Chapter 6
New Developments in Agricultural and Industrial Plant Biotechnology

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Abstract New developments in agricultural and industrial plant biotechnology are quite noteworthy and deserve special mention in this chapter.

In the *agricultural sector*, we have witnessed the advent of no tillage farming; significant increases in the use of organic farming practices, including a decrease in the use of toxic insecticides and herbicides; a quantum leap forward in the spread of farmers' markets and sale of locally grown food crops and products; an increase in the use of seeds of heirloom cultivars of crop plants; an increase in crop species diversity; an increase in the use of genetically modified food plants in America; a slowly emerging trend toward urban agriculture; and increasing use of hydroponic production systems to grow crops year-round in greenhouses.

In the *industrial sector*, we observe the advent of many new industrial-type products that are derived from plants. These include biodegradable plant-derived plastics, paints and varnishes, adhesives, auto biofuels, de-icers, cleaners, vegetable oils, essential oils, industrial solvents, pharmaceutical and industrial proteins; soy-based inks; soy-based spray foam insulation; soy-based carpet backing and padding; and soy-based wood-like composites used for floors, paneling, and table/countertops.

In this chapter, we present selected examples from each of these topics.

6.1 The Implementation of Organic Farming Practices: The Reasons, Benefits, and Disadvantages

Organic farming refers to the use of sustainable, environmentally safe practices in the growing of food crops for humans and domesticated animals. *Organic farming* is a form of agriculture which excludes the use of synthetic fertilizers and pesticides, plant growth regulators, livestock feed additives, and genetically modified (GM) organisms. As far as possible, organic farmers rely on crop rotation, green manure, compost, biological pest control, and mechanical cultivation to maintain

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soil productivity and control pests. Organic farming is often contrasted with conventional, or mainstream, farming (Adeyemi, 2000). *Advantages* include high consumer acceptance of organically grown products and willingness to pay a higher price for such food items; enhanced soil fertility and water-holding capacity, especially long term; gradual purging of the soil of toxic pesticides that may have been used previously after several years of instituting organic farming practices; organic certification of the grower as a certified organic farmer once organic standards have been met; enhanced value of the farmer's land once it has qualified for organic certification; fewer health-related problems for the organic grower because of the practices he/she uses; lower incidence of crop insect pests because of increased incidence of insect predators. *Disadvantages* include higher production costs and greater problems with weeds; hence lower yields over the short term. *Reasons for implementation of organic farming practices* include (1) consumer demand; (2) loss of soil fertility; (3) health problems for the conventional/corporate farmer who is exposed to a multitude of toxic chemical pesticides – herbicides, insecticides, fungicides, nematicides, and fumigants; (4) increased profits for the farmer/grower who grows certified organic crops; and (5) improved adherence to soil conservation practices.

Regarding GM crops (see Chapter 13), the absolutist position taken by organic farming adherents against any use of GM crops is currently meeting immense opposition worldwide from crop biotechnology proponents. The center of the controversy lies in European Union (EU) countries. The latest test comes in the following: The Public Research and Regulation Initiative (PRRI), a worldwide effort of public sector scientists involved in research and development of biotechnology for the public good, have sent an open letter to the members of the European Commission to aid them in their orientation discussion on biotechnology. PRRI has expressed deep concern about the effects of the political situation in Europe affecting genetically modified (GM) foods and crops.

The initiative notes, that despite clear EU rules and The European Food Safety Authority (EFSA) conclusions of GMOs not having adverse effect on human and animal health or the environment, EFSA opinions continue to be ignored. As a result of this situation, detrimental impacts have been felt both inside and outside the EU, particularly in developing countries.

Plant pathologist, Pamela Ronald, from the University of California at Davis, CA, believes that a combination of the two approaches – implementation of organic farming protocols and inclusion of GM crops – will be important for the future of global food production. Her view is that genetically modified seeds, when grown by the use of organic agricultural methods, can significantly increase yields, and at the same time, reduce the use of environmentally damaging chemicals. This hypothesis is not dissimilar from the conclusion of the recently published IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development) report. This 2-year intergovernmental project is designed to investigate the role that agricultural science, knowledge, and technology can play in world poverty. The report concludes that a complete agricultural revolution is needed where agriculture is no longer thought of as production alone.

