Access our presentation at the following link:

https://docs.google.com/presentation/d/1acjw-rxlfochUQWsByiQybu3G1RsNfdH72K9rxh_YGY/edit?usp=sharing

(The formatting changes if we convert to PPT)

From Dirty Laundry to a Cleaner Planet:

Exploring Eco-friendly Alternatives to Polyvinyl Alcohol (PVA) in Detergent Products

ECOS®
Plant Powered Clean

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MPH Student

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MPH Student

Overview

01 **Background**

02 **Approach**
Performance, health, and environmental criteria

03 **Strategies**
1: Polysaccharides, 2: Proteins, Considerations

04 **Conclusion**
Final assessment, future plans, questions

01

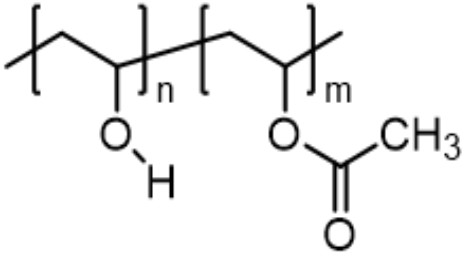
Background

Sheets and packs are promising single-use, low-carbon-footprint, detergent deliverers

De

Plastic Free

Polyvinyl Alcohol (PVA)



Sheets

PVA is an industry standard material with unique properties

Water-soluble
(hot and cold water)

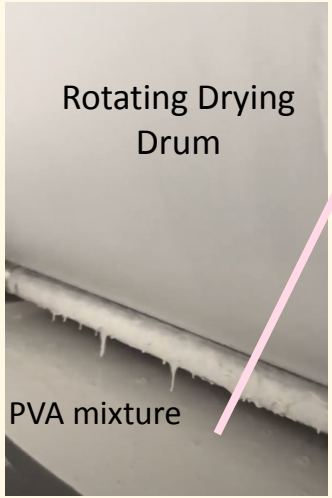
Compatible with active ingredients

Inexpensive

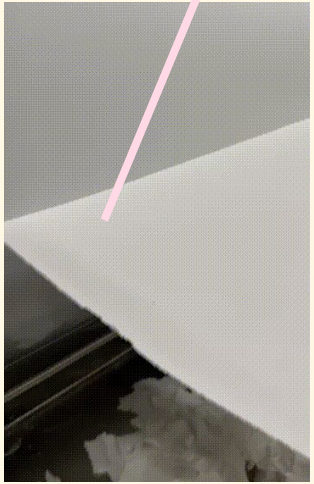
Compatible with manufacturing processes

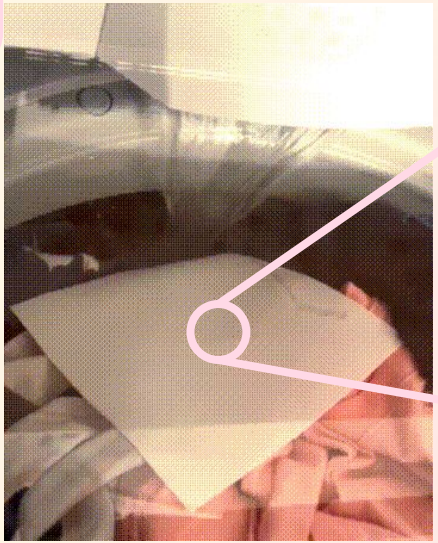
No formation of microplastics

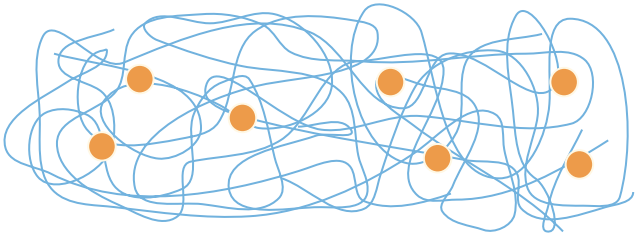
PVA provides the structure of detergent sheets



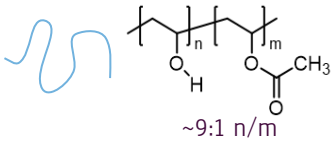
- Viscous mixture
- Dried at 100°C
- Tensile strength between 1 – 10 MPa







