InterfacialSolutions

Novel Modified Biopolymers for Durable Applications

Biopolymers Symposium 2012

Dr. Adam R. Pawloski
Technical Director
Coauthors and Contributors: Zachary Oberholtzer*, Aaron Hedegaard**, Dr. Chris Macosko**, Dr. Paul Fowler***, Garrett Van Gorden, Adam E. Szymanski, Brandon J. Cernohous, Gregg S. Bennett, Jeffery J. Cernohous
**Bucknell University, **University of Minnesota, ***Wisconsin Institute for Sustainable Technology, UWSP*

Presentation Overview

- Brief overview of Interfacial Solutions
- PLA as a PVC Replacement: deTerra® Biobased Polymers and Hyperbranching
- Bringing Down the Cost of PLA Compounds
  → Hyperbranched PLA as a Melt Strength Additive
  → Recycling PLA by Hyperbranching
- Future Outlook

InterfacialSolutions

Interfacial Solutions is a leading and independent provider of R&D services to the plastics industry with a proven track record of helping innovators innovate. Our creative team of scientists possess more than 50 patents and are equipped with state-of-the-art polymer testing equipment, compound and processing equipment, and production capabilities to meet a broad range of plastic industry challenges.

Headquarters: River Falls, WI (45 minutes from Minneapolis, MN)

Founded: 2003

Employees: 30 (14 Technical Degrees, 4 Ph.Ds)

Facility: 40,000 sq. ft.

Website: www.interfacialsolutions.com

InterfacialSolutions

Our Mission: Helping Innovators Innovate

Our Strength: Delivering Material Science Solutions Quickly

Our Record: >$300MM of Customer Sales Enabled in Several Markets

Our Business: Flexible Business Models to Meet Customer Needs

Intellectual Prop. Creation & Development

- Contract Research & Development
- Contract Manufacturing Scale-Up
- Manufacturing Modeling and Transfer
- Patent and Know How Licensing

Products and Contract Services

- Contract Melt Processing Services
- Contract Laboratory Testing Services
- Custom Compounding
- IFS Products
  (deTerra®, deVerde™, SeQuest™)

InterfacialSolutions

Our Mission: Helping Innovators Innovate

Materials Expertise

- Polymers
- Natural Fibers and Fillers
- Adhesives
- Coupling Agents
- Compatibilizers
- Polymer Processing Additives
- Flame Retardants
- Moisture Scavengers
- Nanoparticles
- Biopolymers
- Foaming Agents

Process Expertise

- Twin Screw Extrusion
- Reactive Extrusion
- Super Critical Foaming
- Cast Films and Sheet
- Blown Films
- Injection Molding
- Pelletizing
- Grinding
- Foaming
- Process Development
- Costing

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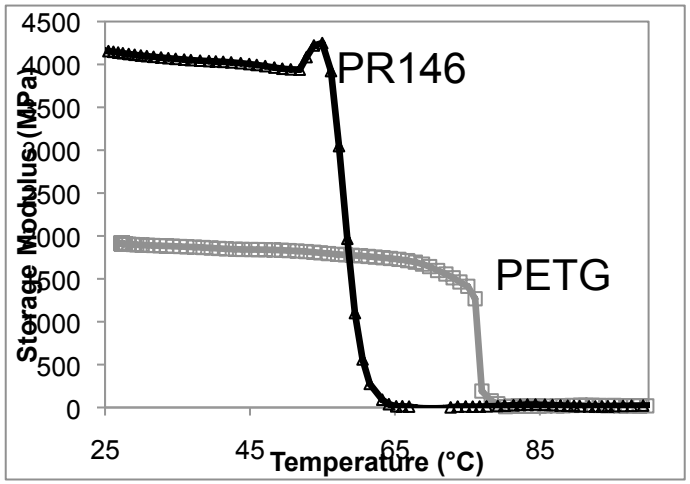
*PLA as a PVC Replacement: **deTerra®** Biobased Polymers and Hyperbranching*

Motivation: The Plastics Industry Needs a PVC Replacement

- PVC has many attributes that make it a good choice for plastics in durables applications:
  - → Inexpensive, good mechanical properties, flame retardant
- However, PVC has a poor environmental profile
- It is desirable to replace PVC with alternatives
  - → PETG is being actively explored by the industry
  - → PLA could be used successfully if cost and properties, like impact resistance and flame retardancy, are engineered into compounds

PVC Replacement Challenges

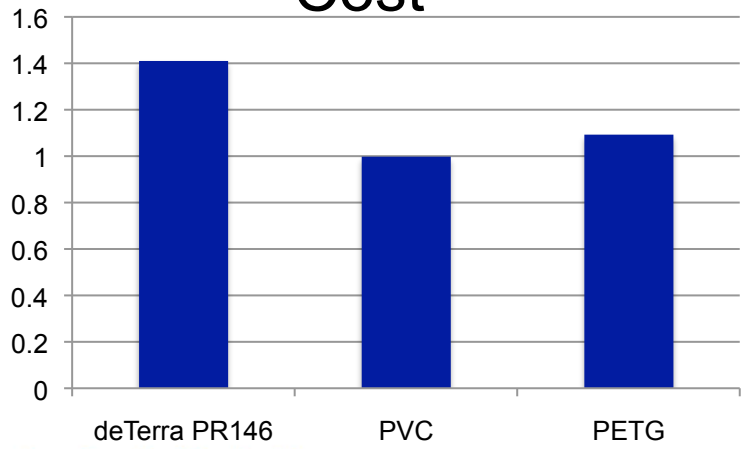
Thermal Resistance



Impact Resistance

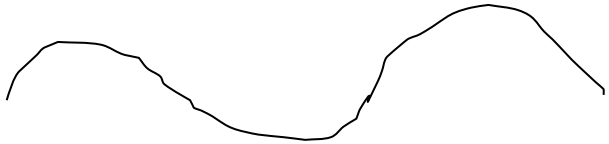
Material	Notched Izod Impact (ft-lbs/in)
PVC	~15
PETG	~10
PR146	~1
Virgin PLA	~0.3

