Towards polymer modularity: Rethinking polymer colorants

Greener Solutions, Fall 2016

Steelcase Team
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Overview

- Introduction
  - Project Motivation, Goal, and Scope
  - Technical Background
  - Hazard Assessment Methodology
- Strategies
  - Hazards
  - Feasibility
- Conclusions

Plastics: Rarely Recycled

Plastics End-of-Life:

- 9.5% recycled[1]
- 75.5% landfill[1]
- Environmental issues

1. Advancing Sustainable Materials Management: 2014 Fact Sheet. US EPA. 2016

Plastics: Difficult to Recycle

- Many different types of plastic
  - Requires separating and sorting

- Many different additives to each type of plastic
  - Cannot recover pure plastic afterwards
    - **DOWN-CYCLING**

Steelcase's Plastic Vision

Polymer Modularity

One plastic to rule them all

LONG TERM GOAL

- Modify the polymer backbone to inherently incorporate desired properties
  - Removes free flowing additives
  - **Increase "TRUE" recyclability**

Project Goal

Can color be imparted to a polymer without a free flowing additive?

Model system:
Node chair seat shell

Current Manufacturing

Steelcase: Node Chair

Tier I: Seat Shell Molding

Tier II: Polymer Resin | Liquid Masterbatch

Tier III: Polymer monomers | Colorants, Other additives, Solvent

Performance Constraints

- ❑ Melt flow (230 C, 2.16 kg) = 12.0 g/10 ft
- ❑ Tensile strength @ yield (2 in/min) = 4,300 psi
- ❑ Notched Izod Impact Strength @ 23 C = 1.1 ft·lb/in

- ❑ Uniform color
- ❑ Pigment needs to survive molding process

Hazard Analysis Procedure

Prepare list of compounds

- Conversations with Steelcase and outside experts
- Literature searches (patents, basic research)

Hazard data for compounds

Authoritative lists
- Pharos Project
- EPA ACToR
- HSDB
- PubChem

Literature search

Consolidate hazard data

- Six endpoint categories
- Hazard score for each endpoint

Categorize compounds

Hazard Analysis

	4	3	2	1
Carcinogenicity / Mutagenicity	Known	Suspected	Possible	Probably not
Reproductive / Developmental Toxicity	Known	Suspected	Possible	Probably not
Sensitization	Known respiratory and skin sensitizer	Suspected resp. and known skin	Suspected skin	Probably not
Persistence / Bioaccumulation	Very persistent and bioaccumulative	Very persistent	Moderately persistent and bioacc.	Low persistence and bioaccumulation
Environmental Toxicity	Very high	High	Moderate	Low
Acute Toxicity	Very high	High	Moderate	Low

Current Pigments

- Halogenated (chlorinated) pigments
  - Pigment Red 254
  - Pigment Yellow 191
  - Phthalocyanine Green G
- Metal pigments
  - Chromium oxide, titanium dioxide
- Carbon black

Hazards for Current Colorants

	Phthalocyanine Green	Chromium Oxide	Titanium Dioxide	Carbon Black
Carcinogenicity / Mutagenicity	1	2	4	4
Reproductive / Developmental Toxicity	No data	1	1	3
Sensitization	2	4	3	3
Persistence / Bioaccumulation	3	2	2	3
Environmental Toxicity	1	4	2	1
Acute Toxicity	1	3	3	4

Strategies

Less Hazardous Colorants

- Torrefied Walnut Shells

Polymer Modularity

- Grafting Polypropylene
- Maleated Polypropylene
- Polypropylene Binding Peptides

Near Term → Long Term

Less Hazardous Colorants

- Alternative for carbon black
  - **Torrefied walnut shells**
    - Re-using agricultural waste
    - Heated under nitrogen
    - Lignin, hemicellulose, and cellulose polymers

Torrefied Walnut Shell Hazards

	Lignin	Cellulose
Carcinogenicity / Mutagenicity	No data	1
Reproductive / Developmental Toxicity	No data	No data
Sensitization	No data	3
Persistence / Bioaccumulation	1	1
Environmental Toxicity	1	1
Acute Toxicity	2	2

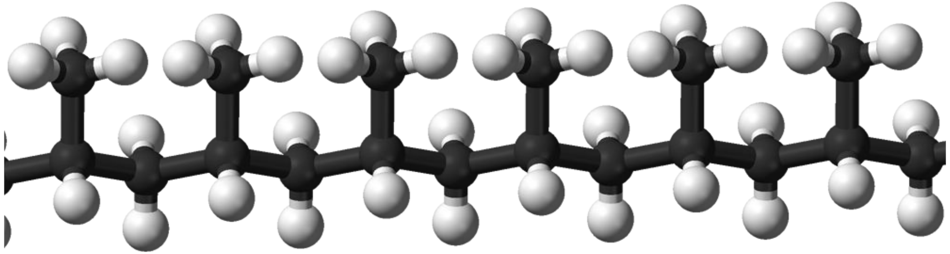
Torrefied Walnut Shell Feasibility

- Final product is a pigment for commercial use
- Testing at USDA (Lennard Torres)
  - Promising results to color polymers
  - Can survive high temperatures

