	++	$	0

Schindler 2004

BIOMIMICRY

TRANSLATING BIOLOGICAL INSPIRATION INTO CHEMICAL SOLUTIONS

Biomimicry 3.8



Crosslinked polysaccharides

Crosslinked protein

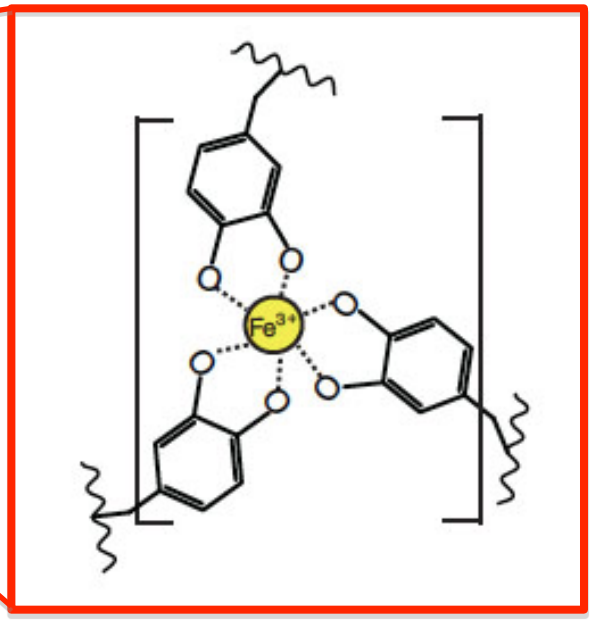
biomimicry.net

TRANSLATING BIOLOGICAL INSPIRATION INTO CHEMICAL SOLUTIONS

Biomimicry 3.8

Crosslinked polysaccharides

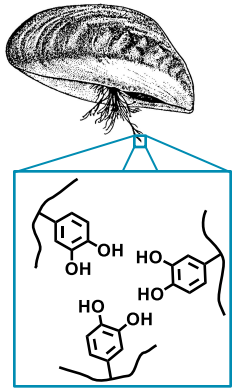
Crosslinked protein



biomimicry.net

APPROACH

Biomimicry



Technical Evaluation

		Green Requirements ✔	Red Requirements X	PMO solution
Crosslinking ability	With Cellulose	Multitude of strong interactions	Zero or unknown interactions	-
	With itself (Durable press)			-
	With DWR compounds			✔
Durability and consumer expectations	Wash stability	Lasts multiple washes; irreversible bonds	Laundry detergent may undo crosslinking	✔
	Fabric strength	No known weakening treatments	Weakens fabric significantly	✔
	Food, sun, etc. stability	No changes	Unstable (fades in sun, etc.)	✔
	Color	No color change	Large color change	✔
Application, curing, and cost	Controllable cured	Very controllable	No control (reacts immediately)	-
	Time of curing	Under 1 hr	Over 12 hrs	X
	Chemical stability and water solubility	No special storage, highly water soluble	Requires special storage and not water soluble	-
	Availability of raw materials	Available industrially	Unavailable at industrial scale	X
	Cost of raw materials	Likely less or equal to current treatments	Likely more than triple current treatments	-

Market Innovation

Informed decision

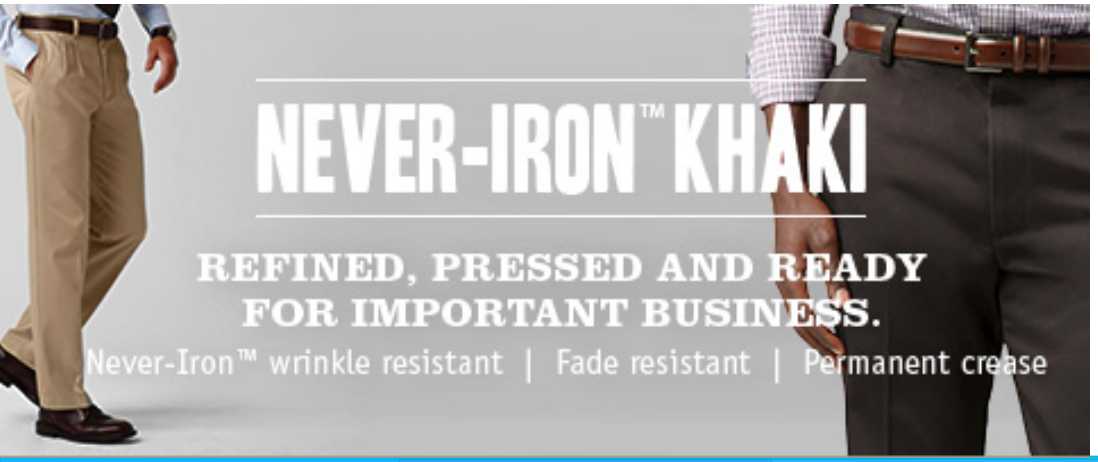
Priority 1	be **less hazardous** than the existing solution
Priority 2	have **performance and durability** *comparable* to existing treatments
Priority 3	minimize changes to the application process, cost, and consumer experience

Health & Env. Evaluation

Chemical Compound	Exposure			Health Endpoints						Environmental Toxicity & Fate		Physical Hazards
				Human Health Group I		Human Health Group II						
Chemical Name (CAS Number)	Process Notes	Potency LD_{50}	Timescale of Effect (Acute or chronic)	Carcinogenicity Mutagenicity	Reproductive Developmental Toxicity Endocrine Activity	Acute Toxicity Sensitiz Irritation	Systemic Toxicity & Organ Effects	Neuro Toxicity	Skin/Eye Irritation	Persistence Bio-accumulation	Aquatic Toxicity (Acute/ chronic)	Reactivity/ Flammability
Dopamine		2859 mg/kg oral-rat	Acute	✔	O	O				✔		✔
Octadecylthiol			Acute	✔		O						
Methyl hydroquinone		200 mg/kg oral-rat				X					X	
4-aminophenol				O		O					X	
Ethanolamine				✔	✔	O				✔	X	
Ethylene diamine			Acute			X			X		X	
Potassium permanganate		750 mg/kg oral-mouse	Acute	O		O			O		X	

