

Development of Biobased Plastics Independent of the Future of Biofuels

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Introduction

As the world population has recently grown to more than 7 billion people and the population will continue to grow past 8 billion people by 2026,ⁱ great concern exists about how all individuals will be fed, clothed and provided energy. A perception exists that using agricultural food products as feedstocks for industrial products such as fuels or materials contributes to food insecurity. This perception gained significant foothold in 2008, when food prices rose sharply sparking protests that in some cases escalated to riots.^{ii,iii}

Because of this concern, a great deal of research and analysis has been conducted regarding connections between biobased industrial products -- fuels and materials -- and food. This research and the concurrent increase in food supply and thus decrease in food prices led to a seeming loss of interest in this discussion.^{iv}

However with the recent U.S. drought, the food versus fuel versus material debate has been revived. The U.S. Department of Agriculture (USDA) has noted that about 80% of agricultural land experienced drought in 2012 and that over 2000 counties were declared natural disaster areas as of September 2012.^v This factor, in addition to the Renewable Fuel Standards, which mandates that U.S. fuel companies ensure that 9% of their gasoline pools are made up of ethanol, has increased discussion around this multifaceted topic.^{vi}

A widely held perception is that the biobased plastics industry is inextricably linked to and dependent on the emergence of a robust biorefining industry focused mainly on providing fuel. This perception is quite understandable, given that this is how the petrochemical industry developed. Since there was demand for fuels, a petroleum refining infrastructure was built to meet that demand. Petrochemicals were a byproduct of petroleum refining, and the petrochemicals industry, indeed the entire plastics industry, grew exponentially.^{vii} If we assumed that biobased plastics are similarly dependent on biofuels, then biobased plastics' impact on food, land use and the like are the same as biofuels, albeit as a relatively incremental additional impact.

In this paper, the SPI Bioplastics Council challenges the widely held perception that biobased plastics cannot develop independently of biofuels. To be sure, some bioplastic feedstocks are byproducts of fuel production, such as glycerol. Bioplastics based on those platform chemicals clearly would benefit from a robust biofuels industry. But other bioplastics can be derived via other routes which may or may not be strongly linked to biofuel production. While it is entirely possible that history will repeat itself, there are some significant differences compared with the early twentieth century. There also are elements inherent to some bioindustrial processes, especially around scale, which open up options that are not viable in an oil-based economy. These differences may enable the biobased plastics industry to develop independently of what happens in the biofuels industry.

Of course, even an independent biobased plastics industry would by necessity have some impact on food, land use and the like. These impacts would not necessarily mirror those of the biofuels industry, either qualitatively or quantitatively. We will examine potential impacts of an independent biobased plastics industry, including technological advances by which those impacts may be more readily mitigated than in the biofuels industry.

Historical Perspective and Today's Opportunities

It is important to recognize that the business context within which biobased plastics are now emerging is different from what it was at the dawn of the petrochemical and plastics industry in the early twentieth century. Two key differences will be examined – one from a demand perspective and the other from an infrastructure perspective.

From a demand perspective, the plastics industry did not exist in the early 1900s. As such, there was no recognized unmet need^{vii} and no latent demand for plastics. Without a ready market, justification of the significant investment required to build facilities specifically designed for production of plastics intermediates and plastics themselves would have been difficult. Rather, innovators took the waste byproducts from oil refining for fuel production and sought to make something useful from them. This approach was very successful, and drove development of not only the infrastructure to make polymers but also to compound and convert plastics into a myriad of useful articles. Because of this and in contrast to the early twentieth century, there is now a vibrant demand for plastics^{viii} which have become an integral part of modern life.

From an infrastructure perspective, the early twentieth century was a time of rapid expansion of manufacturing across all industry sectors. An independent petrochemical industry would have had to compete for limited capital and human resources to build the upstream supply chain from scratch. However since the petrochemical industry was an offshoot of the burgeoning petroleum refining industry, the need for such upstream investment to support petrochemicals was minimal. Therefore, resources could be deployed toward polymer manufacturing, compounding and converting into useful articles – in other words, the downstream infrastructure needed for plastics and plastic products.

