

2024 FlexPack PLACE Conference

April 14-17, 2024 • San Diego, CA • Wyndham San Diego Bayside



Optimizing compostable PLA biopolymer extrusion coatings for improved performance and tailored degradability rates.

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Nature builds things from CO₂ and so do we.



GREENHOUSE GASES

Our process starts with greenhouse gases

Nature looks at greenhouse gases, like atmospheric carbon, as a feedstock, a raw material.



PLANTS

Plants convert CO₂ into sugars

Sustainably grown, renewable agricultural feedstocks are used to convert CO₂ into starches.

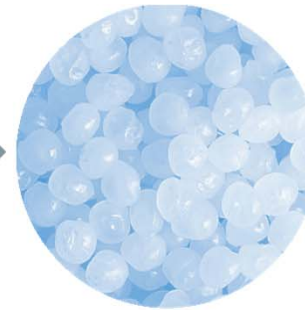
SUGARS



MANUFACTURE

Creating lactic acid, the building block of PLA

Plants are put through a milling process extracting the starch (glucose). Enzymes are added to convert the glucose to dextrose via a process called hydrolysis. Microorganisms then ferment this dextrose into lactic acid.



ingeo BIOPOLYMERS

Transforming lactic acid into lactide

A proprietary two-step process transforms lactic acid molecules into rings of lactide, which is a valuable chemical on its own for use in many downstream markets.



PRODUCTS

Polymerizing lactide into PLA

The lactide ring is opened and linked together to form the long chain of polylactide polymer we call Ingeo. We form this long chain into pellets that are shipped around the world to our customers who transform them into a wide range of innovative products.



Resurgence in Paper-based Packaging

Thinking about Biobased



PAPER +
PACKAGING
BOARD

60% see paper as part of the environmental solution while 53% see plastic as part of the problem (November 2021 Attitudes Survey)



PLA Coated Paper Products are Versatile

Fiber recovery if
paper-based and clean



Compostable packaging for
organics recycling if food soiled



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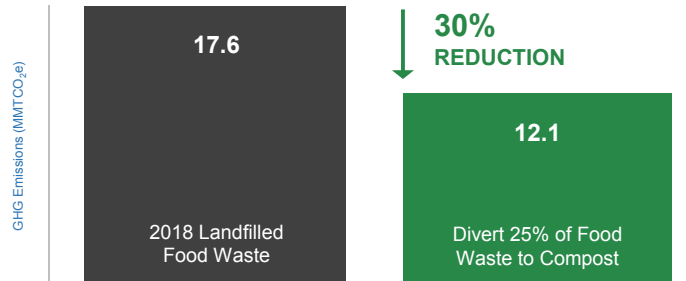


Biotechnology and Biomanufacturing R&D to Further Climate Change Solutions

- Goal 2.2: Spur a Circular Economy for Materials
- Convert bio-based feedstocks into recyclable-by-design polymers that can displace >90% of today's plastics
- Goal 1.4: Reduce Methane Emissions
- By 2030, reduce methane emissions from food waste in landfills, to support the U.S. and global goals



Diverting another 25% of the food waste landfilled in 2019 to compost facilities would reduce the associated GHG emissions by approx. 30%.



Baseline 35.3 million tons of food waste disposed of in landfills in 2018

Divert 25 percent (8.8 million tons) to compost and landfill 26.5 million tons of food waste

Comparison of Life Cycle GHG Emissions for U.S. Food Waste Diversion from Landfills

Bold Goals for U.S. Biotechnology and Biomanufacturing

Harnessing Research and Development to Further Societal Goals

Per Executive Order 14081

Compiled by

The White House Office of Science and Technology Policy

Including
U.S. Department
U.S. Department
U.S. Department
U.S. National Science

Plastics Recycling Coverage PAGES 6-8 POLYMER POINTS WITH FRANK ESPOSITO PAGE 20

Plastics News

March 2



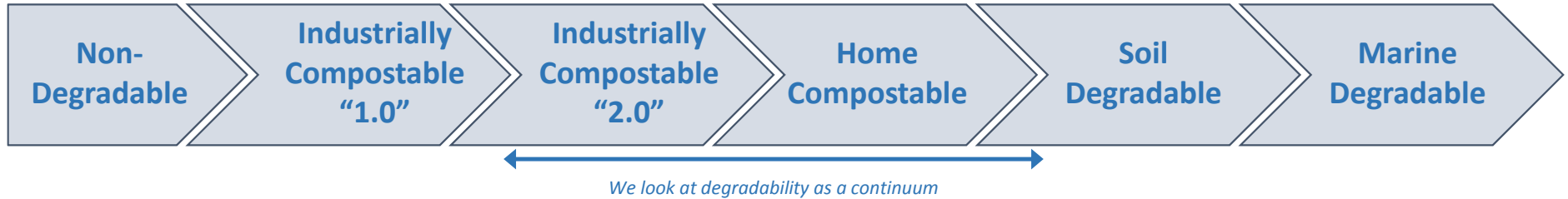
March 2023





Developing Accelerated Degradability / Compostability

Diverting more waste from landfills to compost facilities means there will be increased interest in processing the compost faster on existing acreage across the US.



