CONFIDENTIAL

# The Business Case for Commercial Production of Bioplastics in Maine

A PRELIMINARY REPORT

On the feasibility of cost-effectively manufacturing the bioplastic polylactic acid (PLA) from polymer grade lactic acid (PGLA) fermented from sugars derived from biomass feedstocks such as Maine potatoes and wood chips

submitted to the

**Maine Technology Institute**

in fulfillment of the requirements of a Cluster Enhancement Award
by the

**Tides Center/Environmental Health Strategy Center**
and **Maine Initiatives** with **Jim Lunt & Associates, LLC**

on behalf of the

**Sustainable Bioplastics Council of Maine**

March 2010

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# EXECUTIVE SUMMARY

An expert engineering cost model demonstrates that polylactic acid (PLA), the popular bio-based plastic resin, can be made in Maine from locally sourced biomass feedstocks at a cost that's comparable to the cost of PLA production from Midwestern corn. Further, several strategic advantages would allow Maine-made PLA to command a premium in the market place.

Bio-based plastics are experiencing rapid growth in demand and production, with the market for PLA alone projected to more than quadruple by 2020. The high and volatile price of oil is one major driver toward bio-based materials. When crude oil sells for more than $60 to $80 per barrel, the economics favor bio-based production over fossil-based materials. Impending climate regulations and consumer demand for more environmentally sustainable goods are also fueling the drive toward biomaterials.

Our PLA manufacturing strategy builds on Maine strengths – our rich natural resources, idle industrial infrastructure, innovative research and development, and hard working Maine people. Two feedstock streams will be converted to sugar and fermented to make polymer grade lactic acid – potato starch from processing waste, cull and raw potatoes; and extracts from wood chips destined for biomass boilers or pulping operations. Two lactic acids plants will feed a PLA production plant with a capacity of 50,000 metric tons per year. All the facilities will be co-located with existing host industrial facilities, taking economic advantage of power, steam, water and other infrastructure already in place.

We used an engineering cost model, developed by experts who formerly worked for NatureWorks - the Cargill subsidiary that pioneered PLA production in the U.S., to project manufacturing costs for PLA production in Maine. We estimate that feedstock sugar, which accounts for about one-third the cost of producing PLA resin, will be cost-comparable for potato starch and lower in cost for wood-derived sugars, compared to corn dextrose. Although NatureWorks enjoys economies of scale with a larger plant, a Maine-based enterprise can reduce costs by nearly 30% by using "brownfield" construction on-site at existing industrial facilities and by deploying advanced fermentation technology based on a yeast organism rather than a bacterium.

Employing the above strategy, we calculate that PLA can be produced in Maine at a cost of about $0.90 per pound compared to an estimated production cost of $0.89 per pound for PLA from Midwestern corn, at the current price of corn dextrose at $0.14 per pound. Maine PLA could be sold at a premium due to feedstocks that are not genetically modified organisms (GMOs) unlike corn, higher value-added markets that would be targeted based on improvements in PLA properties, and the value of the Maine brand.

# INTRODUCTION

The purpose of this project is to research, develop and spur the commercial manufacturing of sustainable bioplastics from Maine potatoes, potato waste, wood chips and other biomass. We also aim to develop the network of companies and supporting organizations that will to boost Maine's green economy through the development of non-toxic, petroleum-free and bio-compostable products made from bioplastics.

This preliminary report establishes the business case for bioplastics production. It presents a cost model that integrates known costs for commercial production of the corn-based bioplastic PLA with technical and economic information developed for Maine-based feedstock sugars, plant capacity and manufacturing locations.

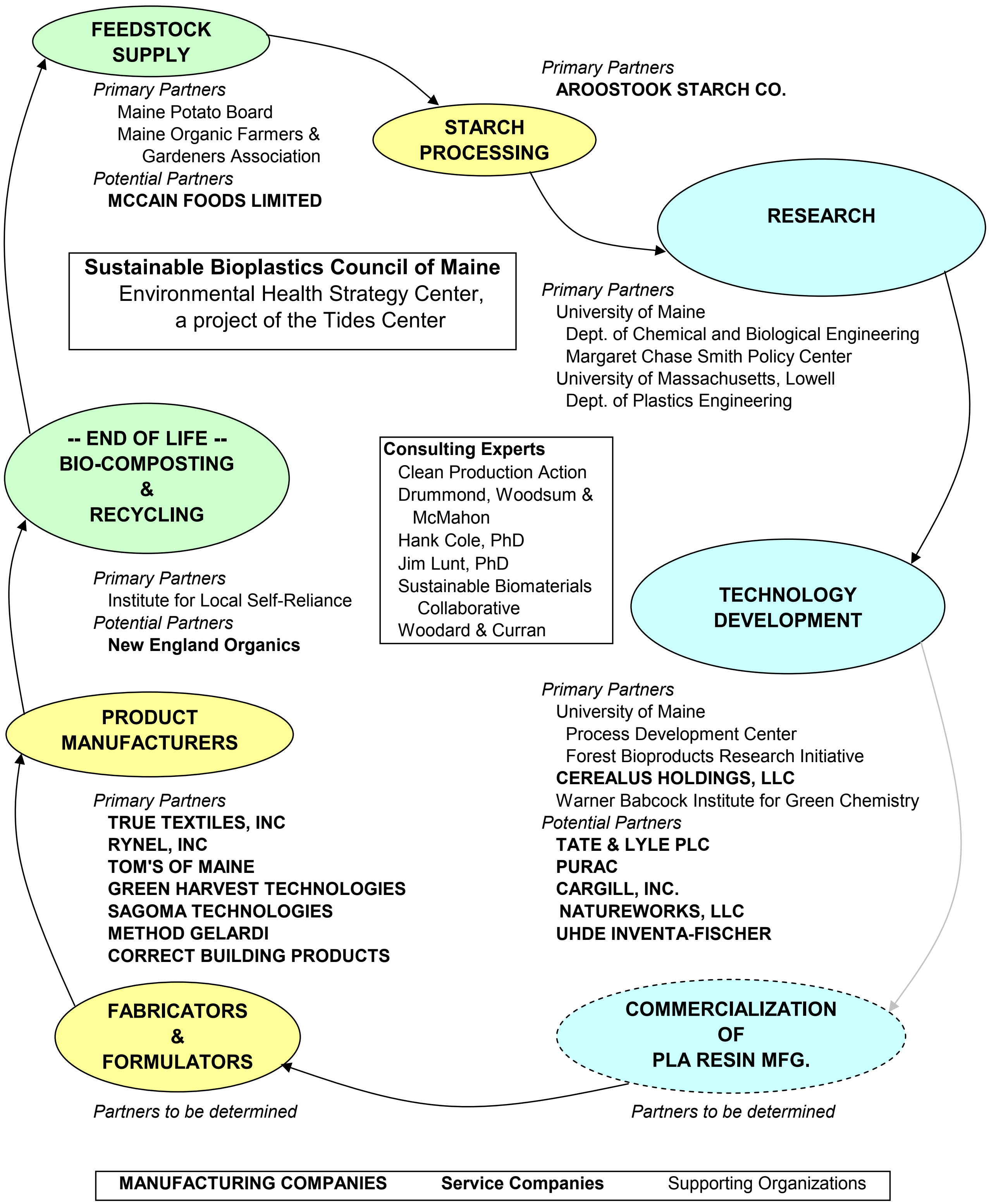
Our final business development plan will assemble the strategic package necessary to attract major capital investment and a management team committed to manufacturing bioplastics under a licensing agreement with our nonprofit consortium. The pieces will include a final cost model, feedstock supply agreements, a technology pathway including intellectual property and clear freedom to practice, and commitments from end-use customers with significant market pull. We will work with an investment banker to develop and pitch this package to investors and major corporations.

We've come a long way since late 2005, when the vision of producing plastics from Maine potatoes arose at an Environmental Health Strategy Center event honoring three Maine manufacturers for their commitment to sustainable production. We praised InterfaceFABRIC, Inc. (now True Textiles, Inc.) based in Guilford, Maine for being the first company in the world to weave, dye and sell a commercial fabric using a bio-based plastic made from Midwestern corn called PLA. [1] "Wouldn't it be cool if we could make this from Maine potatoes!" said Wendy Porter from Interface.

