

# Potatoes to Plastics

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## **Executive Summary**

This research project examined the resource and economic viability of Maine potatoes as a source for polylactic acid (PLA) to support InterfaceFABRIC's manufacturing requirements for use in their bio-based fabrics for commercial interiors. As part of this study, the following data was reviewed:

- the amount of acres currently harvested for potato production and the average number of acres in use;
- the average harvest yield of potatoes;
- the average price paid to growers per hundredweight (cwt) of potatoes;
- the raw materials costs associated with collecting, transporting and pre-processing waste potatoes for production of starch in preparation for PLA production;
- the availability of potato starch to meet the needs of InterfaceFABRIC; and
- the comparison of current cultivars of potato vs. one bred to use less fertilizer and fungicide (the Defender, a non-Genetically Modified Organism), both with approximately the same starch content.

The analysis of these data supports the conclusion that it is economically feasible for Maine potato growers to plant and harvest potatoes specifically for the purpose of providing a source of starch to manufacture PLA. It has also been determined that there would be little to no start-up costs to the potato growers themselves to provide potatoes for PLA using the potato cultivars (varieties) that are currently grown, in particular the Russet Burbank and/or Shepody potatoes. The planting, harvesting and pre-processing of these potatoes would be no different than what the growers are currently doing.

The analysis also shows that the cost of processing potatoes for PLA would be similar to that for a small capacity PLA facility that processes corn and the price which potato growers would receive for PLA potatoes would most likely be comparable to the average price paid to all growers for their potatoes. It also appears that the price of PLA from potatoes would be similar to that for PLA derived from corn.

The analysis further confirms that the amount of PLA needed by InterfaceFABRIC (13 million pounds per year) could, in principle, be supplied solely by waste potatoes, made up of those left in fields after harvesting, those not marketed or below grade, and potato waste from processing. However, the resources or economies to collect those wastes and waste potatoes and provide them to a PLA facility are not available at this time.

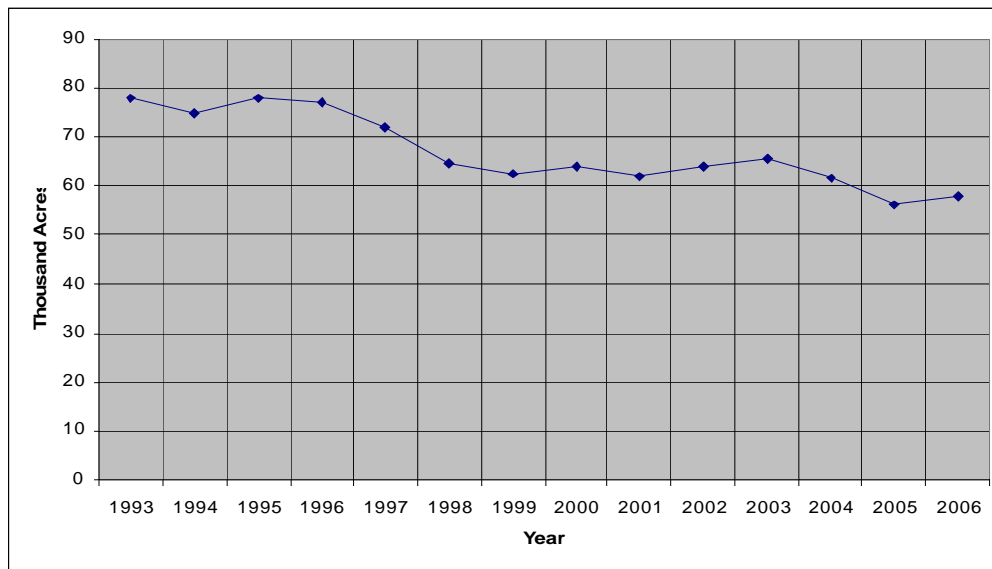
In conclusion, the research supports the concept of producing bio-based plastic feedstock from Maine potatoes. The potential to produce PLA from potato starch will not be limited by the ability of potato growers to provide a viable crop. Furthermore, the cost to growers will not be prohibitive for such a project and the return will be similar to that for food stock potatoes. Finally, no current table-ready or processing potatoes need to be taken out of the supply chain. An increase in the amount of acres planted and harvested can be implemented to provide the starch, and the potato varieties currently grown, in particular the Russet Burbank and/or Shepody potatoes, can be used as the source of starch for PLA manufacturing. The next step is to conduct the research to determine the location and technical specifications for a PLA facility in Maine

and examine the potential contribution of waste potatoes and processed starch to support a PLA facility and to examine the potential for new more cost effective and environmentally sustainable potato varieties which can be grown specifically for the PLA market.