Cost

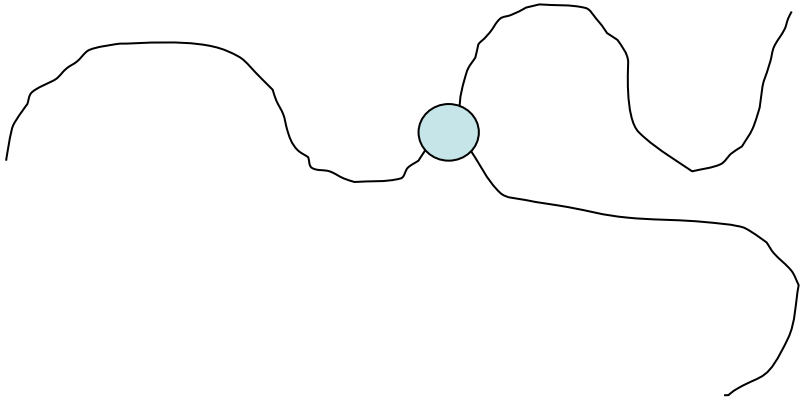


And PVC is intrinsically flame retardant

Linear and Chain Extended PLA



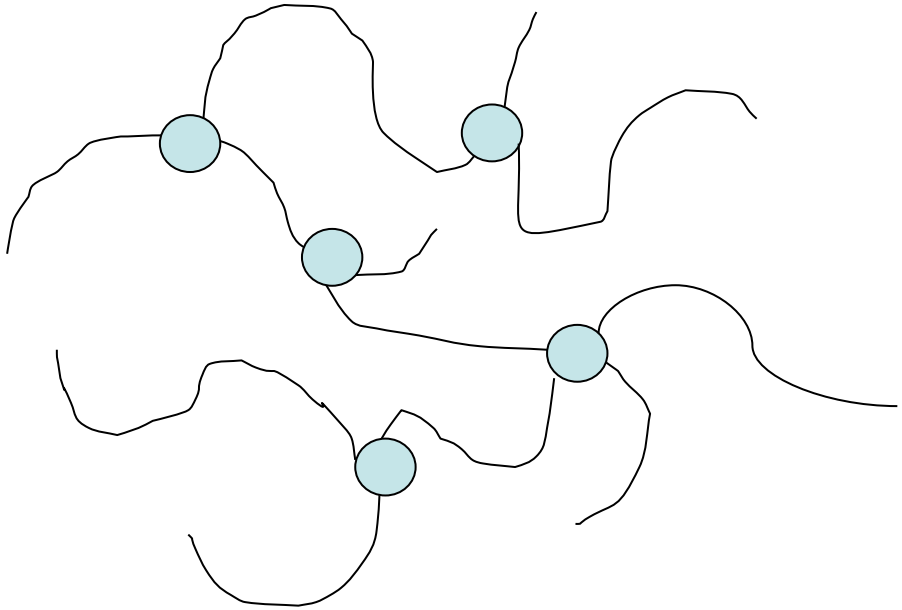
Linear PLA Polymer



Chain Extended Polymer
(PLA + chain extender by reactive extrusion)

Ex: CESA-Extend, Joncryl, other epoxides

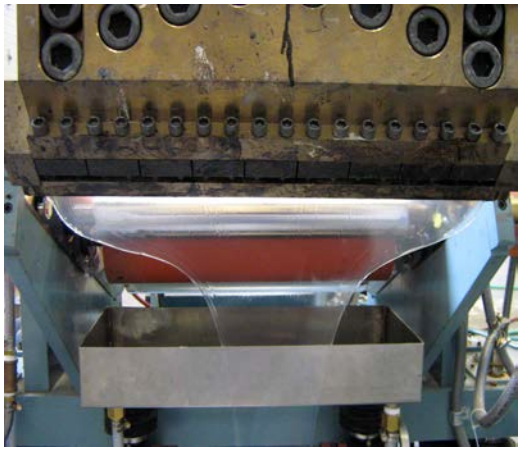
Hyperbranching of PLA



Hyperbranched PLA
(PLA + IFS Proprietary Chemistry by Reactive Extrusion)

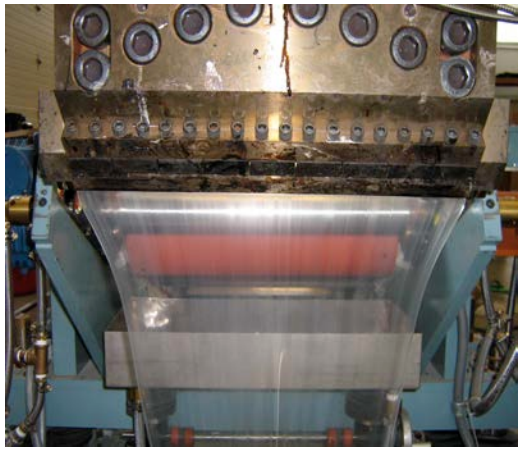
- The basis for IFS deTerra® bio-based polymers
  - → Greatly improved melt strength and processing
  - → Unique rheology
  - → Enables improved compounds, including flame retardant grades