What does faster mean?

- Composts quickly in a broad range of environments
- We have seen capital investment in Aerated Static Piles (ASP) with ~40 days cycle time
- California seeking 60 days to biodegrade

And we're investing significantly in tailoring polymer grade design to vary degradability in appropriate end environments ...



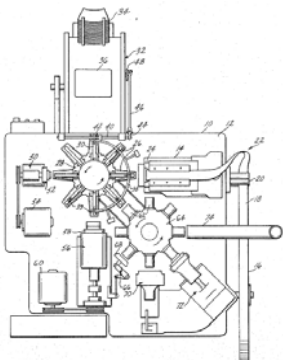
Solution: Equipment + Ingeo™ PLA

Industrially compostable today, home compostable tomorrow

Safe Serviceware



- Food safety compliances
- No taste or odor impact
- Certified compostable, repulpable and recyclable
- 90% biobased



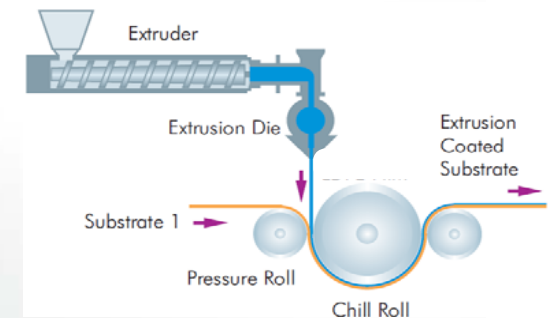
INVENTOR:
PAUL A. CORAZZO

Cup Making

- Ductility to handle fastest production speeds
- Secure seals at seams and caulked pleats and folds preventing leaks
- Tight uniform lip rolls assure good lid fit

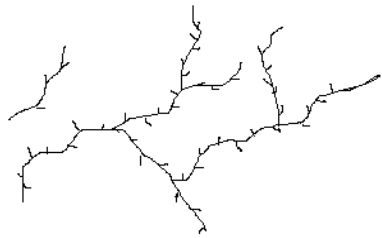
Melt Processing

- Melt curtain strength and stability for high production rates and yields
- Low viscosity for adhesion at low coat weights





A Primer: Molecular Architecture that Forces Compromises



LDPE

Long and short chain branches
Broad molecular weight distribution
Tough at room temperature

- During processing, LDPE has high melt strength and low viscosity.
 - Low neck-in
 - No draw resonance
 - Increase adhesion through oxidation
- Linear PE blended with 10-20% LDPE becomes an extrusion coating grade.



PLA

No branching, all linear molecules
Narrow molecular weight distribution
Brittle at room temperature

- During processing, PLA has **low melt strength** and **high viscosity**.
- High neck-in
 - Draw resonance limits line speeds
 - Increase adhesion reducing heat loss

Legend	Experimental data
LDPE	Marlex™ 4517
PLA	Various types
'Ext Ctg PLA'	Ingeo™ 1102
'Next Gen Ext Ctg PLA'	975-86-03



Expanding our Product Design “Toolbox”

Enhancing processability, functionality and end-of-life

Chemical:

- Additive Content (e.g., prodegradant, enzyme, etc.)
- Polymer Chain Length (Molecular weight)
- Comonomer content
- Chain “end group” chemistry & reactivity
- Polymer Blends (PBS, PBSA, PCL, PBAT, PHA, etc.)
- Copolymers: block, random

Physical:

- Thickness of the part
 - For films or sheet (gauge)
- Surface Area, Morphology

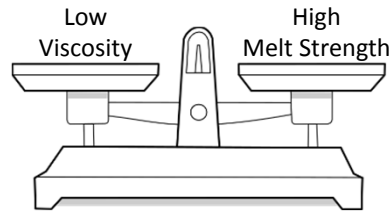
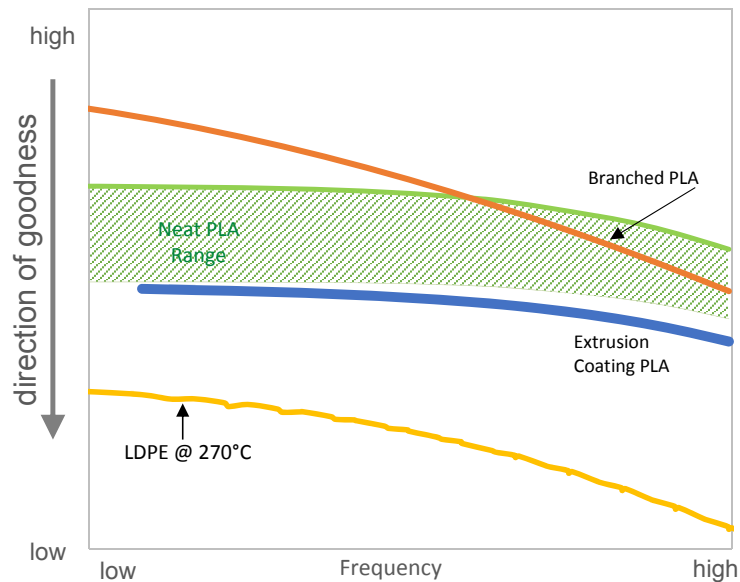