EVALUATE TECHNICAL FEASIBILITY

1. Create framework
   - Crosslinking ability
   - Durability
   - Application, cost, and consumer expectations
2. Assess each solution
3. Make informed decisions

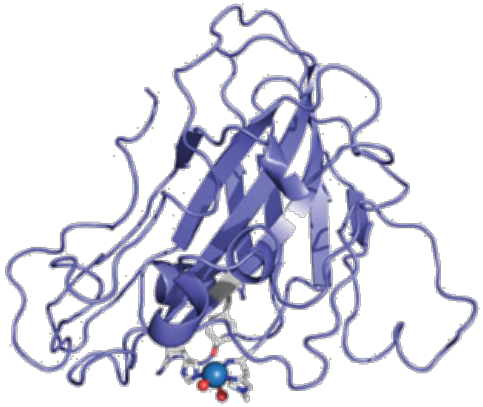


us.levi.com

APPROACH TO EVALUATE HEALTH AND ENVIRONMENTAL IMPACTS

1. Create framework
2. Assess and classify hazards
3. Make informed decisions

PROPOSED SOLUTIONS



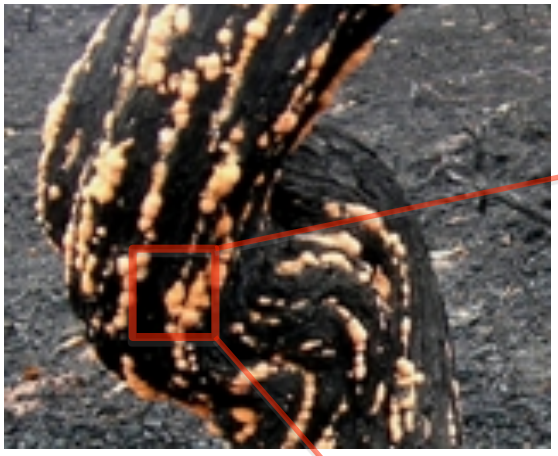
PMO Enzyme

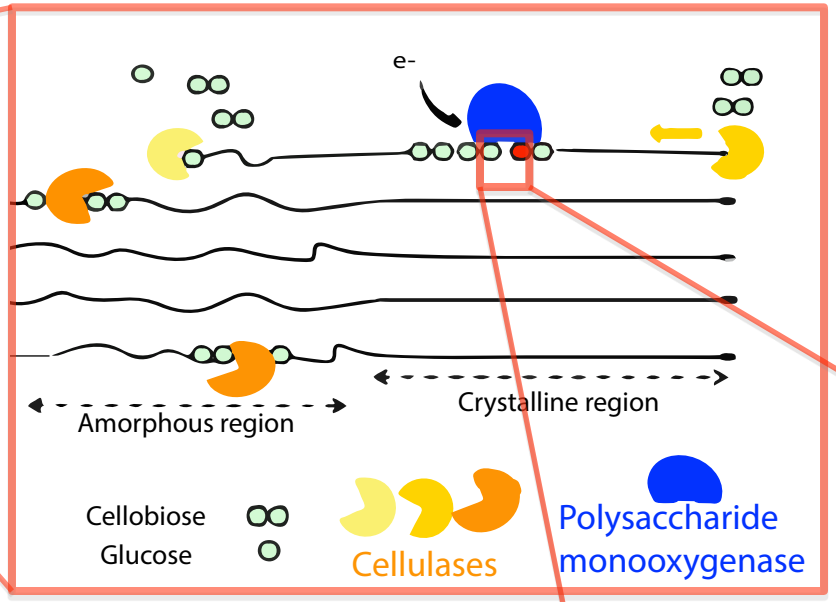
Laccasse Enzyme

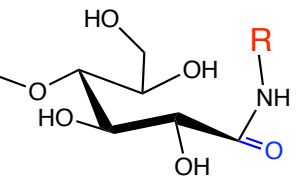
Dopamine

Potassium Permanganate

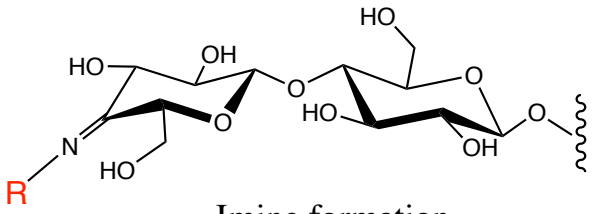
FUNGAL ENZYMES CAN MAKE CELLULOSE MORE REACTIVE



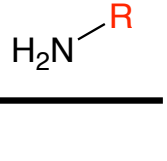


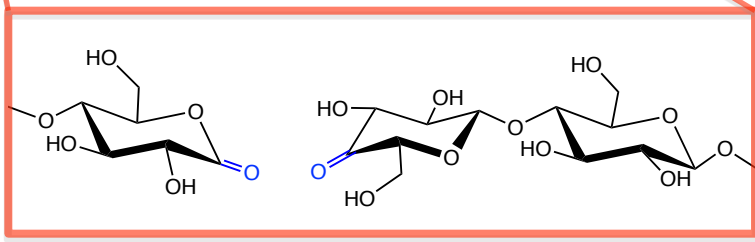


Aminolysis



Imine formation

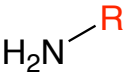




IS THIS SOLUTION TECHNICALLY FEASIBLE?