Melt Strength



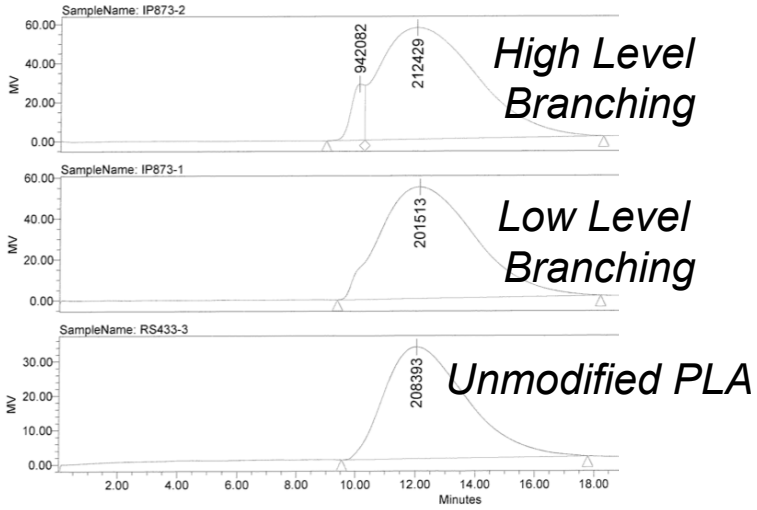
NatureWorks 2003D PLA

Low Level of Branching



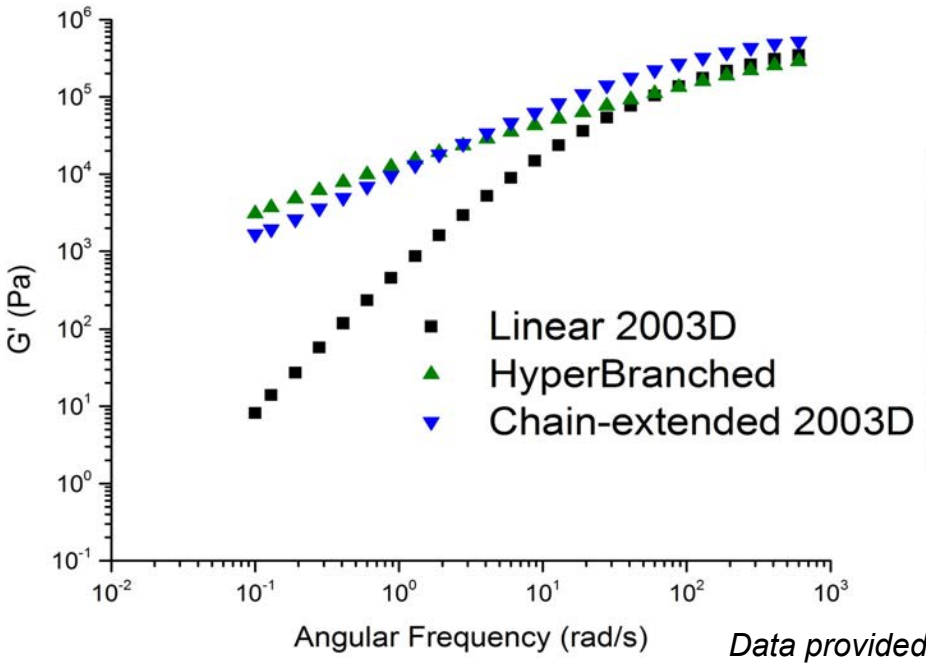
High Level of Branching

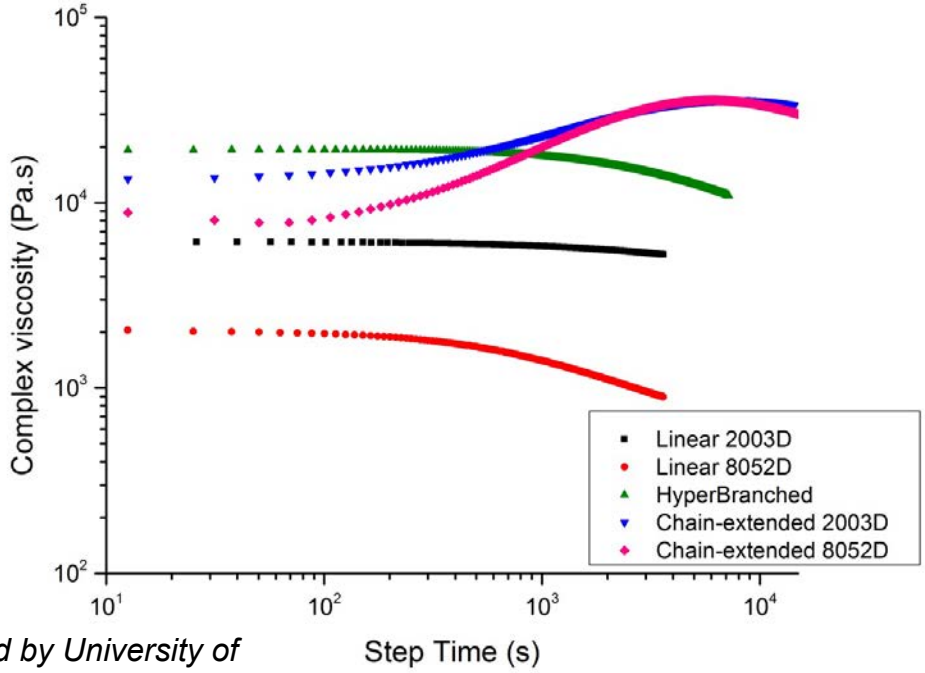
- Linear PLA has poor melt strength
- Chain branching increases melt strength and stabilizes the extrusion curtain