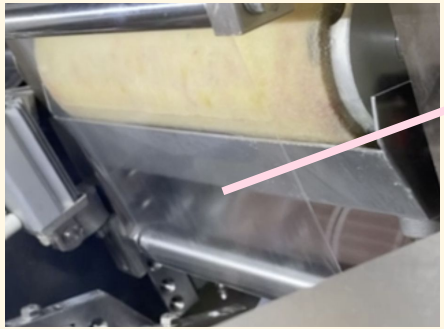
Polyvinyl Alcohol



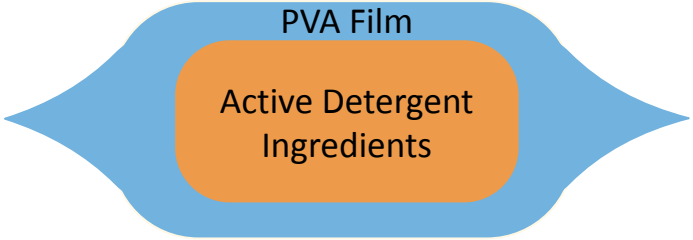
Active Detergent Ingredients

Images from ECOS manufacturing

PVA films encapsulate detergent packs



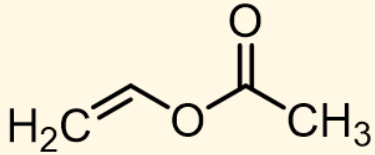
- Heated to 150°C
- 47 MPa tensile strength
- 290% Elongation