That insight sparked a partnership that landed a seed grant from Maine Technology Institute for a biomass availability study. [2] Our consortium has since grown to include several Maine manufacturers, agricultural business groups, University of Maine researchers and nonprofit organizations dedicated to sustainable economic development. Last we year we incorporated as a trade association, the Sustainable Bioplastics Council of Maine, to oversee the research and development work and promote the emerging bioplastics sector. For a map of the cluster, see Figure 1.

In the last three years, we have raised $2.3 million to support research and development, and cluster development activities through financial support received from MTI and private foundations matched by all of the consortium members. Our accomplishments and deliverables produced to date have been previously summarized. [3]

## Figure 1. Map of Maine's Sustainable Bioplastics Cluster



*Source:* Sustainable Bioplastics Council of Maine (2009)

# BEYOND OIL: MARKET DRIVERS for BIOPLASTICS

***"The general rule of thumb, if oil gets above $70-$80 a barrel, it gets very easy to compete on a price basis"***
Steve Davies, NatureWorks,
Director of Communications and Public Affairs [4]

Several factors are driving the rapid growth in market demand for bio-based plastics. [5] These include the rising and volatile cost of oil, corporate sustainability goals, green market consumer demand, pending climate crisis regulation, technology innovation, and the promise and possibilities of technological progress. [6]

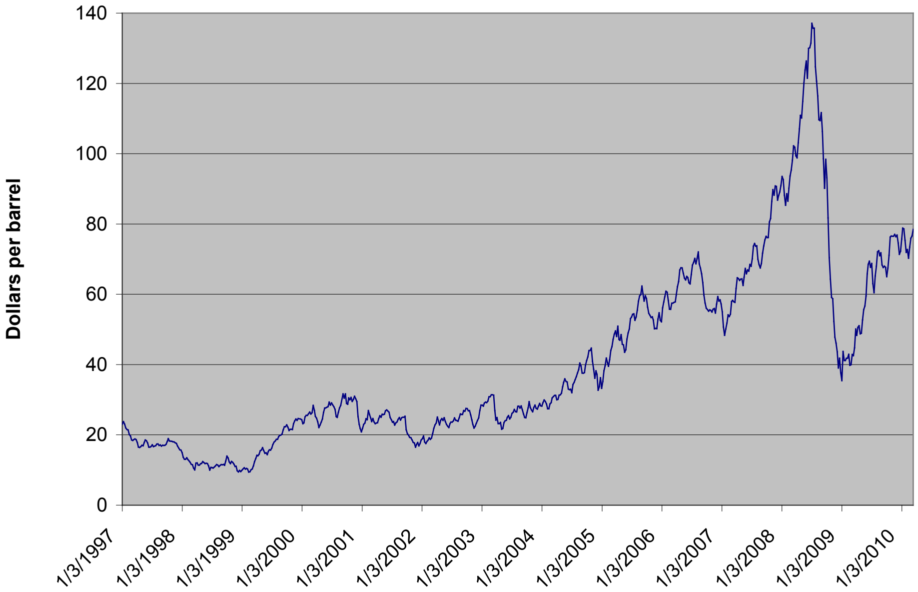
The global average annual growth in bioplastics production was 38% from 2003 to the end of 2007, according to a recent industry report. In Europe, the annual growth rate was as high as 48% in the same period. To meet future demand, capacity to produce bioplastics is projected to increase nearly ten-fold from 2007 to 2020. PLA is one of four bioplastics highlighted for significant growth. Although, in 2007 bioplastics represented only 0.3% of total plastics production worldwide (the balance being fossil-based), technically-feasible substitution of bioplastics could eventually replace 90% of all petrochemical plastics. [7]

**The high cost and volatile prices of fossil fuel feedstocks** are major drivers toward bio-based feedstocks. Figure 2 shows that the average price of crude oil from 2004 to 2009 was about $65 per barrel, reaching a peak of $140 per barrel in 2008. After a recent crash oil prices have risen again to $70 - $80 per barrel of crude oil.

For commercial bioplastics to be price-competitive, crude oil prices must top $70 per barrel, according to bioplastics industry insiders and university researchers. [8] Many product manufacturers who rely on plastics are also looking for more stable and predictable costs than provided by petroleum feedstocks. [9]

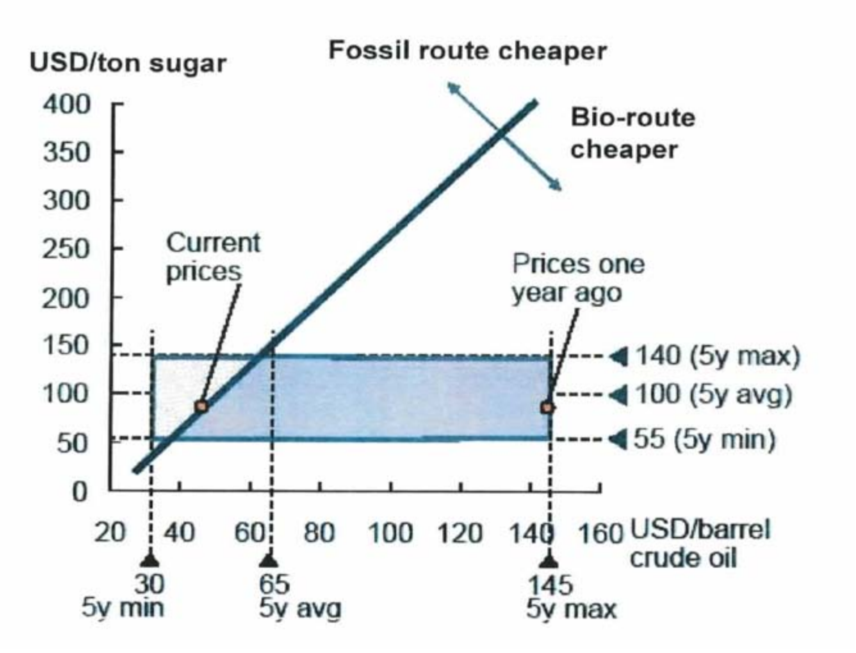
Figure 3 provides one example of how the interplay between the feedstock costs of sugar (for bio-based chemicals) and crude oil (for petrochemicals) affects the economic attractiveness of bio-based production. In this case, the data are derived for bio-ethanol production from sugarcane in Brazil, perhaps the most cost-effective bio-based production scenario available. The dark shading to the right of the cost equivalence line shows the conditions under which bio-based chemical production will be cheaper than petrochemical-based production. According to the figure, when crude oil exceeds $60 dollars per barrel, bio-ethanol production is always cost-effective regardless of the cost of sugar from sugar cane during a recent five year period. When feedstock sugar prices are lower, bio-based chemical production is cost effective at even lower crude oil prices.

