

Crystallizing and Drying Ingeo Biopolymer

The majority of Ingeo biopolymer grades are semi-crystalline polymers with relatively slow nucleation and crystallization rates. As a result, most extruded objects from these grades such as sheet and pellets will be 100% amorphous after normal quenching operations. These grades include 2003D, 4032D, 4043D. Fully amorphous grades such as 4060D will never crystallize and there should be no attempt to process them in crystallization equipment. In addition, all grades are subject to hydrolysis when heated in the presence of water. Therefore, drying is required to prevent a loss in properties. This document fully explains the drying and crystallization options for Ingeo biopolymer grades and provides some resources for equipment testing, purchasing and toll manufacturing.

Theory Behind Drying and Crystallization for Ingeo Biopolymer

Ingeo biopolymer is a hygroscopic thermoplastic. That is, it readily absorbs moisture from the atmosphere. The presence of even small amounts of moisture will hydrolyze the biopolymer in the melt phase, reducing the molecular weight. As a result, the mechanical properties decrease and the end-product quality is compromised. Therefore, Ingeo biopolymer must be thoroughly dry just prior to melt processing. In many cases, recycled polymer may also have to be crystallized prior to drying.

Unlike many other major packaging resins (e.g., polyolefins, polystyrene, and PVC), Ingeo biopolymer is produced by a condensation reaction. This reaction, which also produces water, is reversible. Therefore, when undried Ingeo biopolymer is melted the resin and water chemically react. Hydrolysis occurs and key mechanical properties of the biopolymer are reduced. This hydrolysis reaction also changes the polymer melt viscosity and the crystallization rate, making it very difficult to process into a quality end product.

Virgin Ingeo resin is crystallized and dried to 400 ppm moisture level prior to leaving the production plant. The resin is sold in boxes with moisture resistant foil liners to maintain that moisture level. If the resin is received in undamaged boxes and liners, the drying requirements are minimal but still required. In addition, if the foil liner has been opened, drying will be required. The resin is crystallized to allow easier drying. Uncrystallized Ingeo biopolymer becomes sticky and clumps when its temperature reaches 60°C (140°F). This is the glass transition temperature; the point at which the amorphous portion of the pellet begins to soften. Regrind or recycled product may or may not be crystallized. Flake from clear thermoformed parts, trim scrap, or cast sheet, is highly amorphous. Flake from oriented film or oriented sheet will be a mixture of crystalline and amorphous fractions, while that from fibers will be highly crystalline.

It is the process, the shape and degree of crystallinity, and the percentage of regrind that will determine if the recycled Ingeo material will need to be crystallized. A rule of thumb is that a crystallizer is not required if the amorphous portion of the feed stream is less than 40% of the total and the extruder has screw-cooling capabilities. However, this generalization ignores wide variation in the level of crystallinity and size distribution in the flake. Also, some screw designs have a higher degree of flexibility in handling amorphous regrind than do others. If the process is using amorphous regrind, it is absolutely critical to have screw that has cooling through the root of the screw through the feed section and half way into the melting section of the screw. Due to the rapid rate of moisture pick-up of Ingeo biopolymer, any regrind that has been stored needs to be dried adequately, prior to re-extrusion. Most processors of recycled Ingeo material choose to crystallize the recycle in order to eliminate any problems with drying. Crystallization permits trouble-free drying in conventional equipment at 150°F-190°F. Amorphous Ingeo biopolymer requires drying at much lower temperatures 43-55°C (110-130°F), to prevent sticking in the dryer.

Ingeo biopolymer is typically dried in dehumidifying hoppers using hot air at a very low dew point. The dehumidified air passes through a bed of Ingeo pellets or pellets and flake to extract moisture from the biopolymer. A desiccant material, such as silica, absorbs moisture from the circulating air. Dual desiccant bed systems are common, in which one bed is on-stream while the stand-by bed is being regenerated. Either a time cycle or a predetermined decrease in air dew point is used to shift airflow from one desiccant bed to the other.