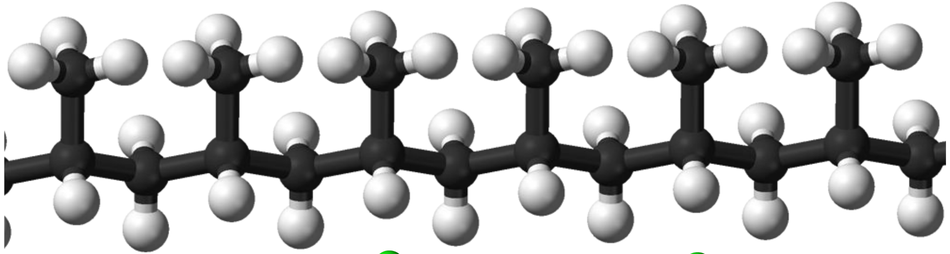
Bonding to Polypropylene

- Inherently difficult to bond to PP

- Focus of our project



Grafting Polypropylene



Procedure

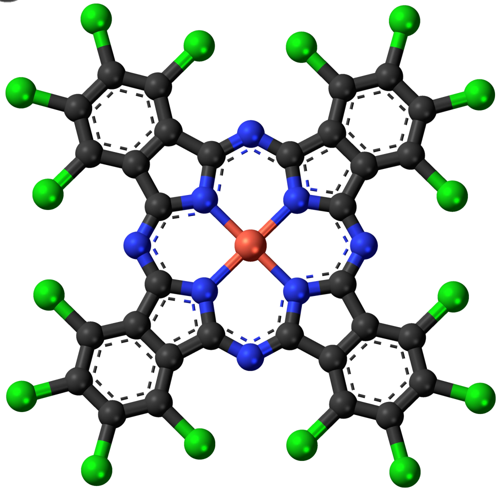
Heat and mix:

Polypropylene

Pigment

Radical Generator

RG



Grafting Polypropylene

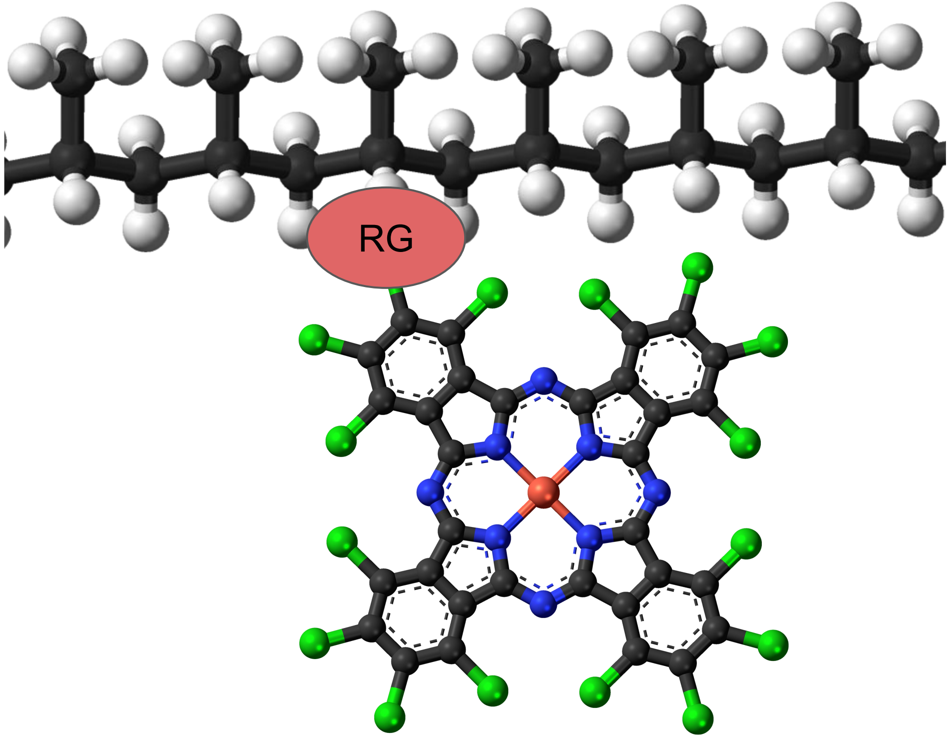
Procedure

Heat and mix:

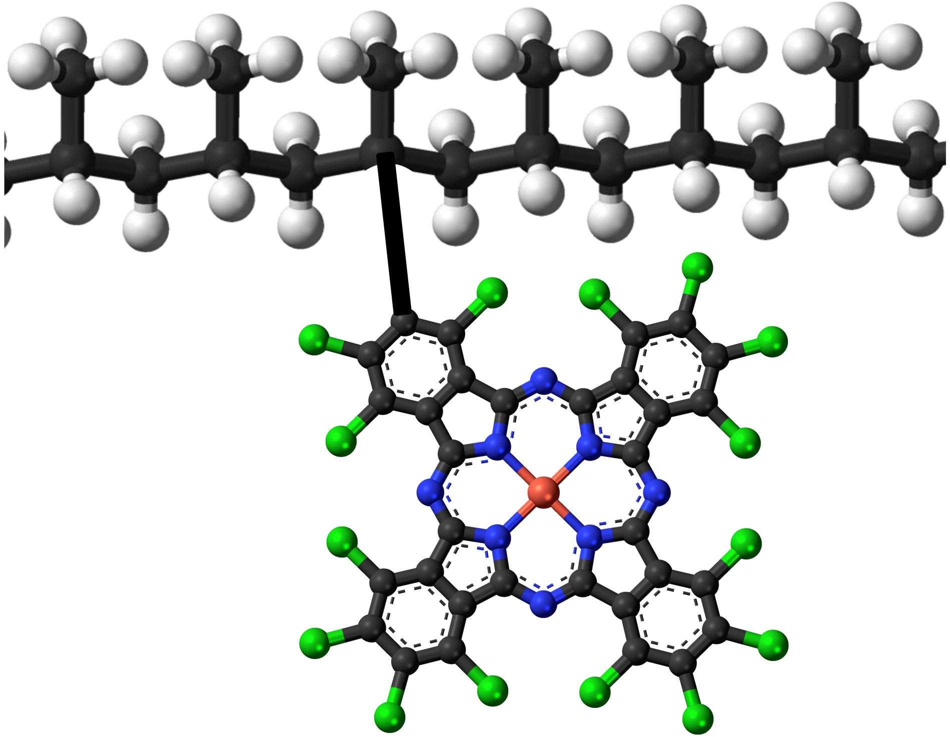
Polypropylene

Pigment

Radical Generator



Grafting Polypropylene



Procedure

Heat and mix:

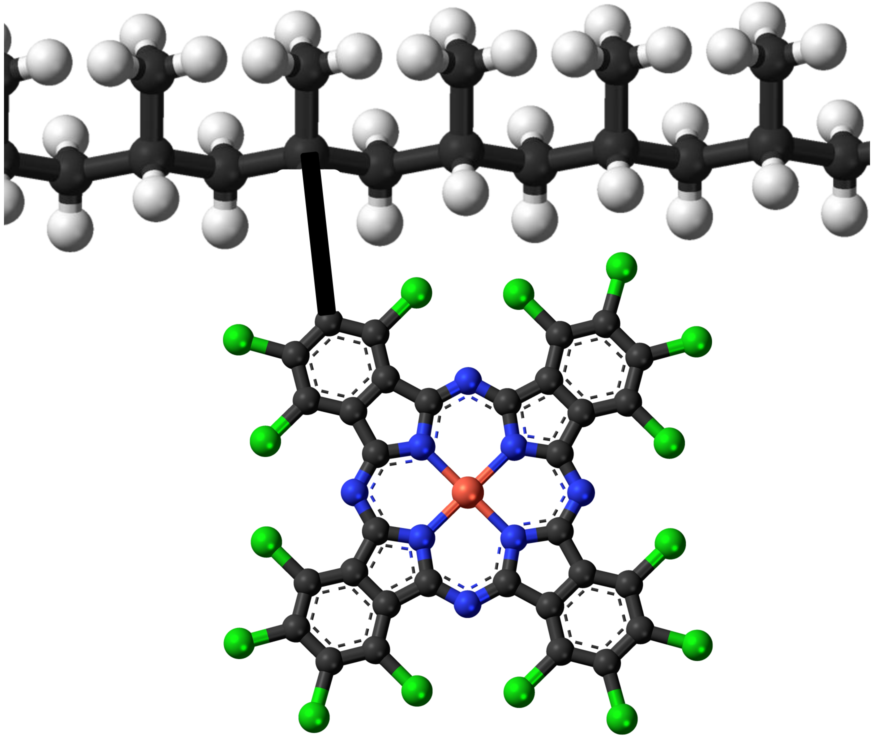
Polypropylene

Pigment

Radical Generator

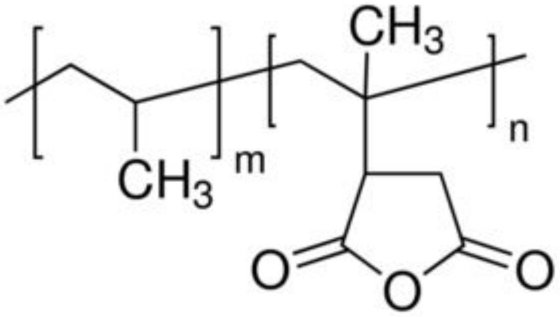
Grafting Feasibility

- ❑ Pigment survival
- ❑ Performance constraints
  - ➥ High concentration
- ❑ Established method