**Figure 2. Volatility of Crude Oil Prices**



*Source:* U.S. Energy Information Administration (2010)[10]

**Figure 3. Feedstock Costs Drive Bio-based vs. Oil-based Production**



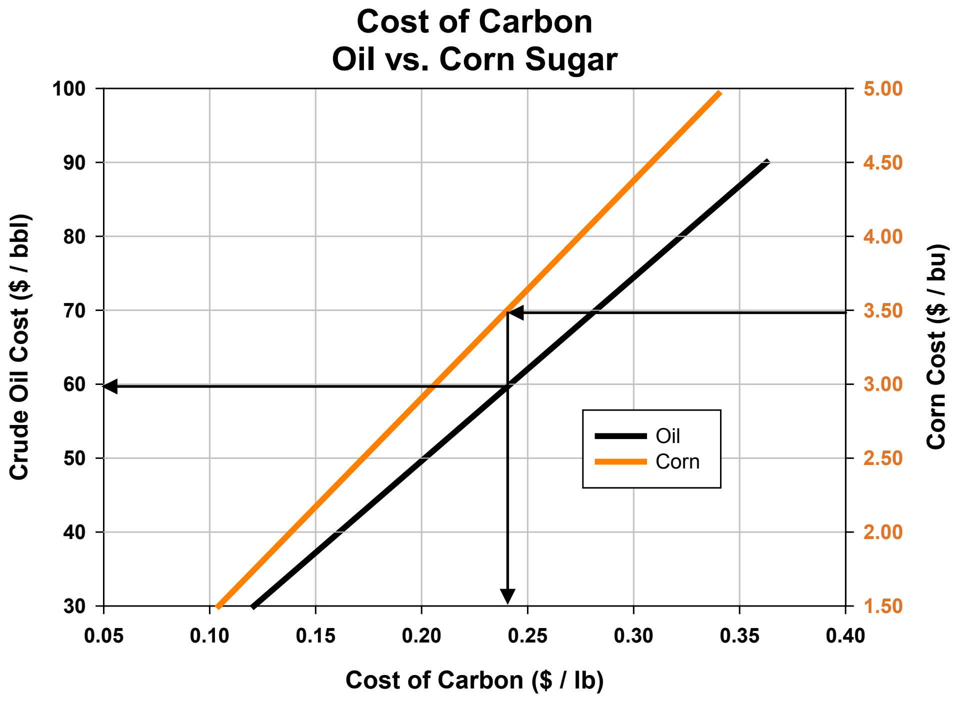
*Source:* McKinsey & Company (2009)[11]

Figure 4 further demonstrates that high oil prices will favor bio-based chemicals manufacturing. This exercise calculates the cost of carbon derived from crude oil and compares it to the cost of carbon derived from corn sugar. The cost of carbon derived from a given feedstock increases as the feedstock cost rises.

For example, today's price of corn is about $3.50 per bushel. (In recent history, commodity corn prices have fluctuated from around $2.00 per bushel to more than $4.00 per bushel). The current price of corn equates to a cost of $0.24 per pound of carbon derived from corn sugar, as indicated by the vertical line that drops from where the corn cost curve (in orange) crosses $3.50 per bushel. The equivalence point is where that vertical line at $0.24 per pound of carbon crosses the oil cost curve (in black). The horizontal line to the left of that point shows that at $60 per barrel of crude oil, carbon can be derived from oil or corn at equal cost.

When oil exceeds $60 per barrel, corn-based carbon is more economically attractive.

**Figure 4.**



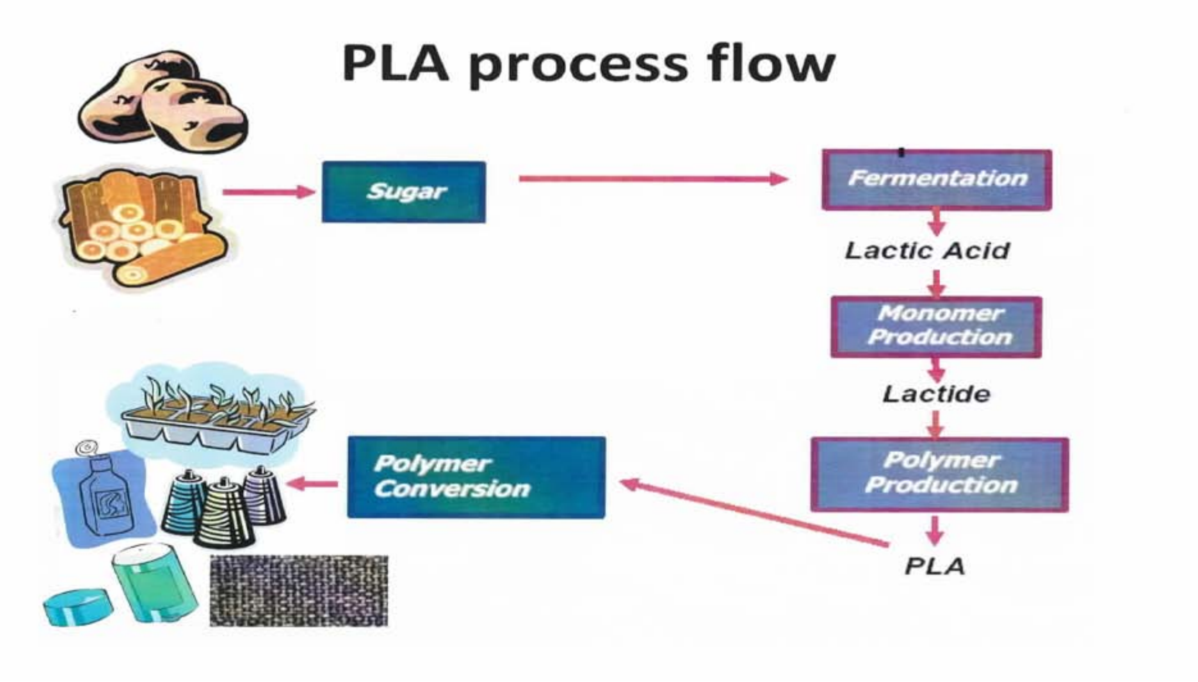
*Source:* Jim Lunt & Associates, LLC (2010) [12]

Clearly, oil prices are one major driver towards increased demand for and production of bio-based plastics. A review of other market drivers is beyond the scope of this report. However, it's worth noting that PLA and other bioplastics offer significant advantages through a smaller carbon footprint compared to petrochemical plastics due to reduced greenhouse gas emissions and lowered fossil resource usage. [13]

# MANUFACTURING STRATEGY FOR MAINE BIOPLASTICS

We have identified a strategy for producing polylactic acid (PLA) in Maine that takes advantage of locally available feedstocks and existing industrial infrastructure. PLA today is made by the fermentation of corn dextrose to lactic acid, which is then polymerized to polylactic acid. Corn dextrose is derived from the hydrolysis of corn starch. Maine has potatoes, potato processing waste, and wood chips as alternative feedstocks locally available today. Figure 5 illustrates a process flow schematic.