Comparing Extrusion Coating Melt Behavior

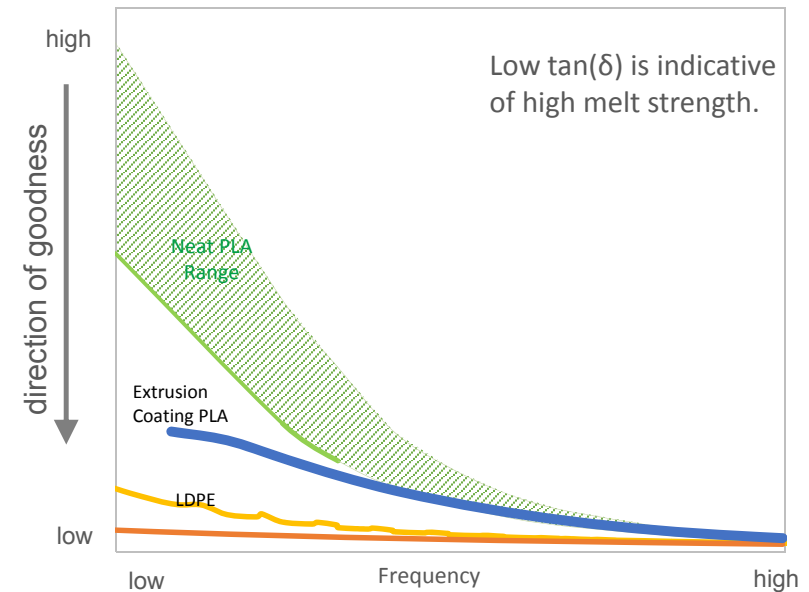
Want Low viscosity to penetrate easily into the paperboard

Viscosity



Want High melt strength to decrease neck-in and stabilize the web

Tan(δ)



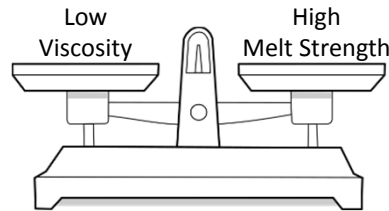
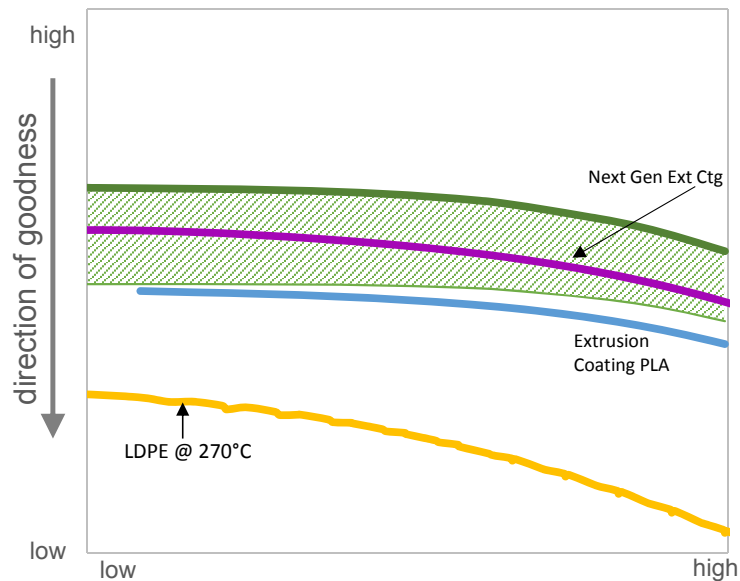
[DMA Rheological Data: Parallel Plate Rheometer @ 210°C]



Comparing Extrusion Coating Melt Behavior

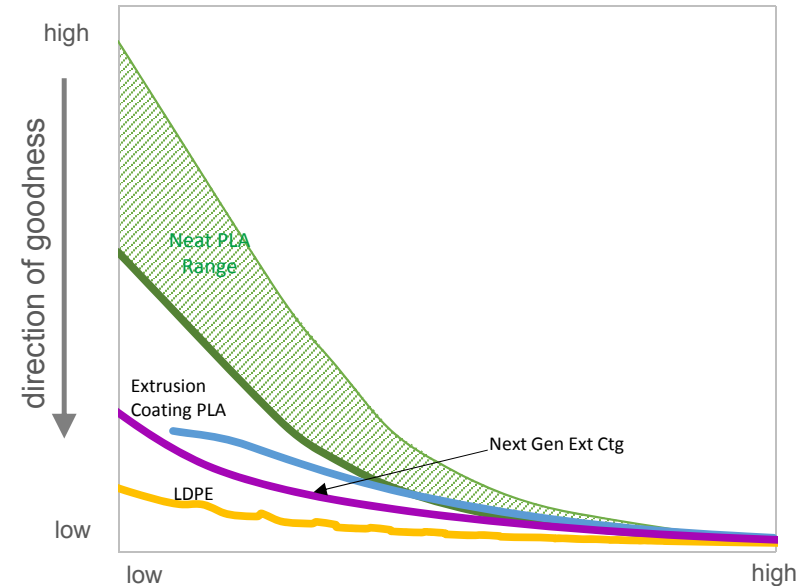
Want Low viscosity to penetrate easily into the paperboard

