Final Report

Renewable Chemicals & Materials Opportunity Assessment

Major Job Creation and Agricultural Sector Engine

January 2014

Prepared For:

U.S. Department of Agriculture

Nexant

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1.1 BACKGROUND

Every so often a new technology emerges with potential for significant economic benefits and job creation. Since the 1990s, biotechnology has transformed the United States agricultural sector through genetically modified seeds that improve yields; increase tolerance to a variety of damaging factors such as drought, heat, and cold; fight pests by internally producing pesticides; and resist weeds, by providing herbicide tolerance. According to the USDA, the value of genetically modified crops in the United States totaled $76 billion in 2010(1). This is over 30 times the $2.3 billion value of these crops in 1999(2). Biotechnology is also only one of several technologies enabling the emergence of a renewable chemicals industry. By renewable chemicals we include both chemicals and renewable polymers or other materials.

The objective of this paper is to characterize the economic opportunities presented by this emerging industry in terms of job creation potential, investment requirements and value added over the next five to ten years. In addition, the obstacles to development are described and options are identified for derisking this emerging industry.

It is important to recognize that the estimates of opportunities presented in this paper are based on Nexant's assessment of emerging renewable chemical products that are currently cost competitive with conventional petrochemicals. Advances in technology are very difficult to project. However, agricultural biotechnology is similar to the industrial biotechnology enabling renewable chemicals developments. We include an upside estimate as well for renewable chemicals. These estimates exclude renewable fuels, which have much lower value in use compared to chemicals.

1.2 RESULTS

1.2.1 U.S. Renewable Chemicals Market Potential

Nexant estimates of the U.S. market potential for production of renewable chemicals are summarized in Table 1.1.

Table 1.1 U.S. Renewable Chemicals/Materials Market Potential
(Thousand metric tons)

	2012	2017	2022	Growth 2012 to 2022
C_2	0	0	1,000	1,000
C_3	40	100	300	260
C_4	100	150	400	300
Aromatics	<10	100	500	495
Specialty Oils	20	400	1,000	980
Total	**165**	**750**	**3,200**	**3,035**

[1] National Bioeconomy Blueprint, April 2012
[2] The Economic Contributions of the Biotechnology Industry to the U.S. Economy, Ernst & Young, May 2000

In the next five years, the greatest opportunities are in the specialty tailored renewable oils businesses that are being developed based on sugar-fed fermentation of genetically modified algae (e.g., by Solazyme) and a catalytic metathesis of oils that also produce unique “bifunctional” molecules finding new uses (e.g., by Elevance). The second largest class of renewable chemical opportunities is in C_4 chemicals such as butanediol, butadiene, and nylon intermediates. Nexant also expects rapid commercialization of renewable C_3 chemicals, with the most likely initial product being acrylic acid. Low cost shale gas and gas liquids will be strong competition for renewable C_2 and C_3 chemicals. Nevertheless, Nexant expects a modest portion of the large ethanol capacity in the United States will be repurposed in the longer term to produce ethylene and its derivatives.

1.2.2 Job Creation

Table 1.2 summarizes the U.S. job creation potential associated with the projected renewable chemical and materials production. The job creation potential estimated by Nexant is based on detailed cost of production estimates for representative chemicals within each class of petrochemical that have been developed as a part of Nexant’s consulting assignments. The estimates combine the number of jobs associated with bio feedstock supply, direct production of the chemicals, the other jobs within the plants and within the companies associated with supporting production. In addition, the indirect job creation associated with logistics of feedstock and product transportation and downstream creation of finished products have been included.

Table 1.2 Renewable Chemical U.S. Job Creation Potential
(Number of jobs)

	2017	**2022**
C_2	0	9,860
C_3	660	1,980
C_4	825	2,200
Aromatics	150	750
Specialty Oils	1,770	4,420
Others	95	190
Total	**3,500**	**19,400**

1.2.3 Capital Requirements and Value Added Potential

Table 1.3 summarizes the projected capital requirements and value added (the difference between price and the cost of raw materials) for the estimated renewable chemical and materials opportunities over the next ten years. These estimates are based on investment and cost of production estimates prepared by Nexant as part of its ongoing consulting work within each class of petrochemicals. By 2017, Nexant sees the potential of $775 million of value added per year for renewable chemicals with a required capital cost of $2.4 billion. By 2022, the value added potential is estimated at $3 billion per year with a required capital cost of $6 billion.

Table 1.3 Renewable Chemicals Value Added and Capital Costs[1]
(Constant 2013 dollars)

	2017 Fixed Investment (MM$)	2017 Value Added (MM$/yr)	2022 Fixed Investment (MM$)	2022 Value Added (MM$/yr)
C_2	0	0	250(1)	660
C_3	565	210	1,420	630
C_4	1,130	200	2,040	530
Aromatics	490	125	1,840	625
Specialty Oils	200	240	455	600
Total	**2,385**	**775**	**6,005**	**3,045**

1 This assumes retrofit of existing ethanol plants for the production of ethylene

1.2.4 Upside Potential

It is important to note that these estimates of the potential for renewable chemicals and materials in the United States are based on the current state of technology development. Nexant anticipates that there will be significant improvements in the technologies during the next ten years. Using the advancements achieved over the past 10-15 years in agricultural biotechnology as an indication, the potential could be as much as six times the values presented above.

1.3 ENVIRONMENTAL BENEFITS

The primary environmental benefits of bio-based chemicals are:

- Reducing carbon dioxide and other “greenhouse gas” emissions related to climate change
- Reducing other pollutant emissions associated with supply, processing, and use of petroleum, natural gas, coal, and petrochemicals
- Production of renewable chemicals that are also biodegradable give added benefits such as:
  - Reduced risks to animals of plastics litter hazards
  - Reduced risks of non-biodegradable detergent, paint, solvent, and other chemical emissions harming the ecosystem

1.4 OBSTACLES TO DEVELOPMENT AND DERISKING

As a consultant active in this industry, Nexant has observed that the greatest obstacle to development of the renewable chemicals and materials industry is obtaining capital for commercialization of first-of-a kind technologies. This is often the case for the introduction of new technologies, and public/private efforts are key potential enablers for "derisking" such investments.

Beyond outright loans, Nexant sees three potential approaches for risk mitigation to facilitate development of renewable chemicals in the United States. They are:

- Investment tax credits
- Loan guarantees
- Production credits

Investment tax credits can be applied to the entire sector or selected broad segments. Loan guarantees require "picking winners" from among the many companies contending for participation in the renewable chemicals business. This presents both political risks for the public sector and financial risk for the private sector.

Production credits (payments to producers for production of renewable chemicals) would require making much broader judgments regarding which segments of the renewable chemicals industry that are most likely to succeed and provide production credits for those products, with time limit provisions, to assist in the introduction of the best of the technologies. The time limits would ensure that once the processes are commercialized and are economically viable, the production credits would expire.

It is not the purpose of this paper to recommend policy; rather, this paper has presented its assessment of the potential based on the current state of technology.

Every so often a new technology emerges with potential for significant economic benefits and job creation. Since the 1990s, biotechnology has transformed the U.S. agricultural sector through genetically modified seeds that improve yields; increase tolerance to a variety of damaging factors such as drought, heat, and cold; fight pests by internally producing pesticides; and resist weeds, by providing herbicide tolerance. According to the USDA, the value of genetically modified crops in the United States totaled $76 billion in 2010[(3)].

Biotechnology is also enabling the emergence of a renewable chemicals and materials industry. These products are inherently more valuable than agricultural commodities and biofuels, so offer even greater potential economic benefits. Other enabling emerging technologies convert cellulose to sugars that serve as cost effective feedstocks for the production of renewable chemicals and polymers, and preempt the food-versus-fuel debate. These technologies are generally feedstock agnostic. Some companies are using corn starch or cane sugar as their initial feedstock with a goal of switching to cellulosic sugars once they have been demonstrated commercially. DuPont and POET are among the U.S. companies currently building commercial scale cellulosic sugar manufacturing plants. Nexant's feedstock cost assumptions herein are conservative, assuming that cellulosic sugars will have a cost[(4)] of 10 to 15 cents per pound, similar to a typical price of conventional corn starch sugars[(5)]. In addition, biomass gasification coupled with conventional catalysis is another route to renewable chemicals and materials. In comparing the competitiveness of renewable chemicals with petrochemicals, Nexant has conservatively assumed an oil price of $100 per barrel in constant 2013 dollars over the next ten years.

This paper does not address biofuels[(6)]. Biofuels have been promoted as a means of diversifying sources of energy and increasing agricultural demand, but they are inherently much lower priced than the target renewable chemicals and materials, which makes the business case more difficult. While this paper does not consider biofuels, Nexant acknowledges that many biorefineries are being planned to produce a synergistic combination of biofuels and renewable chemicals and materials. Many companies that originally targeted the biofuels market have broadened their targets to include renewable chemicals and materials due to their higher value.