6.2 Recent Achievements in Improving Crop Diversity: What Are the Driving Forces in Play Here?

As of 2003, in the United States, there were only 20 major agricultural products (these are listed in a table along with amounts produced) in commercial production (Table 6.1).

The only other crops to ever appear in the top 20 in the last 40 years were, commonly, tobacco, barley, and oats, and, rarely peanuts, almonds, and sunflower seeds (in all, only 26 of the 188 crops the FAO tracks worldwide). Both alfalfa and hay would be in the top 10 in 2003 if they were tracked by FAO.

This has resulted in a major loss in agricultural product diversity as compared with that which existed in the 1800s. For example, concerning vegetable crop diversity, according to the Rural Advancement Foundation (now called ETC Group), 75 types of vegetables, or approximately 97% of the varieties available in 1900, are now extinct (Kimbrell, 2002). Accompanying this decrease in crop diversity of vegetable and most other types of crops is the trend for small farms to disappear and for existing farms to become much larger.

What are the attributes of this trend? Corporate agribusiness is the current model and has ended up controlling farming practices. Linked to this is the fact that monocultures have become most common. Furthermore, chemical agriculture is the primary system in use. As a result, we have increased production costs. Fewer people are engaged in farming. There is an increase in the incidence of crop pests. And, there is a reduction in quality of the crop products produced. As a consequence of these events, we might ask, is there any trend toward outsourcing crops from the

Table 6.1 The top 20 agricultural products of the United States by value as reported by the Food and Agricultural Organization of the United Nations (FAO) in 2003 (Products are ranked by their mass, multiplied by the 1999–2001 international prices. Mass is in metric tonnes.)

	Agricultural products	Mass (tonnes)
1.	Corn	256,904,992
2.	Cattle meat	11,736,300
3.	Cow's,milk,whole,fresh	78,155,000
4.	Chicken meat	15,006,000
5.	Soybeans	65,795,300
6.	Pig meat	8,574,290
7.	Wheat	63,589,820
8.	Cotton lint	3,967,810
9.	Hen eggs	5,141,000
10.	Turkey meat	2,584,200
11.	Tomatoes	12,275,000
12.	Potatoes	20,821,930
13.	Grapes	6,125,670
14.	Oranges	10,473,450
15.	Rice, paddy	9,033,610
16.	Apples	4,241,810
17.	Sorghum	10,445,900
18.	Lettuce	4,490,000
19.	Cottonseed	6,072,690
20.	Sugar beets	27,764,390

United States to other countries? No, this is really not the case because we are simply now using more of crops, such as banana, papaya, mango, star fruit, and kiwi, that are only grown in other countries.

With the advent of organic agriculture (see above), and because of consumer demand, we are now witnessing a steady increase in crop diversity on American farms. Consumers are demanding more nutritious products and foods that are healthier for them. This is driven, in part, by a parallel increase in the use of integrative medicine and preventive medicine in our health system.

What are some of the less common edible crops, not included in the top 20 major crop species that account for this increase in crop diversity? They include teff (*Eragrostis tef* (Zucc.) Trotter), quinoa (*Chenopodium quinoa* Willd.), grain amaranth (*Amaranthus* cruentus L.), wild rice (*Zizania aquatica* L.), canola/rapeseed (*Brassica napus* L.), sunflowers (*Helianthus annuus* L.), giant pumpkins (*Cucurbita pepo* L.), culinary herbs, heirloom vegetables (see Seeds of Change, www.seedsofchange.com), cassava, taro, kiwi, and many edible fruits that include new cultivars of grapes (*Vitis* spp. L.), blueberries, (*Vaccinium* spp. L.), sour cherries (*Prunus cerasus* L.), Goji berry/wolfberry (*Lycium barbatum* Thunb.), elderberry (*Sambucus canadensis* L.), thornless blackberries (*Rubus canadensis* L.), Cornelian cherry (*Cornus mas* L), chokeberry (*Aronia arbutifolia* (L.) Pers. and *A. melanocarpa* (Michx.) Elliott), and hawthorn (*Crataegus laevigata* (Poir.) DC. and *C. monogyna* Jacq.). Reasons why a wide spectrum of colored fruits and vegetables, like many of the above, are desirable for significantly improved health are described in “The Color Code: A Revolutionary Eating Plan for Optimum Health” by Joseph et al. (2002).

