

# Processing Guide for Thermoforming Articles

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This information is intended for use only as a guide for the manufacture of Ingeo™ biopolymer thermoformed articles. Because thermoforming incorporates a wide range of processing variables, an experimental approach may be required to achieve desired results.

## 1.0 Safety and Handling Precautions

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All safety precautions normally followed in the handling and processing of thermoplastic sheet should be followed for sheet made from Ingeo biopolymer resins. Personal protective equipment includes gloves and clothing designed to protect against abrasions and cuts at room temperature in addition to protecting against burns at elevated temperatures.

As with most thermoplastics, thermal processing and the variability of those conditions may result in minor decomposition. A process upset that would involve Ingeo biopolymer sheet resting in the bottom of the oven could involve thermal conditions similar to melt processing the biopolymer. Lactide, a non-hazardous gaseous irritant, is a minor by-product of Ingeo biopolymer melt processing. Process area point source remediation measures such as monomer fume hoods or exhausts are typically recommended, in melt processing, to maintain the acceptable air Threshold Limit Value (TLV) for lactide of less than 5 mg/m<sup>3</sup>.

As with any thermoplastic waste hot enough to be melted or compressed into a solid mass, hot Ingeobiopolymer waste should be allowed to cool before being placed into any waste container to minimize fire risks.

Ingeo biopolymer is considered non-hazardous according to DOT (US Department of Transportation) shipping regulations.

## 2.0 Sheet and Thermoformed Parts Storage Recommendation

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Ingeo biopolymer sheet should be stored in an environment designed to minimize moisture uptake, and in a cool place at temperatures below 40°C (105°F). It is not necessary to dry the sheet prior to thermoforming to obtain haze free parts. At temperatures above 40°C the sheet is susceptible to blocking and would resist unwinding. In environments above 40°C and above 50% RH, the sheet is susceptible to molecular weight breakdown and loss of physical strength.

Ingeo biopolymer thermoformed parts should be shipped and stored in an environment that minimizes exposure to heat, moisture, and humidity; including maximum temperatures below 40°C (105°F). Clear, amorphous Ingeo biopolymer thermoformed parts at temperatures above 40°C are susceptible to distortion. At temperatures above 40°C and above 50% RH, Ingeo thermoformed parts are susceptible to molecular weight breakdown and loss of physical strength.

Ingeo biopolymer is highly polar and can retain a charged surface, if untreated. A charged surface can attract dust; but the charge can be mitigated by the use of local electrostatic eliminator bars. Protection of sheet goods with packaging material is also recommended to control dust collection on the sheet.

## 3.0 Sheet and Thermoformed Article Properties

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### 3.1 Addressing Relative Toughness or Brittleness

Ingeo biopolymer sheet is relatively brittle at room temperature. The elongation to break under tensile stress is between 4 and 8%. Good tension control during web handling is critical as sudden increases in tension during any portion of the unwind process may result in web breaks. Power driven nips at the unwind station are recommended. In addition, unwind stations and skeleton rewind stations should have web paths that minimize tight radius paths of the web. Minimum skeleton rewind radius should be 10-inches (25-cm) to insure smooth travel of the web and minimum breakage.

The toughness of Ingeo biopolymer increases with orientation and therefore thermoformed articles are less brittle than sheet, particularly in the regions that have been highly stretched during the forming operations. Experimentally, the elongation to

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break under tensile stress has been seen to increase from 4-8% in sheet to about 40% in the sidewall of a drinking cup. Flange or lip areas that receive less orientation tend to be more brittle than the rest of the thermoformed part.

If the sheet must be slit to size prior to thermoforming, then a rotary shear knife is required for trimming. Edge preheaters are necessary to prevent the sheet from cracking at the pins and to minimize rail chips. The edge preheaters will be set (temperature and proximity to the sheet) to warm the sheet to near 200°F (90°C). Contact heat edge preheaters would typically be set to 212°F (100°C). Non-contact heat edge preheaters would typically be set warmer than would be used with similar thickness sheet made of polystyrene or PET, and may approach the thermoforming oven set points.