Images from ECOS manufacturing

PVA poses health concerns

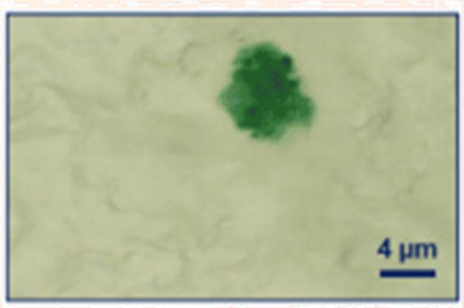
Harmful Precursors



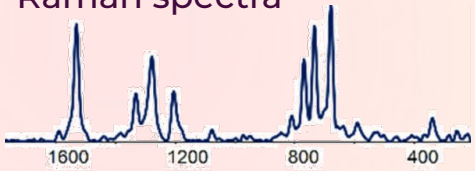
Vinyl acetate

Bioaccumulation

PVA in breastmilk

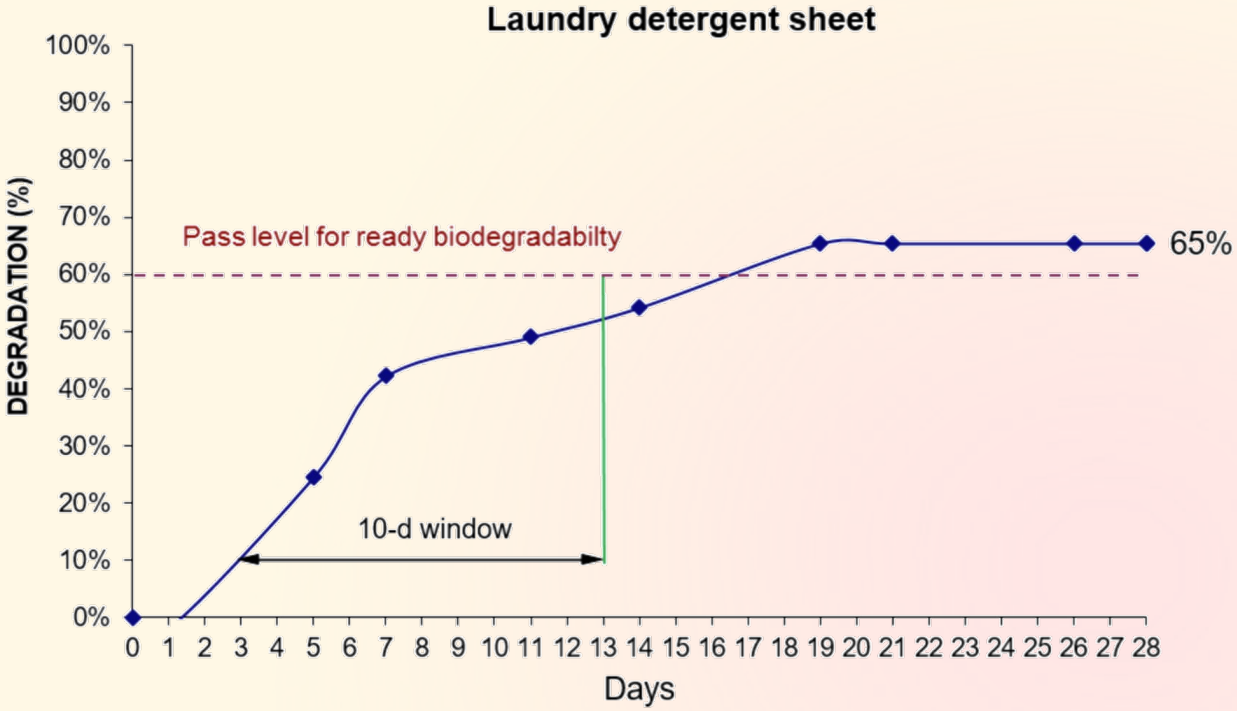


Raman spectra



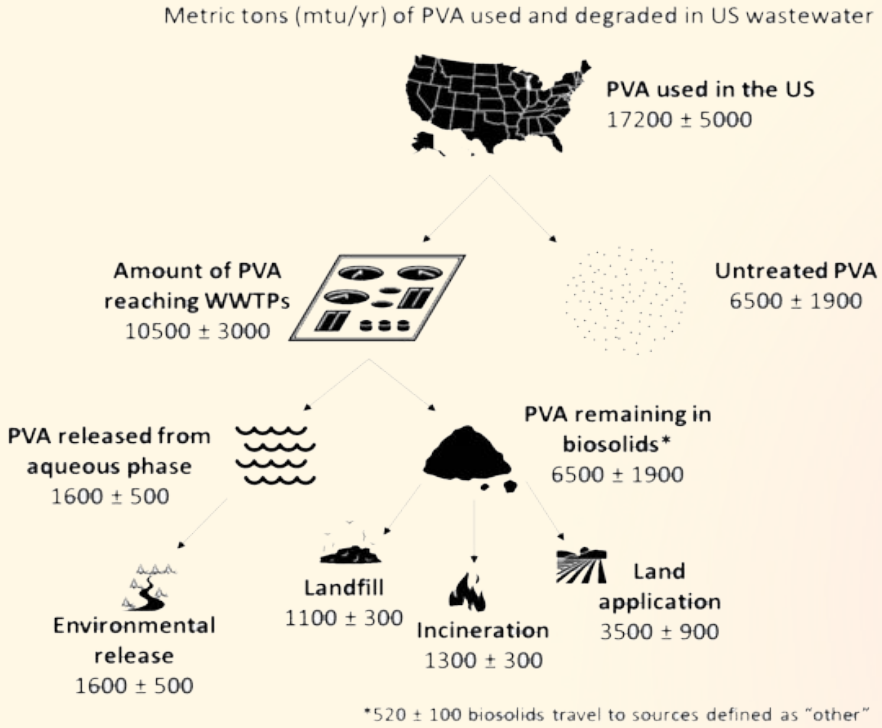
Ragusa et al. 2022

Does PVA pose environmental concerns?



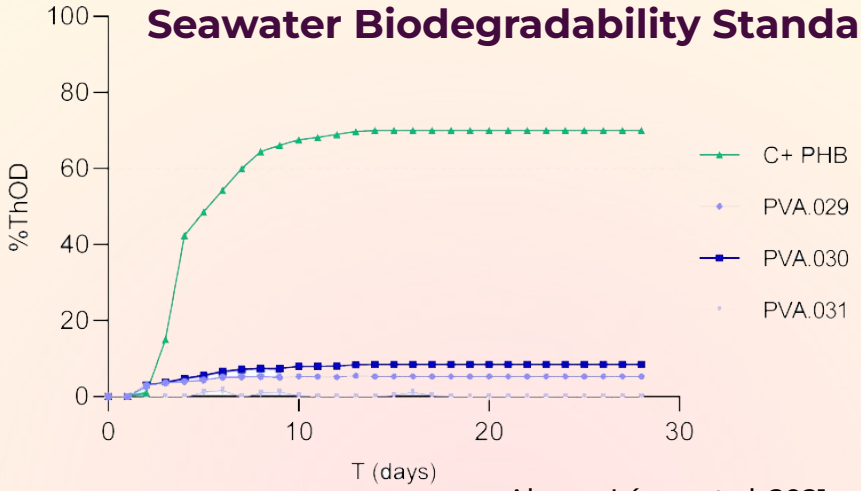
ECOS Sheet passing OECD 301B.
From ECOS rep.

PVA persists in the environment



Rolsky & Kelkar, 2021

PVA Fails UNE-EN ISO 14851:2019 Seawater Biodegradability Standard



Alonso-López et al. 2021

Soil Degradation (Su et al. 2022)

Weeks	0	1	2	3	4	5	6	7
Weight Loss Rate (%)	17	31	33	28	29	29	35	**35**

02

Approach:
Replacing PVA

PVA's replacement must follow ECOS' priorities

Leaping Bunny Certified

100% Vegan

No Nasties

Hypoallergenic

Plant-Powered

https://www.ecos.com/

Criteria for selecting PVA alternative

Technical Performance

- Soluble in all water temperatures
- Shelf stable for 2 years
- Compatible with existing detergent ingredients ($5 < pH < 9$)
- Appearance
  - Consideration for marketability

Health and Environment

- Non-toxic to human and aquatic life
- Biodegradable
  - Must pass OECD 301B Requirements
  - 60% converted to CO_2 over 28 days
- Does not bioaccumulate

Manufacturing Compatibility

- TSCA Chemical List
- Readily available and accessible material
- Physical properties for manufacturing processes
  - Heat stability
  - Flexibility
  - Tensile strength

03

Strategies

1) Polysaccharides

2) Proteins

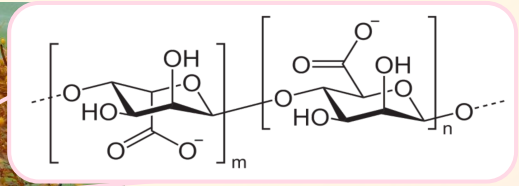
Considerations

Strategy 1: Polysaccharide-based

1. Sodium Alginate
2. Carrageenan
3. Chitosan
4. Pullulan
5. Cellulose

Sodium Alginate

Brown algae polymer used in food industry



Na^+, K^+, NH_4^+, Ca^{2+}, ...