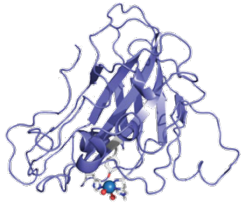
		Green Requirements ✔	Red Requirements X	PMO enzyme
Crosslinking ability	With Cellulose	Multitude of strong interactions	Zero or unknown interactions	✔
	With itself (Durable press)			–
	With DWR compounds			✔

Uncertain level of modification

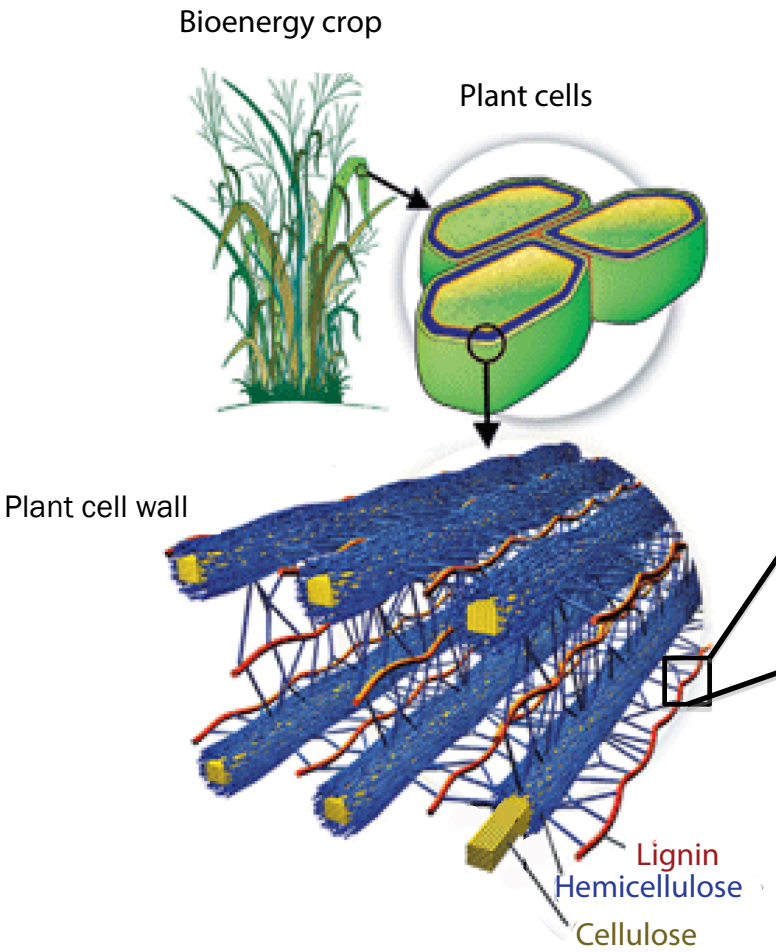


PMO ENZYME SOLUTION IS NOT TECHNICALLY FEASIBLE

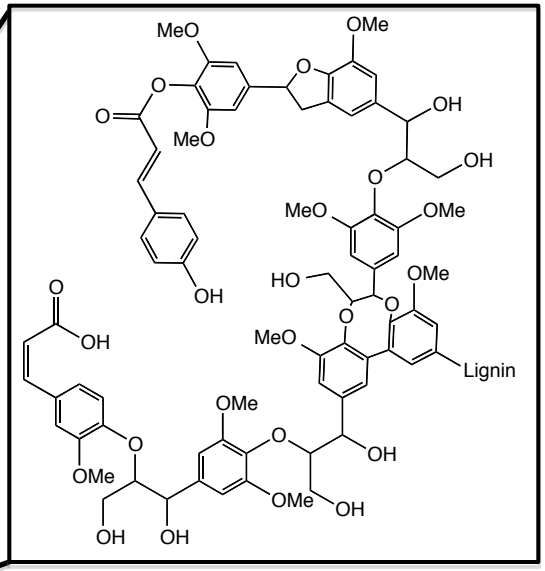
Water repellent

Solution	Benefits	Challenges
 PMO Enzyme	✓Covalent bond to fabric ✓Variety of chemicals possible	✕Uncertain level of fabric modification ✕Slow ✕Enzyme is not available commercially

LIGNIN HAS MANY PROPERTIES DESIRED IN FABRIC FINISHES



Example Lignin Structure

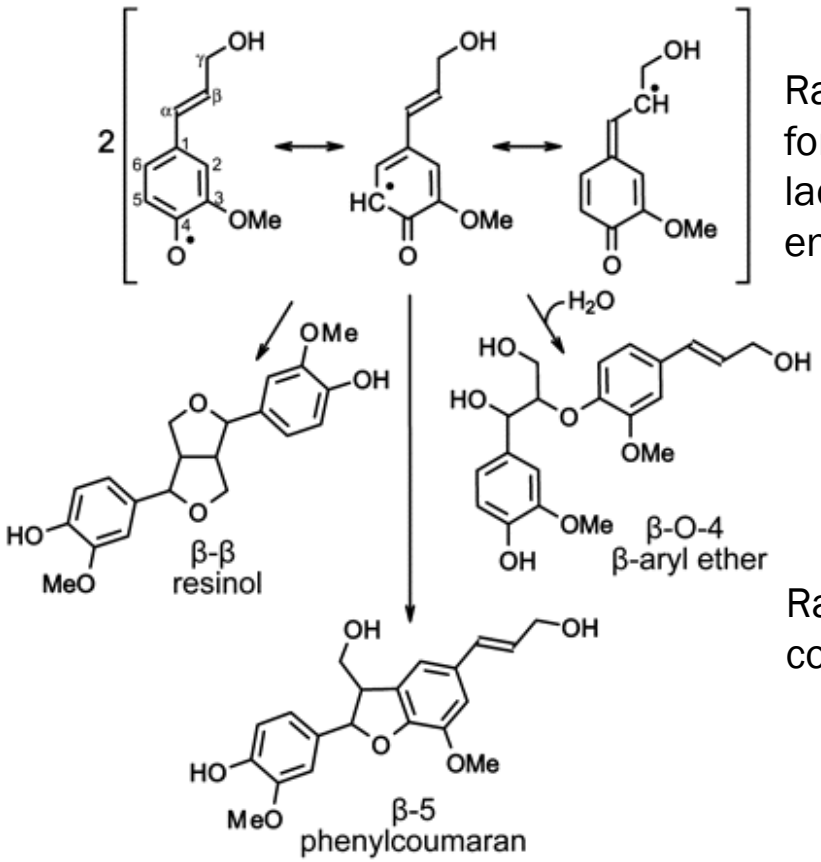


Lignin Attributes

- Fills spaces between cellulose, hemicellulose, and pectin
- Covalently linked to hemicellulose
- Confers mechanical strength, water repellency, and pathogen resistance