Today the demand and the infrastructure exist to support plastics, including biobased plastics. Furthermore, there are several industry sectors such as paper and other heavy industries which are being transformed due to new technologies and the changing economic realities. The infrastructure and talent supporting those industries offer opportunities. In this context, the biobased plastics industry could repurpose existing facilities, supply chains and talent to reduce investment hurdles and accelerate growth. For example, idled automotive parts and yacht factories in the Midwest have been converted to make assemblies for wind turbines.^{ix,x}

Another opportunity with perhaps more relevance to biobased plastics is the paper industry, since that industry already manages the supply chain for and processing of cellulosic feedstocks. While the “paperless office” has not fully taken hold, demand for paper in the internet age is substantially reduced. This means that there may be idle papermaking assets which could be similarly repurposed. Finally, as biofuel consumption is reduced due to decreased gasoline consumption,^{xi} biofuel production assets also should become available for conversion for use to produce biobased plastics, reagents and monomers. While disruptive to local economies, such obsolescence does free up facilities, biomass, and talent that can be repurposed for a new biobased economy.

Impacts of an Independent Biobased Plastics Industry

For the previously mentioned reasons it may be inappropriate to assume that the fortunes of the biobased plastics industry would necessarily be tied to biofuels, in contrast with the historical symbiosis between petroleum fuels and plastics. Still, an independent biobased plastics industry would have some environmental and societal impacts which need to be explored. In this exploration, it is important to recognize the huge differences in scale between plastics and fuels.

Biobased plastics currently represent less than 1%^{xii} of all plastics but the potential impacts of a much larger biobased plastics industry must be considered.^{xiii*} Although not necessarily tied to the biofuels industry from a supply perspective, it is reasonable to look at petroleum-based fuels and chemicals to get a sense of the potential demand for biobased plastics relative to fuels. Toward this end, it is helpful to consider the 2011 Energy Information Administration (EIA) report on the products of petroleum refining.^{xiv} 72% of the output goes to transportation fuels: gasoline, diesel and jet fuel. Per the EIA, only 2% goes to petrochemical feedstocks, or about 1/36th as much. Assuming the output of petroleum refining is matched to meet the relative demands for different end uses, it is reasonable to assume that even if all plastics were converted to biobased plastics, they would still represent only a small fraction of the demand on biomass compared with the demand on biomass required to produce biofuels.^{xv}

With the advent of shale gas, it is even less probable that biobased plastics would displace all conventional plastics; at least in the U.S. chemical composition of shale gas varies by location. As an example, the composition of the Marcellus Shale in the northeastern U.S. ranges between 80-95% methane (C1), about 3-16% ethane (C2) with the remainder distributed among propane (C3), butanes (C4) and other higher hydrocarbons.^{xvi} The methane portion is used as a fuel and the ethane is the feedstock to monomers for polyethylene, polystyrene, polyvinyl chloride and other major families of plastics. Based on 2012 data, polyethylene alone accounts for approximately 41% of all U.S. polymer production.^{xvii} Since it is highly unlikely that an economically competitive route to a biobased replacement for shale ethane could be developed in the foreseeable future, these major plastics families will continue to be mostly fossil based. As consumers become more environmentally conscious they do show a preference for products containing biobased plastics, but only if price and performance are not compromised. Research down the value chain says that consumers are not willing to pay a premium.^{xviii}

Interestingly, though, shale gas may actually make some biobased plastics more economically attractive. Before shale gas, ethane was obtained by refining natural gas or cracking naphtha. The economics of these two approaches were about the same, and were linked to the price of oil. Unlike gas (conventional or shale), naphtha cracking also results in a number of important monomers, such as aromatics and higher order alkanes, which are used to make polyesters, polyamides and others. Today, the natural gas route to ethane is significantly less costly, which puts pressure on naphtha cracking in regions where that is the only available feedstock such as Japan and Southeast Asia.^{xix} If the supply for these more complex monomers tightens, the price would go up. Under this scenario, bio-routes to these monomers could become cost competitive

* Although the European Bioplastics “Bioplastics Facts and Figures” report estimates that global production of bioplastics capacity is set to grow 500% by 2016, the SPI Bioplastics Council along with other recent bioplastics related reports (e.g., Smithers Rapra, Lux Research) estimate a compound annual growth rate between 15-25% through 2016.