Pros

- Very soluble; dissolves fully within 90 seconds
- NaOH is only chemical used in manufacturing
- Strong (25 - 75 MPa), especially with glycerol

Cons

- Unknown shelf life
- Low max concentration; 2% w/w solutions
- Insoluble with divalent ions (very hard water)

Considerations

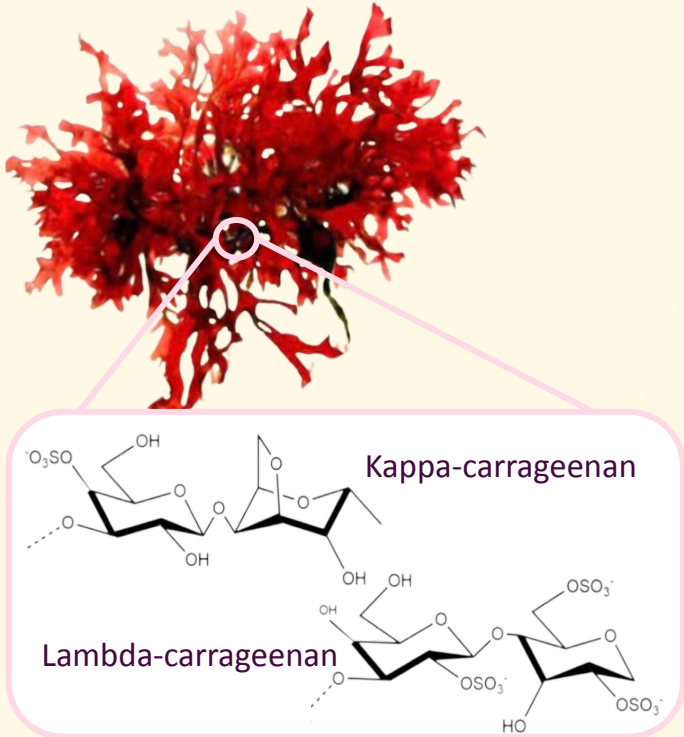
- Kimica, etc. already produce various kinds/ grades of alginates
- Can be sourced sustainably
- Drop-in sheet replacement; elongation is concern for packs

https://www.floridamuseum.ufl.edu/earth-systems/blog/sargassum-seaweed-or-brown-algae/

https://impossiblefoods.com/products/sausage

Kappa- and Lambda- Carrageenan

Red-algae polymers used in food industry



Pros

Kappa-Carrageenan	Lambda-Carrageenan
• Strong films (39 MPa) biodegrade in soil	• Water soluble all water temperatures
• Stable up to 115°C	• Improves flexibility

- Provides nutrient source for algae when degraded in ocean

Cons

Kappa-Carrageenan	Lambda-Carrageenan
• Insoluble in cold water	• Does not form films on its own
• Cannot heat-seal	

Considerations

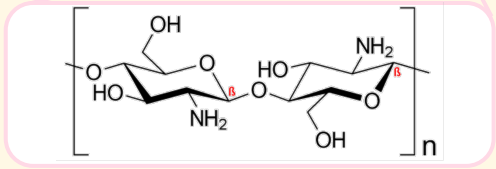
- Packs: Patented water-soluble Carrageenan film, Carraphane developed at German company, Brabender
- Sheets: potentially use a Kappa-Lambda hybrid

https://www.sciencedirect.com/science/article/pii/S2211926421004124

https://www.brabender.com/en/water-soluble-films-made-from-carraphane/

Chitosan

Amine-containing polymer from crustaceans & fungi



Photos from Margret, et al. 2017

Pros

- Strong (20 – 320 MPa)
- Manufacturing only requires acids/bases and mild conditions
- Elongation up to 120%