Unique Rheology of Hyperbranched PLA

- Small amplitude oscillatory shear rheometry (180°C)
- Chain extended and hyperbranched materials show similar increase in modulus (stiffer melt)
- Chain extended materials continue to react

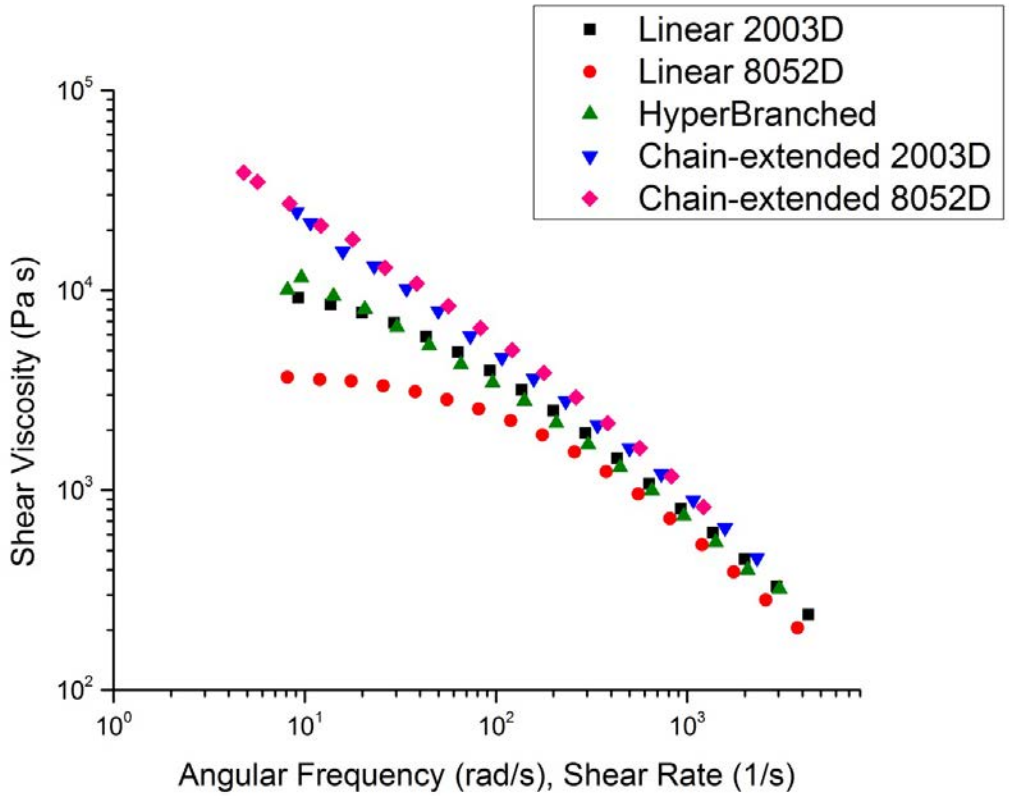




Data provided by University of Minnesota (Macosko Group)

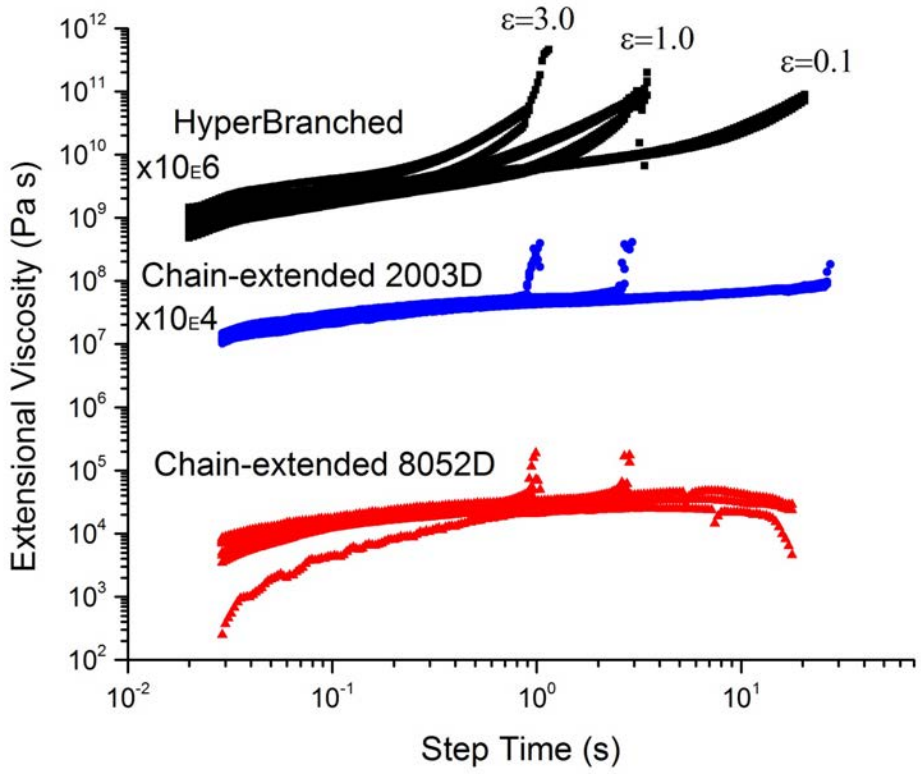
Unique Rheology of Hyperbranched PLA

- Capillary rheometry → extensional viscosity at high extension rates
- Mimics extrusion processing conditions
- Shear viscosity of hyperbranched PLA is less than that of chain extended PLA
- Hyperbranched PLA will exhibit advantage in reduced extruder torque and die pressure