Due to rapid growth in biopolymer processing many new plastic converters are manufacturing end products from Ingeo biopolymer. A number of these companies are just now learning how critical drying is to produce high quality end products from this polymer. Others may not be aware of the differences in behavior between amorphous and crystallized Ingeo grades.

Crystallizing and Drying Ingeo Biopolymer

It is important to note that inadequate drying, (on a ppm level) causes a large portion of all quality problems in Ingeo biopolymer processing.

Best Practices

Drying

Ingeo biopolymer must be dried to <250 parts per million (ppm) moisture and maintained at this moisture level to minimize hydrolysis during melt processing. This is not optional; it is absolutely essential. A dry resin will help control the Relative Viscosity (RV) loss, which should be less than 0.1. A reduction in RV greater than this can result in a product outside of the useful range for several extruded applications. Controlling RV loss is critical to maintaining impact strength, melt viscosity, and other key properties of the starting material.

The crystallized Ingeo biopolymer should be dried at 65-90°C (150-190°F), using dehumidified air with a dew point of -40°C (-40°F). Higher drying temperatures could lead to softening and blocking of polymer in the dryer. Lower drying temperatures will result in extended drying times.

Dew point is an absolute measure of air moisture and is independent of air temperature. Dew point should always be used to control dryer performance, therefore, the dryer should be equipped with a dew-point monitor and alarm plus a temperature monitor on the dryer inlet line. Airflow is another critical component to drying. Airflow to the dryer heats the resin and absorbs its moisture. Sufficient airflow maintains the resin at the proper temperature for its entire residence time. The data in the figures below were obtained using airflow of 0.016 m³ per minute per kg of polymer (0.25 cubic foot per minute (cfm) per pound). This was sufficient for the relatively small, 90 kg (200 pound) capacity dryer, used in the experiments. Commercial extrusion lines typically require higher air volumes and generally use 0.032-0.064 m³/min per kg (0.5-1.0 cfm/pound of resin). NatureWorks recommends consulting your dryer manufacturer and obtaining their recommendations for minimum airflow for their dryer design. At any rate, a volumetric flow indicator is recommended to monitor airflow.

In laboratory experiments, NatureWorks measured the drying times for various grades of Ingeo biopolymer at different drying air temperatures. Figure 1 below shows 4 different drying curves.