– indeed a number of companies and partnerships have emerged in the last few years to focus specifically on bio-routes to these monomers, most notably terephthalic acid for PET.^{xx}

Shale gas also changes the economics for other feedstocks which historically have been supplied via conventional natural gas,^{xxi} namely propane and butane, the feedstocks for polypropylene, butadiene-based plastics and others. Shale gas has a higher ethane content and lower propane and butane contents versus traditional petroleum feedstocks. So as the natural gas industry shifts more toward shale gas versus conventional gas, supplies of these important feedstocks would become tight. As before, biobased routes to these monomers could have a higher likelihood of being cost competitive in that scenario.

From a chemistry perspective, biobased plastics currently predominately use sugar as a feedstock and as such do have environmental and societal impacts which mirror those of biofuels. However emerging biobased plastics can use non-sugar feedstocks such as proteins and amino acids. These feedstocks may be generated as side products from sugar production, which might otherwise be treated as waste. Or, these feedstocks could be waste products from other industrial processes. For example, there is interest in producing biobased plastics from feathers, egg shells and other waste from the poultry processing industry.^{xxii,xxiii}

Furthermore, an independent biobased plastics industry could be better positioned to advance to second and third generation biomass feedstocks than the biofuels industry precisely because of the enormous differences in scale. Because biofuels are a relatively low value commodity, they need scale to be cost competitive. The smaller production volume of biobased plastics and their potentially higher value may make some options viable, which are not feasible for large production volume biofuels.

Since smaller production volumes may be economically viable, the logistics may be more manageable. The geographic reach to obtain sufficient biomass feedstock or the need to concentrate agricultural production to simplify logistics is substantially reduced. Alternatively, one could consider smaller scale distributed processing, bringing the chemical intermediate production facility to the feedstock rather than vice versa. Models have been proposed to co-locate a chemical-producing algae farm next to a facility that generates CO₂ such as a cement facility^{xxiv} or power plant.^{xxv} Alternatively, distributed processing could include co-locating with any producer of the right type and quantity of waste, for example from a food processing facility. One company produces polyhydroxybutyrate (PHB) from methane by co-locating production with a source of stranded biogas, such as a wastewater treatment facility^{xxvi} or landfill.

In addition to potentially simplified logistics, the potential exists for repurposing obsolete facilities for processing biomass into monomers and intermediates as mentioned above. Many of these facilities available for repurposing could be ideally sized for a biobased plastics intermediate operation. Note that a fermentation facility (i.e., where microbes convert the feedstock to chemical intermediates or polymers) scales up mainly by adding fermentation vessels rather than through using a bigger vessel. Yes, there may be economies of scale upstream and downstream of the fermenters, but the core of the process is inherently modular and suited to smaller volume operation.

What is Industry Doing to Alleviate Environmental and Societal Impacts in the Short and Long Term?

Over the last 10 years, companies have greatly increased their attention to and effort spent on managing their supply chains to minimize environmental and societal risks.^{xxvii} Still, there are a number of recent examples of short-sighted abuses in an attempt to take advantage of the growing demand for industrial products from agricultural resources. Such abuses include, but are not limited to: degrading land from unsustainable agricultural practices^{xxviii}, diverting scarce water resources, displacing crops of critical importance to the local community^{xxix} and unethical labor practices. As these abuses come to light, companies recognize the potential threat to their brands and reputations. This is not unlike the human rights scandals that plagued several apparel companies when they moved production off-shore without fully understanding the global and local circumstances. With an informed consumer base in the internet age, companies are highly motivated to actively manage their supply chains to address societal and environmental issues that may be caused by their operations. One should note the increase in Corporate Sustainability Reporting (CSR) and the increased cooperation between industry, academia, governments and non-governmental organizations (NGOs). These are too numerous to list, but one particularly relevant cooperation is between World Wildlife Fund (WWF) and some of the world's leading consumer brand companies identifying the opportunities and challenges in sourcing feedstocks for biobased materials. The goal of this work is to responsively guide the selection and harvesting of feedstocks for biobased plastics in order to encourage an economically prosperous and sustainable flow of materials, creating lasting value for present and future generations. Led by WWF, and supported by major consumer goods companies, and non-profit and academic organizations, the group also engages with an extensive Supplier/Producer Advisory Panel from the commercial sector. We are fully supportive of this work, and several Bioplastics Council members are actively engaged in this project.

