C2B2
Colorado Center for Biorefining and Biofuels
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Survey Sheds Light on Biofuels Future

Results of a recent C2B2-coordinated survey of industry participants show that significant issues remain on the road to commercialization and widespread public acceptance. Of what are the most pressing issues impacting commercialization? Which biofuels might be on the brink of a market breakthrough? Where will biofuels stand in the transportation fuel mix later this century? And how will oil prices figure into the equation? We asked the experts to provide their views during a panel discussion at the C2B2 Semi-Annual Meeting in February in Fort Collins, Colo. Here's a look at how 20 respondents from sponsoring membership companies at the event (nine representing large companies of 500 employees or more and 11 from smaller companies) see the future unfolding. C2B2 Executive Director Dr. Alan Weimer and C2B2 Managing Director Dr. Ryan T. Gill from the C2B2 headquarters at the University of Colorado at Boulder provide insightful commentary on the anonymous survey results.

Short-Term Priorities for Biofuels Companies and Biorefiners

Biofuels and biorefining companies appear to share the view that intellectual property around superior process — innovation — is most vital to accomplishing near-term goals. Respondents rated innovation as more important to them today than access (to commercialization pathways, biomass sources and markets). "During the meeting discussion," explains Gill, "audience members and panelists alike, agreed that superior technology and processes are a priority throughout the biofuels and biorefining industries."

Future Commercialization of Biofuels

What's the single biggest commercialization issue when working with biofuels? According to respondents, it's either the ability of biofuels to fit into existing fuel delivery infrastructure, or their ability to satisfy mandates that next-generation biofuels be greenhouse-gas-negative.

What type of technology breakthrough can push biofuels over the commercial hump? Respondents most often named a new feedstock source and a new method for integrating multiple processes/logistics as the breakthroughs most capable of advancing biofuels commercialization. While moderating the panelists, Gill observed that member responses underscore the importance of "having really good feedstock sources," and of developing the most efficient means of leveraging sunken capital to bring biofuels to market.

Future Commercialization of Commodity Chemical Biorefining

The survey posed similar questions about commercialization at the commodity chemical biorefinery level. More respondents identified production cost as

the most important commercialization trait for a future biorefining commodity chemical. In such a competitive market, Weimer summarizes "it's about who can make it the cheapest."

Respondents identified new catalytic processes and new scalable integrated processes as the technology breakthroughs most capable of advancing commercialization in commodity chemical biorefining. "To have favorable economics, these companies realize the processes must be easily capable of being scaled up to commercial volumes," Weimer notes.

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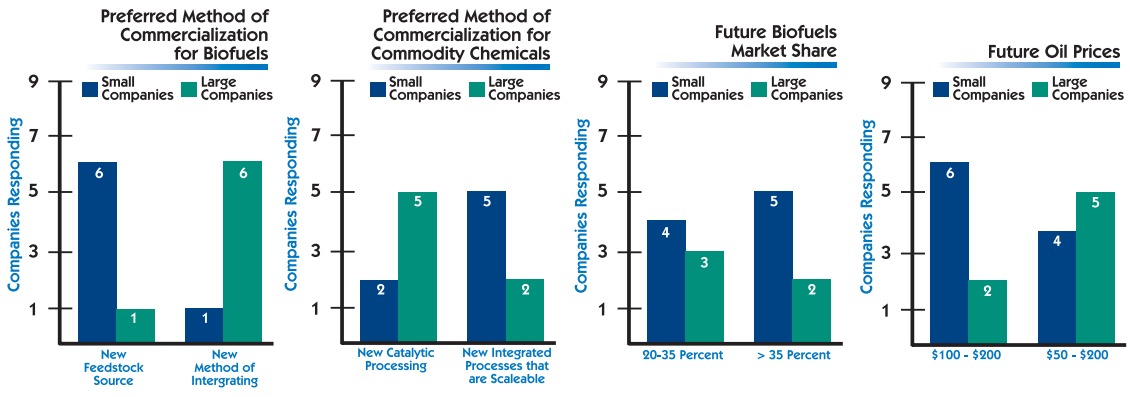
Survey Says...



Responses were compared from large and small companies to identify differences and similarities in thinking, strategies, and knowledge bases among Center membership.