Unique Rheology of Hyperbranched PLA

- Hyperbranched PLA is the only PLA to exhibit strain hardening behavior as determined by extensional viscosity
- Advantage for foams to prevent cell collapse



deTerra® Biobased Polymer Property Summary

Grade	Biobased Content (%)	Specific Gravity (g/cc)	Flexural Modulus (psi)	Flexural Strength (psi)	Notched Izod Impact Strength (ft-lbs/in)	Melt Flow Index (g/10 min @ 190C, 2.12 Kg)
PR146	93	1.25	550,000	12,000	0.8	1.0
XP345	76	1.30	600,000	11,200	0.95	18.0
XP698	85	1.25	380,000	8,600	16.5	28.0
XP696	93	1.26	520,000	12,600	1.2	1.0
XP752	99	1.24	450,000	17,000	1.2	11.0
Ingeo 2003D	100	1.24	450,000	14,000	0.3	7

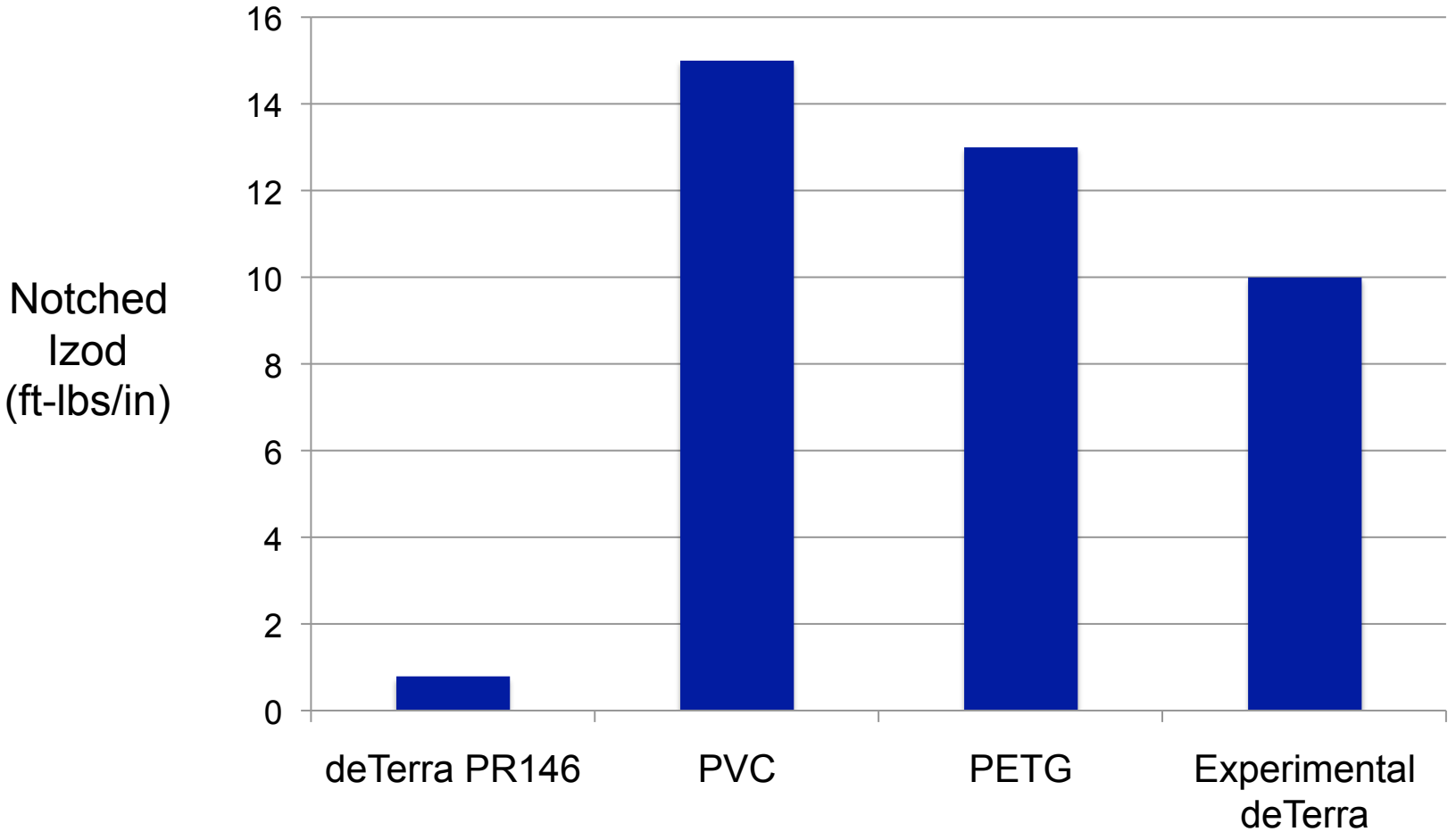
- FR deTerra® grades offer excellent flexural strength and modulus
- Comparable specific gravity to PLA
- The impact strength for deTerra® FR grades are improved vs PLA
- Injection molding grade has impact performance comparable to PVC
- deTerra® melt flow index/rheology can be tailored for extusion or molding