Viscosity



Want High melt strength to decrease neck-in and stabilize the web

Melt Strength



[DMA Rheological Data: Parallel Plate Rheometer @ 210°C]

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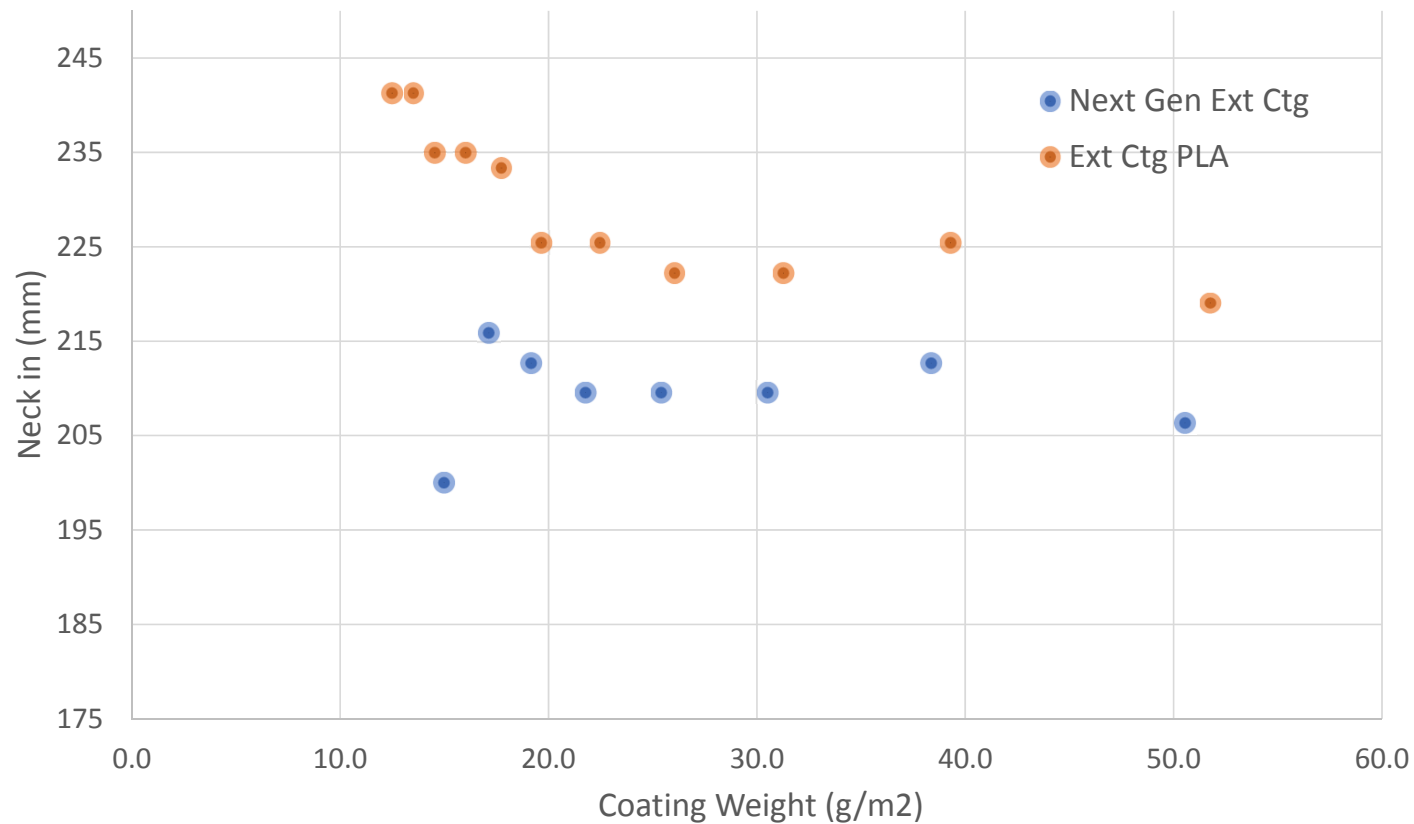


Improved Toughness

Material Property	Testing standard	'Ext Ctg PLA'	'Next Gen Ext Ctg'
Gardner Impact MFE (in*lb)	ASTM D5420	8.7	10.2
Elongation at Break	ASTM D-638	4.82	15.92
HDT	ASTM D-648	49.9	49.51
Vicat	ASTM D-1525	55.8	56.6