**Figure 5. Process flow chart: Potatoes and wood to PLA plastic**

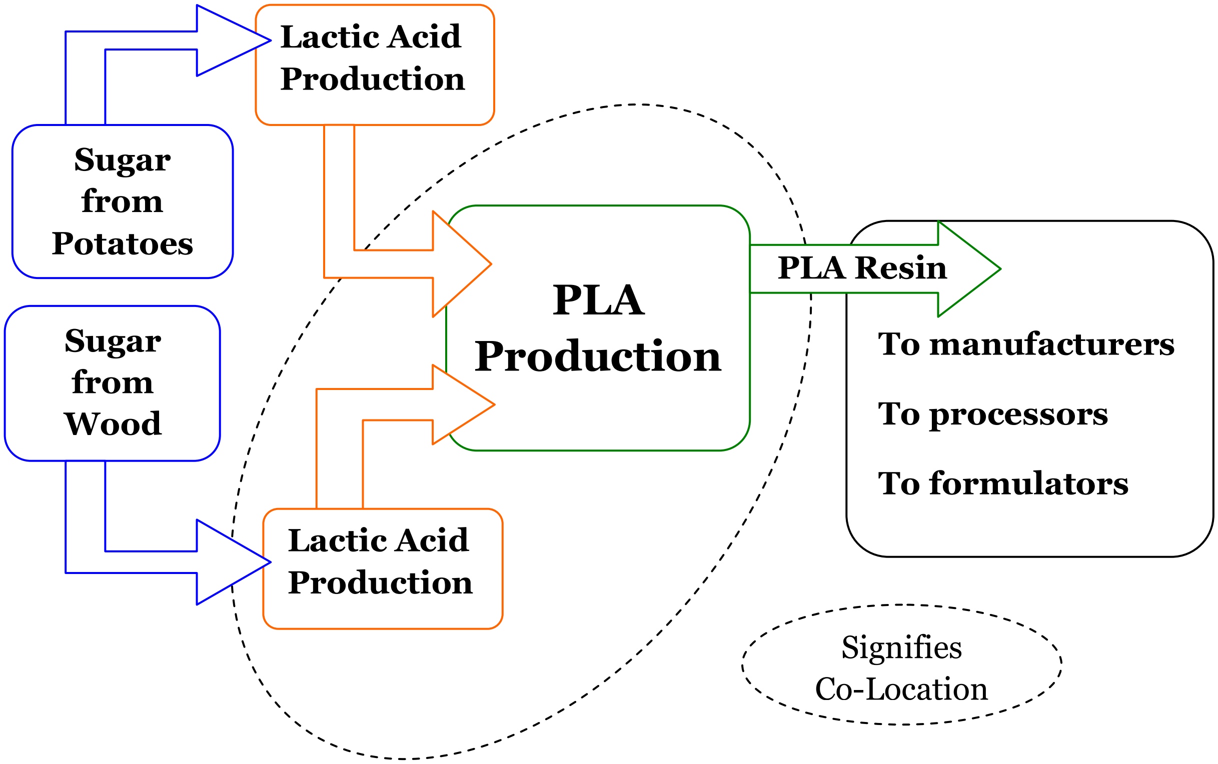


*Source:* Pat Gruber (2004), modified by Environmental Health Strategy Center

Based on our preliminary engineering assessment, we envision two feedstock sources each supplying a fermentation plant that produces polymer grade lactic acid (PGLA). One facility would be located in Aroostook County near a source of feedstock potato processing waste and cull or raw potatoes. The potato-derived starch would be hydrolyzed to sugar and fermented to produce PGLA. The second plant would be co-located near either a biomass boiler facility or a pulp and paper mill, which would provide feedstock wood chips for extraction of sugars prior to burning or pulping the remaining biomass. The wood-derived sugars would be fermented to produce PGLA. Each plant would be scaled to produce about 33,000 metric tons of PGLA per year.

Figure 6 outlines the PLA manufacturing strategy for Maine. Both plants would supply polymer grade lactic acid to a PLA plant that would produce PLA in a two-step polymerization process. The PLA plant would be designed with a capacity of 50,000 metric tons per year, which represents the smallest economically attractive plant capacity based on current technology, according to our project engineers and industry advisors. [14] The PLA plant could be sited next to one of the PGLA plants.

**Figure 6. Maine PLA Manufacturing Strategy**



*Source:* Sustainable Bioplastics Council of Maine (2010)

In our Baseline Scenario (discussed in the next section of this report), we aim to drive down capital costs by co-locating PGLA and PLA plants at existing industrial sites that already have infrastructure in place such as steam, electricity and waste water treatment along with the necessary permits, industrial land and buildings. Several potential co-location sites in Aroostook County and at the Old Town mill have already been identified and assessed in some detail. (See Figure 7). [15] These sites were identified due to their existing ability to handle production level amounts of feedstock, the site's proximity to transportation and expressed interest from the facility management in collaboration.

Following recent trends in commercial lactic acid production, our manufacturing strategy now proposes to rely on the newer yeast fermentation technology. Previous commercial production of PLA was based on a traditional bacterial fermentation process to produce lactic acid. The University of Maine produced lactic acid in the laboratory from potatoes and wood extract using bacterial fermentation. [16] The bacterial fermentation process for lactic acid creates large quantities of waste gypsum as a byproduct.[i] The bacterial culture also is subject to viral phage infections, which will shut down production until extensive sanitary cleanup removes the threat.

Yeast fermentation significantly reduces costs and environmental impacts compared to the bacterial process. (This is the Optimal Scenario discussed in the cost model in next section). The yeast technology significantly reduces the need for process chemicals and slashes the generation of gypsum waste which requires costly disposal. Yeast is also not prone to phage infections. Cargill recently switched to a yeast fermentation process to make lactic acid to supply its PLA plant operated by its subsidiary, NatureWorks. [17]

We are in discussions with Tate and Lyle, a multinational corn sugar processor, which could lead to acquisition of their near-commercial ready lactic acid yeast fermentation technology. Tate and Lyle also operates a starch plant in Houlton, Maine, at which they are looking to expand bio-based materials manufacturing. The Houlton plant site is one of the locations indicated on Figure 7 that could play a host role for a lactic acid plant.

The University of Maine's new Agricultural and Forest Bioproducts Technology Center, which is currently in design, will play a major technology development role in our manufacturing strategy. The Bioproducts Tech Center will be located in the former tissue warehouse at the pulp mill currently operated by Old Town Fuel and Fiber. We will use the Tech Center for demonstration scale fermentation to complement the laboratory capacity at the University. We will also develop capacity to polymerize lactic acid into PLA at the Tech Center in small scale batches and in continuous runs. Key polymer technology for PLA production enters the public domain in 2012 and 2013. With clear freedom to practice and demonstration scale polymer capacity, we will be in a stronger position to attract further financing to complete the optimization of the yeast fermentation technology.

Lastly, our manufacturing strategy emphasizes the development of new value-added applications for PLA that will benefit Maine companies, create market pull and increase the attractiveness of the overall package for investors and major corporate partners.

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[i] Bacterial production of lactic acid is inhibited as the acidity of the fermentation broth builds. Lime is added as a buffer to maintain a more neutral pH. Sulfuric acid must then be added to liberate the lactic acid when fermentation is complete. The sulfur combines with the calcium from the lime and precipitates as a solid waste, calcium sulphate or gypsum. Twice as much gypsum is produced as lactic acid.

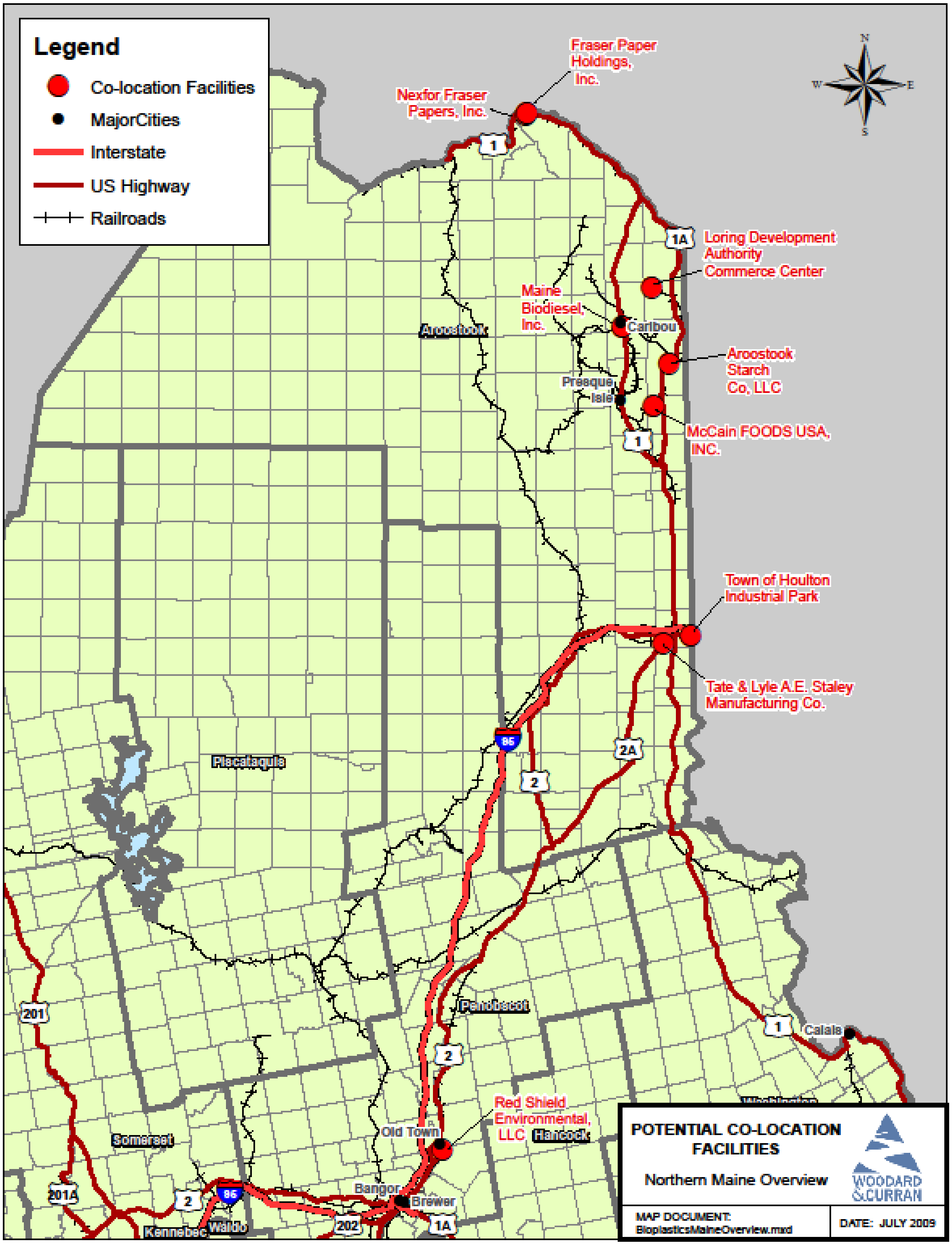


**Figure 7. Potential Co-Location Sites for PGLA and PLA plants**

(Note: An additional site in Westbrook in southern Maine is not shown)