UL94 Flammability

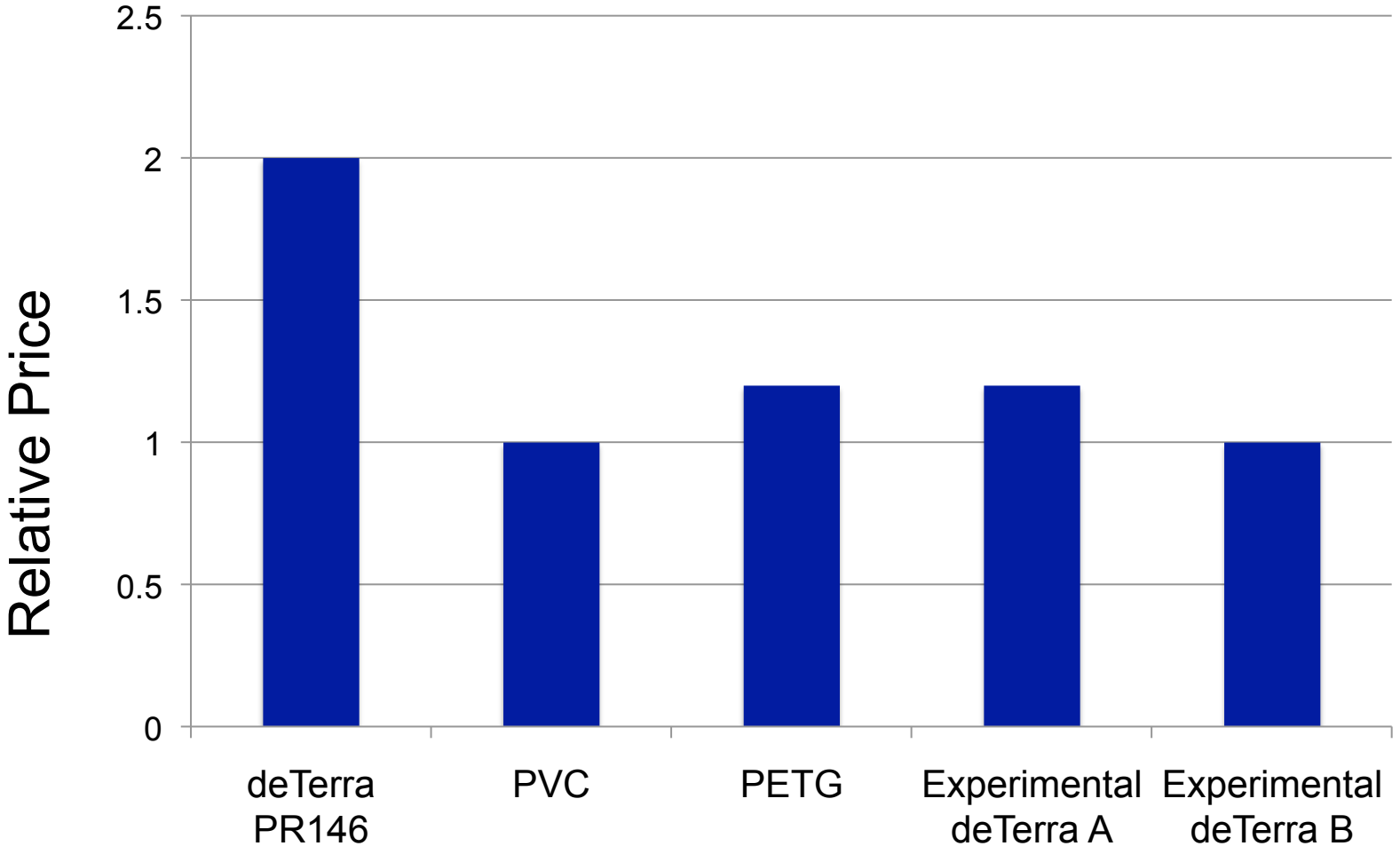
Grade	Biobased Content (%)	Specific Gravity (g/cc)	E84 Results	UL94 V Results	UL94 H Results	Limiting Oxygen Index
PR146	93	1.25	0 Flame Spread, <70 Smoke Index	V2	HB	24
XP345	76	1.30	Not Determined	V0	HB	28
XP696	93	1.26	Not Determined	V2	HB	23
Ingeo 2003D	100	1.24	Not Determined	Not Rated	HB	22

- High biobased content for all FR deTerra® grades
- Comparable specific gravity to PLA
- Outstanding E84 fire ratings and characteristics
- V2 and V0 deTerra® options for molding and extrusion
- LOI results correlate with flame performance observed

FR + Impact Strength Solution



Target Economics



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Bringing Down the Cost of PLA Compounds

- → *Hyperbranched PLA as a Melt Strength Additive*
- → *Recycling PLA by Hyperbranching*

Bringing Down the Cost of PLA Compounds

- Two approaches to reduce PLA compound costs for customers
  - Use less → make hyperbranched PLA an additive for improving melt strength
  - Incorporate recycled PLA (post-industrial or post-consumer)

Hyperbranched PLA as an Additive

- As an additive, hyperbranched PLA can be added to linear PLA and compounds to increase melt strength
  - Non-reactive strategy
  - 5 to 50wt% addition levels effective