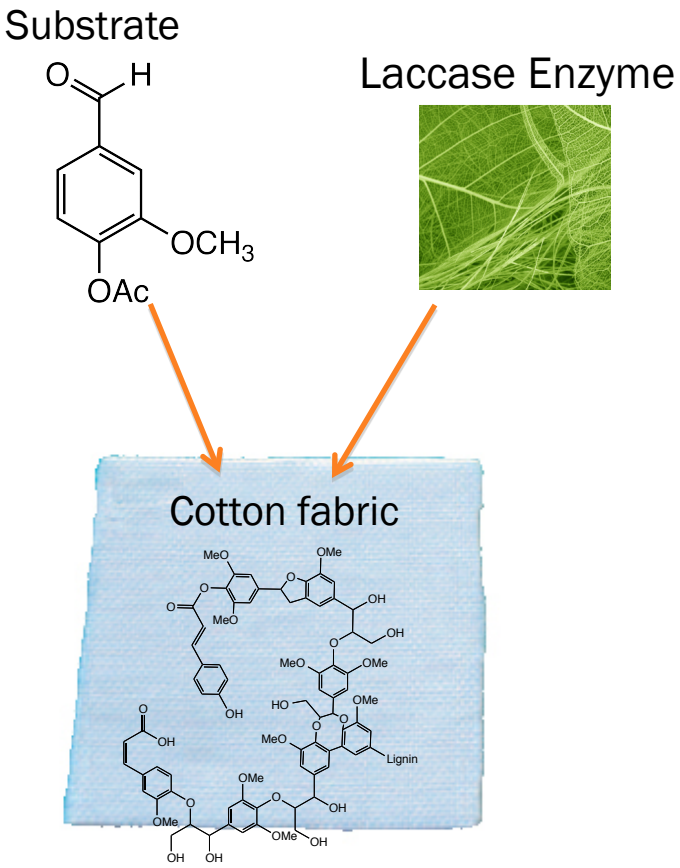
LIGNIN BIOSYNTHESIS CAN BE USED FOR FABRIC FINISHING

Lignin Formation



Radical formed by laccase enzyme

Radical coupling



SOLUTION HAS CHALLENGES BUT THEY CAN LIKELEY BE OVERCOME

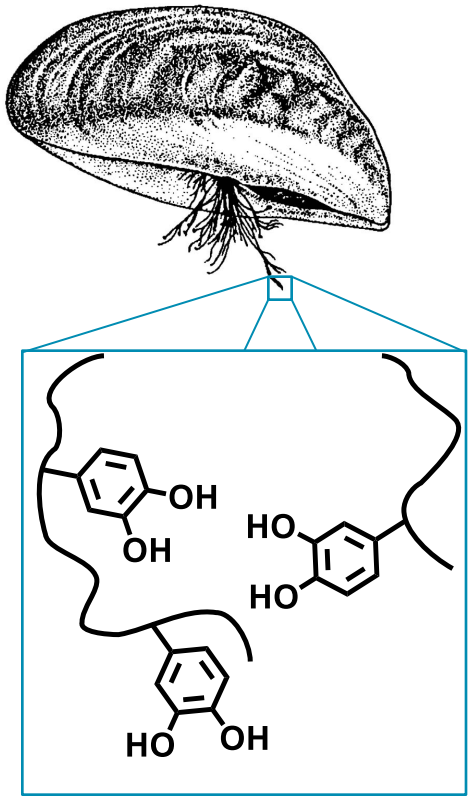
Water repellent

Wrinkle resistant

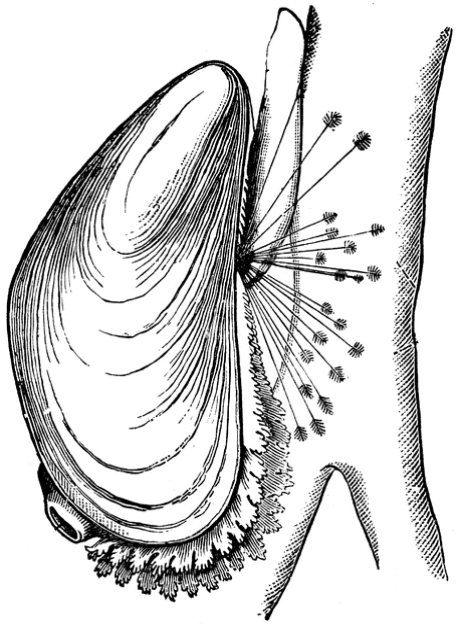
Solution	Benefits	Challenges
 Laccase Enzyme	✓Enzyme initiated coupling ✓Wide range of substrates can be oxidized and coupled ✓Radical transfer can occur	✕Laccases have been used to bleach dyes in the textile industry! ✕Possible color formation