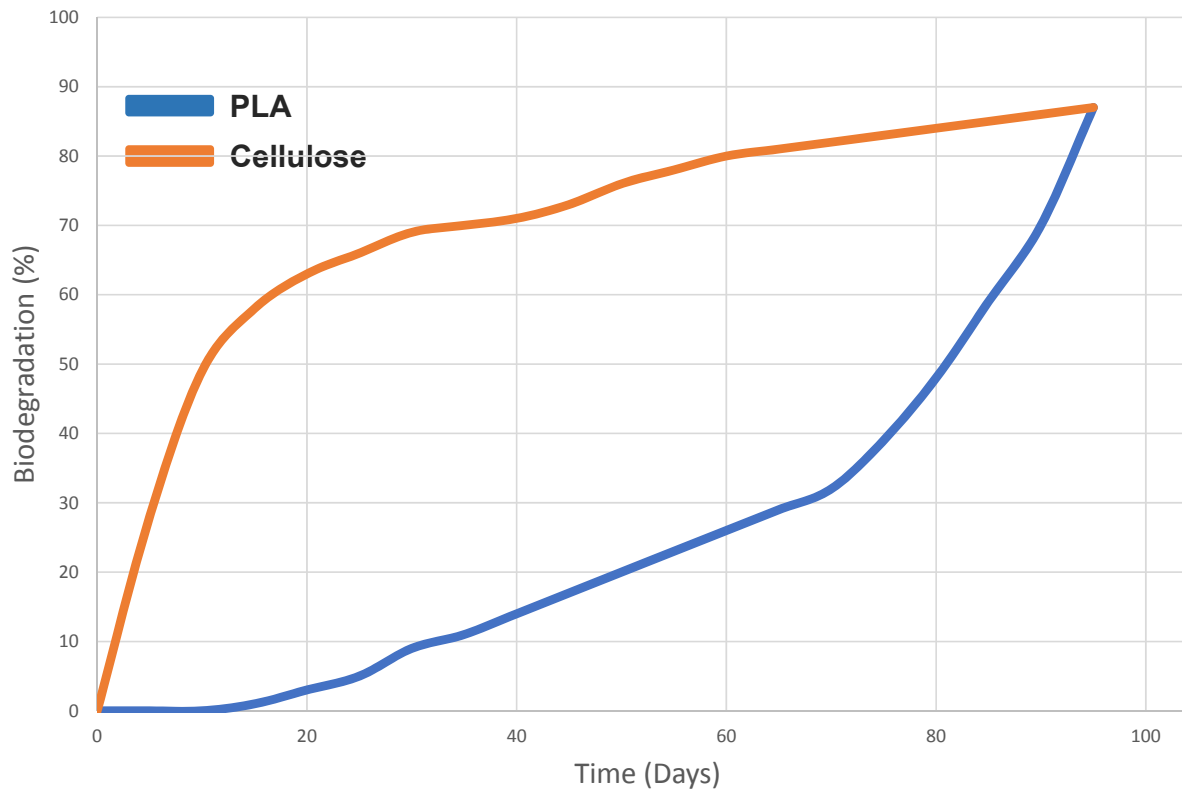
‘Next Gen Ext Ctg’ Shows Less Neck in





PLA Biodegrades Under Industrial Conditions

Biodegradation PLA at 58C



COMPOSTABLE

COMMERCIALY
COMPOSTABLE ONLY

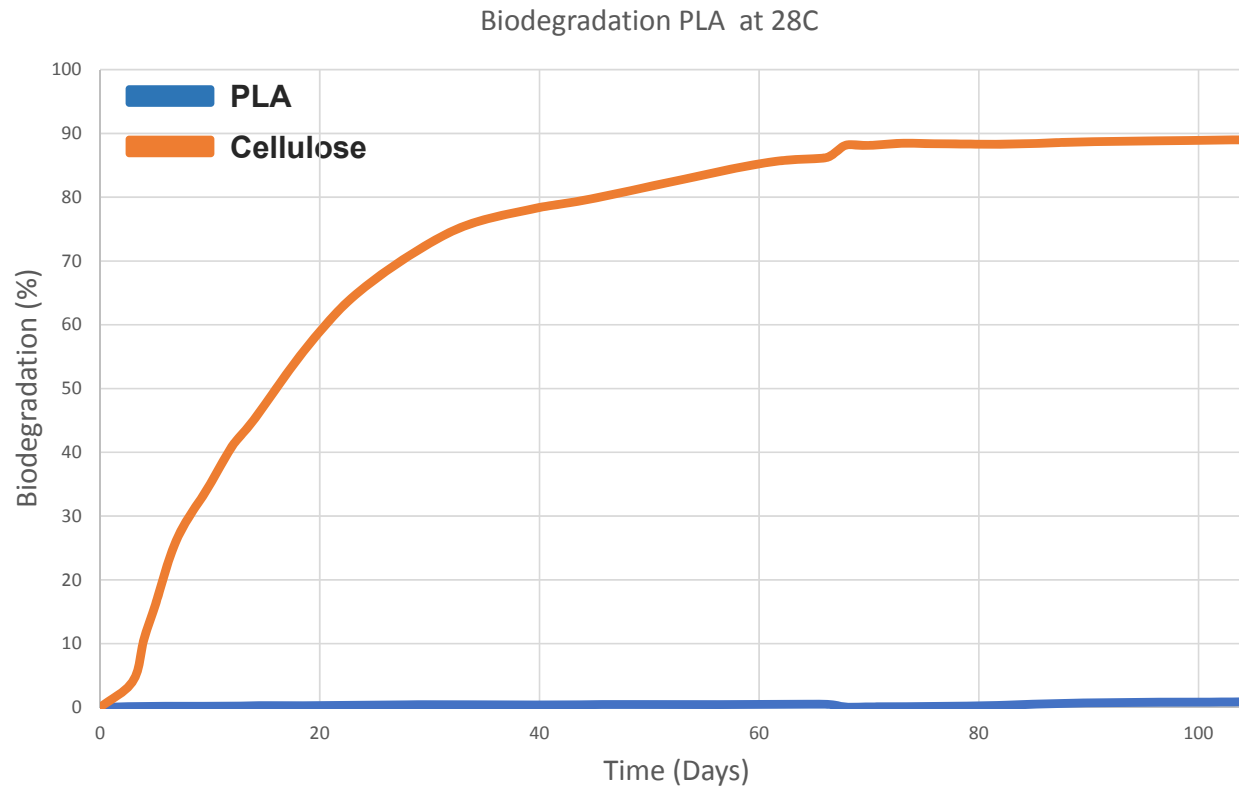


FACILITIES MAY NOT
EXIST IN YOUR AREA

- Biodegradation of PLA under ASTM 5338 (58°C)
- External labs will test biodegradation