Cazón1 & Vázquez, 2020

Cons

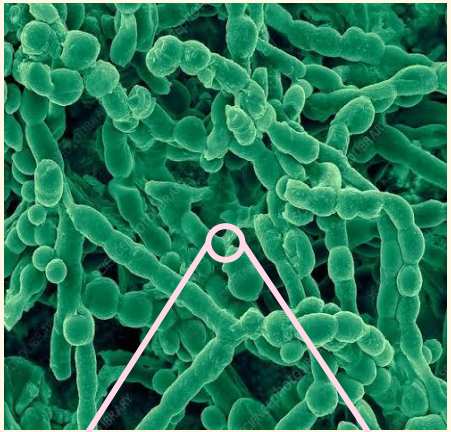
- Only soluble in slightly acidic media (pH < 6.5)
  - Acid controls film properties
- Soluble form is positively charged
- Not a thermoplastic; can be combined with one

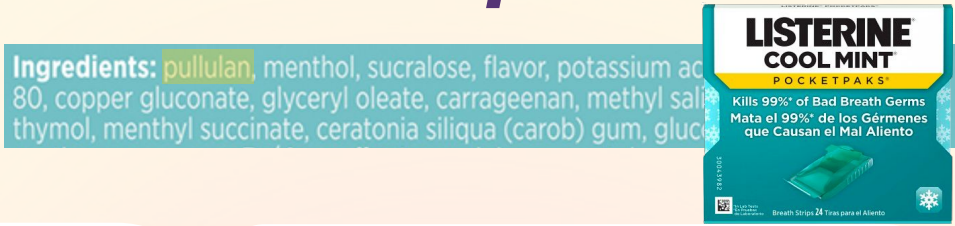
Considerations

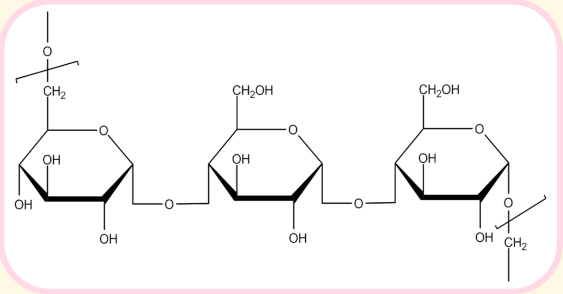
- Sourcing from fungi is expensive (5x) relative to crustacean waste-stream
- Cargill (US) & KitoZyme (EU) produce fungal-based chitosan for food, alcohol, and biomedical applications
- Adding glycerol leads to ↑ elongation & ↓ tensile strength

Pullulan

Polymer produced from *Aureobasidium pullulans*







Pros

- Readily dissolvable in hot and cold water
- Flexible
- Stable up to 250°C
- Biodegradable
- Consumable; non-toxic

Cons

- Low elongation at break (11%)
- Low tensile strength (1.7 MPa)

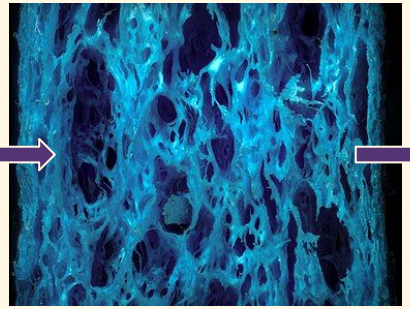
Considerations

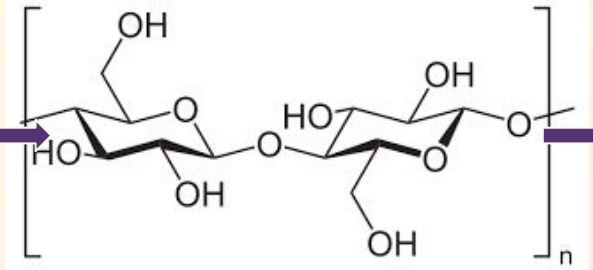
- Expensive (high production charges compared to petrochemicals)
- Compatible with sheets if strengthened with a plasticizer

https://www.sciencephoto.com/media/799900/view/aureobasidium-pullulans-hyphae-and-spores-sem https://www.listerine.com/on-the-go-oral-health/listerine-pocketpaks-cool-mint https://doi.org/10.1111/1750-3841.12400

Cellulose

Polysaccharide from plants





Pros

- Renewable and abundant
- Highly customizable
- Non-toxic to humans and environment
- Biodegradable

Cons

- Brittle
- Low tensile strength (22.4 MPa) and elongation (13.4%)
- Gels at high temp

Considerations

- Vegan and can be derived from waste sources
- Widely available and affordable
- Compatible with sheets and packs

https://en.wikipedia.org/wiki/Cellulose https://logosltd.ru/print/en/node/177/catalog/tovar/62

