

CSM TURNS UP THE HEAT TO MAKE FUEL CELL-READY BIOFUELS

There is the popular route for converting biomass into usable fuel, and then there is the road less traveled. At the Colorado School of Mines (CSM), Anthony M. Dean and his team of researchers are focused on the latter. While biochemical conversion (the process by which alcohol is created from biomass) gets much of the attention from researchers and the general public, Dean and a team of scientists are investigating various aspects of a process known as thermochemical biomass conversion, with an eye toward optimizing it for mobile- and stationary-source applications involving fuel cells and other power sources.

“Our group is essentially most interested in trying to understand what is happening at the molecular level and developing a better understanding of what is going on in individual chemical reactions,” explains Dean, W. K. Coors Distinguished Professor in CSM’s chemical engineering department. “The Holy Grail, for us, is integrating fuel cell technology with biomass conversion technology. That’s really where our work fits within the C2B2 rubric.”

“It’s more of a brute-force method than the biochemical conversion route, but it’s applicable to a broader range of feedstocks.”

Dean’s group includes C2B2 Chevron Postdoctoral Fellow Stephanie Villano. These days their work, funded in part by the National Renewable Energy Lab, is focused on investigating pathways for creating fuels, chemicals and power via the high-temperature thermochemical conversion of biomass — what Dean describes as a “heat and beat” process similar to crude oil refining. “It’s more of a brute-force method than the biochemical conversion route, but it’s applicable to a



Stephanie Villano working in the thermochemical conversion lab at CSM.

broader range of feedstocks,” he says. “It’s also really interesting because a variety of different products could come from it,” including fuels for fuel cells, alternative transportation fuels, and chemicals now produced from petroleum.

One current area of emphasis for Dean’s team is using biomass gasification to create a synthesis gas comprised of carbon monoxide and hydrogen for use as the fuel in solid oxide fuel cells. “It’s a winner on both ends of the system,” he explains. “You have a carbon-neutral fuel on the front and a system that generates electricity twice as efficiently as typical generation sources on the back.”

Developing such a process is not without formidable challenges, however. Dean notes that one of the most daunting is how to optimize the synthesis gas production and the fuel cell architecture so they work efficiently with one another. “We’re working both sides of the street on this,” he says. “We’re working on gas-phase chemistry to clean up the syngas, and we’re working on the design of the fuel cell itself, to make it more robust so it can run on a less clean syngas.”

Dean says he is monitoring advances in diesel fuel steam-reformation technology that his team might be able to incorporate into its work with biomass conversion. The issues regarding cleanup of the diesel

The organizations that sponsor C2B2 are as diverse as the biofuels and biorefining business itself. Here's an up-close look at four sponsors and what they bring to the vibrant C2B2 mix.

Flad Architects

With a mission "to create environments that enhance human potential," it's no surprise that Flad Architects and C2B2 have crossed paths. A charter member of the Green Building Council, the Madison, Wisc.-based firm lately has been busy designing research space for emerging technologies. "It's a natural progression for us to reach out to potential clients involved in protecting the earth through alternative energy research," explains Bob Hodgson, senior associate at the 40-year-old firm.

The firm's expertise lies in designing laboratory and technical spaces that accommodate highly specialized research. Many Flad clients are active in alternative and renewable energy research and applications in such key areas as hydrogen fuel cells, nanomaterials and efficient manufacturing methods. "We feel a great responsibility," says Hodgson, "to be even a small part of the solution to what is clearly one of the most significant challenges of our time and our future — global climate change."

Flad Architects

Several projects in which Flad is involved include:

- Confidential Energy Research Laboratory International — Research work at this 300,000+ square-foot renewable energy lab will focus on biomass conversion as well as development of renewable energy available near the equator.
- Stony Brook University, New York — This research facility will house the Advanced Energy Research and Technology Center, which will pursue new methods for generating power and replacing fossil fuels.
- National Renewable Energy Laboratory (NREL), Colorado —

NREL's new Integrated Biorefinery Research Facility will support national transportation fuel diversification objectives, with an initial emphasis on perfecting technologies for making fuel ethanol from cellulosic biomass. Project components include pilot-scale fermentation, high-bay space, process equipment and laboratories.