6.3 The Rise of Urban Agriculture

Grow gardens refer to collections of vegetables and flowers that are grown in relatively small plots in urban environments. The increasing presence of grow gardens in many cities in the United States, Europe, and Asia is one of the hallmarks of urban agriculture at work. The impetus for this activity is to satisfy the need to obtain our food locally rather than via world commerce, to save energy, to lower production costs, to improve human health, and to obtain fresher produce. Grow gardens allow urbanites to know where their food comes from, to be able to grow food crops without the use of toxic pesticides, to learn how it is grown and harvested, to get good exercise (and thus, to help fight a growing problem of obesity), to provide a greater diversity of foods in the diet, to promote human interactions, and to reduce urban crime. Grow gardens have also helped to restore the work ethic among urbanites. One other spin-off is that urban crops sequester carbon dioxide, and thus, help to reduce global warming. They also mitigate high summer temperatures via evaporative cooling from leaves of the crops grown (via the process of *transpiration* or *water evapo-transpiration* from the leaves).

Many grow gardens are now being developed as “rooftop gardens” where growing space is limited. They are also being located at ground level near churches and schools, in parks, botanical gardens, and arboreta, and in lots where old houses and commercial buildings have been removed. It is essential that they should not be located in brown fields where the soil is contaminated with toxic residual chemicals and waste products.

6.4 The Use of Hydroponics Techniques for Commercial Food Production

Hydroponics refers to the cultivation of plants in complete nutrient solutions in the absence of soil. The first crops to be commercially grown with hydroponics included tomatoes and peppers, but the techniques were soon successfully extended to other crops such as lettuce, cucumbers, many kinds of culinary herbs, and cut flowers (Sustainable Living Articles at http://www.articlegarden.com; Mason, 2000). Valued at 2.4 billion dollars the hydroponic greenhouse vegetable industry has a growth rate of 10% per year and accounts for nearly 95% of the greenhouse vegetables produced in North America.

What are the advantages of hydroponics? Hydroponics, when used in greenhouses, allows for the cultivation of plants throughout the year. Other advantages include nutritious, healthy, and clean produce; improved and consistent quality of produce; and elimination of the use of toxic pesticides and herbicides. Notable, also, is the fact that specialty crops like culinary herbs, or even the above-mentioned vegetable crops or florist crops, can be grown hydroponically in gutter troughs in 42-day turn-around cycles (date of seed planting in biodegradable foam plugs to date of harvest) for most annual culinary herbs in greenhouses. The greenhouses can be heated from natural gas (methane) derived from garbage-filled landfills or from geothermal systems and illuminated continuously with full spectrum lamps with electricity generated by photovoltaic panels or wind generators.

Are there any disadvantages attributed to hydroponics? One entails high start-up costs. Another is that the whole process is highly labor-intensive as compared with field crop production, which, because of it being highly mechanized, involves much less hand labor.

What about yield comparisons? Commercial hydroponics systems have proven to be more productive than conventional systems of agriculture. Most commercial hydroponics greenhouse facilities are built sufficiently large to take advantage of economies of scale. Typically, these cover areas more than 10 acres, while smaller ones measure around 2 acres. In commercial practice, the yield of hydroponically grown tomatoes can be more than double that of soil-based systems due to the reduced turnover time between crops, better nutrition, and crop management. The dramatic increase in yields with hydroponics is best illustrated if we consider the actual production figures of soil-grown and hydroponically grown produce. Field grown tomatoes average yields ranging between 40,000 and 60,000 pounds per acre; on the other hand top growing hydroponics facilities in the United States and Canada report average yields of more than 650,000 pounds of tomatoes per acre.

Additionally, given the fact that only 10 years ago top hydroponics producers were producing around 400,000 pounds per acre, the increase in yields with improvements in growing practices has been truly phenomenal. Similar production figures can be quoted for other agricultural produce like cucumbers with 10,000 pounds per acre for field production and 200,000 pounds per acre for hydroponic greenhouse yields. Hydroponic lettuce and pepper yields too average around four times the corresponding yields of agricultural production.

In terms of global production, according to recent estimates, countries having substantial commercial hydroponics production include Israel – 30,000 acres, Netherlands – 10,000 acres, United Kingdom – 4,200 acres, and Australia and New Zealand – around 8,000 acres between them. The fastest growing area for commercial vegetable greenhouses is Mexico. There are several reasons for this. They include free trade and favorable winter conditions that attract vegetable growers in large numbers. Mexico has summers that are considered to be hot in the summer, but with greenhouses located at the right altitudes, vegetables can be grown in the hot summers as well as in the cold winters.