**Potato Acreage and Yield**

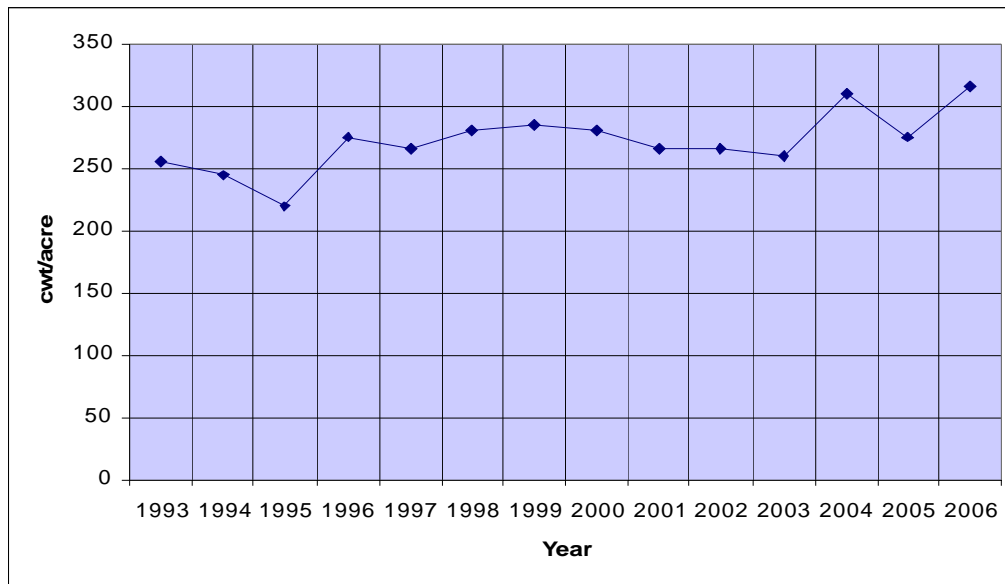
The current amount of acreage in Maine harvested for potatoes has averaged 67,000 acres for the last 13 years<sup>1</sup>. Expanding the harvested area by another 6,667 acres of potatoes, providing the equivalent of another 20,000 acres based upon a three-year rotation of potato crops, to address the need for new potato sources for potato starch for PLA is something that potato growers could accomplish in one planting season.<sup>2</sup> At its peak (1945-46), Maine harvested approximately 220,000 acres of potatoes; by the mid 1950s that acreage had decreased to about 140,000. Maine potato acreage has since continued to decrease, with a harvest of 58,000 acres in 2006.<sup>3</sup> (Figure 1) This decrease in acreage is the result of an expansion of potato growth in the western U.S. and Canada, as well as increased yield in fields in Maine.

**Figure 1: All Purpose Potatoes Harvested in Maine**



Average Harvest: 67 thousand acres

Although potato harvesting acreage in Maine has been steadily declining since the 1970s, the yield (in hundredweight/acre (cwt/acre)) has been steadily increasing. The 2006 crop of potatoes yielded 315 cwt/acre,<sup>4</sup> and Maine has had an average yield of 271 cwt/acre from 1993-2006.<sup>5</sup> (Figure 2<sup>6</sup>)

**Figure 2: Maine Potato Yield in hundred weight/acre, 1993-2006**

Average Yield: 271 cwt/acre

To determine the ability of potato growers to meet the needs of a PLA facility, we looked at the potato starch yield based upon current cultivars, specifically Russet Burbank and Shepody. We have also identified a newer cultivar of potato, the Defender, which may be used in the future as a source of potato starch. A further discussion of the Defender potato is provided below.