## MANUFACTURING COST MODEL

Jim Lunt & Associates, LLC developed an engineering cost model that allows us to estimate the costs to manufacture PLA in Maine. The model was built using engineering expertise and publicly available information. Lunt & Associates have considerable direct experience with commercial production of polylactic acid (PLA) through past employment with NatureWorks, the Cargill subsidiary that first commercialized PLA at its Blair, Nebraska facility. This model allows us to vary different production factors (e.g. scale of plant and sugar costs) in order to understand their impact on the cost of producing PLA. Feedstock cost inputs to this model are based on preliminary estimates for sugar obtained for potato processing waste and wood chips.

A sample output of our engineering cost model for PLA manufacturing is included in Appendix 1 to this report. The actual model, in a spreadsheet format with formulas, is available on request. Appendix 2 identifies the assumptions, sources and other information that explain the basis for each line item in the model. Appendix 3 itemizes the labor costs that feed the model, detailing the jobs necessary to operate the plants.

The discussion and data below are based on application of the engineering cost model to specific scenarios for the manufacturing of PGLA and PLA in Maine. To understand the costs to produce PLA, and hence the economic viability of PLA production in Maine, five elements need to be considered:

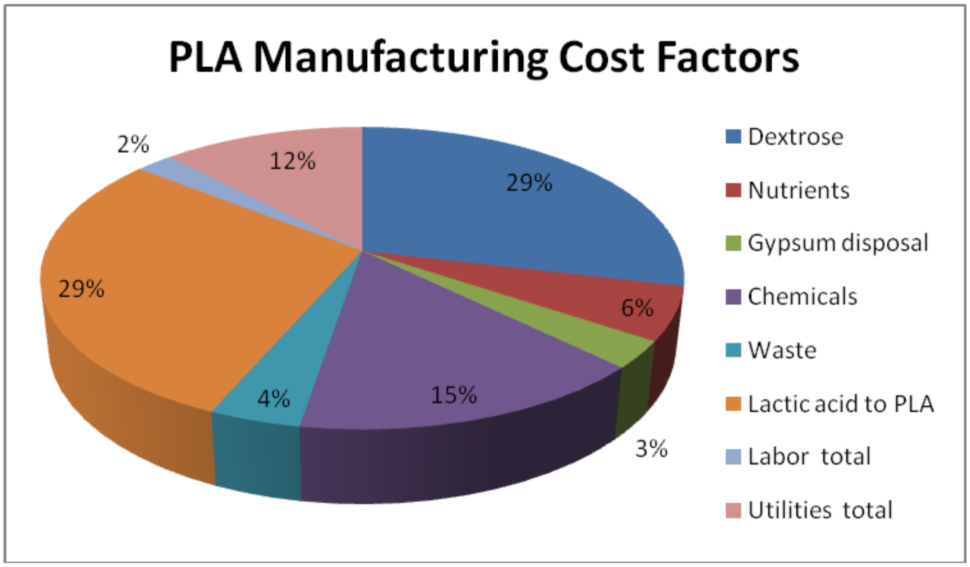
- the cost to make PLA today using corn dextrose;
- the cost of sugar from alternative feedstocks such as potatoes (processing waste, cull and raw) and trees (wood chips and other woody biomass);
- the potential plant capacity for Maine PLA production;
- the potential co-location of the lactic acid and PLA manufacturing plants, and division of operational costs, with other existing industrial facilities; and
- the potential to reduce costs by use of new fermentation technologies.

Based on knowledge of the manufacturing processes and costs of energy, raw materials and scale, the economic model was created to project the costs to manufacture PLA from sugars using the major processes in use for the last several years. In addition, based on local Maine feedstocks and new fermentation technology identified, this model was used to project the manufacturing economics for PLA produced from these feedstocks and from using advanced fermentation technology.

The recent costs of manufacturing PLA using traditional bacterial fermentation of corn dextrose to produce lactic acid is divided into several elements as shown in Figure 8.

The chart represents the percent costs for each material or cost factor (excluding plant costs such as taxes, insurance, maintenance, return on investment and miscellaneous).

**Figure 8.**



*Source:* Jim Lunt & Associates, LLC (2010), based on engineering cost model

The four major drivers for PLA costs are:

- Dextrose or feedstock sugar cost
- Chemicals, nutrients and gypsum waste associated with bacterial fermentation
- Process yields (assumed in our cost model to meet industry standards)
- Utility costs (modified in or cost model to match Maine electricity rates)

Each of these elements represents a key variable in the manufacturing cost model. Below, we discuss sugar costs. Then we discuss plant capacity, which drives capital costs and related operational costs. Following that, we analyze three economic scenarios for the production of PLA in Maine and compare each to the economics of commercial PLA manufacturing by NatureWorks using corn dextrose as feedstock.

## Sugar Cost

Maine feedstock sugar costs are projected to be cost-competitive with or lower than the cost of sugar derived from corn. As shown clearly in Figure 8, the price of the sugar is a dominant contributor to the final cost of PLA (independent of plant capacity). We can estimate the following sugar costs based on preliminary information received to date.

**CORN – Corn sugar costs are estimated at $0.14 to $0.17 per pound.** Today, dextrose from corn, if internally transferred as in the case of the co-located site used by

NatureWorks, LLC in Blair, Nebraska, is around $0.14 per pound based on 100% solids. However, it has been as high as $0.17 per pound. This estimate was provided by Jim Lunt & Associates based on their knowledge of current practices.

Maine will initially use a combination of potato processing waste and potatoes, as well as wood chips, as feedstocks to produce polymer grade lactic acid.

**POTATOES – Potato sugar costs are estimated at $0.14 to $0.17 per pound.** The feedstock cost of dextrose derived primarily from potato processing waste, with some raw potatoes, has been estimated by Aroostook Starch Company in Fort Fairfield, a partner in the Sustainable Bioplastics Project. They manufacture potato starch from potato processing waste generated by the McCain Foods french fry manufacturing plant. Aroostook Starch has also invested in technology to process raw potatoes near the point of production and to transfer the starch slurry to its plant in for processing into starch.

**WOOD – Wood sugar costs are estimated at $0.09 to $0.12 per pound.** This is based on estimates obtained by Jim Lunt & Associates for six carbon sugars only using the technology developed by HCl CleanTech, a start-up company that promises to cost-effectively hydrolyze cellulosic materials of all types into component sugars. A major drawback to the HCl CleanTech process, which uses fuming hydrochloric acid, may be the generation of chlorinated hydrocarbon wastes, which tend toward high toxicity, persistence and bioaccumulation. If so, such a process would be inconsistent with the principles of green chemistry. Nonetheless, this is useful for benchmarking.

Even lower wood sugar costs may be achievable through technology developed by the University of Maine, according to Mike Bilodeau, Director of the Process Development Center. At significantly lower cost, U. Maine engineers can extract *raw* sugar from wood chips with either hot water or green liquor, the raw mill effluent from wood pulp production. However, further separation and purification is necessary to remove impurities that interfere with the fermentation of the wood-derived sugars. How much this clean-up work adds to the cost of the wood sugar has not yet been determined.