One challenge of this analysis is to measure the size of the renewable chemicals and materials business. A number of analysts have estimated the U.S. revenues from biotechnology, including fuels as well as chemicals, materials and industrial enzymes, to be in the range of $80 to $100 billion[(7)]. It has been more difficult to track the size and growth of the renewable chemicals and materials segment. Nexant estimates the size of the 2012 global renewable chemicals and materials market was approximately 1.2 million metric tons (~$2.5 billion per year in sales

[3] National Bioeconomy Blueprint, April 2012
[4] Full cost of production plus 10% return on capital employed in a new plant
[5] Nexant report, Cellulosic Sugars: Unlocking Biomass' Potential, March 2013.
[6] Ethanol is a 33 billion dollar biofuel market in 2013 in the U.S.
[7] See for example Biodesic Bioeconomy Update 2011.

revenue)[8]. It is important to note that this excludes the traditional agriculturally-based oleochemicals market.

The primary objectives of this white paper are to:

- Estimate the potential for bio-based chemicals and materials,
- Make the case for its competitiveness versus traditional petrochemicals and the competitiveness of the United States. compared to other countries, and
- Make the case that industry development is being constrained by the reluctance to finance first of a kind commercial operations, suggesting a need for a public/private effort to derisk these investments

Other countries are ahead of the United States in this last regard. Europe has created a €4 billion private/public fund for this purpose, and Brazil's BNDES, a major public bank, has made several large loans at favorable interest rates that have enabled U.S. companies such as Amyris and Solazyme to commercialize their renewable chemicals technologies in Brazil.

If the United States is to reap the economic and job creation potential from technologies associated with renewable chemicals and materials, much of which has been developed here, a manner in which more of the required investments can be derisked must be developed. This paper will suggest several ways that this can be done. These technologies are just becoming commercially viable; it is critical to act over the next three years or these investments will be lost to other hosting countries.

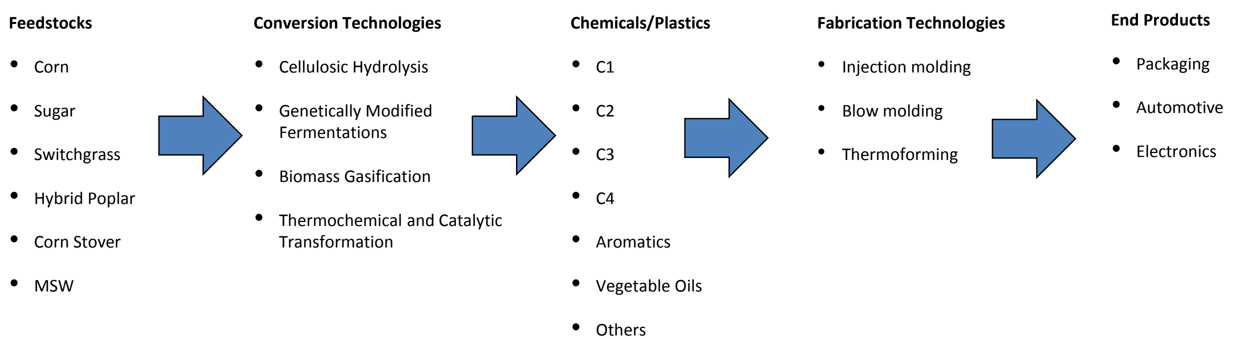
[8] Nexant report, Biobased Chemicals: Going Commercial, January 2012

The natural target for renewable chemicals is the $275 billion U.S petrochemical industry[(9)]. The petrochemical market is often parsed in terms of the number of carbons in the molecules. C_1 chemicals such as urea fertilizers and methanol are not considered a promising target due to the low price of shale gas in the United States. Figures 3.2 through 3.7 in the sections that follow outline the C_2, C_3, C_4, aromatics benzene, xylene, and specialty oils segments to illustrate the extent and breadth of the petrochemical market. The potential renewable market for each of these will be presented in Section 6.

New renewable chemicals and materials such as Naturework's polylactic acid (PLA) and DuPont's polytetraterephthalate (PTT) Sonora™ have taken considerable time to gain sizable market shares. Drop-in renewable replacements for the existing large volume products in the petrochemical market represents a much larger potential market with a much shorter time for commercialization.

The renewable chemicals value chain is outlined in Figure 3.1

Figure 3.1 Renewable Chemicals Value Chain



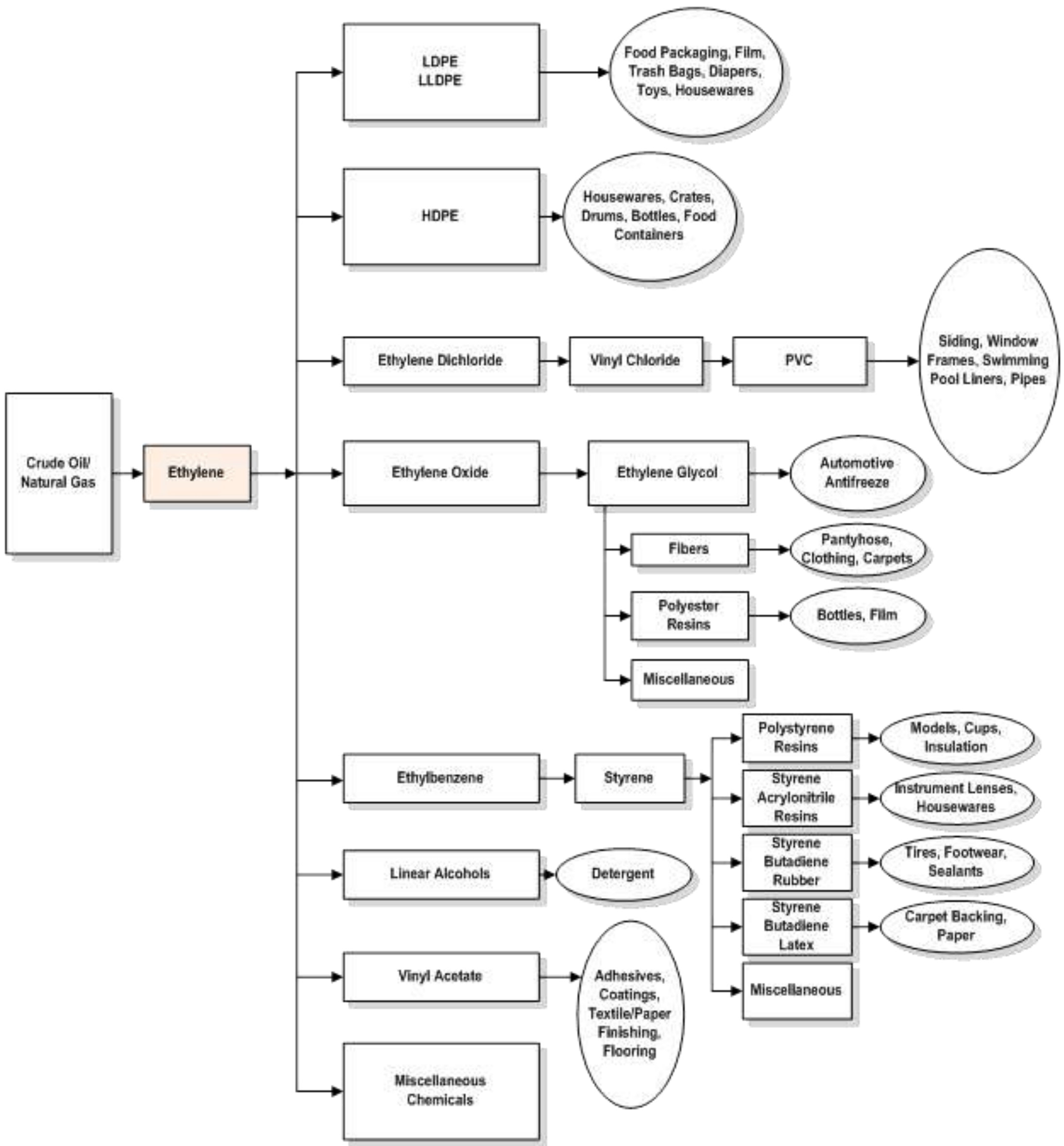
There are conventional renewable commodities used as feedstocks, such as corn starch and cane sugar. In addition, there are processes to utilize cellulosic feedstocks such as corn stover, switchgrass, wood wastes, or municipal solid waste (MSW). To use cellulosic feedstocks, hydrolysis, gasification, pyrolysis, or other methods must be employed to produce intermediate chemicals that can be converted into end use chemicals or materials.

9 From the 2013 Guide to the Business of Chemistry, American Chemistry Council, Table 2.6, consisting of bulk petrochemicals and intermediates, plastic resins, synthetic rubbers and fibers

3.1 C_2 CHEMICALS

Figure 3.2 shows the C_2 chemicals value chain. From ethylene, the largest volume petrochemical intermediate, the major commodity plastics polyethylene, PET, and PVC are produced, as well as polystyrene and a wide variety of paints, adhesives, and detergents.