- They test how long microorganisms take to convert the material to CO₂
- Composting requires biodegradation and disintegration



Biodegradation of PLA Under Home Composting Conditions (28°C)

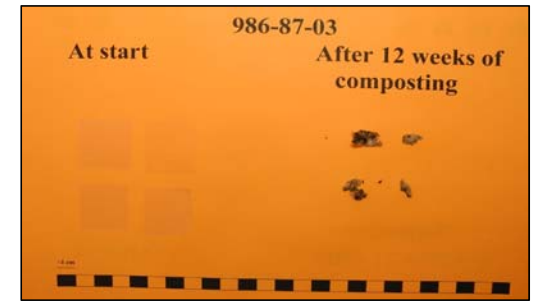
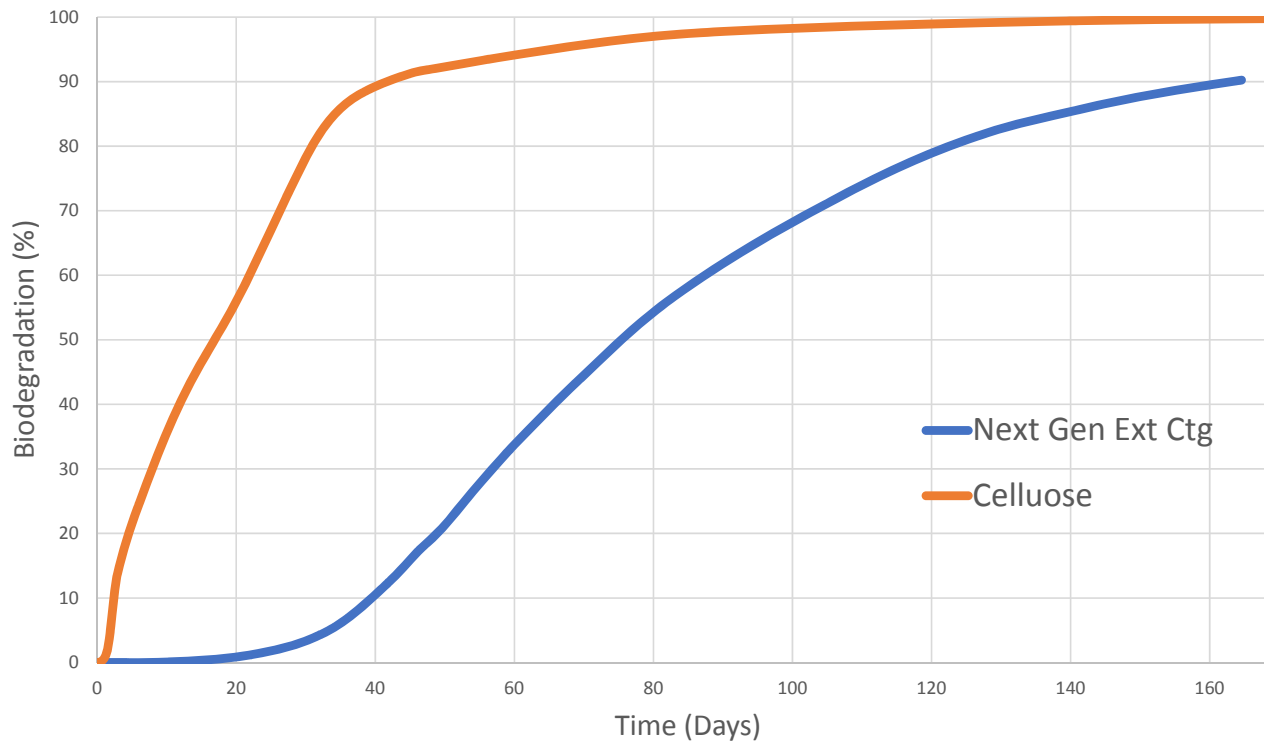


No measurable biodegradation
after 195 days of testing.