## Plant Capacity

As discussed in the previous section, a Maine-based PLA plant should be designed for a 50,000 metric ton capacity. Everything else being equal, PLA from a 50,000 tonne capacity plant in Maine will likely be more expensive to produce than PLA from a currently-operating 150,000 tonne capacity plant in Nebraska -- due to economies of scale. Therefore, other strategies are needed to reduce Maine costs and establish Maine market advantage. Figure 9 shows how PLA costs vary with plant capacity, according to the manufacturing cost modeled used in this report.

Of course the figures on PLA production costs do not represent selling prices or costs to deliver the product to the customer. Delivered costs are significantly influenced by geographic distances and target markets. Maine-derived PLA is intended to be marketed primarily in the New England region keeping delivered costs to a minimum and improving the carbon footprint of the PLA.

The proposed 50,000 tonne capacity for a Maine facility is based on an understanding of the U.S. market for PLA, in particular, and bioplastics in general. NatureWorks, from their 150,000 tonne facility in Blair, Nebraska, while just now manufacturing at full capacity, only markets about one-third of their production within the United States. Additionally, all market reports indicate that bioplastics sales are expected to increase significantly in the foreseeable future.

## PLA Production Costs – Three Maine Scenarios

Table 1 shows the output of the manufacturing cost model for three scenarios for PLA production in Maine in comparison to current commercial corn-based PLA production costs. The Maine-based PLA manufacturing costs under the "Optimal Scenario" are projected to be cost competitive with existing corn-based PLA production.

In all the scenarios, we assumed a 50,000 tonne plant capacity for PLA manufacturing in Maine. The cost estimates for PLA also assume that all process economics and yields between the corn-based facility and the Maine-based facility are equivalent. In addition, the cost model assumes that the lactic acid and PLA plants are co-located (i.e. sharing all utilities and infrastructure). Or if not, the PLA manufacturing plant is assumed to be built at the same facility site (but *not* sharing utilities infrastructure) with an operation that supports the conversion of feedstock into sugar and into lactic acid, which still cuts down on shipping and logistics cost.

We made two adjustments to the cost model based on review and advice from our economic and engineering partners at the University of Maine. We increased the utilities cost to reflect Maine's higher electricity rates. We also increased labor costs to reflect higher likely health insurance costs. These changes are factored into the calculated PLA production costs below.

For the Maine scenarios, the two feedstocks, potato-derived sugar and wood-derived sugar, are assumed to be supplied in equal amounts on average with the resulting lactic acid blended to provide feedstock for the PLA plant. The PLA cost ranges below flow from the model inputs from the low end of the wood-sugar feedstock cost range to the high end of potato-sugar cost range. This captures the full possible range in cost.

## Table 1. Comparative PLA Manufacturing Costs

| Scenario | Construction Strategy | Fermentation Technology | Feedstock | Sugar Costs ($/lb) | PLA Costs ($/lb) |
|---|---|---|---|---|---|
| **Maine PLA** (Projected Plant Capacity = 50,000 MT/yr) | | | | | |
| **Greenfield** | Greenfield | Bacterial | Potato<br>Wood | 0.14 - 0.17 [1]<br>0.09 - 0.12 [2] | 1.29 - 1.35<br>1.19 - 1.25 |
| **Baseline** | Brownfield | Bacterial | Potato<br>Wood | 0.14 - 0.17<br>0.09 - 0.12 | 1.00 - 1.06<br>0.90 - 0.96 |
| **Optimal** | Brownfield | Yeast | Potato<br>Wood | 0.14 - 0.17<br>0.09 - 0.12 | 0.92 - 0.98<br>0.82 - 0.88 |
| **Midwest PLA** (Plant Capacity = 150,000 MT/yr) | | | | | |
| **Natureworks** | Greenfield | Yeast | Corn | 0.14 - 0.17 [3] | 0.89 - 0.95 |

NOTES

[1] Personal communication -- Jim Barressi, VP of Sales and Procurement, Aroostook Starch Co. on February 25, 2010

[2] Personal communication between Dr. Jim Lunt and Paul McWilliams, professional consultant in June, 2009.

[3] Personal communication with Dr. Jim Lunt on February 3, 2010

*Source:* Jim Lunt & Associates, LLC and Environmental Health Strategy Center

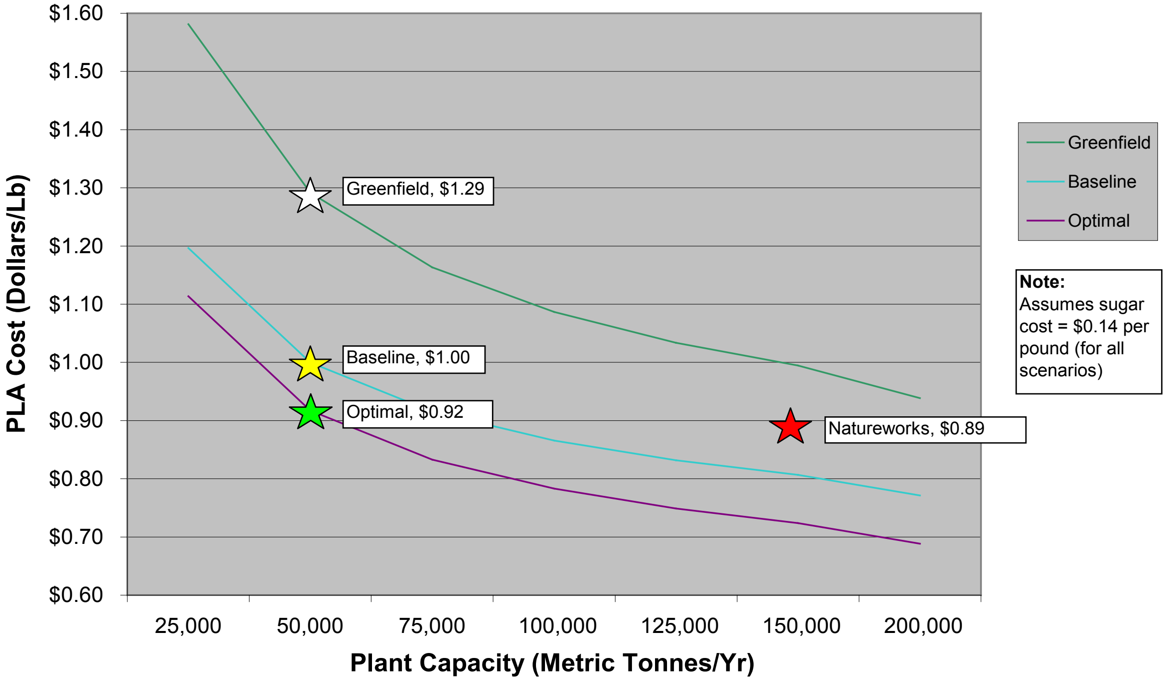
### 1. Greenfield Scenario – PLA costs: $1.19 to $1.35 per pound

For benchmarking purposes, we ran the manufacturing cost model assuming construction from the ground-up. This is the most expensive option because of the higher capital costs associated with "greenfield" construction to provide power, steam and water systems. This scenario also assumes reliance on the traditional bacterial fermentation process for manufacturing lactic acid, which is a higher cost technology. Appendix 1 is the detailed model output for the "Greenfield Scenario" assuming sugar cost at $0.14 per pound and a PLA plant capacity of 50,000 MT.

### 2. Baseline Scenario – PLA costs: $0.90 to $1.06 per pound

This scenario achieves the significant cost savings (about 22%) that result from a "brownfield" construction strategy while still relying on a traditional bacterial fermentation technology. Co-location of PGLA/PLA plants at existing industrial sites significantly reduces capital costs. Such so-called "brownfield" construction requires only 60% (or less) of the capital costs of a "greenfield" site due to the avoided capital investment in wastewater treatment and power plants and other new infrastructure. [18] In addition to making it easier to secure financing for construction of the plant, the reduced capital costs also lowers annual operating costs including taxes, insurance, maintenance, return on investment and miscellaneous expenses.

