A CHEMIST'S QUEST FOR CATALYSTS

Visit a chemistry laboratory at the Colorado School of Mines (CSM) on any given day and you might come across Ryan Richards, exploring ways to adapt tactics that are normally used to destroy chemical weapons to the production of biofuels from algae. Or you might find the CSM Associate Professor of Chemistry delving into high-temperature processes for converting biomass into syngas that can be used to make renewable fuels and chemicals.

These are the types of challenges that scientists such as Richards, a synthetic inorganic chemist and an expert in catalyst preparation, confront in an effort to push new biofuel production processes and technologies toward commercialization. Richards says his work in the field of biomass conversion catalysts basically boils down to finding ways to optimize the conversion process by utilizing nanostructured catalysts that have been designed to possess 'robustness' under demanding reaction conditions. The approach of the Richards group is to prepare new nanostructured materials and study their fundamental properties. The knowledge developed allows the group to "tune the catalytic properties" of nanostructures in the laboratory to identify and further study those that show the most potential for eventually playing a role in the large-scale, cost-effective commercial production of biofuels. While most nanostructured catalysts have difficulty maintaining their properties at high temperatures or other demanding conditions, a key aspect to this research is that they are able to maintain these 'tuned properties' under the requisite reaction conditions.

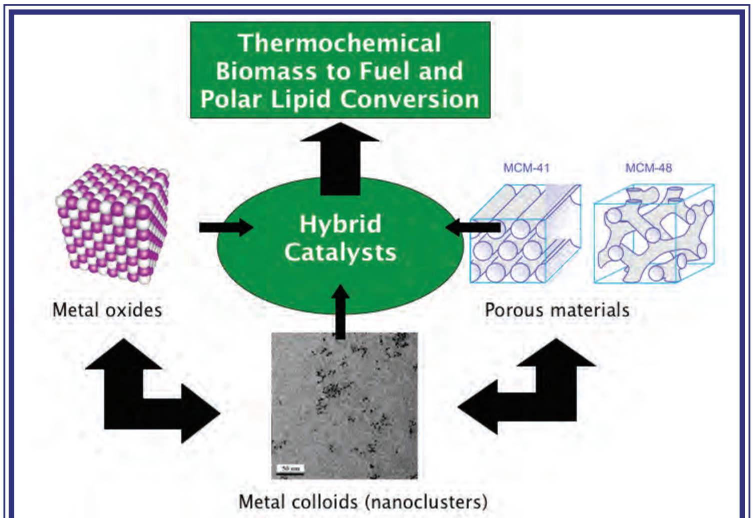

FIG. 1: Schematic overview of the Richards group approach to new catalytic materials.

That work has Richards involved in several projects that fall within C2B2's purview, including one undertaken with CSM colleague Matthew Posewitz. Their research focuses on developing a nanostructured metal oxide catalyst capable of efficiently processing algal biomass into a refinery-friendly hydrocarbon stream. The chief obstacle they are trying to overcome, he explains, is how to separate out and process polar lipids from the algae. Left unprocessed, certain elements of those polar lipids — mainly phosphates and sulfates — may interfere with the downstream hydrocarbon refining process or the polar component of the biomass may be discarded without utilizing its full energy potential. To address the problem, Richards and Posewitz are eyeing techniques proven to work in the decomposition of chemical weapons, whereby the surface chemistry of the metal oxide nanostructures is adjusted to process the potentially problematic polar lipids — phospholipids in particular. Ultimately, he says, "we want to be able to get all the hydrocarbon energy out of these algae."

Though their work toward that goal has been slowed lately by a lack of funding, Richards says a group of C2B2-funded research undergraduate students (REU) put time in on the project this past summer. Resource limitations mean the CSM team is taking a "shotgun approach," he explains, where "if we see something working [during laboratory testing], we can then design a second-generation [catalyst] system." There's no shortage of catalysts for the Richards-Posewitz team to test. "We have a whole portfolio of them sitting on a shelf, ready to go," Richards says, but if work continues at its current pace, testing and developing preliminary data on the performance of those catalysts "will be a long, complicated process."

Finding the right catalyst is the crux of a separate research project that has Richards working with a team led by Kimberly Magrini-Bair and Matt Yung at the National Renewable Energy Laboratory. Funded in part with a seed grant from C2B2, the project seeks to identify and engineer a catalyst that can perform well under the "pretty nasty conditions" involved in the creation of syngas (carbon monoxide and hydrogen) from biomass via thermochemical decomposition. Once again, Richards' chief role involves testing and "tuning" nanostructured catalyst compositions to optimize the efficiency at which they help convert biomass to feedstocks for producing biofuels. In this case, he tests catalyst systems for their ability to remain stable at high temperatures, tolerate poisons, avoid or limit coking, have a high surface area and accommodate selectivity. Richards tests their performance in two different biomass conversion techniques.