SEA MUSSELS MAKE AMAZING GLUE

glue sticks to rock



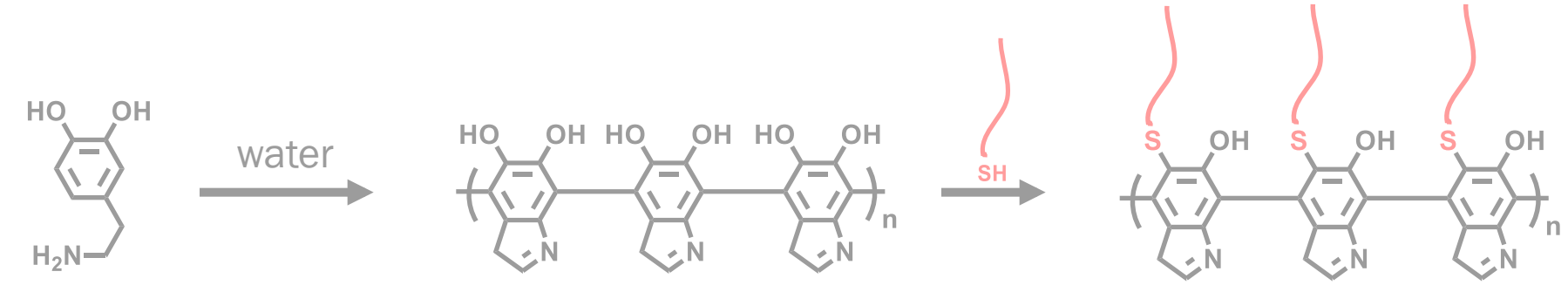
glue sticks to wood



Catechols in byssal threads allow mussels to anchor to almost any surface, even when wet.

Lee 2006

ARTIFICIAL SEA MUSSEL GLUE



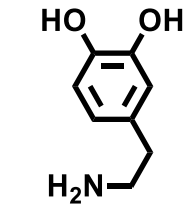
dopamine

polydopamine

polydopamine + water repellent

uncoated

polyester fabric



18 hours

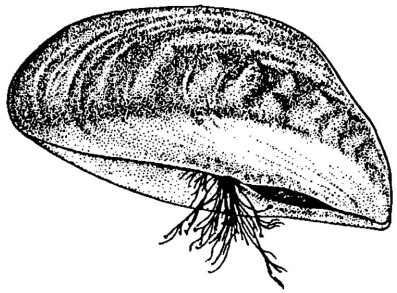
coated in polydopamine

30 washes

Lee 2007, Xu 2013

SEA MUSSEL SUMMARY

Water repellent



Solution	Benefits	Challenges
 Dopamine	✓Likely more durable than current water repellent finish ✓Starting materials largely benign and readily biodegradable	✕Likely slower than current chemicals ✕May discolor fabric ✕Likely more expensive than current finish

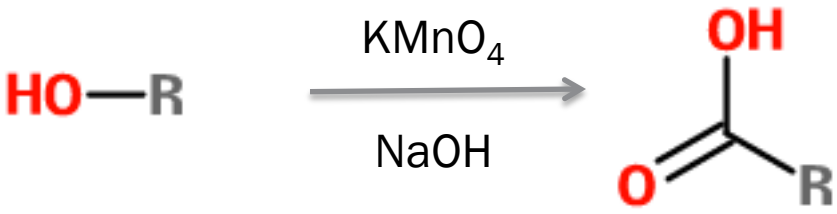
SLUG INSPIRED SOLUTION

- Quick-setting, temporary defensive mucous as protection
- 95% water alongside crosslinked proteins and polysaccharides
- Proteins crosslinked via carboxylic acid groups around divalent metal ion (most likely Fe^{2+})
- Translation to cellulose – functionalization of primary alcohol on cellulose to carboxylic acid

SLUG INSPIRED SOLUTION

Required Chemicals:

- Potassium Permanganate
- Sodium Hydroxide



Recommended Chemicals for Mixing:

- Acetone
- Pyridine
- Dioxane
- tert butyl alcohol

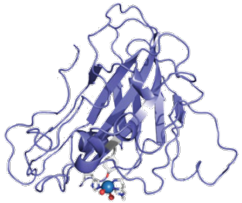
SLUG INSPIRED SOLUTION

Permanent press

Figure 1: The Slug (*Arion subfuscus*)

Solution	Benefits	Challenges
 Potassium Permanganate	✓- Potassium Permanganate and sodium hydroxide already used in Levi's production line	✕Color problems (Fe^{2+} and $KMnO_4$) ✕Durability

COMPARING TECHNICAL FEASIBILITY



PMO Enzyme

✕Unavailability of enzyme is a major problem

Laccasse Enzyme

✓Promising, color could be a challenge

Dopamine

✓Promising, color and cost could be a challenge

Potassium Permanganate

✓Promising, durability and color could be a challenge

EVALUATE HEALTH & ENVIRONMENTAL IMPACTS

1. Create framework
2. Assess & Classify Hazards
3. Make informed decisions

EVALUATE HEALTH AND ENVIRONMENTAL IMPACTS

CREATE A FRAMEWORK

Chemical Compound	Exposure			Health Endpoints						Environmental Toxicity & Fate		Physical Hazards
				Human Health Group I		Human Health Group II						
Chemical Name (CAS Number)	Process Notes	Potency LD_{50}	Timescale of Effect (Acute or chronic)	Carcinogenicity Mutagenicity	Reproductive Developmental Toxicity Endocrine Activity	Acute Toxicity Sensitiz. Irritation	Systemic Toxicity & Organ Effects	Neuro Toxicity	Skin/Eye Irritation	Persistence Bio-accumulation	Aquatic Toxicity (Acute/ chronic)	Reactivity/ Flammability

- Chronic, life-threatening effects
- Potentially induced at low doses
- Transferred between generations

- Also important for understanding and cl chemicals
- These hazards may b

- Info on where chemicals 'end up' in organisms and the environment

- Adapted framework from GreenScreen for Safer Chemicals

- Identified 18 human health, environmental toxicity, fate and physical hazard endpoints

EVALUATE HEALTH AND ENVIRONMENTAL IMPACTS

CREATE A FRAMEWORK

Chemical Compound	Exposure			Health Endpoints						Environmental Toxicity & Fate		Physical Hazards
				Human Health Group I		Human Health Group II						
Chemical Name (CAS Number)	Process Notes	Potency LD_{50}	Timescale of Effect (Acute or chronic)	Carcinogenicity Mutagenicity	Reproductive Developmental Toxicity Endocrine Activity	Acute Toxicity Sensitiz. Irritation	Systemic Toxicity & Organ Effects	Neuro Toxicity	Skin/Eye Irritation	Persistence Bio-accumulation	Aquatic Toxicity (Acute/ chronic)	Reactivity/ Flammability