**Figure 9. Comparative PLA Manufacturing Costs**



Note: Assumes sugar cost = $0.14 per pound (for all scenarios)

*Source:* Jim Lunt & Associates, LLC and Environmental Health Strategy Center (2010)

## 3. Optimal Scenario – PLA costs: $0.82 to $0.98 per pound

This preferred scenario achieves further significant cost reductions by deploying the new yeast fermentation technology, while continuing a commitment to a brownfield construction strategy. These costs are 8% lower than in the Baseline Scenario and 29% less than in the Greenfield Scenario. Recently, Cargill announced a new yeast-based fermentation process which significantly reduces, but does not eliminate, the gypsum by-product. The actual percent reduction has not been disclosed, but the cost reductions are approximated by eliminating the costs for gypsum disposal and for sulfuric acid. Lime costs are not removed in this cost analysis.

### NatureWorks – PLA costs: $0.89 to $0.95

To estimate current costs for commercial production of PLA by NatureWorks, we ran the cost model at 150,000 MT and adjusted costs as in the above scenario for projected savings from their recent switch to yeast fermentation.

### Conclusion

By using advanced fermentation technologies and existing industrial infrastructure, a Maine-based enterprise will produce PLA cost-competitively compared to corn PLA.

## MARKET ADVANTAGE for MAINE BIOPLASTICS

In addition to the pure economic model we must also consider other factors that would offer market advantage to Maine-based bioplastics production. These include:

- Avoiding genetically-modified organisms (GMO) in feedstocks
- Co-development of improved PLA applications
- Targeting of higher value-added markets, rather than the commodity market
- Sustainability advantage of Maine feedstocks over corn
- Value of the Maine brand in the market place

Maine-sourced PLA could command a premium in the market place as a result these advantages. A full examination of these factors is beyond the scope of this report, but will be further developed in future work. Some brief commentary is offered below.

**Maine advantage – Non-GMO feedstocks.** There is significant market resistance in Europe [19] and among leading sustainable businesses to the use of GMO food crops. Neither Maine potatoes or trees are genetically modified, which offers access to markets that NatureWorks can not compete in. Today, about 85% of corn production relies on genetically modified varieties. [20] NatureWorks has encountered resistance to the purchase of PLA based on GMO corn. Although they could use non-GMO corn dextrose as a feedstock, that would raise the selling price by at least 10%. The manufacturing price would also increase by an equivalent amount due to the need to either purchase non-GMO feed corn as an offset, or to manufacture non-GMO derived PLA, which would only be economic at very large volumes. Both of these options are offered by NatureWorks LLC, but it is not known if anyone has purchased such products.

**Maine Advantage – Value-Added PLA Markets.** Using the PLA modification technologies we have outlined in the "Research Needs Plan" Report, which was submitted by the Sustainable Bioplastics Cluster Enhancement Project to Maine Technology Institute in December 2009, will allow us to penetrate more value-added markets where PLA does not perform today. [21] For example, producing more durable alloys of PLA would allow competition with non-commodities such as polycarbonate/acrylonitrile butadiene styrene PC/ABS blends used in electronic and automotive markets. Presently such blends are priced around $1.00 to $1.10 per pound compared with commodity plastics priced at approximately $0.60 to $0.70 per pound.

**Maine Advantage – Sustainable Brand.** The growing market demand for PLA is driven in part by the sustainability goals of product manufacturers and consumers. The sustainability advantages of PLA have been clearly established vis-à-vis petrochemical-based plastics. We believe that Maine-source PLA will be superior than corn-based PLA for several reasons. Rather than relying on a food crop (corn), a Maine PLA enterprise will recover potato processing waste and process non-food crop trees. Maine forest products are available with sustainability certification. Less land disturbance may release less carbon when sustainable forestry is compared to industrial agriculture. This should result in a lower carbon footprint for Maine PLA than corn PLA. The potato industry supports smaller family farms than the large scale industrial corn operations, which provides a social measure of sustainability. Lastly, the Maine brand itself has proven value in the market place. [22] A sustainably-source, Maine-made bioplastic will have distinct cache in the market place.

## CONCLUSION

The commercial production of the bioplastic PLA in Maine appears to be economically viable. By leveraging local biomass feedstocks, existing industrial infrastructure and advanced fermentation technology, PLA can be produced in Maine at a 50,000 MT capacity plant on a cost-competitive basis with commercial PLA made from corn. Further market advantage factors would allow Maine-sourced PLA to command a premium in the market place. The continued volatility and expected rise in the price of oil will continue to fuel rapid growth in demand for bio-based materials, including bioplastics. Growing interest in sustainability and rising concerns about the climate crisis will further drive market demand for more environmentally friendly plastics. An investment in commercial production of PLA will generate significant economic benefits for Maine including new green manufacturing jobs and new markets for local business.

## Appendix 1. Engineering Cost Model for PLA Production in Maine

| | | |
|---|---|---|
| **Plant Capacity PLA (MT/yr)** | **50,000** | |
| PGLA required (MT/yr) | 65,789 | |
| Dextrose Required (MT/yr) | 81,222 | |
| **CAPITAL** | | |
| Green Field capital for PLA ($MM) | | $ 164.32 |
| Green Field capital for PGLA ($MM) | | $ 163.02 |

| **PGLA Costs** | **$/lb raw** | **$/yr** | **$/lb PGLA** |
|---|---|---|---|
| **Raw Materials** | | | |
| **Dextrose** | **0.14** | $ 25,016,244.31 | $ 0.1728 |
| Nutrients | 0.028 | $ 5,003,248.86 | $ 0.0346 |
| Lime | 0.05 | $ 3,305,718.00 | $ 0.0228 |
| Sulfuric Acid | 0.06 | $ 5,253,411.31 | $ 0.0363 |
| Gypsum Disposal | 0.025 | $ 3,841,780.38 | $ 0.0265 |
| **Utilities** | | | |
| Steam $8.5/1000 lbs steam | | $ 4,654,495.61 | 0.0322 |
| Electricity | | $ 1,447,368.42 | 0.0100 |
| **Fixed Charges** | | | |
| LABOR (refer to separate spreadsheet) | | $ 3,119,765.29 | $ 0.0216 |
| Insurance and Taxes (1.5% RAB) | | $ 2,445,253.98 | $ 0.0169 |
| Maintenance (3% RAB) | | $ 4,890,507.96 | $ 0.0338 |
| Misc charges ($.01/lb) | | $ 1,447,368.42 | $ 0.0100 |
| Depreciation 10 year | | $ 16,301,693.21 | $ 0.1126 |
| ROI (10%) | | $ 16,301,693.21 | $ 0.1126 |
| **Total PGLA costs** | | **$ 93,028,548.97** | **$ 0.6427** |

| **PLA Costs** | **$/lb raw** | **$/yr** | **$/lb PLA** |
|---|---|---|---|
| **Raw Materials** | | | |
| PGLA | $ 0.6427 | $ 93,028,548.97 | $ 0.8457 |
| Waste disposal (5% Yield loss) | 0.025 | $ 131,578.95 | $ 0.0012 |
| Misc Additives and Catalyst ($0.02/lb) | | $ 2,200,000.00 | $ 0.0200 |
| **Utilities** | | | |
| Natural gas ($7.5 MM BTU) | | $ 1,121,228.07 | $ 0.0102 |
| Electricity | | $ 1,100,000.00 | $ 0.0100 |
| **Fixed Charges** | | | |
| LABOR (refer to separate spreadsheet) | | $ 3,119,765.29 | $ 0.0284 |
| Insurance and Taxes (1.5% RAB) | | $ 2,464,764.17 | $ 0.0224 |
| Maintenance (3% RAB) | | $ 4,929,528.34 | $ 0.0448 |
| Misc charges ($.01/lb) | | $ 1,100,000.00 | $ 0.0100 |
| Depreciation 10 year | | $ 16,431,761.13 | $ 0.1494 |
| ROI (10%) | | $ 16,431,761.13 | $ 0.1494 |
| **Total PLA cost** | | **$ 142,058,936.05** | **$ 1.2914** |