### 3.2 Addressing Forming and Trimming of Parts

Ingeo biopolymer is frequently thermoformed using forming ovens, molds and trim tools designed for PET or polystyrene (more specifically in the classifications HIPS or OPS). It is critical to note that PP shrinks much more than Ingeo biopolymer so that molds and trim tools designed for PP are less optimally used with this biopolymer. Chain rail systems designed to stretch warm sheet to compensate for sagging PP are not necessary or desirable systems for Ingeo biopolymer, and may cause the sheet to be pulled out of the pin chains. In post trim operations we observe comparable shrinkage between Ingeo biopolymer and PET, so PET trim tools adapt well to service in trimming Ingeo parts. In trim in place operations we observe comparable shrinkage between Ingeo biopolymer, PET, and polystyrene. Trim in place molds, matched metal die punches and less optimally heated steel rule die punches (120°C or 250°F) are recommended for trimming Ingeo thermoformed articles. An ambient temperature steel rule die punch would not be recommended.

For plug assist thermoforming, plugs manufactured from Syntactic foam are typically used. The plug can be coated with a slip coating to prevent sticking in some deep draw applications. Plug shape has had more impact on part quality than has the material of construction. Plug shape is more dependent upon the particular part being molded so no general recommendation can be made regarding Ingeo biopolymer.

Ingeo biopolymer has a lower softening temperature than PET or PS. Typically oven settings are about 55°C (100°F) or more lower than PS, and about 40°C (75°F) or more lower than PET oven settings. The sheet should be about 90 to 110°C (190-230°F) entering the mold. Aluminum molds are recommended for thermoforming Ingeo biopolymer. In addition to being the traditional choice for production thermoforming molds, aluminum is a good metallurgical choice for this biopolymer (in contrast to carbon steel, which would be more susceptible to corrosion).

Ingeo biopolymer has a thermal conductivity that is lower than polystyrene and PET. The Tg (or deformation temperature) is also lower than both polymers. In addition, the density is greater than polystyrene. All of these factors indicate that the cooling time in the mold will be greater for Ingeo biopolymer than either PS or PET. In many thin wall parts, this increase in cooling time is negligible compared to the overall cycle time so that forming rates equivalent to PS and PET have been achieved. However, some thick wall parts will require additional cooling time, which will adversely affect the overall cycle time. The following table summarizes some of the key properties of Ingeo biopolymer, PS and PET.

	Ingeo biopolymer	PS	PET
Thermal Conductivity (BTU/ft-h-°F) (cal/cm-s-°C)	0.075 0.00029	0.105 0.00043	0.138 0.00057
Heat Capacity (BTU/lb-°F) (cal/g-°C)	0.39 0.39	0.54 0.54	0.44 0.44
Glass Transition Temp (°F) (°C)	131 55	221 105	167 75
Density (lb/ft <sup>3</sup> ) (kg/m <sup>3</sup> )	78 1250	65.5 1050	85.5 1370
Thermal Expansion Coefficient x 10 <sup>-6</sup> (°F <sup>-1</sup> ) (°C <sup>-1</sup> )	39 70	39 70	39 70

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Ingeo biopolymer has a lower extensional viscosity than PET or PS, and is therefore capable of transferring mold detail including tooling marks readily. The natural surface energy of Ingeo articles is 38 dynes. Corona or flame treatment can be used to ensure high quality printed graphics.

### **4.0 Regrind Considerations**

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Ingeo biopolymer regrind is not compatible with regrind from any other sheet product. It is necessary to both wipe and water wash clean the grinding equipment and transfer lines or to have dedicated systems for Ingeo biopolymer. The biopolymer sheet must be about 40°C (105°F) or less to grind efficiently. Some grinding systems require additional cooling to efficiently grind Ingeo biopolymer.

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## Best Practices for Ingeo Processing

### Safety and Handling Considerations

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Safety Data Sheets (SDS) for Ingeo biopolymers are available from NatureWorks. SDS's are provided to help customers satisfy their own handling, safety, and disposal needs, and those that may be required by locally applicable health and safety regulations. SDS's are updated regularly; therefore, please request and review the most current SDS's before handling or using any product.