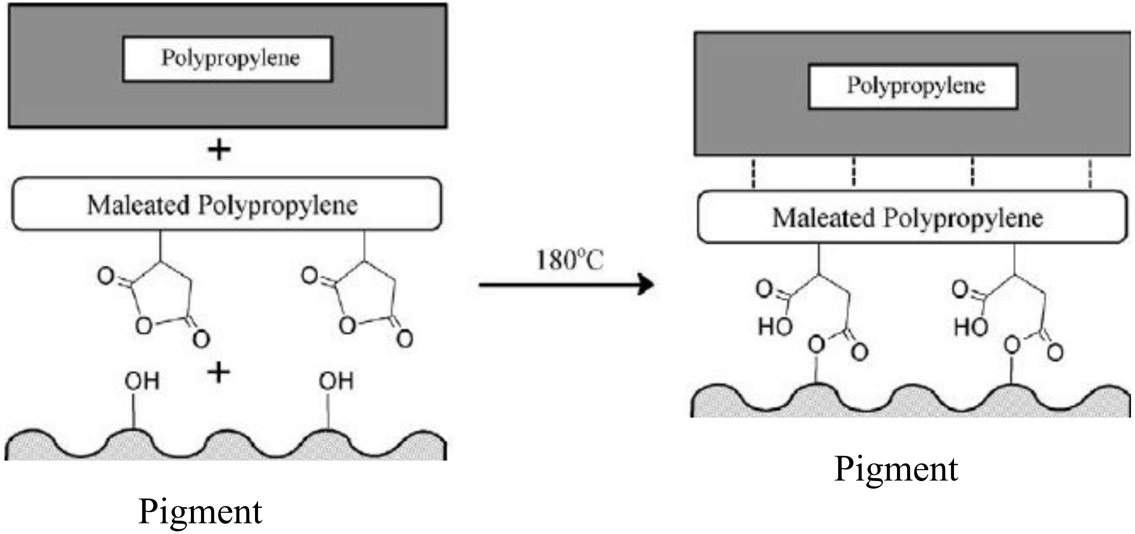
Maleated PP

- Maleic anhydride grafted PP
- Heavily researched



Img: sigmaaldrich.com

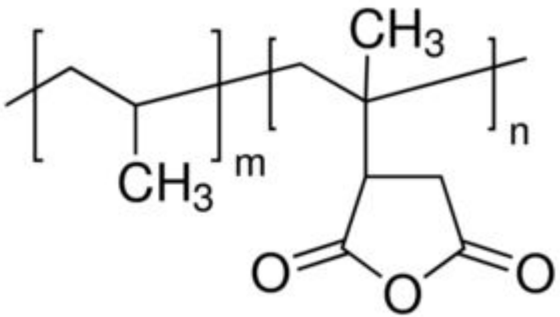
Pigment + Maleated PP



Img: Utilization of cocoa pod husk as filler in polypropylene biocomposites: Effect of maleated polypropylene. J. Thermoplastic Comp. Mat. 2013

Maleated PP Feasibility

- Pigment compatibility
- Polymer properties
  - High concentration, small scale
- Commercially available