Strategy 1: Polysaccharide Hazards

Common Name or Trade Name	Group I Human Endpoints			Group II and Group II* Endpoints			Ecotoxicity	Fate	Physical Hazard
	Carcinogenicity / Mutagenicity	Developmental and Reproductive Toxicity	Endocrine Activity	Systemic Toxicity	Neurotoxicity	Skin, Eye, Respiratory Irritation/ Sensitization	Aquatic Toxicity Acute/Chronic	Persistence Bioaccumulation	Reactivity, Flammability / Other Pchem Traits
Polyvinyl Alcohol	*L*	L	DG	L	L	L	H*	M*	L
Sodium Alginate	L	L	L	L	L	*L*	*L**	vL	vL
Carrageenan	L	L	L	L	L	L	vL	L	L
Chitosan	L	L	*L*	L	L	L	*L**	L	DG
Pullulan	L	*L*	L	L	*L*	*L*	*L*	vL	vL
Cellulose	*L*	L	L	L	L	M+	L	L	L

italicized: low confidence *mixed literature +not a consumer hazard gradient: reasonable assumption of safety

data gap DG | very low vL | L | M | H | vH very high

Strategy 1: Polysaccharide Performance

	Solubility (temp, pH)	Tensile Strength (MPa)	Flexibility	Commercial Availability	Packs, Sheets, or Both
Polyvinyl Alcohol	Cold & hot, pH 5-9	47 (film)	✓	Yes (powder, film)	Both
Sodium Alginate	Cold & hot, pH > 4	25 – 75	✓	Yes (powder)	Both
Carrageenan	Cold & hot, pH 6-10	39.3	✓	Yes (powder, *film*)	Both*
Chitosan	Cold & hot, pH < 6.5	20 – 320	✓	Yes (powder, film)	Packs
Pullulan	Cold & hot, pH 3-8	1.7	✓	Yes (powder)	Sheets
Cellulose	Cold & hot, pH 2-13	4.5 - 22.4	✓	Yes (powder, film)	Both

italicized: potential company partner *marketing aesthetic considerations

03

Strategies

1) Polysaccharides

2) Proteins

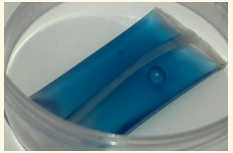
Considerations

Strategy 2: Protein-based

1. Brewer’s Spent Grain (BSG) Protein
2. Soy Protein
3. Pea Protein

Brewer's Spent Grain (BSG) Protein

Byproduct of brewing industry



https://www.miterro.com/products/beer-waste-water-soluble-film-sample

Pros

- Upcycling
- Can be hydrolyzed to adjust water solubility
- Stable for >300 min at 140° C and pH 6-12
- Biodegradable in soil and water
- Can form into a film with plasticizer

Cons

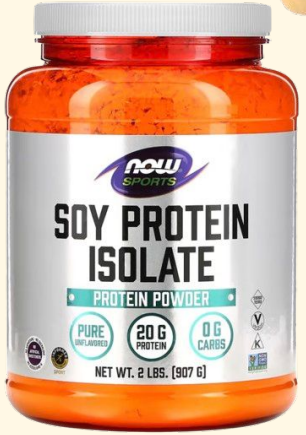
- Protein degradation during malting and extraction
- Brown color
- Low tensile strength (1.6 MPa) and elongation (60%)
- Not listed on TSCA Chemical List

Considerations

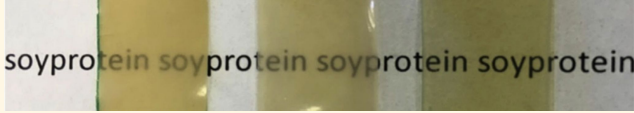
- Available from EverPro (powder) and MiTerro (film)
- Suitable for both sheets and packs

Soy Protein

Derived from soybeans



https://truenutrition.com/products/soy-protein-isolate
https://www.iherb.com/pr/now-foods-sports-soy-protein-isolate-pure-unflavored-2-lbs-907-g



Soy protein films on paper.
Image from Zhao et al. (2016)

Pros

- Comparable water solubility to PVA at 20C
- Consumable, non-toxic for amounts in this application
- Flexible films biodegradable in wastewater treatment sludge

Cons

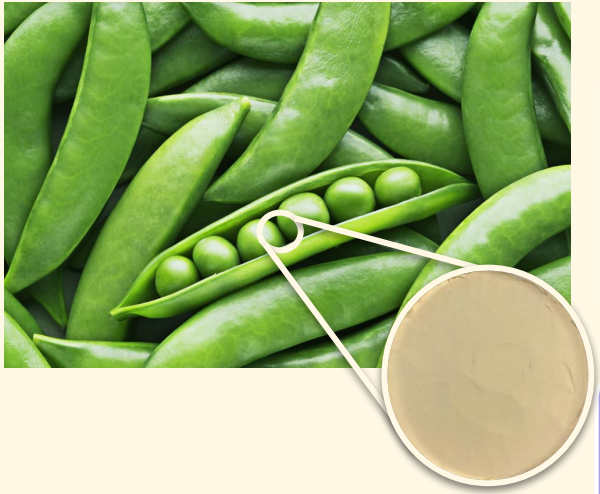
- Common allergen, may cause skin sensitization or asthma
- Needs chemical treatment for cold-water solubility
- Only stable up to 80C before onset of coagulation