Figure 3.2 C_2 Petrochemical Value Chain



3.2 C_3 CHEMICALS

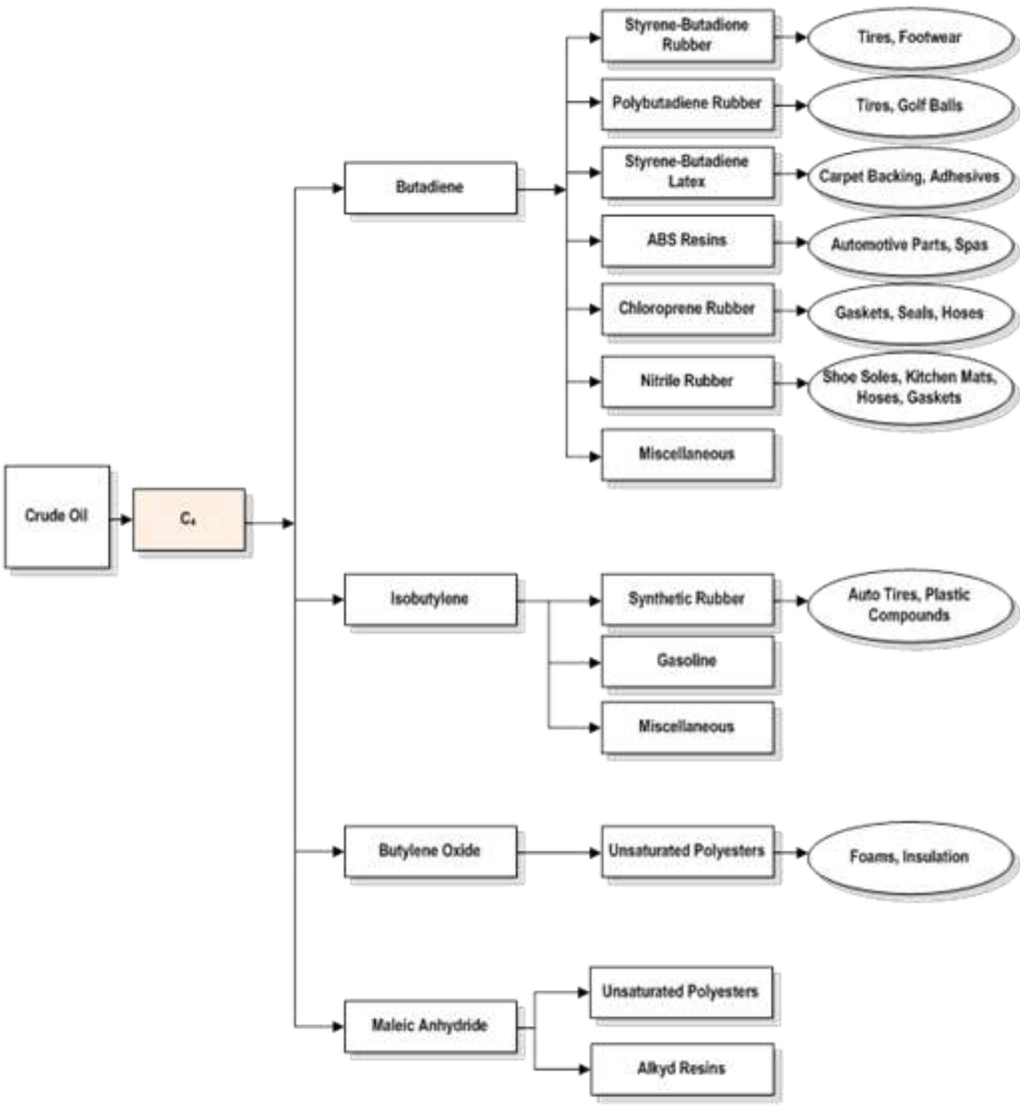
The C_3 value chain presented in Figure 3.3 includes polypropylene, polyurethanes, and acrylics.

Figure 3.3 C_3 Petrochemical Value Chain

3.3 C_4 CHEMICALS

Figure 3.4 presents the C_4 chemicals value chain. C_4s are used to produce engineering plastics, polyurethanes, nylons, and various rubbers.

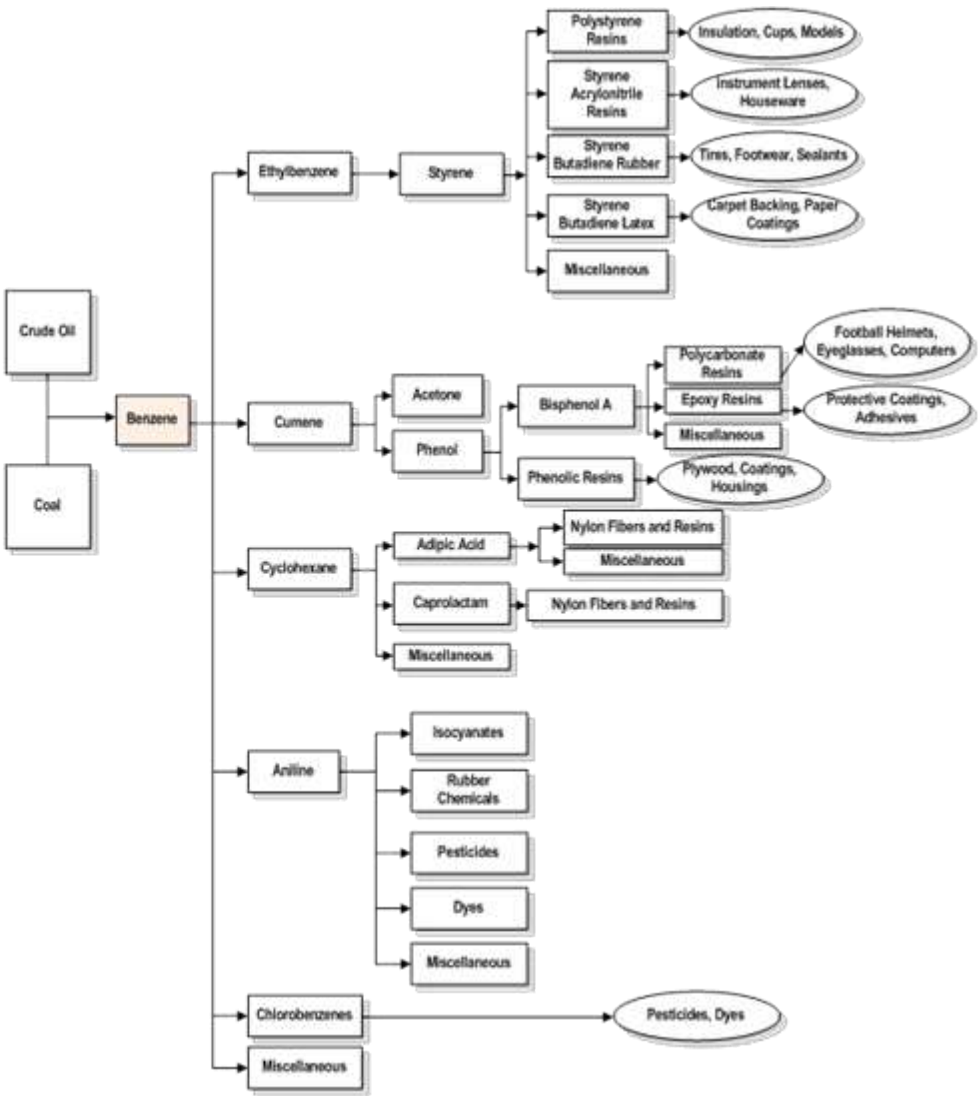
Figure 3.4 C_4 Petrochemical Value Chain



3.4 BENZENE

Benzene is the largest volume and one of the important aromatic chemicals. Its value chain in Figure 3.5 includes polystyrene, nylons, polyurethanes and polycarbonates.

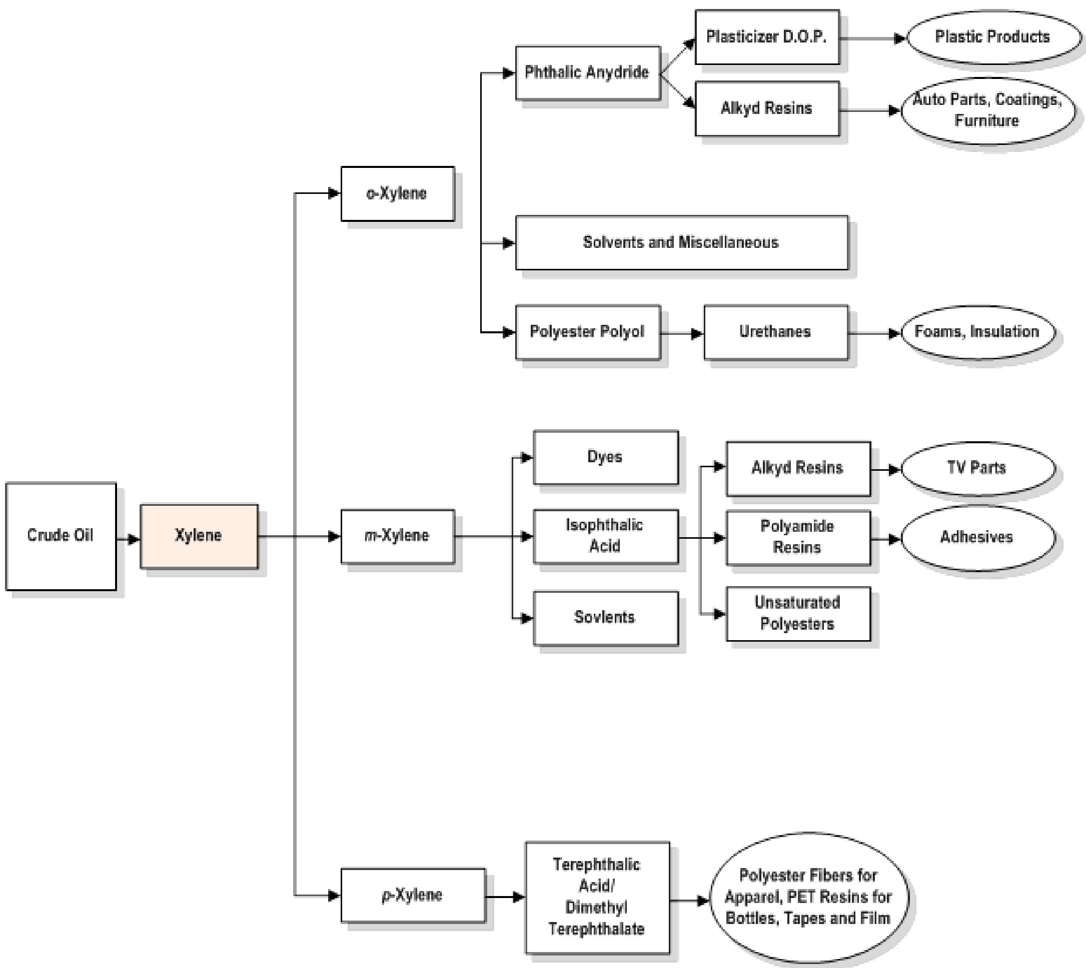
Figure 3.5 Benzene Petrochemical Value Chain