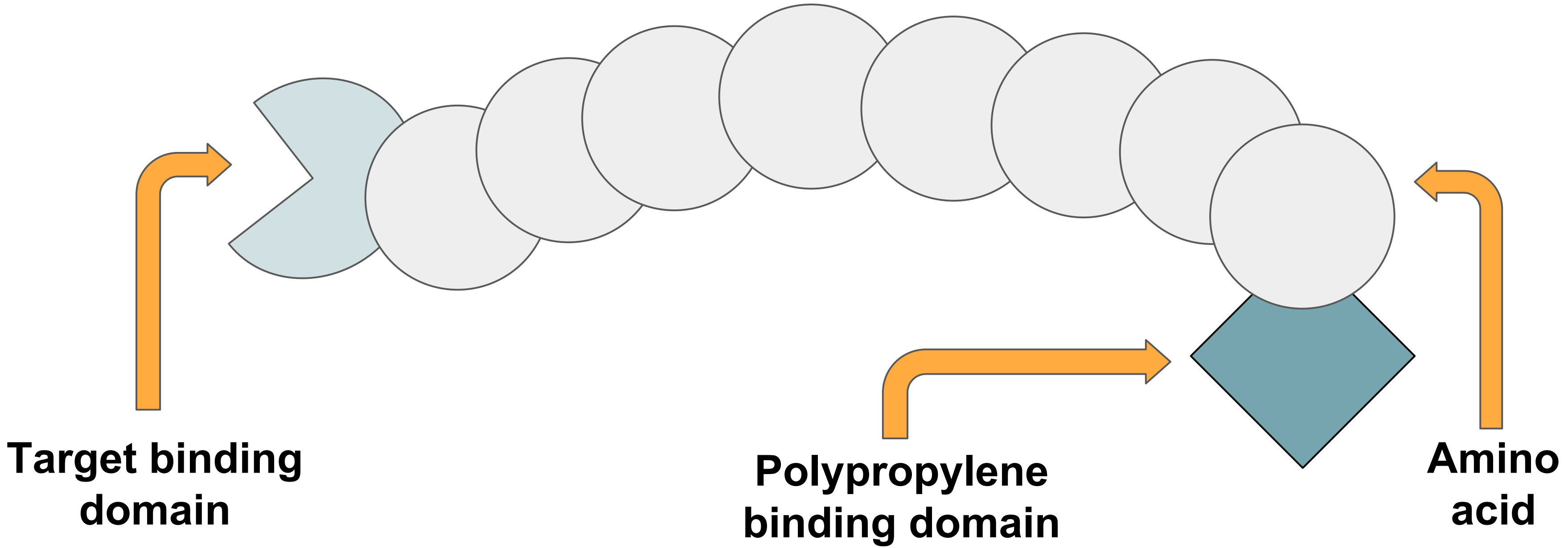


Img: sigmaaldrich.com

Grafting Hazard Assessment

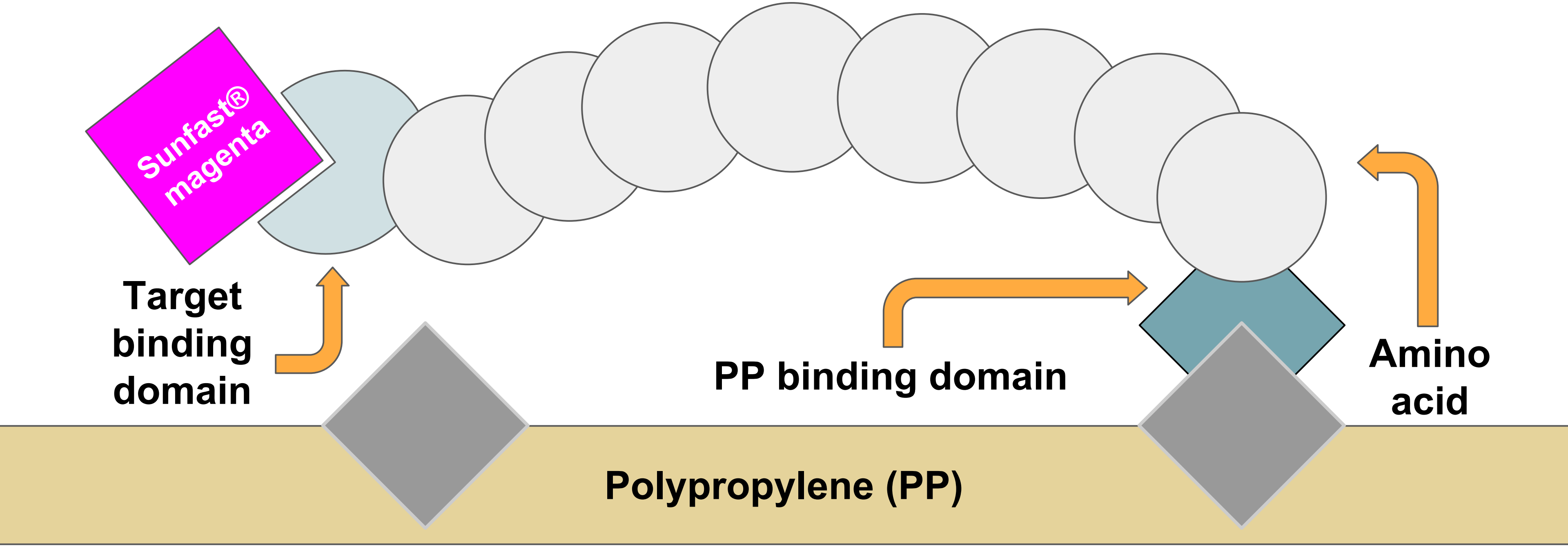
	Maleated Polypropylene	Luperox 101
Carcinogenicity / Mutagenicity	No data	1
Reproductive / Developmental Toxicity	No data	1
Sensitization	3	No Data
Persistence / Bioaccumulation	3	2
Environmental Toxicity	1	2
Acute Toxicity	1	4

Polypropylene Binding Peptide



Cunningham, S. D., Lowe, D. J., O'brien, J. P., & Wang, H. (2011). Polypropylene binding peptides and methods of use. US Patent Office.

Polypropylene Binding Peptide

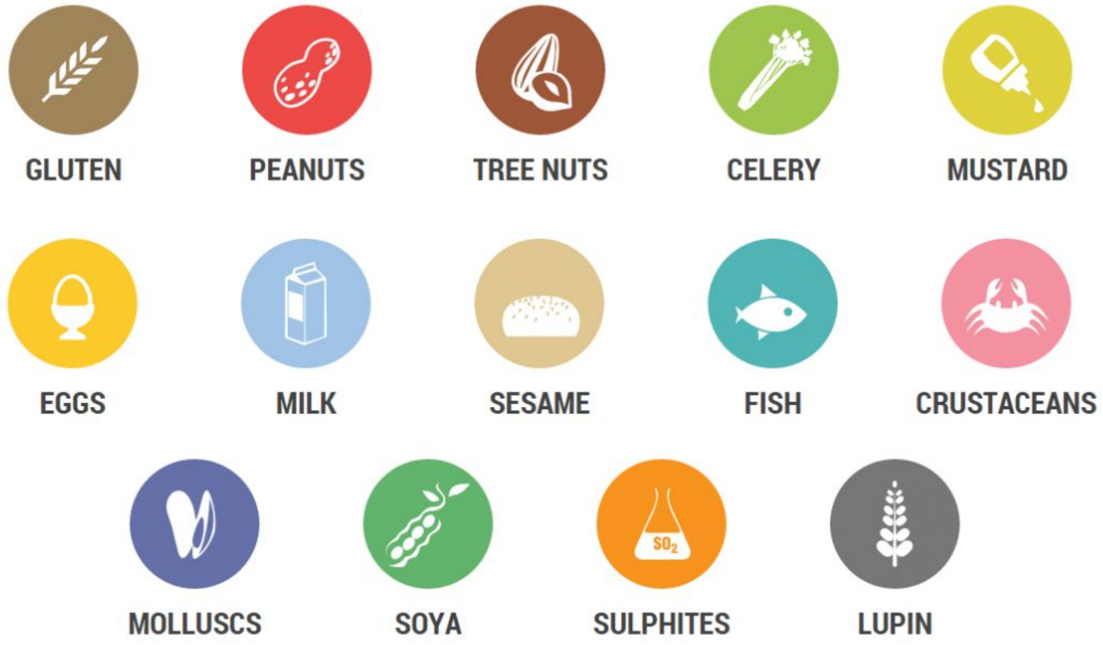


Peptide Colorant Hazards

	Carbon Black	Sunfast® Magenta	Sunfast® Blue
Carcinogenicity / Mutagenicity	4	1	1
Reproductive / Developmental Toxicity	3	No data	1
Sensitization	3	1	1
Persistence / Bioaccumulation	3	1	3
Environmental Toxicity	1	2	1
Acute Toxicity	4	1	1