Info relating to exposure

Lethal dose 50: Indicator of a substance's acute toxicity

Acute: sudden & severe exposure, often reversible (CO poisoning)

Chronic: prolonged or repeated exposure over many days, months or years. Symptoms may not be readily apparent, often irreversible

EVALUATE HEALTH AND ENVIRONMENTAL IMPACTS

ASSESS & CLASSIFY HAZARDS

Chemical Compound	Exposure			Health Endpoints						Environmental Toxicity & Fate		Physical Hazards
				Human Health Group I		Human Health Group II						
Chemical Name (CAS Number)	Process Notes	Potency LD_{50}	Timescale of Effect (Acute or chronic)	Carcinogenicity Mutagenicity	Reproductive Developmental Toxicity Endocrine Activity	Acute Toxicity Sensitiz. Irritation	Systemic Toxicity & Organ Effects	Neuro Toxicity	Skin/Eye Irritation	Persistence Bio-accumulation	Aquatic Toxicity (Acute/ chronic)	Reactivity/ Flammability
Formaldehyde (50-00-0)	Readily absorbed via inhalation	800 mg/ kg (rat)	Both acute and chronic effects	Group 1 carcinogen; nasopharyngeal cancer & leukemia (IARC monograph 2012)	Suspected reproductive, developmental effects, data is inconclusive (Duong, 2011)	Nasopharyngeal irritation, asthma sensitization (IARC monograph, 2012)			Contact skin irritation (IARC monograph, 2012)	Breaks down quickly, half life of ~30-50 minutes		Flammable gas at room temperature

EVALUATE HEALTH AND ENVIRONMENTAL IMPACTS

ASSESS & CLASSIFY HAZARDS

Chemical Compound	Exposure			Health Endpoints						Environmental Toxicity & Fate		Physical Hazards
				Human Health Group I		Human Health Group II						
Chemical Name (CAS Number)	Process Notes	Potency LD_{50}	Timescale of Effect (Acute or chronic)	Carcinogenicity Mutagenicity	Reproductive Developmental Toxicity Endocrine Activity	Acute Toxicity Sensitiz. Irritation	Systemic Toxicity & Organ Effects	Neuro Toxicity	Skin/Eye Irritation	Persistence Bio-accumulation	Aquatic Toxicity (Acute/ chronic)	Reactivity/ Flammability
Formaldehyde (50-00-0)	Volatile may be easily Inhaled		Acute & chronic	✕	o	o			✕	✔		✕

Formaldehyde (50-00-0)

Readily absorbed via inhalation

800 mg/ kg (rat)

Both acute and chronic effects

Group 1 carcinogen; nasopharyngeal cancer & leukemia (IARC monograph 2012)

Suspected reproductive, developmental effects, data is inconclusive (Duong, 2011)

Nasopharyngeal irritation, asthma sensitization (IARC monograph, 2012)

Contact skin irritation (IARC monograph, 2012)

Breaks down quickly, half life of ~30-50 minutes

Flammable gas at room temperature

EVALUATE HEALTH & ENVIRONMENTAL IMPACTS

ASSESS & CLASSIFY HAZARDS

(Partial Key)

		Evaluation Metrics		
		High	Moderate	Low
		✕	O	✔
Human Health Group I	**Carcinogenicity Mutagenicity Reproductive Developmental Toxicity**	Known or presumed for any route of exposure; authoritative lists, strong weight of evidence (human)	Suspected for any route of exposure; limited or marginal evidence (animal)	Adequate data, negative studies, or clear evidence of no effect
	Endocrine	Evidence of endocrine activity and related human health effect	Evidence of endocrine activity	Adequate data available; negative studies

Not applicable

Data Gap

EVALUATE HEALTH AND ENVIRONMENTAL IMPACTS

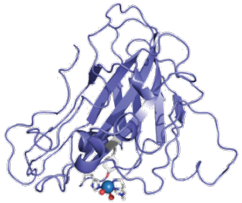
MAKE INFORMED DECISIONS

Chemical Compound	Exposure			Health Endpoints						Environmental Toxicity & Fate		Physical Hazards
				Human Health Group I		Human Health Group II						
Chemical Name (CAS Number)	Process Notes	Potency LD_{50}	Timescale of Effect (Acute or chronic)	Carcinogenicity Mutagenicity	Reproductive Developmental Toxicity Endocrine Activity	Acute Toxicity Sensitiz Irritation	Systemic Toxicity & Organ Effects	Neuro Toxicity	Skin/Eye Irritation	Persistence Bio-accumulation	Aquatic Toxicity (Acute/ chronic)	Reactivity/ Flammability
Dopamine		2859 mg/kg oral-rat	Acute	✔	O	O				✔		✔
Octadecylthiol			Acute	✔		O						
Methyl hydroquinone		200 mg/kg oral-rat				×					×	
4-aminophenol				O		O					×	
Ethanolamine				✔	✔	O				✔	×	
Ethylene diamine			Acute			×			×		×	
Potassium permanganate		750 mg/kg oral-mouse	Acute	O		O			O		×	

In considering our solutions:

- If a chemical scored red across any category, we moved to a better alternative
- A score of yellow in Human Health Group I & II was researched more thoroughly
- Looking for solutions with the lowest impact (green is good)

HEALTH & ENV. IMPACTS OF PROPOSED SOLUTIONS



PMO Enzyme

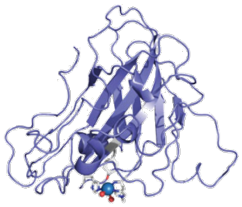
Laccasse Enzyme

Dopamine

Potassium Permanganate

Chemical Compound	[ ]
Function	Crosslinker, increases reactivity, etc.
Exposure	Acute vs. chronic
Health Endpoints	✗ ● ✓
Environmental Toxicity & Fate	✗ ● ✓