3.5 XYLENES

The value chain for three isomers of xylene is presented in Figure 3.6. *para*-Xylene is the largest market of the three as a key raw material in the product of PET. *ortho*-Xylene is used in alkyd resins, plasticizers, and polyurethanes. *m*-Xylene is a much smaller volume product.

Figure 3.6 Xylenes Petrochemical

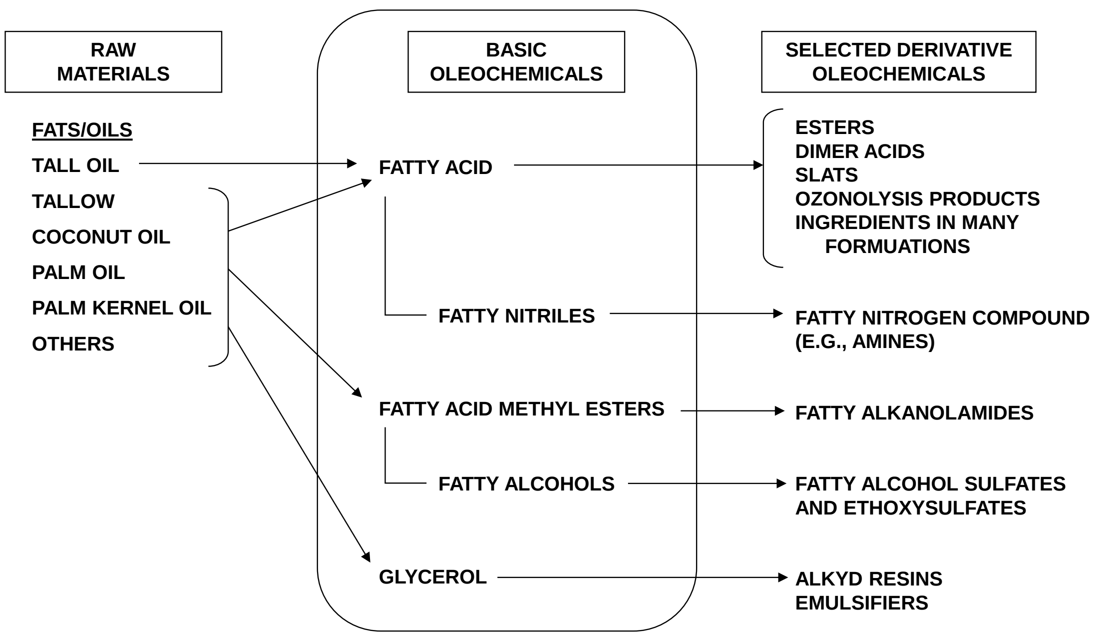


3.6 SPECIALTY OILS

The natural vegetable oil business is a $250 billion global business. The largest segment is food, but industrial applications and oleochemicals are a $72 billion business. Several new specialty tailored renewable oils businesses are being developed based on sugar-fed fermentation of genetically modified algae (e.g., Solazyme) and a catalytic metathesis of oils that also produce unique "bifunctional" molecules finding new uses (e.g., Elevance). Nexant has estimated the potential global market for these specialty oils at over $50 billion[(10)].

Figure 3.7 prevents an overview of the conventional oleochemical market. The new specialty tailored renewable chemicals market is finding applications in composition-driven, value-added end use markets such as low molecular weight fatty acids, enhanced drying oils, hydroxyl or epoxy substituted oils, high oleic acid oils, and single fatty acid oils. Property-driven emerging markets include advanced (Group IV) lube base oils, lube additive oils, bio lubes, and greases and oils. Finally, property and acceptance-driven emerging markets include emollients, vegetal butters, healthy margarines and polyunsaturated fatty acids (PUFAs).

Figure 3.7 Oleochemical Market Structure[(11)]



[10] Confidential client study
[11] Soybean oil,, sunflower, canola, cotton seed, tallow, tall oil, corn oil, rendered fats are domestic, the others are tropical and are not domestically produced in the U.S.

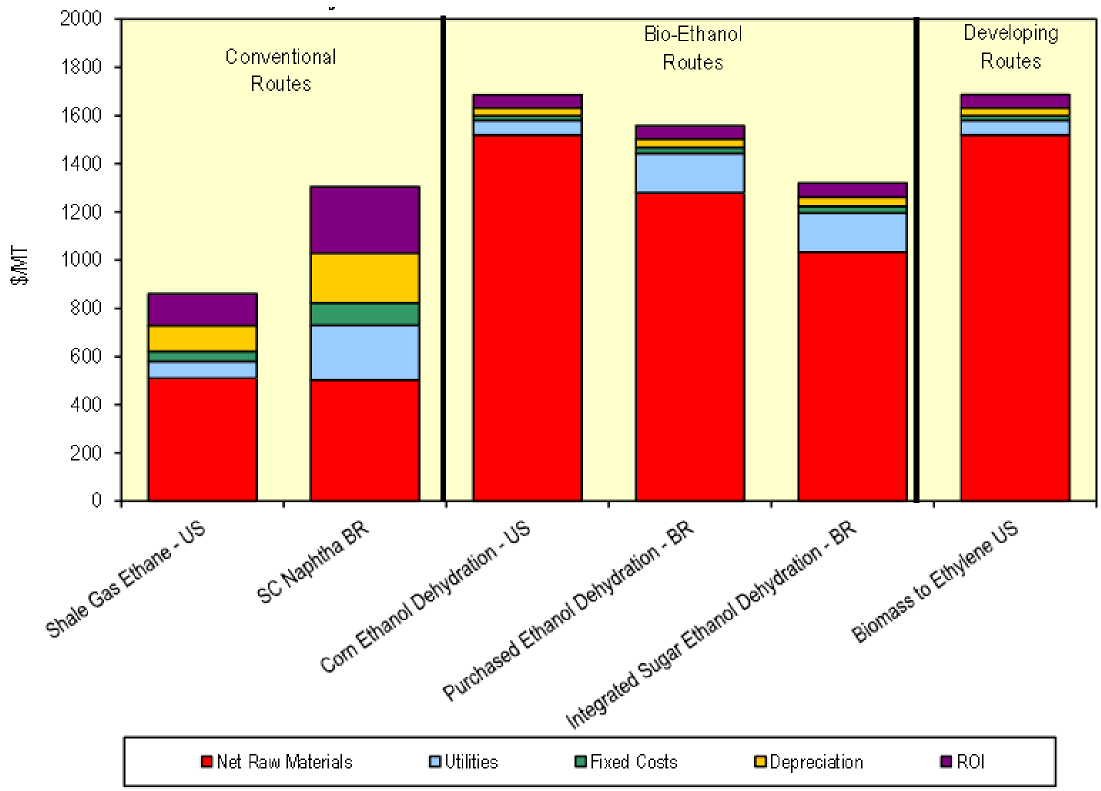
Nexant has projected the potential of the renewable chemicals and materials business in the United States strictly on the basis of its cost competitiveness versus petrochemical routes. While there may be a “green premium” for renewables, it is risky to assume that consumers will be willing to pay a premium for a renewable product. However, one of the larger drivers of interest in biorenewables is the potential to provide greater price stability, especially if non-food residual resources are exploited.

Our analysis of cost competitiveness of renewable chemicals has been undertaken using the classification of the petrochemical business in Section 3. The impact of shale gas on cost competiveness has been specifically addressed for each product group. In general, the impact of shale gas has been to decouple from oil prices the prices of natural gas and ethane, the most competitive feedstock for ethylene production. The low natural gas and ethane prices resulting from shale gas are dramatically increasing the share of ethylene produced from ethane and decreasing the share produced from naphtha, a crude oil refining byproduct. The result is that supply of ethylene co-products of naphtha cracking (propylene, butylenes, and aromatics) are decreasing, increasing the prices of C_3, C_4, and aromatics product chains in the United States.