In terms of value generation, small companies tended to emphasize IP providing a path to commercialization as well as developing the right network more so than large companies. As most large companies already

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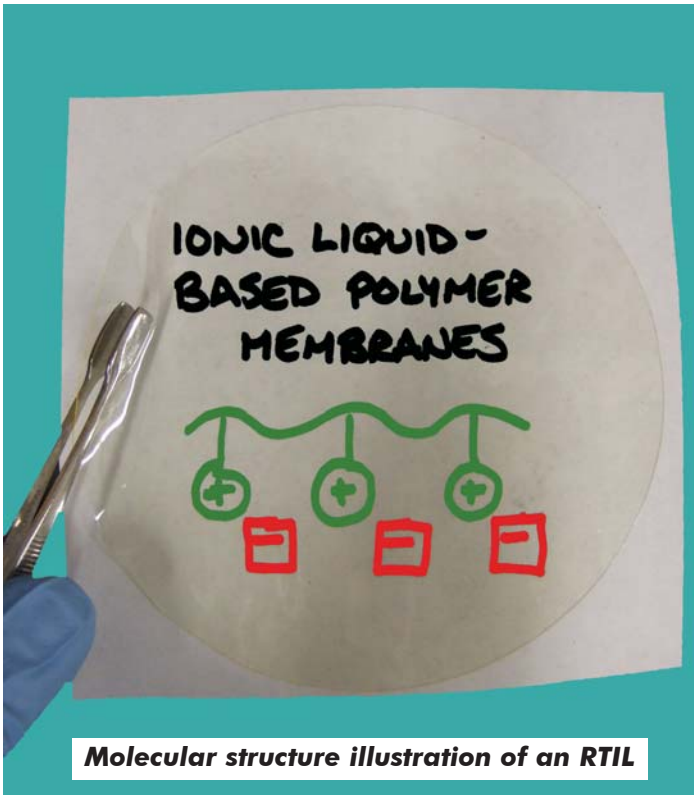
C2B2 Chemical Separation Key to Making Biomass-to-Biofuels a Reality

Professor Richard Noble hasn't lost sight of the big picture, despite being focused on the minute details of chemical separation and nanotechnology. He acknowledges that the work he and his chemical engineering team at the University of Colorado are conducting could have important implications in the effort to commercialize advanced biofuels in the U.S.

Professor Noble's résumé includes some 15 patents, 200 research publications and 10 textbooks and monographs. He notes that "at the end of the day, chemical separation steps are one of the key issues in making biomass-to-biofuels a reality."

These days, Noble, the Alfred T. and Betty E. Look Professor of Chemical Engineering and Co-Director of the National Science Foundation Center for Membrane Applied Science and Technology (MAST) at the University of Colorado, is focused on developing energy-efficient, cost-effective processes for highly selective chemical separations, with an eye toward adapting those processes to commercial applications such as the conversion of biomass to chemicals for refining into transportation fuels. For one project, (supported in part by seed grant funds from C2B2) he's testing ionic liquid polymer as a separation material. Meanwhile, ongoing work by Noble and his MAST team could have an impact in such vital areas as water supply and greenhouse gas mitigation. Researchers at MAST are also collaborating with Shell Global Solutions to develop new processes for removing carbon dioxide from natural gas supplies.



Molecular structure illustration of an RTIL

Zeolite membranes, room-temperature ionic liquids, pervaporation and carbon nanotubes are not yet household terms in the biomass and biofuels world, but Noble says those are among the promising processes and technologies his team is exploring to make the biomass-to-biofuels conversion process more efficient.

Noble's team of researchers is testing nanoporous structures known as zeolite membranes as a means to separate organics (alcohol) from water to produce a feedstock for making biofuels via fermentation. Zeolites achieve separation through pervaporation, a separation process that is especially effective with mixtures that are difficult to separate by distillation, extraction and sorption. It is also effective in separating azeotropes, close-boiling mixtures and thermally sensitive compounds, as well as in removing species present in low concentrations.

Additionally Noble's team is working to incorporate room-temperature ionic liquids (RTILs) to accomplish separation through absorption. One advantage of RTILs is they can perform their separation work solely through adjustments in pressure, without the introduction of heat, making the process "much less energy-expensive" according to Noble. Using RTILs such as organic salts in the separation process also curbs emissions of carbon dioxide, a greenhouse gas, during the process. Further, the structure of separation materials can be adjusted in the laboratory to conform to the specific requirements of a given application. "You can tune them to take more water or more organic material out."

For these and other reasons, he suggests, separation processes that incorporate zeolite membranes or RTILS may prove preferable to the "very thermally expensive" process of water distillation. "These polymers provide better selectivity with equivalent productivity" to today's widely used biofuel separation processes and materials.