'Next Generation Extrusion Coating PLA' at 28°C

Biodegradation 'Next Gen Ext Ctg' at 28C



Very small and very fragile pieces

Passing biodegradation in 365 days, and disintegration in 26 weeks

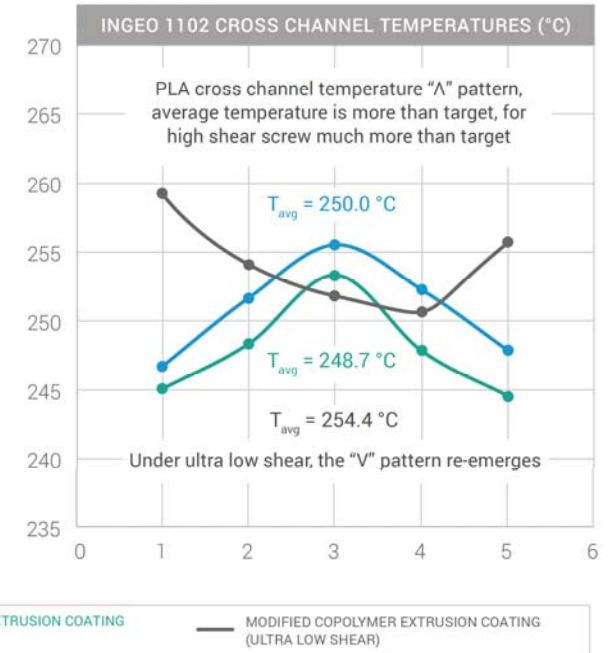
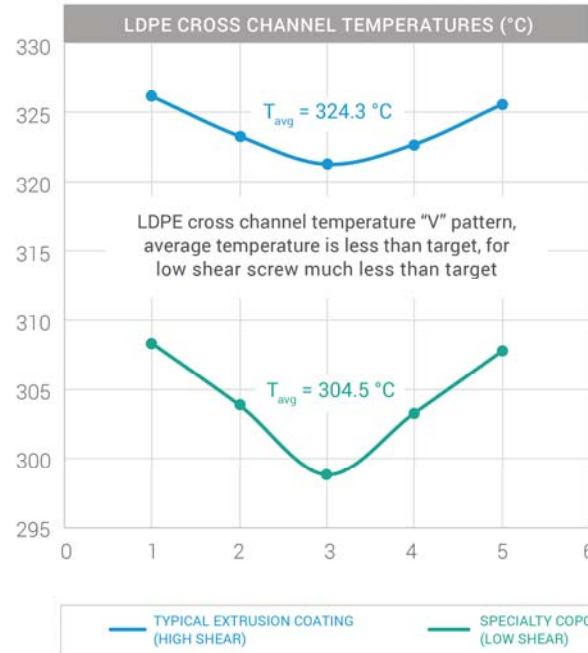
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Differing melt temperature profiles should drive design changes that can increase extruder output at acceptable temperatures.

- What is good for a low viscosity thermally stable polymer (LDPE) is not good for a high viscosity thermally sensitive polymer (PLA)
- Measuring temperature only at channel edge does not accurately reflect mid-channel melt temperatures. With Ingeo, the true melt temperature is likely hotter than edge measurements indicate.