4.1 C_2 RENEWABLE CHEMICALS

Figure 4.1 summarizes Nexant’s assessment of the cost competitiveness of C_2 renewable chemicals. The cost competitiveness analysis has been conducted in terms of ethylene, the key intermediate for C_2 chemicals.

Figure 4.1 Ethylene Competitive Costs
(Cost of Production Plus 10% Return on Investment)



The figure compares various conventional routes, several bio-ethanol routes, and finally, a hypothetical biomass to ethylene route in the United States. The conventional routes show how shale gas ethane is a much more competitive route to ethylene than is naphtha cracking. The bio-ethanol-based routes displayed include corn ethanol dehydration in the United States, ethanol dehydration in Brazil (as currently practiced by Braskem based on purchased ethanol), and integrated sugar to ethylene in Brazil as proposed in a Dow/Mitsui project (currently suspended). The benefits of integration with a sugar mill are apparent. Finally, the production economics of biomass to ethylene in the United States are shown with cellulosic sugar cost of 12 cents per pound assumed. Clearly, ethylene made from shale gas ethane is much lower cost than biomass-based ethylene production in the United States.

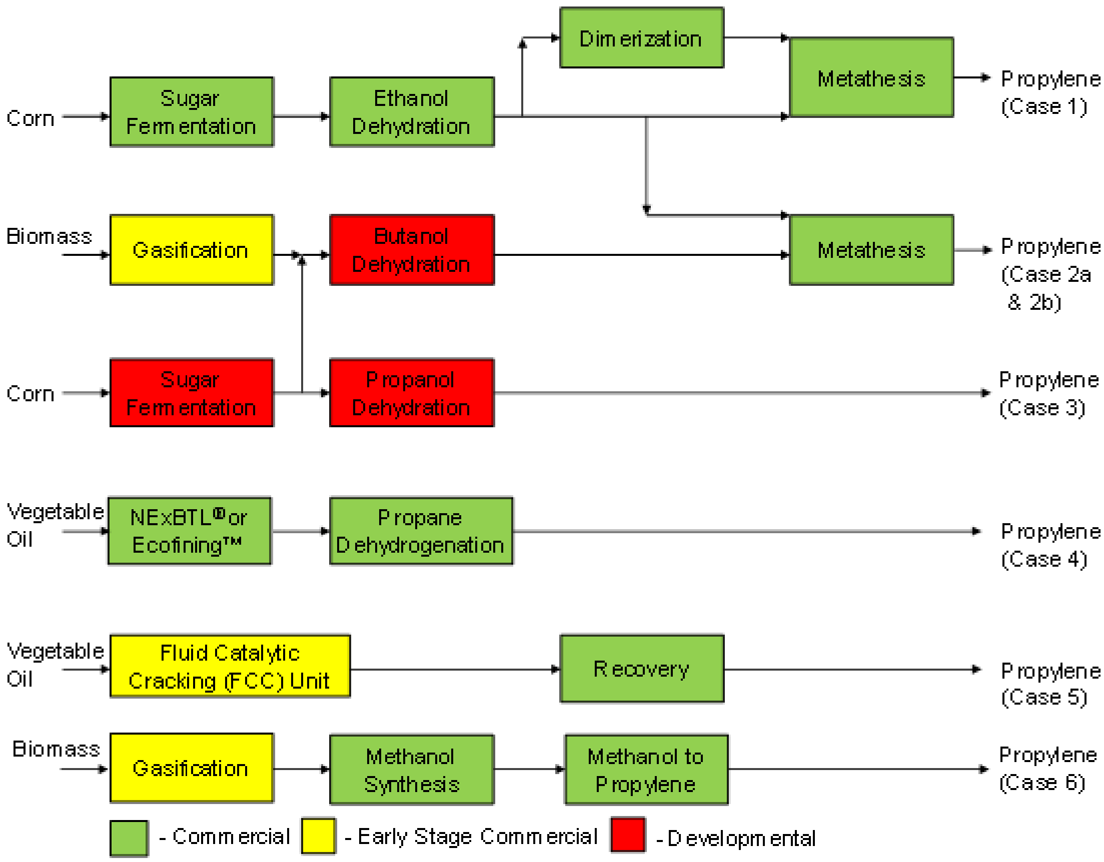
The big question is the future cost of natural gas in the United States and resulting ethane prices. Low cost natural gas is driving additional demand for power generation, gas to liquid fuels production, compressed natural gas vehicles, and liquefied natural gas exports. Nexant projects U.S. natural gas prices will increase to $6 to $8 per MM Btu by 2020, which will increase the cost plus return for ethylene from shale gas ethane to roughly $1300 per metric ton, still much lower than biomass to ethylene.

On the basis of this analysis, Nexant concludes that renewable C_2 chemicals are unlikely to be competitive with petrochemical based products in the foreseeable future, primarily due to the impact of shale gas. If however, routes based on waste biomass gasification or fermentation are demonstrated to be competitive, especially using the large existing ethanol manufacturing facilities in the United States, this conclusion might be changed.

4.2 C_3 RENEWABLE CHEMICALS

There is a large number of conventional and emerging routes for producing the primary C_3 chemical, propylene. As summarized in Figure 4.2, there are at least six renewable routes which have been evaluated by Nexant[12].

Figure 4.2 Green Routes to Propylene



Of these renewable routes, the most promising economically is biobased methanol to propylene with a cost of production plus 10% ROI of $1310 per metric ton in 2013, projected to increase to $1,440 by 2018. Among the many emerging routes to propylene, propane dehydrogenation (PDH) is becoming especially popular. Eight new PDH units have been announced in the United States. The current and projected 2018 production economics of bio-based propylene and PDH are compared in Figure 4.3. PDH is significantly more competitive.

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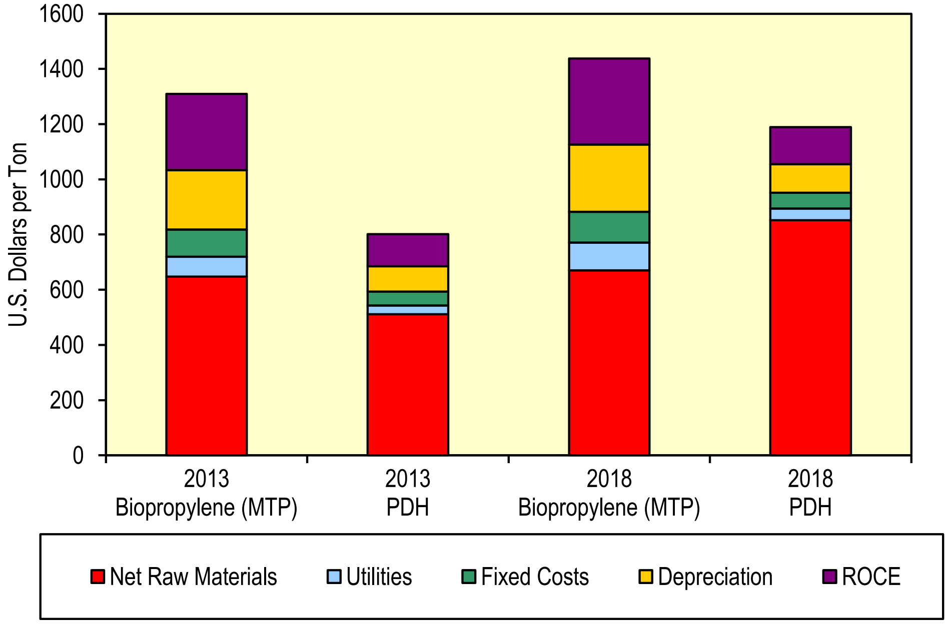
12 Nexant Process and Evaluation Research (PERP) report 2013-1, Propylene, to be published shortly

Figure 4.3 Comparison of Bio-Propylene with PDH
(COP plus 10% ROI, $ per mt)



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The key question is the future shale gas propane price. Currently, U.S. propane prices are depressed due to oversupply. However, in addition to the PDH plants being built, LPG export terminals are being planned. LPG is an important industrial, commercial, transportation, and domestic fuel in Asia, Africa, South America, and other tropical and sub-tropical and developing economies elsewhere and in rural areas globally. While the United States has traditionally been a net importer of LPG, which includes propane and butane, it is expected to be a net exporter in the future. Future LPG prices will be driven more by export netbacks, which are directly related to oil prices.