*The following comments apply only to Ingeo biopolymers; additives and processing aids used in fabrication and other materials used in finishing steps have their own safe-use profile and must be investigated separately.*

### Hazards and Handling Precautions

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Ingeo biopolymers have a very low degree of toxicity and, under normal conditions of use, should pose no unusual problems from incidental ingestion or eye and skin contact. However, caution is advised when handling, storing, using, or disposing of these resins, and good housekeeping and controlling of dusts are necessary for safe handling of product. Pellets or beads may present a slipping hazard.

No other precautions other than clean, body-covering clothing should be needed for handling Ingeo biopolymers. Use gloves with insulation for thermal protection when exposure to the melt is localized. Workers should be protected from the possibility of contact with molten resin during fabrication.

Handling and fabrication of resins can result in the generation of vapors and dusts that may cause irritation to eyes and the upper respiratory tract. In dusty atmospheres, use an approved dust respirator.

Good general ventilation of the polymer processing area is recommended. At temperatures exceeding the polymer melt temperature (typically 175°C), polymer can release fumes, which may contain fragments of the polymer, creating a potential to irritate eyes and mucous membranes. Good general ventilation should be sufficient for most conditions. Local exhaust ventilation is recommended for melt operations. Use safety glasses (or goggles) to prevent exposure to particles, which could cause mechanical injury to the eye. If vapor exposure causes eye discomfort, improve localized fume exhausting methods or use a full-face respirator.

The primary thermal decomposition product of PLA is acetaldehyde, a material also produced during the thermal degradation of PET. Thermal decomposition products also include carbon monoxide and hexanal, all of which exist as gases at normal room conditions. These species are

highly flammable, easily ignited by spark or flame, and can also auto ignite. For polyesters such as PLA, thermal decomposition producing flammable vapors containing acetaldehyde and carbon monoxide can occur in almost any process equipment maintaining PLA at high temperature over longer residence times than typically experienced in extruders, fiber spinning lines, injection molding machines, accumulators, pipe lines and adapters. As a rough guideline based upon some practical experience, significant decomposition of PLA will occur if polymer residues are held at temperatures above the melting point for prolonged periods, e.g., in excess of 24 hours at 175°C, although this will vary significantly with temperature.

### Combustibility

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Ingeo biopolymers will burn. Clear to white smoke is produced when product burns. Toxic fumes are released under conditions of incomplete combustion. Do not permit dust to accumulate. Dust layers can be ignited by spontaneous combustion or other ignition sources. When suspended in air, dust can pose an explosion hazard. Firefighters should wear positive-pressure, self-contained breathing apparatuses and full protective equipment. Water or water fog is the preferred extinguishing medium. Foam, alcohol-resistant foam, carbon dioxide or dry chemicals may also be used. Soak thoroughly with water to cool and prevent re-ignition.

### Disposal

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**DO NOT DUMP INTO ANY SEWERS, ON THE GROUND, OR INTO ANY BODY OF WATER.** For unused or uncontaminated material, the preferred option is to recycle into the process otherwise, send to an incinerator or other thermal destruction device. For used or contaminated material, the disposal options remain the same, although additional evaluation is required. Disposal must be in compliance with Federal, State/Provincial, and local laws and regulations.

### Environmental Concerns

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Generally speaking, lost pellets, while undesirable, are benign in terms of their physical environmental impact, but if ingested by wildlife, they may mechanically cause adverse effects. Spills should be minimized, and they should be cleaned up when they happen. Plastics should not be discarded into the environment.

### Product Stewardship

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NatureWorks has a fundamental duty to all those that use our products, and for the environment in which we live. This duty is the basis for our Product Stewardship philosophy, by which we assess the health and

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environmental information on our products and their intended use, and then take appropriate steps to protect the environment and the health of our employees and the public.

### **Customer Notice**

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NatureWorks encourages its customers and potential users of its products to review their applications from the

standpoint of human health and environmental quality. To help ensure our products are not used in ways for which they were not intended or tested, our personnel will assist customers in dealing with ecological and product safety considerations. Your sales representative can arrange the proper contacts. NatureWorks literature should be consulted prior to the use of the company's products.

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15305 Minnetonka Blvd., Minnetonka, MN 55345