Main Peptide Hazards

- Data gaps
- Proteins and allergenicity[1]



1. Hartmann, R., Wal, J. M., & Bernard, H. (2007). Cytotoxic and allergenic potential of bioactive proteins and peptides. *Current Pharmaceutical …*, *13*(9), 897–920. http://doi.org/10.2174/138161207780414232

PPBP Feasibility

- The binding mechanism is unknown
  - Apply PPBP before molding
    - **High temperature (PPBP)**
    - **Performance constraints**
  - Surface modification
    - **Longevity of color**

Summary of Strategies

Less Hazardous Additives

Torrefied Walnut Shells

Polymer Modularity

Grafting Polypropylene

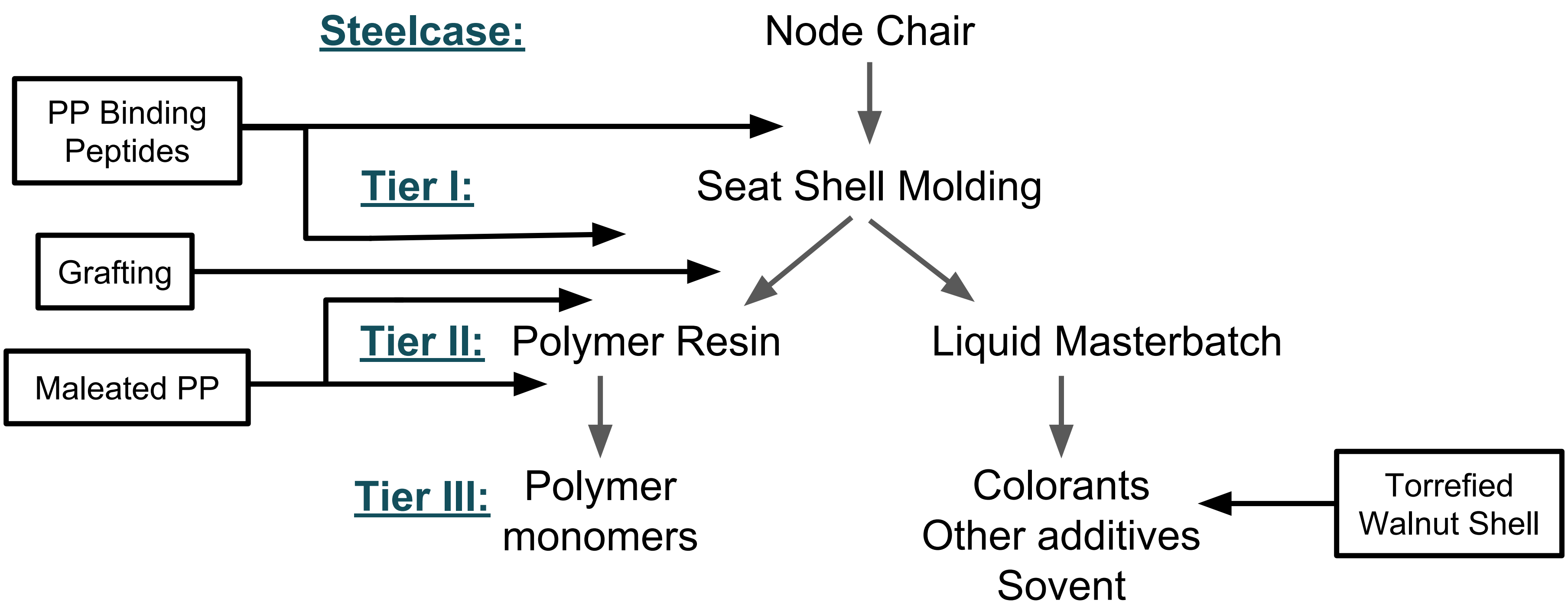
Maleated Polypropylene

Polypropylene Binding Peptides

Near Term

Long Term

Strategy Implementation



Next Steps

- Torrefied Walnut Shells
  - Test color fastness
- Grafting Polypropylene and Maleated Polypropylene
  - Evaluate suitable colorants
- Polypropylene-Binding Peptides
  - Broad research into binding mechanism

Conclusions

- ❑ Performance requirements are less known, but the chemistry of polymer modularity is possible

- ❑ Polymer modularity: a long-term vision of the circular economy

Acknowledgements

- Steelcase
  - Jon Smieja
  - Clinton Boyd, Megann Head, Steve Wasson
- Greener solutions
  - Megan, Tom, Akos
  - Everyone in the class!
- Billy Hart-Cooper, Lennard Torres

Questions?