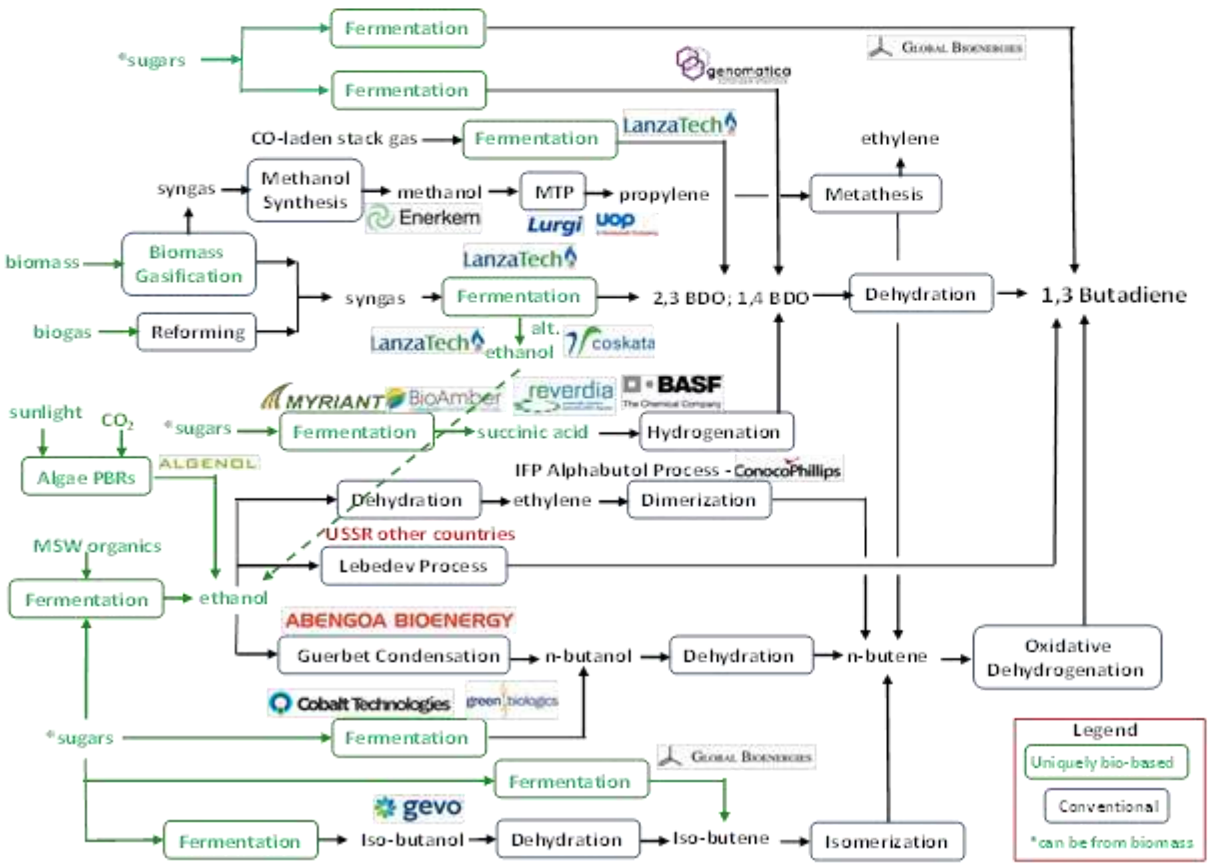
Several U.S. companies are working on renewable routes to propylene derivatives, such as acrylic acid via lactic acid, 3-hydroxypropionic acid (3HP), or fumaric acid. They include OPX/Dow Chemical, Cargill/BASF/Novazyme, Myriant, and Metabolix.

While it faces economic challenges, Nexant concludes that a modest share of future U.S. C_3 chemicals will be economically viable via renewable routes.

4.3 C_4 RENEWABLE CHEMICALS

C_4 chemicals has been one of the most actively pursued renewable chemicals segments. Many major metabolic pathways produce C_4s as intermediates in the metabolism of sugars. The pathways being pursued for renewable chemicals are quite complex, as summarized for one of the key C_4 chemicals, butadiene, in Figure 4.4.

Figure 4.4 C_4 Renewable Chemical Routes Under Development



The renewable C_4 derivatives most actively being developed are 1,4 butanediol (BDO), butadiene, and adipic acid and hexamethylenediamine (the two raw materials for nylon 6,6). Nexant has studied the competitiveness of renewable BDO[13] and butadiene[14]. There are at least five conventional routes to BDO. In addition, several renewable commercial plants are in the process of starting up. They include a 15,000 ton per year bio succinic acid plant (a BDO intermediate) currently being started up in Louisiana, a 20,000 ton per year plant starting up this year in Adria, Italy by a joint venture of Genomatica, a U.S technology company, and Novamont, and a 23,000 metric ton per year BDO plant under construction in Sarnia, Ontario,

[13] Nexant report, Is Bio-BDO Here to Stay, July 2012
[14] Nexant PERP Report 2013-7, to be published by the end of 2013

scheduled for completion in 2014. BASF, the global leader in BDO and derivatives has also licensed Genomatica technology for biobased BDO.

U.S companies Genomatica, Gevo, and Invista, among others, are developing promising renewable routes to butadiene, and Nexant is currently evaluating the competitiveness of these routes[(15)]. Promising, but at an early stage of development, are fermentation routes. Other renewable routes were formerly practiced in Russia (Lebedev) and Brazil (Corperbo).

A third major renewable C_4 chemical platform is adipic acid and hexamethylenediamine (HMDA), the two raw materials for nylon 6.6. Nexant is evaluating bio-routes to adipic acid[(16)]. Rennovia has a renewable catalytic process for adipic acid production which has been demonstrated at pilot plant scale to have manufacturing costs 30 percent lower than conventional costs. It has formed a joint venture with Verdezyne to build a commercial plant by 2014. Rennovia's HDMA process is similar, but at an earlier stage of development.

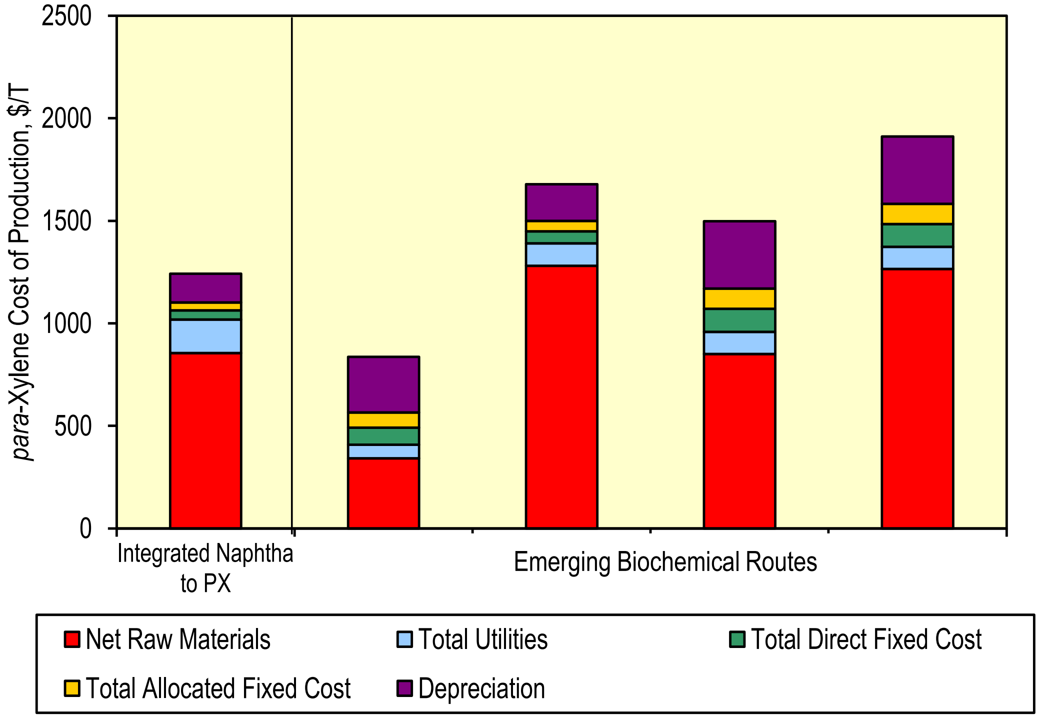
Nexant concludes that several C_4 chemicals have significant potential for U.S. production.

4.4 RENEWABLE AROMATICS

Nexant has recently assessed the economics of several renewable routes to *para*-xylene, the principal raw material for production of polyethylene terephthalate (PET), a major plastic for retail bottles and textile fibers[(17)]. Figure 4.5 shows that renewable *para*-xylene is potentially competitive with conventional petrochemical supplies. The conclusion is speculative because the processes have not reached the commercial scale.

[15] Ibid
[16] Nexant PERP report, Adipic Acid, to be published by the end of 2013
[17] Nexant PERP report, Bio Routes to *para*-Xylene, March 2012

Figure 4.5 *para*-Xylene Competitive Costs



The Anellotech process also has an analogous process for producing other aromatics. Gevo has a three step process for converting isobutanol to *para*-xylene. Virent, which offers an Aqueous Phase Reforming process to convert sugar solutions to hydrocarbons, is also capable of extracting aromatics, and has interest and funding from Coca-Cola for this.

Cool Planet is another U.S. company targeting aromatics production. It started its technology development for modular agricultural waste pyrolysis with co-production of "bio-reformate," which closely resembles the refinery stream from which aromatics are conventionally extracted, and "carbon-negative" bio-char, which is a valuable soil amendment to enhance agricultural production and reduce irrigation and fertilizer requirements. Cool Planet is now examining strategies to extract the aromatics as chemicals for,(e.g., plastics production).

Nexant concludes that renewable aromatics production routes look to be economically competitive.

Section 5 U.S. Renewables Cost Competitiveness Versus Other Regions

There are three primary sources of competitiveness for renewable chemicals and materials: bio-feedstock cost and availability, accessible market, and technology availability.