HEALTH & ENV. IMPACTS OF PROPOSED SOLUTIONS



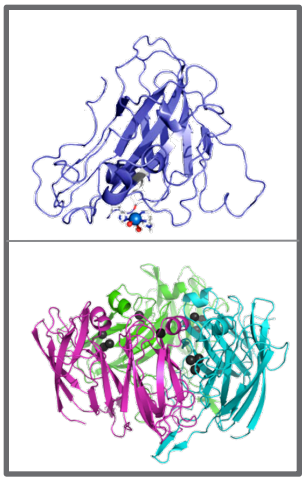
PMO Enzyme

Laccasse Enzyme

Dopamine

Potassium Permanganate

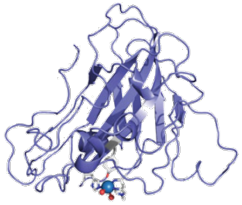
enzyme + substrate



Both enzymes work at milder conditions

Chemicals with different functions need to be evaluated differently

HEALTH & ENV. IMPACTS OF PROPOSED SOLUTIONS



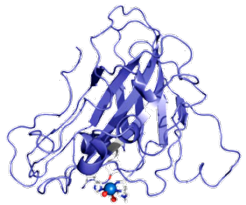
PMO Enzyme

Laccasse Enzyme

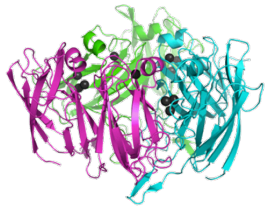
Dopamine

Potassium Permanganate

enzyme + substrate

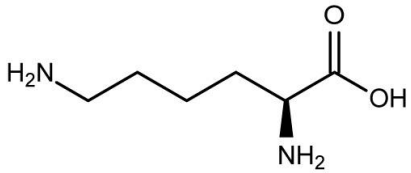


+



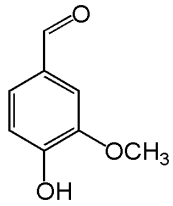
+

Amines
o-phenylenediamine
ethylene diamine
lysine



+

Aromatic compounds
methyl hydroquinone
4-aminophenol
vanillin

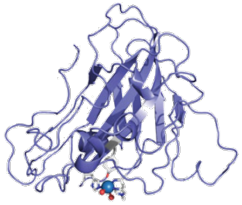


Both enzymes work at milder conditions

Crosslinking substrate needs to be selected carefully

Chemicals with different functions need to be evaluated differently

HEALTH & ENV. IMPACTS OF PROPOSED SOLUTIONS



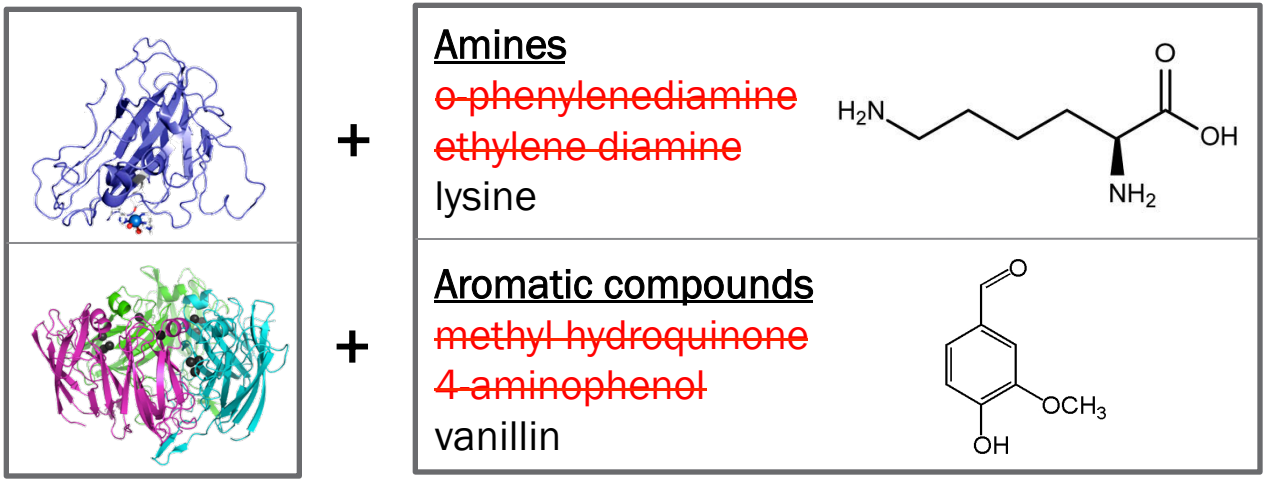
PMO Enzyme

Laccasse Enzyme

Dopamine

Potassium Permanganate

enzyme + substrate

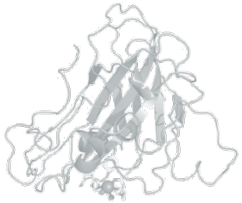


Both enzymes work at milder conditions

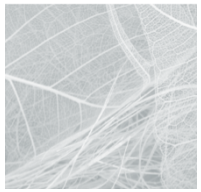
Crosslinking substrate needs to be selected carefully

Chemicals with different functions need to be evaluated differently

HEALTH & ENV. IMPACTS OF PROPOSED SOLUTIONS



PMO Enzyme

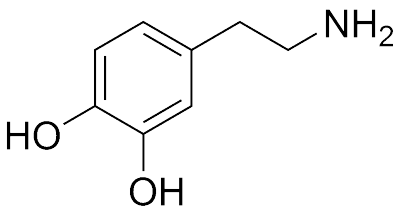


Laccasse Enzyme

Dopamine

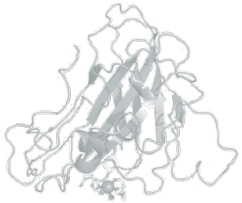
Potassium Permanganate

Main chemical: Dopamine

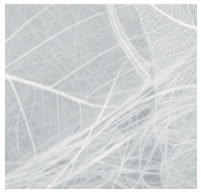


Function	crosslinker
Exposure	● Timescale of effect: acute
Health Endpoints	✓Not carcinogenic ● Moderate endocrine activity
Environmental Toxicity & Fate	✓Not bioaccumulative