Gevo

Formed three years ago in Southern California as a CalTech spin-off, Gevo moved to Colorado in 2008 to use the state's bustling biofuels community as the launch point for its proprietary biofuels processes and products. Now, thanks to



a recent funding infusion and continued progress in development of its bread-and-butter product, isobutanol made from biomass, one of C2B2's newest members is on track to open its first demonstration plant this year and its first commercial plant in 2010.

Gevo's strength, explains co-founder and chief scientific officer Matthew Peters, lies in its metabolic engineering capabilities, which have yielded host microorganisms that utilize carbon and energy efficiently for fuel production. The company has developed a proprietary process for producing isobutanol via fermentation using a biocatalyst. This process technology enhances productivity and reduces product separation costs.

According to the company, isobutanol offers several benefits as a fuel:

- a higher energy content per gallon than many first-generation biofuels and an energy content similar to gasoline.
- transportability through the existing oil and gas distribution infrastructure because it does not absorb water.
- the ability to function in gasoline-powered vehicles without modification or blending.
- a relatively high octane content to improve performance.

- a relatively low Reid vapor pressure that minimizes evaporative emissions.

Peters and Tom Dries, Gevo's vice president of business development, envision isobutanol — and its derivatives — being commercially viable in the transportation fuels market, where it can be converted to hydrocarbons for use as a replacement for petroleum-based diesel fuel, jet fuel, aviation gas, ethanol, etc., and in the chemicals market, where it shows promise as a "green" material used in the production of plastics and fibers.

Much of the strategic maneuvering at Gevo of late is designed to position the company for commercialization. Fueled in 2007 by a capital infusion from Richard Branson's Virgin Green Fund and in early 2008 from Burrill & Company and the Malaysian Life Sciences Capital Fund, the company is rapidly shifting from research mode to business mode under CEO Dr. Pat Gruber, who joined Gevo in 2007. On the production side, the company is seeking partners interested in retrofitting existing ethanol plants to make isobutanol. Meanwhile, a pilot plant was successfully tested, and the performance of the biocatalyst validated, says Dries. Plans call for a one-million-gallon-per-day demonstration plant to be operational by this summer and for Gevo's first commercial plant to launch in the fourth quarter of 2010.

From a strategic standpoint, the timing for coming to Colorado and joining C2B2 appears ideal. "The networking [within C2B2] has been great," says Peters. "Several potential customers and partners are also members."

Ecopetrol S.A.

What is Ecopetrol S.A., a Colombian company whose main business is petroleum, doing sponsoring C2B2?



Simple: the company is seeking a competitive edge by diversifying into biofuels.

FUEL CELL-READY BIOFUELS

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Involvement in C2B2 hopefully will help Ecopetrol toward its goal of becoming a prominent player in the biofuels market in Colombia and elsewhere, explains company executive Luis Javier Hoyos Marin. "C2B2 [sponsorship] is an opportunity for us to get information about the latest scientific and technological advances in biofuels."

Ecopetrol is focused on oil exploration and production opportunities in its home country as well as in Brazil, the Gulf of Mexico and Peru. Also, it has initiated research efforts in the biofuels arena with the goal of producing 450,000 tons per year by the end of 2015. Being based in a country that is considered to be one of the most biodiverse in the world gives it an inherent advantage when it comes to accessing various biomass feedstock options.

Work is already underway to achieve the 2015 production goal. On the R&D side, Ecopetrol is active on several fronts, including fat oils and biomass co-processing in refineries, development of biomass resources for biofuels production and development of glycerin transformation technologies. Thus far in its Barrancabermeja refinery, the company has performed several co-processing trial tests during which crude palm oil was charged to hydrotreatment units diluted with diesel. The last of these tests took place in July and was deemed a success. Tests at the pilot plant confirmed that hydrotreated palm oil is an excellent cetane and sulfur corrector. Now the company is investigating ways to continuously hydrotreat crude palm oil in its refineries. It also is eyeing the possibility of financing specific C2B2 projects.

Blue Sun Biodiesel

A company that grows 1078% in just three years is bound to get noticed. And that is exactly what has happened with Golden-based Blue Sun Biodiesel, which was ranked #242 on Inc. Magazine's "Inc. 500" list of the fastest growing, privately held companies last August.