Considerations

- Readily available commercially
- Could be used for both sheets and packs

Hypoallergenic

Pea Protein



https://www.packworld.com/news/sustainability/article/21796972/worlds-first-edible-dissolvable-packaging-made-from-pea-protein
https://morro.earth/material/morro-soluble-film/

Pros

- Soluble in hot and cold water
- Consumable; non-toxic
- High thermal stability (190-200 °C)
- Moderate tensile strength and good elongation (200%)
- Biodegradable in soil and water

Cons

- Not on TSCA Chemical List

Considerations

- Available from Xampla's Morro materials (soluble film)
- Could be used for both packs and sheets

Strategy 2: Protein Hazards

Common Name or Trade Name	Group I Human Endpoints			Group II and Group II* Endpoints			Ecotoxicity	Fate	Physical Hazard
	Carcinogenicity / Mutagenicity	Developmental and Reproductive Toxicity	Endocrine Activity	Systemic Toxicity	Neurotoxicity	Skin, Eye, Respiratory Irritation/ Sensitization	Aquatic Toxicity Acute/Chronic	Persistence Bioaccumulation	Reactivity, Flammability / Other Pchem Traits
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Brewer's Spent Grain Protein	L	L	L	L	L	L	L	vL	L
Soy Protein	L	L	M+	L	L	H	L	L	L
Pea Protein	L	L	L	L	L	L	L	L	L

italicized: low confidence

*mixed literature

+not a consumer hazard

gradient: reasonable assumption of safety

data gap DG

very low vL L M H vH very high

Strategy 2: Protein Performance

	Solubility (temp, pH)	Tensile Strength (MPa)	Flexibility	Commercial Availability	Packs, Sheets, or Both
Polyvinyl Alcohol	Cold & hot, pH 5-9	47 (film)	✓	Yes (powder, film)	Both
BSG Protein	Cold & hot, pH 6-12	1.6	✓	Yes (powder, film)	Both*
Soy Protein	Cold & hot, pH 3-8.5	2.3	✓	Yes (powder)	Both
Pea Protein	Cold & hot, pH 6-12	7.0	✓	Yes (powder, *film*)	Both

italicized: potential company partner *marketing aesthetic considerations

03

Strategies

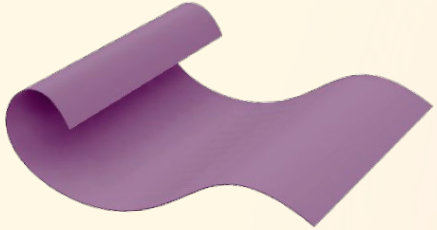
1) Polysaccharides
2) Proteins

Considerations

Additives can be used with polysaccharides or proteins

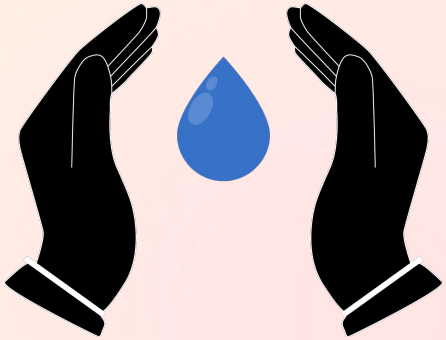
Incorporated to improve functionality of the detergent sheets and/or packs with respect to:

Flexibility



Improve manufacturing compatibility

Hygroscopicity

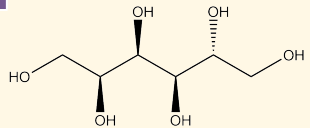


Prevent moisture absorption and improve shelf life

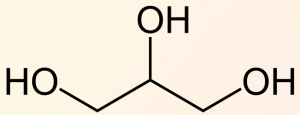
Plasticizers increase flexibility of polymer films

Plasticizers to consider:

1 Sorbitol



2 Glycerol

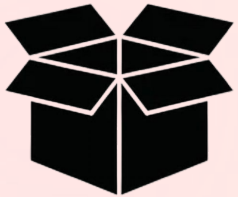


Already used in ECOS products!