As noted above, potato growers in Maine would have little, if any, difficulty expanding their current acreage an additional 20,000 acres under cultivation, resulting in 6,667 harvested acres of potatoes per year within an existing rotation scheme. This should provide enough available potato starch (and thus PLA) to meet the needs of InterfaceFABRIC (Table 1<sup>7</sup>), determined to be 13 million pounds of PLA per year. Thus, new potato crops could be grown for the sole purpose of providing potatoes for processing into starch. Growers have enough storage capacity for an increase of this size, and additional storage can be constructed if the market demands it and potato contracts require it.<sup>8</sup>

Our analysis also shows that the amount of PLA needed by InterfaceFABRIC could, in principle, be supplied solely by waste potatoes (Table 2). There are three potential sources of waste potatoes: those left in fields after harvesting, those below grade or not marketed for the table or processing markets, and the waste from processing potatoes. However, the resources and economic incentives to collect those waste potatoes and provide them to a PLA facility are not available at this time. Most potatoes that do not meet the minimum size required in grower contracts are left in the field. Using waste potatoes left in fields would require a change in current harvesting practices and contractual requirements since going back into the fields to retrieve these potatoes is not economically practical. Because current contracts do not allow growers to cull potatoes once they are pulled from the field, the contracts would have to be re-negotiated to allow growers to “strip out” below grade potatoes going into storage. In some years potatoes harvested but not marketed have to be disposed of at a cost to growers and processors (e.g., in 1996 and 2004, 21,175 thousand cwt and 19,065 thousand cwt of potatoes,

respectively<sup>9</sup>). While potentially attractive as a source for PLA, the uneven availability of this resource (i.e., there may be no excess availability in some years), makes it too unpredictable for an industrial process. Finally, using waste from the processing of potatoes might be feasible, but further study is needed to determine if it is economical to collect and use this waste at a facility that is removed from where the PLA processing takes place.

**Table 1: Potato Starch and resulting PLA Yields with Russet Burbank and/or Shepody Potatoes**

Potato Yield	27,100 lbs potatoes/acre
Percentage of starch in Russet Burbank and Shepody potatoes	14.8 %
Potato starch	4,011 lbs/acre
PLA from Starch (1:0.65)	2,607 lbs/acre
Additional acres for potatoes (in 3-year rotation)	6,667 acres
PLA yield with new acreage	17,380,133 lbs

**Table 2: Starch and PLA Availability from Potato Wastes**

Potato Harvest	67,000 acres	
Yield	27,100 lbs of potatoes/acre	
Fresh Weight	1,815,700,000 lbs	
Starch	268,723,600 lbs	
<b>Waste Percentage availability</b>	<b>lbs starch available</b>	<b>lbs of PLA</b>
If 10% of production culls and smalls (waste potatoes)	26,872,360	17,467,034
If 50% of production is for fries and 30% waste occurs (potato waste)	40,308,540	26,200,551

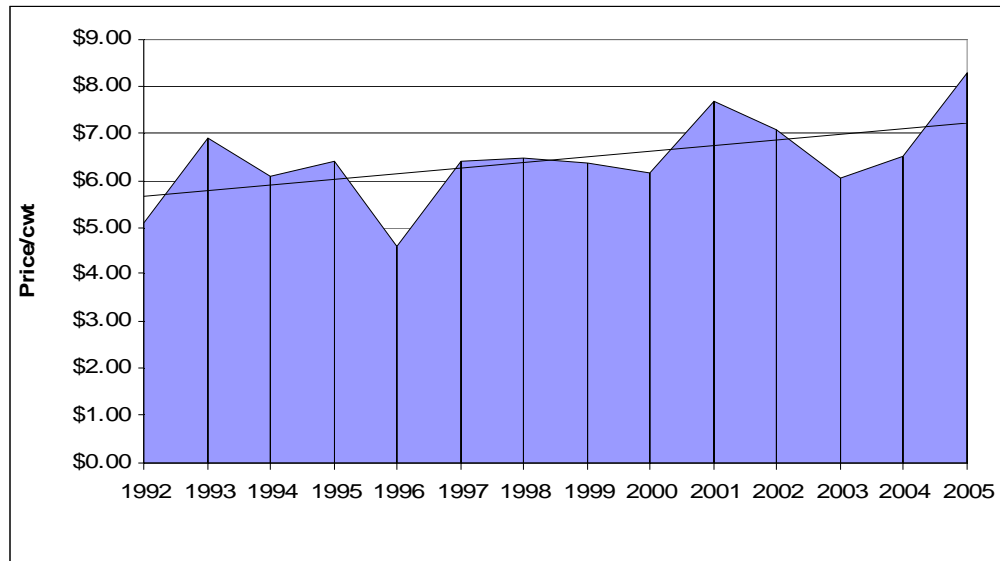
Assumptions based on averages for potato harvesting and yield noted in Figures 1 and 2. Percentage of starch used is 14.8%. PLA from starch 1:0.65