100% 2003D PLA

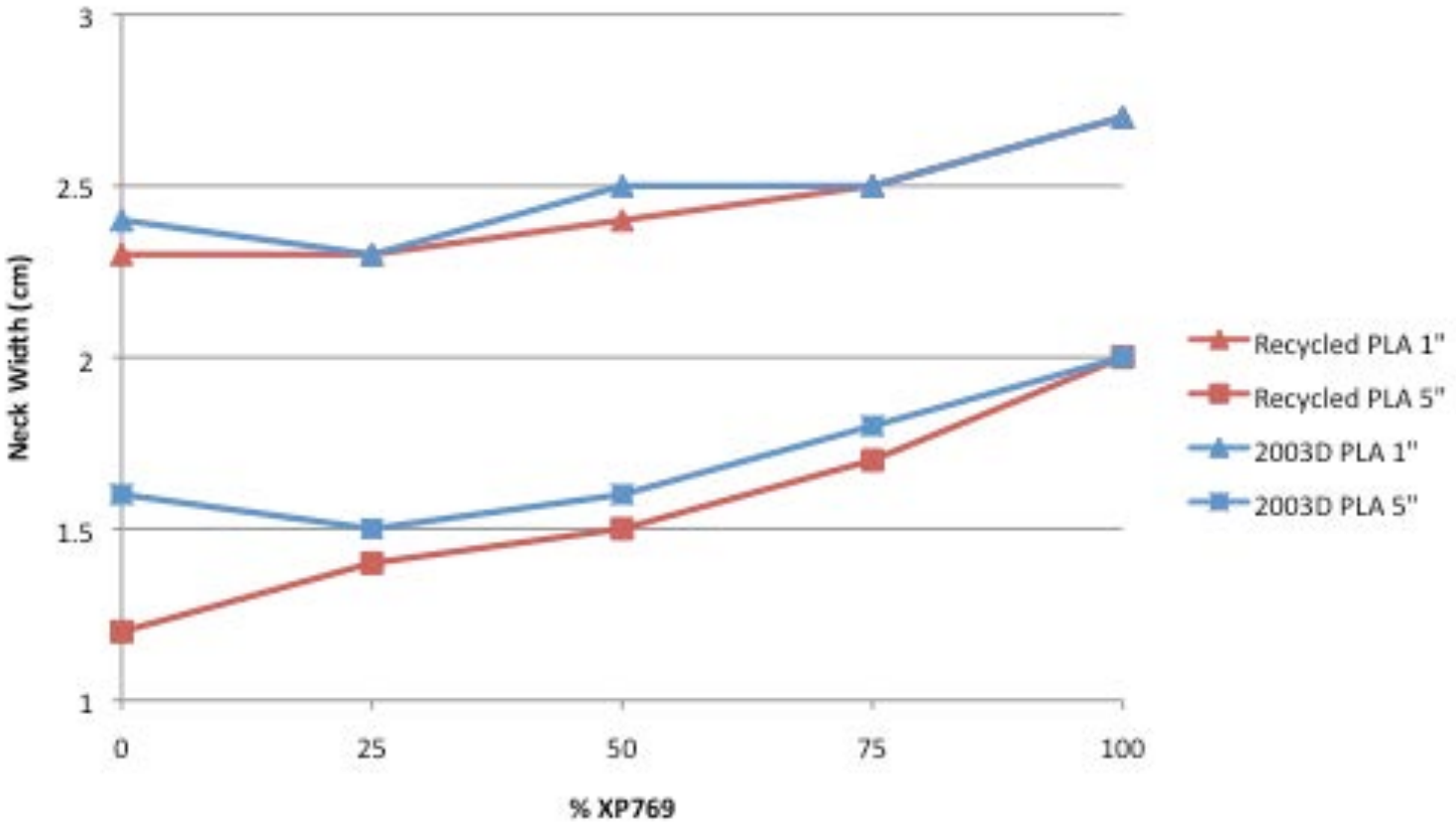
100% Recycled PLA

50% Recycled PLA
50% XP769

50% 2003D PLA
50% XP769

Hyperbranched PLA as an Additive

- More is better for improving processability, but addition levels of 10 to 50% can be effective in many processes



Hyperbranched PLA as an Additive

- Modified PLA resins with high levels of hyperbranching can be let down into standard PLA resins to improve processability
- Retains good mechanical properties and increases processability

Resin	MFI (g/10min, 190°C, 2.16kg)	Tensile Strength (psi)	Tensile Modulus (psi)	Tensile Elongation (%)	Notched Izod Impact Strength (ft-lb/in)	Unnotched Izod Impact Strength (ft-lb/in)
Virgin PLA (NatureWorks 2003D)	6.0	8600	511000	2.1	0.61	4.2
XP759	2.7	9100	492000	2.3	0.57	5.5
5% Hyperbranched PLA Additive	6.2	8070	479000	2.0	0.54	4.4
20% Hyperbranched PLA Additive	3.9	8370	485000	2.0	0.55	4.5