Researchers at the MAST Center are also incorporating carbon nanotube technology into the process of separating alcohol from water in biomass; the current emphasis is on increasing the selectivity of the technology. One reason carbon nanotubes are promising as a setting for the separation process is their more efficient use of space. Noble explains that separation units that incorporate carbon nanotubes have a much smaller footprint than comparable units used today.

Ultimately a process that incorporates both ionic liquid polymers and carbon nanotubes could prove to be the most commercially viable route for separating chemicals prior to refining them into biofuels, Noble points out. However, it may take a couple years to develop effective screening approaches using ionic liquid polymers in that context. "No one has really looked at these applications before. There's no background knowledge with liquid polymers. It's a challenge, but it's also an opportunity—we think a pretty exciting one."

Also exciting is the possibility that some of the separation techniques and materials the MAST team is testing will prove equally valuable in other critical applications such as hydrogen separation and water desalinization.

"The technology to do these things in an energy-efficient way is not available on the shelf today," Noble says.

At the end of the day, cost and scalability are the two main factors that will determine whether zeolite membranes, carbon nanotubes and room temperature ionic liquids ever find their way onto the commercial shelf and into the mainstream of biofuels production. The collaborative projects undertaken through C2B2 will likely encourage various segments of the biofuels business to lend their support and expertise to the effort, he says, thus helping push advanced separation processes closer to commercialization. "One of the things I like about C2B2 is that the Center really covers the whole gamut of the biofuels and biomass market."

POST-DOCTORAL FELLOWSHIP PROGRAM

The Colorado Center for Biorefining and Biofuels (C2B2) is currently reviewing applications for the inaugural C2B2 Post-Doctoral Fellows Program. This program aims to attract the best early-career researchers from around the world to focus on fundamental scientific challenges across the broad range of disciplines relevant to the renewable energy industry. Research disciplines include plant biotechnology, biochemical and thermochemical conversion technologies, as well as process, product, and systems engineering.

Fellows will be funded at $65,000/year in direct costs, which includes stipend, supplies, and travel costs. Application review will began on April 15, 2008 and will continue until all positions are filled. Look for awardee announcements and research project information in upcoming newsletters.

C2B2 STUDENT SPOTLIGHT

Lee Elliott is a first-year M.S. student in the Environmental Science and Engineering Division at the Colorado School of Mines and an intern at the National Renewable Energy Laboratory. He graduated from the University of Colorado at Colorado Springs with a B.A. in Biology and Chemistry with Honors in Biology. Lee's current research project is funded from a C2B2 seed grant and focuses on the establishment of a bioenergy-focused microalgal strain collection using rapid, high-throughput methods.

Amy Swan is pursuing a Master's Degree in Ecology at Colorado State University and works at the Natural Resource Ecology Laboratory. She is a 2002 graduate of South Dakota State University with a Bachelor's in Environmental Management. Amy is currently working on a project in western Nebraska examining the impacts of corn stover utilization for cellulosic ethanol, on soils and greenhouse gas offsets. She is investigating how farmers may adopt alternative management practices to mitigate negative impacts.

Brittany Lancaster is in her fourth year as an undergraduate in the Chemical and Biological Engineering department at the University of Colorado at Boulder. Brittany's research focuses on thermal conversion of cellulosic biomass to synthesis gas and this semester she will complete her senior thesis project on kinetic models of a high temperature reaction of corn stover and water. After graduation in May, she plans to continue her research at CU and attend graduate school in chemical engineering in the fall of 2009.

Jonathan Meuser is a fourth-year doctoral candidate in the Environmental Science and Engineering Division at the Colorado School of Mines and works in collaboration with the National Renewable Energy Laboratory. His research focuses on the diversity and molecular biology of biological hydrogen production in the green algae and is partially funded by a NASA Graduate Student Research Program fellowship.

SURVEY (CONTINUED FROM PAGE 1)

have commercialized relevant processes, and thus may already have relevant IP and the appropriate network. It follows that such larger companies have different priorities: accordingly, companies with 500 or more employees tended to more greatly value the generation of IP around a highly innovative process.

In terms of biofuels technology breakthroughs there appears to be a considerable disconnect between small and large companies. Small companies accounted for 6 of the 7 votes for "new feedstock source" while large companies accounted for 6 of the 7 votes for "new method for integrating multiple processes/logistics." Interestingly, the opposite trend was noted for biorefining chemicals technology: large companies strongly favored the development of "new catalytic processes" while small companies emphasized the need for "new integrated processes that are scalable."

One interpretation of these results is that most sponsors agree on the importance of developing new integrated biorefining processes, yet small and large companies appear to have conflicting views on the importance of new feedstock sources. This is particularly interesting in light of the recent announcements or major investments by several large companies in research programs directed at the development of new feedstock sources.