The costs and grower requirements for the Russet Burbank and Shepody potatoes are well established, and the percentage of starch found in these species makes them a reliable source for our empirical estimates. In addition, both of these are staple crops for potato growers in Maine, with fairly steady yields and both are part of current contracts and crop rotations.

### **Prices**

The average price in Maine paid to all growers for potatoes between 1992-2005 was \$6.43/cwt (Figure 3<sup>10</sup>). One acre of Russet Burbank or Shepody grown and sold for processing would bring a grower \$1,742 – based upon the average yield of 271 cwt/acre during that same time.

**Figure 3: Potato prices per cwt, Maine; 1992-2005**



Average Price: \$6.43 Price increase per year: \$0.12/yr

As indicated on Figure 3, there has been an increase of \$0.12 per year in the hundredweight price paid to growers from 1992-2005. If only the last five years of those data are considered (2000-2005), the trend indicates an average increase paid to growers per hundredweight of \$0.17 per year.

Standard contracts for potato growers set a price per hundredweight for the harvest season. We assume that the same type of contractual agreement would be in place for growers who are growing potatoes to be harvested for starch as for growers harvesting for processing. An overview of a representative potato enterprise budget costs and performance measures, based on a medium-large conventional potato farm, is provided in Table 3<sup>11</sup> and is based upon data found in MAFES Bulletin 850, November 2004.

**Table 3: Potato Enterprise Budget, Conventional Potato Farm**

	<b>Total</b>	<b>Per Acre</b>	<b>Per cwt</b>
Number of Acres	320		
Potato Yield (cwt)	86,720	271	
<b>Annual Operating Expenses</b>			
Seed	\$37,440	\$117.00	\$0.43
Fertilizer and Lime	\$80,000	\$250.00	\$0.92
Chemicals (insect, weed and disease control; potato vine desecration)	\$96,000	\$300.00	\$1.11
Labor	\$64,925	\$202.89	\$0.75
Diesel Fuel and Oil	\$42,240	\$132.00	\$0.49
Maintenance and Upkeep	\$35,507	\$110.96	\$0.41
Supplies	\$18,430	\$57.59	\$0.21
Insurance	\$17,729	\$55.40	\$0.20
<b>Miscellaneous</b>			
Utilities	\$12,202	\$38.13	\$0.14
Custom Hire	\$0	\$0.00	\$0.00
Rent or Lease (land)	\$18,000	\$56.25	\$0.21
Freight and Trucking	\$5,698	\$17.81	\$0.07
Storage and Warehousing	\$3,759	\$11.75	\$0.04
Other Expenses	\$1,920	\$6.00	\$0.02
Interest	\$10,377	\$32.43	\$0.12
Total Operating Expenses	\$444,227	\$1,388.21	\$5.12
<b>Annual Ownership Expenses</b>			
Depreciation and Interest	\$90,345	\$282	\$1.04
Tax and Insurance	\$5,603	\$18	\$0.06
Total Ownership Expenses	\$95,948	\$300	\$1.11
Total Annual Cost	\$540,175	\$1,688.05	\$6.23
<b>Performance Measures</b>			
Breakeven Revenue		\$/acre	\$/cwt
Long-run to cover all costs		\$1,688.05	\$6.23
Short-run to cover Operating Costs		\$1,388.21	\$5.12
Source: MAFES Bulletin 850, November 2004: Representative Farm Budgets and Performance Indicators for Integrated Farming Practices in Maine (ISBN: 1070-1494). Data taken from Table 13. Potato enterprise budget for a medium-large conventional farm. Modifications to original table made to seed, fertilizer, lime, chemical <sup>12</sup> , diesel fuel and oil costs <sup>13</sup> , and estimated yield of potatoes. Yield changed to average yield from 1993-2006. Seed price per acre based upon Russet Burbank potatoes. ;Management costs and return on investments are not included in this budget.			