One of these techniques is gasification, where the catalyst helps remove tar from the syngas and tune it for refining into liquid fuel. With the gasification approach, Richards and other team members are seeking to develop an effective and economical tar-reforming catalyst,

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Sponsors of C2B2 are agressively driving the biofuels and biorefining industry on a daily basis. Here is a detailed look at three sponsors and their contributions.

C2B2 Seen as U.S. Gateway for German Biogas Producer

A key player in the European waste-to-energy market is hoping its involvement in C2B2 leads to big things in North America.

GICON
Großmann Ingenieur Consult GmbH

The United States is frontier territory for landfill diversion, and GICON, along with its daughter company GICON Bioenergie, based in Dresden, Germany, are aiming to be pioneers by developing facilities in the U.S. to convert organic waste into biogas. This biogas could be used to fuel vehicles, heat homes and generate electricity. More than 25% of the material by weight delivered to landfills across the U.S. is non-paper, solid organic waste. According to GICON, this mineral- and energy-rich material could be converted to biogas before it enters a landfill through the company's patented large-scale anaerobic conversion process, which incorporates two-stage fermentation with split hydrolysis.

GICON's technology is distinct from other landfill gas production systems in that it makes biogas from organic waste before, not after, that waste hits the landfill. What's more, the process is carbon neutral; no new CO_2 is released during conversion.

Wayne Brown of GICON explains, "Our biogas process is designed to be able to anaerobically digest the organic fraction in residential and commercial food wastes, and even municipal solid wastes, so that this methane-producing fraction does not end up in landfills. We intend to work with developers, waste haulers, and communities to divert these materials from entering landfills and then produce biogas from them."

Brown says GICON views C2B2 as a vehicle to help forge those relationships in the U.S. Initially, he explains, the company is pursuing research and business partnerships, with the goal of starting work on its first biogas plant in North America sometime this year. The facility would be similar to a 250 kW-electric plant GICON opened two years ago in Europe to "digest" corn silage into biofuel. Several U.S. sights are currently being considered for such a plant, he notes.

This type of facility could represent the first step into what Brown says is a market with huge upside. "The potential for this technology [in North America] is enormous, especially due to the likelihood that additional regulations will be enacted to control greenhouse gas emissions as part of international climate change agreements."

The ultimate goal, Brown says, is to have plants throughout North America making biogas from renewable organic waste. But he acknowledges that much work lies ahead to make that a reality. "The biggest challenge is finding the right combination of an engaged municipality, adequate siting, and suitable partners for construction and operation of the initial plant. Since this is a new concept in the United States (although many plants are already in operation in Europe), very few people are aware of the opportunity for landfill diversion to power generation. Suitable project partners are few and far between. However, once the initial plant has been constructed and proven technologically and financially, we believe the demand for this type of technology will increase rapidly."

GICON is looking forward to enhancing its U.S. contact base through its partnership with C2B2.

Growth in the Genes at OPXBIO

Three years is all it took for OPX Biotechnologies to scale up from three to forty employees and bring its proprietary technology for converting renewable feedstocks into biomass-based products to the pilot production phase. Three years from now, the Boulder-based company, a founding member of C2B2, could be close to bringing its first commercial facility on-line.

opxbio™
good chemistry.

The platform for OPXBIO's aggressive demonstration and commercialization strategy is bioengineering technology developed several years ago at the University of Colorado, Boulder by company co-founders Dr. Michael Lynch and Dr. Ryan Gill. Dubbed EDGE ™ — Efficiency Directed Genome Engineering — the technology has been proven in the laboratory to rapidly and efficiently optimize microbes and bioprocesses used to produce biofuels and bio-based chemicals. Using first-of-its-kind, massively parallel, full genome search technology known as SCALEs, EDGE identifies genes that control microbial metabolism. It then responds with a genetic change strategy to simultaneously optimize microbial production pathways and vitality, as well as overall bioprocess productivity, all at a rate 1,000 to 5,000 times faster than conventional genetic engineering methods.