Benefits of these additives:

Water-soluble
(hot and cold water)

High thermal stability

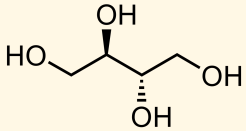


Commercially-available from use in food/cosmetics industry

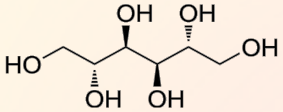
Reducing hygroscopicity improves stability

Sugar-free sweeteners that improve hard-candy lifetime:

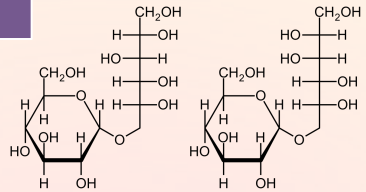
1 Erythritol



2 Mannitol

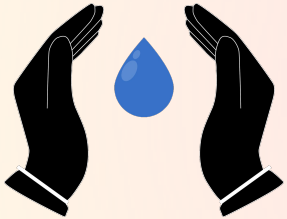


3 Isomalt

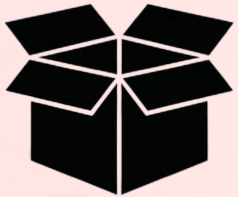


Benefits of these additives:

Water-soluble
(hot and cold water)



Low hygroscopicity:
Prevents moisture absorption



Commercially-available from use
in food industry

Additive Hazards

	Common Name or Trade Name	Group I Human Endpoints			Group II and Group II* Endpoints			Ecotoxicity	Fate	Physical Hazard
		Carcinogenicity / Mutagenicity	Developmental and Reproductive Toxicity	Endocrine Activity	Systemic Toxicity	Neurotoxicity	Skin, Eye, Respiratory Irritation/ Sensitization	Aquatic Toxicity Acute/Chronic	Persistence Bioaccumulation	Reactivity, Flammability / Other Pchem Traits
Plasticizers	Sorbitol	L	vL	L	vL	L	M+	L	L	vL; M
Plasticizers	Glycerol	*L*	L	L	L	*L*	*L*	*vL*	L	vL; H
Hygroscopicity Reducers	Erythritol	L	L	L	L	L	M+	L	vL	vL
Hygroscopicity Reducers	Mannitol	*vL*	*vL*	L	*vL*	M+	L	L	L	vL, M
Hygroscopicity Reducers	Isomalt	L	L	L	L	L	M+	DG	L	L

italicized: low confidence

*mixed literature

+not a consumer hazard

gradient: reasonable assumption of safety

data gap DG

very low vL L M H vH very high

04

Conclusion

PVA Alternative Comparison

	Solubility (temp, pH)	Tensile Strength (MPa)	Flexibility	Commercial Availability	Packs, Sheets, or Both
Polyvinyl Alcohol	Cold & hot, pH 5-9	47 (film)	✓	Yes (powder, film)	Both
Sodium Alginate	Cold & hot, pH > 4	25 – 75	✓	Yes (powder)	Both
Carrageenan	Cold & hot, pH 6-10	39.3	✓	Yes (powder, *film*)	Both*
Chitosan	Cold & hot, pH < 6.5	20 – 320	✓	Yes (powder, film)	Packs
Pullulan	Cold & hot, pH 3-8	1.7	✓	Yes (powder)	Sheets
Cellulose	Cold & hot, pH 2-13	4.5 - 22.4	✓	Yes (powder, film)	Both
BSG Protein	Cold & hot, pH 6-12	1.6	✓	Yes (powder, film)	Both*
Soy Protein	Cold & hot, pH 3-8.5	2.3	✓	Yes (powder)	Both
Pea Protein	Cold & hot, pH 6-12	7.0	✓	Yes (powder, *film*)	Both

italicized: potential company partner *marketing aesthetic considerations


Takeaways

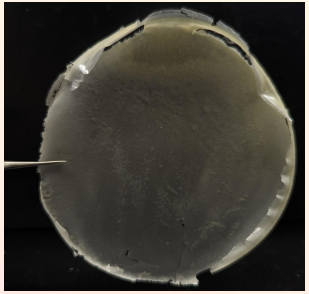
Only experimentation can answer remaining questions

Compatible with active ingredients

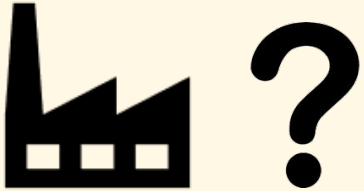
Sheets:

Film Variables: concentration, polymer molecular weight, counterion, synthetic modification, additives

Good Film ≠ Good Sheet

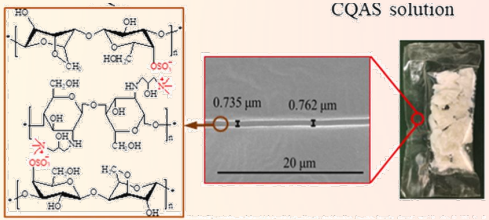


Sheet Variables: composition of ingredients, drying time and temperature



Compatible with manufacturing processes

Packs:



Low Temp Heat Sealing

Chi et al. 2023

Form-Fill-Seal vs. Premade Pouch Machine

vikingmasek.com/packaging-machines/

Acknowledgements

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Dr. Megan Arnett
Dr. Billy Hart-Cooper

Thanks!

Do you have a laundry list of questions?

Any stains of curiosity about PVA replacements?

Let’s launder the details!

I’m ready for a sudsy discussion.

Feel free to fabricate your queries!