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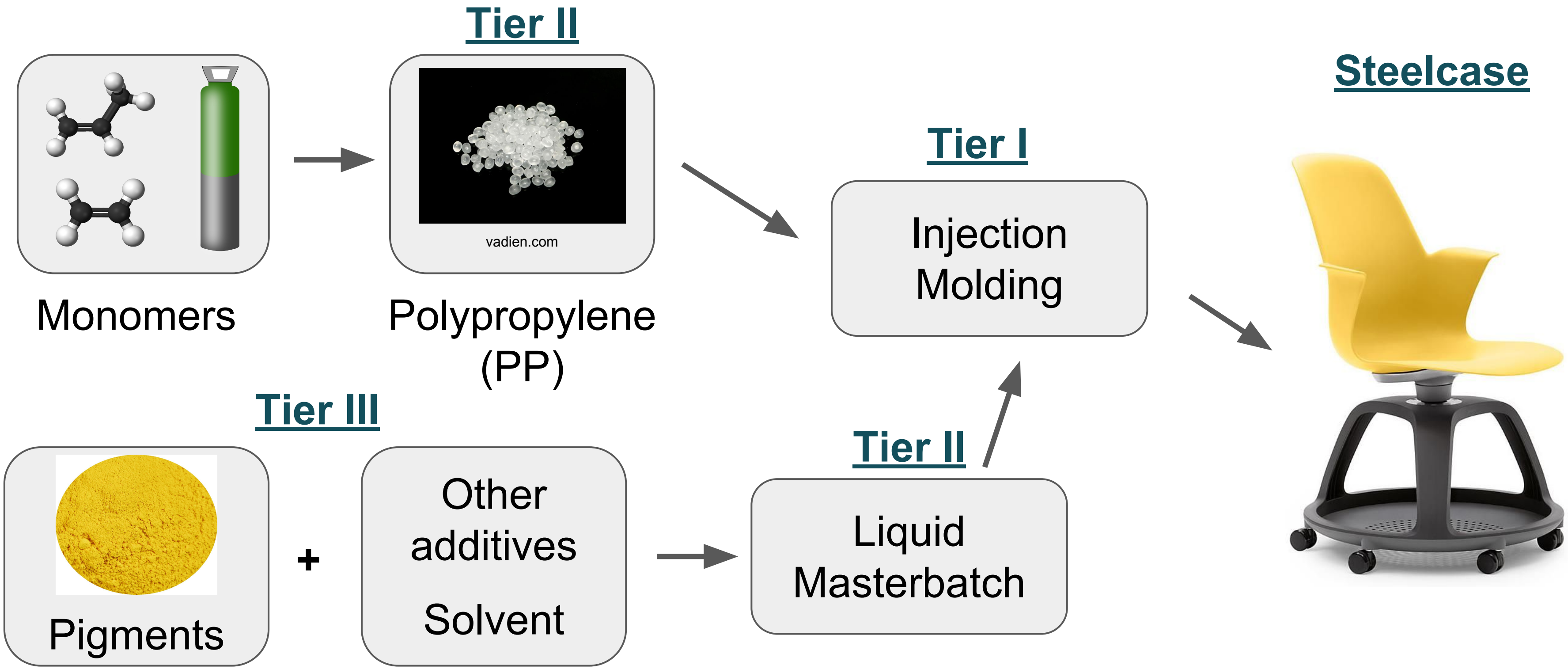
Strategy Implementation



Current Manufacturing

Steelcase

Tier I

Injection Molding

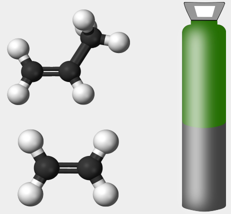
Tier II


vadien.com

Polypropylene (PP)