5.1 BIO-FEEDSTOCK COST AND AVAILABILITY

Nexant has analyzed various conventional and cellulosic biofeedstocks[18]

- North America
  - Conventional Feedstock: Corn is the dominant feedstock, though there are other minor feedstocks used
  - Cellulosic Feedstock: Agricultural Wastes (e.g., corn stover), wood/wood wastes, municipal solid waste (MSW), and other large volume biomass
- South America
  - Conventional Feedstock: Sugarcane is the dominant feedstock
  - Cellulosic Feedstock: Sugarcane bagasse and field trash, agricultural wastes (e.g., corn stover), wood/wood wastes, MSW
- Western Europe
  - Conventional Feedstock: Corn, wheat, and sugar beets
  - Cellulosic Feedstock: Agricultural Wastes (e.g., wheat straw), wood/wood wastes, MSW, and other large volume biomass
- Asia & Oceania
  - Conventional Feedstock: Rice , Corn, Cassava, and Sugarcane
  - Cellulosic Feedstock: Agricultural Wastes (e.g., rice straw), wood/wood wastes, MSW, and other large volume biomass

Nexant draws two conclusions from this report. First, the estimated cost plus return on investment for cellulosic sugars in the United States are comparable to that for conventional corn sugars.

Secondly, the United States and Europe are at a cost disadvantage versus Brazil and Southeast Asia with regard of the cost of biomass (roughly $40 per metric ton disadvantage). However, this cost disadvantage is offset by the superior distribution infrastructure in the United States versus Brazil and Southeast Asia.

Clearly, U.S. corn is globally competitive and a major export commodity.

[18] Nexant Report, Cellulosic Sugars: Unlocking Biomass' Potential, March 2013

5.2 ACCESSIBLE MARKET

As stated in Section 3, the United States is a $275 billion petrochemical market. By comparison, the Brazilian petrochemical industry is estimated at $75 billion of which $15 to $20 billion is imported(19). The fact that Brazil is such a large importer is significant as to its underlying competitiveness. Similarly, the Southeast Asian petrochemical business is even smaller than Brazil's. Hence, the United States has access to a very large domestic petrochemical market for penetration by renewable chemicals and materials.

5.3 TECHNOLOGY AVAILABILITY

The United States is the global leader in renewable chemicals and materials technology development. Appendix 1 lists the many U.S. startup companies emerging in this space and status of their plans for commercialization.

[19] Derived from Potential de Diversificacao da Industrial Quimica Brasileira, BNDES, June 2013

Nexant has estimated the U.S. market potential for renewable chemicals and materials over the next five to ten years. Results are summarized in Table 6.1 by the segments defined in Section 4.

Table 6.1 U.S. Renewable Chemicals/Materials Market Potential
(Thousand metric tons)

	2012	2017	2022	Growth 2012 to 2022
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Aromatics	<10	100	500	495
Specialty Oils	20	400	1,000	980
Total	**165**	**750**	**3,200**	**3,035**

6.1 C_2 RENEWABLE CHEMICALS

With the low current prices of shale gas ethane, there is no near term opportunity for renewable ethylene derivatives in North America. However, with the low cost of shale gas, additional natural gas demand is likely for power generation, gas to liquid fuels production, compressed natural gas vehicles, and liquefied natural gas exports. While not anticipated in Nexant's base case forecast, it is not inconceivable that natural gas demand will increase to the point that natural gas price reaches or exceeds the Btu value of crude oil. It is not so long ago that natural gas, a clean burning fuel, did command a 10 percent price premium over crude oil. If that were to occur, Nexant could see the development of demand for 1 million metric tons per year for renewable ethylene, either for green MEG for production of renewable PET bottles, or green polyethylene, as is being produced by Braskem today in Brazil and used in "green" packaging, which constitutes a small part of total product cost and where a price premium is achieved today.

6.2 C_3 RENEWABLE CHEMICALS

Today, DuPont produces Sonora polymers from renewable 1,3 propanediol. Its demand continues to grow. However, the largest renewable C_3 chemicals are likely to be acrylic acid and renewable polyether polyols. Nexant foresees the potential for 100,000 tons per year of such demand by 2017. Prospective renewable acrylic acid producers could be OPX Bio/Dow or ADM/BASF. A number of companies are already producing renewable polyether polyols and more development is anticipated. Assuming 10 percent of the U.S. market for glacial acrylic acid for superabsorbent diapers as a base load, plus some additional exports to global markets, and a modest polyether polyol position in existing applications like automotive seating, the potential U.S. market could be 300,000 metric tons in 10 years.

6.3 C_4 RENEWABLE CHEMICALS

This is the largest current renewable chemical market, primarily for *n*-butanol, D-lactic acid and polylactic acid (PLA). In the future, renewable 1,4 butanediol, butadiene, fumaric acid, and nylon 6,6 will be added to the C_4 chemicals. Potential demand is estimated at 150,000 metric tons by 2017 and 400,000 metric tons by 2022.

6.4 RENEWABLE AROMATICS

Renewable para-xylene for PET bottle production is the largest potential renewable aromatics market. Coca Cola, Pepsi, and others are strongly promoting renewable PET bottles and other packaging. Several U.S. companies have joint development programs with these companies, and Coca Cola has a goal of 100 percent of its Coke and water bottles being renewable by 2020. Nexant has estimated the potential renewable aromatics market by assuming that renewable PET captures 5 percent of the U.S. PET bottle market by 2017 and 20 percent by 2022.

6.5 SPECIALTY OILS

The current total U.S. specialty vegetable oils market is estimated at almost 7 million metric tons per year. Nexant projects new tailored oils production will reach 400,000 metric tons by 2017, a market share of about 5 percent. By 2022, the market share will approach 10 percent. The ability to produce tailored oils with desired composition is a major improvement over conventional oleochemicals, driving these projections. Moreover, the prospect is not only for replacing petrochemicals (linear alpha olefins, etc.), but also for already incumbent domestic and imported vegetable oils.

6.6 OTHERS

There are other target renewable chemical and materials markets outside the ones described above. They include isoprene, farnesene, new specialty nylons, among many others. Nexant has excluded C_1 chemicals, methanol and ammonia/urea, as unlikely due to the low price of shale gas. However, BioNitrogen has received $300 million from the state of Louisiana for five biomass to urea plants it intends to build in the state. These other potential opportunities can be considered upsides to the market potential estimated in this report.

Table 7.1 summarizes the job creation potential associated with the projected potential U.S. renewable chemical and material opportunity. The job creation potential estimated by Nexant is based on detailed cost of production estimates for representative chemicals within each class of petrochemical that have been developed as a part of Nexant's consulting assignments. The estimates combine the number of jobs associated with bio feedstock supply, direct production of the chemicals, the other jobs within the plants and within the companies associated with supporting production. In addition, the indirect job creation associated with logistics of feedstock and product transportation and downstream creation of finished products are added.

Figure 7.1 Renewable Chemical U.S. Job Creation Potential

(Number of jobs)

	2017	**2022**
C_2	0	9,860
C_3	660	1,980
C_4	825	2,200
Aromatics	150	750
Specialty Oils	1,770	4,420
Others	95	190
Total	**3,500**	**19,400**

Table 8.1 summarizes the projected capital requirements and value added for the estimated renewable chemical and materials opportunities over the next ten years. These estimates are based on investment and cost of production estimates prepared by Nexant as part of its ongoing consulting work for representative chemicals within each class of petrochemicals. By 2017, Nexant sees the potential of 775 million dollars of value added per year for renewable chemicals with a required capital cost of 2.4 billion dollars. By 2022, the value added potential is estimated at 3 billion dollars per year with a required capital cost of 6 billion.

Table 8.1 Renewable Chemicals Value Added and Capital Costs
(Constant 2013 Dollars)

	2017 Fixed Investment (MM$)	**2017 Value Added** (MM$/yr)	**2022 Fixed Investment** (MM$)	**2022 Value Added** (MM$/yr)
C_2	0	0	250(1)	660
C_3	565	210	1,420	630
C_4	1,130	200	2,040	530
Aromatics	490	125	1,840	625
Specialty Oils	200	240	455	600
Total	**2,385**	**775**	**6,005**	**3,045**

(1) This assumes retrofit of existing ethanol plants for the production of ethylene

The primary environmental benefits of bio-based chemicals are:

- Reducing carbon dioxide and other "greenhouse gas" emissions related to climate change
- Reducing other pollutant emissions associated with supply, processing, and use of petroleum, natural gas, coal, and petrochemicals
- And, if biodegradable products are produced:
  - Reduced risks to animals of plastics litter hazards
  - Reduced risks of non-biodegradable detergent, paint, solvent, and other chemical emissions harming the ecosystem

There are three types of bio-renewable products:

- Chemicals or polymers that are completely identical to the incumbent petrochemically-based products (i.e., drop-ins), which are generally not biodegradable
- Biodegradable, but also "synthetic" substitutions that are compositionally different from the petrochemical versions, such as PLA or PHA polymers, or viscose rayon fibers
- Materials that are completely biologically-derived and are naturally biodegradable, such as wood flour fillers or natural fiber re-enforcements in plastics, etc.

It must be pointed out that the greatest volume of bio-based products is likely to be of the first type, identical to petrochemical products, but based on renewable carbon.