6.5 Examples of Food, Feed, and Industrial Products That Are Derived from Soybeans (*Glycine max* (L.) Merr.)

Soybeans are a versatile crop with many uses (see Indiancommodity.com). But before they can be used in food, feed, or industrial products, soybeans must be processed. More than 95% of the soybeans are processed by solvent-extraction industrial plants. When arriving at the processing plant, the soybeans are checked for quality. The soybeans then are processed to extract the *oil* and *meal*. From 100 pounds of soybeans, the soybean-crushing process produces 18 pounds of soybean oil and 80 pounds of soybean meal. There are several steps in the soybean-crushing process: *Dehulling* – First, the soybeans are cracked and the hulls are removed. *Soaking* – The soybeans then are flaked in special machines and moved to towers or tanks where they are soaked in a chemical solution. This solvent removes about 99% of the *pure, crude soybean oil* from the flake. *Refining*– The crude soybean oil may be refined further depending on how it is to be used. In the refining process, crude oil can be degummed, bleached, deodorized, or hydrogenated with hydrogen gas. In "degumming," the fatty acid content of the oil is neutralized with a caustic acid to produce some products like soap. The oil may also be "bleached" by treating it with an absorbent clay material before it is "deodorized" through a vacuum steam-distillation process. *Toasting and grinding* – After the oil is removed, the soybean flake then is cleaned, toasted, and ground to improve its nutritional value. This produces the *soybean meal*, which consists of 48% protein.

Soybeans are found in hundreds of human foods, animal feeds, and industrial products that are based on soybean oil and soybean meal. Some examples are as follows: *Soybean oil:* About 97% of soybean oil is used in a wide range of products for human use, such as cooking oils, salad dressings, sandwich spreads, margarine, salad oils, coffee creamer, mayonnaise, shortenings, chocolate coatings, a flour ingredient, and medicines. Soybean oil also is used in such industrial products as printing inks, cosmetics, linoleum, vinyl plastics, paints, caulking compounds, pesticides, epoxy glue, protective coatings, yeast soaps, shampoos, and detergents. Other examples of industrial products that have been developed from soybeans include candles, cleaners, composite materials, crayons, diesel additives, fabric conditioners, flooring, paint removers, pens, polish, solvents, tables/furniture, and waxes (see information at soyworld.com). *Soybean meal:* About 98% of soybean meal is used as a feed ingredient in mixed rations for poultry, hogs, and beef and dairy cattle. The remainder is used for human food or industrial products. High-protein (48%) soybean meal is used as a starter ration and high-performance feed. A lower-protein soybean meal (44%) also may be produced by adding the high-fiber hulls for use in bulky feeds, or as a carrier for molasses and other ingredients.

6.6 Production of Biodegradable Plastics from Plant-Derived Starch

Biodegradable plastics derived from plant sources are now being developed in the United States, Europe, and Asia from renewable resources such as corn, wheat, and potato starches as substitutes for conventional and petroleum-based plastics. Examples are provided in Table 6.2.

The term *biodegradable* means that a substance is able to be broken down into simpler substances by the activities of living organisms, and therefore, is unlikely to persist in the environment (Gross and Kalra, 2002). There are many different standards used to measure biodegradability, with each country having its own standards. The requirements range from 90 to 60% decomposition of the product within 60–180 days of being placed in a standard composting environment.

The reason traditional plastics are not biodegradable is because their long polymer molecules are too large and too tightly bonded together to be broken apart and assimilated by natural decomposer organisms. However, plastics based on natural plant polymers derived from wheat or corn starch have molecules that are readily attacked and broken down by microorganisms (Fig. 6.1).