Company executives explain that the speed and efficiency of the process should significantly reduce production costs so that products made with the help of EDGE technology, such as bio-acrylics and biodiesel, can compete economically with petroleum-derived chemicals and fuels, without a drop-off in performance. At the same time, these products have the advantage of coming from less-polluting renewable sources and processes.

Lynch, who now serves as OPXBIO's chief scientific officer, explains that essentially, EDGE manipulates the genetic structure of microorganisms to "map the fastest route" for optimizing those biomass materials as feedstocks for production of industrial chemicals and fuels. Perhaps the biggest technical challenge OPXBIO faces on the road to commercialization, according to Lynch, is getting the feedstock microorganisms to behave as intended in a large-scale, high-volume setting.

Bolstered by a $17.5 million funding infusion from investors in March 2009, OPXBIO is targeting the $10 billion global acrylics market for its first commercial foray. By 2013 or 2014, the company plans to launch a commercial-scale plant that produces bio-acrylic acid derived via fermentation from corn-based feedstocks for use in consumer products such as diapers, paint and adhesives. First, however, the company must complete pilot-phase work "to confirm the economic and design parameters for a commercial-scale plant," explains Chief Executive Officer Chas Eggert. The next step is to construct and operate a demonstration production facility, probably sometime in 2011.

Meanwhile, outside the laboratory, company executives are confident enough in the viability of the EDGE technology that they are "actively engaging with potential strategic partners" to explore development of bio-acrylic production facilities, says Eggert, adding that those discussions have intensified in recent months. Whether or not it leads to external strategic alliances, OPXBIO's involvement in C2B2 is proving valuable in fostering relationships. According to Eggert, being part of C2B2 also gives the company a say in the direction of research funded by the Center, and a role in developing Colorado's clean technology ecosystem.

OPXBIO intends to be part of that ecosystem for the long term. Company officials say that biodiesel and advanced alcohols for fuels and industrial applications are likely next in the company's commercialization queue. The versatility of the EDGE process will help in the development of additional feedstocks and products. Explains Eggert, "The power and flexibility of OPXBIO EDGE™ will make us a multiproduct - multifeedstock company."

Colorado Company Converts Sun's Energy Into Clean, Affordable Fuels

First came the idea of harnessing the world's most abundant, affordable renewable energy source — solar energy — to produce another — biofuels. Then came years of work in research labs and in the field to prove the concept. Now a new energy company with roots at C2B2 is preparing to enter the marketplace with a unique solar gasification process that turns almost any kind of plant material into clean, affordable liquid transportation fuel for use in today's autos, diesel engines and aircraft.

sundropfuels

Core elements of Louisville-based C2B2 sponsor Sundrop Fuels, Inc.'s technology were developed by and are licensed through University of Colorado at Boulder (CU-Boulder) and the National Renewable Energy Laboratory (NREL) – two cornerstones of C2B2. In 2008, the company acquired Copernican Energy, a CU-Boulder technology transfer spinoff founded by C2B2 Executive Director, Dr. Alan Weimer. The company's initial backing comes from two of the world's premier venture groups, Kleiner Perkins Caufield & Buyers and Oak Investment Partners.

The Sundrop Fuels process centers on its proprietary SurroundSun™ technology, a solar-thermal biomass gasifier that is mounted on a tower and powered by a concentrating mirror field below. The solar reactor creates ultra-high temperatures of more than 1,300°C, gasifying any feedstock within seconds. The resulting "syngas" – a mixture of carbon oxides and hydrogen – is then made into various forms of liquid transportation fuel using well-established commercial processes.

According to Sundrop Fuels, the company's solar-driven gasification technology is the first process in which nearly one hundred percent of the biomass used actually becomes transportation fuel. This astonishing efficiency and other aspects of the production process allows Sundrop Fuels to compete directly with petroleum products by creating green gasoline and other fuels for an unsubsidized cost of less than $2 per gallon.

Just as important, company officials say, the Sundrop Fuels production life-cycle leaves no carbon footprint, and depending on the feedstock used, actually reduces greenhouse gas in the atmosphere.

"We're introducing the first solar-powered approach to producing massive quantities of renewable drop-in biofuels using any type of feedstock," said company spokesman Steven Silvers. "From field to fuel, Sundrop Fuels represents the best possible use of the world's economic, environmental and energy resources."