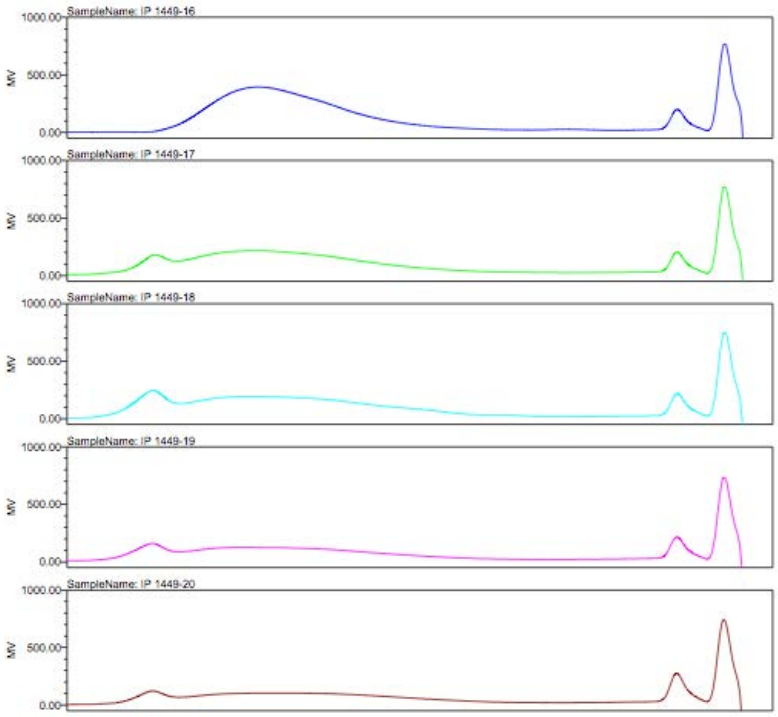
Recycling PLA

- The sustainability message of PLA is not as good as it could be
- Many product applications seek biobased content over compostability
  - → Compostability standards are challenging for durables
  - → Industrial composting is limited in US
- Only limited recycling of PLA
  - → Recycled PLA exhibits poor properties due to loss of MW by hydrolysis; difficult to process
  - → Consumer waste goes into mixed plastics and is not recycled
  - → Much goes into landfill

Hyperbranched, Recycled PLA

- IFS hyperbranching technology to upgrade recycled PLA resins to better-than-virgin properties
- Prestigious NSF SBIR Phase I award granted in July 2012

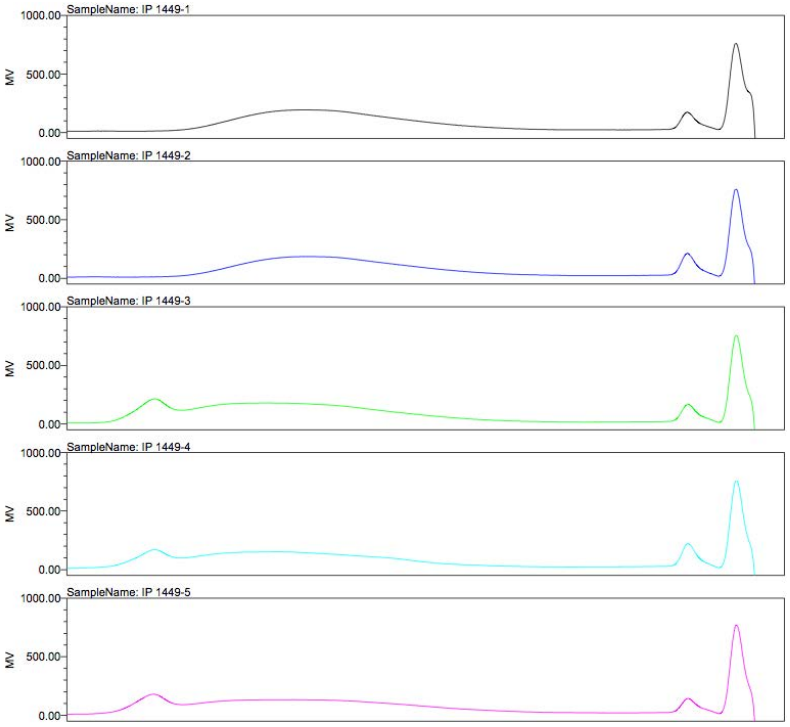
Hyperbranching with Virgin PLA



Starting Resin

Increasing Degree of Branching

Hyperbranching with Post-Industrial PLA



Hyperbranched, Recycled PLA

Resin	MFI (g/10min, 190°C, 2.16kg)	Mw (g/mol)	Flexural Strength (psi)	Flexural Modulus (psi)	Tensile Elongation (%)	Notched Izod Impact Strength (ft-lb/in)	Unnotched Izod Impact Strength (ft-lb/in)
Virgin PLA (NatureWorks 2003D)	6.0	219907	15500	500000	2.1	0.61	4.2
XP759	2.7	426625	15600	470000	2.3	0.57	5.5
Prime Grade Post-industrial PLA	11.8	145331	15300	475000	2.2	0.61	5.0
Low level hyperbranching	6.8	141684	15300	474000	2.2	0.65	5.0
Intermediate level hyperbranching	3.2	464396	15500	470000	2.3	0.60	6.8
High level hyperbranching	1.6	469717	15500	474000	2.3	0.61	6.0
Low Grade Post-Industrial PLA	420.0	108147	6400	502000	0.8	0.50	3.5
Low level hyperbranching	285.0	125181	9800	500000	1.4	0.50	4.2
Intermediate level hyperbranching	290.0	144722	12200	505000	1.6	0.50	4.9
High level hyperbranching	130.0	299369	13500	489000	1.7	0.60	3.7
Post-Consumer PLA							

- Source of recycled PLA can vary substantially
- Emerging market for PLA regrind from distributors
- Teamed with Wisconsin Institute of Sustainable Technology (WIST) at UWSP for collection of post-consumer PLA
- Tuning the chemistry and process conditions for reactive extrusion can “dial-in” the properties of the hyperbranched, recycled product

Future Outlook

- Interfacial Solutions' proprietary hyperbranching technology can dramatically improve the quality of virgin and recycled PLA resins
- deTerra® compounds with extremely high biobased content can compete with PVC in many application areas

  → Sustainable solutions exist
- Further improvements in performance and cost are under development

Acknowledgements

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- Disclaimer: Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Thank You!

Interfacial Solutions, LLC
949 Antler Ct.
River Falls, WI 54022
(715) 425-7957