Table 6.2 Examples of products using plant-based plastics and the companies that produce them

Plant-based plastics	Producer companies
Plastic bags	BioBag
Water bottles	Biota Water
Disposable forks and knives	Cereplast
Wall carpets	Interface
Cups for smoothies	Mrs. Fields Brands
Electronics packaging and products	Sony
Car floor mats	Toyota
Produce packaging	Wal-Mart
Deli containers	Wild Oats

Plant-based plastics provide an alternative to conventional plastics, especially for *polyvinyl chloride* (*PVC*) that relies heavily on extremely toxic feedstocks and additives that have devastating impacts on our health and environment through their production, use, and disposal. Many of the chemicals used in PVC production are linked to cancer, birth defects, reproductive harm, and a host of other health problems. In contrast, bio-based plastics are generated from renewable materials, such as corn starch into plastic. The production of bioplastics uses fewer fossil fuels compared to petrochemical plastics, even after accounting for the fuel needed to plant and harvest the corn or other feedstocks. Plant-based plastics are also compostable. They can be effectively composted in a large-scale facility, where it will degrade

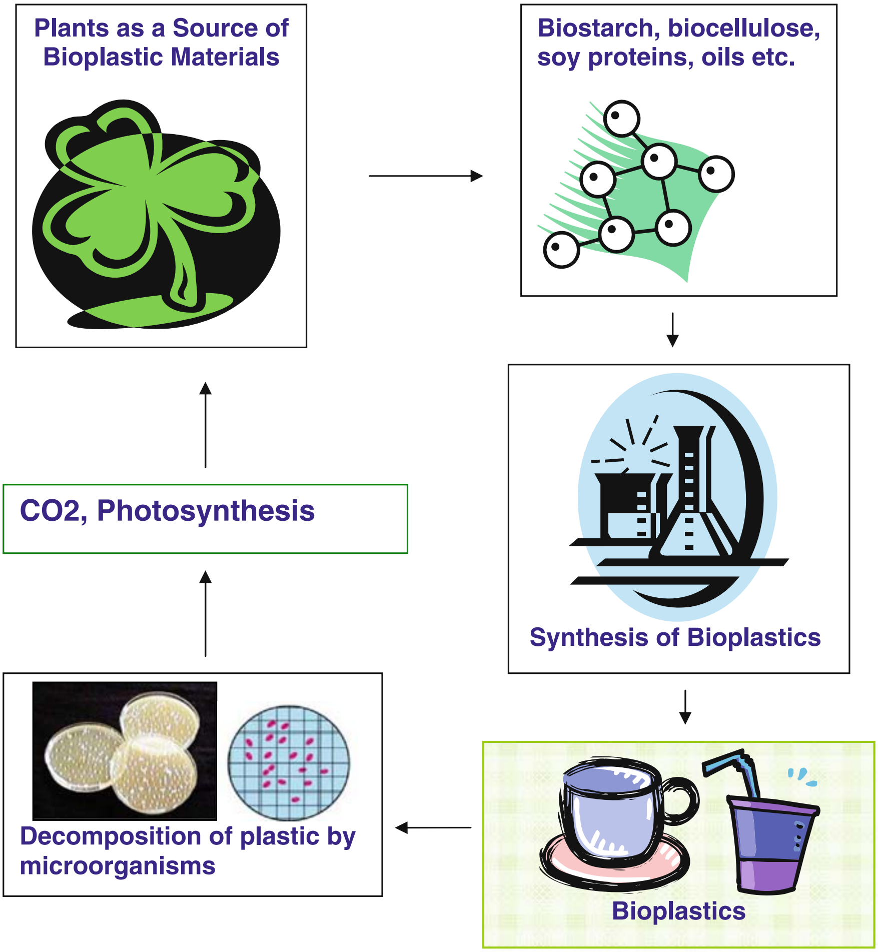

Fig. 6.1 Natural, plant-based plastics and their decomposition

within 45 days. Conventional plastics, in contrast, can take over 100 years just to begin the degradation process.

Starch is a natural storage polysaccharide-type polymer made up of α-(1,4)-linked glucose (amylose or straight-chain starch) or α-(1,4) + α-(1,6)-linked glucose (amylopectin or branch-chain starch) (see Cseke et al., 2006). It is a white, granular carbohydrate produced by plants during photosynthesis and it serves as one of the plant's energy stores. Grains of cereal plants and potato tubers normally contain starch in large proportions. Starch can be processed directly into a bioplastic, but because it is soluble in water, articles made from starch will swell and deform when exposed to moisture, thus limiting its use. This problem can be overcome by modifying the starch into a different polymer. First, starch is harvested from corn, wheat, or potatoes, then microorganisms transform it into lactic acid, a monomer. Finally, the lactic acid is chemically treated to cause the molecules of lactic acid to link up into long chains or polymers, which bond together to form a plastic called *polylactide* (*PLA*).