Blue Sun, which markets a brand of B20 biodiesel fuel called Fusion, was rated

among the 10 fastest-growing energy companies in the country.

Mike Miller, Blue Sun President and COO, says the company emphasizes an integrated approach. "As the industry evolves, we are positioned to respond. Our involvement with developing new feedstock crops for biodiesel, our distributor support programs and our fuel, which we think is superior not only to other biodiesel on the market but also to conventional diesel, have each contributed to our success."

Besides producing, distributing and selling its own biodiesel formulations, Blue Sun also conducts advanced biodiesel feedstock research. In the summer of 2008, the company landed an ACRE (Advancing Colorado's Renewable Energy) grant from the State of Colorado to commercialize a non-food energy crop, camelina, for use in biodiesel. Blue Sun plans to use the \$41,000 grant to advance camelina production practices by conducting water-use efficiency trials, fertility experiments, date-of-planting studies and also observing on-farm production. The project will culminate with production of a spring camelina production guide.

Blue Sun is actively breeding spring and winter camelina, through traditional breeding practices, to develop superior, regionally adapted camelina cultivars. It estimates that the crop, if developed as a biofuel feedstock, could add nearly 30 million gallons of capacity — or about \$80 million in rural economic activity — to Colorado's dryland farming regions (in rotation with winter wheat). In addition to its low cultivation costs, the camelina plant can withstand cold temperatures and produce good yields when planted early (February 1 to March 30).

True to its Colorado roots, seven-year-old Blue Sun is also a C2B2 sponsor, a role that positions the company as a catalyst to biofuel research and commercial development. Sponsoring C2B2 "puts us in position to help focus where research is directed, and to bring the ideas that come out of that research into the commercial market," explains Steve Bond, the company's marketing manager.

reformate and the biomass gasification process are very similar. One especially promising application for a fuel cell that generates power via diesel reforming is in auxiliary power units used in over-the-road trucks and high-end recreational vehicles. "I think there is an abundance of opportunity with this technology. It's much more efficient, completely quiet, and pollution-free to operate."

On the fuel cell side of the equation, Dean envisions potentially broad ramifications for his group's work. "We hope that the computational techniques we are using to characterize gas-phase chemistry can spill over into fuel cell and reforming catalyst research."

Beyond fuel cells, ongoing work by the CSM team in other areas of thermochemical conversion also shows promise, says Dean. One current area of focus for the group is the production of bio-oil from biomass via pyrolysis. The oil created through the process is energy-dense enough to transport by pipeline; the challenge is figuring out how to reduce its viscosity and acidity such that it is pipeline-ready. Another area is the production of hydrogen from the partial oxidation of bio-oil.

Obstacles aside, thermochemical biomass conversion in general "can have an enormous potential impact on energy security," says Dean, whether it is incorporated into fuel cells for power generation or used to produce transportation fuels and chemicals.



blue sun
BIODIESEL

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).

SPONSORS

C2B2 welcomes NEW Sponsoring Member: ZeaChem

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General Motors
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Kimberly-Clark
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Mascoma**

**OPX Bioproducts
San Juan Bioenergy
Shell Global Solutions
Solix Biofuels
Sundrop Fuels
Symbios Technologies
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ZeaChem**

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C2B2 SEMI-ANNUAL MEETING AGENDA FEBRUARY 5-6, 2009 • BOULDER, CO

Thursday, February 5, 2009

1:30-3:30 pm..... Tours of University of Colorado
at Boulder Facilities

Rembrandt Yard — 1301 Spruce Street, Boulder, CO

4:30 pmWelcome – Al Weimer,
C2B2 Executive Director

4:45 pmC2B2 Postdoctoral Fellow
Oral Presentations

6:00 pmPoster Session &
Networking Event

7:30 pmDinner

Friday, February 6, 2009

St. Julien Hotel — 900 Walnut Street, Boulder, CO

8:00 am.....Breakfast

9:00 am2007 Seed Grant Oral Presentations

10:45 amBreak

11:00 am2007 Seed Grant Oral Presentations

12:00 pmLunch

12:15 pmGuest Speaker

1:00 pmC2B2 Planning/
Strategy Session & Business Meeting

1:45 pmSteering Committee

2:30 pmSponsored Research Agreement
Meetings, RSVP Only