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Chemical Manufacturers Face Challenges and Opportunities in Switch to Bio-based Materials

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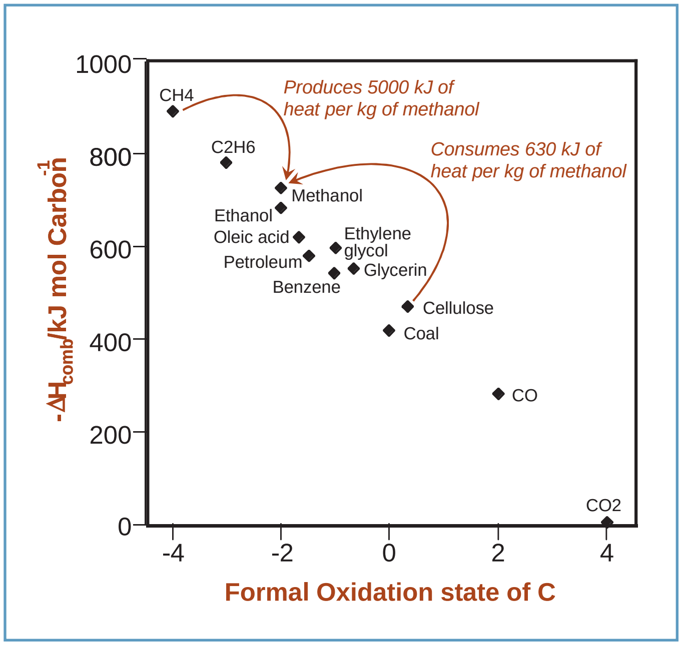
The chemical industry has a long history of using natural materials in its products—charcoal and turpentine have been derived from wood, ethanol from grain, caffeine from tea leaves, and many natural medicines, nutrients and sweeteners from a variety of plants. But producing some of these products from natural materials has often been more expensive than using feedstocks based on coal, petroleum or natural gas. Clearly, today's spike in the cost of both oil and natural gas has changed all that, and every major chemical manufacturer is rushing to develop its portfolio of products derived from natural materials. That's because the chemical industry is one of the world's largest energy consumers—in the United States alone, chemical companies use more natural gas than California and more electricity than the entire state of New York, according to the American Chemistry Council. Those energy costs now top $50 billion a year, with no sign of slowing down. But it isn't economics alone that are creating this push for bio-based alternatives—concerns for the environment, energy security, and rural economic development are also important drivers. Taken together, they suggest that today's popularity of using natural materials as a starting point for chemical processes may be more of a fixture than a fad. That being said, the chemical industry must now address the technical challenges, economic tradeoffs, and operating inefficiencies that accompany this approach.

The Biomass Research and Development Technical Advisory Committee estimates that the production of chemicals and materials from bio-based products will increase to 12 percent of current production of target U.S. chemical commodities by 2010—up from five percent in 2001—and then rise to 25 percent by 2030. European manufacturers are also now sharply focused on the conversion from fossil fuels to renewable sources. Most recently, in the recent 2006 State of the Union Address by President Bush to Congress, even U.S. energy policy appears to be changing to include an increased emphasis on biomass substitutes for petroleum-derived fuels, which would also affect the petrochemical industry.

These trends herald a radical shift in the way that chemicals are manufactured. The processes for making chemicals from natural products rather than from petroleum-derived sources—the only other option—couldn't be more different (Figure 1): the former are either endothermic (require the addition of heat) or thermoneutral, while the latter are typically exothermic (release heat). For example, consider the manufacture of methanol from methane and from cellulose. In principle, methanol can be made by partial oxidation of methane, a process that *releases* 5000 kJ/kg of product. On the contrary, converting cellulose into methanol requires the addition of hydrogen, which, if it is manufactured by steam reforming of the cellulose, requires the *addition* of 628 kJ for each kg of product. Evidently, different sorts of catalysts and

Figure 1. ***Transforming biomass-derived feedstocks to chemicals will require new chemistries and major changes in heat flows.***



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reactors will be needed for these two processes. Processes that use petroleum feedstocks are usually extremely energy intensive, operating at high temperature and high pressures. Natural materials, such as corn and soybeans, are processed at much lower temperatures, typically in a water solution where microorganisms do the chemical conversion in much the same manner that a sewage treatment plant decomposes its waste. Rather than solely employing chemical processes, this treatment requires the use of biological and/or biochemical processes to break down materials that can later be reconfigured into useful chemical intermediates or functional products.