Process recommendations
In addition to drying resin

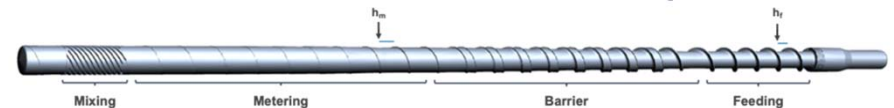
Low shear high output
screw design

Minimize
Die Lip Gap

Keep melt temperature
<250°C or <482°F

Consider edge
encapsulation
extruder

Low Shear Design for PLA

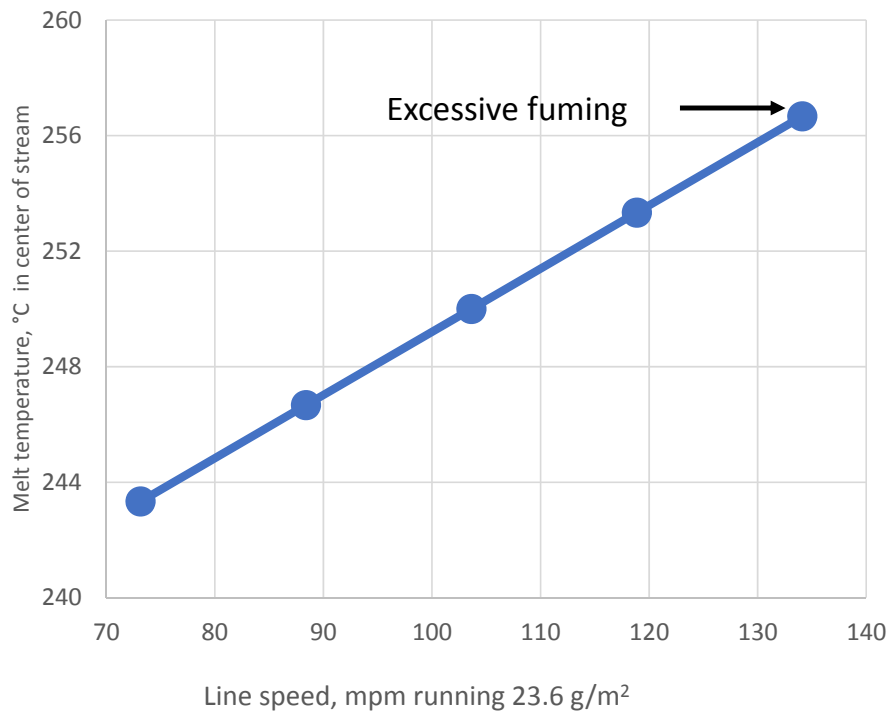


General Business

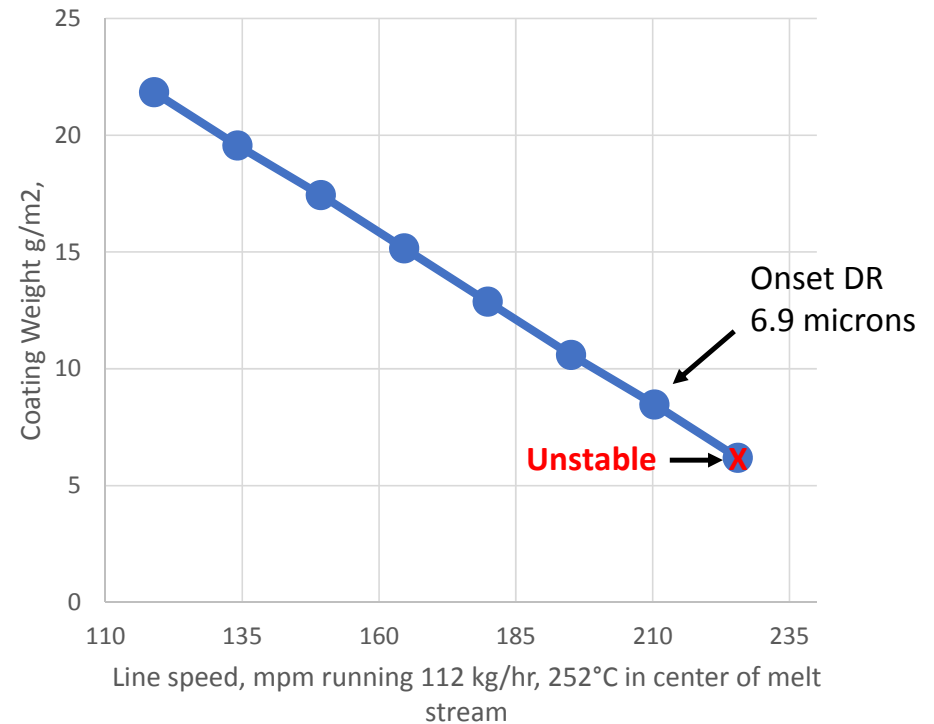


Optimized processing further demonstrates stable melt curtain and low coat weight potentials

Center of melt stream °C; testing max screw speed
(output)



Coating weight potential; testing max draw down
(reduced, 0.508 mm die gap)





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Optimizing the extrusion coating process could double output and triple line speed

SCREW DESIGN	OUTPUT AT 75 RPM			LINE SPEED		
	LDPE	Extrusion Coating PLA		Extrusion Coating PLA		
	Output (kg/hr) Temp. °C	Output (kg/hr) Temp. °C	Increase over typical screw design	Increase over typical screw design	Increase by reducing die lip gap	Increase by edge encapsulation and no change in die lip gap
Single Flight Double Mixer High Shear Design Typical Extrusion Coating Design	50 (324)	78 (252)			30%	
Melt Barrier Flight Single Mixer Moderate Shear Design Compromise Extrusion Coating Design	66 (314)	107 (253)	37%	31%		
Melt Barrier Flight Single Mixer Low Shear Specialty Copolymer Extrusion Coating Design	64 (304)	119 (249)	53%	43%	86%	102%
Melt Barrier Flight Single Mixer Ultra Low Shear Design Modified Copolymer Extrusion Coating Design		145* (252)	86%		197%	

*Increased screw speed to 100RPM due to low temperatures found with ultra low shear screw

Process recommendations
in addition to drying resin

Low shear high output
screw design

Minimize
die lip gap

Keep melt temperature
<250°C or <482°F

Include edge
encapsulation
extruder

General Business



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For more information see

Nicole Whiteman et al (2021) Rethinking the paper cup – beginning with extrusion process optimization for compostability and recyclability *Tappi Journal* Vol. 20 (No. 6) page 353-362

TAPPI JOURNAL

WWW.TAPPI.ORG

THE PAPER AND PACKAGING INDUSTRIES' TECHNICAL RESOURCE

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RECYCLING 353

Rethinking the paper cup — beginning with extrusion process optimization for compostability and recyclability

Nicole Whiteman, Andrea Auchter, Andrew Christie, and Michael Prue

PAPERMAKING 365

A guide to eliminating baggy webs

Frédéric Parent, Jean Hamel, and David McDonald



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Thank You

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