HEALTH & ENV. IMPACTS OF PROPOSED SOLUTIONS



PMO Enzyme

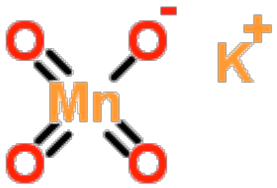


Laccasse Enzyme

Dopamine

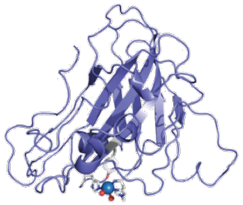
Potassium Permanganate

Main chemical: Potassium permanganate



Function	Makes cellulose more reactive
Exposure	● Timescale of effect: acute
Health Endpoints	● Suspected reproductive toxicant ✕ Corrosive
Environmental Toxicity & Fate	✓ Not bioaccumulative ✕ Acute aquatic toxicity

COMPARING: HEALTH & ENV. IMPACTS OF PROPOSED SOLUTIONS



PMO Enzyme

✓Enzyme is relatively safe, need to choose crosslinking substrate carefully selected, may use lysine

Laccasse Enzyme

✓Enzyme is relatively safe, need to choose crosslinking substrate carefully selected, may use vanillin

Dopamine

✓Dompamine relatively safe

Potassium Permanganate

✕Potassium permanganate relatively less safe

MAKE INFORMED DECISIONS
OUR GREENER SOLUTION MUST:

Priority 1	be **less hazardous** than the existing solution
Priority 2	**have performance and durability metrics that** are *comparable* to existing treatments
Priority 3	**Minimize changes** to the application process, cost, and consumer experience

FINAL RECOMMENDATIONS

Solution	Technical	Health/Env
 PMO Enzyme	×Unavailability of enzyme makes this solution technically unfeasible	
 Laccasse Enzyme		
 Dopamine		
 Potassium Permanganate		×Potassium permanganate relatively less safe

FINAL RECOMMENDATIONS

Solution	Technical	Health/Env
 PMO Enzyme	✕Unavailability of enzyme makes this solution technically unfeasible	
 Laccasse Enzyme		
 Dopamine		
 Potassium Permanganate		✕Potassium permanganate relatively less safe

✓Demonstrate greatest potential as solutions based on our priorities and definition of "greener solution"

CONCLUSIONS

1. What counts as a greener solution?

"Greener"

CONCLUSIONS

1. What counts as a greener solution?

"Greener"


2. Solutions are possible!
But have tradeoffs




CONCLUSIONS

1. What counts as a greener solution?

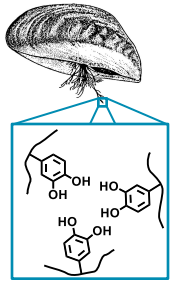
"Greener"

2. Solutions are possible! But have tradeoffs




3. Framework= helpful tool for the future

Biomimicry



market innovation

Technical evaluation

		Green Requirements ✔	Red Requirements X	PMO solution
Crosslinking ability	With Cellulose			-
	With itself (Durable press)	Multitude of strong interactions	Zero or unknown interactions	-
	With DWR compounds			✔
Durability and consumer expectations	Wash stability	Lasts multiple washes; irreversible bonds	Laundry detergent may undo crosslinking	✔
	Fabric strength	No known weakening treatments	Weakens fabric significantly	✔
	Food, sun, etc. stability	No changes	Unstable (fades in sun, etc.)	✔
	Color	No color change	Large color change	✔
Application, curing, and cost	Controllable cured	Very controllable	No control (reacts immediately)	-
	Time of curing	Under 1 hr	Over 12 hrs	X
	Chemical stability and water solubility	No special storage, highly water soluble	Requires special storage and not water soluble	-
	Availability of raw materials	Available industrially	Unavailable at industrial scale	X
	Cost of raw materials	Likely less or equal to current treatments	Likely more than triple current treatments	-

Informed decision

Priority 1	be **less hazardous** than the existing solution
Priority 2	have **performance and durability** *comparable* to existing treatments
Priority 3	minimize changes to the application process, cost, and consumer experience

Health & Env. Evaluation

Chemical Compound	Exposure			Health Endpoints						Environmental Toxicity & Fate		Physical Hazards
				Human Health Group I			Human Health Group II					
Chemical Name (CAS Number)	Process Notes	Potency LD_{50}	Timescale of Effect (Acute or chronic)	Carcinogenicity Mutagenicity	Reproductive Developmental Toxicity Endocrine Activity	Acute Toxicity Genetic Irritation	Systemic Toxicity & Organ Effects	Neuro Toxicity	Skin/Eye Irritation	Persistence Bio-accumulation	Aquatic Toxicity (Acute/ chronic)	Reactivity/ Flammability
Dopamine		3320 mg/kg oral-rat	Acute	✔	o	o				✔		✔
Octadecylthiol			Acute	✔		o						
Methyl hydroquinone		200 mg/kg oral-rat				x					x	
4-aminophenol				o		o					x	
Ethanolamine				✔	✔	o				✔	x	
Ethylene diamine			Acute			x			x		x	
Potassium permanganate		750 mg/kg oral-mouse	Acute	o		o			o		x	

ACKNOWLEDGMENTS

Thank you

Dr. Megan Schwarzman, UC Berkeley

Dr. Marty Mulvihill, UC Berkeley

Amanda Cattermole, Levi's

Biomimicry Institute

Claudia Polsky

Greener Solutions Class Members

THANK YOU!
QUESTIONS?