Liquid Masterbatch

Tier III



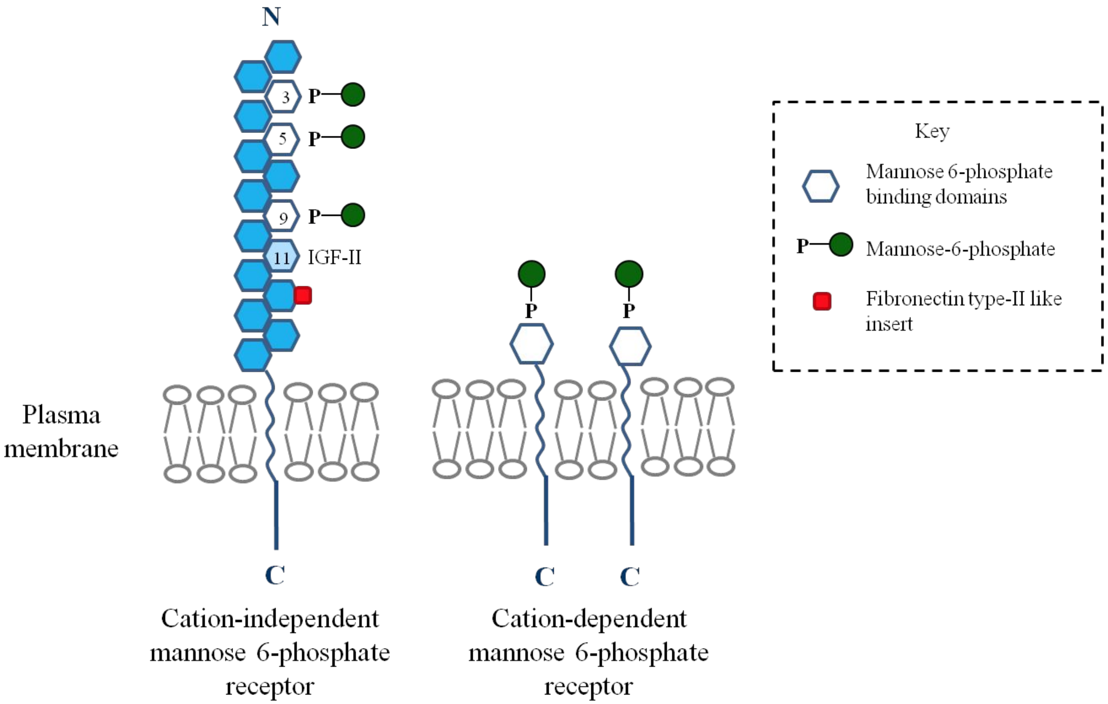
Monomers

Other additives
Sovent
Pigments

PPBPs: Biological Inspiration

Need: System that selectively binds target molecules

Cell surface receptor proteins



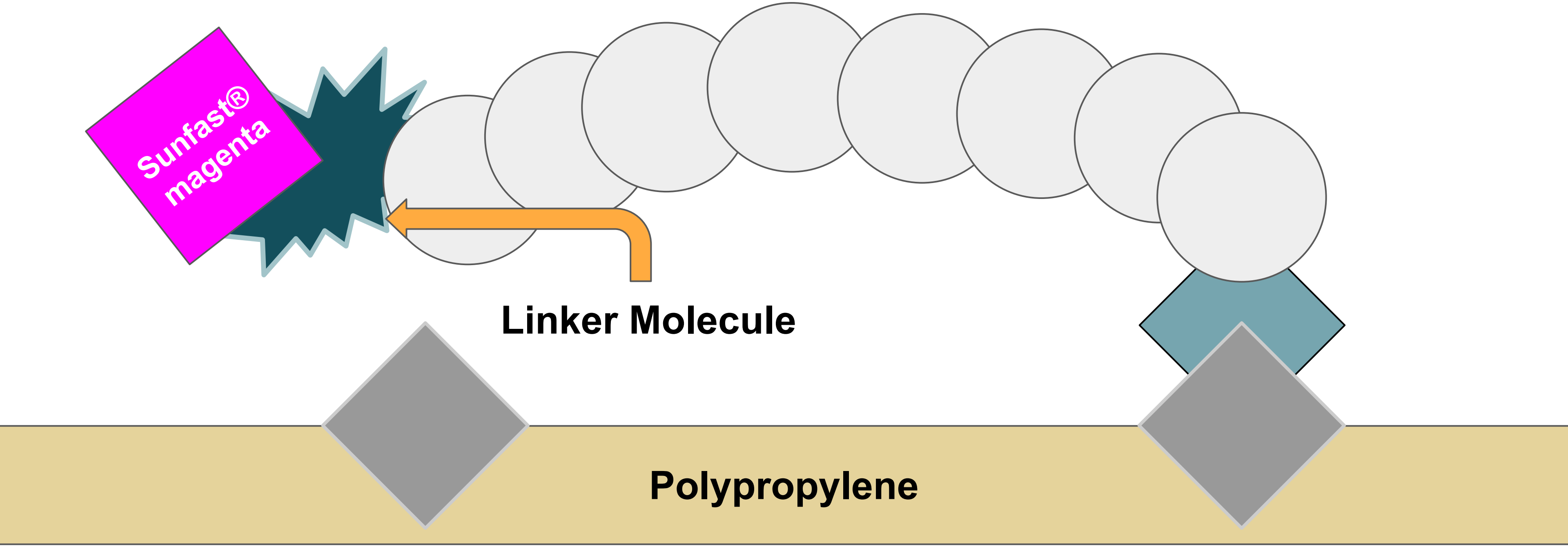
Biological Inspiration Translation

Cell receptor system

Cell Surface Protein	Cell Membrane	Target Molecule
↓	↓	↓
?????	Polypropylene	Pigment

Polypropylene binding system

Polypropylene Binding Peptide



Linker Molecule Hazards

	1-amino-2-propanol	Ethylene glycol	Butylene glycol	Ethanol amine	Phenoxy ethanol
Carcinogenicity / Mutagenicity	No data	1	1	1	2
Reproductive / Developmental Toxicity	No data	2	2	1	2
Sensitization	2	3	1	4	2
Persistence / Bioaccumulation	2	1	1	1	1
Environmental Toxicity	1	1	2	2	2
Acute Toxicity	3	1	1	2	2

Polypropylene Binding Peptide

- Polypropylene binding peptides (PPBP)
- Benefit agent (pigment molecules)
- Optional linker molecules

Cunningham, S. D., Lowe, D. J., O'brien, J. P., & Wang, H. (2011). Polypropylene binding peptides and methods of use. US Patent Office.