The renewable resources used to make plastics continue to evolve and advance. Food and feed crops used for biomaterials include canola, cassava, corn, flax, rice, sorghum, soybeans, sugar beets, sugarcane and wheat.^{xxx} Presently, the major biobased plastic feedstocks are sugar-based, derived primarily from plants such as corn or sugar cane. In addition, some companies are beginning the transition to other purpose grown industrial crops such as sorghum or cassava.^{xxxi} While these feedstocks could be used for food, the diversity of crop options offers the opportunity to select the most efficient and least ecologically disruptive choice for a given locale.

Longer term, the market is moving to second and third generation feedstocks which have the potential to have less impact than corn and other first generation feedstocks.^{xxxii,xxxiii} Many brand owners have stated sustainability goals which include moving to packaging based on renewable feedstocks, and in many cases specifically non-food renewable feedstocks -- whether cellulosic or waste products -- because these may reduce the impacts associated with feedstock production. If a waste product is used as feedstock, this could dramatically reduce or eliminate the impacts associated with feedstock production all together. Brand owners stating such goals include the major players in the food industry such as Danone, Coca-Cola, Proctor & Gamble, Pepsico, Unilever and Nestlé. This is not just to build brand equity, but rather true triple bottom line (i.e., environmental, economic and societal) thinking. In addition to the societal and environmental advantages of using non-food feedstocks, there are economic ramifications. As buyers of huge

amounts of food commodities, it would be counterproductive for these companies to take actions that could drive up food prices.

Suppliers are eagerly working to meet the market's desire to move away from food-based feedstocks. Many of these non-food feedstocks are cellulosic rather than starch or sugar-based, so often the first step is to convert those cellulose to a sugar (saccharification). Here is one area where the biobased plastics industry can benefit from the efforts in the cellulosic fuels by leveraging saccharification technologies. And as noted above, the smaller scale of biobased plastics versus biofuels may better position biobased plastics to reach commercial viability.

Conclusions

There is reason to believe that the biobased plastics industry could develop regardless of what happens with biofuels. In fact, biobased plastics companies could innovate and thrive precisely because of that independence. The biobased plastics industry is emerging in a world of mature and sometimes obsolete manufacturing facilities, which presents opportunities to leverage and repurpose infrastructure which the petrochemical industry, nascent in the early twentieth century, did not enjoy. The net result is that the model set by the petrochemical industry, which was dependent on a strong petroleum-based fuels infrastructure, does not necessarily hold for the biobased plastics industry. The biobased plastics industry is also emerging in a world filled with well-established applications for plastics, so the market uncertainties are much reduced relative to what the nascent petrochemical industry faced.

The biobased plastics industry, even if it were wildly successful in displacing all conventional plastics, is dwarfed by the biofuels industry. The potential environmental and societal impacts of biobased plastics will not be as large as the impacts of the biofuels industry. Furthermore, this scale difference positions biobased plastics for more rapid innovation and movement to second and third generation feedstocks than the biofuels industry. While the science that is being developed for next generation biofuels is often directly relevant to biobased plastics, the smaller scale of biobased plastics suggests that biobased plastics could commercialize these new technologies more rapidly.

Where shale gas is available, the plastics industry is changing the landscape in many ways, biobased plastics included. With the recently dramatically increased availability of North American shale gas and petroleum, the transition to biobased feedstocks for many polymers may be hampered due to the low cost of the natural gas and petroleum feedstocks in North America. This may be especially true for the largest volume plastics considering the recent announcements by Dow and Braskem to delay construction of a biobased polyethylene plant and a biobased polypropylene plant respectively in Brazil. Surprisingly, though, there are significant areas where shale gas indirectly enhances the economic drivers for biobased equivalents of other polymers such as polyesters and polyamides. Activities in development, partnerships and investments are understandably increasing with these targets in mind.

First generation biobased plastics do indeed have impacts on food security, land use and the like. Described herein are the motivations and actions that industry, in partnerships with NGOs,

academia and governments, are taking to minimize those impacts to navigate toward a future with a vibrant and more sustainable biobased plastics industry.

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