PLA has been commercially available since 1990. Certain blends have proved to be successful in medical implants, sutures, and drug delivery systems because of their capacity to dissolve away over time. However, because PLA is significantly more expensive than conventional plastics, it has failed to win widespread consumer acceptance.

Biodegradable plastic products currently available in the market are from 2 to 10 times more expensive than traditional petroleum-based plastics. Environmentalists argue that the cheaper price of traditional plastics does not reflect their true cost when their full impact is considered. A case in point is this: when we buy a plastic bag, we do not pay for its collection and waste disposal after we use it. If we included these kinds of associated costs, then traditional petroleum-based plastics would cost more and biodegradable plastics might be more competitive.

Another way of making biodegradable polymers involves getting bacteria to produce granules of a plastic called *polyhydroxyalkanoate* (*PHA*) inside their cells. Bacteria are simply grown in culture in bioreactors and the plastic is then harvested. Going one step further, scientists have taken genes from this kind of bacterium and transferred them into corn plants, which then manufacture the plastic in their own cells.

Unfortunately, as with PLA, PHA is significantly more expensive to produce. As yet, it is not having any success in replacing the widespread use of traditional petrochemical-based plastics. Perhaps as the price of oil increases and supply dwindles, biodegradable plastics will come into more favor benefit to our environment.

If cost is a major barrier to the acceptance of biodegradable starch-based plastics, then the solution lies in investigating low-cost options to produce them. In Australia, the *Cooperative Research Centre (CRC) for International Food Manufacture and Packaging Science* is examining ways of using basic starch, which is cheaper to produce, in a variety of blends, with other more expensive biodegradable polymers to produce a variety of flexible and rigid plastics. These are being made into film-molded and injection-molded products, such as plastic wrapping, shopping bags, bread bags, mulch films, and plant pots. Depending on the application, scientists can alter polymer mixtures to enhance the degradative properties of the final product. For example, an almost pure starch product will dissolve upon contact with water and then biodegrade rapidly. But, by blending quantities of other biodegradable plastics into starch, scientists can now make a waterproof product that degrades within 4 weeks after it has been buried in the soil or composted (Fig. 6.1).

In the United States, the primary company manufacturing bioplastics is NatureWorks, owned by Cargill. They can produce 300 million pounds a year of a plastic called PLA or poly lactic acid that is made from corn grown in Nebraska and Iowa. Starch from the corn is extracted and converted into its basic monomer, D-glucose, and then into lactic acid by fermentation. The lactic acid is further refined into pellets that can be made into different end-products. This is actually a much better use of non-feed corn than the production of ethanol. It gives more and is much more efficient. Other companies manufacturing plant-based plastics include Dupont, BASF, Eastman, Proctor & Gamble, and Cereplast. The end plastic products, indistinguishable from those derived from petrochemicals, are used to create food packaging, disposable cups and forks, water bottles, auto parts, carpeting, compact disks, bedding materials, and other consumer products.

In Europe, bioplastics are even more popular. Consumption doubled between 2001 and 2003. An Italian company called Novamont manufactures a plant-based plastic called *Mater-Bi* that is used in many similar applications to PLA, including food packaging and disposable food service items. Production is expanding across the globe where capacity for bio-based plastics is around 800 million pounds and is expected to top 1.3 billion pounds in 2008.

Despite numerous environmental and health benefits of plant-based plastics, significant environmental challenges need to be addressed. These include the impacts of industrial agricultural production, the use of harmful additives, and the impact on recycling infrastructure and markets. Conventional corn production uses significant amounts of toxic pesticides that can adversely impact groundwater and surface water, leads to soil erosion, and impacts soil production and wildlife habitats. In addition, much of the corn made into NatureWorks' plastic is genetically modified. Many environmental organizations are working to address the use of genetically modified organisms (GMOs) in NatureWorks' feedstock.

One concern raised by recyclers is the impact that bioplastics have on the recycling of conventional plastics. Bio-based plastics, such as PLA, cannot be mixed with conventional plastic such as *PET/PETE* (*polyethylene terephthalate*) because these materials are not compatible for recycling purposes. PLA itself can be recycled, but at present, the infrastructure to separate and recycle this material does not exist in the United States. Until these problems are solved, the most sustainable disposal option for bio-based plastics is composting. Clear labeling of bio-based plastics is critical to ensuring that these materials are properly disposed of in composting facilities. The technology is a step in the right direction in terms of responsible use of plastics.

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