Several posed to the panel and member audience dealt primarily with cost modeling and future projections regarding biofuels markets. Here again small and large companies had varying responses. In general, large companies were less optimistic about future biofuels market share (5 companies choosing >35% equally weighted versus >20% was chosen by 80% of small companies) and favored a larger range of future oil prices ($50-200 versus $100-200 as more readily selected by small companies). In line with this observation, large companies and small companies appear to have differences their internal cost modeling. Large companies indicated that biofuels become cost competitive at oil prices generally lower than what small companies selected. Moreover, large companies exhibited much more certainty about their responses regarding biorefining chemicals (picking >$70/barrel 80% of the time) than small companies, which selected "depends too much on the chemical" in 5 of 9 recorded responses.

In an industry with a future that has been characterized as "bright, but uncertain," this survey provides an important glimpse into the thinking of its key players The observations and interpretations collected suggest that internal information, know-how, and, thus, strategy differ between small and large company sponsors.

Colorado Renewable Energy Collaboratory

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C2B2 is a cooperative research and educational center devoted to the conversion of biomass to fuels and other products, supported by state, institutional, and industry funds. The mission of C2B2 is to become the world's leading center in biorefining and biofuels research and education.

We provide private industry with one-stop access to researchers, laboratories, students, and educators from four innovative institutions, each having unique strengths in biofuel and biorefining application areas.

Colorado Renewable Energy Collaboratory
Created to develop energy technologies for rapid commercialization, the Collaboratory consists of the following institutions:

University of Colorado at Boulder
Ranked in the top 25 nationally in Chemical and Biological Engineering, Molecular and Cellular Biology, and Biochemistry.

Colorado State University
Ranked in the top 10 nationally in Agricultural Sciences with an internationally renowned Engines and Energy Conversion Laboratory.

Colorado School of Mines
One of the few universities uniquely focused on energy research.

National Renewable Energy Laboratory
The only national laboratory dedicated to renewable energy and energy efficiency research and development (R&D).

Biofuels of the Future (continued from page 1)

Fuel Price Dynamics

Among the many macro factors affecting the present and future of biofuels (and of the global economy, for that matter), oil prices loom especially large. Forecasting future prices for a barrel of petroleum is a perilous proposition, but that didn't keep respondents from registering their opinions. Asked to provide their "best estimate" of an oil price range for the next 25 years, a vast majority of respondents leaned toward higher, more volatile prices. Ranges of $50-$200/barrel and $100-$200/barrel were named most often.

Asked to name the oil price range at which biofuels become commercially attractive, many respondents identified $70-$90/barrel as the sweet spot; however, nearly as many named $50-$70/barrel or $90+/per barrel. As for the oil price range at which biorefining commodity chemicals become commercially attractive, the majority of respondents said the answer to that question would depend largely on the individual chemical, though a significant segment also identified the $70-$90/barrel and $90+/barrel options.

As witness to the discussion, Weimer noted that commodity chemical refining operations are understood by the membership to be "less tied to feedstock prices than are biofuels."

What's Next for Biofuels?

The future for biofuels is bright, but uncertain. Asked to choose "the next big biofuel in the commercialization pipeline after lignocellulosic ethanol and conventional biodiesel," more respondents named a Fischer-Tropsch or other thermochemically derived liquid fuel as most likely to succeed. This response was more readily selected than alternatives such as biobutanol, pyrolysis oil, hydrogen, or biosynthesized diesel and gasoline (which came in a close second).

Weimer admits he was surprised by the respondents' top choice, "mainly because producing fuels via a thermochemical process is typically costlier than other methods." However the C2B2 Executive Director says he sees the appeal of having a familiar and accepted fuel such as gasoline (in this case, a synthetic variety) as the end product. On the other end of the spectrum, not a single respondent identified hydrogen as next in the commercialization line.

When asked to peer further into the future to predict a market share for biofuels in the next 30-40 years, respondents were decidedly optimistic. Most said they expect a share of 20-35% or a share of greater than 35%. Not a single respondent indicated they expect a share of less than 5%.

Although the C2B2 memberships' missions and products vary, each envisions a future that aligns with the technology produced from the biofuels and biorefining industries. After observing the dynamic interface of expertise at this panel discussion on February 12th, Gill believes members left with a single lingering impression, "We work in a field with so many disparate technologies and processes that need integrating. To do that, we need everyone talking to each other. That's why we need a broad-based center like C2B2."