### **PLA From Corn**

The wholesale price of PLA made from corn varies considerably, ranging from \$0.65/lb up to \$1.10/lb<sup>14</sup>, based upon the grade (e.g., prices for fluff, yarn, pellets and film grades), the volume needed, and the scale of production. The willingness of a purchaser to be co-branding starch PLA on their products (branding acceptance) will also affect the price. In general, manufacturers using corn to make PLA are attempting to directly compete with the price of polyethylene



terephthalate (PET), and are keeping the price for PLA comparable to PET. It should be noted that PLA for fibers will be more expensive than the upper range listed here.

### **PLA Processing**

Based on an existing processing plant in Germany, Green Harvest Technologies has estimated the annual operating costs of a small capacity PLA facility, as opposed to large-scale production discussed above, using glucose from corn as a raw material and based in Germany. Translating the operating costs to U.S. dollars results in \$26.6 million per year. This price consists of the costs for depreciation, interest, labor, repairs and maintenance, raw material, catalyst and additives, energy, and wastewater. At such a facility, PLA can be produced at a price of \$1.20/lb,<sup>15</sup> and is comparable with the projected cost of PLA production in Maine.

### **PLA From Potatoes**

Currently, there are no facilities in the United States manufacturing PLA from potato starch. The only PLA production facility in the U.S. uses corn starch to produce PLA, and as noted above, the estimates made for a small capacity PLA facility in the U.S. are based on deriving glucose from corn from a similar sized facility in Germany. For this study, we have assumed that the PLA facility will work with the potatoes, and not from a processed source of potato starch. This assumption has been made in order to evaluate the project based upon the current infrastructure, especially with regard to storage requirements and current contract agreements. Using potato starch as a source for PLA is also technically feasible and may merit additional study.

As noted in Figure 3 above, the price paid to potato growers for all types of potatoes (processing, table stock and seed potatoes) is an average of \$6.43/cwt of potatoes, or \$0.06 per pound of fresh weight potatoes. For a PLA facility to convert this starch to sugar for PLA production, the cost to the facility per fresh weight of potatoes is an additional \$0.06 per pound of fresh potatoes within the process itself, for a total of \$0.12 per pound. It is reasonable to assume that potato growers could continue to be paid a price for their potatoes that is comparable to that paid for processing, and the PLA facility will be able to produce PLA at approximately \$1.26/lb.

### **The Defender Potato**

As we studied the possibilities of using either Russet Burbank or Shepody potatoes as a starch source for PLA, we also looked at one that had the possibility of being grown with fewer pesticides and fungicides in a typical growing season. It is possible that potato growers could see an increase in profitability if they grow a cultivar that fits these requirements. One such potato is the Defender potato, a species that has been studied by the Department of Plant, Soil and Environmental Sciences (PSE) at the University of Maine. The Defender potato has high levels of starch and yield and can be grown in Maine during typical years using one-third less nitrogen fertilizer and one-half the fungicide as the Russet Burbank, thereby having an immediate impact on increasing the sustainability of the potato fields. The Defender has been studied extensively by researchers across the nation,<sup>16</sup> including PSE, and has been found to resist late blight, a devastating disease for potatoes throughout the world, as well as other potato diseases.<sup>17</sup> In eight test sites in Maine, it was estimated that Defender could use approximately 25% less nitrogen and 50% less fungicide compared with Russet-Burbank.<sup>18</sup> In studies conducted by the United

States Department of Agriculture (USDA) Agricultural Research Service (ARS), it was found that growers could use either reduced amounts of pesticides or none at all.<sup>19</sup>

It must be noted that the Defender has at least one serious roadblock before it can be implemented for PLA production: seed for this cultivar is not currently available in sufficiently large quantities for large-scale production. In addition, once it becomes available, the seed costs per acre are likely to be slightly higher than those for Shepody and nearly double those for Russet Burbank.