The strategic implications of this change are increasingly being recognized. DuPont, for example, has put together an increasingly valuable biomass-based portfolio, particularly in the area of corn-based polymers as a platform for use in clothing, carpets, and automobile interiors. The company announced last October that bio-based materials would be elevated to a corporate technology platform, where it would be appropriately resourced and aggressively leveraged across the company's growth platforms. Dow is focusing its efforts on corn and soybean-based materials, and Cargill is exploring a host of biotech applications for carbohydrates, fats, and proteins found in common crops. For instance, the company is attempting to convert a plastic derivative of lactic acid (derived from fermented starch) into inexpensive polymers for medical implants.

New Initiatives are Challenging the Chemical Industry...

These new initiatives are challenging the chemical industry to come out of its comfort zone and embrace whole new classes of technology as the new basis of competitive advantage. Clearly, the industry is very efficient at designing processes for converting petroleum-based materials into chemicals. After all they've been doing it for years. They know the intricacies of scaling up and are adept at developing catalysts for these processes. But they often don't have the in-house expertise in biological pathways to develop the bacteria needed to ferment and work with a natural materials base. Nor do they necessarily have the skills to address the unique issues of scaling-up the reaction engineering and separations of bio-mass fed processes. By contrast, many leading universities are hotbeds of biological talent, with exceptional abilities for developing the micro-organisms needed in fermentation, but they typically don't have the ability to scale-up these processes and almost certainly lack any understanding of the potential commercial viability. Bringing the expertise of these two entities together will be critical to establishing an organization's success in a future dependent on bio-based materials development. This is no small challenge for many organizations that have cut much of their ability to interface with leading researchers to focus on optimizing well established petrochemical processes.

In addition to fermentation, biomass can be converted to energy or chemicals through the use of a gasifier in which biomass is dehydrated and converted to a gas that can be subsequently converted to liquid fuels or chemicals. But with this method of gas generation comes significant questions concerning economic tradeoffs. Does it make more economic sense to use that gas to generate electricity or to produce chemicals? Or should one just completely burn the biomass and use the heat for energy generation? The answer will depend on the relative costs of the feedstocks and the value of the products, including credits for reducing carbon dioxide emissions. In addition, because biomass is cumbersome to transport and typically becomes available locally only in comparatively small quantities (1–1,000 tonnes/day), the economics of constructing and operating a small plant must be considered.

Recognizing the practical realities and business opportunities, TIAX is working on a way to convert small quantities of biomass to fuel through an integrated gas-to-liquids (GTL) process. GTL uses the Fischer-Tropsch catalysis (the reaction of hydrogen plus carbon monoxide to make long chain hydrocarbons) to produce valuable clean liquid fuels from natural gas and biomass-derived gas. The integrated TIAX process, called GTL-in-a-Can™, can be used to access part of the world's natural gas reserves that are not economically suited for larger plants. Such plants are mobile and could be sited at sources of biomass, small stranded natural gas fields at drilling platforms, or at existing industrial sites with producer gas available. GTL-in-a-Can™ is compact enough to be collocated with a paper mill or food processing plant or to fit directly onto a platform or barge. Elsewhere, TIAX also recently began work to convert a variable composition food waste stream into energy. To exemplify the potential, a typical Army base camp generates large amount of trash—about three to four pounds per soldier per day—mostly related to food waste from mess hall operations. On a daily basis, a typical maneuver battalion of approximately 550 soldiers has to dispose of about 1,000 kg of trash. As part of this work, our team of engineers and scientists are developing a solid waste preprocessor system to reduce the burden of trash waste at Army base camps. This solid waste preprocessor will also supply the dried, mixed, and compacted trash to a waste-to-energy conversion system that generates electricity.

Use of natural materials for producing gaseous and liquid fuels, heat, electricity, and valuable chemicals and materials will significantly increase over the next decade. Continued research, technology development, and innovation will be required to assure that processes are safe, effective, economically and environmentally sound. Collaboration among chemical, agricultural and forest product industries with universities and technology development partners will all be critical to the successful introduction of novel technologies such as those described above. The nature of R&D will change and the level of collaboration will require a significant reversal in the trends away from "R" in R&D, while maintaining the "D" capabilities to produce products at the required quality and cost.

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