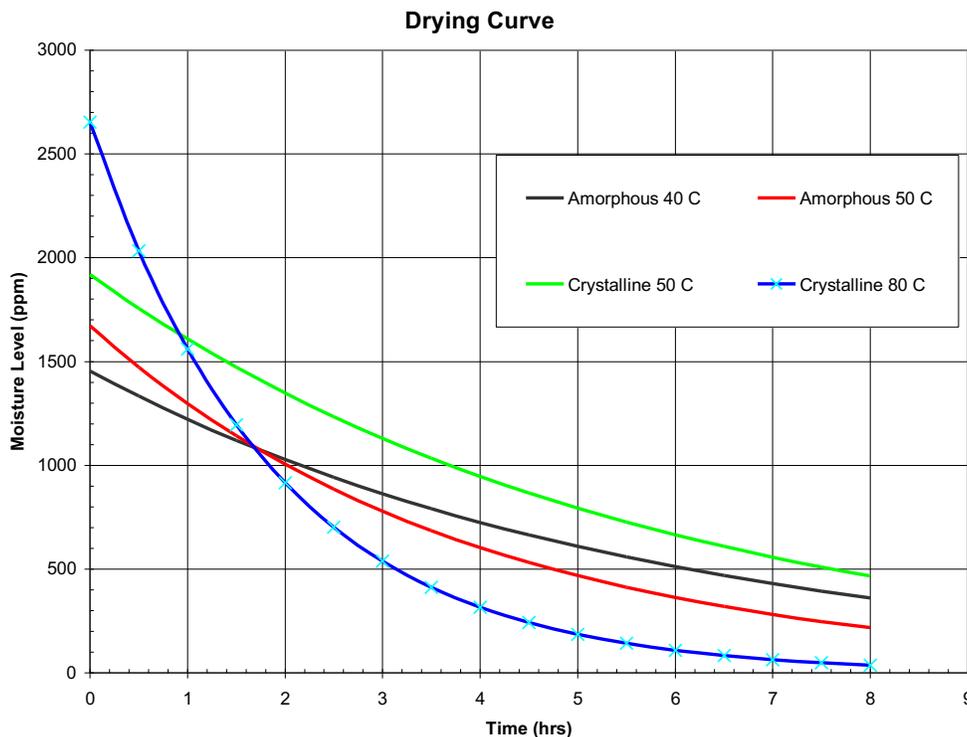


Figure 1: Drying curve of Ingeo pellets at various temperatures. Airflow volume rate was 0.016 m³/min per kg (0.25 cfm/lb) of pellets. The air dew point was -40°C.

Crystallizing and Drying Ingeo Biopolymer

From these drying curves, one can extract drying half times ($t_{1/2}$), which is the time required for the resin to reduce its moisture concentration to one half the initial value. The drying half times for amorphous and crystalline Ingeo biopolymer are listed in Table 1 below.

| Product Type and Temperature | Drying Half Time ($t_{1/2}$) |
|------------------------------|--------------------------------|
| Amorphous Pellets | |
| 40°C (104°F) | 4.0 hr |
| Crystalline Products | |
| 40°C (104°F) | 4.3 hr |
| 50°C (122°F) | 3.9 hr |
| 60°C (140°F) | 3.3 hr |
| 70°C (158°F) | 2.1 hr |
| 80°C (176°F) | 1.3 hr |
| 100°C (212°F) | 0.6 hr |

Table 1: Drying Half Times for Ingeo Pellets with Dry Air (- 40°C/°F dew point) at 0.016 m³/minute per kg (0.25 cfm/lb).

Drying times are determined by measuring the initial moisture content and using the drying half time values in Table 1. The half time is the time in hours it takes for the moisture level to drop to ½ of its initial value. For example, if you wanted to dry Ingeo biopolymer with initial moisture content of 1600 ppm down to 200 ppm at 80°C (176°F), you would need to use the half time of 1.3 hours. Therefore, it would take 1.3 hours to drop the moisture level from 1600-ppm to 800-ppm. It would then take an additional 1.3 hours to drop the moisture it from a level of 800-ppm to 400-ppm. Finally it would take an additional 1.3 hours to drop the level from 400-ppm to 200-ppm for a total of 3.9 hours at 80°C (176°F). Other times and temperatures will be appropriate depending upon the initial moisture level and the time available for drying.

Another best practice for minimizing moisture-related Ingeo biopolymer degradation is to dry any blending ingredients, colorants, additives, or internal scrap that could potentially contribute moisture to the base resin. If any portion of the formulation is hygroscopic, it must be dried according to the supplier's recommendation. Some non-hygroscopic components may not have to be dried if their equilibrium moisture content and percentage of the formulation are small.

Crystallization

As mentioned before, crystallized Ingeo pellets and flake will not stick or clump together at temperatures above the glass transition temperature, 60°C (140°F). This allows the material to be dried at much hotter temperatures. NatureWorks has done extensive experimentation and determined that Ingeo pellets and flake will not stick together or clump if the crystallinity level is greater than 10 joules/gram. At this level of crystallinity or greater, the Ingeo pellets will appear cloudy instead of the very transparent appearance of the amorphous pellets. It is critical that the pellets achieve a uniform crystallinity so that some amorphous pellets do not remain which could cause clumping problems in subsequent drying steps. There are a number of types of crystallizers in the industry as explained below but just as in drying, there are some best practices for achieving desirable results.