Although it is beyond the scope of this project to determine ideal crop rotations and soil conditions, it should be noted that Defender farming is optimal when grown in soils with a low pH (below 5.5) – due to its susceptibility to common scab.<sup>20</sup> In addition, if Defender is used as the starch source for PLA, then rotational crops would have to be chosen that can also grow well in a low pH soil. If growers choose to use the Defender potato, the yield will be more than enough for InterfaceFABRIC's manufacturing requirements for polylactic acid (Table 4).

**Table 4: Potato Starch and PLA Availability, with Defender Potato**

	Average yield of potato harvest, 1993-2006	Average yield of Defender potato Maine test fields
Potato Yield (lbs of potatoes/acre)	27,100	33,200
Percentage of starch in Defender potatoes	15.0	15.0
Potato starch (lbs/acre)	4,065	4,980
PLA (lbs/acre)	2,642	3,237
Total lbs PLA from Defender	17,614,214	21,581,079

There are additional variables to consider if the Defender potato is to be used:

- The Defender is a protected variety. Many new potato varieties such as Defender are subject to plant variety protection laws, which were developed by the U.S. and other countries to protect plant varieties as a form of intellectual property.<sup>21</sup> Moreover, the current rules for protected potato varieties have not yet been set.
- The seed cost for the Defender potato is likely to be higher than the other potato cultivars discussed as a comparison. We estimated \$11.75/cwt for Defender seed potatoes compared to \$9.75 for Russet Burbank and Shepody. At seeding rates of 20 cwt/A for Defender and Shepody and 12 cwt/A for Russet Burbank, the seed costs per acre are estimated at \$235, \$195, and \$117, respectively.<sup>22</sup>
- As noted above, the seed supply of the Defender potato is small right now (1 acre of certified Defender seed grown in Maine during 2006).<sup>23</sup> It will take a number of years for seed production to scale up and meet the demand if the Defender potato is to be used as the starch source for PLA production.

Although there is potential for a significantly larger return for the growers and an increased environmental benefit to using Defender, it has to be noted that at this time, there is not a

sufficient supply of Defender seed to meet the demand for PLA production and cost savings in chemical use would be somewhat offset by higher seed costs. After a scale-up in seed production, the seed cost for Defender potatoes should drop significantly, perhaps to levels only slightly higher than Russet Burbank and Shepody potatoes. However, the actual price is not known at this time.

### **Conclusions**

The potential to produce PLA from potato starch will not be limited by the ability of potato growers to provide a viable crop. Furthermore, the cost to growers will not be prohibitive for such a project. Finally, no current table-ready or processing potatoes need to be taken out of the supply chain. An increase in the amount of acres planted and harvested can be implemented to provide the starch, and the potato cultivars currently grown, in particular the Russet Burbank and/or Shepody potatoes, can be used as the source of starch for PLA manufacturing.

The Defender potato also appears to be a promising crop, both for yield potential, starch content, and increasingly sustainable farming practices. For the Defender to be readily used, the seed supply will have to be increased. In order to do that, seed growers will need to have contracts or other means to assure that there will be demand for the seed.

The use of waste potatoes and wastewater from potato processing should be further investigated. As noted in Table 2, there appears to be enough waste available to supply the necessary starch for a PLA facility. Further questions remain, including:

1. How is the starch in the waste potatoes and waste stream currently being used?
2. Can the waste be used more efficiently as a supply source for a PLA facility?
3. Is there a way to collect waste potatoes from the fields, either by altering current contractual requirements, or a different harvesting technique? Is plowing waste potatoes back into the field their best use and necessary for the soil?
4. Where would be the best location for a PLA facility, in terms of transportation, energy and storage costs?

Determining the answers to these questions will assist in determining the most economical and ecologically sound location of a PLA facility in Maine.

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