The company plans to build multi-tower solar fuels "parks" in the Southwestern U.S. — on sun-drenched industrial land located in places such as Arizona, Nevada and New Mexico — capable of producing one billion gallons of clean transportation fuel annually. A single commercial solar unit will be comprised of a tall tower with heliostat mirrors positioned on the ground below, coupled with an integrated biofuels production facility. Agricultural waste, woody biomass, energy crops and other feedstock readily available throughout the Rocky Mountain and Midwest regions will be delivered to Sundrop Fuels' biorefinery facility via railroad. The feedstock could range from beetle-kill trees, rice and wheat straw, corn stover or future energy crops like miscanthus and rhubarb.

"Being able to use any feedstock to create drop-in biofuels is a tremendous commercial advantage over any other biomass process," said Silvers. "It also positions Colorado to benefit from the broad economic impact related to growing and transporting millions of tons of renewable biomass."

Following successful completion of laboratory and on-sun demonstration systems, Sundrop Fuels began operating a 1.5 megawatt thermal Receiver Development Facility (RDF) in Broomfield, Colorado last September. The company is now securing strategic partners to begin construction this year of a commercial-scale, revenue-generating facility that will be coupled with an integrated pilot-scale biorefinery to produce seven to eight million gallons of transportation fuel annually. A full-scale biorefinery producing 100 million gallons a year is planned for completion in 2015.

While Sundrop Fuels started as a concept born in the labs of C2B2 mainstays CU-Boulder and NREL, its technology will soon have a regional presence.

A CHEMIST'S QUEST FOR CATALYSTS

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capable of cleaning up and conditioning syngas in the biomass gasification process. Tars are an unwanted byproduct of the gasification process. The systems currently tested include metal oxides and mixed metal oxide aerogels.

The second technique used is pyrolysis, or thermal deconstruction, where the biomass is heated to an extremely high temperature, creating bio-oil and vapors that can be treated ("cracked") with a catalyst before refining. The team is seeking a catalyst that will neither rapidly coke nor deactivate in the process of cracking the bio-oil and vapors. To that end, among the catalysts being tested are nanostructured metals entrapped in mesoporous silica and ionic liquid templated mesoporous silica supports.

Both systems will be put to the test in a soon-to-be-completed small scale reactor at the Colorado School of Mines. "We have been building up large quantities of catalytic material and we're about at a stage where we can run a series of reactions at our lab," explains Richards, "If anything interesting happens during those tests, we can take it to the larger reactor at NREL."

The work Richards and his colleagues are doing is important in the overall scheme of biofuels development. They acknowledge that "to achieve the [Department of Energy] goal of enabling new technologies to provide 60 billion gallons of bioethanol by 2030, significant improvement in the catalytic conditioning of biomass-derived syngas must be achieved."

Colorado Renewable Energy Collaboratory
Partners for Clean Energy

National Renewable Energy Laboratory

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C2B2

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.

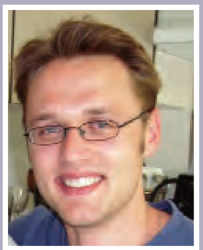
Colorado School of Mines
One of the few universities uniquely focused on energy research.

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

C2B2 Student Spotlight

Meghana Rangan is a fourth year graduate student in the Chemical and Biological Engineering Department at CU Boulder. Funded by NREL, Meghana is studying the sulfur tolerance of different bimetallic nickel catalysts. The greater goal of this research is to make biofuel production from biomass gasification a more efficient and economically feasible process. After graduation, Maghena would like to continue work in the field of catalyst design for biofuel production.

Dave McKenna is a second year Ph.D. candidate in the Department of Mechanical Engineering at Colorado State University. Dave is currently funded by the NSF IGERT Program in Multidisciplinary Approaches to Sustainable Bioenergy at CSU. He primarily works at the Engines and Energy Conversion Lab (EECL) with advisement from faculty in both Mechanical Engineering and Environmental and Radiological Health Sciences. Dave is working to quantify the health effects caused by burning various forms of biodiesel in diesel engines. To accomplish this, he is developing a novel in-vitro exposure system that deposits particulate emissions directly onto living human bronchial tissue. After graduation Dave hopes to continue working with renewable fuel technology, focusing on health effects and long term sustainability.



David Grzenia is a second year Ph.D. candidate in the Chemical and Biological Engineering Department at Colorado State University and works at the National Renewable Energy Laboratory. His research focuses on implementing and evaluating a new method in the biomass detoxification stream. Dave uses membrane extraction to detoxify hydrolysate. He holds a B.S. degree in Biotechnology from the University of Applied Sciences Giessen and an M.S. degree in Chemical Engineering from CSU. After completing his doctorate, David plans to continue working in the field of renewable fuel production.