The crystallizer should be capable of heating the regrind at a steady rate with constant agitation or motion of the regrind to prevent clumping. The clumps that form due to sticking of amorphous or partly amorphous resin do not break up as the temperature rises without mechanical interference. In fact, they will stick to the container walls and thermocouples and cause bridging as the clumps grow. A well-designed crystallizer not only minimizes the formation of clumps, but also is efficient at breaking up any clumps that may form. Optimum crystallization temperatures for Ingeo biopolymer depend upon the grade. Regrind from low D percent grades such as 4032D, 3001D or 3251D can be crystallized at 100-110°C (210-230°F) while regrind from equilibrium grades such as 2003D, 3052D, 4043D, 7001D, or 8052D should be crystallized at 88-99°C (190-210°F). At these temperatures, it will take between 10-20 minutes to crystallize. Amorphous grades such as 4060D will never crystallize and should not be loaded into a crystallizer.

With equilibrium grades, it could be advantageous to add 200-400 ppm of an external lubricant such as erucamide to reduce the COF of the pellet bed. This serves to reduce agitator loads and aids in preventing agglomeration particularly at higher

Crystallizing and Drying Ingeo Biopolymer

rates. This would not be typical when the regrind came from a thermoforming process. The regrind from thermoforming processes would typically have an external lubricant, called a denest additive, on the flake surface.

Figure 3 is a graph of the degree of crystallinity as a function of time for various inlet air temperatures. As you can see, at all but the lowest temperature, the flake was crystallized above the recommended 10 J/gm limit in 20 minutes or less.

Regrind exiting the crystallizer should be checked for moisture level as some drying action occurs in the crystallizer. Knowledge of moisture level at this point will allow efficient use of the drying resources.