## Appendix 2. Sources and Notes for Information Used to Construct Engineering Cost Model

| Overall Process Information | Sources | Notes |
|---|---|---|
| 1 PGLA required | | Loss of water and 95% yield |
| 2 Dextrose required | | Fermentation yield and purification yield at |
| **PGLA Costs** | | |
| 1 PGLA Capital costs - $0.75 per lb/yr capacity at 400 MM lbs/yr | Wisconsin Biorefinning Development initiative, Fermentation of 6 Carbon Sugar And Starches Under capital and operating costs | Use .6 scale factor from 400 MM lbs/yr and $.75/lb; assume brownfield capital equals 60% of greenfield |
| 2 Dextrose price | Basic Knowledge of dextrose pricing | |
| 3 Assume process is fermentation neutralization with a base Lime and sulfuric acid added to protonate the neutralized solution to produce gypsum and PGLA | Chemicals From Renewable resources MICS March 232, 2004. Patrick R. Gruber, PhD. Slide 45 Current LA process | |
| 4 Assume purification process is some type of distillation after gypsum removal | Wisconsin Biorefinning Development initiative, Fermentation of 6 Carbon Sugar And Starches Under Product Recovery Processes | |
| 5 Electricity | National Average = $0.035 per KWh | Guess at 1 cents per pound PGLA |
| 6 PGLA fermentation yield - 90% | Wisconsin Biorefinning Development initiative, Fermentation of 6 Carbon Sugar And Starches Under Fermentation processes | |
| 7 PGLA purification yield - 90% | Assume 90% yield for distillation purification | |
| 8 Nutrients | Chemicals From Renewable resources MICS March 232, 2004. Patrick R. Gruber, PhD. Slide 39 estimated cost of Nutrients on Pie chart] | 1/5th of dextrose cost |
| 9 Lime - 5 cent/lb | Basic Knowledge of pricing | 90% yield of dextrose to PGLA in fermentation is neutralized. One mole of Ca(OH)2 is used to neutralize two moles of PGLA and dextrose converts from one mole of dextrose to two moles of PGLA so one mole of Lime per one mole of dextrose |
| 10 H2SO4 - 6 cents per pound | Basic Knowledge of pricing | One mole of sulfuric acid is used to react with two mole of PGLA |
| 11 Gyspum Disposal - Tipping fees $40/ton | Phone conversation between Andrew Files and Tom Gilbert, Casella Waste Systems on March 15, 2010 | Every two moles of PGLA we make one mole of Gypsum DiHydrate |
| 12 Gypsum disposal - Trucking fees $10/ton | Basic Knowledge of pricing | |
| 13 110 grams per liter final concentration of Broth | Chemicals From Renewable resources MICS March 232, 2004. Patrick R. Gruber, PhD. Slide 45 Current LA Process | |
| 14 Steam costs - $8.5 per 1000 lbs | Basic Knowledge of steam pricing | Remove all the water (9 lb of H20 per 1 lb PGLA) triple effect efficiency and phase change Lactic acid once 1.5 to use 50% reflux on distillation to purify assume Lactic acid heat capacity is 300 btu/lb |
| 15 Waste Water Charges | Do not know but would include in1 cent per pound misc charges | |
| 16 Labor | | Refer to Labor commerial work book page; can multiply by 0.75 if joint PGLA/PLA processing to take advantage of common management and operations personnel |
| **PLA Costs** | | |
| 1 PLA Capital costs - $1.00 per pound at 300 MM lbs/yr | Cargill Dow Sows Seeds of future fibers will build $300 MM PLA polymer plant to produce 140,000 MT | Use .6 scale factor from 300 MM lbs/yr and $1.00/lb; assume brownfield capital equals 60% of greenfield |
| 2 Process is prepolymer formation condensation reaction with water removal followed by lactide formation distillation and Meso and D lactide separation via distillation followed by polymerization and unreacted monomer is recycled back | As described in Nature fibers Biopolymers and Biocomposits Chapter 16 Polylactic acid technology page 529-530 | |
| 3 Yield PLA - 95% theoretical | Estimate based on distillation steps and ring open polymerization | |
| 4 Charges for waste Tipping fee $20/ton | Basic Knowledge of pricing | |
| 5 Charges for waste trucking costs $10/ton | Basic Knowledge of pricing | |

## Appendix 3. Labor Costs for a PGLA/PLA Facility in Maine

| | | |
|---|---|---|
| **Location** | **Maine** | |
| **PGLA** | **65,789** | **metric tonnes (dry basis) / year** |
| **PLA** | **50,000** | **metric tonnes (dry basis) / year** |
| **Operating Basis** | **8,400** | **hours per year** |

| **PLANT PERSONNEL** | Rate | | Number | Base | Total | TOTAL |
|---|---|---|---|---|---|---|
| Plant Manager | $46.00 | S | 1.00 | $ 128,800 | $ 193,200 | $ 2,318,768 |
| Production Manager | $41.00 | S | 1.00 | $ 114,800 | $ 172,200 | |
| Lab Manager | $31.00 | S | 1.00 | $ 86,800 | $ 130,200 | |
| Shift Supervisor | $24.06 | H | 1.00 | $ 67,375 | $ 101,063 | |
| Maint. Supervisor | $24.06 | H | 1.00 | $ 67,375 | $ 101,063 | |
| Admin Supervisor | $24.06 | H | 1.00 | $ 67,375 | $ 101,063 | |
| Operators | $19.25 | H | 12.00 | $ 646,800 | $ 970,200 | |
| Laboratory Technicians | $19.25 | H | 4.00 | $ 215,600 | $ 323,400 | |
| Shipping/Receving Clerk | $15.40 | H | 1.00 | $ 43,120 | $ 64,680 | |
| Yard | $19.25 | H | 2.00 | $ 107,800 | $ 161,700 | |
| **ADMIN PERSONNEL** | | | | | | |
| Accountant | $34.07 | S | 1.00 | $ 95,397 | $ 143,096 | $ 800,998 |
| Process Engineer | $45.43 | S | 1.00 | $ 127,196 | $ 190,794 | |
| Maintenance Engineer | $37.48 | S | 1.00 | $ 104,937 | $ 157,405 | |
| Plant Chemist | $30.00 | S | 1.00 | $ 84,000 | $ 126,000 | |
| Analytical Instrument Specialist | $25.00 | S | 1.00 | $ 70,000 | $ 105,000 | |
| Plant Engineer | $37.48 | S | 0.50 | $ 52,468 | $ 78,703 | |
| **TOTAL PLANT PERSONNEL** | | | 25 | | | |
| **TOTAL ADMIN PERSONNEL** | | | 6 | | | |
| **TOTAL ALL PERSONNEL** | | | 31 | | | |

**Notes**

1.These costs are for a Independent PGLA or PLA plant . To obtain total costs for both facilites multiply these figures by 2.

2.If the two plants are combined you can multiply the above cost times 2 and then by 0.75 to take advantage of two plants with the same control room

## ENDNOTES

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[11] McKinsey & Company. *Op. cit.*

[12] The carbon cost curves were calculated as follows. **Crude oil:** The percent carbon in oil is 84% based on isooctane. Assume crude oil grade 35.6° API which has a density of 847 kg/$m^3$. The volume of a barrel of oil is 0.159 $m^3$. Therefore, a barrel of oil weighs 134 kg or 295.4 lbs. The cost of oil-based carbon equals the cost of crude oil divided by (0.84 times 295.4). **Corn sugar:** The percent carbon in dextrose is 40%. The percent dextrose extracted from corn is 65%. The weight of a bushel of corn is 56 pounds. The cost of corn-based carbon equals the cost of a bushel of corn divided by (56 times 0.65 times 0.4). **Limitations:** This analysis only looks at pure carbon content. It fails to account for the oxygen content, which for corn sugar is a significant portion and from a renewable resource, but for oil the carbon is a minor fraction and from a fossil fuel. Also it does not account for which petrochemical plastic PLA would compete against.

[13] *Ibid.*

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