There are three major fates for plastics in the garbage that determine potential benefits:

- Recycling – a minor fraction of all plastics, approaching 30 percent for some, such as PET, PE and PP, but much less for others
- Landfill – still about 50 percent of the waste stream. The absolute volume of annual landfilling has been about the same for the last 30 years or so, because, since the 1980s, the natural growth of waste volume with population/GDP has been taken up by recycling of metals, paper, and plastics
- Combustion in a waste-to-energy facility for electricity production

It is environmentally beneficial if any carbon-based chemical or plastic is recycled, whether liquid or solid, petrochemical or renewable. Most of the petrochemical industry's products by volume end up in polymers (plastics, coatings, paints, foams, etc.), some of which are used in disposable items, such as bottles and other packaging, disposable diapers, etc., and others in durable goods such as cars, clothing, appliances, buildings, etc.

If a petro-plastic is landfilled, it will have no additional impact on global carbon emissions, since plastics are essentially inert and will persist in the landfill indefinitely. Although this is not desirable, it is better than the case of biodegradable paper, wood, natural fiber, food waste, yard waste, etc. These natural carbon-based materials can decay in a landfill to generate methane, carbon dioxide, and other greenhouse gases, and can make major contributions to climate change unless their emissions are completely collected and controlled or utilized. Bio-renewable drop-in plastics also do not decay in landfills. However, when a bio-renewable chemical or polymer is landfilled, this amounts to taking carbon out of the atmosphere, as a type of "carbon sequestration." If these bio-renewable materials are instead burned and thus utilized for their energy content, they will add no new carbon to the atmosphere, and can substitute for combustion of fossil fuels.

As to reducing pollutant emissions, the largest reductions resulting from substituting the production of bio-renewable chemicals or polymers is in avoiding the production, transport, and processing of petroleum, natural gas, and natural gas liquids to make petrochemical building blocks. These activities are sources of large volumes of toxic and otherwise harmful gaseous pollutants, greenhouse gases, solid hazardous residues, ocean and other oil spills, methane leaks, surface water pollution, groundwater contamination, and thermal pollution. One is easily reminded of numerous recent petroleum rail and pipeline accidents, deep ocean oil and gas rig catastrophes, refinery explosions, fracking controversies, etc. that could perhaps be made less frequent by using bio-based feedstocks as first steps in chemicals and polymer value chains.

As a consultant active in this industry, Nexant has observed that the greatest obstacle to development of the renewable chemicals and materials industry is obtaining capital for commercialization of first-of-a kind technologies. This is often the case for the introduction of new technologies, and public/private efforts are key potential enablers for "derisking" such investments.

Beyond outright loans, Nexant sees three potential approaches for risk mitigation to facilitate development of renewable chemicals in the United States. They are:

- Investment tax credits
- Loan guarantees
- Production credits

Investment tax credits can be applied to the entire sector or selected broad segments. Loan guarantees require "picking winners" from among the many companies contending for participation in the renewable chemicals business. This presents both political risks for the public sector and financial risk for the private sector.

The last would make much broader judgments on the segments of the renewable chemicals industry most likely to succeed and provide production credits for those products, with time limit provisions, to assist in the introduction of the best of the technologies. The time limits would ensure that once the processes are commercialized and are economically viable, the production credits would expire.

It is not the purpose of this paper to recommend policy; rather, this paper has presented its assessment of the potential based on the current state of technology. It is impossible to project future technology improvements that could increase the potential for renewable chemicals and materials substantially. However, using the historical advances in agricultural biotechnology as a guide, the potential opportunities over the next ten years could be as much as 6 times those estimated in this white paper.

Appendix A List of U.S. Renewable Chemical Companies and Announced Plans

Company	Target Products	Description of status of technology demonstration	Plan for commercialization	Comments
OPXBio	acrylic acid	3000 liter in 2012	50 ktons by 2017	
Solazyme	algae oils	1,820 tons fermentors in Peoria in 2011; demonstarted production at 500,000 liter in 2012 at ADM facility in Iowa; 2M liter IBR facility in 2012	20 ktons by 2014, increase to 100 ktons after with ADM in Iowa; 100 kton facility in construction in Brazil with Bunge, scheduled to begin operation by 4Q 2013 and expansion to 300 ktons by 2016	
Amyris	farnesene, squalene, other isoprenoids	~8kta kta in 2011 in Illinois, demonstrated production of 34-43 kton in 2011 in US, Spain, Brazil	ramp up production to 50 M liter by 2016 at Brotas plant in Brazil	
LS9	long chain fatty alcohols	135,000 liter	looking for commercialization partners	
Codexis	detergent alcohols	1500 liter	60 kton post 2014	
Virent	BTX	37,800 liter	30,000-225,000 liter by 2015	
Gevo	*para-X*ylene	demonstration scale in 2013	commercial production in 2014	
Cobalt	*n*-butanol	Large pre-commercial demonstration achived	Rhodia, GranBio to build sugar-based commercial plants inAlpena, MI and Brazil	
Zeachem	ethanol & C2 chemicals like acetic acid	250,000 liter in 2013	25 M gallon per year facility in development	
Lanzatech	ethanol/2,3 BDO (easily convertible to butadiene) from waste gases (CO + H2)	15,000 gallons per year pilot scale	demonstration scale by 2013, and commercial scale by 2014	
Lanzatech	direct butadiene	lab scale*	commercialization by 2016	
Elevance	long chain fatty acids and esters	180 ktons in Indonesia in 2013	150 - 350 ktons plant at Natchez currently under engineering, originally scheduled to begin in 2H 2013; planning another refinery in South America. ERS expects 3 biofineries	
Verdezyne	adipic acid	300L pilot scale/ 1000 kg per yr in 2011	285,000 liter by 2014	
Verdezyne	DDDA	kg samples	no commercialization timeline announced	also demonstrated production of nylon 6,6 and sebabic acid
Rennovia	adipic acid	pilot scale 2012	demonstration scale by 2014; and 135,000 liter commercial scale by 2018	
Rennovia	HMD	pilot scale in 2013	demonstration scale	
Rennovia	nylon 6,6	lab/pilot scale in 2013		
Rivertop Renewables	glucaric acid	1000 lbs	10 M lbs by 2014	
Myriant	succinic acid	13.5 ktons in 2013	64 ktons by 2015 most likely in Asia	
BioAmber	succinic acid	350,000 liter scale in France since 2010	30 ktons by 2014 and 50 ktons by 2016 in Canada; plant by 2014 in Thailand	
BioAmber	BDO, THF, GBL	several tons BDO and THF in Germany in 2012	23 ktons BDO by 2014 in Canada (not firm plan); another 50-100 ktons BDO/GBL plant by 2016/2017; 2 - 4 kton scale in US by 2014	
ADM	lactic acid		already commercial technology	
NatureWorks	PLA		already commercial technology	
Purac	PLA		already commercial technology	
Genomatica	1,3 PDO		achieved commercial production in 2006	
Genomatica	BDO	2 kton in 2012	50 kton plant in jv with BASF	
Genomatica	PBT	lab scale in 2013	plans to test the PBT samples with customers in 2013	
Genomatica	butadiene	lab scale	plans to commercialize	
Metabolix	PHA	10 kton scale in China and Spain	already commercial technology	
Metabolix	3-HP, acrylic acid/ GBL,BDO	lab scale	has not announced any commercial timeline	
Micromidas	p-xylene from waste paper	integrated pilot plant nearing full demonstration at 1000 kg/day	Seeking partnerships for commercialization, licensing	
Micromidas	PHAs from sewage sludge, manure, etc.	2000 L demonstration	long-term commercializaion plans on hold to focus on p-xylene platform	
SGA Polymers	acrylic acid	lab scale	5-10 M lbs per year by 2013; commercial scale plant by 2015	
Cargill/Novozymes/BASF	3-HP,acrylic acid	lab scale since 2008	plans to commercialize technology	
Blue Marble Biomaterials	carboxylic acids & esters	100,000 liter per month refinery in 2011	collaborated with Anheuser-Busch in 2012 to build pilot facility, purchased a former GC OATS refinery recently in 2013	
Anellotech	BTX	lab scale	pilot scale in 2H 2013, 100 kg samples	
Syngest	ammonia		50 kta in 2013 (might be delayed)	
BioNitrogen corp	urea		plant in preconstruction phase, 327 tons per day	
Agrebon	ammonia, urea		plant in financing stage, 25 tons ammonia per day, and 35 tons urea per day	
Genencor	isoprene		planned to complete pilot scale in 2011, but company no longer pursuing isoprene	
GlycosBio	isoprene		10 ktons by 2013 in Malaysia, plans to develop 4 production facilities in next 4 years	
Aemetis	isoprene	lab scale in 2011	52 ktons plant by 2013	
Maine BioProducts	levulinic acid	pilot scale	no commercialization timeline announced	
Itaconix	polyitaconic acid	launched commercial product, scale unclear		
Coskata/Total	propanol, propylene	lab scale in 2011	no commercialization timeline announced	
Allylix	terpenes (nootkatone, valencene)	commercial at small scale	achieved commercial production, 20,000 liter	
Isobionics	terpenes (nootkatone, valencene)		achieved commercial production	
Dow/Mitsui JV	PE	Commercial	350 ktons by 2015 in Brazil	

Notes:
tons is metric tons
* Nexant speculation