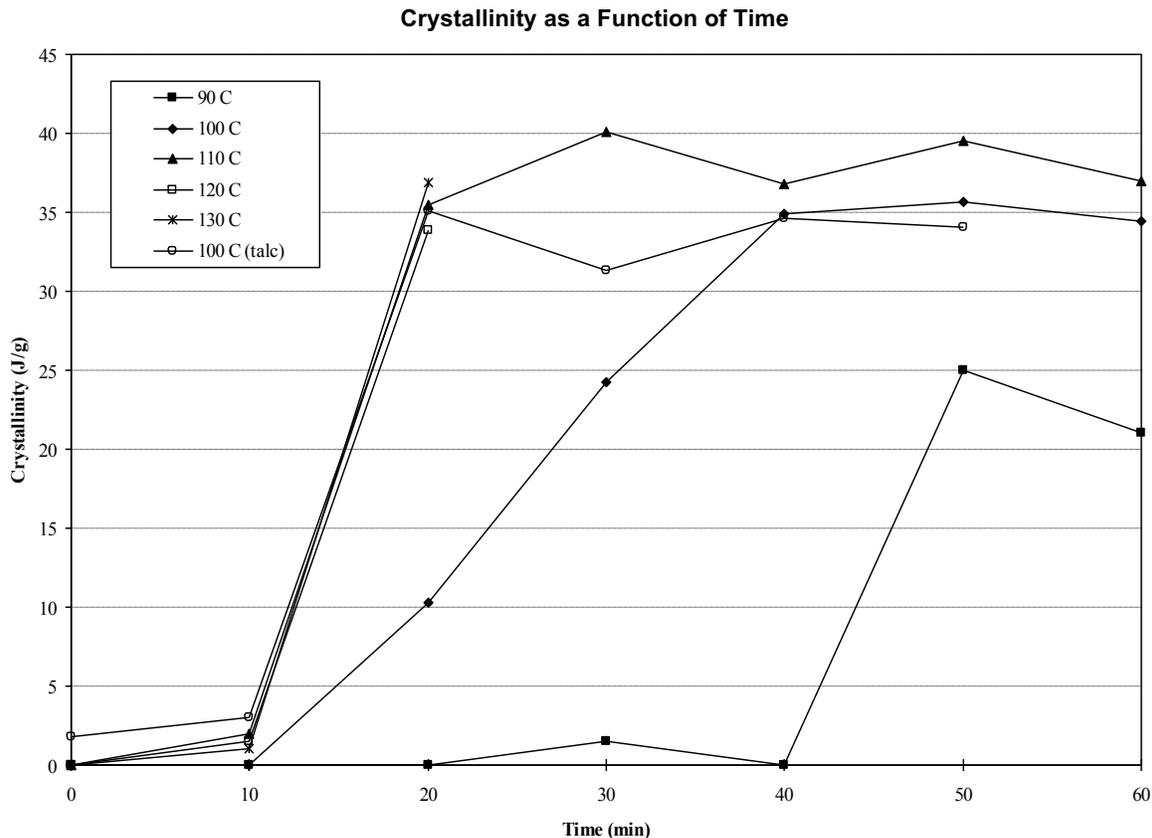


Figure 3: Crystallization of Ingeo biopolymer as a Function of Time. Conair Model CR500 500 liter crystallizer with 17 rotating blades and 3 stationary breaker bars. The agitator arm rotated at a fixed speed of 2 RPM. The Hopper capacity was 0.4m³ (14ft³). The heating capacity was 33 KW and the blower output at full damper opening was 10 M³/min (360 CFM).

Moisture Control

Drying must be coordinated with production at all times. Dryness must be maintained until the resin or regrind enters the processing equipment. It is best to use dried material right away so it does not absorb ambient moisture. Depending on ambient conditions, dried Ingeo biopolymer that is not kept in a sealed enclosure can pick up enough moisture in five minutes to defeat most of the benefits of drying.

To maintain dryness, it is best to vacuum load the pellets and/or regrind directly from a centralized drying unit to feed hoppers above the processing equipment. In some instances, portable hopper dryers are used and the dried resin is conveyed directly to the feed hopper.

Moisture Analysis

The best practice for moisture analysis of dried samples is to check two to three samples at the end of each drying cycle to confirm that moisture content is below 250 parts per million. NatureWorks recommends using a Karl-Fischer titration method that heats the sample at 150°C (302°F) for 30 minutes.

Crystallizing and Drying Ingeo Biopolymer

Equipment

Dryers

There are a large number of dryer manufacturers who can design and specify a dryer suitable for your needs using the above data. NatureWorks, LLC does not recommend any particular dryer supplier since there are many that provide a quality product. Ideally, any dryer that is being considered for Ingeo biopolymer service should have the following features:

1. Desiccant beds capable of achieving a dew point of -40°C (-40°F) in the supply air
2. An after cooling unit between the drying hopper and desiccant bed to eliminate high temperature spikes in the supply air which can cause blocking when drying amorphous products.
3. Excellent temperature control in the target drying range, $40\text{-}100^{\circ}\text{C}$ ($104\text{-}212^{\circ}\text{F}$)
4. Ability to use dry air to convey pellets from the drying hopper to the extruder hopper (closed loop conveying).
5. High temperature alarm on the inlet air temperature and shut off control to prevent melting or blocking in the hopper
6. Dew point monitor and indicator
7. Air flow indicator

Note: A new type of dryer has been introduced recently, using Infrared drying (IR). Due to the high rate of energy transfer with IR heating in combination with the specific wave length used, the energy costs involved with these systems can be greatly reduced, along with the size. First tests have shown that virgin Ingeo biopolymer can be dried and amorphous flake crystallized and dried within only about 15 minutes. The output levels of these tests were at a rate between 200-300 kg/h (440-660 lbs/h). As this technology is still developing, it is necessary to discuss the individual drying purpose (e.g. virgin or blend of virgin/flake) with the equipment manufacturers UPM or Kreyenborg.

Crystallizers

General Background

There are four general types of crystallizers used in the industry for crystallizing either pellets or ground flake: Vertical Hopper Units with Convection Heating, Horizontal Conductive Units, Solid State Reactors Tumblers and Fluidized Bed Crystallizers. In addition, IR dryers have been shown to effectively crystallize Ingeo biopolymer during drying. NatureWorks LLC has used all five types of crystallizers on various Ingeo grades. Each type of unit has its own advantages and limitations.

Vertical Hopper Unit with Convection Heating

This is the most common type of crystallizer in the industry. The vertical hopper crystallizer resembles a vertical drying hopper with the addition of a center agitator arm. This arm is powered by a drive unit typically mounted on the top of the vessel. While there are many dryer manufacturers that have tried to retrofit existing dryer designs with a simple agitator, the key to proper operation with Ingeo biopolymer is the design of the agitator arm. One company, Conair Franklin has tested and developed a design that not only works well for PET, but has also been demonstrated with Ingeo. In this design, the central agitator arm is equipped with many angled agitator arms which are specially designed to keep material in motion and prevent agglomeration. In addition, there are a number of stationary breaker bars mounted into the vessel walls that help break any polymer agglomerates. More recently, Universal Dynamics has developed a line of crystallizers and associated dryers that are uniquely suited to the properties of Ingeo biopolymer. In this design of dryer, the polymer is heated by way of forced air from an external blower and electrical heater that is blown into a bottom mounted diffusion plate. Spent air is typically exhausted into the surrounding atmosphere although recycle systems could be designed. In operation, the material is continuously drawn out of the unit from the bottom while a level indicator controlling a hopper loader maintains a constant level at the top of the hopper. It is necessary to start up the unit with a previously crystallized material in the bottom half of the hopper since airflow, heat transfer and agitation is not sufficient enough at the bottom to immediately crystallize the polymer. Once the unit is started and temperatures are at steady state, fresh amorphous material can slowly be added to the system to build the level. Once the level is achieved, material can be drawn off of the bottom. The unit operates best in steady state continuous mode. In some cases, it is necessary to feed a mixture of crystallized resin and fresh feed, to avoid blocking. It is recommended to start with a 50/50 blend of fresh amorphous resin and crystallized resin. After stable operation is established, the mixture can be moved to lower fractions of pre-crystallized resin, while avoiding sticking or blocking.

Crystallizing and Drying Ingeo Biopolymer

The advantages of these units are the relatively low cost and small footprint. They integrate well with most conventional drying systems. Depending upon the design of the agitator, they may be susceptible to material agglomeration, which could hinder rates.

Horizontal Conduction Heating Units

This is a unique crystallizer design that relies on high pellet to metal contact area to heat the material and constant particle motion to eliminate agglomeration. Bepex International LLC makes a unit called a Torusdisc. The Torusdisc is a disc dryer using hot air or gas as drying media in combination with a heating jacket and a heating rotor. The Torusdisc rotor consists of special heated discs within a cylindrical housing, which is jacketed. The rotor is designed with vertically mounted double walled hollow discs. Heating media flow through the rotor, the discs and the jacketed vessel surrounding the rotor. These discs provide 85% of the total heating surface.

The rotor speed varies from 0.1 up to 0.5m/s and is independent from the residence time, so optimum mixing and heat transfer can be obtained. The residence time can be adjusted from minutes up to several hours. The compact size makes it especially appropriate for high heat transfer requirements at minimum floor space requirements.

The Torusdisc crystallizer has been used successfully with all semi-crystalline grades of Ingeo biopolymer. Advantages are once that the process window has been identified, operation is trouble free. There is less air movement and heating so operation costs are less. However, initial equipment cost is high.

Solid State Reactors (Also known as Tumbler Dryers or Vacuum-Dryers)

This is basically a jacketed tumbling mixer that has special rotary unions that allow a vacuum to be applied to the unit. This is batch type unit and generally, the throughput is low since there is a lot of time required to load the unit, heat the unit while tumbling and pulling a vacuum, cool the unit to resin pack out temperature and finally unloading the unit. The vessels can range up to 9,000 kg (20,000 lbs) in capacity. Ingeo biopolymer will not increase in RV as PET will but the unit does dry the resin as it crystallizes. Advantages are the ease of use and drying during crystallization. Disadvantages are that it is a batch operation and throughputs can be low on small units due to long cycle times (typically about 8 hours with Ingeo). All semi-crystalline grades of Ingeo biopolymer have been processed on this type of crystallizer.

Fluid Bed Crystallizers

These units are essentially modified pellet classifiers that use heated air to crystallize the regrind. Typically used for pellets, they have also been used successfully for ground flake. They have extensive experience crystallizing PET and PET copolymers. Although there may not have been any commercial scale use with Ingeo biopolymer, successful laboratory tests have been performed with all grades of semi-crystalline Ingeo.

Crystallizing and Drying Ingeo Biopolymer

Fluid Bed Crystallizers

The Witte Company, Inc

P.O. Box 47, 507 Route 31 South
Washington, NJ 07882-0047 USA

Jim Schak

Fax: (908) 537-6806

jschak1@aol.com

www.witte.com

Note: Crystallizers are not featured as such on the website. They have extensive experience designing fluid bed crystallizers for PET pellets and flake. They do have equipment in the New Jersey lab for evaluation.

Barr-Rosin Ltd.

48 Bell Street
Maidenhead, Berkshire
SL6 1BR
United Kingdom

Tel: +44(0) 1628 641 700

Fax: +44(0) 1628 776 118

<http://www.barr-rosin.ca/>

Note: Mfg of fluid bed crystallizers. Extensive experience with PET and PET copolymers (crystallization rates similar to crystallizable Ingeo grades). Lab facilities available.

Bühler GmbH

Ernst-Amme-Strasse 19
D-38114 Braunschweig
Germany

Tel: +49 (531) 594-0

Fax: +49 (531) 594 22 54

email: stefan.scheiber@buhlergroup.com

Crystallizing and Drying Ingeo Biopolymer

Vertical Hopper Units with Convection Heating

Conair Corporate Office & Technology Center

200 West Kensing Drive
Cranberry Township, PA 16066

Pete Stoughton
Tel: (724) 584-5500
Fax: 724-584-5299
email: Pstoughton@conairgroup.com
www.conairnet.com

Note: Crystallizers are not featured on their web site. They do have a brochure they can fax you upon request. They have extensive experience designing PET crystallizers for pellets and flake. They do have equipment in the Franklin, PA lab for evaluation.

Labotek A/S

Strøbjergvej 29
DK-3600 Frederikssund
Denmark

Tel: +45 / 48 21 84 11
Fax: +45 / 48 21 80 00
email: info@labotek.com
www.labotek.com/

Note: Have designed and built PET crystallizers. NatureWorks has no experience with crystallizers from Labotek but owns a dryer unit and has been satisfied with performance and service.

Novatec, Inc.

222 E. Thomas Avenue
Baltimore, MD 21225 USA

Tel: (410) 789-4811
Fax: (410) 789-4638
email: novatec@novatec.com
www.novatec.com

Note: NatureWorks has no experience with crystallizers from Novatec but has had good experience with dryers

Universal Dynamics, Inc

A Piovan Company
13600 Dabney Road
Woodbridge, Va. 22191
Tel: (703) 490-7000
Fax: (703) 490-7001
email: info@una-dyn.com
www.unadyn.com

Note: Universal Dynamics has extensive experience crystallizing and drying Ingeo biopolymer; developed by serving a number of NatureWorks partners in North America.

Crystallizing and Drying Ingeo Biopolymer

Horizontal Units with Conductive Heating

Bepex International LLC

Contact person: Mr R. Imholte
333. N.E. Taft Street
Minneapolis, MN 55413

Tel.: (1) 612 3314370
Fax: (1) 612 627 1444
email: info@bepex.com
rimholte@bepex.com

Hosokawa Micron b.v.

Gildenstraat 26,
P.O.Box 98, 7000 AB Doetinchem,
The Netherlands,

Tel. +31 314 37 33 33.
Fax +31 314 37 34 56.
www.hmbv.nl

IR Drying

KREYENBORG Plant Technology GmbH & Co. KG

Messingweg 18
48308 Senden
Germany

Marcus Vogt
Sales Manager IR Technology
Tel.: +49 2597 93997-152
email: m.vogt@kreyenborg.com
www.kreyenborg.com

Note: Infrared crystallizers and dryers are used for Ingeo PLA pellets, regrinds and masterbatches.

Crystallizing and Drying Ingeo Biopolymer

Companies That Will Crystallize on a Tolling Basis

Bepex International LLC

Contact person: Mr R. Imholte
333. N.E. Taft Street
Minneapolis, MN 55413

Tel.: (1) 612 3314370
Fax: (1) 612 627 1458
E-mail: info@bepex.com
rimholte@bepex.com

Ancos

4817 Country Drive
Disputanta, VA 23842

Joe Woody
Tel : 804-732-3356
Fax: 804-732-3443
email: joewoody@ancos-usa.com

Crystallizing and Drying Ingeo Biopolymer

Safety and Handling Considerations

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

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.

NOTICE:

No freedom from infringement of any patent owned by NatureWorks LLC or others is to be inferred. No information in this publication can be considered a suggestion to infringe patents.

The technical information, recommendations and other statements contained in this document are based upon tests or experience that NatureWorks believes are reliable, but the accuracy or completeness of such information is not guaranteed. Many factors beyond NatureWorks control can affect the use and performance of a NatureWorks product in a particular application, including the conditions under which the product is used and the time and environmental conditions in which the product is expected to perform. Since these factors are uniquely within the user's knowledge or control, it is essential that the user evaluate the NatureWorks product to determine whether it is fit for a particular purpose and suitable for the user's method of application. In addition, because use conditions are outside of NatureWorks control and applicable laws may differ from one location to another and may change with time, Customer is solely responsible for determining whether products and the information in this document are appropriate for Customer's use and for ensuring that Customer's workplace, use and disposal practices are in compliance with applicable laws and regulations. NatureWorks LLC assumes no obligation or liability for the information in this document.

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

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

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

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

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 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

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.

Crystallizing and Drying Ingeo Biopolymer

NATUREWORKS MAKES NO WARRANTY, EXPRESS OR IMPLIED, REGARDING THE INFORMATION CONTAINED HEREIN OR ITS PRODUCTS, INCLUDING BUT NOT LIMITED TO ANY WARRANTY AS TO ACCURACY OR COMPLETENESS OF INFORMATION, OR ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

NOTICE REGARDING PROHIBITED USE RESTRICTIONS: Unless specifically agreed to in writing by NatureWorks, NatureWorks LLC will not knowingly sell or sample any product into any of the following commercial or developmental applications (i) components of or packaging for tobacco products, (ii) components of products intended for human or animal consumption, (iii) any application that is intended for any internal contact with human body fluids or body tissues, (iv) as a critical component in any medical device that supports or sustains human life, (v) in any product that is designed specifically for ingestion or internal use by pregnant women, (vi) in any application designed specifically to promote or interfere with human reproduction, (vii) in microbeads, including those used in personal care/cosmetic applications, or (viii) to manufacture bottles or bottle pre-forms in North America.

For additional information please contact NatureWorks via our [website](#) on the tab called [FAQ's](#) or by clicking [here](#).

 **NatureWorks**
15305 Minnetonka Blvd., Minnetonka, MN 55345